INVESTIGATING VARIOUS TEST METHODS FOR ASSESSING THE EFFECT OF SULPHATE ATTACK ON CONCRETE PROPERTIES

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ABSTRACT

The degradation mechanisms related to the numerous chemical and physical reactions associated with external sulphate attack are undeniably complicated and are difficult to assess in the field. This study compares various sodium sulphate exposure regimes by using novel testing procedures to assess the level of sulphate attack degradation throughout an extended exposure period. A total of four exposure regimes designed to simulate those encountered in practice were replicated to compare the differences between each transport mechanism: diffusion, diffusion combined with wet-dry cycling, evaporative wicking and wicking combined with wet-dry cycling. The laboratory specimens were exposed for periods of 3, 6, 12, 18 or 24 months to three different solutions; the ASTM standard solution (5% Na_2SO_4), a less concentrated version representative of severe field exposure (2% Na_2SO_4) and the control solution (lime-saturated). Once the end of the exposure term was reached, the specimens were subjected to a series of mechanical tests.

This investigation evaluated the potential and reliability of various testing techniques to identify a sulphate related distress and to quantify its extent. Prior to destructive testing, ultrasonic pulse velocity was conducted; herein, two test frequencies were compared (54 kHz and 300 kHz). The change in tensile strength was measured in three different ways: an indirect splitting tensile test, a four point bending test and a direct gas pressure tension test. During the splitting tensile tests, acoustic emission monitoring was used to quantify and qualify damage progression under stress by locating the events in three dimensional space. The results demonstrate the sensitivity of each test in measuring the variance in mechanical properties related to the sulphate exposure types and offered insight into which experimental procedure is better suited for early sulphate damage detection.

SOMMAIRE

Les mécanismes de dégradation dûs aux réactions chimiques et physiques associés aux attaques sulfatiques externes sont complexes et difficiles à évaluer sur le terrain. Cette étude compare différents mécanismes d'exposition au sulphate de sodium en appliquant de nouvelles procédures d'évaluation pour évaluer le niveau de dégradation relié à l'attaque sulfatique durant une période d'exposition prolongée. Un total de quatre régimes d'exposition, similaires à ceux communément retrouvés dans la pratique, ont été reproduits afin de comparer les différences entre chaque mécanisme de transport: la diffusion, la diffusion combinée au mouillage-séchage cyclique, l'effet de mèche et l'effet de mèche combiné au mouillage-séchage cyclique. Les spécimens ont été exposés durant 3, 6, 12, 18 ou 24 mois à trois différentes solutions; soit la solution standardisée (5% Na_2SO_4), une solution plus représentative de conditions d'exposition sévères (2% Na_2SO_4) et la solution de contrôle de chaux saturée. À la fin de chaque période d'exposition, les spécimens ont été sujets à une série d'essais mécaniques.

Cette étude a analysé le potentiel et la fiabilité de plusieurs techniques d'évaluation de détresse reliées aux sulphates et de quantifier leur ampleur. Préalablement aux essais destructifs, des essais de vitesse d'impulsions ultrasoniques ont été effectués à deux fréquences, soit 54 kHz et 300 kHz. La variation de résistance à la traction a été mesurée de trois façons différentes: traction transversal, flexion à quatre points et traction directe sous pression de gaz. Durant l'essai à la traction transversale, du monitoring par émission acoustique a été utilisé pour qualifier et quantifier la progression des dommages sous tension en localisant chaque événement de façon tri-dimensionnelle. Les résultats démontrent la sensibilité de chaque essai à mesurer la variation des propriétés mécaniques reliée aux types d'exposition aux sulphates et offrent un aperçu de quelle procédure expérimentale est mieux adaptée pour le dépistage précoce de dommages reliés à l'attaque sulfatique externe.

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PREFACE

With respect to concrete sulphate attack studies, the methodology devised by the author, Ms. Hartell, and contributing research advisor, Prof. Boyd, diversifies itself from past and current research works on the topic. Traditionally, sulphate attack studies have focused on evaluating cement properties, as it is the culprit in the degradation mechanism. Mortar expansion measurement has been the benchmark method for qualifying the deteriorative process for nearly a century, but it offers no information on the mechanical performance of a concrete mixture under attack. This is problematic when assessing the structural integrity of affected concrete in service or, when establishing the performance of a concrete mixture design. There has yet been an adequate method (representative of service conditions) developed for evaluating the mechanical performance and the extent of the deteriorative process. Recently expressed in a Rilem committee report, this deficiency must be addressed. (Van Tittelboom et al. 2013)

Herein, the focus of the experimental investigation was not on evaluating the effects of sulphate attack on concrete properties; has these processes are already well known and documented. In accordance with the experimental outcomes of past research investigations, various test methods (both destructive and nondestructive in nature) were evaluated to determine whether they can be considered as acceptable means for assessing the performance of concrete subjected to various sulphate transport regimens.

Herein, three destructive methods were studied. First, a novel test method, known as the gas-pressure tension test, was considered due to promising results obtained in past investigation. (Boyd and Mindess 2004)(Boyd 2005). However, the test procedure utilised to measure the degraded specimens' strength using the gas-pressure test

principle was original to this investigation. It was developed as a consequence of the physical deteriorative mechanism characteristic of external sulphate attack. Thereafter, the viability of two other test methods for determining the tensile strength of concrete was evaluated. The standard ASTM procedures for the splitting tensile test and the fourth-point bending test were utilised.

Moreover, two stress-wave nondestructive testing methods were performed to determine whether they constitute suitable methods for monitoring ongoing attacks in the field and potential candidates for performance-based test development. Through-pulse velocity testing was revisited to investigate its potential in evaluating microstructural changes due to sulphate attack. And, since acoustic emission (AE) monitoring has never been investigated as a possible mean for assessing sulphate-damaged concrete, its test principles were utilised to complement the splitting tensile test analysis. An experimental method was devised by the author specifically for this study to determine the region of strain localization and microcrack propagation during splitting tensile loading of the degraded samples. The results offered insight on microstructural weakening of concrete due to sulphate movement and its resulting behaviour under mechanical stress.

In relation to external sulphate attack, the results of this investigation will contribute to establishing a viable experimental approach for the development of a new concrete performance based test method along with developing investigative tools for field condition assessment.

CHAPTER 1

INTRODUCTION

"sulphate attack represents a complex set of chemical and physical processes and thus cannot be fully characterised by a single mechanism" (Skalny and Pierce 1999, p.49).

Before the turn of the 20th century, the effects of ettringite formation in hardened concrete had already been identified by Candlot. Afterwards, Thorvaldson pioneered sulphate attack studies and developed the first method for assessing its disruptive effects: expansion monitoring of mortar bar samples submerged in sulphate solution. (Swenson and Mackenzie 1968)(Monteiro, 2006)

As field cases emerged and structural problems arose, sulphate attack studies became of interest to the scientific community. Extensive, long-term studies were initiated by the Portland Cement Association and the US Bureau of Reclamation. With the development of advanced analytical equipment, our understanding of sulphate interactions with the cement paste and its effects on concrete in service improved. Investigations resulted in many proposed solutions, and specifications were developed accordingly, based on expansion monitoring of mortar bar samples submerged in sulphate solution. Nearly a century of research work and data acquisition later and expansion-based testing is still the accepted way to go! (Hartell 2008)

Many authors have expressed the need for a change in the current means of assessing the performance of cement or concrete mixtures in the presence of an external source of sulphates. The general comments are directed towards the prescriptive guidelines (e.g. limits on cement chemical composition, water-to-cement ratio, and compressive strength); specifications and standards do not take into consideration the performance

aspect of concrete mixtures. Concrete technology is evolving: new cementitious materials are being developed, mix design improvements are permitting high performance concretes and better control of construction practices (batching, placement, curing). (Clifton et al. 1999) Moreover, there are significant flaws with the existing test procedure that create highly variable results. (Ferraris et al 2005) In order to address the negative comments, there have been many studies in the last decade contributing to the development of new testing methods to better assess the performance of concrete in service under external sulphate attack (ESA), with the added challenge of accelerating the attack mode in the laboratory while remaining representative of field exposure. As indicated by the review in Chapter 2, it would seem that the call for change has not yet been answered, as many published works still concentrate on expansion based measurements.

Consequently, the basis of this dissertation is to determine the potential of various types of mechanical and non-destructive testing methods to assess the level of degradation and the degree of loss of engineering properties (tensile strength and stiffness) which are associated with the external sulphate attack mechanism. To accomplish this objective, a research methodology, presented in Chapter 3, was first devised based on previous research work (Boyd and Mindess 2004) (Hartell 2008) (Hartell et al. 2011). This was followed by the implementation of a long-term experimental regime where novel test procedures were developed specifically for this study.

Over an exposure period of two years a total of four exposure regimens designed to simulate those encountered in the field were evaluated to compare the differences in degradation induced: diffusion, diffusion combined with sorption/ evaporation cycling, wicking, and wicking combined with sorption/evaporation cycling. The specimens were exposed to three different solutions; the standard ASTM solution (5% Na_2SO_4), a solution more representative of severe field exposure (2% Na_2SO_4) and the control solution (lime-saturated). Once the end of the exposure term was reached, the

specimens were subjected to a series of mechanical tests. Details of the experimental procedure are presented in Chapter 4.

This investigation evaluated the potential and reliability of various testing techniques to identify sulphate related distress and to quantify its extent. Herein, ultrasonic pulse velocity was conducted using two test frequencies (54 kHz and 300 kHz). The change in tensile strength was measured in three different ways: an indirect splitting tensile test, a four-point bending test and a direct gas pressure tension test. During the splitting tensile tests, acoustic emission monitoring was used to monitor and evaluate damage progression under stress by locating the events in 3-d space. The results presented in Chapter 5 demonstrate the sensitivity of each test method in measuring the variance in mechanical properties related to the sulphate exposure types and offer insight into which experimental procedures are better suited for early sulphate damage detection. The important research contributions and main remarks are summarized in the last section of the dissertation.

CHAPTER 2

LITERATURE REVIEW

The phenomena involving hydrated cement paste and a source of sulphate anion have been extensively studied over the last four decades. Many works have been published which have influenced our current assessment methods for sulphate resistant cements and our ability to make durable concrete in the field. The present chapter provides an overview of past external sulphate attack studies along with current views on the accuracy of the ASTM C1012 standard to evaluate the performance of a concrete mixture in service; illustrating the need to find other means of laboratory testing based on "real" exposure conditions representative of sulphate reaction kinetics encountered in field structures. Moreover, tensile strength and stress-wave propagation testing methods are reviewed in order to better evaluate their suitability as methods to detect concrete microstructural disparities related to sulphate-induced damage.

2.1 Overview of External Sulphate Attack

This section reviews previously published work on concrete sulphate attack investigations. It elaborates on the common products resulting from the physico-chemical reactions involving sulphates, the potential sources of sulphates, their transport mechanisms through a cementitious matrix to induce an attack, and the testing methods used to identify and evaluate an ongoing attack.

2.1.1 External Sodium Sulphate Attack Mechanism

The primary visual manifestations of sulphate attack in cementitious materials include spalling, delamination and macrocracking, which evolve from the following

microstructural changes: loss of cementing properties, paste cohesion and paste-aggregate bond. These are the consequences of complex chemical reactions and processes between the components of hydrated cement paste and sulphate compounds. A typical instance of sodium sulphate attack may involve some, or even all, of the following physico-chemical processes:

- decomposition, dissolution or removal of unhydrated components and hydration products;
- formation of ettringite, gypsum and thaumasite;
- repeated recrystallisation of sulphatic salts;
- complex and continuous changes in the ionic composition of the pore liquid phase. (Skalny et al. 2002) (Neville 2004)

There are many sources of sulphates that may potentially shorten the service life of a structure: sulphuric acid rich sewage water or industrial waste and sulphate compounds found in water sources such as lakes, rivers, seawater and groundwater. The ensuing damage to concrete structures does not solely depend on the concentration levels of sulphates, but is highly influenced by the transport mechanism driving the sulphates moving through the material. (Skalny et al. 2002)

For a further comprehensive review on sulphate attack mechanisms, the author would like to refer to a previous dissertation (written by the author) which has served as the basis for this research investigation. (Hartell 2008)

2.1.2 Sulphate Transport Mechanisms and Exposure Types

The majority of structures in service that are in contact with sulphates can be considered as partially exposed (e.g. building foundations exposed to groundwater). In this case, the lower portion can be saturated due to groundwater exposure while the upper part remains at ambient atmospheric conditions, typically producing an evaporation surface

just above the soil or water line. This moisture gradient within the concrete element generates a transport mechanism for the sulphate-solution as it is drawn into the concrete and permeates upward towards the drier regions of the structure. The resulting degradation effects are accelerated by this wicking action, transporting larger amounts of sulphates throughout the matrix than would be seen in a completely buried or submerged structure. (Boyd and Mindess 2004) Under these conditions, the concrete elements undergo a physical type of attack where the ionic solution migrates toward the evaporative region, leaving the salts to precipitate out into the hydrated cement paste pores near the surface. The nucleation and growth of sulphate crystals within the surface material can result in expansive forces that crack and weaken the concrete. Visually, this transport mechanism results primarily in surface scaling of the concrete. (Haynes et al. 2008) (Rebel at al. 2005) (Hime and Mather 1999) However, Brown and Doerr (2000) state that this form of efflorescence may be an indication of other ongoing sulphate attack mechanisms within the bulk material. Based on practical experience, it is contentious whether the migrating soluble ions chemically interact with the bulk material before they precipitate as evaporation takes place near the surface. From a long-term study initiated by the Portland Cement Association, Stark (2002) states that for concrete prisms partially immersed in soil, the immersed portion appeared intact, similar to companion prisms completely immersed in solution. (Stark 1984, 1989) Therefore, based solely upon visual examination, salt crystallisation was concluded to be the primary damaging mechanism. Conversely, Hartell's (2008) study comprised of uni-axial compression testing performed on cylinders of various w/c partially exposed to sulphate solution produced failures within the visually undamaged sulphate-laden half while the half damaged by salt crystallisation remained intact. Similar results were reported by Boyd and Mindess (2004) using tension testing.

Specimens subjected to constant wetting and drying cycles also exhibit physical damage due to salt crystallisation at the exposure surface. A study carried out over a period of

20 years by the US Bureau of Reclamation (USBR) compared specimens subjected to wetting and drying cycles to continuously submersed specimens. The researchers concluded “that 1 year of accelerated testing equaled 8 years of continuous immersion in solution” (Santhanam et al. 2001). This is in accordance with studies conducted by Pavoine et al. (2006) and Guyenisi et al. (2010) where wet-dry cycling was found to be effective in accelerating expansion based tests and strength based tests by forcing a larger draw of sulphate by the porous matrix. Still, this method of exposure “has not received wide recognition since other disruptive mechanisms may be involved that would affect the interpretation of the results” (Cohen and Mather 1991). For example, gypsum crystallisation could arise if evaporation takes place from a surface filled with ettringite. This might lead to crystallisation pressure resulting in volume instability and paste cohesion issues. (Skalny et al. 2002) It may, however, provide a better understanding of the actual field kinetics of sulphate attack.

It appears that the transport mechanism present in partially or cyclically exposed structures does not induce the same distress as in completely saturated concrete elements, which are rarely encountered in the field. In saturated conditions, diffusion is the primary transport mechanism responsible for the observed disruptive expansion of the cementitious matrix, which primarily involves the chemical interactions between C_3A hydrates and sulphate ions. As stated above, diffusion, as an aqueous ionic transport mechanism, is very slow relative to the two other mechanisms. (Stark 2002) Even so, the diffusion-based exposure regime is widely used as the method of exposure to investigate sulphate attack. The commonly used slender mortar bar test (ASTM C 1012) is an example of this problem.

Moreover, the ASTM C 1012 standard prescribes a 5% sodium sulphate solution to induce the attack. Though the test is considered to be overly severe because of this high concentration level, which might not necessarily be representative of concentration levels encountered in the field, the increased concentration level is used to accelerate

laboratory simulations. However, the mechanism of attack changes with concentration level, altering the resulting products. (Cohen and Mather 1991) According to Biczok (1967) at low concentrations of sodium sulphate, below 1000 ppm SO_4^{2-}, the main product of attack is ettringite; for higher concentrations, above 8000 ppm SO_4^{2-}, only gypsum formation is observed. Between these ranges both products are encountered. (Santhanam et al. 2001) Moreover, during laboratory simulation, one needs to monitor the pH levels of the exposure solution because it rapidly increases, from 7 to 12, as the cement's alkalis leach out into the surrounding sulphate-laden solution. The pH and concentration levels observed in the field tend to be more constant as the sulphate source is constantly replenished. (Mehta 1975) An acidic solution (approximate pH of 6.2) yields primarily gypsum as a product of attack; higher pH levels (around 12) stabilize the hydrated cement components and ettringite is favoured. Both cases misrepresent interpretation of the results and prediction of field behaviour.

Furthermore, the size of the specimen subjected to the solution must be considered when analyzing the results. An increase in surface reaction is one way to accelerate the attack's development. However, the shape and size of the specimen may affect the course and uniformity of the reaction kinetics. (Cohen and Mather 1991) Gollop and Taylor (1992) noticed in their investigations on submerged cubic specimens that material was lost at the edges and the faces showed little visible damage. These changes in shape and volume may ultimately influence the interpretation of results if the specimens are subjected to both physical and mechanical testing. (Hartell 2008)

2.1.3 Testing Methods and Evaluation of Sulphate Attack

The current means of evaluating sulphate resistance has often received much criticism in litreature but it is still the only standardized test to measure the performance of Portland cements or blends subject to an external source of soluble sulphates and it is widely used in research studies to assess the performance of various cementitious

blends to external sulphate attack. (Hartell 2008) Although the test is supposed to represent the volumetric change over the entire specimen, it has been demonstrated by Ferraris et al. (2005) that the tri-dimensional ingress front at the prism's ends may affect the results prematurely. Increased reactivity at the ends, thus inducing larger expansive stresses near the pins, was sufficient to actually dislodge the pin and change the accuracy of the measurement. The test is not based solely on chemical reactivity with sulphates ions, but on ionic diffusivity transport mechanisms. If the cementitious matrix is dense enough to limit ionic transport the external attack mode will be limited. In this case, time-to-deterioration models have arisen in litreature as potential indicators to ESA performance. (Batista and Weglewski 2009)(Tixier and Mobasher 2003) However, they are not necessarily indicative of ''real'' exposure conditions in service.

Traditionally, physical testing such as expansion measurement (Kurtis et al. 2000) (Monteiro 2006) (Monteiro and Kurtis 2003) and visual grading (Stark 2002) have been utilised for evaluating the level of deterioration due to sulphate attack. NIST researchers proposed an accelerated version of the mortar bar test by reducing the size of the sample, thus increasing the exposures surface-to-volume ratio. (Ferraris et al. 2005) Conclusive results were obtainable in a few weeks rather than months. Loss of mass has also been suggested in some investigations as a way for quantifying the extent of degradation. (Haynes et al. 2008). These tests take into account two of the known consequences of sulphate attack: expansion due to the formation of new expansive sulphate compounds and the visual signs of damage, macrocracking and scaling. Even so, some may argue that quantifiable degradation of mortars bars immersed in sulphate solutions arises before expansion occurs. (Wong and Poole 1988)

Mechanical testing is considered adequate for measuring the loss in engineering properties of a cementitious material subjected to sulphate attack. However, during the early stages of the attack, as the pores fill with the products of the chemical reactions, an increase in compressive strength is noticed, primarily due to the densification of the

porous hydrated cement paste matrix. In this case, the test may not reflect actual changes in microstructural properties. Nonetheless, Cohen and Mather (1991) state that mechanical properties, such as elastic modulus, compressive strength or tensile strength, can be used to investigate the effects of the softening-spalling type damage. Compressive strength monitoring has been used in numerous studies to evaluate concrete deterioration (i.e. loss of strength) caused by sulphate attack. (Figg 1999)(Irassar et al. 1996) Monteiro et al. (2000) proposed an accelerated test to evaluate a cement's resistance to sulphate exposure using the loss in compressive strength of mortar cubes. It was found to be more accurate than traditional methods. However, there is disagreement over the validity of compressive strength to determine the actual level of damage when comparing the rate of change in tensile strength versus the rate of change in compressive strength. (Neville 2004) (Boyd and Mindess 2004) Ju et al. (1999) argue that the "test is not indicative or suitable for layered damaged concrete".

The use of nondestructive testing (NDT) methods has not been investigated as much as the other testing methods in litreature, but is starting to gain popularity due to their numerous advantages in condition assessment of structures. Brunetaud et al (2012) used ultrasonic testing to evaluate the change in dynamic modulus of elasticity for samples of various sizes, cement type and w/c. The sensitivity of the result for smaller sized samples suffering greater damage was found to be more adequate than mass change and expansion measurements alone. Rozière et al. (2009) used a similar experimental approach with resonant frequency testing which demonstrated reliable results in the early detection of sulphate distress. However, the interpretation of the results from these tests is again dependent on the physical condition of the specimen. For example, impact echo testing is very sensitive to the exterior (skin) condition of a concrete sample whereas ultrasonic pulse velocity testing is unaffected. The latter measures the internal condition of the specimen or the fastest path between

transducers. (Boyd and Ferraro 2005) Moreover, as deterioration progresses, the accuracy of these tests suffers due to the decrease in homogeneity of deteriorated concrete. (Whitehurst 1966) Therefore, one NDT may be more suitable for a specific type of damage encountered.

As reviewed above, the suitability of a test method to detect concrete microstructural disparities seems to be dependent on "what" the test actually measures. It is therefore important to properly understand the underlying test mechanism in order to better interpret results obtained.

2.2 Destructive Methods for Evaluating Tensile Properties of Concrete

All materials have their "weakest link". Under sufficient stress cracks will initiate and propagate, which may lead to complete failure of the material. It is known that tensile strength testing is generally more sensitive to the presence of micro-flaws than compression testing. Load orientation, sample type, and sample size, with respect to directionality of flaws, will influence the outcome of a result. (Neville 1996) "There are three commonly used test procedures for determining the tensile strength of concrete: the direct tension test, the flexural test and the splitting tension test. The first test procedure, direct tension, is difficult to accomplish. Applying a uniaxial load free from eccentricities and without creating secondary stresses at the material's gripping interface is very complicated to carry out. The use of bonded end plates is usually preferred but still, bonding issues between the material and the plates may be problematic." (Hartell 2008) For this reason the test is not popular and there are standard methods proposed to accomplish the procedure. Herein, a novel procedure is proposed as an alternative, the gas pressure tension test. The other two methods are generally preferred for determining required tensile design values such as the modulus of rupture for pavement design. However are they sensitive to the entire bulk volume of the sample tested? The fracture mechanisms proposed for all three methods are reviewed in the following

sections, including a discussion on whether these tests are sensitive to damages resulting from sulphate exposure.

2.2.1 Splitting Tensile Testing

The splitting tensile strength test has been used to assess the loss in tensile properties for many studies and results are considered to be controversial. (Hartell 2008, 2011) Nonetheless, it is considered to be the standard method for determining the tensile strength of concrete materials. (ASTM C 496) Although the test is performed under a compression load, the indirect effect causes a tensile facture along the vertical diametral loading plane of the cylinder, due to internal stress distributions, and the tensile strength may be calculated using Equation 1. (Figure 2.2.1)

$$\sigma = \frac{2P}{\pi l d} \qquad \text{Eq. 1}$$

Where:

σ : Tensile strength

P : Applied load

l: Length of sample

d: Diametre of sample

The following is suggested as the fracture mechanism for the test. A tension crack will first initiate at the weakest point or most severe defect (though this is dependent upon its location with respect to the applied stress fields as well) and then propagate into surrounding material until it is inhibited by the biaxial compressive zone located beneath the packing strips. Then, the specimen will either fail if the crack grows around the compressive zone or if the compressive zone fails under shear forming a wedge towards the side of the sample as seen in Figure 2.2.2. (Hannant et al. 1973)

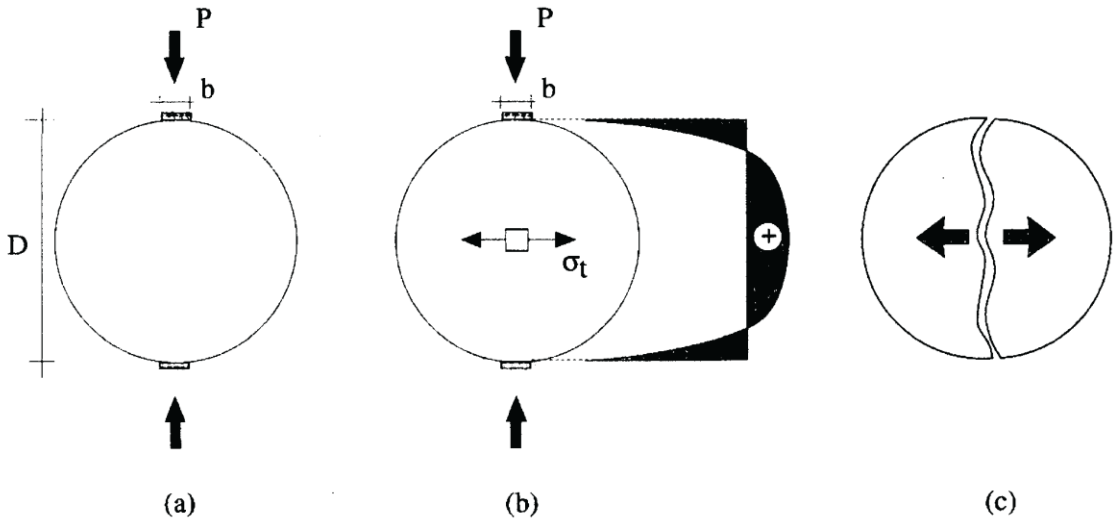


Figure 2.2.1: Splitting tensile test: (a) load alignment; (b) stress distributions; (c) ideal rupture. (Rocco et al. 1999, p.52)

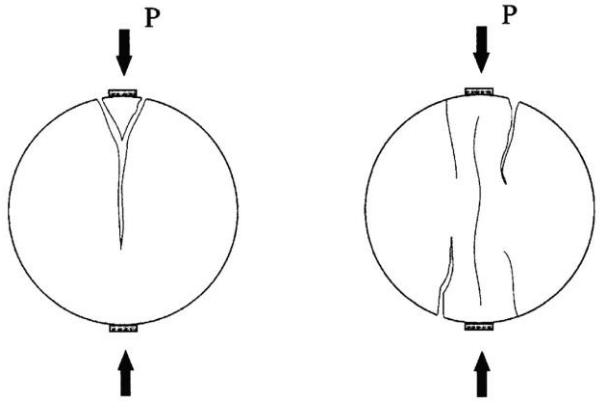


Figure2.2.2: Splitting test: (left) Failure mode with wedge formation; (right) failure mode with secondary crack formation. (Rocco et al. 1999, p.52)

A uniformly distributed load is almost impossible to achieve because concrete samples rarely present a perfectly uniform surface. Samples come with defects and uneven surfaces, therefore needing a bearing strip soft enough to pass the load onto the samples surfaces but sufficiently stiff so as to not influence the outcome of the test results. The packing strip will also influence the resulting strength of the material. With an increase in width there is generally a decrease in measured strength. The standard method suggests a bearing strip width equal to one inch, however it has been

determined that a width equal to 1/12 of the cylinder's diametre should suffice. (Hughes et al. 1993)(Lin and Wood 2003)

Moreover, the stress distribution along a specific plane engages the aggregates to participate more in the fracture process and measured ultimate strength. The fact that most of the aggregates present along the fracture plane are generally also fractured instead of being pulled-out of the cement matrix is an indication that the mechanisms is highly depend on the strength of the aggregates. The strength of the aggregates will have more influence on the test results than the paste itself; thereby minimizing the effects of the interfacial transition zone (ITZ) or even the degradation mechanisms in the paste.

It is generalized that the interfacial transition zone is considered to be the "weak link" in a concrete material because of its chemical composition and microstructural arrangement. The strength of the ITZ, primarily influenced by the bond strength between the aggregate surface and the cementitious phase, has a measurable effect on the tensile properties of concrete. The roughness of the aggregates and its mechanical bond strength in the ITZ will also have an influence on the concrete tensile strength and crack propagation. Generally, an improvement of the paste-aggregate bond will lead to an increase in mechanical properties; in part due to the improved cementitious properties of the ITZ. Consequently, a degraded ITZ should have a direct influence on the tensile response of concrete. The paste-aggregate properties, however, are not adequately measured under splitting tensile testing, thus making the test procedure less sensitive to degradation mechanisms involving chemical phase changes. (Mindess 2002)

2.2.2 Flexural Testing

The theoretical maximum tensile strength of concrete may be determined by subjecting a concrete beam to a three or four point loading test. The tensile stress developed at

the extreme fibre (face) of the concrete beam is known as the modulus of rupture (Eq. 2). There are two standard test methods which measure the modulus of rupture of concrete beams under flexural loading: ASTM C 293 - *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Centre-Point Loading)* and ASTM C 78 - *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading*).

The first test induces a centreed load at the mid span on the beam. The peak load is found at the mid-span therefore forcing a critical crack to develop at that point. For the second test, the load is distributed evenly over one-third of the middle span; therefore the critical crack causing failure should develop at any point over that length. Thus, the probability of the weakest link being along the maximum loaded length of the beam is greater than being specifically at the centre point. This fact is demonstrated through typical results of such testing, where the modulus of rupture obtained from a centre-point loading test is typically greater than for a two-point loading test. Moreover, coefficients of variation are also generally greater, taking into account the heterogeneous nature of concrete. (Neville 1996)

$$\sigma = \frac{PL}{bd^2} \qquad \text{Eq. 2}$$

Where:

σ : Modulus of Rupture

P : Applied load

L : Length of the support span

d : Thickness of beam

b : Width of beam

Based on elastic beam theory, the tensile strength of concrete can be evaluated from the measured modulus of rupture found using either method. The respective equations assume that the tensile stress distribution is linear from the neutral axis of the beam to

its extreme fibre. However, the strain rate gradually increases with applied stress above 50% of the ultimate tensile stress resulting in a parabolic stress distribution block near failure, not the theoretical triangular stress block. The actual tensile strength of the material may be estimated at 75% of the calculated modulus of rupture. (Neville 1996)

In comparison to direct tension testing, the modulus of rupture will typically be higher due to the dependency on stress distributions within the sample. In direct tension testing, the whole volume is subjected to a direct tensile stress. This increases the probability of initiating a tension crack at the weakest point. Then, the tension cracks will continue propagating with the increase in required fracture energy until complete failure is attained. In comparison to flexural loading, only a small portion of the beam at its extreme fibre is subject to high tensile stresses. In this case, the lesser stressed material near the neutral axis may inhibit crack propagation due to a lack of required fracture energy. This will result in an increase in applied load necessary for propagating a tension crack toward complete failure. (Neville 1996)

Flexural testing has been used in a few investigations as a means to measure the level of distress caused by ESA or to actually measure its influence on the long-term properties of an ongoing ESA. (Long et al. 2007) (Bassuoni and Nehdi 2009) (Yang and Luo 2012) (Gao et al. 2013) In all studies, flexural testing was determined to be adequate for evaluating sulphate degradation because of the test sensitivity to the surface damage.

2.2.3 Gas Pressure Tensile Testing

The concept of the gas pressure tension test was initially investigated by Clayton and Grimmer in the late 1970's. As researchers at the Building Research Establishment in the UK, they evaluated the test's conceptuality in evaluating the uniaxial tensile strength of concrete material based on Therzagy's effective stress theory. The material is

considered as a diphase system, where the concrete matrix is considered as a combination of a solid phase and fluid phase. In this case, the effective stress seen by a concrete sample is the difference between the applied stress and the corresponding pore pressure acting on the solid phase (Figure 2.2.3). (Clayton 1978) (Clayton and Grimer 1979) Therefore, the degree of porosity of the concrete matrix and the level of saturation appears to have an important effect on the outcome of the test. (Uno et al. 2010)

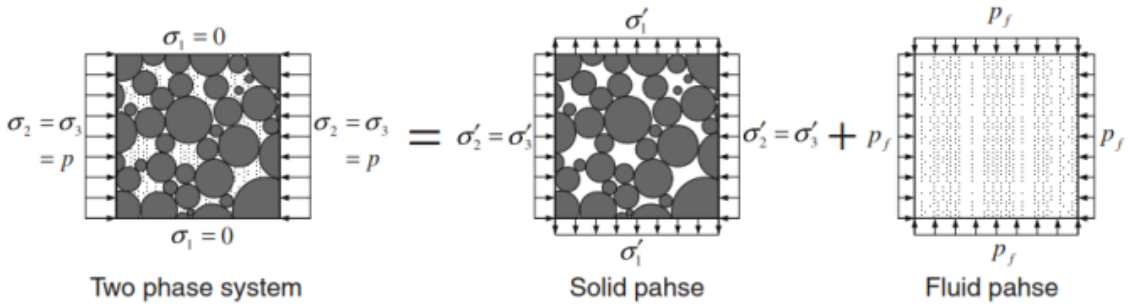


Figure 2.2.3: Stress distribution on a di-phase solid under asymmetrical stress. (Uno et al. 2010)

Clayton and Grimmer used water as the pressurizing medium. Later, the water fluid was replaced by gas in order to accomplish the same level of pressurization and simplify testing procedures. A series of investigations using nitrogen gas as a confining agent were conducted and proposed a failure mechanism for axisymmetric loading along the circular surface of the concrete cylinder. (Uno et al. 2005, 2010) (Fujikake et al. 2010)

''First, a tension crack occurs on the surface of the concrete specimen at a gas pressure almost equal to the tensile strength of the concrete. Once the crack occurs, it is continuously driven by the pressurized nitrogen gas intruding into the crack under the pressure essentially equal to the tensile strength of the concrete. Since the concrete materials contain microcracks and flaws even before the application of any load, the tension crack seems to be formed from those defects on the surface of specimen.

However, to gain a better understanding of the exact failure sequence and failure mechanism, a fracture mechanics approach to this problem might be necessary.'' (Uno et al., 2005) The results of this study imply that the test is sensitive to surface damage rather than internal damage.

The test has been used in assessing the change in strength of deteriorated concrete. Concretes damaged by alkali-silica reaction, sulphate attack and freeze-thaw damage were evaluated. The results show a positive response of the test in evaluating early changes in strength when microcracking is a result of the deterioration mechanism. (Bremner et al. 1995, 1998) (Boyd and Mindess 2001, 2004) (Boyd 2005) (Komar et al. 2013)

2.3 Non-Destructive Methods for Evaluating Mechanical Properties of Concrete

When studying concrete durability mechanisms in the field, residual strength and microstructural integrity are the primary concerns. NDT methods are commonly used in practice as a diagnostic tool to evaluate such parameters without further compromising the integrity of the structure (i.e. destructive load testing or sampling parts of structural elements); also, avoiding costly repairs. However, the theoretical principles of these methods (e.g. electrical, acoustic, thermal, electromagnetic) are based on specific material characteristics (e.g. density, modulus of elasticity, porosity, chemistry) which may provide insight into engineering properties such as compressive strength and permeability. Extensive past research investigations have provided useful correlation databases but are limited to these singular studies. (Kaplan 1959, 1960) (Carino 1997) It is therefore important to understand that these tests have limitations and acquired data must be analysed with care. (ACI 228.2R-13) (ACI 228.1R-03)

As a research tool, non-destructive techniques offer a unique opportunity to monitor the change in material properties of a given sample over a period of time. Unlike destructive

testing, the same sample may be tested numerous times without affecting it. Several data types may be affiliated with the investigated material condition thus increasing our understanding of material properties and refining test methods to better address field interpretations and improving general practice.

There are many methods currently used in practice to estimate the strength of a material in service. The following NDT methods are listed in the Concrete Construction Engineering Handbook and included in the ACI 228 committee report: rebound hammer, ultrasonic pulse velocity, probe penetration, pullout test and break-off test. (Carino 1997) (ACI 228.1R-03) From these techniques, only the rebound hammer and ultrasonic pulse velocity test may practically be used on lab scale samples without destroying the sample. (ASTM C 805, ASTM C 597) The other tests are, in fact, destructive in nature, by actually inducing a stress fracture within a small portion of material to evaluate its mechanical response. (ASTM C 803, ASTM C 900, ASTM C 1150) As for the rebound hammer, the impact load induced by the hammer may cause surface damage/microcracking on small scale samples if the test is repeated over time; thus, changing its long-term characteristics. Moreover, all of these tests assess surface characteristics (i.e. covercrete) only. The results are largely affected by the concrete's surface condition (e.g. presence of voids, large aggregates and cement paste). They are not sensitive to overall bulk characteristics. Finally, the ultrasonic pulse velocity test is the only one of these methods that may be conducted endlessly without altering the sample or inducing damage. Based on stress-wave propagation theory, the method is sensitive to internal microstructural conditions; therefore gaining popularity as a viable non-destructive assessment method. (Carino 1997)

On that note, monitoring stress waves emitted by the material itself through the release of elastic energy by a material under stress (i.e. acoustic emission) is also a technique gaining acceptance in the structural concrete industry. Several research studies in Japan used acoustic emission techniques to evaluate ongoing degradation mechanisms

in the field and in the lab, such as corrosion processes, and several attempts to quantify and qualify fracture mechanisms have been investigated. Experimental studies proved the reliability of the method to produce adequate conclusions. Certain structural monitoring procedures have been proposed, but acoustic emission continues to pose certain challenges due to the heterogeneous nature of concrete. (Yuyama et al. 1999) (Yuyama and Ohtsu 2000) (Yoon et al. 2000) (Ohtsu et al. 2002) Despite the wave property attenuation through cementitious concrete, advanced analysis techniques such as moment tensor analysis and b-value analysis have been developed to characterise the fracture process of materials. (Ohtsu et al. 1998)(Li et al. 1998)(Shiotani et al. 2000)

In recent years, stress-wave propagation techniques have been used to assess degradation mechanisms associated with sulphate exposure because of their sensitivity to density and stiffness. As previously described in Section 2.2, stress-wave propagation related to pulse velocity has shown promising results. The following sub-section will review the principals of the technique in accordance with the two presented test methods using stress-wave propagation theory to assess concrete material properties: ultrasonic pulse velocity and acoustic emission.

2.3.1 Stress-Wave Propagation Theory

One of the first principles of stress-wave propagation theory is that the velocity of a stress wave or mechanical wave traveling through a solid medium is directly related to the elasticity constant of the medium, along with its density. As shown in Figure 2.3.1, stress waves may propagate in a material via three different modes: “(1) compressional waves (also called longitudinal or P-waves), (2) shear waves (also called transverse or S-waves), (3) and surface waves (also called Rayleigh waves)” (Naik et al. 2004). Each wave type travels according to its distinctive velocity. (Eq. 3 to 5) For concrete materials, this inherent property enables empirical correlations between wave velocity and

mechanical properties based on stress-strain behaviour or stiffness-strength relationships (Eq. 6).

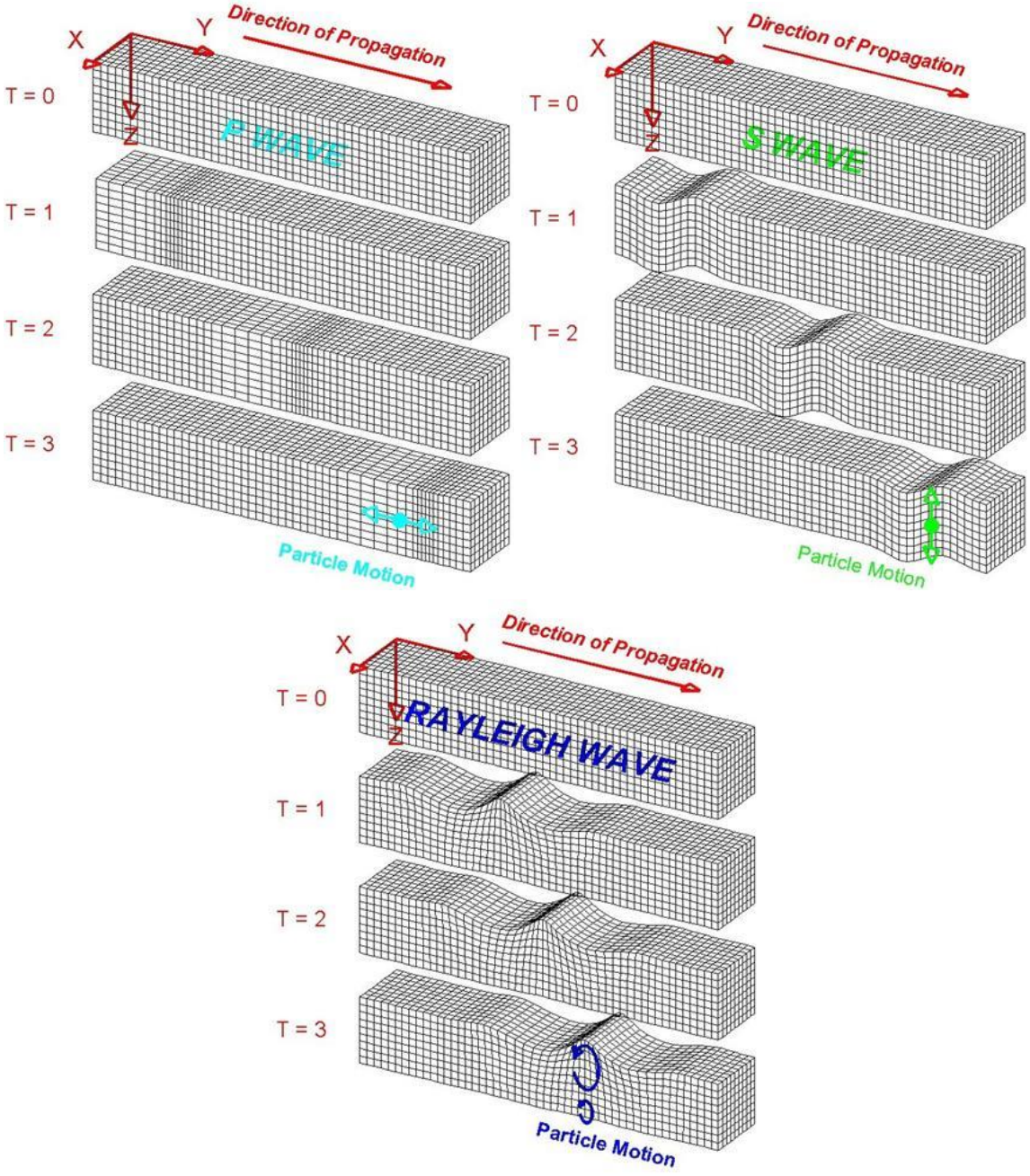


Figure 2.3.1: Perspective view of particle motion related to wave mode propagation types through a solid medium: a) compressional mode, b) shear mode and c) Rayleigh mode. (Braile 2010)

$$C_p = \sqrt{\frac{E\,(1\ -v)}{\rho(1+v)(1\ -2v)}}$$ Eq. 3

Where:

C_p : P-wave velocity

v : Poisson's ratio

E: Modulus of Elasticity

ρ : Density

$$C_s = \sqrt{\frac{G}{\rho}} = \sqrt{\frac{E}{\rho 2(1+v)}}$$ Eq. 4

Where:

C_s : S-wave velocity

G: Shear Modulus of Elasticity

$$C_r = C_s\ \frac{0.87\ +1.12v}{1+v}$$ Eq. 5

Where:

C_r : R-wave velocity

$E_c = W_c^{1.5} \times 33 f'_c{}^{1/2}$ Eq. 6

Where:

Ec: Estimated modulus of Elasticity of concrete

f'_c: 28 day Compressive strength (psi)

W_c : Unit weight of concrete (lb/ft^3)

$$C = f \times \lambda$$ Eq. 7

Where:

f: Wave frequency

λ: Wavelenght

Another feature of stress-wave theory is the fact that the velocity is independent of the distance traveled. As discussed, the velocity of a transient wave is dependent on the elastic modulus and density of the materials, its value will not change if the distance traveled changes. This is inferred by the basic wave velocity equation relating frequency to wavelength. (Eq. 7) If a wave front is propagating at a given speed and vibrating the particles along its path at a specific frequency, the wavelength may be computed or vice versa.

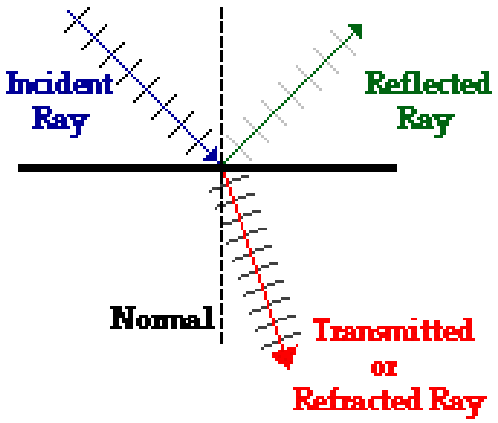


Figure 2.3.2: Incident wave reflection and transmission at a medium boundary. (The Physics Classroom, 2013)

When studying wave propagation through a heterogeneous material such as concrete, a transient wave will encounter boundaries (changes in medium densities) which will influence its behaviour because of the change in acoustical impedance at the boundary (i.e. boundary behaviour). First, a portion of an incident wave traveling through a solid medium will be reflected once it encounters another solid medium boundary of different density. The reflected wave will travel back into the medium at the same velocity. The other portion of the transient wave will continue traveling through the second medium at a different velocity. (Figure 2.3.2) The degree of reflection depends on the difference in acoustical impedances (Eq. 8 and 9). Although wave frequency is not altered as the incident wave is transmitted to the other medium, wave characteristics such as energy and amplitude will be diminished. Only a portion of the incident energy is transmitted

hence lowering the wave amplitude. The remaining energy is contained in the reflected wave, thus altering its wave parameters also. This loss in energy and amplitude is referred as wave attenuation. (Carino 1997) (Mistras Group Inc. 2011)

$$Z = C \times \rho \qquad \text{Eq. 8}$$

Where:

C : wave velocity

ρ : Density

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1} \qquad \text{Eq. 9}$$

Where:

R : Reflection coefficient

Z_1: Acoustic impedance of medium 1

Z_2: Acoustic impedance of medium 2

Another contributor to wave attenuation is through energy absorption and particle friction (released as heat) as a wave travels through a medium. Although speed and frequency are maintained, the amplitude will decay along its travel path until all energy is dissipated. (Mistras Group Inc. 2011)

Lastly, if a signal is generated through a mechanical impact or a release of elastic energy by the material itself, the incident signal containing a wide frequency spectrum will decompose into its component frequencies as it travels through the medium. This dispersive process also causes amplitude attenuation as the incident energy is dispersed into the multiple signals traveling at different wavelengths. (Mistras Group Inc. 2011) (Carino 1997)

Thus, testing techniques have been developed through the different factors of wave propagation, which permits the evaluation of specific material characteristics such as

material stiffness, density, microstructure, and the presence of flaws and voids; making this principle well suited for concrete property assessment.

2.3.2 Ultrasonic Pulse Velocity Testing

The ultrasonic through-transmission method, better known as ultrasonic pulse velocity (UPV), is a nondestructive test method widely used in the concrete industry to evaluate the condition of a concrete element. As early as the 1940's, instruments were developed to assess cracking in structures and empirical models were developed correlating pulse velocity and internal structure. (Leslie and Cheesman 1949) (Jones 1949, 1953) In the 1960's, the battery operated PUNDIT (Portable Ultrasonic Nondestructive Digital Indicating Tester) was invented, making ultrasonic velocity measurement on structures easy and practical. The versatility of the PUNDIT has since been proven; it is still the equipment of choice amongst today's practitioners. Whether related to damage detection or general material strength, the results (although rough) offer a reliable method for assessing a structure, making it the preferred NDT technique of many. (Aggelis et al. 2012) (Carino 1997) (Naik 2004)

The basic principle of ultrasonic testing is presented in Figure 2.3.3. *"A pulser sends a short-duration, high-voltage signal to a transducer, causing the transducer to vibrate at its resonant frequency. At the start of the electrical pulse, an electronic timer is switched on. The transducer vibrations are transferred to the concrete through a viscous coupling fluid. The vibrational pulse travels through the member and is detected by a receiving transducer coupled to the opposite concrete surface. When the pulse is received, the electronic timer is turned off and the elapsed travel time is displayed. The direct path length between the transducers is divided by the travel time to obtain the pulse velocity through the concrete."* (ACI 228.1R-03, p. 10)

Because the elastic modulus and the velocity are related through wave propagation theory, the test may provide an approach for evaluating the strength of a material as explained in the previous section. (Popovics 2001) However, as concrete matures the rates in strength gain versus stiffness gain are not necessarily linear over a range of concrete maturities thus limiting the possibilities of the test. This fact may be due to the heterogeneity of a concrete material and its ever-changing microstructure over time.

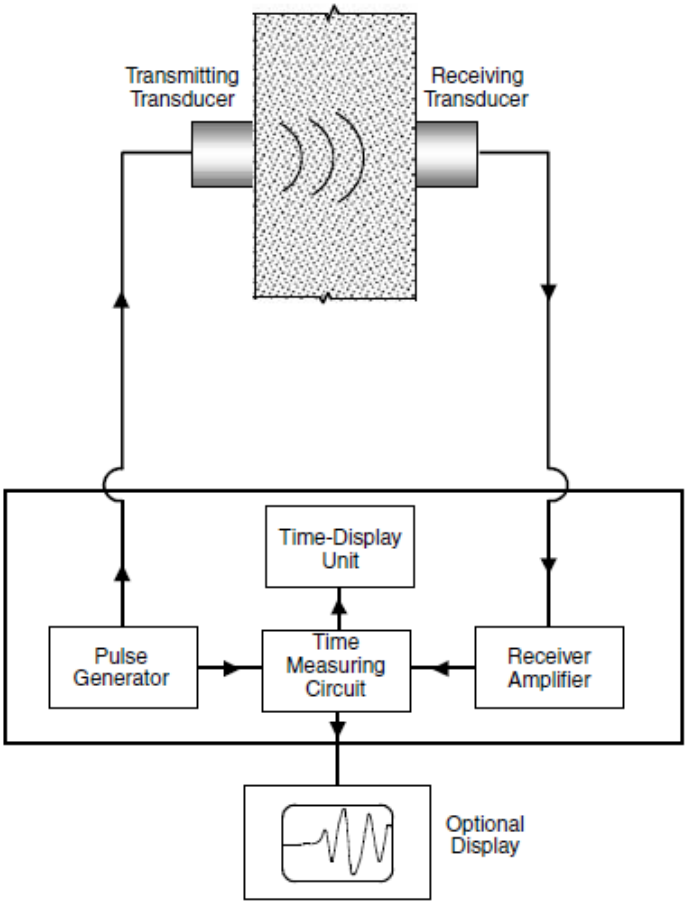


Figure 2.3.3: Schematic diagram of pulse velocity test circuit. (Naik et al. 2004)

The presence of aggregates, void space occupied by water and air, and varying chemical phases of the hydrated cement paste make it a moderately dispersive material. The measured path (assuming linear propagation) may not actually be the real path traveled by the wave. The changes in acoustic impedance between the materials present and the presence of numerous material boundaries will greatly affect the wave

velocity and attenuation of the incident pulse (Table 2.3.1). The moisture content of concrete alone will contribute to a variance in the measured pulse velocities. (Boyd and Ferraro 2005) Moreover, the frequency of the emitted wave will have an impact on the various attenuation processes as the wave travels. All these facts combine to produce limitations of the test for assessing the overall elasticity since multiple parameters are at play. Nonetheless, it may offer general insight into the internal properties when monitoring an element over its service life. (Carino 1997) (Naik 2004)

After a few decades of research, ultrasonic testing is still a topic of interest. Further studies are being carried out on evaluating the effects of wave attenuation on velocity measurements and dispersion features in order to further improve the diagnostic technique. These are focused on damaged, cracked and deteriorated concretes, where the increase in inhomogeneity generates further material boundaries. Thus, the velocity dependence on frequency should be much more evident due to the increase in wave scattering and the dispersive nature of the affected material. (Philippidis and Aggelis 2003, 2005) (Aggelis and Philippidis 2004)

Table 2.3.1: Acoustic Impedance for various materials related to structural concrete. (Carino 1997)

Material	Acoustic Impedance (kg/m^2s)
Air	0.4
Water	1.5 x 106
Concrete	7 x 106 to 10 x 106
Steel	47 x 106

2.3.3 Acoustic Emission Testing

Based on the same physics principles as ultrasonic testing, acoustic emission (AE) monitoring has been developed to monitor and characterise transient stress waves

generated by the material itself. If a material is stimulated (e.g. mechanical loads, physical changes or chemical reactions), it may rapidly release stored kinetic energy locally producing transient elastic waves (acoustic emissions). These waves will travel toward the surface of the material, where they can be recorded by a sensor. (Figure 2.3.4)

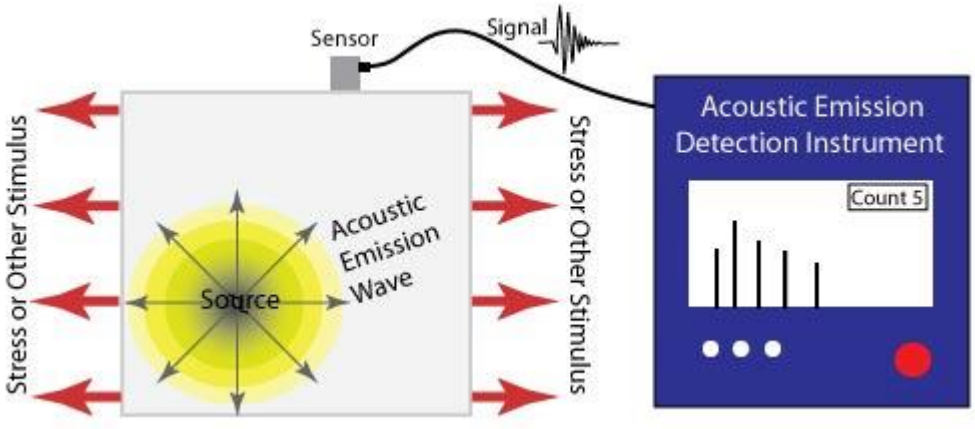


Figure 2.3.4: Schematic representation of acoustic emission testing.

(NDT Resource Centre 2012)

Acoustic emission monitoring may possibly be the oldest NDT method known to mankind. As early as 6500 BC, potters listened for cracking sounds during the ceramic's cooling stage. Though, it is not until the 1900's that characterizing wave propagation through materials started gaining interest in the research community. The first modern day acoustic emission monitoring application is due to Kaiser's research efforts, followed by Schofield's work on implementing the technique in engineering applications. (NDT Resource Centre 2012)

Over half a century has passed and AE has evolved into a reliable means for monitoring the performance of various structure types and industrial processes. AE applications in structural health monitoring have proven to be a useful tool. Several studies using comparative analysis of recorded waveform parameters (Figure 2.3.5) have been

conducted to assess damage levels related to durability mechanisms and structural integrity. A study was performed comparing the level of emission produced by beams affected by alkali-silica reaction (ASR) and the subjected to three-point flexural loading. The criteria used to assess sustained sample damage were; the quantity and amplitude of AE hits, the historic index and the Felicity ratio. The Felicity ratio was deemed the most effect parameter to determine the onset of ASR mechanisms for beams under flexural loading. (Eskridge et al. 2004)

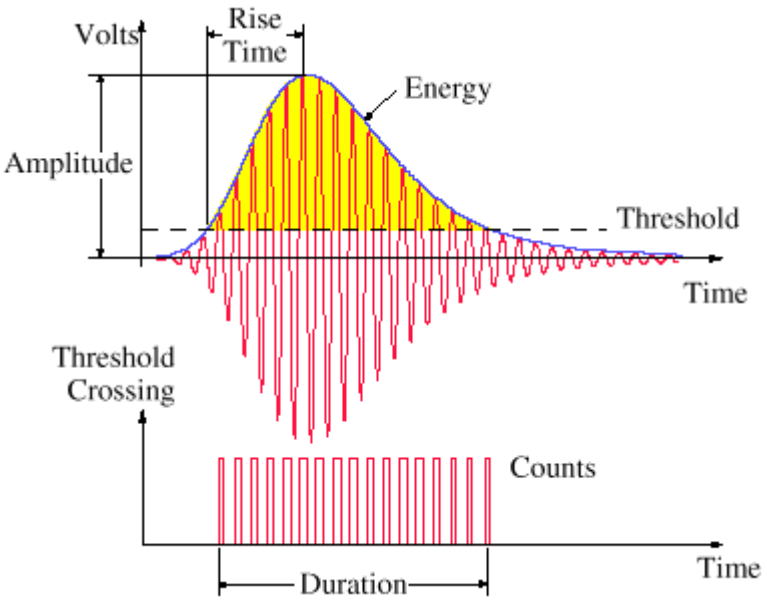


Figure 2.3.5: AE waveform parameters. (Huang 1998)

Derived from an experimental study conducted on reinforced concrete beams of a bridge in-service, monitoring and test procedures were proposed using specific AE parameters because of their increased sensitivity to structural damage detection and evaluating material soundness. Based on Kaiser's effect, they proposed recording AE activity versus incremental loading and unloading cycles. Routinely performing such tests may also indicate the presence of an ongoing deterioration mechanism by evaluating the change in energy and amplitude distributions. An increase in activity detected through counts, hits and events may be indicative of near failure. Meanwhile, damage zones may also be detected via localizing event clusters generated by the increased emissions

as an element reaches failure. (Ohtsu et al. 2002) (Yuyama et al. 1999) Similar techniques were also used to evaluate the behaviour of reinforced concrete slabs under fatigue loading. (Yuyama 2001) Herein, event localization techniques correlated well with actual crack development during testing and failure location.

Aggelis et al. (2013) demonstrated from his experimental study on notched mortar beams under three point bending load that accurate characterization of fracture modes is possible using acoustic emission analysis techniques with a single AE receiver. Tensile fracture modes and shear fracture modes produced distinct waveforms enabling fracture process characterisation. However the effects of attenuation seem to render the task complicated when analyzing events related to a fracture processes using multiple sensors due to the inherent attenuation properties of a transient wave in concrete. A few centimetres was sufficiently significant to alter the received wave characteristics. The source signal's frequency spectrum and waveform were considerably dissimilar at different distances from the AE point location. As previously discussed, the heterogeneous microstructure of concrete changes the incident signal properties as it travels through the material. This fact may become problematic when using AE technics to locate the source of the transient wave, but still remains possible with a good understanding of material properties. (Mistras Group Inc. 2012)

Different source location techniques may be used to identify the location point of an acoustic event. With greater accuracy, computed location techniques are based on the recorded times of received hits (time difference between each hit) and the determined wave velocity through ultrasonic pulse velocity testing. (Figure 2.3.6) Linear, planar, three-dimensional monitoring techniques may be used based on the monitored element's size and shape, along with the desired location information.

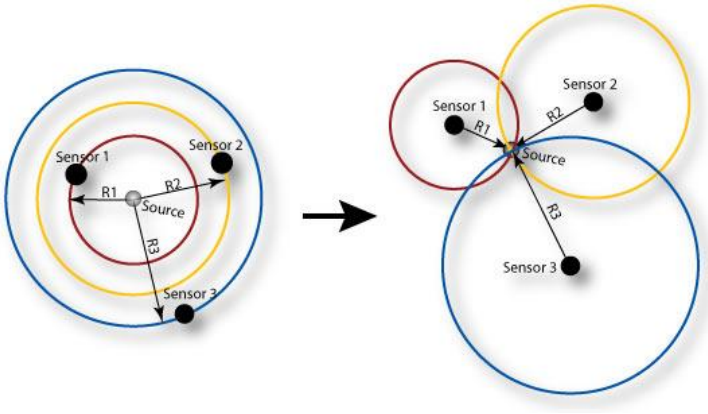


Figure 2.3.6: Point location of AE source. (NDT Resource Centre 2012)

The minimum amount of sensors required for localizing an event is two. For linear location, seen in Figure 2.3.7, two sensors are placed at a known distance apart and any event occurring between the sensors will be localized along their linear path (x axis) based on the time difference between the two received hits. This form of computed location is generally used for thin and narrow elements.

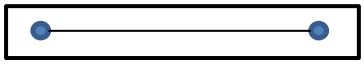


Figure 2.3.7: Sensor positioning for linear source location.

If used with planar structures, an event may not necessarily be in-line with the sensors thus producing unreliable event localization. In this case, planar location is more appropriate by using a minimum of three sensors to locate the source of emission. Again, the differences in arrival times are calculated and with known sensor geometry and inherent wave velocity, the two-dimensional location of the event may be computed. For larger surfaces, multiple sensors may be placed in “zones”, each zone monitoring their surface area only. These are determined by the operator when defining monitoring and equipment parameters in the software. It is recommended to use triangular layouts for sensor positioning to maximize location accuracy. (Figure 2.3.8) (Mistras Group Inc. 2011)

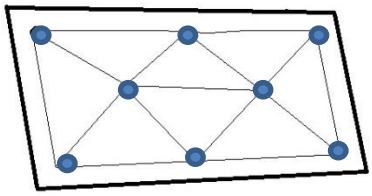


Figure 2.3.8: Triangular sensor layout for planar/zonal source location.

When monitoring an element where internal source location is desired, 3D location is possible using a minimum of three sensors. However, the complexity of that element and the desired source location accuracy will dictate the required number of sensors. As demonstrated in Figure 2.3.9, an array of sensors are placed throughout the body of the element under investigation, each assigned three spatial coordinates. As described above, the spatial coordinates of an event may be found by computing the arrival time differences from each sensor. With this increased complexity and equation sets, the least squares interaction technique is typically used for computing 3D source locations. (Moradian et al. 2012)

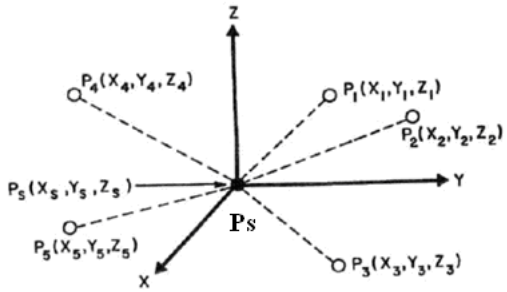


Figure 2.3.9: Spatial positioning of sensors (P_n) for 3D source (P_s) location. (Moradian et al. 2012)

Attenuation may be simply defined as the loss of signal amplitude with an increasing distance from the source signal. Amplitude is an important parameter in AE monitoring as it enables detectability of AE sources. This fact governs sensor spacing and positioning in order to maximize detectability of strong signals which, in turn, improves source localization. Inadequate sensor spacing may result in inefficient monitoring if source signals are lower than the amplitude threshold to filter noise. Prior to testing, the rate of attenuation or attenuation versus distance relationships may be determined by

conducting simple experimental procedures dependant on the element and material studied. (Mistras Group Inc. 2011)

Therefore, in order to maximize the use of such techniques, properly understanding the possible limitations and associated material properties are of much importance. Planning the experimental methodology before material testing is undeniably necessary to maximize positive and conclusive results.

CHAPTER 3

RESEARCH METHODOLOGY

Taking into account all of the concerns raised in litreature, a research methodology was devised to compare various sodium sulphate exposure regimes (replicating transport mechanisms reminiscent of those seen in the field) by using multiple testing procedures to assess the level of degradation throughout an extended exposure period. Figure 3.1.1 illustrates the exposure parameters considered in order to accomplish the research objectives.

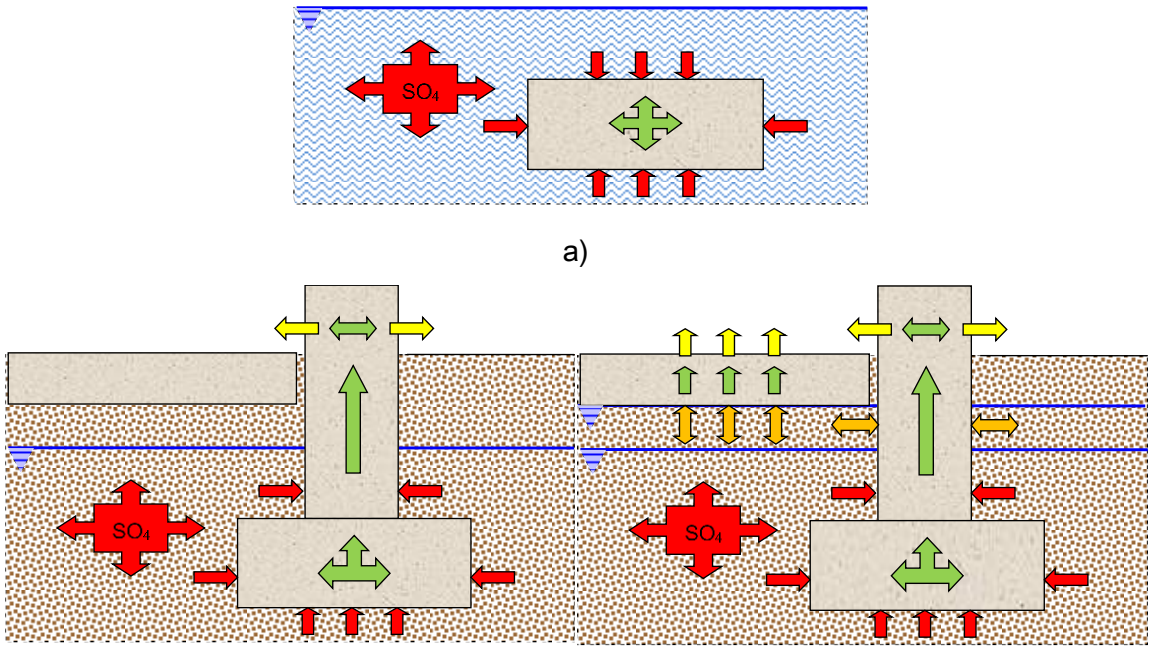


Figure 3.1.1: Examples of transport mechanism encountered for structural elements: a) diffusion, b) wicking and c) cyclic absorption and evaporation combined with wicking.

In order to adequately represent field exposure parameters and compare them with current means of testing, the laboratory specimens were exposed to two different

solution concentrations; the standard ASTM concentration (5% Na_2SO_4) and a concentration more representative of field exposure (2% Na_2SO_4). A total of four exposure regimens were replicated to compare the differences between each transport mechanism. These regimens were designed to adequately represent the transport mechanisms generally encountered in the field: diffusion, absorption/evaporation cycles, wicking and wicking combined with absorption/evaporation cycles. The latter transport mechanism was considered to be the most representative of true field conditions. (Figure 3.1.1) This was accomplished in the laboratory by creating a controlled exposure setup and by sealing certain faces of the specimens to create adequate transport mechanisms without causing premature failure induced by tri-dimensional exposure (corner effects).

Novel methods of testing were used in this research to investigate the extent of degradation during the exposure period. In accordance with the experimental outcomes of past research investigations, tensile strength was deemed to be the preferred mechanical property to quantify the level of disruption caused by the exposure regimes regardless of the degradation mechanisms induced. The size and shape of the specimens exposed to the solutions was dictated by the choice of test methods. Such testing could provide further information on which type of degradation mechanism is more detrimental to the structural integrity of concrete (e.g. physical damage vs. paste softening) by analyzing the fracture types. Furthermore, the region of strain localization and initiation of microcrack propagation was determined during loading using acoustic emission (AE) monitoring, which can accurately determine what types of exposure mechanisms are more detrimental to concrete structures in terms of mechanical strength (not physical appearance) and how the deterioration mechanism progresses in service. Finally, complementing the above testing, ultrasonic nondestructive testing methods were performed for all exposure regimes to determine whether they constitute suitable methods for monitoring ongoing attacks in the field.

CHAPTER 4

EXPERIMENTAL PROGRAM

In order to properly assess a degrading concrete structure it is important to utilise appropriate test methods to properly quantify and/or qualify the loss in engineering properties of the concrete. Herein, this study focuses on evaluating the change in engineering properties of sulphate-degraded concrete. The devised experimental procedure investigated both the degradation mechanisms behind the exposure conditions reminiscent of sulphate transport mechanisms in the field and the means to evaluate them. It combined both nondestructive and destructive means of testing with a special interest on tensile behaviour and stiffness characteristics as discussed in previous sections.

4.1 Specimen Preparation

The following section describes the methods by which the specimens were prepared and conditioned prior to long term exposure. This includes a description of the materials used in the making of the concrete mixtures along with their means of quality control, details on sample fabrication and the curing procedure implemented for these specimens, and their exposure regimes.

4.1.1 Materials

The characteristics and properties of each material type, namely: aggregates, portland cement, water and admixtures used to prepare the three types of samples (cylinders, disks and prisms) are detailed in their respective sections.

4.1.1.1 Aggregates

The concrete mixtures were made with crushed granite fine and coarse aggregates, which met the ASTM C 33 standard for concrete coarse and sand composition and gradation. The granitic rock was chosen because of its low reactivity to chemical attack (Kosmatka et al. 2002), which was determined using the CSA A23.2-9A test, (soundness of aggregate exposed to magnesium sulphate). The fine aggregate met the 0-5 mm gradation class and the coarse aggregate corresponded to a 5-14 mm coarse aggregates class. Both aggregates were manufactured from the same source, a granite quarry in the region of St-Hippolyte, Quebec, produced by Sables LG. They were donated by Bauval, Saint-Laurent, QC. The commercial laboratory specification sheets can be viewed in Appendix A. The general qualitative properties used in formulation of the concrete mixture are presented in Table 4.1.1.

Table 4.1.1: Properties of aggregates.

Aggregate	Type	Fineness Modulus	Specific Gravity				Percent Absorption
			Bulk	Rodded	Relative (SSD)	Relative (Dry)	
Fine	Crushed Granite	2.95	-	-	2.72	2.71	0.38
Coarse		-	1.44	1.60	2.73	2.72	0.64

4.1.1.2 Portland Cement

The Portland cement used in the preparation of all concrete mixtures was donated by Lafarge and manufactured at their St-Constant cement plant. According to Canadian specification CAN/CSA-A3000-08, a type GU (general use hydraulic cement) was chosen for this experimental investigation instead of a sulphate resistant cement type in order to accelerate the degradation mechanisms related to sulphate attack. All of the cement used throughout the project came from the same production batch. The manufacturer's mill test is provided in Appendix A.

4.1.1.3 Water

The water used to prepare the concrete mixtures was tap water from the city supply of Montreal, Quebec. No quality control testing was performed on the mixing water, the potable water source was considered to be adequate as concrete mixing water.

4.1.1.4 Admixtures

A set-retarding admixture was used to delay the time of initial set and increase the fluidity of the fresh mixture (since it also acted as a water reducing agent); thus making the mixture more workable for an extend period of time. Given that over 100 samples were cast at the same time from a single batch, this ensured proper compaction of all samples in an appropriate manner. For that purpose, the Daratard 17 admixture was donated by Grace Construction Products, Lasalle, Quebec. The chosen dosage, 195 ml per 100 kg of cement, permitted a set delay of approximately 2 hours. The supplier's specification sheet may be consulted in Appendix A. Further quantitative details on the admixture and the materials described above and the way in which they were batched are provided in Section 4.1.2.

4.1.2 Mixing and Casting Procedures

The present section offers information on the mixture proportions of the materials described in the previous section complete with the desired fresh concrete mixture properties. The casting and conditioning procedures performed for the making the various sample types are also given.

4.1.2.1 Mixture design

Herein, the objective of the study was not to evaluate the effects of cement composition nor specific concrete mixture parameters (e.g. water-to-cement ratio) and their effect on

sulphate durability. Only one mixture design was formulated and used since the study concentrated on evaluating the potential of various test methods for assessing different external sulphate attack regimes. The mixture was formulated using Cement Association of Canada guidelines, *Design and Control of Concrete Mixtures,* 7th ed. The water to cement ratio chosen for this study was 0.48, similar to that prescribed in the ASTM C 1012 standard which evaluates a cement's resistance to sulphate attack. This w/c meets the compressive strength requirements (35 MPa) for a very severe degree of exposure to sulphates (S-1) but only satisfies a moderate degree of exposure (S-3) in terms of water-to-cement ratio (< 0.5 w/c). Although the requirements also specify air entrainment, no air entraining admixture was added to the mix in order to accelerate the attack. (CSA A23.1) The mixture design is detailed in Table 4.1.2.

Table 4.1.2: Concrete mixture design.

Material	Description	Quantity (kg)	
		1.00 m^3	0.055 m^3
Water	Potable, city of Montreal	217.45	11.96
Cement	Type GU	448.18	24.65
Coarse aggregate	5-14 mm, Granitic rock, St-Hippolyte quarry (dry)	848.00	46.64
Fine aggregate	0-5 mm, Granitic rock, St-Hippolyte quarry (dry)	838.00	46.09
Set retarder	Daratard 17, Grace	872.73 ml	48.00 ml

4.1.2.2 Casting steps

The casting of the specimens was carried out within the controlled environment of McGill's construction materials laboratory facilities. To maximize reproducibility, all aggregate preparation, mixing and casting procedures were carried out as per the ASTM C 172 and ASTM C 192 standards. The quality control, by which the desired fresh mix

properties were monitored, was performed in accordance with the standardized procedures. The air contents and slumps were verified for each batch. (ASTM C 143 and ASTM C 231)The design values were 2.5% for air content and 60 mm for slump (140 mm after adding admixture). Measured values varied less than ±10% between batches.

Approximately 700 specimens were made over seven individual casts. The required specimens to accomplish the various destructive and nondestructive testing for one exposure period were made from a single cast to improve reproducibility. Each cast consisted of four 0.055 m^3 batches of concrete to make the following specimens:

- 20 rectangular prisms – 75 mm x 75 mm x 280 mm
- 50 disks – ø150 mm x 100 mm
- 30 cylinders - ø100 mm x 200 mm

The prism and cylinder specimens were prepared in two equal layers, both using vibration as the method of consolidation. For the disks, the specimens were prepared in two equal layers with rodding (25 hits/layer) and slight external vibration to consolidate the fresh concrete into the molds.

The molds used in the making of the ø100 mm x 200 mm long cylindrical specimens conformed to the ASTM C 470 standard. The molds used in the forming of the disk specimens were fabricated from ø152.4 mm (ø6 in) standard schedule 40 polyvinyl chloride (PVC) pipe cut to the desired length (102 ±1 mm). They were each fixed to a treated wood form board using a silicone caulk to seal the bottoms. Lastly, the prism molds complied with the ASTM C 78 standard.

4.1.3 Sample Curing and Conditioning

Once initial set had occurred, approximately 4 hours after mixing, a moist curing regime was initiated by covering the samples with wet burlap loosely sealed under a plastic tarp for a period of 24 hours. The following day, the samples were demolded and stored in ambient laboratory conditions for a period of 7 days. Meanwhile, the specimens were prepared for their respective exposure regimes (described in Section 4.2.1) by applying an epoxy coating (Sikadur 32 – hi-mod) in three consecutive layers to seal the non-exposure surfaces. No additional curing was conducted during this time. This sample conditioning practice was chosen in order to represent true field conditions such as those typically followed in residential construction methods. It is customary in the construction industry to cast in place, remove the forms, and then backfill just a few days after construction. The concrete structure is thus exposed to sulphate-laden soils at a very young age. This phase of field exposure is considered herein.

4.2 Specimen Exposure Regimen

As discussed in the literature review, different exposure conditions and different means by which the water born sulphate ion may enter a cementitious matrix cause diverse deleterious effects. A total of four transport mechanisms were replicated for the various types of samples: diffusion, cyclic absorption/ evaporation, wicking, and wicking combined with cyclic absorption/evaporation. Each transport mechanism was combined with two solutions of different sulphate concentrations, plus a control solution of lime-saturated water. This section describes how they were accomplished experimentally.

4.2.1 Transport Mechanisms

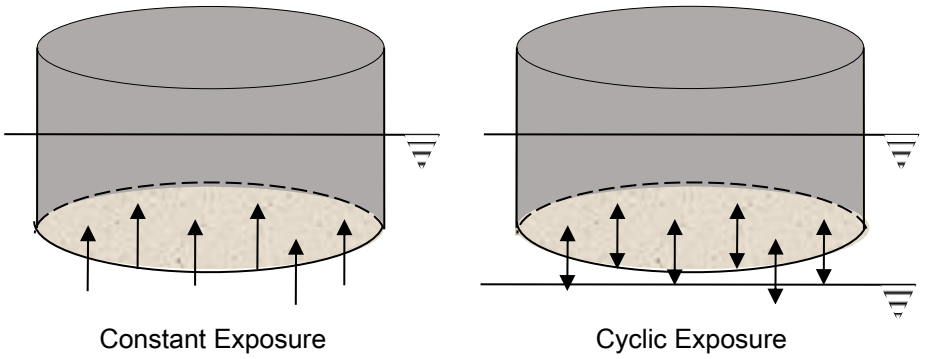


Figure 4.2.1: Uni-dimensional transport mechanisms: a) diffusion and b) absorption/evaporation cycles.

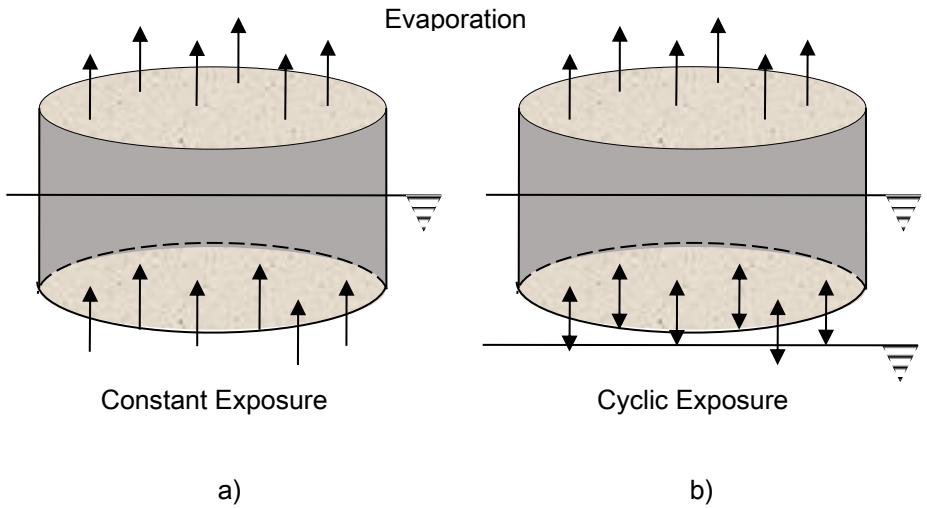


Figure 4.2.2: Uni-dimensional transport mechanisms for disk samples: a) wicking and b) wicking combined with absorption/evaporation cycles.

Starting with the disk specimens; Figure 4.2.1 illustrates two disks sealed on all faces and leaving one face either constantly or cyclically exposed to the solution. The first exposure simulates a one dimensional diffusion transport mechanism, similar to the ASTM C 1012 exposure (Figure 3.2.1a). The second simulates an absorption transport combined with evaporation due to the effects of wetting and drying cycles (Fig 3.2.1b).

Then, in order to simulate changes in moisture gradients within a concrete element which will create a wicking action, one face of a disk was subjected to ambient laboratory conditions while its opposing face remained constantly immersed (Figure 4.2.2a) or cyclically immersed (Figure 4.2.2b).

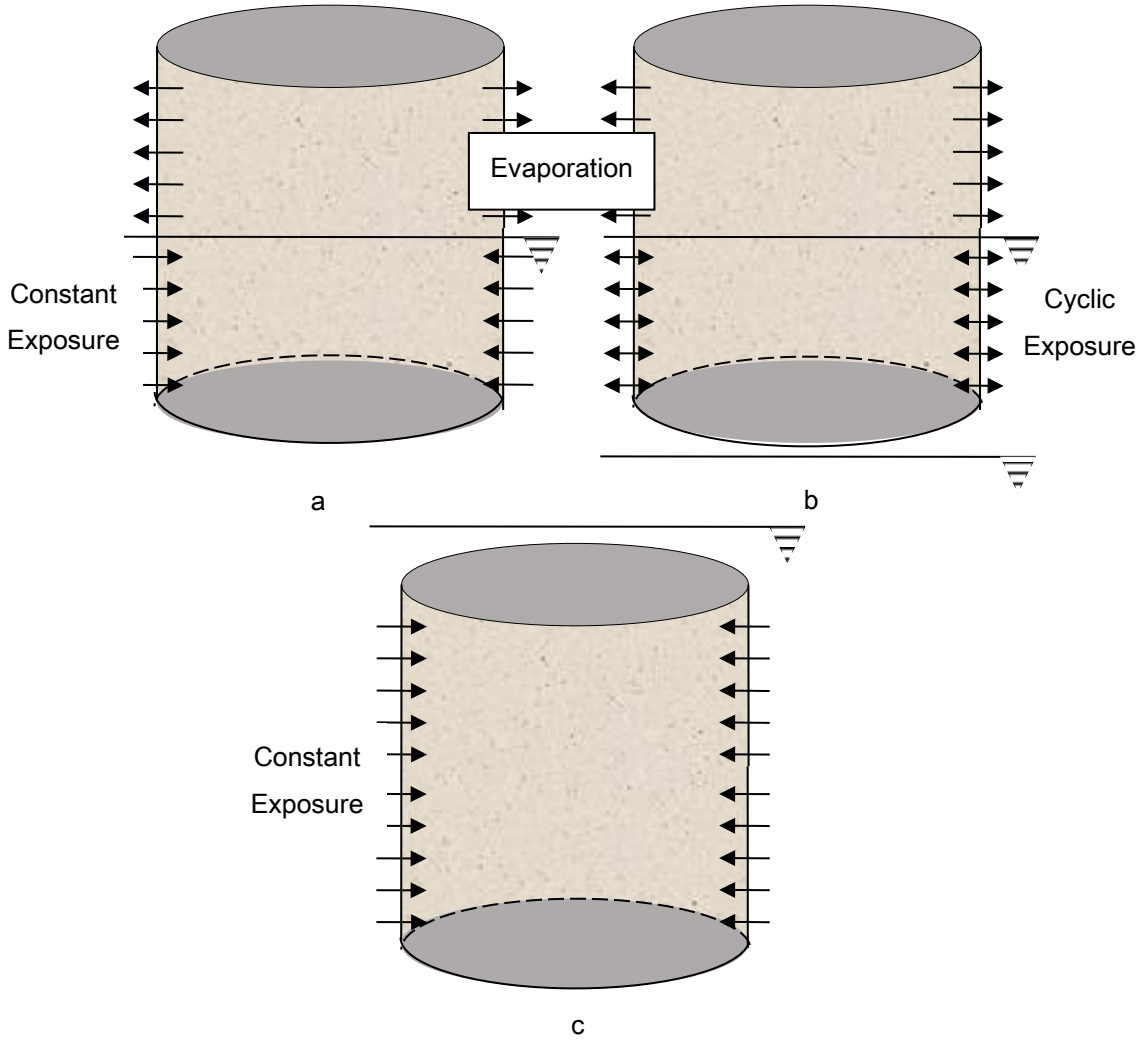


Figure 4.2.3: Bi-dimensional transport mechanisms for cylinder samples: a) wicking, b) wicking combined with absorption/ evaporation cycles and c) diffusion.

This wicking transport mechanism was also recreated for the cylindrical samples partially submerged in solution, where the bottom half of the cylinder was either exposed continuously or cyclically immersed while the top was continually exposed to ambient

conditions (Figure 4.2.3a and Figure 4.2.3b). Finally, complete immersion was used to simulate a third exposure regime for the cylindrical specimens, diffusion only (Figure 4.2.3c). Both end faces of the cylinders were sealed to create a bi-dimensional transport mechanism where the corner effect was eliminated due to the continuous circular exposure surface of the cylinder.

Finally, the prismatic samples also underwent a bi-dimensional transport mechanism where two opposing faces of the prism were constantly or cyclically immersed; the remaining four faces were sealed, again, creating a diffusion mechanism (Figure 4.2.4a) or absorption/evaporation cycles (Figure 4.2.4b).

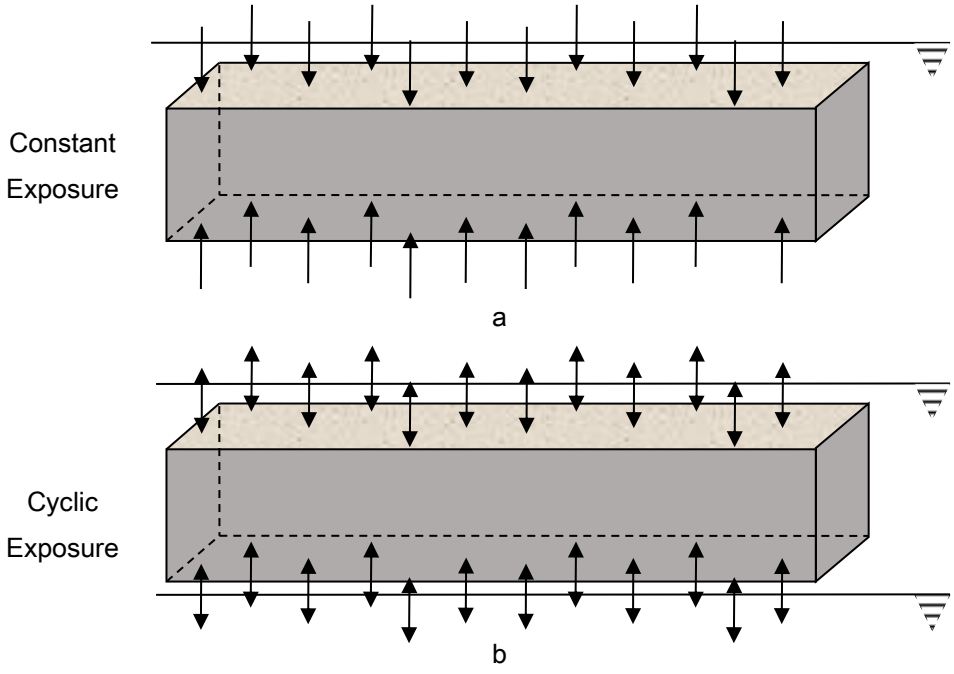


Figure 4.2.4: Bi-dimensional transport mechanisms for prism samples: a) diffusion and b) absorption/evaporation cycles.

4.2.2 Exposure Setup

The exposure regimes were replicated using an elaborate system of tanks connected in series where the three different solutions circulated cyclically from a feeding tank through a pump. (Figure 4.2.5) Through leveled in-flows and out-flows on the exposure tanks, a continuous flow of solution was created and the precise level of immersion was maintained; thus eliminating the effect of solution evaporation. Two wet/dry cycles per day were created by allowing the upper tanks (upper two rows) to drain twice a day via a solenoid valve. Every six hours, a timer would either turn on the solenoid valve to drain the exposure tanks and turn off the pump to stop the solution feed, or turn on the pump and turn off the solenoid valve to fill the exposure tanks with solution again. Therefore, the cyclic samples were in contact with the solution for 6 hours and allowed to dry for 6 hours.



Figure 4.2.5: Setup for long-term solution exposure.

This mimicked conditions encountered in the field where marine structures are affected by bi-daily tidal action; the concrete will suffer the adverse effects of wet/dry cycles with the ionically aggressive seawater. The connected tank system also ensured that all 124

ponding samples were subjected to the same solution at any given time. This eliminated the variation in exposure parameters arising when using multiple separate tanks.

The setup was housed in a temperature controlled closed room with constant exhaust ventilation. The ambient room temperature was kept at 23°C. Temperature readings of the exposure solutions were taken periodically in the tanks. Temperatures recorded ranged between 21.4°C and 23.7°C.

4.2.3 Solution Preparation

The specimens strategically placed in the exposure tanks were exposed to one of the two different solution concentrations: the ASTM C1012 standard 5% Na_2SO_4 concentration or a 2% Na_2SO_4 concentration classified as a severe field exposure. (CSA A23.1) Meanwhile, the control specimens were exposed to lime-saturated water to prevent leaching of the alkalis and soluble calcium compounds of the cementitious matrix. The solutions were prepared by diluting a measured quantity of reagent grade sodium sulphate salt with potable water from the city supply of Montreal, Quebec. The sulphate solutions were changed monthly to replenish the amount of available sulphates for reaction with the concrete. The control solution was prepared by adding lime to the tap water until it could no longer dissolve the added salt (i.e. until it reached saturation). However, to minimize leaching effects every time there was a solution change, the limewater solution was only changed once during the course of the exposure terms. For the latter, as well as the sulphate solutions, the feeding tanks were periodically replenished with potable water to compensate for evaporation in order to maintain their levels of concentration. In each case, samples were exposed to their respective solution for periods of 3, 6, 12, 18 or 24 months. Table 4.2.1 provides a brief description of the significance of the nomenclature used to identify each specimen according to sample type exposure regimen and exposure age.

Table 4.2.1: Specimen nomenclature.

Sample Type	Duration (Months)	Solution Concentration	Transport Mechanism
C: Cylinder	**03**	**LW0**: Limewater	**A** :Diffusion
D: Disk	**06**	**SS2**: 2% Na_2SO_4	**C** :Cyclic Sorption/Evaporation
P: Prism	**12**	**SS5**: 5% Na_2SO_4	**W** : Wicking
	18		**F**: Field
	24		

4.3 Specimen Testing Program

As discussed in the Methodology section, various test procedures were chosen for evaluating the extent of degradation caused by the ingress of sulphate compounds. The testing regimen chosen focused on the mechanical properties of the degraded material at two structural levels of the material's matrix (macrostructural and microstructural) to assess its behaviour after being subjected to aggressive sulphates.

Table 4.3.1: Summary of experimental procedures.

Sample Type	Exposure Regimen	Experimental Procedure
Cylinders	Diffusion (A)	54 kHz Longitudinal UPV
	Wicking (W)	300 kHz Diametral UPV
	Field (F)	Gas Pressure Tension Test
Disks	Diffusion (A)	Splitting Tensile Test
	Cyclic sorption/evaporation (C)	Acoustic Emission Monitoring
	Wicking (W)	
	Field (F)	
Prisms	Diffusion (A)	Third Point Bending Test
	Cyclic Sorption/Evaporation (C)	

Nondestructive ultrasonic testing and mechanically destructive testing were used to qualify and quantify the change in engineering properties over the exposure's time

period. The test procedures devised for each specimen type are listed in Table 4.3.1 and described in the next sub-sections.

4.3.1 Tests Procedures for Cylindrical Specimens

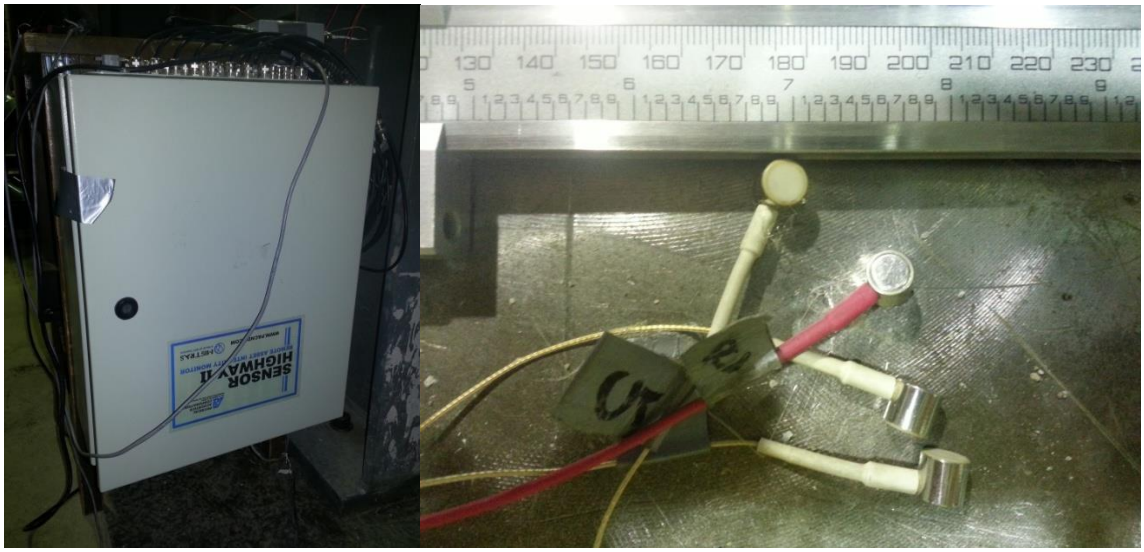
The standard cylindrical specimen with 100 mm x 200 mm dimensions was used to evaluate the effects of an evaporative plane on sulphate migration through a cementitious matrix and the damage caused along its path. To do so, a procedure was devised to minimize the variability of each individual experimental result while maximizing reliability of the data. Before commencing the series of tests, the samples were completely submerged in potable water containing lime for a period of 5 ± 0.5 days. All tests needed to be carried out in saturated conditions to ensure positive results. All tests were conducted in a controlled environment within the Construction Materials laboratory at McGill University, Montreal, Quebec.

4.3.1.1 54 kHz Longitudinal Ultrasonic Pulse Velocity Test

The ultrasonic pulse velocity test (UPV) was carried out according to the specifications listed in the ASTM C 597-09 standard. The longitudinal transit time of an emitted 54 kHz pulse was measured using a PUNDIT device. First, the specimen ends were smoothed using an automatic surface grinder to ensure maximal contact between the concrete face and transducer. A water based couplant gel was applied onto the transducers and they were firmly pressed against the surface. During pulse emission, the transit time was recorded once the device displayed a steady reading. The procedure was repeated twice, by alternating the emitting and receiving transducers. The results were considered acceptable if the difference between both readings was less than 0.3 μs which corresponds to a percent difference lower than 2% as recommended in the standard. To calculate the velocity, the length of the cylinder was measured with a digital caliper (0.01 mm accuracy). Two readings were taken along the longitudinal axis of the cylinder.

4.3.1.2 300 kHz Diametral Ultrasonic Pulse Emission Test

In order to compare the extent of damage induced by the migrating sulphates within the porous matrix, a damage rating profile was created for each cylinder by comparing the change in parameters of a sonic pulse emitted by 300 kHz resonant sensors. The principle of the test followed the requirements listed in the ASTM C597 standard. The test was performed using a Highway II acoustic emission (AE) monitoring system, from Physical Acoustics Corporation (Figure 4.3.2a). The Nano30 miniature sensor was chosen for its small size and high sensitivity, which could be glued onto the circular surface without losing contact sensitivity (Figure 4.3.2b).



a) b)

Figure 4.3.2: a) Highway II AE system and, b) Nano30 sensors.

The pulsing capability of the resonant sensor made it possible to use the Automatic Sensor Test (AST) feature integrated in the AE system's operating software AEWIN. During the AST test, the emitting sensor produces a sonic pulse and the receiver registers all parameters of the transient wave.

As seen in Figure 4.3.3, each sensor was fixed onto the circular surface of the cylinder using hot glue. Readings were taken every 25 mm along two diametral axes, at 90

degrees to each other, for the entire length of the cylinder. The information was saved in data files from which the desired wave parameters could be found. For the purpose of this study the transit time, amplitude, and energy of the wave were of interest. To calculate the velocity of the wave, diametre measurements were taken every 25 mm, at the sensors' positions, along both diametral axes.

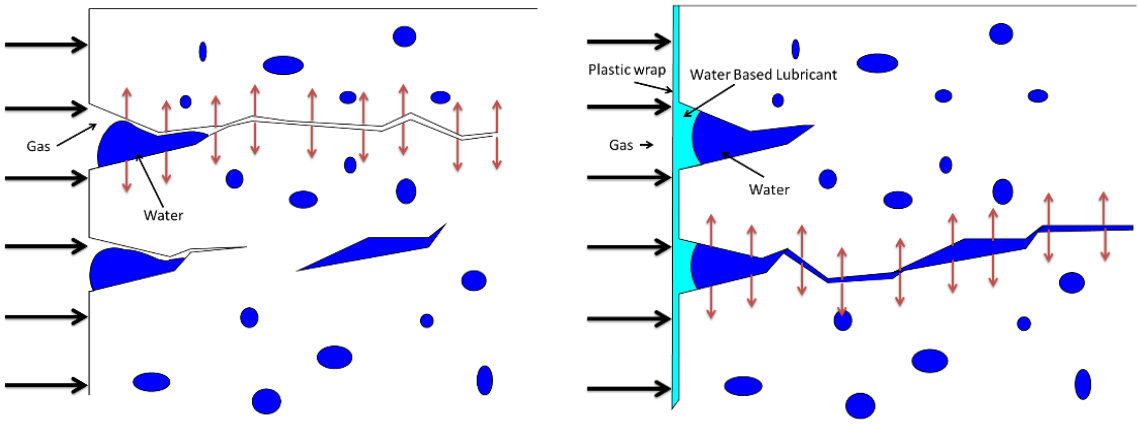


Figure 4.3.3: Diametral ultrasonic pulse emission test.

4.3.1.3 Gas Pressure Tension Test

There are no existing standards covering a test procedure for determining the tensile strength of concrete using the gas pressure method; therefore, a series of tests were conducted on control samples prior to the investigation on the sulphate deteriorated samples. Based on past investigations (Boyd and Mindess 2004) (Uno et al. 2011), the test apparatus was refined and the experimental method was developed by McGill's Construction Materials Research Group (Komar et al 2013). One concern raised during these investigations was the fact that the gas pressure was distributed on an uneven surface; the physically damaged zone presenting a micro-cracked porous surface versus a pristine looking zone assumed to have withstood chemical changes. According to the proposed failure mechanism theory discussed in Chapter 2.2.3, the development and propagation of a tension crack would be facilitated in the physically damaged zone.

(Figure 4.3.4a) In order to maximize internal pressure distribution and minimize the effects of gas penetration potentially causing a premature failure, a surface coating was applied prior to testing. (Figure 4.3.4b)



a) b)

Figure 4.3.4: Propagation of a tension crack during pressure tension test: a) without surface coating and b) with surface coating.

Plastic wrap was chosen because of its durability, flexibility without influencing the specimen's mechanical behaviour while loading. Before enveloping the sample, a generous amount of water-based lubricant was applied on the surface of the sample. This enabled the plastic wrap to properly adhere to the surface of the concrete while avoiding air pockets between the wrap and the concrete's surface thus a uniform load distribution over the uneven surface is maximize. A layer of PVC tape was still used at both ends of the cylinder to provide a good air seal at the ends of the pressure chamber. Then, the sample was fixed in the chamber and the gas pressure was applied at a computer controlled rate of 0.1 MPa/s. (Figure 4.3.5) The load rate was chosen in accordance with other standard means of tension testing such as the Brazilian test. The ultimate pressure at failure was recorded as the tensile strength of the concrete sample. The location of the failure plane was also recorded for comparison purposes.



Figure 4.3.5: Gas pressure test apparatus.

4.3.2 Tests Procedures for Disk Specimens

150 mm x 100 mm long pucks were used to assess the effects of uni-dimensional sulphate transport mechanisms through a cementitious matrix. Tensile testing and acoustic emission methods are of interest as viable means to quantify and qualify the extent of degradation in terms of engineering properties. All tests were carried out under the same conditions as previously described.

4.3.2.1 54 kHz Longitudinal Ultrasonic Pulse Velocity Test

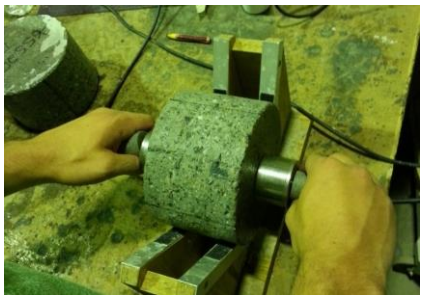


Figure 4.3.6: Ultrasonic Pulse velocity test on puck specimen.

The ultrasonic pulse velocity measurements were conducted in the same manner as described in Section 4.3.1.1.; except that the end surfaces of the concrete samples were smoothed using a lathe. (Figure 4.3.6) UPV measurements were taken to conduct initial analysis of event localization using acoustic emission monitoring, as the speed of the transient pulse is required to compute the point location coordinates.

4.3.2.2 300 kHz Diametral Ultrasonic Pulse Emission Test

The test procedure to determine the diametral ultrasonic pulse velocities of the disk samples was conducted in the same way as described in Section 4.3.1.2. In this case, the amplitude and energy wave parameters were not compiled, only the transit time was recorded to calculate the velocity, which was required to conduct acoustic emission localization during the splitting tension loading.

4.3.2.3 Splitting Tensile Test

In order to assess changes in tensile properties of the different sulphate related degradation mechanisms, the standardized splitting tensile test was utilised. The test was carried out in accordance with the procedures stated in the ASTM C 496 standard entitled *Standard Test Method for Splitting Tensile Strength of Cylindrical concrete Specimens.* The experimental setup utilised a standard metal frame to hold the specimen on its long axis during loading. A thin wooden platen was placed at the interfaces of the concrete and loading device to enable even load distribution (Figure 4.3.7).

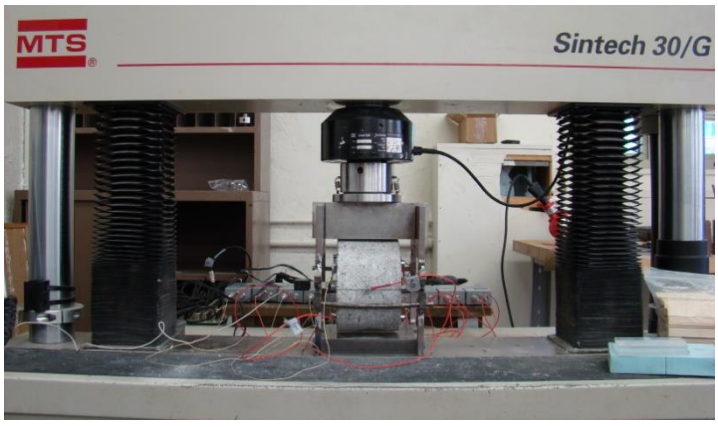
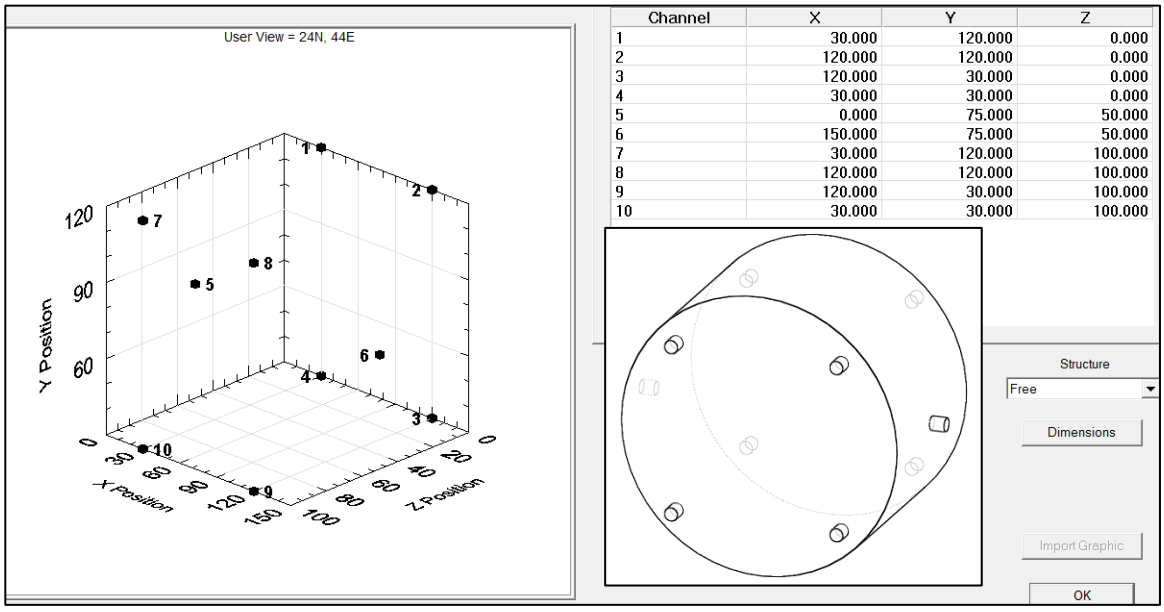


Figure 4.3.7: Splitting tensile test apparatus and disk specimen.

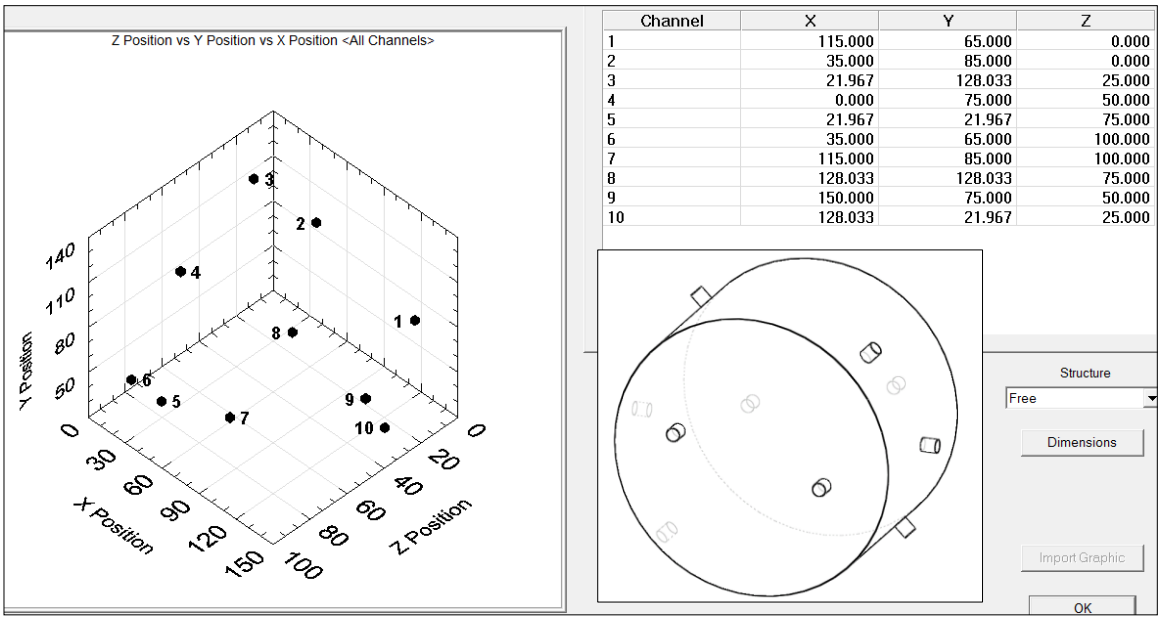
4.3.2.4 Acoustic Emission Monitoring and Localization

As described in the literature review, AE as proven to be a useful tool to monitor ongoing physical and chemical changes within a specimen when subjected to a source of stress. In this case, AE monitoring was used to detect events within the concrete samples during splitting tension loading. These events caused by external loading are assumed to be linked to the initiation and propagation of microcracks. Moreover, the presence of disparities due to the effects of long-term solution exposures may also emit stress-waves due to the closing and opening of cracked surfaces and the friction between them.

The same AE system and sensors described in Section 4.3.1.2 were used. A minimum of 7 sensors, and maximum of 10, were strategically glued onto the surface following a triangular pattern as shown in Figure 4.3.8. The sensor configuration corresponding to Setup 1, Figure 4.3.8a, was used at the beginning of the experimental program. Due to low event locability with the latter, the sensor positioning was changed to maximize source localization knowing the directionality of the failure plane. The demonstrated sensor configuration in Figure 4.3.8b demonstrated superior results.



a)



b)

Figure 4.3.8: Schematic sensor identification and location on disk specimen:

a) Setup 1 and b) Setup 2.

A series of parameters related to the hardware and software were entered in AEWIN which may be consulted in Table 4.3.2. These parameters were chosen according to common practice in acoustic emission monitoring of concrete structures. The only parameter that varied during the course of testing was the event threshold; it varied between 35 dB and 45 dB. It was determined by trial prior to commencing a series of tests to make sure no exterior noise would interfere with ongoing tests. If there were no major lab activities or running machinery in the vicinity of the loading press, a threshold of 35 dB was adequate to eliminate undesired signals and maximize recording of low level signals emitted by the stressed concrete sample.

Table 4.3.2: Acoustic emission hardware parameters in AEWIN.

Threshold	Signal Amplification	High Pass Analog Filter
35 to 45 dB	40dB	20 kHz

In order to localize AE events, the wave speed of the concrete sample being tested must first be determined. Herein, both the averages of the longitudinal 54 kHz and the 300 kHz diametral pulse velocity results, obtained for the sample being tested, were compared. Thereafter, the localized events were mapped using a colour scale signifying the signal strength levels of the events as per wave characteristics of interest (amplitude and energy). This map helped in the identification of strain commencement due to disparities within the degraded concrete matrix. Moreover, it offered information on the effects of sulphate transport mechanisms and their related degradation patterns.

4.3.3 Tests Procedures for Prism Specimens

Finally, the last test performed to determine the response of a prism under tensile stress was the flexural loading test. Standard 75 mm x 75 mm x 280 mm prismatic samples were subjected to a third-point bending test in order to help assess the influence of solution concentration along with exposure conditions on flexural strength properties. All tests were carried out under the same conditions as previously described; however, only two transport mechanisms where evaluated, the diffusion mechanism and the cyclic absorption/ evaporation mechanism.

4.3.3.1 Flexural Test

The test was carried out in accordance with the procedures stated in the ASTM C 78 standard entitled *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).* The experimental setup utilised a standard metal frame insuring adequate load transfer through the middle third of the specimen. (Figure 4.3.9)



Figure 4.3.9: Flexural test apparatus and prism specimen.

CHAPTER 5

RESULTS AND DISCUSSION

As sulphate compounds migrate through a cementitious medium, a series of chemical and physical interactions take place, causing the concrete material to deteriorate over time and result in changes to engineering properties. These changes will eventually distress the integrity of an affected concrete structure. Therefore, it is of importance to properly understand the behaviour of the attack mechanisms, and how they progress over time, based on quantifiable mechanical properties. This experimental program attempted to provide these answers. Through analysis of the obtained experimental results, the next chapter presents a discussion on the behaviour by which the concrete specimens responded to their exposure regimes.

5.1 Condition Assessment of Cylindrical Samples

In a first attempt to understand the change in mechanical behaviour of concrete subjected to external sulphate attack, standard 100 mm x 200 mm cylindrical samples were subjected to a series of tests (ultrasonic and tensile testing) to help distinguish particularities related to each exposure condition and assess their consequence on concrete durability.

5.1.1 Comparative Study of 54 kHz Longitudinal Ultrasonic Pulse Velocity Test

As reported in Section 2.3 of the Literature Review, ultrasonic pulse velocity (UPV) testing has long been utilised as a means to estimate the strength of a concrete material without the need for destructive testing. UPV is a widely used nondestructive technique for assessing in-situ conditions of concrete structures. It is particularly sensitive to the

presence of voids and cracks in a porous concrete material (e.g. changes in density properties); which makes it a favourable tool to detect deficiencies within a concrete structure. For the purpose of this study, the standard procedure for determining the speed of a 54 kHz ultrasonic compressional wave (ASTM C597) was used to evaluate whether the cylindrical specimens exposed to the various exposure regimens sustained any microstructural changes over time.

Figures 5.1.1 to 5.1.5 demonstrate the UPV test results obtained per exposure period. Each sulphate exposure regime was compared with the control exposure, complete immersion in limewater (LW0A), for their corresponding exposure period. Each individual result represents the average value recorded for three replicate cylinders. (Appendix B) For comparison purposes, the standard deviations were computed for each sample and plotted on the results chart. Symbolized by a dash, one standard deviation above and below the corresponding average are shown (±1σ). Between these limits, the ranges of values represent a margin of error within a 68% confidence interval. Representing a margin of error for a 95% confidence interval, two standard deviations above and below the charted values are symbolized by a diamond (±2σ). In addition, the 95% confidence interval error margin for the control sample is plotted as two dashed lines (±2σ LW0A). Any results falling outside this range were considered to be statistically different. In this case, exterior results will be considered to be a causal effect of the exposure regimes on the concrete's properties and not part of the inherent variation of the experimental test procedure.

In order to evaluate whether the test procedure remains adequate to assess the properties of deteriorating concrete, an F-test was performed to test for equality of the variances. In turn, a two-tailed normal distribution pooled-variance student's t-test was also performed to test for the equality of the means between exposure regimens. For both instances, the calculated p-values may be viewed in Tables 5.1.1 to 5.1.5. The analysis was conducted with a level of significance (α) equal to 0.05. Any results below

0.05 (i.e. probability of 1 in 20) were considered to be statistically different; therefore, a causal effect of the exposure regimes on the concrete's properties. As a visual reference, the cells demonstrating significantly different results between specimen pairs are shaded in grey. This comparative statistical analysis will further help in evaluating whether UPV testing is a viable method for assessing ESA related deterioration.

5.1.1.1 Longitudinal UPV Results after 3 Months of Solution Exposures

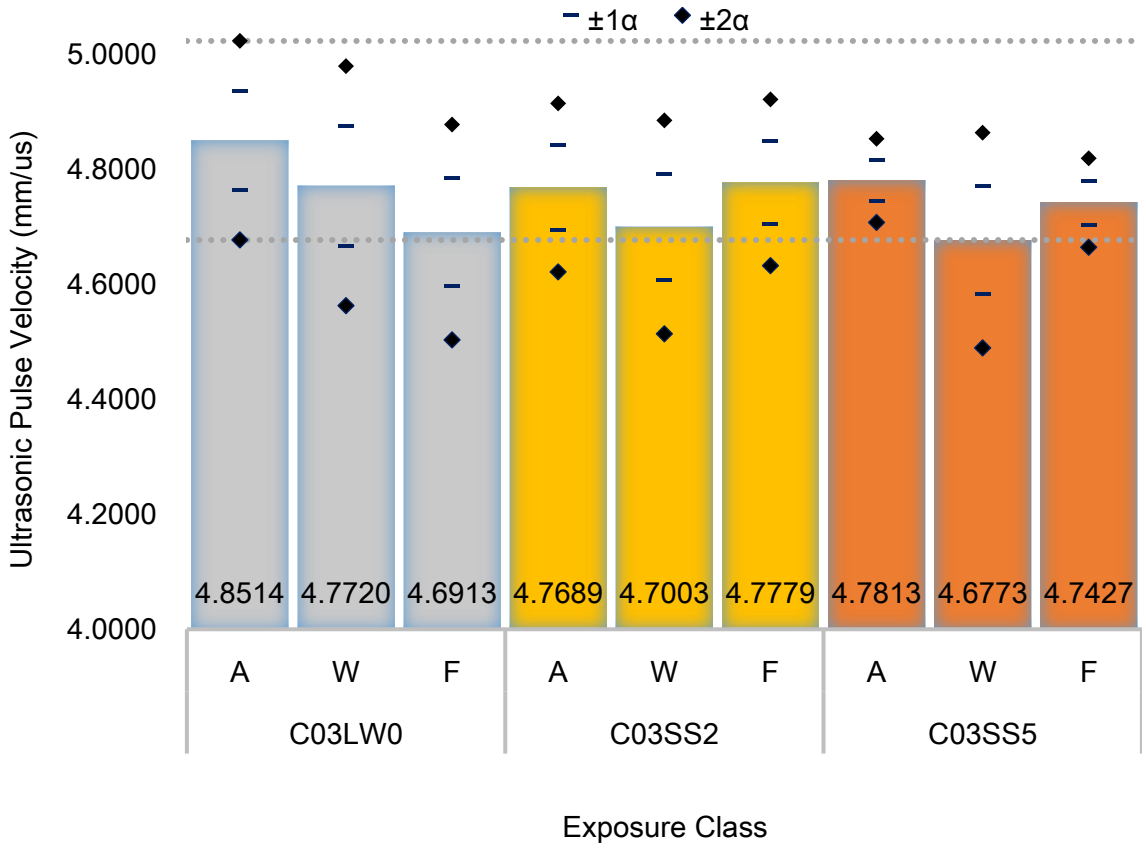


Figure 5.1.1: Ultrasonic pulse velocity results and sample statistics: cylindrical specimens, 3-month solution exposure period.

The initial set of results noted after 3 months of solution exposure can be viewed in Figure 5.1.1. With a coefficient of variation (CV) equal to 1.79%, all results fall within one standard deviation (±1σ) of the control sample; therefore, the results are considered

to be statistically similar. Although the CVs fall within the allotted 2% stated in the ASTM C597 standard, these are the highest noted for the 54 kHz UPV testing program.

Also seen in Table 5.1.1, the results of the t-test also support the above analysis. After 3 months of solution exposure, there is no evidence of damage which may be detected using UPV testing even if there are visual signs of minor physical damage above the immersion line, at the evaporation plane of the cylinder's surface (Appendix B). As described in literature, ultrasonic testing sensitive is to changes of bulk concrete properties. As the wave propagates through the concrete matrix its velocity may change depending on the matrix's microstructural composition. Here, sulphate ingress may not be advanced enough to affect the core of the concrete cylinders.

Table 5.1.1: Results of F-test and t-test for verification of equality of two sample variances and means: cylindrical specimens, 3-month solution exposure period.

Specimen Exposure	t-Test								
	C03LW0A	C03LW0W	C03LW0F	C03SS2A	C03SS2W	C03SS2F	C03SS5A	C03SS5W	C03SS5F
C03LW0A	1.000	0.368	0.096	0.277	0.109	0.323	0.266	0.077	0.118
C03LW0W	0.817	1.000	0.375	0.969	0.424	0.940	0.891	0.307	0.672
C03LW0F	0.921	0.894	1.000	0.322	0.912	0.274	0.196	0.863	0.430
C03SS2A	0.834	0.662	0.759	1.000	0.372	0.888	0.807	0.253	0.613
C03SS2W	0.930	0.885	0.991	0.767	1.000	0.318	0.233	0.778	0.506
C03SS2F	0.822	0.650	0.747	0.987	0.755	1.000	0.945	0.215	0.499
C03SS5A	0.300	0.218	0.262	0.396	0.267	0.404	1.000	0.148	0.277
C03SS5W	0.922	0.894	0.999	0.759	0.992	0.747	0.263	1.000	0.326
C03SS5F	0.333	0.243	0.292	0.437	0.296	0.445	0.939	0.292	1.000
	F-Test								

5.1.1.2 Longitudinal UPV Results after 6 Months of Solution Exposures

After a 6-month exposure period, the results in Figure 5.1.2 and Table 5.1.2 demonstrate that the specimens exposed to a wicking transport mechanism and those exposed to a combination of the latter with absorption and evaporation cycles are different from their control sample. The drop in wave velocity is indicative of two ongoing mechanisms. First, a differential curing regime where only half of the cylinder is hydrating since it is immersed in solution while the other half (exposed to ambient conditions) may not achieve the same level of hydration due to lack of moisture; second, the onset of an ESA degradation mechanism changing the concrete's matrix properties.

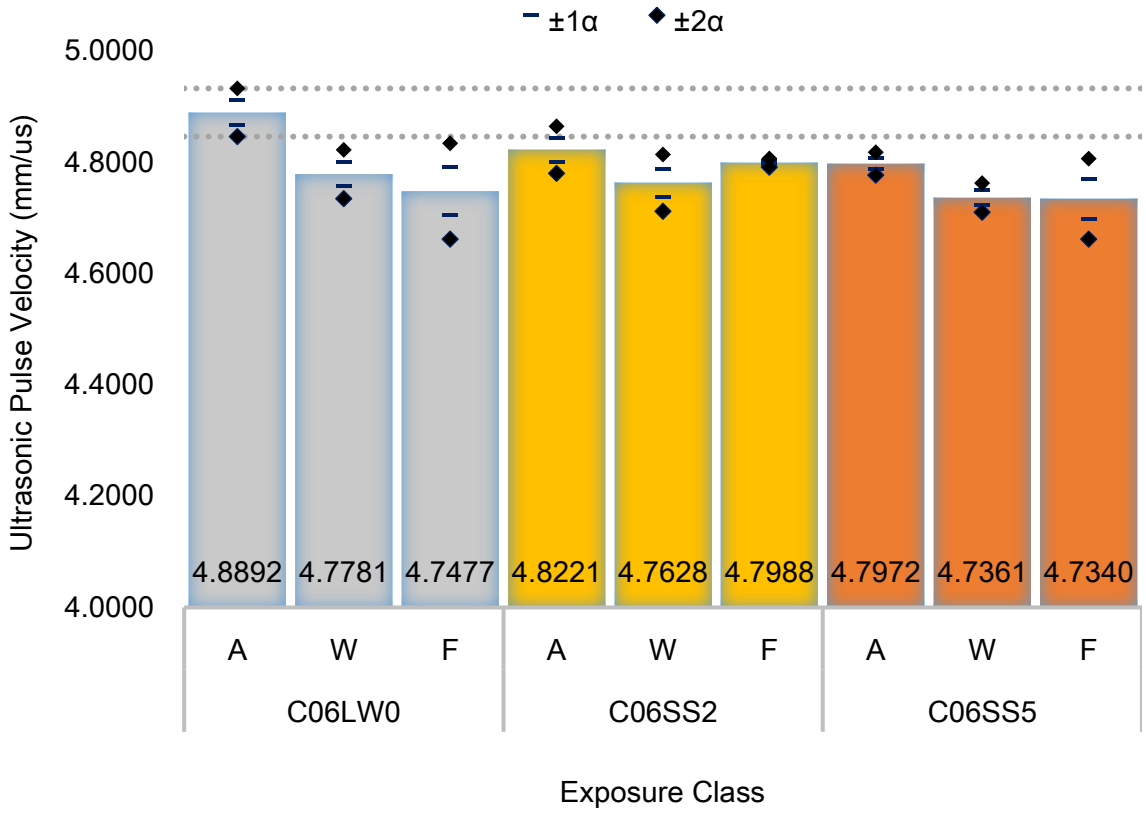


Figure 5.1.2: Ultrasonic pulse velocity results and sample statistics: cylindrical specimens, 6-month solution exposure period.

The second proposed mechanism is also valid for the samples where sulphate entered the cementitious matrix via a diffusion based mechanism only. For both solution concentrations, 2% and 5% Na_2SO_4, the UPV results are respectively lower by 1.37% and 1.88% than that of the limewater control.

Table 5.1.2: Results of f-test and T-test for verification of equality of sample variances and means: cylindrical specimens, 6-month solution exposure period.

Specimen Exposure	T-Test								
	C06LW0A	C06LW0W	C06LW0F	C06SS2A	C06SS2W	C06SS2F	C06SS5A	C06SS5W	C06SS5F
C06LW0A	1.000	0.003	0.007	0.019	0.003	0.016	0.003	0.000	0.003
C06LW0W	0.989	1.000	0.337	0.067	0.474	0.242	0.244	0.046	0.145
C06LW0F	0.406	0.413	1.000	0.055	0.629	0.175	0.125	0.678	0.695
C06SS2A	0.975	0.964	0.389	1.000	0.036	0.192	0.141	0.004	0.022
C06SS2W	0.840	0.851	0.520	0.815	1.000	0.132	0.096	0.182	0.323
C06SS2F	0.061	0.060	0.016	0.064	0.045	1.000	0.823	0.001	0.089
C06SS5A	0.370	0.363	0.109	0.385	0.282	0.244	1.000	0.003	0.044
C06SS5W	0.532	0.524	0.169	0.552	0.416	0.160	0.770	1.000	0.929
C06SS5F	0.529	0.538	0.828	0.510	0.664	0.022	0.151	0.231	1.000
F-Test									

5.1.1.3 Longitudinal UPV Results after 12 Months of Solution Exposures

The trend previously observed after 6 months of solution exposure is not consistent with the results obtained after one year of exposure. For the 5% Na_2SO_4 diffusion mechanism (C12SS5A), although the average velocities are similarly lower than the control by 1.29%, both samples are considered to be the same. (Figure 5.1.3) Here, the higher CV obtained for the C12SS5A sample (1.19%) in comparison to C12LW0A's CV (0.3%) is responsible for the probability value (0.143) obtained from the t-test. (Table 5.1.3) An

increase in coefficient of variation of test results is often observed when evaluating deteriorated concrete, since the degree in damage may not be exactly the same for all replicates at the evaluated age. (Boyd and Mindess 2004) Hence, the properties of damaged concretes are not as uniform as pristine concrete which represents an added challenge to comparative assessment. However this fact was not noticed for the C12SS5W and C12SS5F specimens. The partially immersed specimens recorded lower velocities with a high reliability (0.21% and 0.11% CVs respectively) making them statistically distinct from the control specimen.

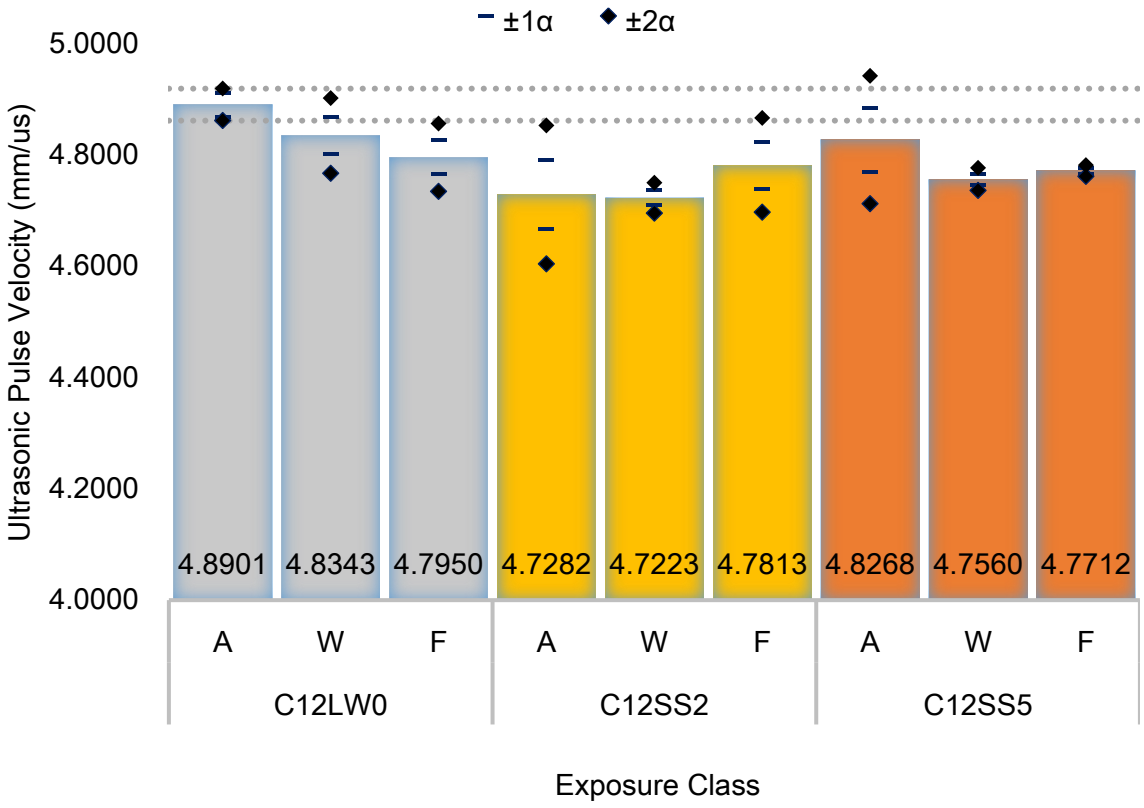


Figure 5.1.3: Ultrasonic pulse velocity results and sample statistics: cylindrical specimens, 12-month solution exposure period.

Table 5.1.3: Results of f-test and T-test for verification of equality of sample variances and means: cylindrical specimens, 12-month solution exposure period.

Specimen Exposure	t-Test								
	C12LW0A	C12LW0W	C12LW0F	C12SS2A	C12SS2W	C12SS2F	C12SS5A	C12SS5W	C12SS5F
C12LW0A	1.000	0.058	0.008	0.012	0.000	0.014	0.143	0.002	0.002
C12LW0W	0.307	1.000	0.209	0.060	0.006	0.165	0.861	0.056	0.088
C12LW0F	0.365	0.897	1.000	0.170	0.020	0.673	0.462	0.194	0.374
C12SS2A	0.101	0.456	0.387	1.000	0.886	0.289	0.173	0.593	0.423
C12SS2W	0.944	0.279	0.333	0.091	1.000	0.083	0.047	0.060	0.019
C12SS2F	0.207	0.778	0.682	0.633	0.187	1.000	0.375	0.488	0.770
C12SS5A	0.115	0.462	0.400	0.906	0.103	0.615	1.000	0.229	0.306
C12SS5W	0.890	0.414	0.457	0.228	0.931	0.333	0.222	1.000	0.199
C12SS5F	0.482	0.210	0.233	0.115	0.508	0.168	0.112	0.589	1.000
F-Test									

5.1.1.4 Longitudinal UPV Results after 18 Months of Solution Exposures

For the first time, the wave velocity surpassed the control's after 18 months of diffusion based exposure. In Figure 5.1.4, the average values for the C18SS2A and the C18SS5A samples are higher by 2.71% and 0.17%, the latter not sufficiently higher to be considered significantly different though. The calculated CV (2.45%) is the highest noted for the UPV testing program but, according to the F-test, the sample variance may still be considered acceptable with a probability of 5.3%. (Table 5.1.4) This increase in wave velocity may be attributed to the changing cementitious phases as a result of gypsum and ettringite corrosion, which tend to fill surrounding micro-voids. As reviewed in Sections 1.1 and 1.3, the presence of fewer medium boundaries and denser matrix, due to filling of the pores with a solid of greater density then air or water for that matter, increases the wave propagation velocity.

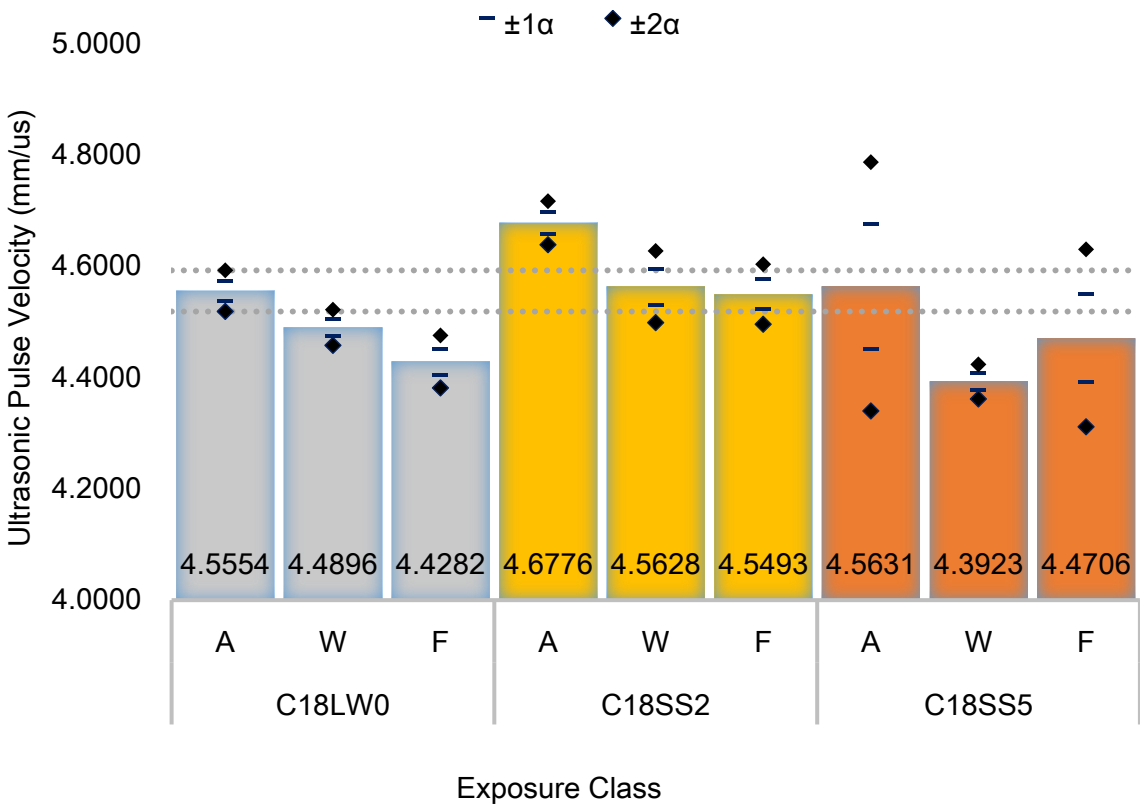


Figure 5.1.4: Ultrasonic pulse velocity results and sample statistics: cylindrical specimens, 18-month solution exposure period.

As this process takes place for the diffusion samples, it seems to also be responsible for the increases in transient wave velocity for the other 2% sulphate exposure mechanisms, wicking and field. The densification process in the lower half exposed to the sulphate solution seems to have reverse the effects noticed at younger exposure ages for the 2% Na_2SO_4 solution only. Here, the samples are considered to be similar with average values differing by only 0.16% and -0.13% (C18SS2W and C18SS2F) from the control's average. As for the 5% sulphate partially exposed specimens, the specimens recorded a decrease in average velocities of 3.58% and 1.86%. The wicking regime is the only specimen considered to be different (Figure 5.1.4 and Table 5.1.4) due to the high coefficients of variation obtained for the other two 5% sulphate regimens.

Table 5.1.4: Results of f-test and T-test for verification of equality of sample variances and means: cylindrical specimens, 18-month solution exposure period.

Specimen Exposure	t-Test								
	C18LW0A	C18LW0W	C18LW0F	C18SS2A	C18SS2W	C18SS2F	C18SS5A	C18SS5W	C18SS5F
C18LW0A	1.000	0.010	0.002	0.001	0.746	0.765	0.916	0.000	0.147
C18LW0W	0.860	1.000	0.020	0.000	0.024	0.030	0.373	0.002	0.722
C18LW0F	0.761	0.634	1.000	0.000	0.004	0.004	0.167	0.092	0.427
C18SS2A	0.942	0.804	0.817	1.000	0.006	0.003	0.216	0.000	0.012
C18SS2W	0.494	0.397	0.697	0.539	1.000	0.608	0.996	0.001	0.137
C18SS2F	0.638	0.523	0.865	0.690	0.824	1.000	0.846	0.001	0.181
C18SS5A	0.053	0.040	0.085	0.059	0.153	0.110	1.000	0.115	0.308
C18SS5W	0.832	0.971	0.609	0.776	0.379	0.501	0.038	1.000	0.228
C18SS5F	0.102	0.078	0.160	0.113	0.280	0.205	0.675	0.073	1.000
	F-Test								

5.1.1.5 Longitudinal UPV Results after 24 Months of Solution Exposures

First, looking at the variance in the results, the calculated CV for the control sample (0.14%) is quite low. In this case, the reliability of UPV testing for a mature concrete sample is very good. This is in accordance with past research investigations on ultrasonic testing where the reliability of the test method increases for mature concretes. (Carino 1997) The CVs obtained for the degraded samples vary between 0.10% and 1.18% which is still considered to be very low and within acceptable standard limits. However, the results obtained from the F-test suggest that there are differences between the results' variances for specimens C24SS2A, C24SS2W and C24SS5F. A coefficient of variation above 0.9% for the degraded specimens was significant enough to differentiate the effects of the test procedure or the samples themselves.

Next, looking at the measured velocities, the increase in velocity observed for the 18-month samples is not noticed after 24 months of exposure. The velocities are lower than the control sample for all regimen types. As seen in Figure 5.1.5, the velocity trend diminishes with an increase in solution concentration and with transport mechanism. They are considered to be statistically different. The exception, C24SS2A is statistically equal to the control according to the results of the t-test (Table 5.1.5) and the standard deviation interval (Figure 5.1.5).

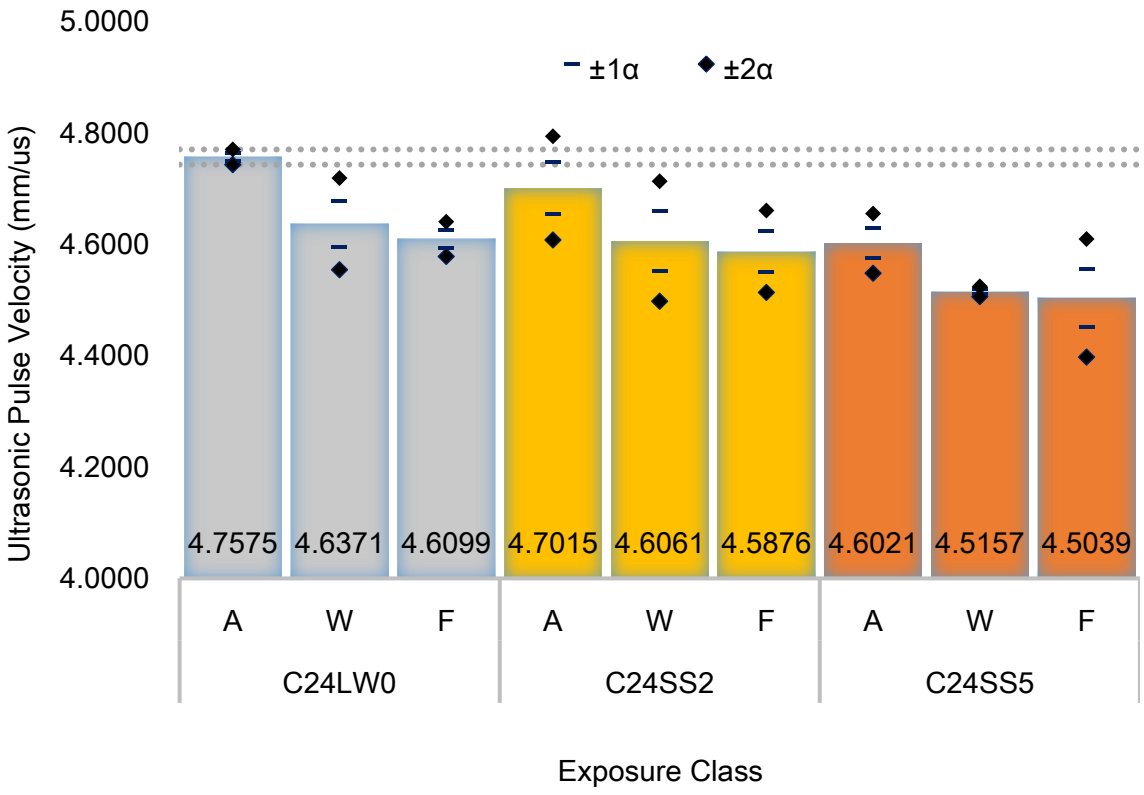


Figure 5.1.5: Ultrasonic pulse velocity results and sample statistics: cylindrical specimens, 24-month solution exposure period.

For the C24SS5F specimen, the calculated probability from the t-test (0.090) is higher than the set confidence level (0.050) because only two replicates were tested and a larger CV (1.17%) was obtained in comparison to the control's CV (0.143%). However, looking at Figure 5.1.5, the standard deviation corresponding to a 95% confidence

interval falls well outside the control's confidence interval. Therefore, the average result obtained for the C24SS5F specimen is considered to be different in this case.

Table 5.1.5: Results of F-test and t-test for verification of equality of sample variances and means: cylindrical specimens, 24-month solution exposure period.

Specimen Exposure	t-Test								
	C24LW0A	C24LW0W	C24LW0F	C24SS2A	C24SS2W	C24SS2F	C24SS5A	C24SS5W	C24SS5F
C24LW0A	1.000	0.034	0.000	0.170	0.038	0.013	0.002	0.000	0.090
C24LW0W	0.053	1.000	0.344	0.147	0.473	0.195	0.376	0.029	0.049
C24LW0F	0.320	0.252	1.000	0.032	0.912	0.389	0.699	0.004	0.040
C24SS2A	0.042	0.877	0.202	1.000	0.081	0.029	0.077	0.013	0.021
C24SS2W	0.031	0.736	0.155	0.855	1.000	0.649	0.931	0.111	0.128
C24SS2F	0.066	0.888	0.306	0.768	0.635	1.000	0.670	0.080	0.122
C24SS5A	0.118	0.838	0.456	0.755	0.664	0.917	1.000	0.046	0.145
C24SS5W	0.866	0.159	0.410	0.140	0.121	0.177	0.218	1.000	0.784
C24SS5F	0.032	0.653	0.154	0.746	0.858	0.573	0.597	0.111	1.000
	F-Test								

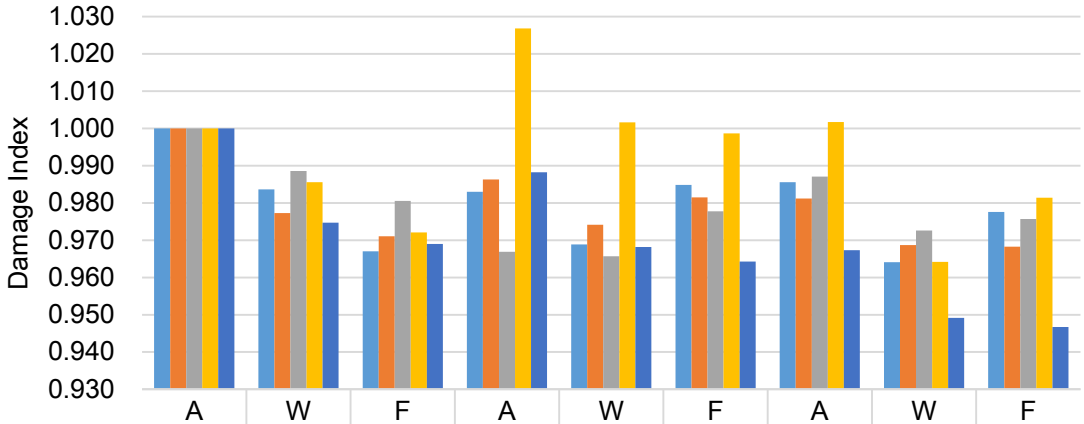
Therefore, based on the principles of wave propagation theory, the results demonstrate differences in material structures. After 24 months of exposure, the chemical and physical effects related to migrating sulphate ions and solution exposure may have altered the cementitious properties of the specimens. Incidentally, the decrease in ultrasonic wave velocity is an indication of a decline in stiffness properties, thus a change in modulus of elasticity and matrix density. This is consistent with past investigations where the change in dynamic modulus of elasticity was monitored using ultrasonic methods. (Long et al. 2007)

5.1.1.6 Longitudinal Ultrasonic Pulse Velocity Damage Index

In order to better evaluate the trends discussed in the above section on a timeline, the average values are expressed as a factor of their respective control specimen. Figure 5.1.6 exhibits these normalized results which are referred as a damage index (DI). The specimens which were completely submerged in limewater (LW0A) have a damage index of 1. The results for the other exposures regimens are therefore higher or lower in comparison to their control. As discussed above, the UPV test is sensitive to changes in material composition. Hence, this eliminates the variance due to individually batching each cylinder lots per exposure times.

Assessing the diffusion based mechanism; the recorded velocities are higher than the other exposure conditions. This is consistent with the proposed theory explained previously. With time, the denser matrix provides a medium for the stress-wave to better propagate. As seen in Figure 5.1.6, the peak values are reached after 18 months of constant sulphate exposure followed by a drop at 24 months.

When looking at the effects of partial immersion with respect to full immersion on the wave speed properties, the calculated DI factors range between 0.947 and 1.002 for both the wicking and field exposures. The latter exposure recorded the lowest values. It would seem that the addition of a cyclic exposure to the bottom half also adds additional damage to the concrete matrix. To better evaluate the extent of adding a corrosive solution to these processes, each regime is compared to their limewater counterpart in terms of transport of mechanism.

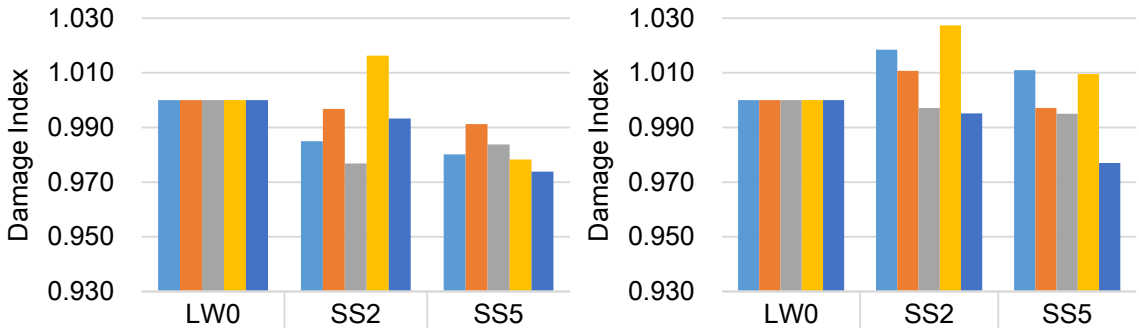


	LW0			SS2			SS5		
3 mts	1.000	0.984	0.967	0.983	0.969	0.985	0.986	0.964	0.978
6 mts	1.000	0.977	0.971	0.986	0.974	0.981	0.981	0.969	0.968
12 mts	1.000	0.989	0.981	0.967	0.966	0.978	0.987	0.973	0.976
18 mts	1.000	0.986	0.972	1.027	1.002	0.999	1.002	0.964	0.981
24 mts	1.000	0.975	0.969	0.988	0.968	0.964	0.967	0.949	0.947

Figure 5.1.6: 54 kHz Ultrasonic pulse velocity damage index for: comparison between types of transport mechanism and sulphate solution concentration.

Figure 5.1.7a demonstrates the damage index according to the control limewater wicking regime. Over time, effects of 2% sodium sulphate solution exposure are not noticed. As previously discussed, even if the damage index for the 3-month sample are low, because of the higher coefficients of variation, the results are considered to be the same according to the t-Test and standard deviation comparisons. After 6 months, there is slight decrease for the 2 % solution (0.997) but the damage index is more significant for the 5% solution exposure at 0.991. After 12 months, the values drop for both exposure concentrations. From then on, the damage index peaks after 18 months of 2% sodium sulphate solution exposure while the 5% continues to diminish to a factor of 0.978. This trend continues after 2 years of exposure where the still high damage factor 0.993 for the 2% SS is considered to be insignificant while the 24SS5W exposure records the lowest damage factor at 0.974. Here, the presence of independent deterioration mechanisms influenced the results in different manner. The presence of three different

levels of material presenting dissimilar physical and chemical characteristics influences the overall bulk velocity in a manner that no particular trend may be distinguish even if the results presented herein have relatively low coefficients of variation.



W	LW0	SS2	SS5
3 mts	1.000	0.985	0.980
6 mts	1.000	0.997	0.991
12 mts	1.000	0.977	0.984
18 mts	1.000	1.016	0.978
24 mts	1.000	0.993	0.974

F	LW0	SS2	SS5
3 mts	1.000	1.018	1.011
6 mts	1.000	1.011	0.997
12 mts	1.000	0.997	0.995
18 mts	1.000	1.027	1.010
24 mts	1.000	0.995	0.977

a) b)

Figure 5.1.7: 54 kHz Ultrasonic pulse velocity damage index: comparison between sulphate solution concentrations for

a) wicking exposure regimen and, b) field exposure regimen

The addition of an absorption and evaporation cycle to the wicking mechanism was thought to induce further loss. However, the damage index factors are higher when compared to that of their corresponding field controls. (Figure 5.1.7b) During the exposure period, the trends seen for both solution concentrations over time are consistent but, in accordance with the t-test, they are not statistically significant. Apart, the gain in velocity seen (1.027 DI) after 18 months of 2% solution exposure and the drop recorded (0.977 DI) after 24 months of 5% solution exposure are of value. These same extremes are noticed for the wicking exposure; however the previously stated assumptions remain valid.

Because various deterioration mechanisms are at play through distinct parts of the cylinder, the combination of their effects is difficult to assess. Thus, determining which mechanism is prevalent cannot be determined using longitudinal pulse velocity testing. Each portion of the cylinder must be considered individually. The next experimental test evaluates just that by measuring the properties of a stress wave traveling diametrically across the specimen, at various points along the longitudinal axis.

5.1.2 Comparative Study of Diametral 300 kHz Ultrasonic Pulse Emission Test

The velocity of a mechanical pulse through a solid medium is characteristic to that material. In contrast to the standard longitudinal testing method, herein the test procedure examines the changes in material property along the length of the cylinder by conducting the ultrasonic test on its diametral axis. Since the cylindrical specimens exhibit different degradation mechanisms below and above the immersion line, a damage profile over the length of the cylinders seemed appropriate to quantify the level of degradation observed along the travel path of the sulphate ions.

For the purpose of this comparison study, the individual transport mechanisms were compared with their respective regimen control per exposure age. The averages for each transport mechanism (diffusion, wicking and field) are organised accordingly in Tables 5.1.6 to 5.1.8. The details of the sample statistics and the tests to evaluate the equality of the samples variances and means are elaborated in Appendix B. For visual comparison and better understanding of the change in material property along the cylinder's longitudinal axis, tomographic velocity profiles are presented for each specimen type.

5.1.2.1 300 kHz Diametral UPV Profile for Diffusion Transport Regimens

Table 5.1.6 shows the average value of the diametral ultrasonic pulse velocities recorded for 3 cylindrical replicates subjected to the diffusion transport mechanisms (i.e. complete immersion). Starting with the 3-month diffusion exposure, the samples exposed to all three solutions recorded similar velocities (Figure 5.1.8); the C03SS5A sample being the lowest. Based on a t-test at a 95% confidence interval, there are no significant differences between the results' means. As for the coefficients of variation, they vary between 0.6% and 3.8% for the limewater exposure, between 0.5% and 2.0% for the 2% sulphate exposure and between 0.7% and 2.7% for the 5% sulphate exposure. The latter are slightly more elevated than that obtained in the 54 kHz UPV study. This may be due to the variation in concrete surface texture and couplant effect. (Aggelis 2004)

Table 5.1.6: Results for 300 kHz ultrasonic pulse velocity over 24-month exposure period, diffusion transport mechanisms.

Height (mm)	Diffusion (A)														
	3 Months			6 Months			12 Months			18 Months			24 Months		
	LW	SS2	SS5	LW	SS2	SS5	LW	SS2	SS5	LW	SS2	SS5	LW	SS2	SS5
	Velocity (mm/μs)														
25	4.342	4.320	4.293	4.390	4.338	4.245	4.510	4.445	4.398	4.326	4.200	4.117	4.408	4.357	4.281
50	4.347	4.276	4.254	4.407	4.325	4.262	4.476	4.403	4.351	4.301	4.166	4.093	4.364	4.347	4.205
75	4.227	4.277	4.285	4.358	4.284	4.261	4.407	4.366	4.343	4.265	4.184	4.090	4.344	4.294	4.192
100	4.248	4.245	4.234	4.324	4.276	4.246	4.412	4.320	4.381	4.244	4.160	4.057	4.317	4.296	4.129
125	4.306	4.265	4.262	4.277	4.331	4.261	4.434	4.380	4.398	4.281	4.190	4.071	4.335	4.349	4.197
150	4.280	4.273	4.267	4.256	4.342	4.295	4.464	4.409	4.330	4.274	4.211	4.169	4.374	4.384	4.191
175	4.328	4.277	4.212	4.353	4.333	4.242	4.458	4.361	4.039	4.309	4.219	4.182	4.402	4.376	4.247

To ensure successful results, adequate coupling between the sensor surface and the material's test surface is key to minimizing the effects of attenuation of the emitted mechanical pulse. It must be addressed that proper coupling was challenging on degraded surfaces, though feasible using hot glue as a coupling agent. However, the

higher spread in the results may be consequential of this procedure or actually due to the effects of wave diffraction by the increased amount of disparities present along its travel path. The latter will be discussed in the next section.

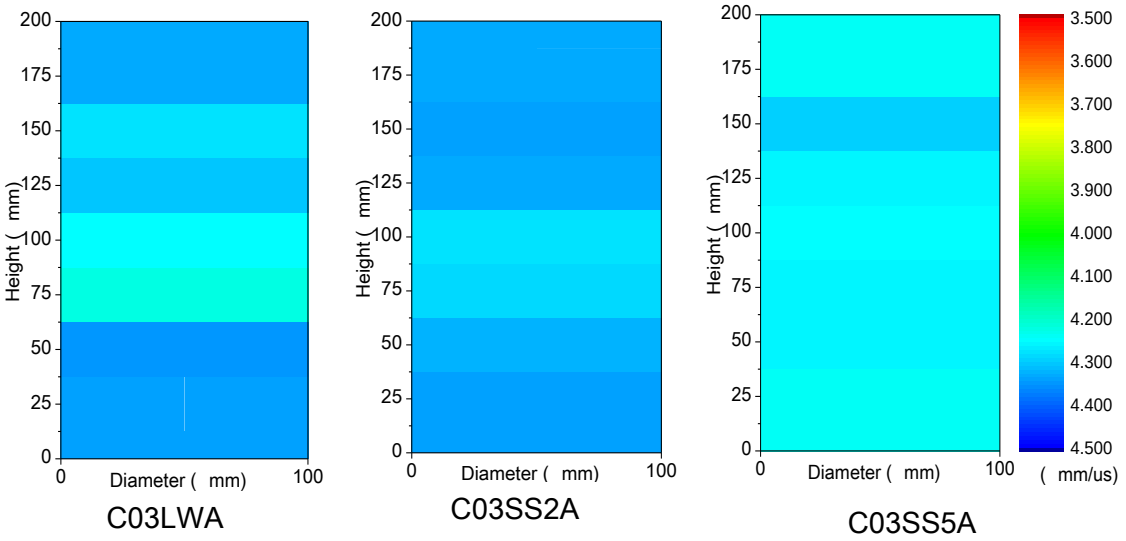


Figure 5.1.8: 300 kHz Diametral UPV Profiles for after 3 months of diffusion transport regimens.

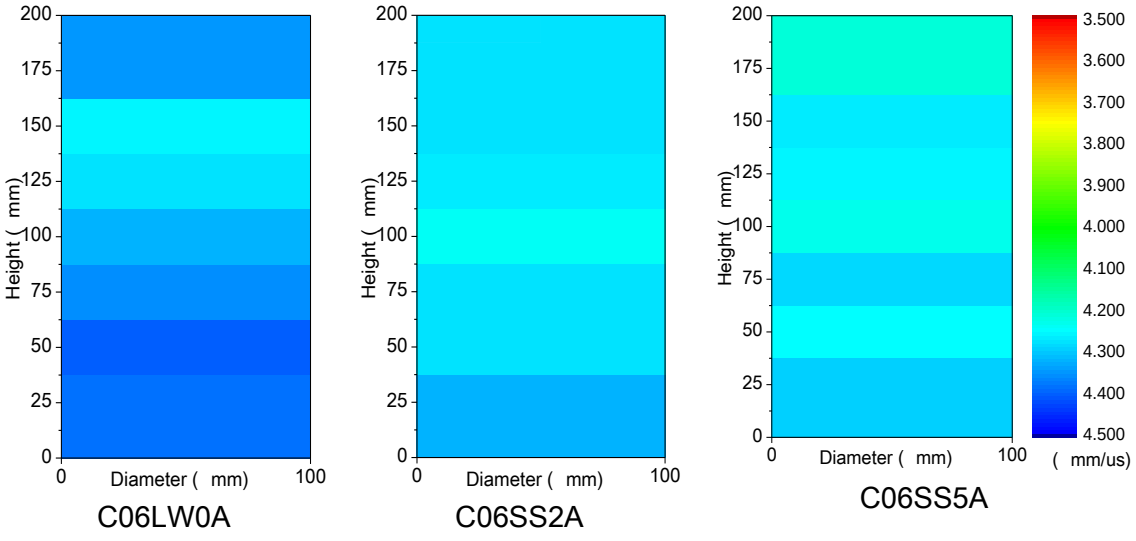


Figure 5.1.9: 300kHz Diametral UPV Profiles after 6 months of diffusion transport regimens.

The range in CV's is similar after 6 months of exposure. However, for the lower calculated CV's, the velocities are considered to be different according to the t-test. As seen in Figure 5.1.9, the recorded velocities are lower in the bottom half of the cylinder for both sulphate solutions. On average, they are 1.5% (C06SS2A) and 2.7% (C06SS5A) lower than their control.

It can be seen from Figure 5.1.10 that the C12LW0A specimen tested the highest wave velocities of the test program. Regardless, the sulphate samples only read an average percent difference of -1.5% and -2.9% across the entire length of the cylinder. Because of the very low CV's obtained for both the limewater and 2% sulphate samples (below 1%), they are considered to be statistically different. The same cannot be affirmed for the 5% sulphate exposure even if the wave velocities are lowest.

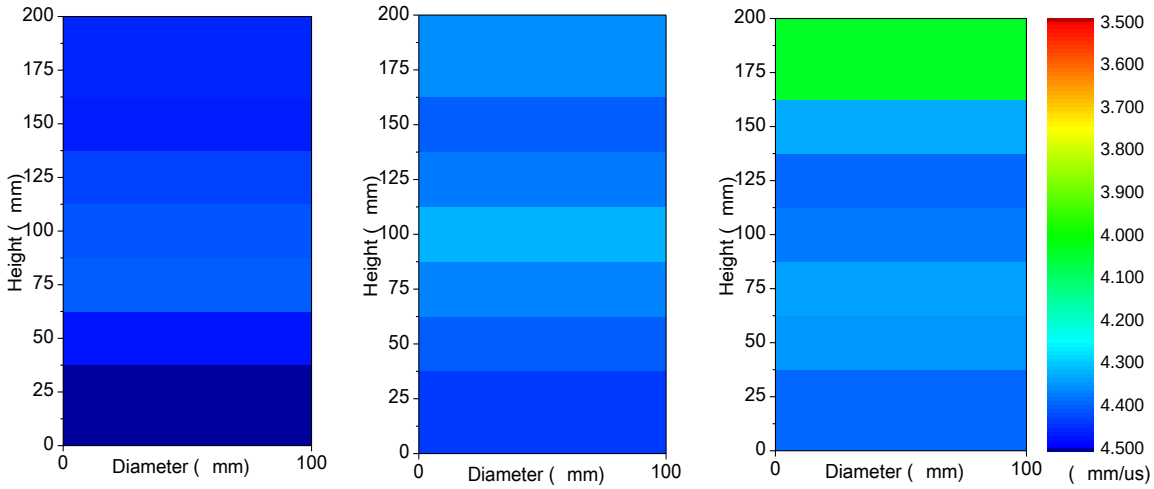


Figure 5.1.10: 300kHz Diametral UPV Profiles after 12 months of diffusion transport regimens.

The results of the statistical analysis performed on the 18-month samples demonstrate for the first time a significant change in measurements for both sulphate solutions. There is an average decrease in velocity of 2.2% and 4.1% for the 2% and 5% sulphate

solutions respectively, making these the highest drops recorded for the diffusion exposure term.

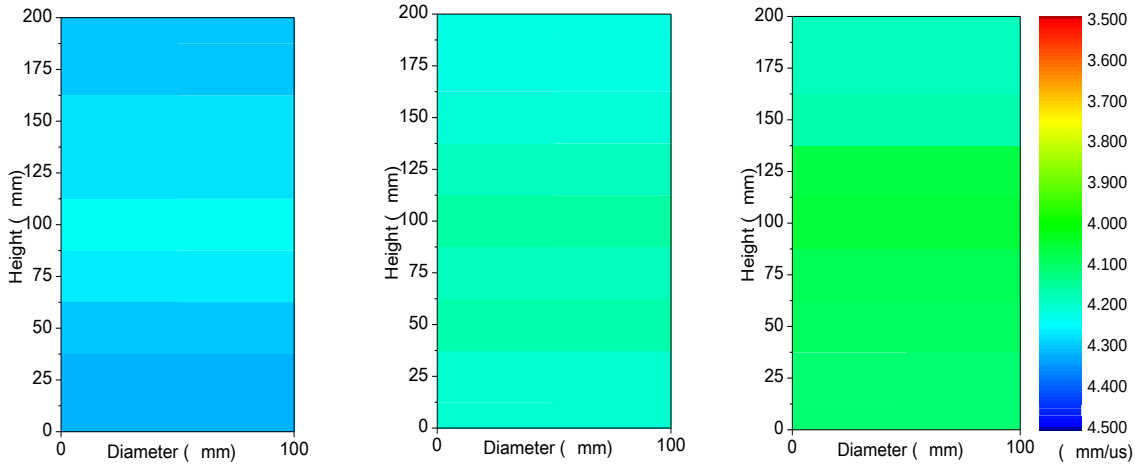


Figure 5.1.11: 300kHz Diametral UPV Profiles after 18 months of diffusion transport regimens.

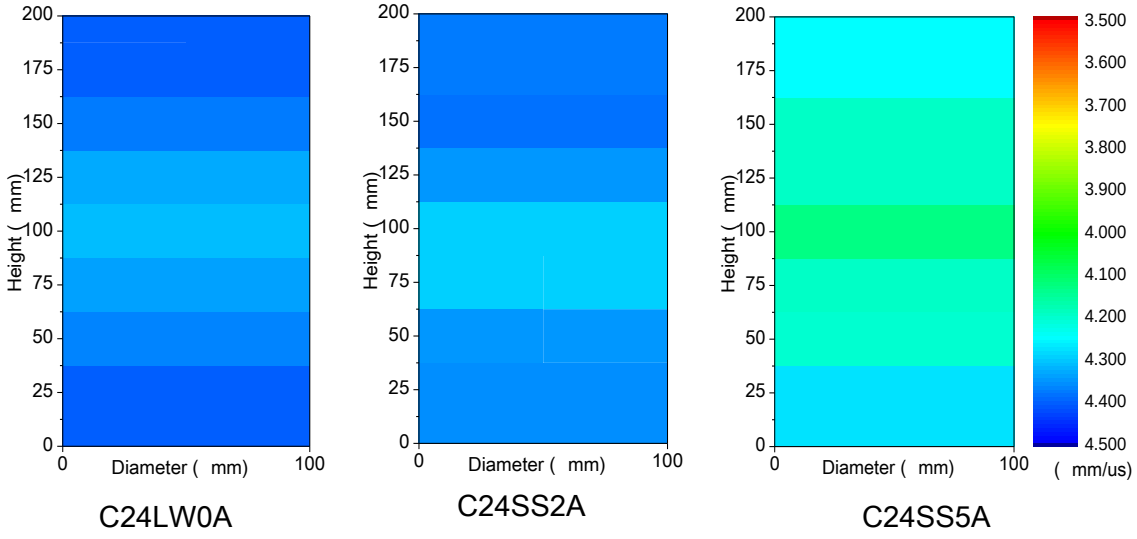


Figure 5.1.12: 300kHz Diametral UPV Profiles after 24 months of diffusion transport regimens.

After 2 years of exposure, there were no particular trends noticed over the course of the 2% sulphate exposure but, there was an overall 3.6% drop in velocity for the C24SS5A specimen, making it statistically dissimilar from the other two. In the end, the results

discussed may be due to the presence of a deterioration mechanism changing the cementitious material's microstructural properties. It needs to be addressed that after the exposure term of 2 years no visual sign of degradation was observed for the specimens exposed to the corrosive solutions. Therefore, the experimental procedure is considered to be successful in assessing early changes within the material. At this stage of experimental analysis, which mechanism altered the properties cannot be addressed. Further analysis is needed to confirm the reason for the disparities.

5.1.2.2 300 kHz Diametral UPV Profile for Wicking Transport Regimens

As discussed in Section 5.1.1, the presence of multiple layers of different cementitious properties influences how a wave propagates through it. In the presence of a concentrated ionic solution, the wicking transport mechanism created by the presence of an evaporation front further amplifies the differences in microstructure over time. The tomographic profiles (Figures 5.1.13 to 5.1.17) clearly demonstrate differences between the lower half of the cylinder, continuously exposed to solution, and the upper half exposed to ambient conditions. Also demonstrated in Table 5.1.7 is a consistent drop in wave velocities for the upper half of the cylinder.

Table 5.1.7: Results for 300 kHz ultrasonic pulse velocity over 24-month exposure period, wicking transport mechanism.

Height (mm)	Wicking (W)														
	3 Months			6 Months			12 Months			18 Months			24 Months		
	LW	SS2	SS5	LW	SS2	SS5	LW	SS2	SS5	LW	SS2	SS5	LW	SS2	SS5
	Velocity (mm/μs)														
25	4.370	4.206	4.248	4.375	4.314	4.289	4.469	4.372	4.387	4.326	4.204	4.248	4.397	4.362	4.258
50	4.291	4.254	4.256	4.307	4.333	4.271	4.443	4.369	4.387	4.300	4.150	4.234	4.351	4.287	4.194
75	4.370	4.100	4.133	4.239	4.326	4.252	4.385	4.324	4.323	4.264	4.101	4.193	4.303	4.266	4.159
100	4.298	4.062	4.125	4.245	4.280	4.162	4.367	4.184	4.257	4.227	3.988	4.095	4.268	4.309	4.049
125	4.251	4.114	3.970	4.187	4.050	4.116	4.212	3.952	3.776	4.179	3.576	4.096	4.202	4.023	3.526
150	4.102	4.144	4.188	4.098	4.066	3.867	4.130	3.725	3.982	4.196	3.689	3.936	4.140	3.934	3.428
175	4.123	4.085	4.057	4.034	4.098	4.113	4.051	4.021	4.175	4.150	3.749	4.079	4.054	3.922	4.070

From the statistical analysis (Appendix B), after 3 months of exposure the dispersion in the results is much greater than that of previous ultrasonic testing. With CVs ranging between 0.8% and 6.8% for all three specimen types, only the C03SS5W specimen is statistically dissimilar along the immersion line (75 mm to 125 mm). This can be observed in Figure 5.1.13, where the trend is seen for both sulphate exposures.

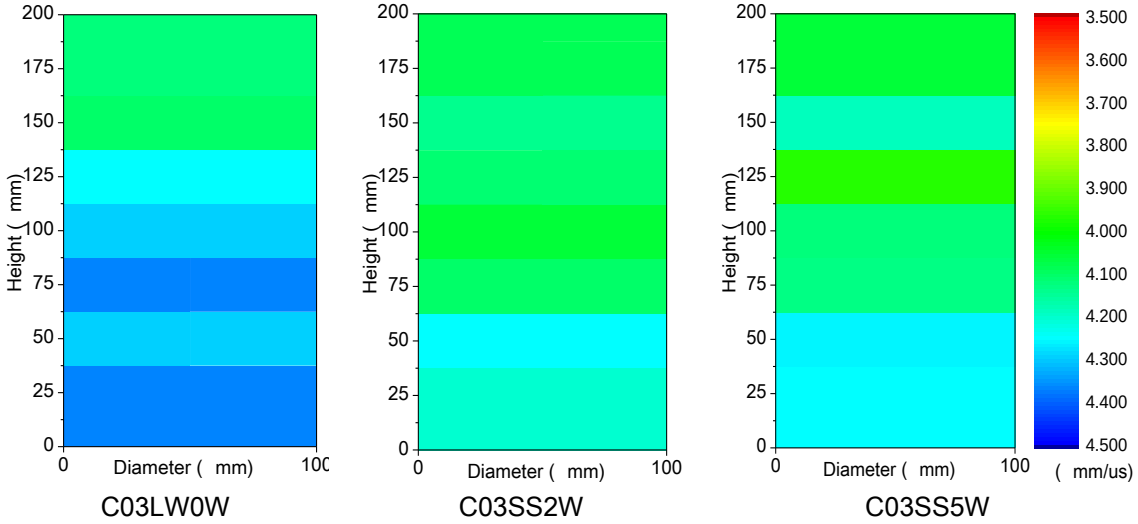


Figure 5.1.13: 300kHz Diametral UPV Profiles after 3 months of wicking transport regimens.

Similar results are observable in Figure 5.1.14; however, there are no statistical distinctions between the three exposure types. In comparison to the control, there is barely a -1% difference in wave velocities for the region in contact with the sulphate solution. But, there are 3.3% and 5.6% drops for the C06SS2W and C06SS2W specimens, respectively, in the region showing surficial physical deterioration.

The same degradation in wave velocities is seen in Figure 5.1.15 after 12 months of solution exposure, though to a larger extent. The physically degraded region exhibit a 9.8% and 10.3% negative difference to that of the control's equivalent region, making the region surrounding the immersion line statistically different.

After 18 months of sulphate exposure, there is a distinct trend, as seen in Figure 5.1.16, where the results above and below the immersion are significantly lower. The coefficients of variation calculated for the immersed portion is near 1% for all three regimens. Regarding the 2% and 5% sulphate solution, the average drop in velocities for the submerge portion was 3.9% and 2.0% respectively.

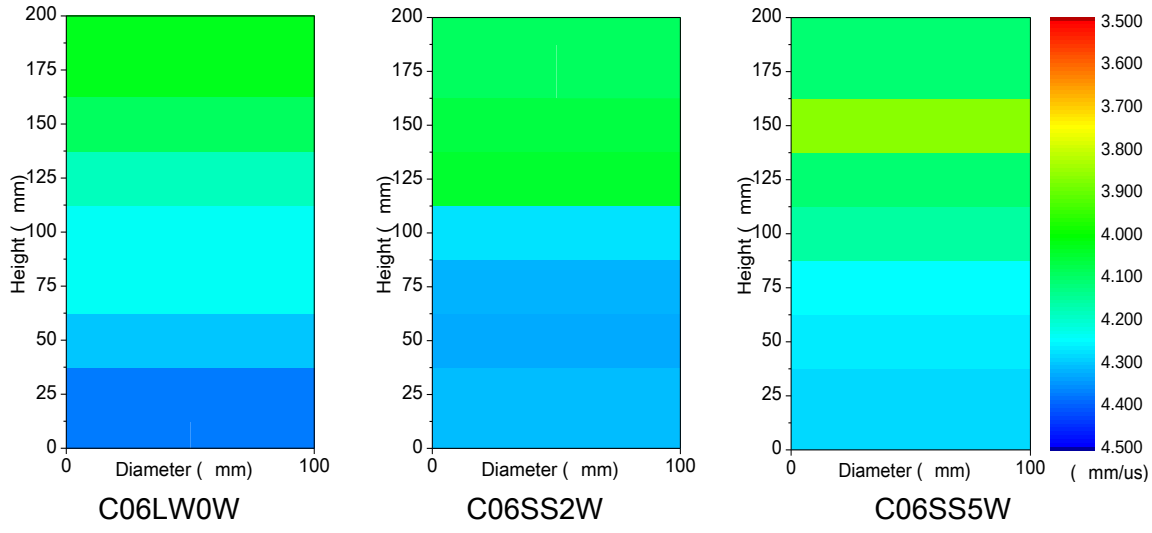


Figure 5.1.14: 300kHz Diametral UPV Profiles after 6 months of wicking transport regimens.

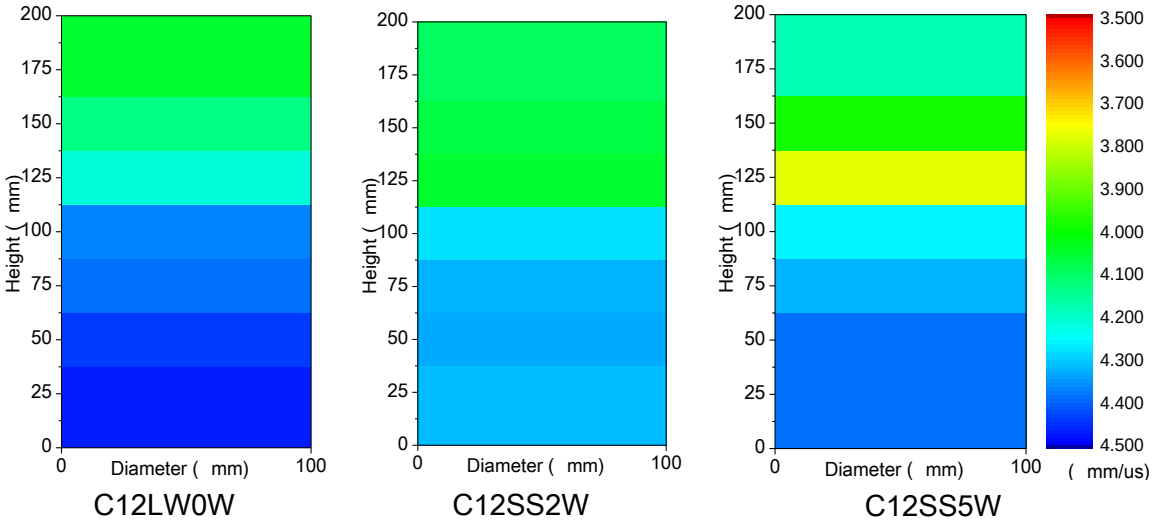


Figure 5.1.15: 300kHz Diametral UPV Profiles after 12 months of wicking transport regimens.

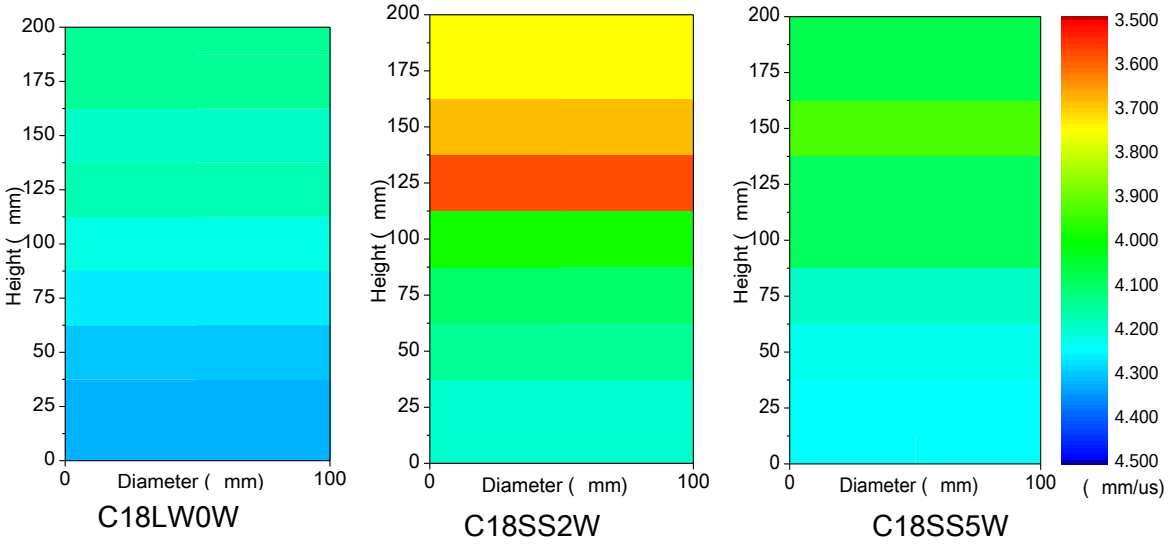


Figure 5.1.16: 300kHz Diametral UPV Profiles after 18 months of wicking transport regimens.

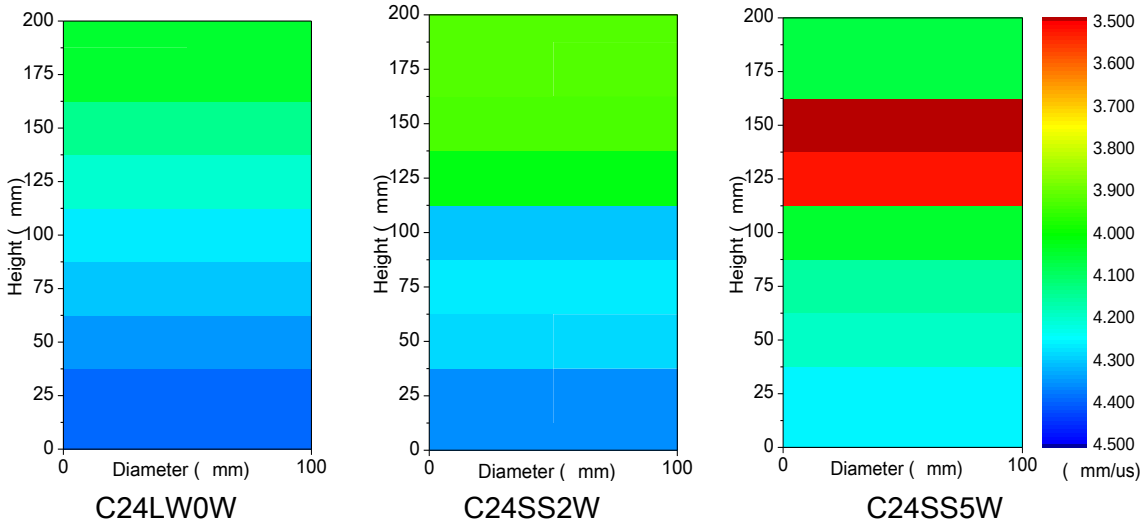


Figure 5.1.17: 300kHz Diametral UPV Profiles after 24 months of wicking transport regimens.

The same trend observed for the 18 months samples is continued after 24 months of exposure; however, to a lesser extent for the 2% sulphate regimen. The bottom half exposed to the solution experienced a change in material properties, with a 3.8% reduction in wave speed making this part significantly distinct from the other two samples. Meanwhile, for the upper portion showing signs of physical degradation

extending pass 175 mm, there is an 11.0% drop in wave speed. The C24SS2W specimen did not experience the same level of physical degradation noticed for the C24SS5W; hence, the wave speeds were 0.5% and 4.2% lower for both the lower and upper halves respectively. At the end of the exposure term, the results obtained demonstrate that there is evidence of a mechanism altering the microstructure of both portions of the C24SS5W cylinder, the chemically attacked zone and the physically attacked zone.

5.1.2.3 300 kHz Diametral UPV Profile for Field Transport Regimens

Table 5.1.8: Results for 300 kHz ultrasonic pulse velocity over 24-month exposure period, field transport mechanism.

Height (mm)	Field (F)														
	3 Months			6 Months			12 Months			18 Months			24 Months		
	LW	SS2	SS5	LW	SS2	SS5	LW	SS2	SS5	LW	SS2	SS5	LW	SS2	SS5
	Velocity (mm/μs)														
25	4.279	4.248	4.299	4.323	4.338	4.224	4.425	4.424	4.372	4.235	4.220	4.222	4.310	4.369	4.343
50	4.311	4.227	4.280	4.282	4.311	4.283	4.397	4.407	4.364	4.226	4.150	4.185	4.229	4.315	4.249
75	4.282	4.244	4.249	4.252	4.315	4.221	4.320	4.350	4.341	4.174	4.131	4.096	4.207	4.262	4.210
100	4.268	4.127	4.257	4.178	4.275	4.236	4.335	4.228	4.315	4.144	4.042	4.081	4.179	4.228	3.646
125	4.255	4.222	3.788	4.133	4.267	4.076	4.249	3.812	3.288	4.104	3.581	3.999	4.101	4.148	3.831
150	4.209	4.013	4.072	4.076	3.977	3.910	4.246	4.090	3.877	4.033	3.930	3.954	4.150	4.131	4.119
175	4.187	4.083	4.171	3.946	4.053	3.817	4.174	4.136	4.177	4.033	3.822	3.881	4.020	4.072	4.040

The addition of a wet-dry cyclic exposure to the immersed portion changed the progression of the degradation mechanism. As seen in Table 5.1.8, the values (25 mm to 100 mm) slowly decrease until 18 months but, opposite to the wicking transport mechanism, then increased after 24 months of exposure.

Illustrated in Figure 5.1.18, there was a slight decrease in wave velocity for the cyclically immersed half and the half exposed to ambient conditions. The observed change in velocities was not sufficiently significant to affirm that the corrosive solution affected the

cylinder's microstructural properties. The same trend continued after 6 months of the field exposure regimen. (Figure 5.1.19)

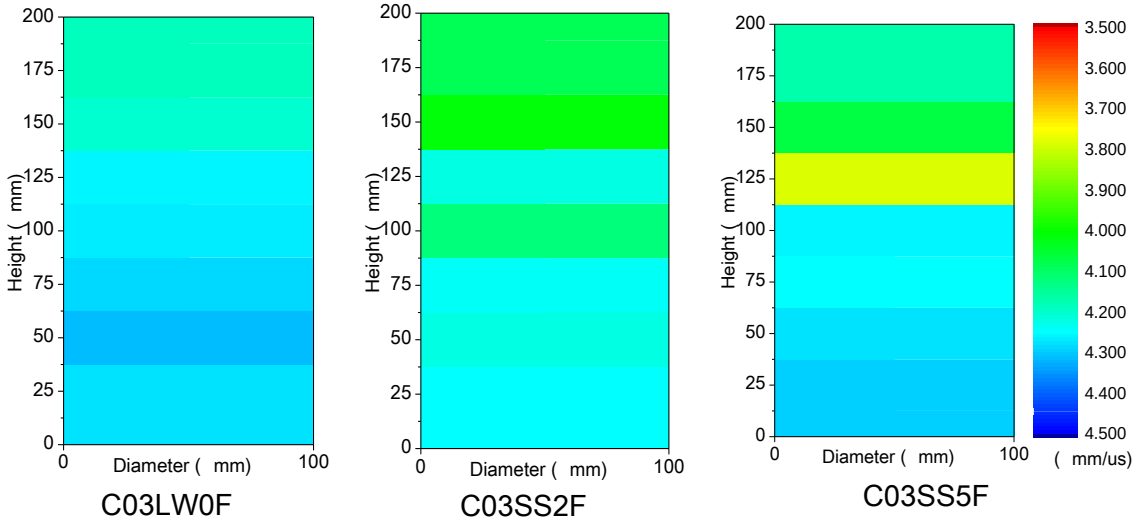


Figure 5.1.18: 300kHz Diametral UPV Profiles after 3 months of field transport regimen.

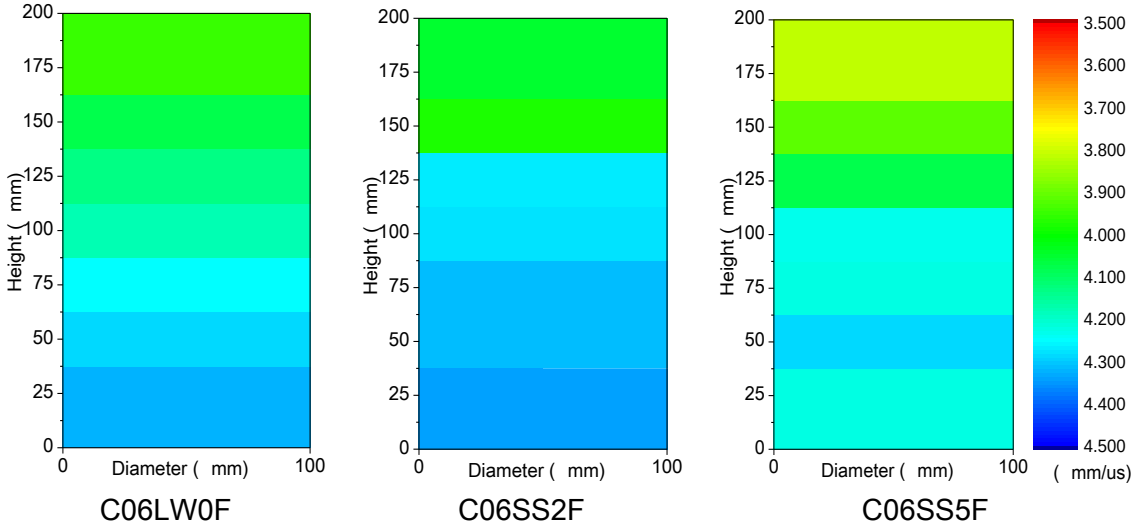


Figure 5.1.19: 300kHz Diametral UPV Profiles after 6 months of field transport regimen.

After one year of solution exposure, it is interesting to see from the statistical analysis that the coefficients of variation obtained for the limewater exposure were below 2%. However, there was a large spread in the results at the level of the evaporation front for both the C12SS2F and C12SS5F specimen; the CVs were equal to 21.2% (125mm) and 13.7% (150 mm), respectively. Moreover, the wave velocities dropped by 5.0% and

10.4% for both the 2% and 5% solutions. Meanwhile, the bottom half remained unchanged. Even with the noticeable differences, the latter are considered insignificant due to the large sample variance.

As for the 18-month samples, the same trend continued where there was a large dispersion in the results for the measurements taken above the immersion line. At the 125 mm level the recorded CVs were 20.5% (C18SS2F) and 7.1% (C18SS5F). On the other hand, the average 1.4% drop in velocities noticed for the bottom part of the C18SS2F specimen made it different from its two companions.

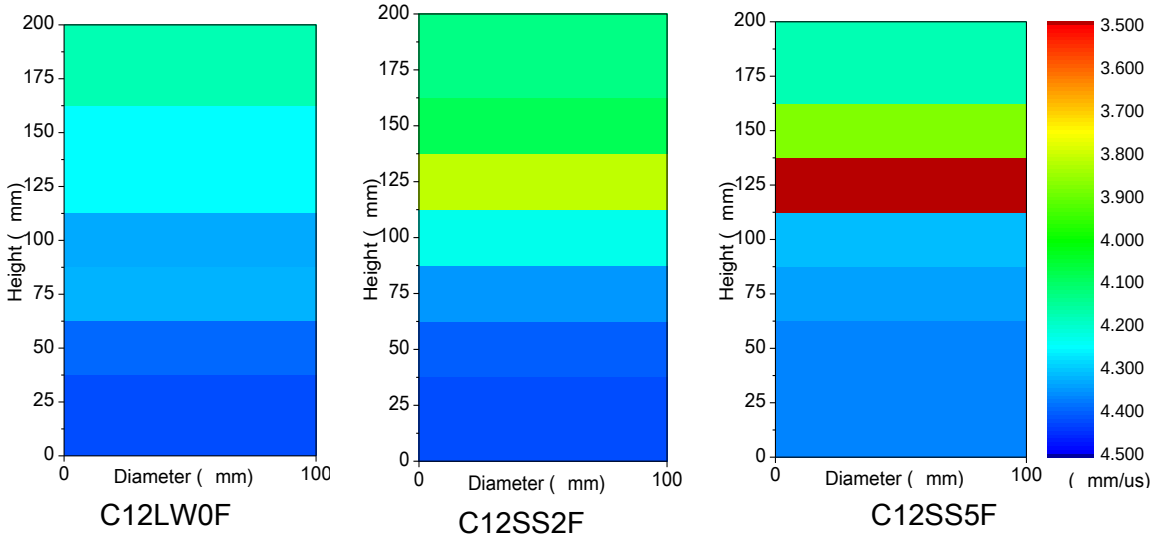


Figure 5.1.20: 300kHz Diametral UPV Profiles after 12 months of field transport regimens.

At the end of the exposure term, there were no significant changes to report. The bottom half of the cylinder reached its lowest percent difference, 2.9% for the C24SS5F specimen, On the other hand, for the first time in this experimental program, the C24SS2F specimen experienced a 1.5% increase in velocity, making it statistically different.

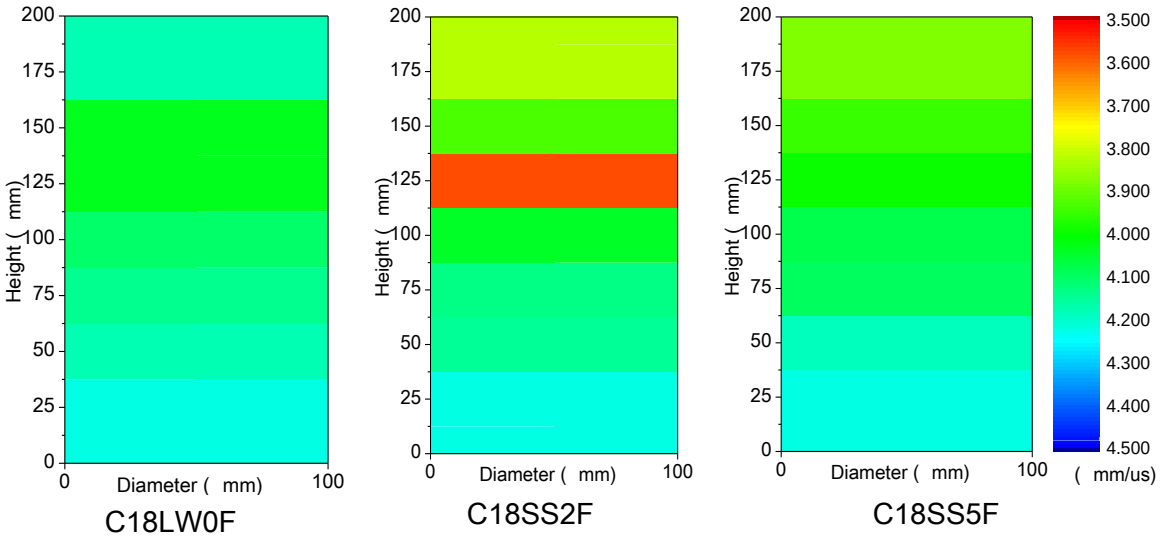


Figure 5.1.21: 300kHz Diametral UPV Profiles after 18 months of field transport regimens.

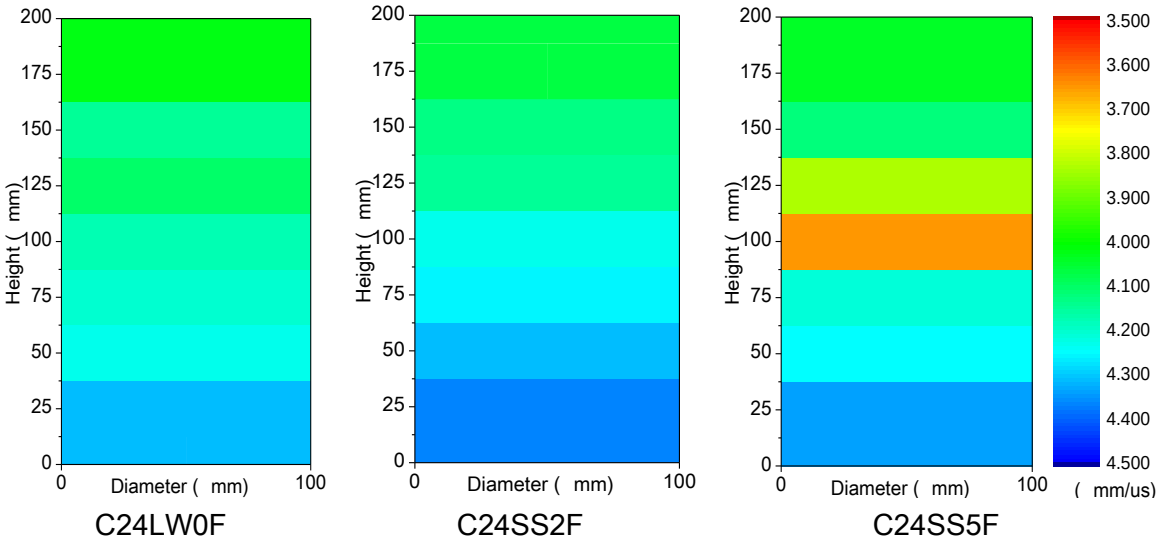


Figure 5.1.22: 300kHz Diametral UPV Profiles after 24 months of field transport regimens.

The CV's calculated over the course of this experimental study were higher than that determined for the longitudinal UPV tests; though the CVs were higher, they surpassed standard prescriptions. The study was successful in differentiating the various deterioration processes taking place along the sulphate migration path for the three different transport mechanisms. However, the change in surface texture due to physical

degradation clearly had an effect on the repeatability of the test method. In this case the elevated CVs did not permit statistically reliable results; however, certain differences between all specimens were visually noticeable when looking at the tomographic profiles. First, there was clearly a difference between the solution exposed portion and the part that was not. Second, for both the wicking and field regimens, the discussed deviations in velocity below the immersion line (control vs. sulphate exposures) were not statistically important; even if the CV's obtained were on average acceptable (below 2%) according to the UPV standard. Based on these conclusions, an analysis on the effects of the transport mechanisms on their own is of importance.

5.1.2.4 300 kHz Diametral UPV Profile for 24 Months of Limewater Exposure Regimens

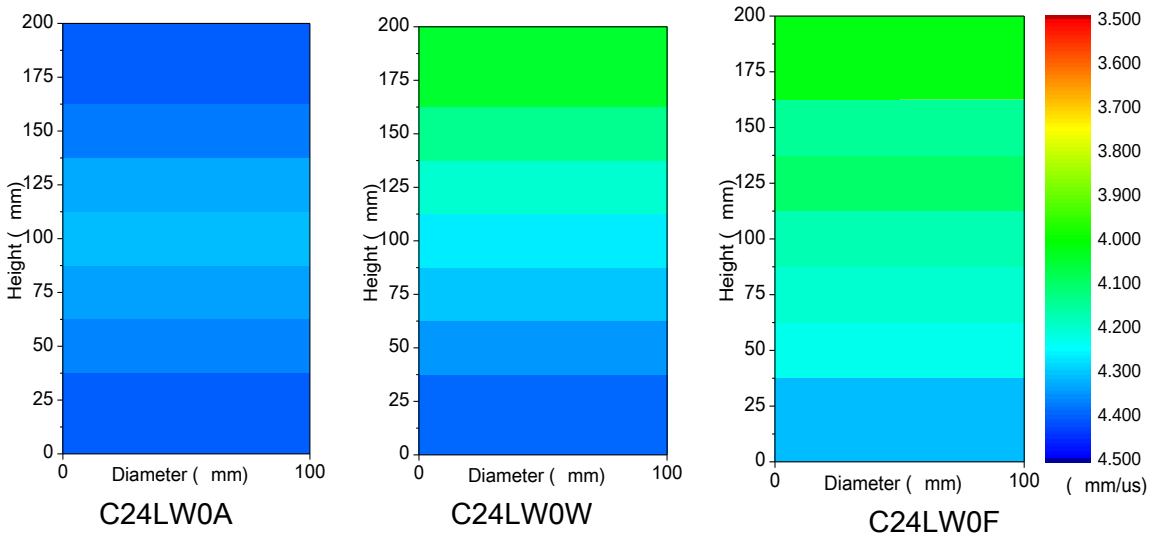


Figure 5.1.23: 300kHz Diametral UPV Profiles after 24 months of limewater exposure regimen.

Figure 5.1.23 shows the tomographic profiles for the control specimens after 2 years of diffusion, wicking and field exposures. For the purpose of this comparison, only the 24-month samples were analysed since the trend for each exposure time is applicable (Table 5.1.9). The results of the statistical analysis may be consulted in Appendix B.

Table 5.1.9: Results of F-test and t-test for verification of equality of sample variances and means: cylindrical specimens, 24-month limewater solution exposure.

Height (mm)	Limewater														
	Average			Coefficient of variation			Percent Difference			F-Test			t-Test		
	A	W	F	A	W	F	A	W	F	A	W	F	A	W	F
	Velocity (mm/μs)			%			%								
25	4.408	4.397	4.310	0.775	0.921	0.664	C24LW0A	-0.27	-2.24	C24LW0A	0.718	0.709	C24LW0A	0.601	3.E-4
50	4.364	4.351	4.229	1.431	0.390	0.611		-0.31	-3.09		0.012	0.075		0.633	0.002
75	4.344	4.303	4.207	1.371	1.009	0.937		-0.95	-3.16		0.505	0.385		0.202	0.001
100	4.317	4.268	4.179	0.815	1.391	0.864		-1.14	-3.22		0.275	0.956		0.111	5.E-5
125	4.335	4.202	4.101	0.984	0.931	4.532		-3.08	-5.40		0.853	0.006		2.E-4	0.026
150	4.374	4.140	4.150	0.961	1.351	0.925		-5.36	-5.13		0.546	0.847		9.E-6	2.E-6
175	4.402	4.054	4.020	1.369	0.984	0.980		-7.90	-8.69		0.386	0.372		3.E-7	1.E-7

The results of the sample statistical study demonstrated in Table 5.1.9 show the differences due to partial immersion. As seen for the C24LW0W specimen, there was a gradual drop in velocity along the longitudinal axis from the bottom toward the top of the cylinder, ranging from 0.27% to 7.9%. For equal variances in test measurements, the sample means were the same for the portion below the immersion line and different for the portion above the immersion line. Therefore, the half having received the same type of curing regimen as the fully immersed sample (C24LW0A) via a diffusion mechanism had similar microstructural properties as the latter. However, the upper half exposed to ambient conditions, having received no curing regimen, recorded lower wave velocities. This is consistent with hydration theory where water curing promotes cement hydration towards completion resulting in a denser cementitious matrix. This fact is clearly distinguishable looking at the results of the t-test above the immersion line. The probability of the concrete material being the same above 150 mm is actually near one in a million. Moreover, adding a cyclic wet-dry exposure further amplified the differences in the upper half with a percent difference reaching 8.7%. But, it also had an effect on the bottom half which was cyclically exposed to the solution. It would seem that cyclic

absorption and evaporation changes the microstructure with respect to pure diffusion only. This is consistent with the theory where drying may cause contraction stresses at the microstructural level due to loss of chemically bound water. Repeated action will eventually cause microstructural damage such as microcracking. (Neville 1996) This is well exhibited when looking at the trend in results for the field regimen over the two-year exposure term. Therefore, what role does the sulphate ion play within these chemical and physical processes?

Conclusive results are hard to achieve due to higher variations within the test measurements. Only after 18 months of exposure were the differences sufficiently significant to differentiate certain parts of the cylinder which could be attributed to sulphate exposure. However, it would seem that apart from the physically degraded zone, degradation due to sulphates may not be the primary player in the degradation mechanisms associated with wicking and cyclic exposures. They could play a secondary role, but what? Further analysis is required to determine the full extent of their interaction with the cementitious phases.

5.1.3 Comparative Study of Gas Pressure Tension Test

The gas pressure tension test has been used in past research investigation as a means to evaluate the change in strength properties of degraded concrete due to various durability issues. (Boyd 2005) The test procedure was considered to be particularly sensitive to microstructural damage such as microcracking, making it appropriate to assess sulphate related damage. Therefore, a procedure was devised using this novel apparatus to quantify the evolution of strength properties over the length of the exposure regimes.

As for the 54 kHz longitudinal ultrasonic velocity study, the results are demonstrated on graphs also showing the standard deviations associated with each sample data. Figures

5.1.24 to 5.1.28 were prepared in the same manner as previously explained in Section 5.1.1. Again, the results of the statistical evaluation may also be consulted in Tables 5.1.10 to 5.1.14, with further details on the latter available in Appendix B.

5.1.3.1 Gas Pressure Tensile Strength Results after 3 Months of Solution Exposures

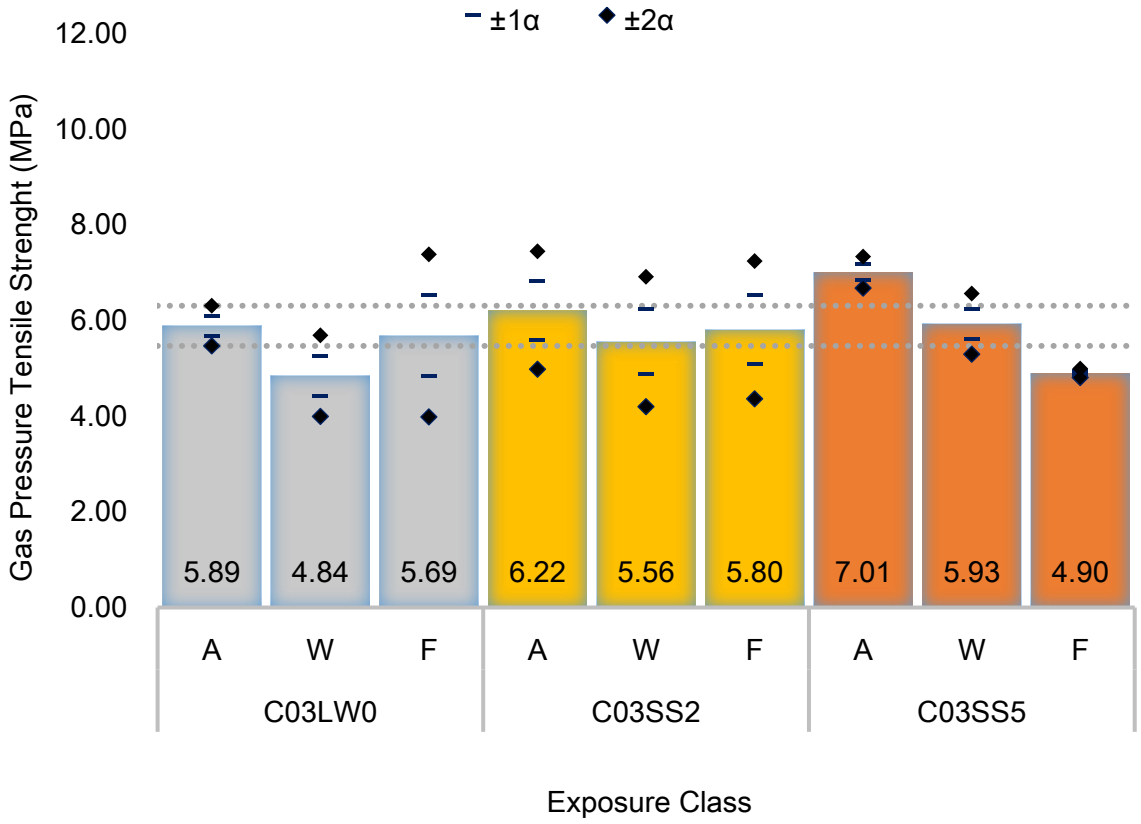


Figure 5.1.24: Gas pressure tensile strength results and sample statistics: cylindrical specimens, 3-month solution exposure period.

According to the statistical results shown in Figure 5.1.24 and Table 5.1.10, there was a marked difference for the C03LW0W, C03SS5A and C03SS5F specimens in comparison to the control. The two sulphate samples already exhibited a 19% increase and 16.8% decrease in tensile strength for the diffusion and field mechanisms, respectively. The minimal spread in the data for the latter contributed to the conclusive results. It would seem that from the start of the diffusion regimen there is an ongoing chemical process increasing the mechanical properties of the concrete cylinders. This

fact is also seen for the 2% solution, but to a lesser extent. As for the decrease in strength seen for the other regimes, it might be attributed to the differences in material microstructure in the upper portion of the cylinder. As previously discussed, the loss in strength could be attributed to the lack of cement hydration in the upper half of the cylinder.

Table 5.1.10: Results of F-test and t-test for verification of equality of two sample variances and means: cylindrical specimens, 3-month solution exposure period.

Specimen Exposure	t-Test								
	C03LW0A	C03LW0W	C03LW0F	C03SS2A	C03SS2W	C03SS2F	C03SS5A	C03SS5W	C03SS5F
C03LW0A	1.000	0.018	0.704	0.438	0.464	0.850	0.002	0.864	0.012
C03LW0W	0.392	1.000	0.199	0.034	0.196	0.117	0.001	0.024	0.831
C03LW0F	0.115	0.399	1.000	0.432	0.851	0.862	0.109	0.663	0.251
C03SS2A	0.207	0.643	0.690	1.000	0.284	0.495	0.097	0.518	0.066
C03SS2W	0.174	0.561	0.780	0.904	1.000	0.690	0.023	0.438	0.235
C03SS2F	0.156	0.515	0.836	0.846	0.941	1.000	0.095	0.793	0.162
C03SS5A	0.762	0.261	0.072	0.133	0.111	0.099	1.000	0.006	0.000
C03SS5W	0.608	0.718	0.245	0.419	0.358	0.325	0.423	1.000	0.028
C03SS5F	0.097	0.025	0.006	0.012	0.010	0.009	0.154	0.044	1.000
F-Test									

5.1.3.2 Gas Pressure Tensile Strength Results after 6 Months of Solution Exposures

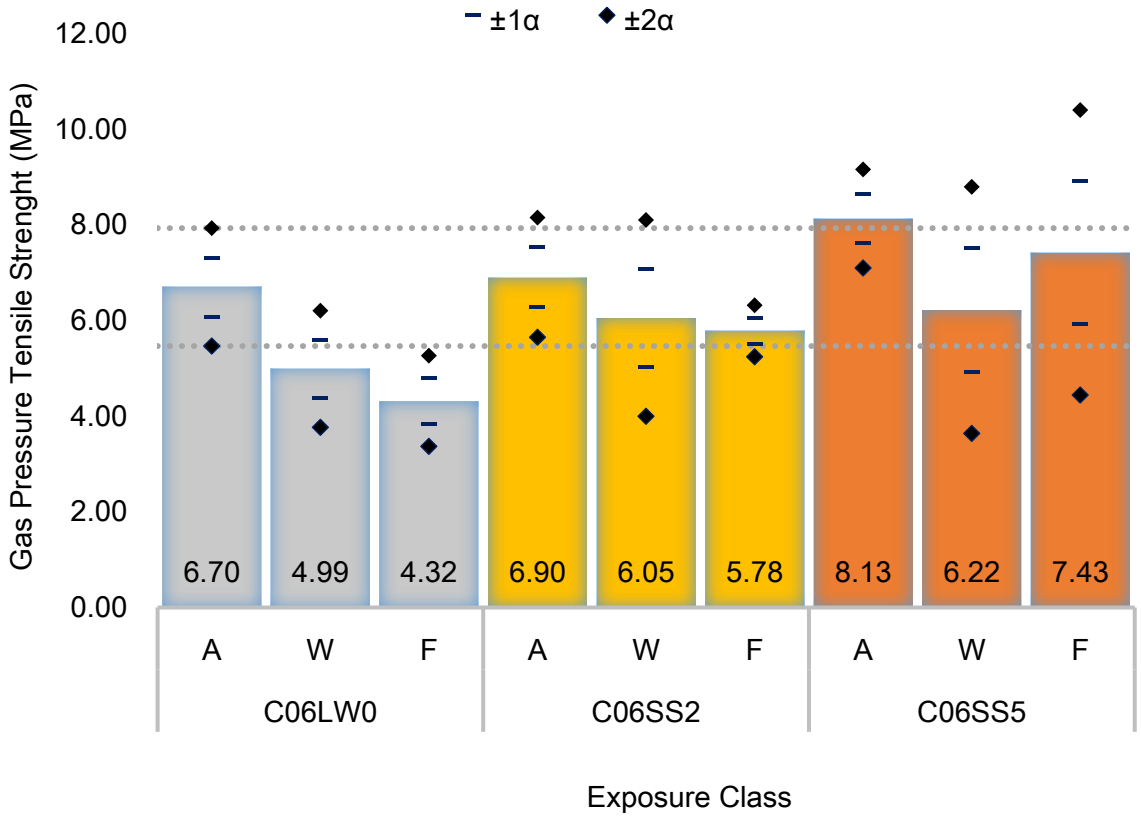


Figure 5.1.25: Gas pressure tensile strength results and sample statistics: cylindrical specimens, 6-month solution exposure period.

The same trends are continued after 6 months of sulphate exposure; however, the larger coefficients of variation did not permit substantial conclusions. Although the f-test results (Table 5.1.11) predicted a significant increase in strength for the C06SS5A specimen (21% difference), the strength measurements for both it and the control fell within each other's second standard deviations (Figure 5.1.24). In fact, the coefficients of variation ranged between 4.7% and 20.7% for this study, making it difficult to assess any changes between exposure regimens.

Table 5.1.11: Results of F-test and t-test for verification of equality of two sample variances and means: cylindrical specimens, 6-month solution exposure period.

Specimen Exposure	t-Test								
	C06LW0A	C06LW0W	C06LW0F	C06SS2A	C06SS2W	C06SS2F	C06SS5A	C06SS5W	C06SS5F
C06LW0A	1.000	0.027	0.006	0.710	0.401	0.077	0.037	0.590	0.481
C06LW0W	0.990	1.000	0.208	0.019	0.198	0.108	0.002	0.209	0.059
C06LW0F	0.746	0.755	1.000	0.005	0.057	0.010	0.001	0.075	0.026
C06SS2A	0.984	0.974	0.731	1.000	0.287	0.046	0.058	0.454	0.607
C06SS2W	0.529	0.522	0.352	0.542	1.000	0.682	0.035	0.869	0.259
C06SS2F	0.322	0.327	0.488	0.313	0.129	1.000	0.002	0.619	0.193
C06SS5A	0.824	0.833	0.918	0.808	0.402	0.430	1.000	0.075	0.480
C06SS5W	0.372	0.366	0.239	0.382	0.777	0.084	0.276	1.000	0.349
C06SS5F	0.292	0.287	0.184	0.300	0.644	0.063	0.214	0.856	1.000
F-Test									

5.1.3.3 Gas Pressure Tensile Strength Results after 12 Months of Solution Exposures

All but the sulphate diffusion specimens were considered to be significantly different from the limewater control after one year of exposure. These were consistently lower than the control's average tensile strength. The percent differences ranged between -39.6% and -33.6%. It would seem that the partially submerged specimens were limited by the weakest part of the cylinder (i.e. the non-hydrated half); meanwhile, the hydration kinetics of the diffusion specimen continued to progress.

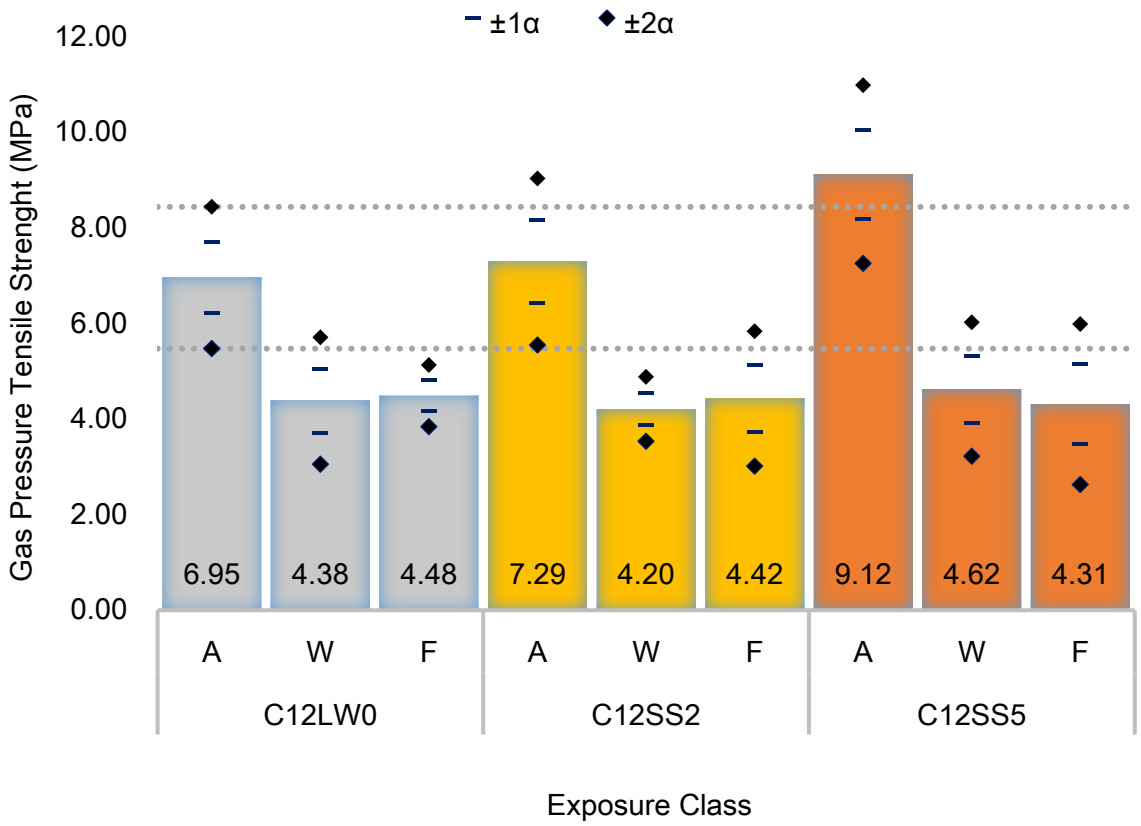


Figure 5.1.26: Gas pressure tensile strength results and sample statistics: cylindrical specimens, 12-month solution exposure period.

As for the C12SS5A, even if its sample average was 31.2% greater than that of the control's average strength, it was still considered statistically insignificant. The strength gain here was accompanied by a high variation in the results (CV = 19.5%).

Table 5.1.12: Results of F-test and t-test for verification of equality of two sample variances and means: cylindrical specimens, 12-month solution exposure period.

Specimen Exposure	t-Test								
	C12LW0A	C12LW0W	C12LW0F	C12SS2A	C12SS2W	C12SS2F	C12SS5A	C12SS5W	C12SS5F
C12LW0A	1.000	0.011	0.006	0.641	0.004	0.013	0.061	0.039	0.033
C12LW0W	0.891	1.000	0.820	0.010	0.704	0.942	0.007	0.724	0.918
C12LW0F	0.317	0.381	1.000	0.006	0.358	0.900	0.003	0.777	0.748
C12SS2A	0.839	0.734	0.240	1.000	0.005	0.011	0.110	0.038	0.032
C12SS2W	0.343	0.410	0.954	0.260	1.000	0.653	0.003	0.421	0.854
C12SS2F	0.951	0.939	0.344	0.792	0.371	1.000	0.007	0.780	0.875
C12SS5A	0.671	0.591	0.203	0.794	0.219	0.635	1.000	0.032	0.032
C12SS5W	0.889	0.804	0.323	0.988	0.346	0.851	0.821	1.000	0.724
C12SS5F	0.750	0.667	0.242	0.875	0.261	0.713	0.933	0.886	1.000
F-Test									

5.1.3.4 Gas Pressure Tensile Strength Results after 18 Months of Solution Exposures

The results obtained after 18 months of exposure continued to follow the same trend where the partially immersed samples failed at lower strengths than the completely immersed control specimen. However, only the 5% sulphate regimens were considered to be similar to the control specimen; as seen from the samples statistics in both Figure 5.1.27 and Table 5.1.12.

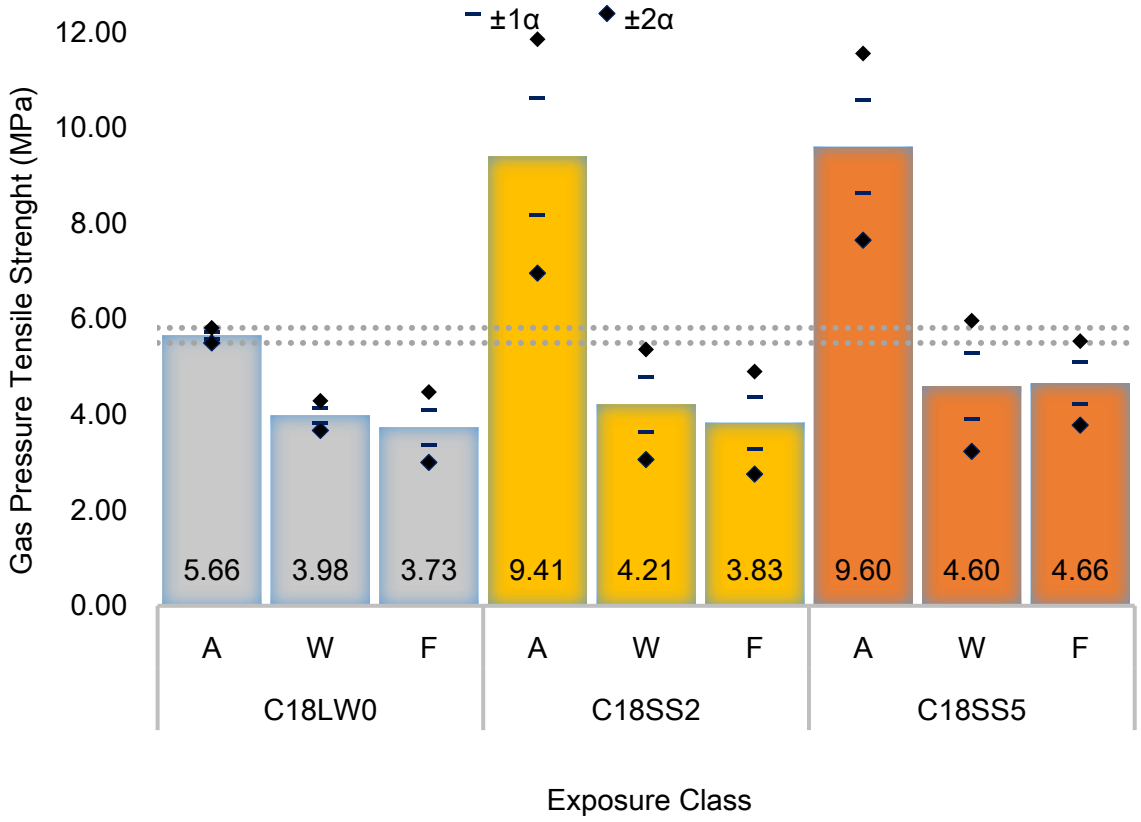


Figure 5.1.27: Gas pressure tensile strength results and sample statistics: cylindrical specimens, 18-month solution exposure period.

On the other hand, as shown in Figure 5.1.27, the sulphate diffusion specimens reached their highest strength of the test program. At this time, there was a corresponding 66.3% and 69.6% increase in strength for the C18SS2A and C18SS5A specimens, making these statically different from their companion. For these replicates, the variation in the

results was still below the maximal value prescribed in the splitting tension test (CV=16%).

Table 5.1.13: Results of F-test and t-test for verification of equality of two sample variances and means: cylindrical specimens, 18-month solution exposure period.

Specimen Exposure	t-Test								
	C18LW0A	C18LW0W	C18LW0F	C18SS2A	C18SS2W	C18SS2F	C18SS5A	C18SS5W	C18SS5F
C18LW0A	1.000	0.001	0.006	0.033	0.044	0.020	0.012	0.130	0.056
C18LW0W	0.679	1.000	0.353	0.015	0.535	0.663	0.009	0.254	0.065
C18LW0F	0.300	0.301	1.000	0.002	0.294	0.821	0.001	0.127	0.050
C18SS2A	0.091	0.032	0.167	1.000	0.003	0.002	0.840	0.004	0.003
C18SS2W	0.194	0.136	0.583	0.362	1.000	0.445	0.001	0.496	0.346
C18SS2F	0.207	0.154	0.642	0.323	0.931	1.000	0.001	0.199	0.107
C18SS5A	0.114	0.049	0.250	0.778	0.515	0.464	1.000	0.002	0.001
C18SS5W	0.163	0.098	0.451	0.476	0.829	0.763	0.658	1.000	0.904
C18SS5F	0.253	0.222	0.827	0.228	0.736	0.802	0.336	0.585	1.000
	F-Test								

5.1.3.5 Gas Pressure Tensile Strength Results after 24 Months of Solution Exposures

After 24 months of detrimental exposure the strength results appeared to level in comparison to the control. As before, the failure strengths for the C24SS2A and C24SS5A specimens were higher than the controls, but they were within the upper limit of the second standard deviation. They differed by only 6.5% and 20.1% for the 2% and 5% sulphate solutions, respectively. In comparison to the previous results, this drop in strength was considered to be significant. The cause for this effect cannot be confirmed and further analysis is required; however, this mechanical behaviour corroborates past research investigations. (Hartell 2008) The matrix densification process seems to have reached a maximal point after 18 months of exposure, mimicking an increase in mechanical properties followed by a drop in strength due to microstructural degradation.

As in previous research, the test procedure proposed in Section 4.3.1 to assess the level of damage caused by sulphate exposure was successful in differentiating deterioration mechanisms. Although the coefficients of variation were elevated in comparison to the ultrasonic study, they did not influence the statistical analysis. Conclusive results were obtained, making the test reliable in assessing changes in material properties. On the other hand, it was clear from the results that the presence of an evaporation plane diminished the mechanical behaviour of the concrete material. However, as previously discussed in the ultrasonic study, the mechanisms at play are unclear. For this reason, the partially immersed samples were compared with their respective control regimen.

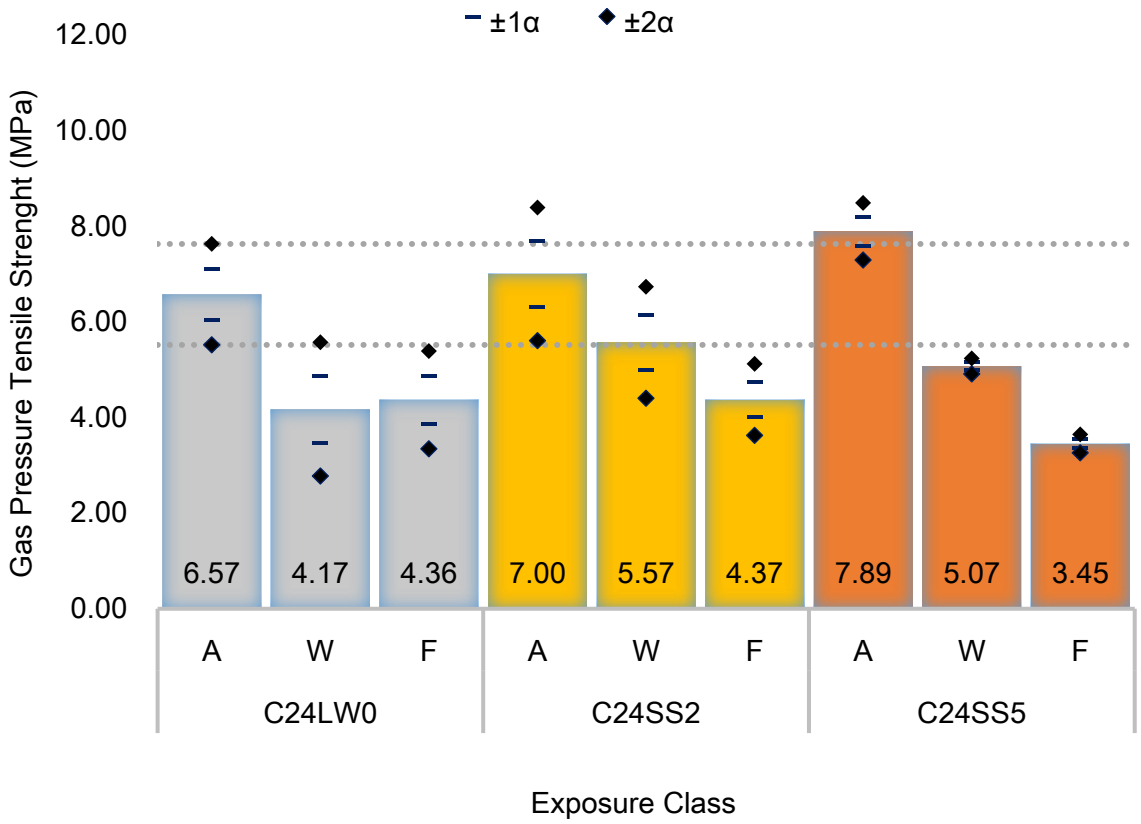


Figure 5.1.28: Gas pressure tensile strength results and sample statistics: cylindrical specimens, 24-month solution exposure period.

Table 5.1.14: Results of F-test and t-test for verification of equality of two sample variances and means: cylindrical specimens, 24-month solution exposure period.

Specimen Exposure	t-Test								
	C24LW0A	C24LW0W	C24LW0F	C24SS2A	C24SS2W	C24SS2F	C24SS5A	C24SS5W	C24SS5F
C24LW0A	1.000	0.009	0.006	0.449	0.090	0.004	0.053	0.032	0.004
C24LW0W	0.725	1.000	0.720	0.008	0.057	0.684	0.006	0.184	0.263
C24LW0F	0.969	0.697	1.000	0.006	0.055	0.984	0.003	0.163	0.098
C24SS2A	0.730	0.995	0.701	1.000	0.052	0.005	0.199	0.034	0.007
C24SS2W	0.900	0.820	0.870	0.824	1.000	0.041	0.015	0.340	0.017
C24SS2F	0.670	0.446	0.698	0.449	0.584	1.000	0.002	0.090	0.048
C24SS5A	0.743	0.578	0.763	0.580	0.681	0.982	1.000	0.006	0.002
C24SS5W	0.214	0.162	0.221	0.163	0.194	0.300	0.335	1.000	0.003
C24SS5F	0.255	0.193	0.263	0.194	0.231	0.357	0.396	0.888	1.000
F-Test									

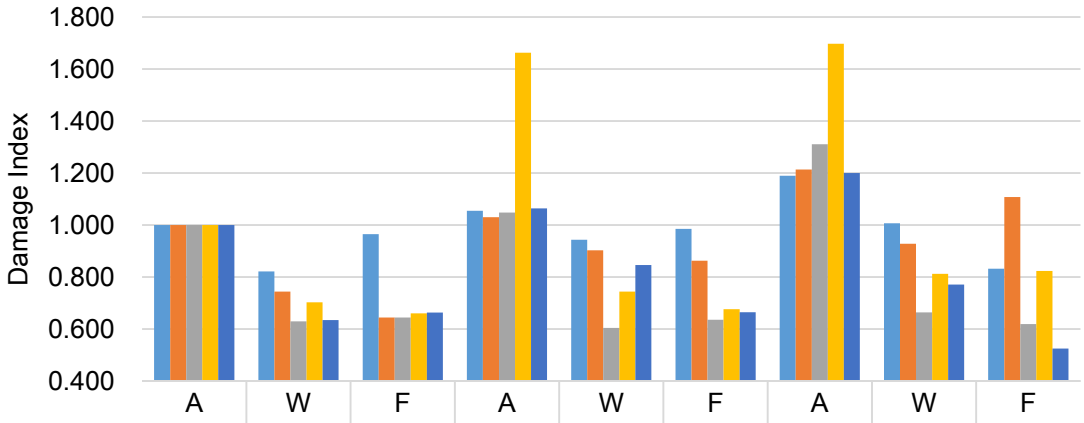
5.1.3.6 Gas Pressure Tension Damage Index

The damage factor method was again used here to better understand the change in mechanical behaviour over the course of the two-year exposure. Figure 5.1.29 exhibits the individual damage factors calculated as a ratio of the ultimate gas pressure strengths of a regime over that of their respective control specimen.

As previously discussed, all of the sulphate diffusion regimes had damage factors above 1 and the wicking and field regimens were below the control value. There was one exception to this, the C06SS5F specimen recorded a damage factor of 1.108, making it the only field exposure stronger than the limewater control specimen.

Starting with the 2% sulphate diffusion regime, there was no observable trends in the first 12 months of exposure; the damage factors varying between 1.030 and 1.055. As seen from the results of the statistical analysis in the above sections, any changes in

failure strength were considered to be insignificant compared to that of the limewater control. Only after 18 months of exposure did the sample fail with a nearly 60% gain in strength. The next series of replicates submitted to the destructive test recorded strengths similar to that of the 3-month exposure. At this stage of the experimental assessment, there are no explanations for this sudden increase. The correlative study between test procedures (Section 5.1.4) may provide more answers to this spike in strength.



	LW0			SS2			SS5		
3 mts	1.000	0.822	0.965	1.055	0.944	0.985	1.190	1.007	0.832
6 mts	1.000	0.744	0.644	1.030	0.903	0.863	1.214	0.928	1.108
12 mts	1.000	0.630	0.645	1.048	0.604	0.636	1.311	0.664	0.619
18 mts	1.000	0.703	0.660	1.663	0.744	0.676	1.698	0.813	0.823
24 mts	1.000	0.634	0.664	1.064	0.847	0.665	1.200	0.771	0.525

Figure 5.1.29: Gas pressure tensile strength damage index: comparison between exposure regimens.

With an increase in solution concentration, there was also an increase in damage factor for the diffusion specimens. From the start of the exposure term, there was a noticeable change in mechanical properties with a damage factor of 1.19. Up to 18 months of exposure, there was a steady increase in strength before dropping after 2 years of exposure. The results of the statistical analysis were unclear as to whether these

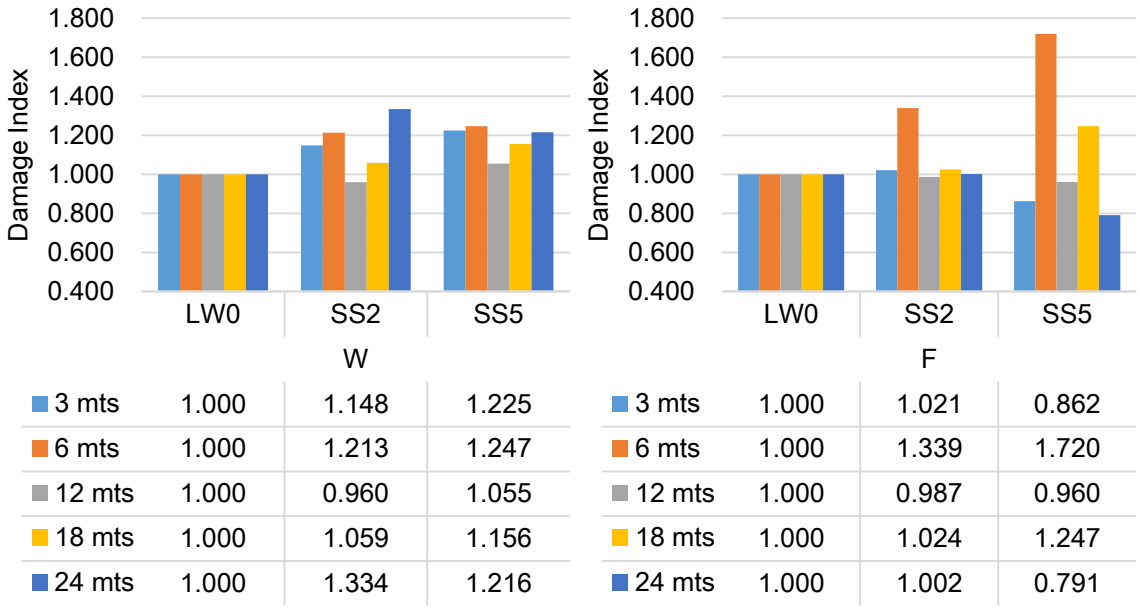
increases were significant. The results of the F-test for the 12-month and the 24-month specimen were 0.061 and 0.053, respectively. These were very close to the 0.05 limit and the probability of having microstructural discrepancies was very high, especially for the C24SS5A sample. After looking at the trend over time, the drop in strength was definitely due to an ongoing degradation mechanism; however, the ultimate strength recorded was still higher than that of the limewater control. In practice, this could lead to serious misinterpretations. If the concrete material was mechanically assessed during this stage of the attack mechanisms, the similar or higher strength results may lead to the wrong conclusions. Moreover, the presence of an evaporation front may further complicate the analysis.

The partially immersed samples exhibited different trends than their diffusion companions. As previously stated, the loss in strength may be due to the differences in the degree in hydration between the upper part and the lower. The limewater specimens failed at significantly lower strengths then that of the cured specimens. In order to better compare the influence of sulphate exposure, the regimens were compared to their respective regime.

Figure 5.1.30 demonstrates the damage factors calculated for the wicking and field transport mechanisms. When compared to their companion control regime, the failure pressures were generally higher. Statistically, only the C03SS5W specimen was considered to be different with an index of 1.225 for the wicking regime, and the C06SS2F, C06SS5F and C18SS5F for the field regime with indexes of 1.339, 1.720 and 1.247, respectively.

Shown in Figure 5.1.30a, the trend in the results was consistent for both the 2% and 5% sulphate solutions. It would appear that there was an initial increase in strength up to 6 months followed by a drop at 12 months and then the strength climbed again in the second year of exposure. The maximal damage index (1.334) was obtained at the end of

the exposure term for the 2% solution, making it the highest of this transport mechanism type. On the other hand, the maximum damage index was obtained after 6 months of exposure. One assumption for the increase in strength seen here is the presence of sulphate compounds at the evaporative plane. Although the surface is physically degraded, the presence of sulphate salts filling the voids of the cementitious matrix contribute to sustaining the axisymmetric pressure.



W	LW0	SS2	SS5
3 mts	1.000	1.148	1.225
6 mts	1.000	1.213	1.247
12 mts	1.000	0.960	1.055
18 mts	1.000	1.059	1.156
24 mts	1.000	1.334	1.216

F	LW0	SS2	SS5
3 mts	1.000	1.021	0.862
6 mts	1.000	1.339	1.720
12 mts	1.000	0.987	0.960
18 mts	1.000	1.024	1.247
24 mts	1.000	1.002	0.791

a) b)

Figure 5.1.30: Gas pressure tensile strength damage index: comparison between sulphate solution concentrations for

a) wicking exposure regimen and, b) field exposure regimen.

When adding a cyclic solution exposure to mimic that of field conditions, the damage suffered by the sample during the attack process may overcome densification effects; thus, the properties of the concrete material will diminish. This was the trend observed for the field regimes. The lowest value recorded (3.45 MPa) for this experimental program was for the C24SS5F sample with a deterioration factor of 0.791. These assumptions can only be confirmed with further investigation at the microstructural level. However, certain correlations between test methods may provide further answers.

5.1.4 Correlative Study between Experimental Tests

The first test performed on the cylinders was nondestructive in nature, ultrasonic testing, and may offer information on a concrete material based on its macrostructural and microstructural condition. The 54 kHz ultrasonic pulse velocity test has been used in numerous studies on sulphate attack and there is still debate whether it is a viable method to assess the condition of a concrete structure in the field. (Boyd and Ferraro 2005) Here, two types of ultrasonic testing were performed on the cylinders before being subjected to destructive testing. The experimental program was devised to investigate whether any correlation exists between the wave transit velocity and the tensile strength of a concrete material exposed to an external source of sulphates.

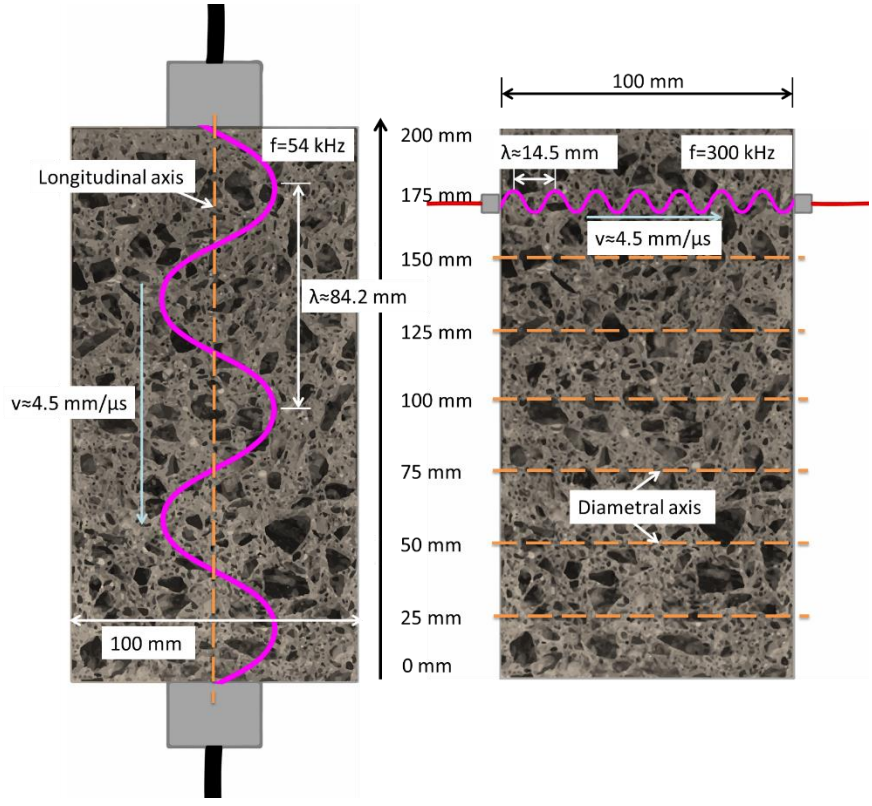


Figure 5.1.31: UPV test locations and properties of 54 kHz longitudinal transient wave and 300 kHz diametral transient wave.

Two different methods of ultrasonic testing were investigated; the traditional 54 kHz UPV method and a non-conventional 300 kHz ultrasonic pulse emission test. Firstly, it appears that the velocities measured to create the diametral profiles were lower than those recorded for the 54 kHz longitudinal pulse velocity. This is in accordance with a study by Aggelis and al. (2004) on the effect of wave frequency on transit velocities. With an increase of test frequency (54 kHz to 300 kHz), the ensuing velocity diminishes. Moreover, sample geometry also seems to influence wave propagation properties. For example, taking the average of the diametral velocities along the longitudinal axis (25 mm to 175 mm) obtained for the C03LW0A specimen compared to that of the longitudinal velocity; there was a percent difference of 11.42% (4.851 mm/μs vs. 4.297 mm/μs). This tendency carries throughout the 300 kHz UPV testing program, to various extents, though the differences were more pronounced for samples showing signs of deterioration. This may be due to the differences in parameters of a propagating wave.

Figure 5.1.31 schematically illustrates how a mechanical pulse travels through a 100 mm x 200 mm concrete cylinder. For equal transient speeds, the calculated wavelength of a 54 kHz wave is much longer than that of a 300 kHz wave. The example presented in the figure is for a speed of 4500 m/s. As seen, the wavelength for the higher pulse frequency is much shorter; thus, interacting with the material at a finer scale. In this case, the calculated wavelength is approximately the same as the maximal aggregate size, as opposed to nearly 7 times the max aggregate size for the 54 kHz UPV test method. It has been argued that high frequency may not be appropriate because concrete is a dispersive material; hence, wave attenuation is enhanced by the presence of voids and aggregates. In turn, this may diminish the reliability and repeatability of the test itself. (Popovics et al. 1990) The loss in amplitude and energy of the signal was measured for the 300 kHz UPV study and the data may be consulted in Appendix B. On average, the loss in amplitude recorded was between 25 and 40 dB with coefficients of variation below 10%. The highest losses in amplitudes where recorded at the cylinder

levels showing physical degradation. Nonetheless, the study was successful in differentiating the microstructural subtleties such as the degree of cement hydration as well (if not better) than the 54 kHz UPV study. The advantage here was the fact that higher test frequency permitted taking readings across the diametral axis to create the damage profiles discussed in Section 5.1.2. This would not have been possible with the 54 kHz frequency since the wavelength is approximately the size of the cylinder diametre. (Popovics et al. 1990)

The ultrasonic profiles were also found to be very useful when analyzing the fracture location of the cylindrical samples submitted to the gas pressure tension test. Figure 5.1.32 demonstrates a comparative example of a UPV profile against a failed concrete sample. It was found that the fracture locations usually occurred at the levels showing the lowest velocity readings. Here, the tensile strength recorded for the 18SS2A2 sample was the second highest of the test program (9.98 MPa); the third replicate being the highest at 10.24 MPa. The specimen failed slightly above the 75 mm level, in the region where the lowest UPV readings were recorded for that sample. For the second example, a partially immersed sample subjected to cyclic wet-dry sulphate exposure (C18SS5F3) is shown with a failure plane above the physically degraded zone (a visually pristine region). The location of the failure plane was again concurrent with the level recording the lowest velocity in its respective UPV profile. In this case, the sample still failed in a region microstructurally weaker even if it showed macroscopic signs of physical degradation below the immersion plane, due to wet-dry dimensional changes, and surface scaling caused by salt crystal growth at the evaporation front. Therefore, the ultrasonic test at a frequency of 300 kHz was capable of predicting the weakest region of the concrete samples under an asymmetric pressure failure. Therefore, a relationship may be present between the transient wave velocity and the tensile strength of a concrete cylinder.

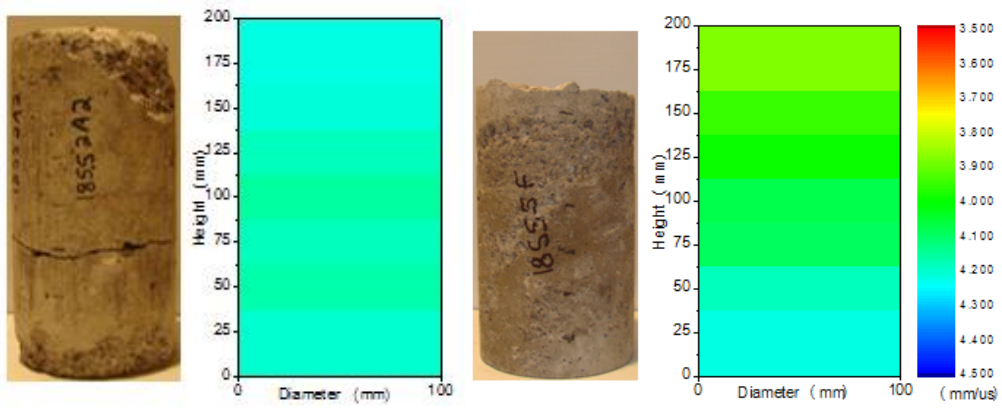


Figure 5.1.32: Comparison between C18SS2A and C18SS5F 300 kHz diametral UPV profiles and fracture location of corresponding failed concrete samples.

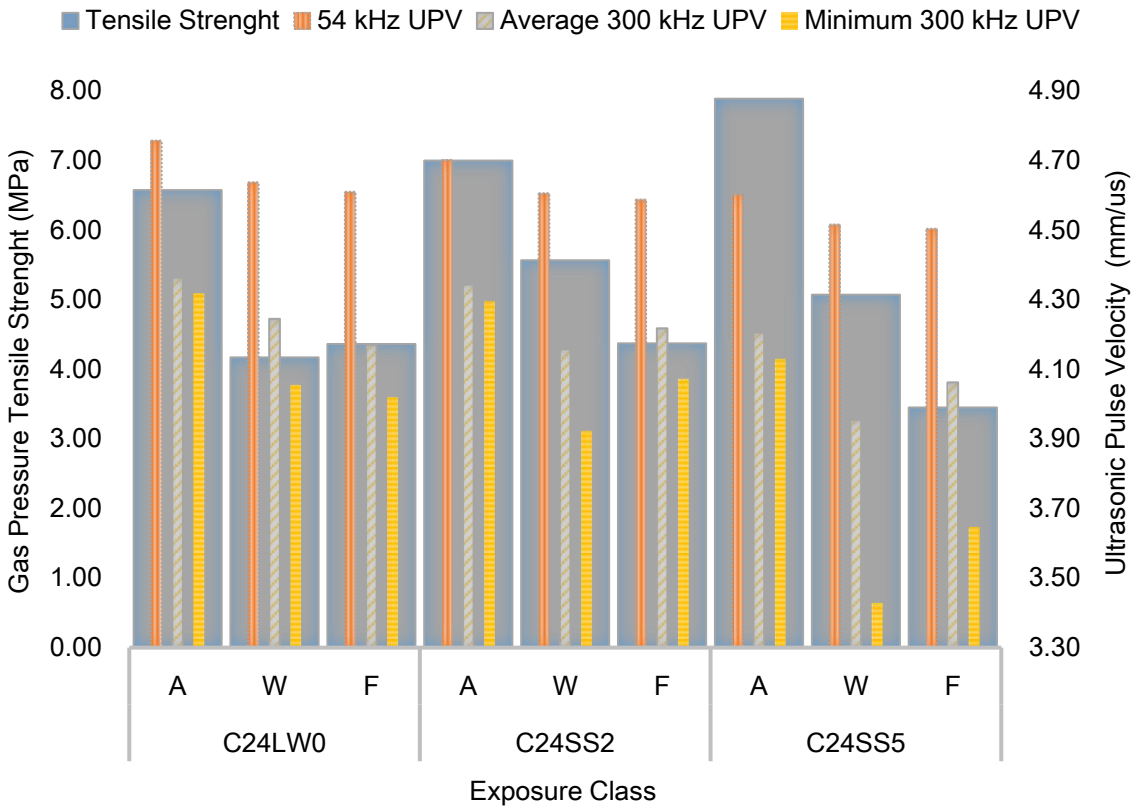


Figure 5.1.33: comparison between gas pressure tensile strength and results of 54 kHz and 300 kHz ultrasonic pulse velocity study 24-month exposure regimen:

Figure 5.1.33 compares the gas pressure tensile strength with the three different ultrasonic pulse velocities: the 54 kHz longitudinal velocity, the average value from the 300 kHz diametral velocity profile and the minimal value from the latter. For discussion purposes, only the 24-month exposure term is presented herein. Comparative graphs for all exposure times are presented in Appendix B.

The trends observed for the test methods were similar for the control exposures where both strength and wave velocity diminished with exposure type. Meanwhile, this trend was not observed for both sulphate solutions. The wicking mechanism produced lower wave velocities in comparison to their companion specimens. Moreover, the increase in strengths with increase in sulphate concentration is opposite to the trend exhibited for both UPV test results. These trends are not coherent with the general exponential correlations between strength of concrete and its transient wave velocity properties. (Carino 1997) For this reason, a regression analysis was performed to determine if any such correlation existed between both test methods and whether UPV testing may predict the gas pressure tensile strength of a degraded material.

From both UPV test methods, the wave velocities for the longitudinal 54 kHz UPV test, the average and the minimal values of the 300 kHz UPV profile were evaluated. The average value was chosen as a direct comparison to the longitudinal value and the minimal value was also considered since the failure plane under gas pressure tension coincided with the level showing minimal UPV readings, as discussed above. The graphical representations of the analysis may be consulted in Appendix B. The coefficients of determination (R^2) calculated from each regression analysis are tabulated below (Table 5.1.15).

Table 5.1.15: Coefficients of determination (R^2) from regression analysis on the relationship between ultrasonic pulse velocity and gas pressure tensile strength.

Regimens	Coefficients of Determination											
	Velocity 54 kHz				Average Velocity 300 kHz				Minimum Velocity 300 kHz			
	D	W	F	All	D	W	F	All	D	W	F	All
C03	0.4040	0.9934	0.0002	0.0736	0.9349	0.8946	0.2088	0.1158	0.4261	0.8453	0.7280	0.3617
C06	0.6461	0.7242	0.0549	0.1097	0.9913	0.4026	0.3360	0.0863	0.5303	0.2927	0.6136	0.1355
C12	0.0014	0.0498	0.9290	0.1248	0.8641	0.0530	0.9708	0.7155	0.9967	0.0058	0.9978	0.5583
C18	0.2703	0.4665	0.0067	0.4395	0.8311	0.0512	0.0088	0.2107	0.7372	0.0641	0.0124	0.2885
C24	0.9997	0.1898	0.9583	0.4069	0.9594	0.2301	0.9189	0.2366	0.9572	0.1543	0.9902	0.2939
All	0.2215	0.0802	0.4242	0.2837	0.4746	0.0136	0.3436	0.2716	0.6066	0.0325	0.1737	0.3266

As seen in Table 5.1.15, the results are scattered and no clear correlations can be determined. Hence, the ultrasonic nondestructive test method cannot be considered an acceptable means to predict the gas pressure tensile strength of a concrete sample. The coefficients vary between 0.0002 and 0.9997. The second order polynomial regression produced the best data fit when analysing the results obtained for all regime types combined. From the latter, the highest coefficient calculated is 0.3266 corresponding to the minimum value of the 300 kHz UPV study. The latter is illustrated in Figure 5.1.34. It appears that as the strength increased the velocity positively followed during for the early exposure terms. However, after the first year of exposure, the upward tendency eventually peaked and dropped. This change in behaviour appears to be associated with sulphate exposure, and especially with its increase in concentration. This implies that even if the sulphate exposed samples fail at higher strengths than their controls, the corresponding ultrasonic velocities are still lower than their controls. This behaviour is better illustrated on Figure 5.1.35 where only the diffusion regimens are considered in the regression analysis.

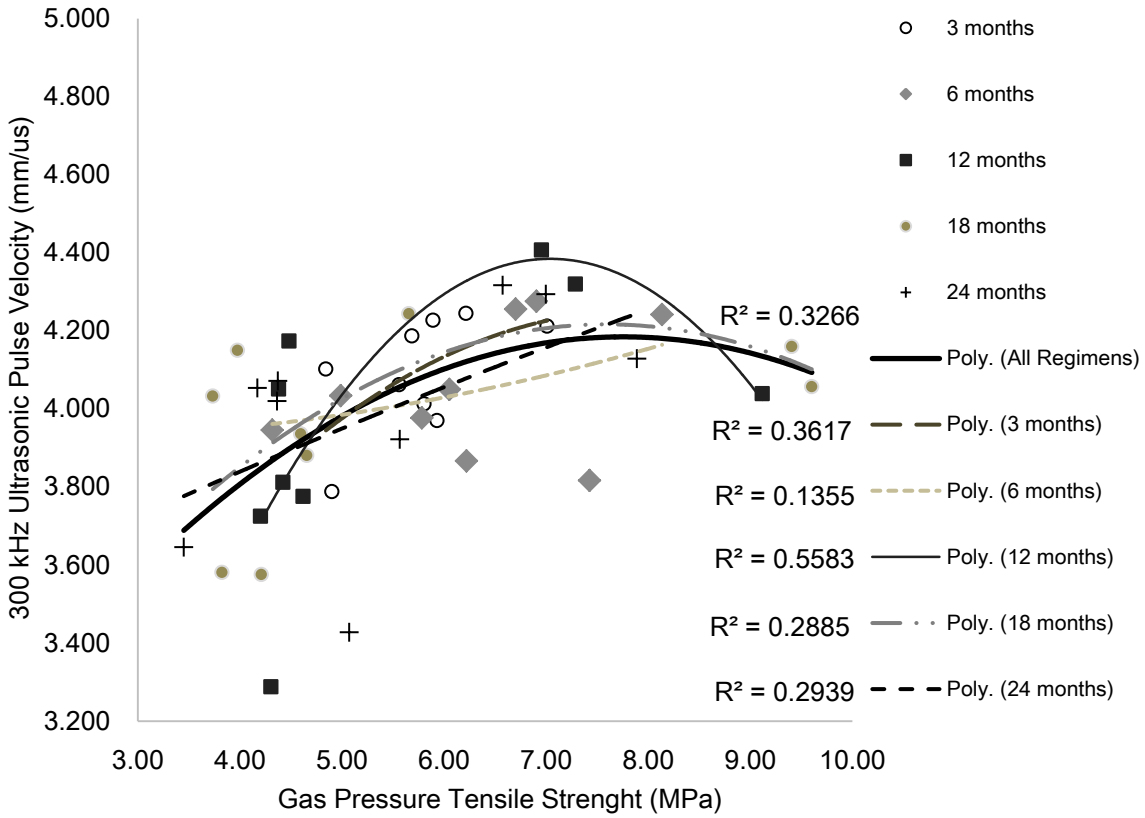


Figure 5.1.34: Regression analysis: average value of 300 kHz ultrasonic pulse velocity profile versus gas pressure tensile strength for all exposure regimens.

As depicted in Figure 5.1.35, the effects of sulphate exposure produced a downward trend for all exposure ages. Ranging from 0.8311 to 0.9913, it seems that the average value of the 300 kHz diametral UPV profiles (diffusion regimens only) yielded the best correlation fits for each individual exposure time. But, when all exposure times were considered together the R^2 value dropped to 0.4746 along with a change in regression curve type. This is indicative that the material's microstructure is changing overtime; therefore, the transient wave's travel path is influenced by micro or macroscopic changes.

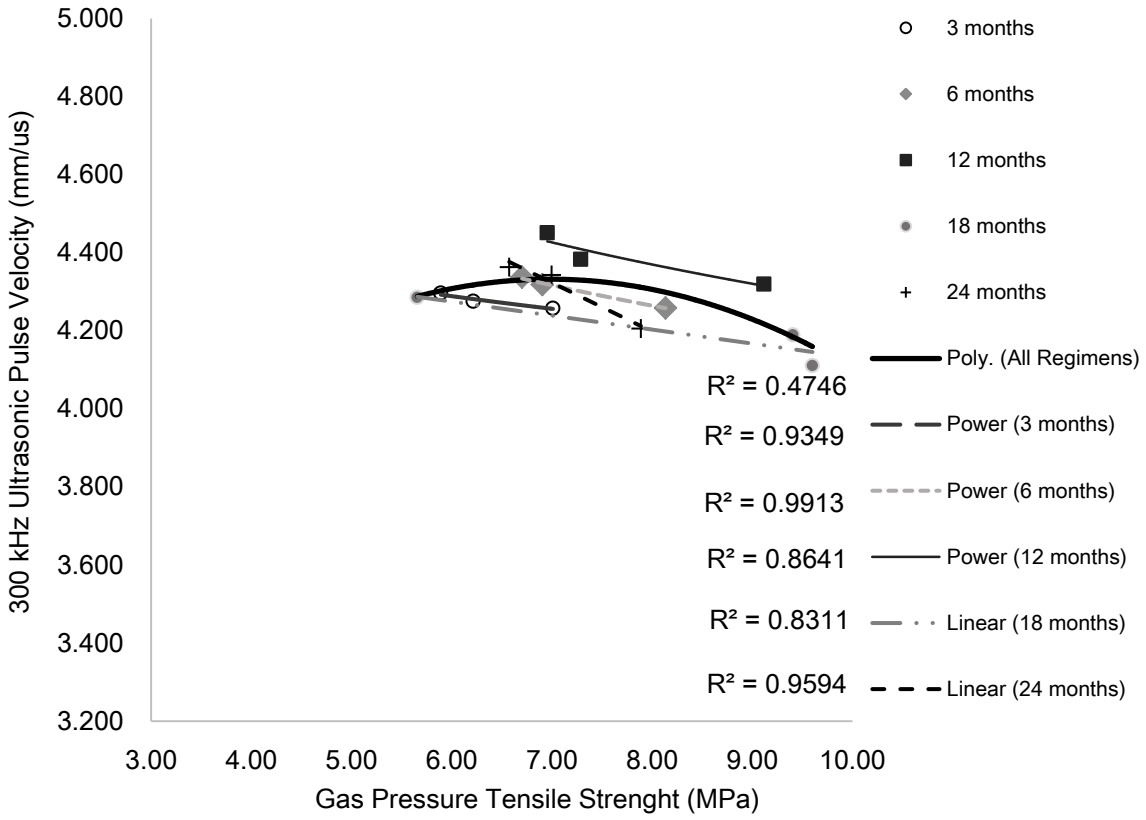


Figure 5.1.35: Regression analysis: average value of 300 kHz ultrasonic pulse velocity profile versus gas pressure tensile strength for diffusion regimens.

Figure 5.1.36, demonstrates the 54 kHz longitudinal velocity data obtained for the limewater and the 5% sulphate solution diffusion specimens. Both trend lines clearly show opposing behaviours. The presence of a degradation mechanism is definitely ongoing and must be analysed further. Something is giving strength to the material, but also changing its microscopic properties.

These trends do not reflect past research investigations positively correlating compressive strength to wave velocity. (Popovics and al. 1990) In these instances, the direct comparison of bulk material properties was appropriate. However, a concrete sample presenting layered microstructural differences and superficial damage may not behave as perfectly as one would like. Here, the standard means of testing, the

longitudinal 54 kHz UPV, evaluated the overall condition of the bulk concrete material. The diametral analysis also provided information on the bulk material to a finer scale but, superficial damage was also an influential factor. In turn, the failure mode of the gas pressure tension test, being sensitive to both surface imperfections and bulk properties, may explain the better data fit between the latter two test methods. Therefore, exploring other means of testing may provide further insight on how this type of degradation process responds to mechanical testing.

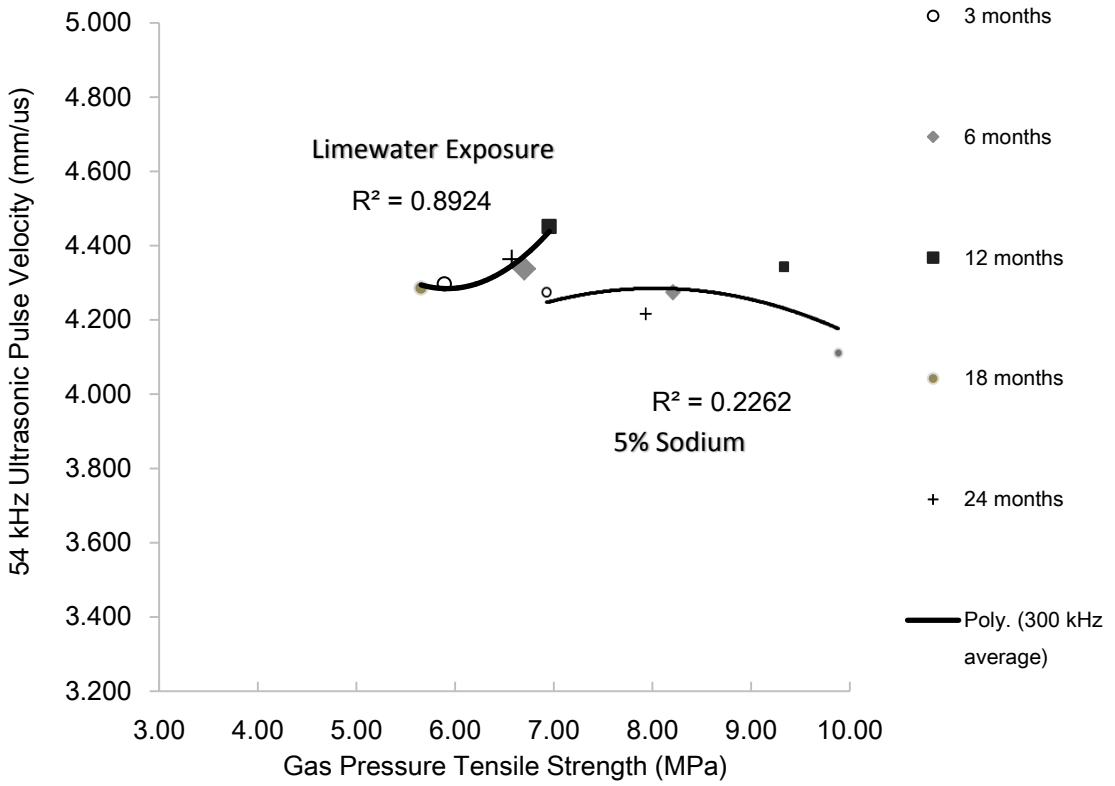


Figure 5.1.36: Regression analysis: average value of 54 kHz ultrasonic pulse velocity profile versus gas pressure tensile strength for control and 5% Na_2SO_4 diffusion regimens.

5.2 Condition Assessment of Disk Samples

The next sub-sections present the results obtained for the splitting tension test combined with acoustic emission monitoring study conducted on 150 mm x 100 mm disk specimens which have endured external sulphate attack damage. The procedure was devised to compare the mechanical effects of the deterioration mechanisms in relation with four different transport mechanisms reminiscent of field exposures. The latter created by soluble sulphates traveling along the longitudinal direction of the concrete disk creating a single ingress front. The change in splitting tensile strength may be indicative of the depth of sulphate penetration and the concrete's microstructural changes since the tensile stress plane of the disk under uniformly distributed load is perpendicular to the sulphate ingress front. Localizing the acoustic events caused by the failing concrete sample may provide further information on stress crack initiation and propagation, along with identifying the weakest regions of the concrete specimen for each regimen type.

5.2.1 Comparative Study of Splitting Tensile Test

As described in Section 5.1.1, each regimen type is compared to the control being the disk specimen completely immersed in limewater for the analysed exposure time period. To determine the potential and reliability of the splitting tension test to detect and quantify the level of damage caused by ESA, each regimen type was statistically compared. The results are illustrated in Figures 5.2.1 through 5.2.5 and Tables 5.2.1 to 5.2.5. In the end, the strengths were normalized and compared over time to evaluate whether there is any existing trends representative of ESA.

5.2.1.1 Splitting Tensile Strength Results after 3 Months of Solution Exposures

The first exposure time analysed was considered to be reliable where the variances in experimental results were considered to be equal apart for the D03LW0W specimen.

The three replicates recorded a low coefficient of variation just below 1.0%. In comparison to the CVs calculated for the rest of the regimens, above 3.0%, the difference here is considered to be significant.

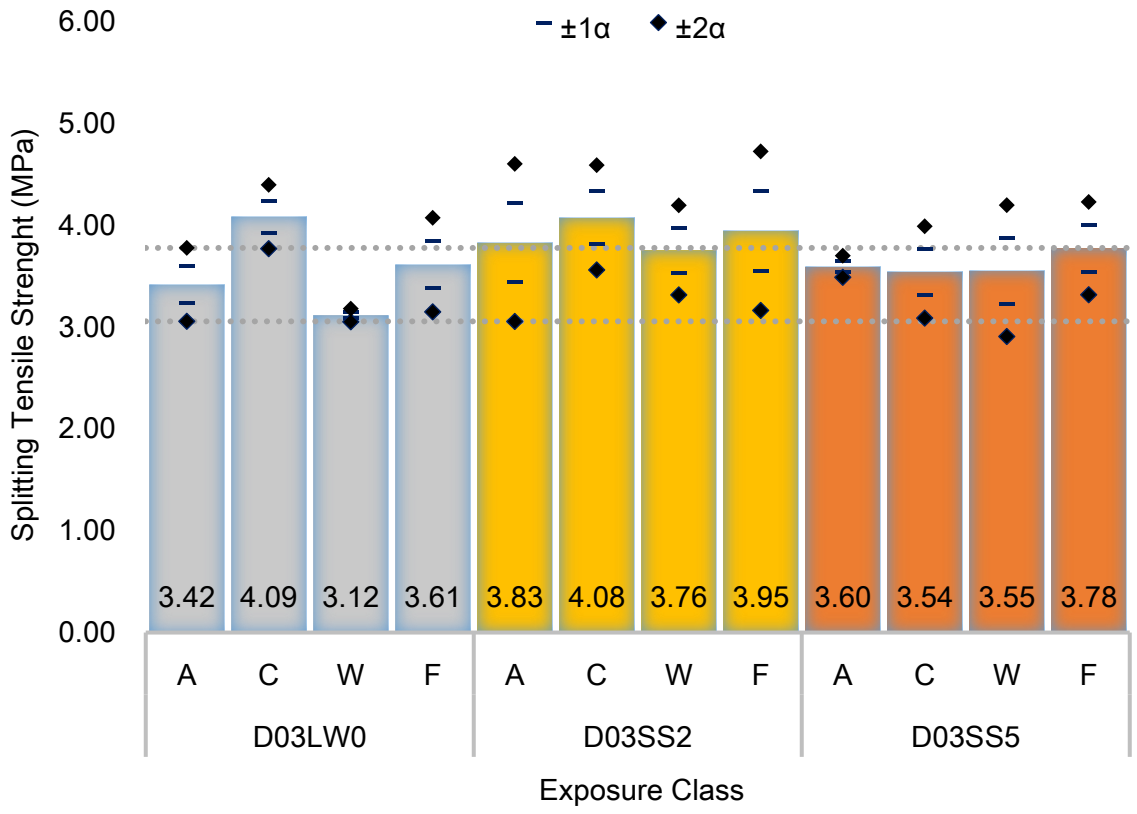


Figure 5.2.1: Splitting tensile strength results and sample statistics: disk specimens, 3-month exposure regimens.

After 3 months of solution exposure, the strongest specimen (D03LW0C) reached a splitting tensile strength of 4.09 MPa; which failed at a similar strength of its 2% sulphate solution exposure companion (D03SS2C). Both specimens recorded an increase in strength of 19.6% and 19.3% percent respectively making them the only specimens statistically different from the control according to the T-test results shown in Table 5.2.1. Illustrated in Figure 5.2.1, even if the average results for the other 2% sulphate regimens surrounded the control's standard deviation limits, they are still considered to be similar

according to the results of the t-test. On that note, all 2% sulphate exposure types failed at higher strengths than the 5% sulphate solution regimens. As seen in Figure 5.2.1, the latter specimens are within the controls standard deviation limits (95% level of confidence).

Table 5.2.1: Results of F-test and t-test for verification of equality of two sample variances and means: disk specimens, 3-month solution exposure period.

Specimens		D03LW0				D03SS2				D03SS5			
		A	C	W	F	A	C	W	F	A	C	W	F
		t-Test											
D03LW0	A	1.000	0.008	0.098	0.316	0.171	0.022	0.108	0.101	0.179	0.506	0.562	0.101
	C	0.860	1.000	0.007	0.043	0.350	0.965	0.111	0.599	0.007	0.027	0.062	0.124
	W	0.062	0.081	1.000	0.063	0.085	0.022	0.035	0.066	0.000	0.080	0.143	0.036
	F	0.759	0.631	0.038	1.000	0.450	0.081	0.476	0.272	0.907	0.719	0.809	0.436
D03SS2	A	0.357	0.282	0.014	0.525	1.000	0.410	0.791	0.733	0.405	0.326	0.396	0.842
	C	0.659	0.541	0.031	0.891	0.614	1.000	0.178	0.654	0.078	0.053	0.093	0.203
	W	0.806	0.674	0.042	0.951	0.488	0.843	1.000	0.506	0.283	0.299	0.417	0.929
	F	0.352	0.277	0.013	0.517	0.990	0.606	0.481	1.000	0.259	0.194	0.251	0.547
D03SS5	A	0.159	0.206	0.538	0.100	0.037	0.081	0.110	0.036	1.000	0.702	0.843	0.256
	C	0.781	0.651	0.040	0.977	0.507	0.869	0.974	0.500	0.105	1.000	0.957	0.275
	W	0.477	0.382	0.020	0.677	0.820	0.779	0.634	0.810	0.053	0.657	1.000	0.387
	F	0.771	0.642	0.039	0.987	0.515	0.879	0.964	0.508	0.103	0.990	0.666	1.000
		F-Test											

5.2.1.2 Splitting Tensile Strength Results after 6 Months of Solution Exposures

First, the author would like to address the reason for the missing values seen in Figure 5.2.2. No data was recorded for the D06LWC and D06LW0F samples due to equipment failure. Moreover, the data for one D06SS2F replicates was also lost. The values graphed in Figure 5.2.2 represent the failure strength for two replicates only with a very low coefficient of variation (0.03%).

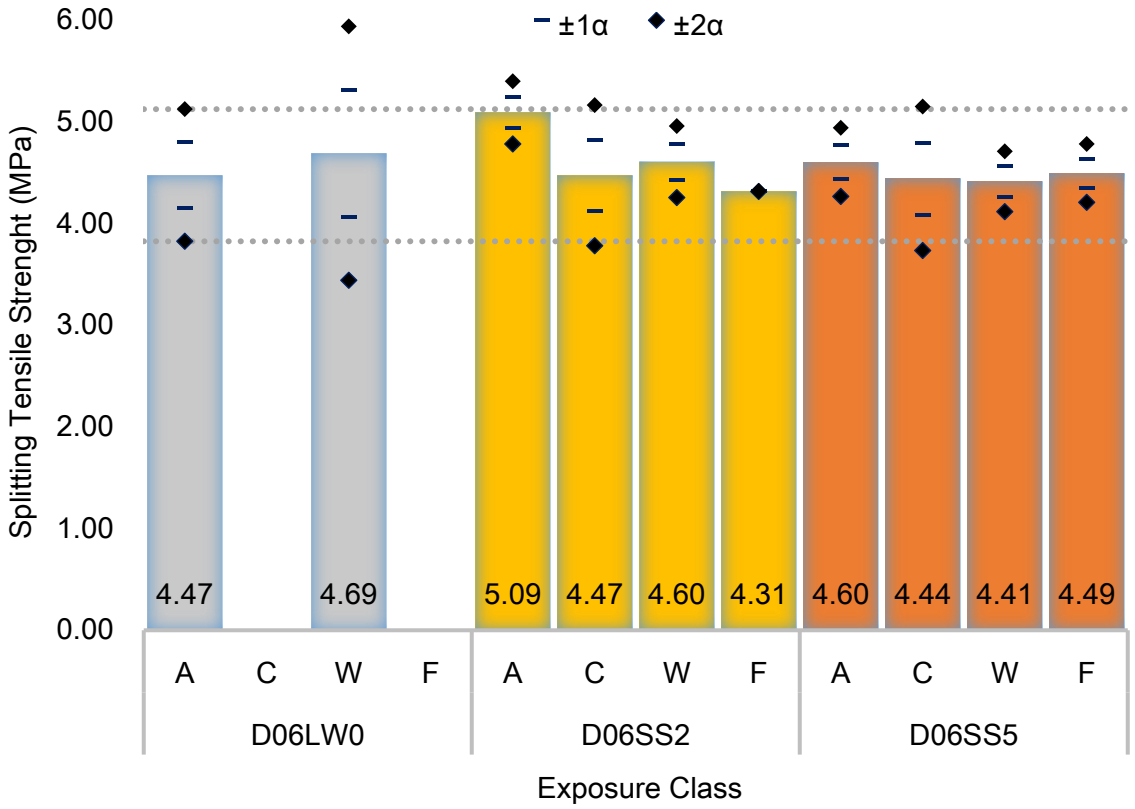


Figure 5.2.2: Splitting tensile strength results and sample statistics: disk specimens, 6-month exposure regimens.

Similar to the 3 months trend, the resulting failure stresses are similar for all exposure types (Table 5.2.2). According to the results of the t-test, there are no distinctions between the 2% regimens and their 5% sulphate companions. One exception, with a probability of 4.1%, only the 2% sulphate solution diffusion regimen is considered to be statistically different from the control (and all other sulphate regimens for that matter) even if it falls between the limits of the control's 95% level of confidence. The specimen failed under a splitting tensile stress 13.8% higher than its control.

Table 5.2.2: Results of F-test and t-test for verification of equality of two sample variances and means: disk specimens, 6-months solution exposure period.

Specimens		D06LW0				D06SS2				D06SS5			
		A	C	W	F	A	C	W	F	A	C	W	F
		t-Test											
D06LW0	A	1.000		0.626		0.041	0.992	0.572	0.488	0.578	0.910	0.778	0.930
	C												
	W	0.426		1.000		0.341	0.626	0.836	0.410	0.829	0.582	0.497	0.626
	F												
D06SS2	A	0.367		0.115		1.000	0.047	0.023	0.013	0.021	0.044	0.005	0.008
	C	0.938		0.469		0.331	1.000	0.581	0.518	0.587	0.920	0.798	0.924
	W	0.454		0.147		0.867	0.412	1.000	0.104	0.982	0.511	0.219	0.441
	F	0.005		0.003		0.011	0.005	0.010	1.000	0.099	0.603	0.380	0.166
D06SS5	A	0.425		0.136		0.909	0.385	0.958	0.010	1.000	0.516	0.216	0.443
	C	0.915		0.486		0.319	0.977	0.397	0.005	0.371	1.000	0.902	0.824
	W	0.345		0.107		0.961	0.311	0.829	0.012	0.870	0.299	1.000	0.532
	F	0.327		0.100		0.929	0.294	0.798	0.012	0.839	0.283	0.968	1.000
		F-Test											

5.2.1.3 Splitting Tensile Strength Results after 12 Months of Solution Exposures

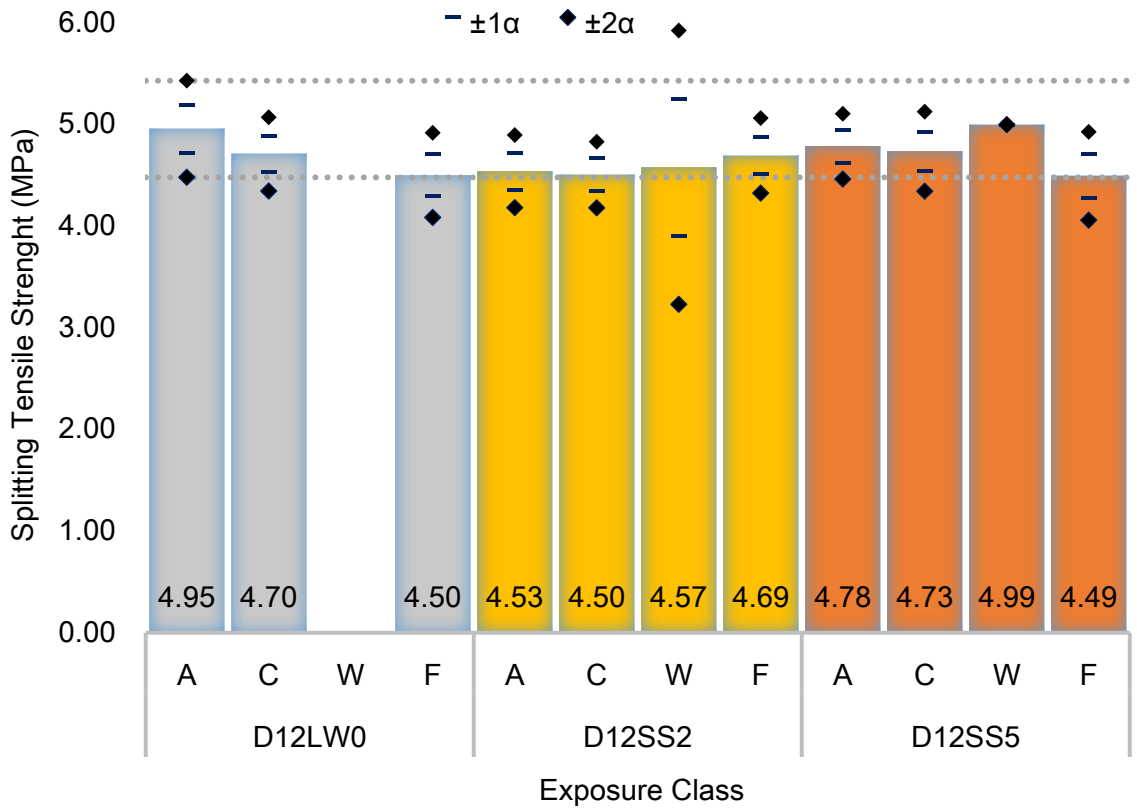


Figure 5.2.3: Splitting tensile strength results and sample statistics: disk specimens, 12-month exposure regimens.

From Figure 5.2.3, there are no observable particularities which are considered to be statistically significant. The results from the F-test and coefficients of variation obtained suggest that the experimental procedure followed was acceptable. From Table 5.2.3, the variances between each sample types are considered to be equal for coefficients of variation between 3.4% and 14.7%. At 5.0 MPa, the D12SS5W value is the highest recorded; it is only 0.8% greater than the control. However, there is a noticeable drop in ultimate strength for the other sulphate regimens. At 4.5 MPa, the D12SS5F is the lowest value recorded with a strength difference of 9.3%. It appears that the slight

increase in strength noticed at the beginning of the exposure term, is now starting a downwards trend.

Table 5.2.3: Results of F-test and t-test for verification of equality of two sample variances and means: disk specimens, 12-month solution exposure period.

Specimens		D12LW0				D12SS2				D12SS5			
		A	C	W	F	A	C	W	F	A	C	W	F
		t-Test											
D12LW0	A	1.000	0.224		0.067	0.071	0.053	0.410	0.204	0.358	0.280		0.067
	C	0.736	1.000		0.265	0.311	0.220	0.773	0.924	0.617	0.874		0.257
	W												
	F	0.870	0.862		1.000	0.832	0.988	0.861	0.300	0.137	0.232		0.961
D12SS2	A	0.723	0.985		0.847	1.000	0.822	0.926	0.354	0.151	0.268		0.795
	C	0.637	0.890		0.755	0.905	1.000	0.863	0.254	0.101	0.192		0.945
	W	0.221	0.135		0.175	0.132	0.110	1.000	0.789	0.633	0.718		0.845
	F	0.753	0.983		0.879	0.968	0.873	0.140	1.000	0.554	0.803		0.290
D12SS5	A	0.629	0.881		0.746	0.895	0.990	0.108	0.864	1.000	0.751		0.135
	C	0.809	0.924		0.937	0.909	0.815	0.156	0.941	0.806	1.000		0.225
	W												
	F	0.910	0.823		0.960	0.808	0.718	0.188	0.839	0.709	0.897		1.000
		F-Test											

5.2.1.4 Splitting Tensile Strength Results after 18 Months of Solution Exposures

Similarly to the 12 months exposure, a downward trend is noticeable for the 2% sulphate regimens; each regimen have failed with a negative percent difference of 1.9% (D18SS2A), 3.3% (D18SS2C), 8.6% (D18SS2W) and 7.2% (D18SS2F) in comparison to the control. For the higher solution concentration, the specimens failed at slightly higher strengths in comparison to the weaker solution which happen to be very similar to the control regimens. The exception, the field mechanism failed at a strength of 3.8MPa, 11.4% lower than the control. However, only the D18SS2W regimen is considered to be statistically dissimilar to the control because of its low coefficient of variation.

Tabulated in Appendix C, the coefficients of variation vary between 0.04% and 12.1%. For the coefficients below 1%, the variances in the results are considered to be different form the rest according to the F-test seen in Table 5.2.4. As a consequence, the higher CV's obtained for the D18LW0F, D18SS2F and D18SS5F specimens do not permit conclusive results with the t-test even if the measurements are outside the control's confidence level limits.

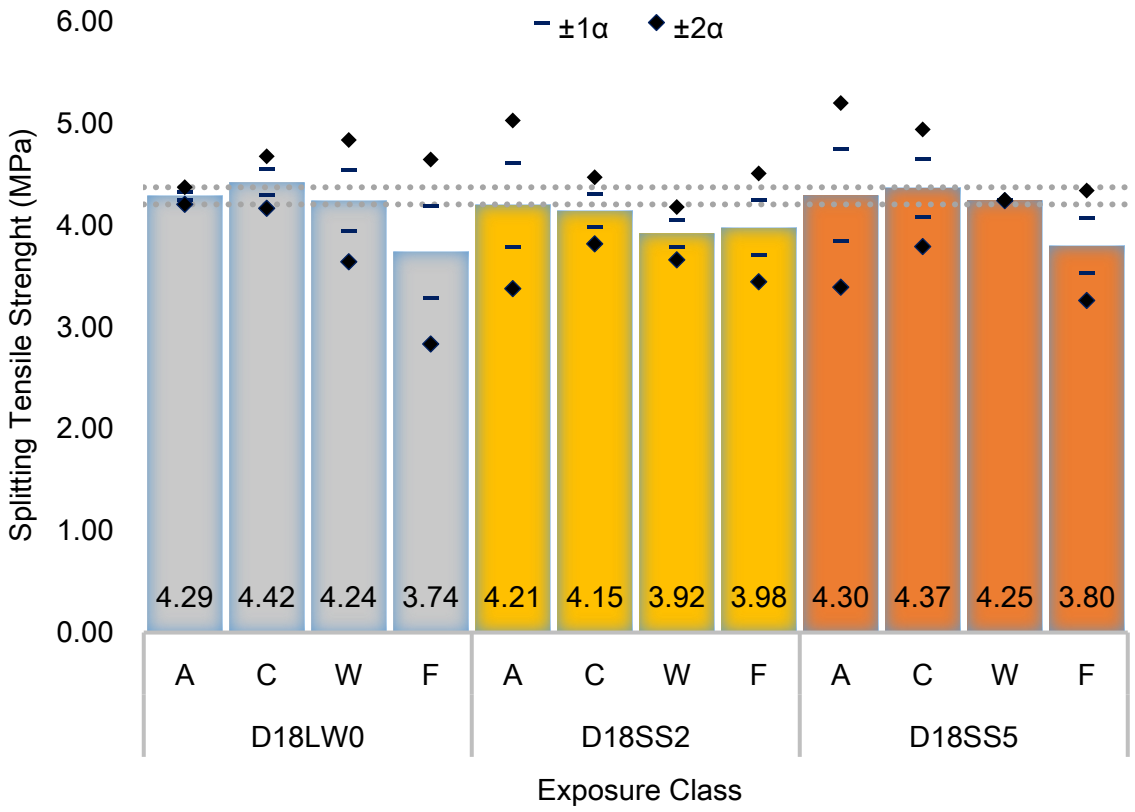


Figure 5.2.4: Splitting tensile strength results and sample statistics: disk specimens, 18-month exposure regimens.

Another aspect which must be considered here is the failure mechanism behind the splitting tensile test. After 18 months of exposure to corrosive solutions, there are still no conclusive results differentiating an external sulphate attack from the limewater control specimen. Because of the highly directional stress concentrations of the splitting tensile

test (i.e. tensile stresses forced to develop along the longitudinal plane of the cylindrical disk specimen), the splitting tensile strength of the material may be governed by the strength of the aggregates. (Neville 2004) The properties of the interfacial transition zone will play a secondary role until it has sustained sufficient change in micro-properties to induce a failure by aggregate pull-out. As seen on Figure 5.2.5, all the samples exhibited failure planes through the aggregates and not around the aggregates (implicating the ITZ). Therefore, the effects of paste degradation may only be noticed via splitting tensile testing at a later stage of its progression.

Table 5.2.4: Results of F-test and t-test for verification of equality of two sample variances and means: disk specimens, 18-month solution exposure period.

Specimens		D18LW0				D18SS2				D18SS5			
		A	C	W	F	A	C	W	F	A	C	W	F
		t-Test											
D18LW0	A	1.000	0.163	0.801	0.170	0.753	0.211	0.009	0.176	0.980	0.692	0.206	0.085
	C	0.194	1.000	0.387	0.066	0.430	0.082	0.009	0.059	0.669	0.773	0.139	0.023
	W	0.038	0.309	1.000	0.186	0.908	0.654	0.164	0.320	0.864	0.626	0.979	0.133
	F	0.017	0.148	0.608	1.000	0.261	0.220	0.545	0.478	0.207	0.114	0.193	0.851
D18SS2	A	0.020	0.175	0.689	0.907	1.000	0.830	0.320	0.470	0.804	0.605	0.878	0.231
	C	0.123	0.759	0.459	0.230	0.271	1.000	0.135	0.406	0.613	0.311	0.399	0.133
	W	0.190	0.989	0.315	0.151	0.179	0.770	1.000	0.752	0.237	0.070	0.049	0.531
	F	0.049	0.376	0.881	0.512	0.586	0.549	0.383	1.000	0.351	0.161	0.223	0.466
D18SS5	A	0.017	0.148	0.609	0.998	0.909	0.231	0.151	0.513	1.000	0.834	0.861	0.179
	C	0.042	0.330	0.961	0.575	0.654	0.488	0.336	0.920	0.576	1.000	0.542	0.068
	W	0.056	0.018	0.008	0.005	0.006	0.014	0.018	0.009	0.005	0.008	1.000	0.104
	F	0.047	0.367	0.896	0.523	0.599	0.537	0.374	0.985	0.525	0.935	0.009	1.000
		F-Test											

5.2.1.5 Splitting Tensile Strength Results after 24 Months of Solution Exposures

For the first time, there is a significant drop in strength which may be attributable to changes in material properties and not the outcome of variance related to the

experimental procedure. Shown in Table 5.2.5, the results of the t-test for equality of the means are statistically significant for almost all of the regimens. With a probability of 1 in 20, the samples have sustained some form of microstructural changes which have contributed to their apparent loss in strength. Also, depicted in Figure 5.2.5, the average tensile strength results for all regimens are below the 95% level of confidence of the control. Therefore, with probabilities of 0.054, 0.113, 0.095 and 0.067 for the D24LW0C, D24LW0W, D24SS2C and D24SS5A regimens respectively the results are not negligible. Hence, there is an average probability of 1 out of 10 that these specimens' loss in engineering properties may be attributed to an ongoing degradation mechanism.

Starting with the limewater exposures; three specimens where subjected to a form of transport mechanisms reminiscent of that encountered in the field. Apparently, the action of wetting and drying cycles on one face of the disk samples caused sufficient damage to diminish the strengths by 13.8% and 15.1% for the D24LW0C and D24LW0F specimens respectively. Here the presence of an evaporation plane caused additional loss in strength properties similarly to the wicking specimen where it is 6.0% lower than the control. Therefore, the means by which the specimens are exposed to the solution do cause differences in microstructural properties, whether it is related to the degree of hydration or micro damage, which reflects in the macro-mechanic behaviour of the materials.

The addition of sodium sulphate to the exposure solution also caused additional damage by changing the kinetics of the degradation mechanism. For the 2% sulphate solution, the statistically distinct specimens are on average 15.2% lower than the control's splitting tensile strength. Meanwhile, the D24SS2C specimen closely follows with a drop in strength of 9.1%. It would seem that the effects of an evaporation front and drying cycles are not as predominant here. In comparison to each other, the results of the t-test dictate that they are statistically similar. Therefore, it is unclear whether the loss in engineering properties is due to sulphate deterioration mechanisms or the physical

effects caused by the transport regimens. On that note, D24SS2A and D24SS2W are the only specimens to be statistically different from their limewater companion regimens (Table 5.2.5). Likewise for the 5% sulphate wicking regimen.

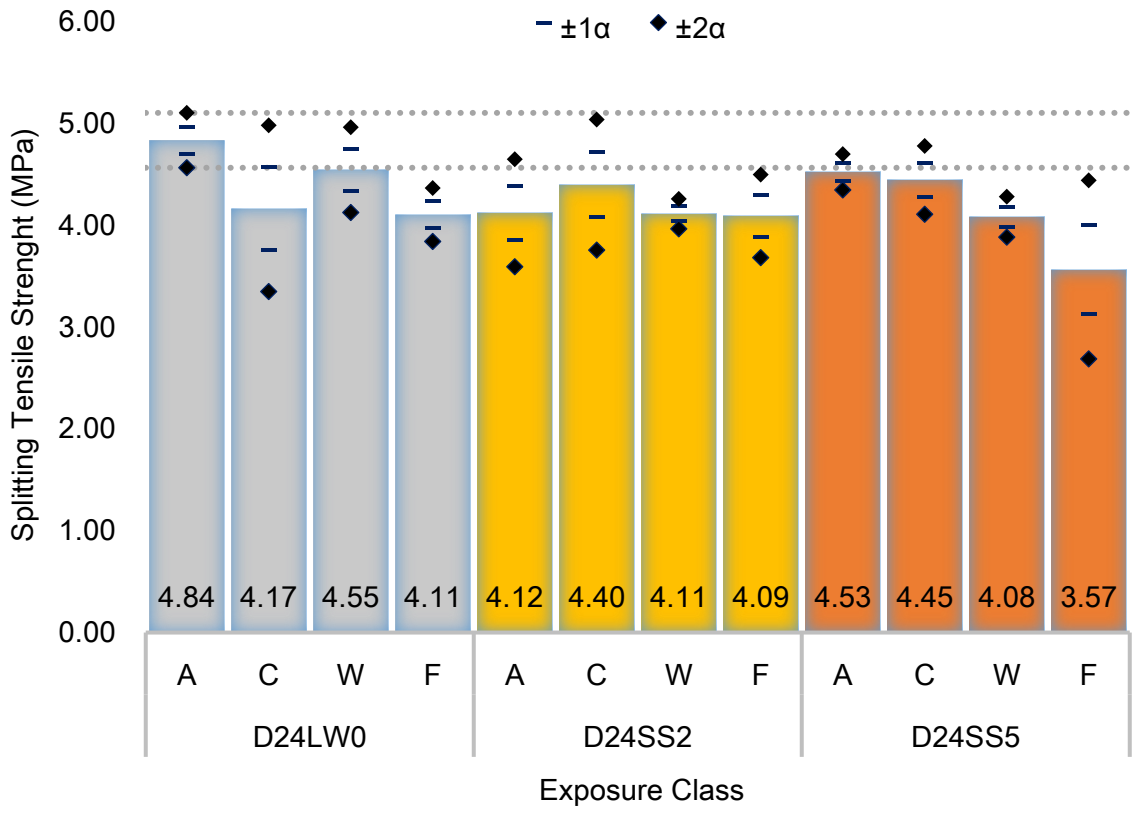


Figure 5.2.5: Splitting strength results and sample statistics: disk specimens, 24-month exposure regimens.

After 2 years of corrosive exposure, the D24SS5W specimen is the only regimen to be distinct from its limewater companion regimen with a negative percent difference of 10.3%. With respect to the control limewater diffusion sample, each transport mechanism reported losses in tensile strength of 6.4% (A), 8.1% (C), 15.7% (W) and 26.2% (F). Moreover, between themselves, there seems to be distinguishable differences of the means. Although the larger coefficient of variation calculated for D24SSF (12.3%), the results of the t-test demonstrate that the manner by which the

corrosive solution was transported within the concrete matrix may have further influence results than the corrosive solution alone; and, the transport mechanism alone for that matter. To better evaluate the extent of damage, a comparative study over the exposure period is conducted in the following section.

Table 5.2.5: Results of F-test and t-test for verification of equality of two sample variances and means: disk specimens, 24-month solution exposure period.

Specimens		D24LW0				D24SS2				D24SS5			
		A	C	W	F	A	C	W	F	A	C	W	F
		t-Test											
D24LW0	A	1.000	0.054	0.113	0.003	0.014	0.095	0.001	0.006	0.067	0.034	0.001	0.015
	C	0.196	1.000	0.226	0.815	0.882	0.482	0.843	0.789	0.329	0.336	0.748	0.214
	W	0.584	0.417	1.000	0.037	0.095	0.543	0.028	0.055	0.906	0.550	0.026	0.039
	F	0.978	0.188	0.566	1.000	0.923	0.215	0.927	0.928	0.030	0.051	0.831	0.121
D24SS2	A	0.412	0.591	0.772	0.398	1.000	0.313	0.957	0.879	0.141	0.149	0.821	0.164
	C	0.300	0.763	0.599	0.289	0.809	1.000	0.260	0.234	0.641	0.837	0.178	0.087
	W	0.459	0.063	0.219	0.475	0.144	0.100	1.000	0.869	0.011	0.035	0.694	0.324
	F	0.605	0.401	0.975	0.587	0.748	0.578	0.229	1.000	0.072	0.082	0.953	0.154
D24SS5	A	0.838	0.301	0.569	0.854	0.458	0.381	0.709	0.582	1.000	0.591	0.015	0.094
	C	0.782	0.290	0.783	0.761	0.576	0.431	0.321	0.806	0.694	1.000	0.033	0.044
	W	0.707	0.112	0.369	0.728	0.249	0.176	0.705	0.384	0.941	0.520	1.000	0.123
	F	0.165	0.790	0.343	0.159	0.478	0.609	0.054	0.330	0.252	0.241	0.096	1.000
		F-Test											

5.2.1.6 Splitting Tensile Strength Damage Index

As described in Section 5.1.1.6, Figure 5.2.6 demonstrates the damage index calculated for each regimen in comparison to their respective limewater diffusion control. The effects of sulphate solution concentration in combination with exposure type on the splitting tensile strength properties are compared over a period of two years. It can be observed that within the first 3 months of solution exposure, the concrete disk specimens experience an increase in strength for all specimen types. The extent of the increase

varies with exposure type and solution concentration. The 2% sulphate solution failed at higher strengths than their companion 5% sulphate specimens. Here the difference in strength may be attributed to the differences in reaction products caused by chemical interactions with the cementitious phases.

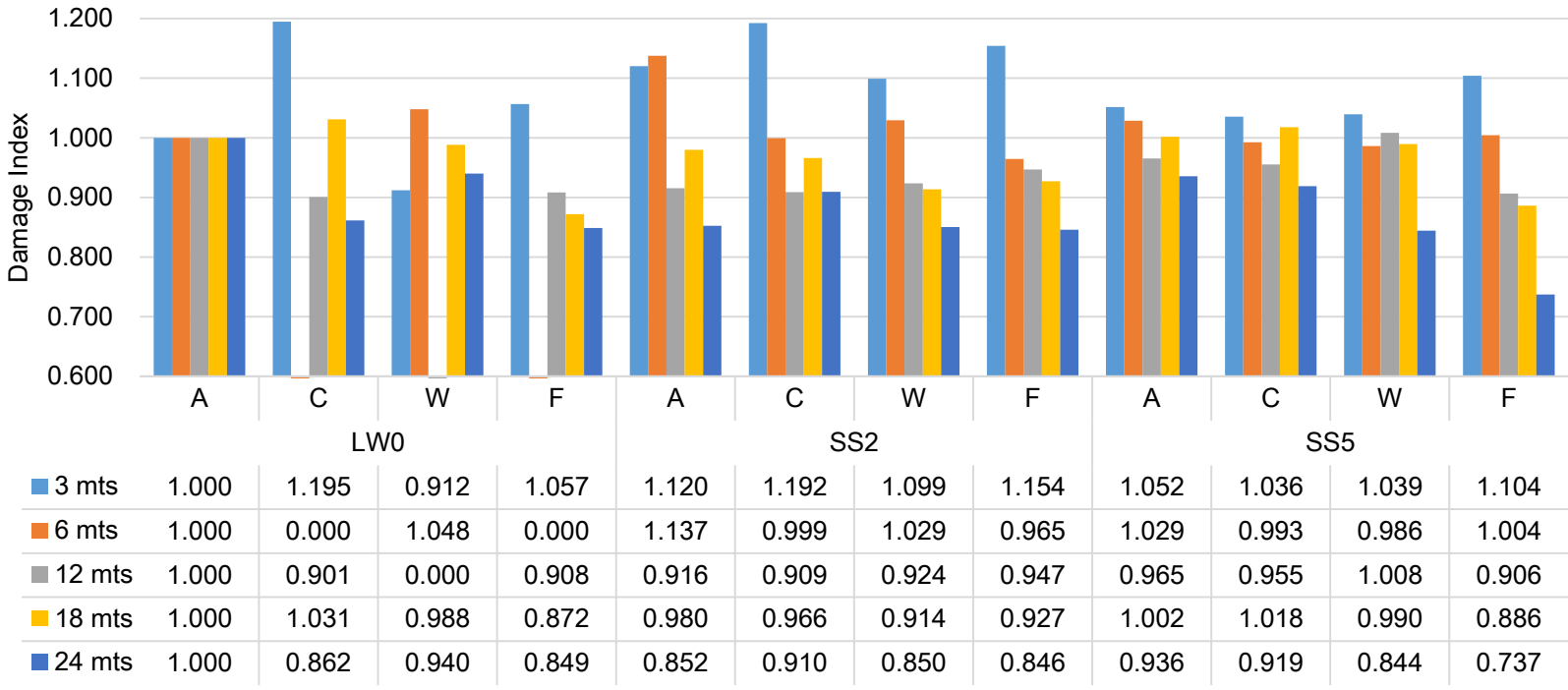
For lower concentrations of sodium sulphate solution exposure, ettringite formation is favoured. At higher concentrations, gypsum formation is favoured. For the weaker solution of sodium sulphate, the reactant is capable of interacting with the aluminate phases present in the cement matrix giving way to ettringite formation; which would lead to the development expansive stress. Stronger solution concentrations are more acidic in nature (6.0–6.5 pH) thus facilitating chemical interactions with the soluble calcium hydroxide phase producing gypsum. Its depletion would then lead to a loss in binding properties; therefore, accelerating the degradation process due to sulphate exposure. (Bizcok, 1967) (Van Tittelboom et al., 2013) Associated with diffusion transport mechanisms, from the beginning there are mechanical property changes accompanying the initial ionic uptake. Followed by a reactive period where paste softening is compensated by the formation of new products filling neighboring pores and capillary space. Once the reaction productions may no longer be accommodated and crystallisation pressures are initiated, the drop in strengths properties are inevitable along with visual signs of degradation, volumetric changes, cracking, and surface scaling to name a few. (Ferraris et al. 2005)

The reaction mechanisms caused by ionic diffusion exposure have been repeatedly argued to be slow. As reviewed in Chapter 1, the introduction of wetting and drying cycles has been evaluated as a viable way to accelerate the experimental process. However, there has been debate whether the physical effects of cyclic exposure outweigh the effects of chemical degradation due to sulphate exposure. (Van Tittelboom et al. 2013) Therefore, in an attempt to isolate the consequences of corrosive solution exposure from its transport mechanism, the tensile strength results of each regimen are

next compared with their companion limewater control regimen. Figure 5.2.7 presents the calculated damage index of each transport mechanism.

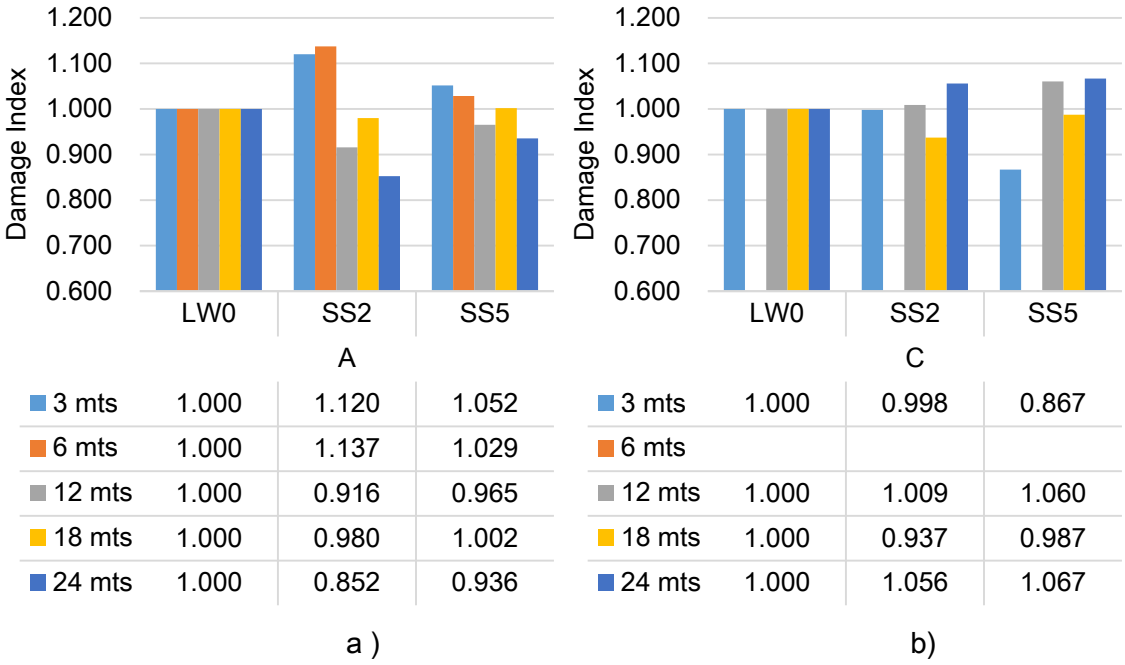
According to Figure 5.2.7b, the effects of cyclic sorption and evaporation of sulphate solution by the porous concrete does not seem to have a negative effect on the concrete properties. When compared to the limewater cyclic exposure, the strengths are actually higher than their control companion. What was initially considered a drop in strength with respect to diffusion mechanisms is now an actual increase; and, one that is not significant over the course of the exposure period for that matter. It was stated by Clifton et al. (1999) that, depending on the duration of the drying cycle, the physical and the chemical mechanisms may be co-existing. But, the chemical processes may be the dominating degradation mechanism at slower drying rates. In this case, it seems like the physical deteriorative effects are the leading mechanisms behind the decrease in strength. The presence of a sulphate solution is only bridging the voids and cracks formed due to stressful volumetric changes of the cementitious material; explaining the increase in strength over time. However, these assumptions need to be verified at the microstructural level to confirm the hypothesis stated. Not part of this current study, such testing is underway as the next phase of this experimental program.

As for the presence of an evaporation plane, it would seem that the initial gain in strength demonstrated in Figure 5.2.7c (after 3 months of sulphate exposure) may be due to the wicking action thus drawing more solution within the concrete's capillary matrix. Comparing the wicking regimens, the damage index obtained for both the 2% and 5% sulphate solutions (1.205 and 1.140) (Figure 5.2.7c) are greater than those of the diffusion regimens (1.12 and 1.052) (Figure 5.2.7a). This increase in solution uptake, inducing higher mechanical strengths initially, is however followed by a quick drop in tensile properties; also, making the wicking mechanism more detrimental (lower damage indexes) in comparison to the diffusion regimens. Meanwhile, the gradual drop noticed for the diffusion mechanism is less extensive over the 2 year exposure period.



	LW0				SS2				SS5			
3 mts	1.000	1.195	0.912	1.057	1.120	1.192	1.099	1.154	1.052	1.036	1.039	1.104
6 mts	1.000	0.000	1.048	0.000	1.137	0.999	1.029	0.965	1.029	0.993	0.986	1.004
12 mts	1.000	0.901	0.000	0.908	0.916	0.909	0.924	0.947	0.965	0.955	1.008	0.906
18 mts	1.000	1.031	0.988	0.872	0.980	0.966	0.914	0.927	1.002	1.018	0.990	0.886
24 mts	1.000	0.862	0.940	0.849	0.852	0.910	0.850	0.846	0.936	0.919	0.844	0.737

Figure 5.2.6: Splitting tensile strength damage index: comparison between exposure regimens.



A

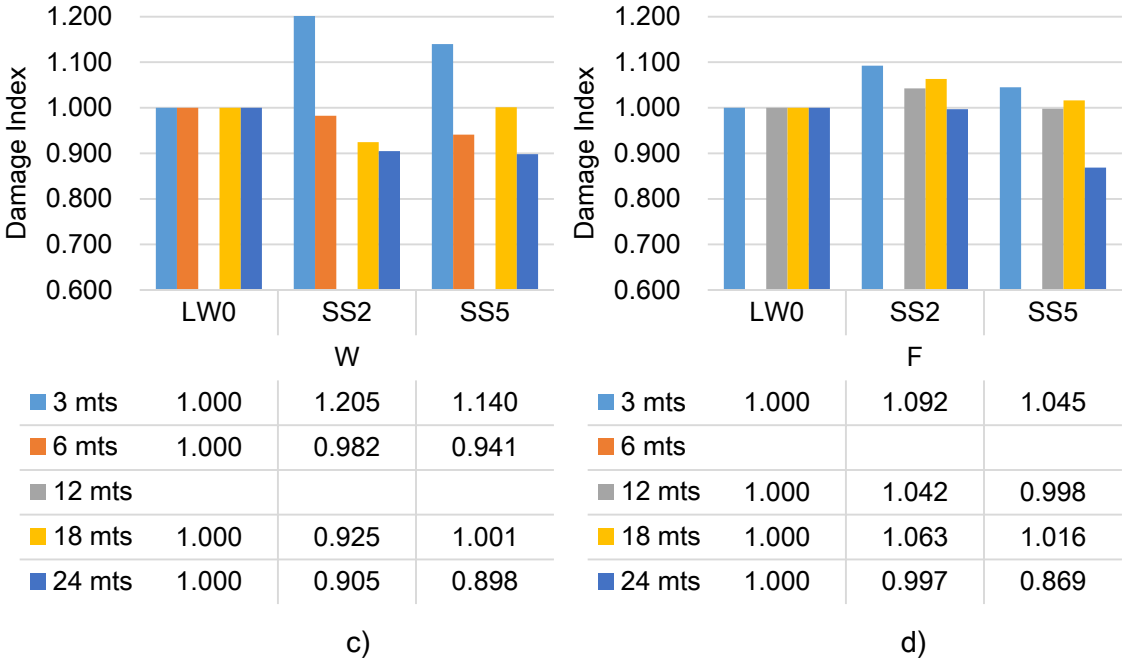
	LW0	SS2	SS5
3 mts	1.000	1.120	1.052
6 mts	1.000	1.137	1.029
12 mts	1.000	0.916	0.965
18 mts	1.000	0.980	1.002
24 mts	1.000	0.852	0.936

a)

C

	LW0	SS2	SS5
3 mts	1.000	0.998	0.867
6 mts			
12 mts	1.000	1.009	1.060
18 mts	1.000	0.937	0.987
24 mts	1.000	1.056	1.067

b)



W

	LW0	SS2	SS5
3 mts	1.000	1.205	1.140
6 mts	1.000	0.982	0.941
12 mts			
18 mts	1.000	0.925	1.001
24 mts	1.000	0.905	0.898

c)

F

	LW0	SS2	SS5
3 mts	1.000	1.092	1.045
6 mts			
12 mts	1.000	1.042	0.998
18 mts	1.000	1.063	1.016
24 mts	1.000	0.997	0.869

d)

Figure 5.2.7: Splitting Tensile strength damage index: comparison between sulphate solution concentrations for

a) diffusion exposure regimens, b) cyclic exposure regimen,

c) wicking exposure regimen and, d) field exposure regimen.

The same process is observable in Figure 5.2.7d where the field indexes are higher than those of the cyclic exposure at the beginning of the exposure period. Inversely to the cyclic regimen, it is followed by a drop in failure strength after two years of exposure making the D24SS5F specimen the lowest damage factor calculated (0.869). Now comparing the field mechanism to the wicking action, a similar trend is noticed. There is an initial gain followed by a drop in strength; however the negative trend is not as extensive as that noticed for the wicking regimen. It would seem that the combination of both transport mechanism (constituting the field regimen) also had a combining effect on the strength development. The wicking action may be responsible for the initial strength gain and the cyclic action may be responsible for maintaining the trend near the control values. Between the initial uptake in strength and drop in strength, the failure strengths are surrounding that of the controls. If only one could point out where the failure mechanism begins and how it evolves. Acoustic emission monitoring and localization offers this possibility.

5.2.2 Comparison Study of Acoustic Emission Localization

To help distinguish the effects of each regimen on the concrete properties, acoustic emission monitoring was conducted during the splitting tensile loading test. As a concrete specimen is being mechanically loaded, the material absorbs a certain amount of elastic energy until the failure processes initiates. At this point, a portion of the cumulated energy is released which initiates a stress-pulse. As reviewed in Section 2.3, this pulse travels from the source towards the sample's external boundaries in the form of mechanical waves (compression, shear, or Raleigh waves). These minute vibrations, or acoustic waves, may be recorded by AE sensors placed at strategic places on the surface of the sample. In this case, if multiple AE sensors record an acoustic signal with similar wave characteristics, than localizing the source of the emitted pulse is possible with known characteristic wave velocity.

First, in order to localize acoustic events emitted during the splitting tensile test, the wave velocities were determined using the same experimental procedure for determining the diametral and longitudinal velocities of cylindrical samples in the previous sections (4.1.1 and 4.1.2). The results of the 300 kHz diametral and the 54 kHz longitudinal ultrasonic pulse velocity tests may be consulted in Appendix C. Then, the acquired AE data file was analysed post-test using the different wave speeds determined for each individual sample. It was determined that the 300 kHz diametral wave velocity measured at the mid-section of the puck produced the best localizing results for the majority of the samples; therefore, the mid-section velocity was used for all sample analysis. Although, the AE localization test was performed on all specimens, for the purpose of this study, only the 24-month regimens are presented herein. Considering the results obtained from the statistical study conducted in the previous section (4.2.1), it is the only series showing distinct failure strengths for all regimen types. The results of the AE analysis for each 24-month sample are presented in Appendix C.

As tensile stresses build within the material, the weakest link of the material will be associated with the onset of material failure. Although the signal amplitude threshold during monitoring was set between 38dB and 45dB (according to surrounding noise), the results analysis considered events of greater amplitudes only (superior to 55 dB). It was noticed during the experimental process that the reliability of locability increased with higher amplitude signals. This is in accordance with Pollock (1989) investigations. As reviewed in Section 2.3, wave attenuation and velocity scattering are considered to be limiting effects for accurate AE source localization. From various impact tests performed at the surface of the samples prior to loading, it was noticed that signals greater than 60dB were located within a 5 mm radius of its actual location point.

Moreover, the more material involved in the strain process, the larger the amplitude and energy the source signal will generate. Therefore, the amount of events of high amplitude and energy was considered in the analysis. It is an indication of the degree in

emissivity which may be related to changes in material properties and failure mechanisms of the sample under load. The peaks in amplitude and energy associated with a specific load (seen on hit activity graphs) may be related to microcrack initiation and propagation. Therefore, the percent of the ultimate strength at which these peaks occurred are of interest. This may offer insight on initiation of failure versus the level of degradation. Moreover, these peaks are often associated with the production of multiple events offering further information as location and orientation of failure processes. Tables 5.2.6 through 5.2.10 show certain parameters of interest (listed below) for analytical purposes.

- Location of events per ultimate stress level (%) and according to amplitude.
    - (B) The majority of the events are located towards the bottom face of disk specimen which was in contact with the exposure solution, between 0mm to 20 mm disk of height.
    - (M) The majority of the events are located in the middle section of the specimen, between 20mm to 80mm of disk height.
    - (T) The majority of the events are located towards the top face of disk specimen which was either exposed to laboratory ambient conditions or sealed with epoxy, between 80mm to 100 mm of disk height.
- Event count: total number of acoustic events recorded with amplitudes above 55 dB.
- Peaks in AE hits of high amplitude and/or energy, expressed as percent of ultimate splitting tensile stress at which they were recorded.

Although all location graphs are presented in Appendix C, four examples are presented in the following sections, one for each 5% Na_2SO_4 exposure regimen. Each example displays the progression of hits and events recorded up to a certain level of the ultimate strength (from 20% to 100% by increments of 20% of ultimate failure load). These are

illustrated in Figures 5.2.9 to 5.2.12. As shown in Figure 5.2.8, the results were graphically organised according to the studied parameters.

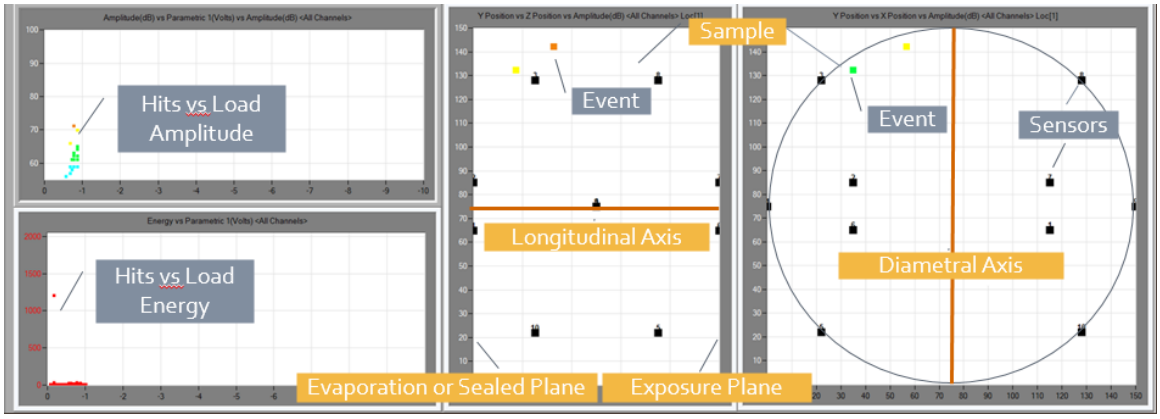


Figure 5.2.8: Description of graphical representation of AE results

5.2.2.1 Results of Acoustic Emission Monitoring for Diffusion Transport Regimens

Starting with the control specimen (24LW0A), the degree in emissivity was low at the beginning of the splitting tensile test. Between 20% and 60% of the applied load, there was a large increase in emissivity during which the majority of the localized events occurred. As seen in Table 5.2.6, these events mainly befell in the middle to top section of the disk specimen. Here, strain initiation may be correlated with an uneven distribution of aggregates. Due to segregation, there may be a lower density of aggregate material in the upper portion of the disk specimen. Since the aggregate material contributes to the splitting tensile strength of the concrete cylinder, it may explain the onset of failure in this region. This is assuming the degree in hydration is similar throughout the sample for the diffusion specimen type. Moreover, the events seem to be concentrated in the compression zone beneath the load baring strip (refer to Figure 5.2.1). These emissions may be attributed to particle friction. As the edge surface of the cylinder is being compressed causing movement between the loaded material and the adjacent material at rest. After 60% of applied load, this type of AE activity seemed to quiet which was then followed by a period of very low emissivity. A

small number of high energy and high amplitude hits were recorded until 80% of the applied load was reached. Events located in the tension zone generally occurred near the failure strength. These events are likely to be related to cracking since the AE signal contained a high amount of energy. This would mean that a greater amount of material was involved in the release of elastic energy creating the transient stress-wave.

Since the D24LW0A specimen is considered to be the control specimen, this trend in acoustic emissivity and event location will be used as the comparative baseline for the other exposure regimens. The analysis is based on any differences observed which may be related to the decrease in strength noticed in Section 5.2.1.5 and the effects of sulphate exposure.

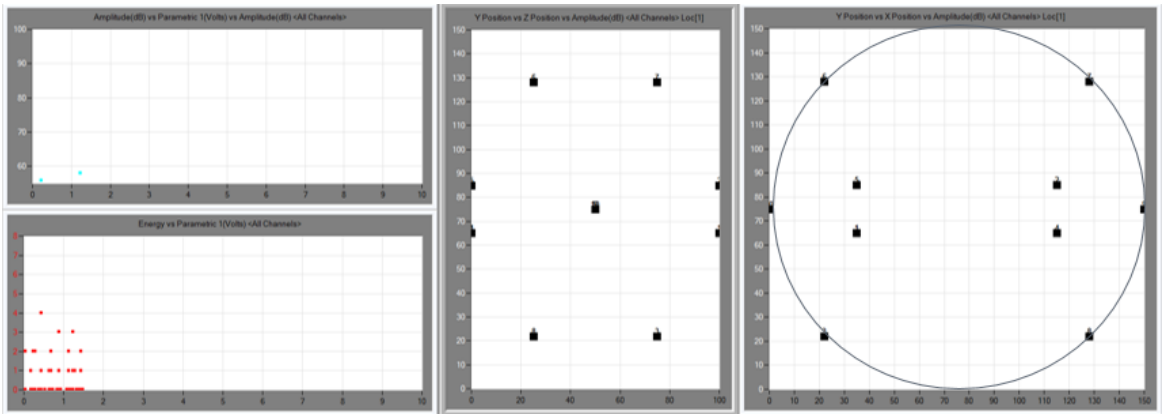
Table 5.2.6: Qualification and Quantification of AE hit and event parameters recorded during splitting tensile test for disk specimens exposed to diffusion transport regimens.

Specimens		D24LW0A			D24SS2A			D24SS5A		
		1	2	3	1	2	-	1	2	-
Location of AE Events										
Ultimate Strength	20%	M	-	T	B	-	-	B	-	-
	40%	M	M	T	B	M	-	B	M	-
	60%	M	T	T	B	M	-	B	M	-
	80%	M	M	-	-	T	-	-	-	-
	100%	B	B	B	B	B	-	T	T	-
Total Number of AE Events Above 55 dB Amplitude										
Event Count		15	23	36	17	23	-	12	26	-
Percent of Ultimate Strength at Peaks in AE Hits (%)										
Peak 1		2.5	29.9	21.2	34.3	32.4	-	23.9	31.5	-
Peak 2		85.9	55.8	28.7	37.3	44.1	-	56.3	43.8	-
Peak 3		99.0	99.0	35.6	52.2	72.1	-	99.0	59.9	-
Peak 4		-	-	93.2	86.6	82.3	-	-	97.3	-

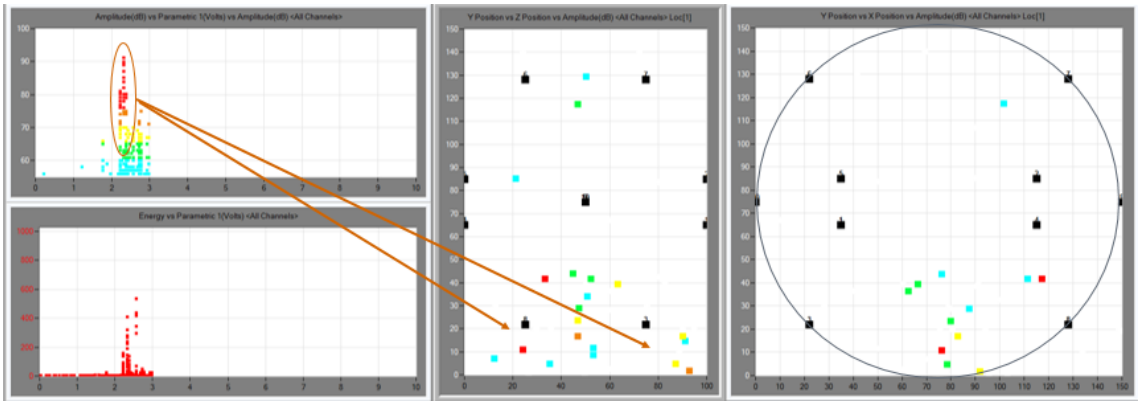
Seen in Table 5.2.6, the samples immersed in the 2% sulphate solution exhibited a similar failure patter as their control although the recorded energy peaks were slightly

lower. The trend was reversed for the 5% sulphate solution where the final events localized were situated towards the top section, not in contact with the solution.

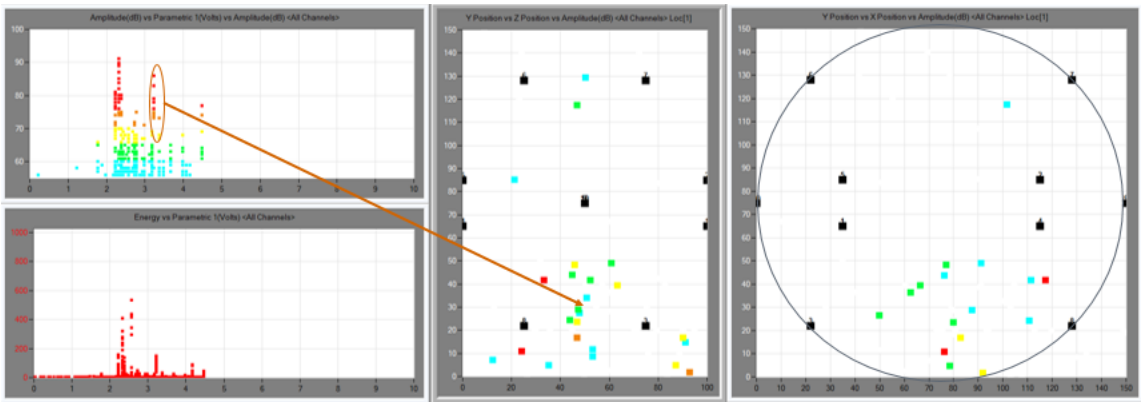
Figure 5.2.9 demonstrates the evolution of recorded hits and events during loading for the D24SS5A2 sample. Up to 20% of the ultimate load applied, no events were localized due to very low emission activity. The first events recorded occurred between 30% and 35% of applied load (Figure 5.2.9b), with a peak in hits of high amplitude and energy recorded at 31.5% (Table 5.2.6) making it the highest recorded during the test. The events were localized in the compression zone of the disk sample along its entire length. This peak was followed by two subsequent peaks at 43.8% and 59.9% of the ultimate each recording lower amplitudes and energies. The events related to the peaks in hits were localized passed the compression zone at the sample's mid-length. (Figure 5.2.9c) Then, there was period of low activity until 95% of the ultimate load was reached (Figures 5.2.9d and 5.2.9e). Figure 5.2.9e demonstrates the cumulative events at failure. The events located near failure load originated along the diametral axis of the sample, near the centre point of the axis. This is consistent with the failure mechanism under splitting tensile loading where a tension crack propagates along the diametral axis thus splitting the cylindrical sample in two halves. Moreover, looking at the longitudinal plane-view, the events recorded near failure load were located in the upper section of the cylinder. These may be related to cracking which lead to complete failure of the sample.



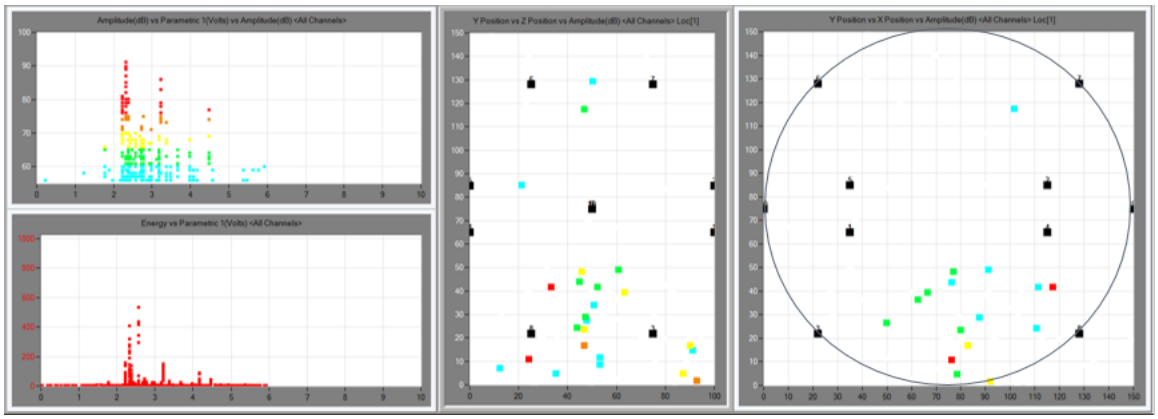
a)


Amplitude(dB) vs Parametric 1(Volts) vs Amplitude(dB) <All Channels>
Energy vs Parametric 1(Volts) <All Channels>
Y Position vs Z Position vs Amplitude(dB) <All Channels> Loc[1]
Y Position vs X Position vs Amplitude(dB) <All Channels> Loc[1]

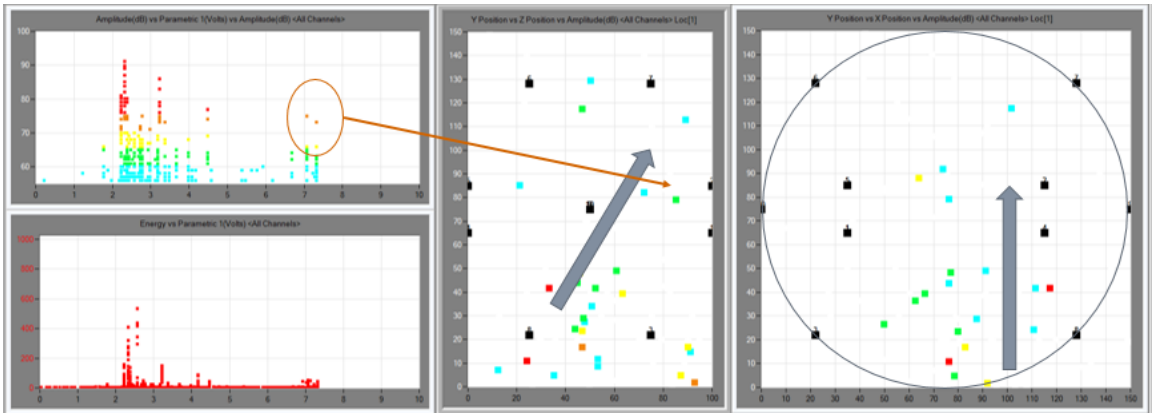
b)


Amplitude(dB) vs Parametric 1(Volts) vs Amplitude(dB) <All Channels>
Energy vs Parametric 1(Volts) <All Channels>
Y Position vs Z Position vs Amplitude(dB) <All Channels> Loc[1]
Y Position vs X Position vs Amplitude(dB) <All Channels> Loc[1]

c)


Amplitude(dB) vs Parametric 1(Volts) vs Amplitude(dB) <All Channels>
Energy vs Parametric 1(Volts) <All Channels>
Y Position vs Z Position vs Amplitude(dB) <All Channels> Loc[1]
Y Position vs X Position vs Amplitude(dB) <All Channels> Loc[1]

d)



e)

Figure 5.2.9: Hit parameters and event localization for disk specimen, 24-month, 5% sodium sulphate diffusion transport regimen up to a) 20% of failure load b) 40% of failure load, c) 60% of failure load d) 80% of failure load and e) 100% of failure load.

From Figure 5.2.9, it is noticed that there are little acoustic events located in the bottom portion of the cylinder, which was continuously exposed to the sulphate solution for a 2-year period. Here, the pore densification process may have played a role in strengthening the concrete matrix thus causing failure to initiate from the middle section of the cylinder and propagate towards the upper portion of the cylinder (depicted by an arrow on the events graphs). Or, event locability was difficult due to attenuation of the source wave characteristics. As stated in Section 2.3, wave characteristics are altered with distance traveled due to the dispersive nature of concrete. The process is further amplified for damaged concrete where the presence of additional medium boundaries (microcracks and density changes) further attenuates the signal characteristics of a transient pulse. Moreover, considering the change in diametral velocities recorded along the longitudinal axis, this may have had an influence in computing events with inaccurate wave properties.

5.2.2.2 Results of Acoustic Emission Monitoring for Cyclic Transport Regimens

Demonstrated in Table 5.2.7, all specimens recorded very few hits of high amplitude and energy below 20% of applied load. For the limewater specimens, as the load gradually increased, the majority of the events localized were generated in the bottom portion of the disk specimen. Then, the events leading to complete failure of the samples were located near the upper portion. Strain initiation near the exposure face may have been facilitated by the presence of microcracks caused by the repeated effects of wetting and drying exposure. This trend continued for the 2% sulphate samples but changed for the 5% sulphate samples were little emission were located along the solution exposure face until complete failure of the specimen.

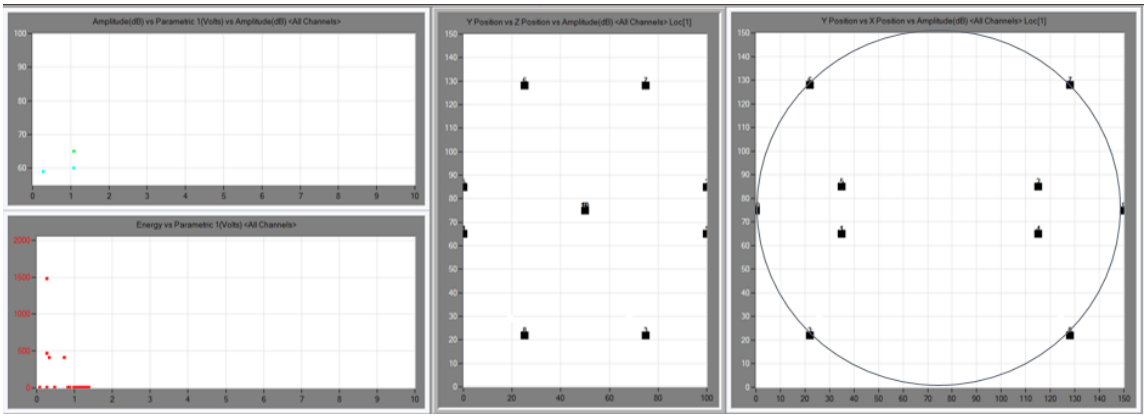
Table 5.2.7: Qualification and Quantification of AE hit and event parameters recorded during splitting tensile test for disk specimens exposed to cyclic transport regimens.

Specimens		D24LW0C			D24SS2C			D24SS5C		
		1	2	3	1	2	3	1	2	3
Location of AE Events										
Ultimate Strength	20%	B	-	-	B	-	M	-	-	M
	40%	M	B	B	M	M	B	M	M	M
	60%	M	M	B	M	T	B	M	T	T
	80%	M	-	B	B	-	-	T	M	-
	100%	M	T	T	M	M	T	M	B	B
Total Number of AE Events Above 55 dB Amplitude										
Event Count		12	5	35	78	22	10	18	46	9
Percent of Ultimate Strength at Peaks in AE Hits (%)										
Peak 1		23.5	26.8	24.1	28.4	32.3	22.1	32.4	26.1	26.1
Peak 2		36.7	45.1	36.2	43.3	66.2	51.5	37.8	36.2	31.9
Peak 3		67.6	98.5	63.8	55.4	95.3	91.2	45.9	53.6	46.4
Peak 4		98.5	-	98.3	98.6	98.5	98.5	98.0	89.9	99.0

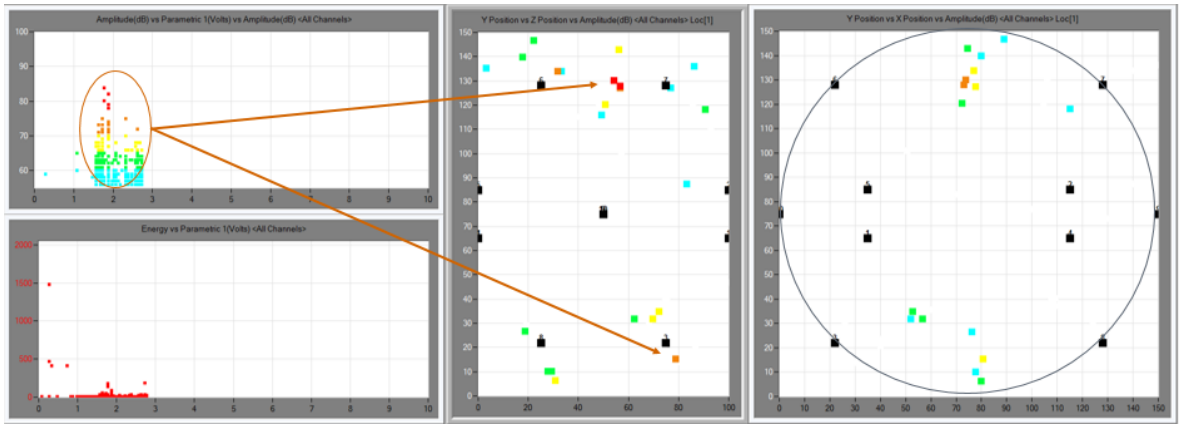
As previously seen for the diffusion specimen in Section 5.2.2.1, there were very few hits above 55 dB recorded at the beginning of the test. No event was localized before 20 %

of the ultimate load applied. However, many emissions were registered just after that loading point facilitating locability of the source signals. As seen in Figure 5.2.10b, consecutive amplitude and energy peaks were recorded which generated multiple events located near the top and bottom section of the diametral axis of the disk which were subjected to compression stresses according to stress distribution theory under indirect tensile loading. As seen on the longitudinal plane-view, the majority of the events were distributed along the middle section of the disk.

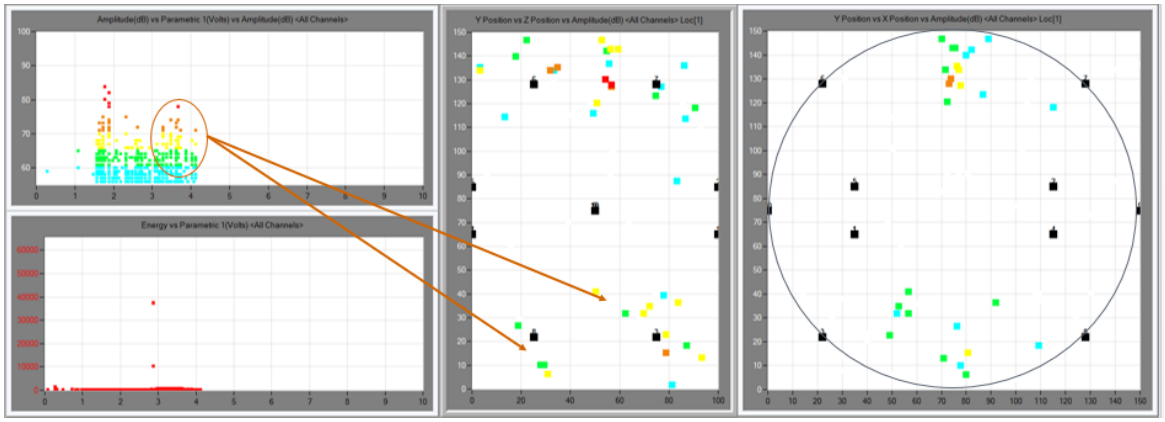
A second peak in amplitude is noticeable in Figure 5.2.10c, corresponding to 53.6% of applied load, which corresponds to events generated again in the lower compression zone. The intense activity was then followed by a dormant period were very little emissions were recorded until near failure. (Figure 5.2.10d) As seen on Figure 5.2.10e, two events of low amplitude related to the splitting tensile fracture process were located near the exposure face. The latter were preceded by two events located near the mid-section of the cylinder (next to arrow on diametral-plane view). Here it is assumed that the failure mechanisms initiated from the middle section of the sample which then propagated towards the exposure face. (Figure 5.2.10e) As discussed previously, locability in the exposure zone may have been influenced by the presence of additional sulphate products however the effects related to cyclic wetting and drying may have further deteriorated the surface facilitating crack growth under load.



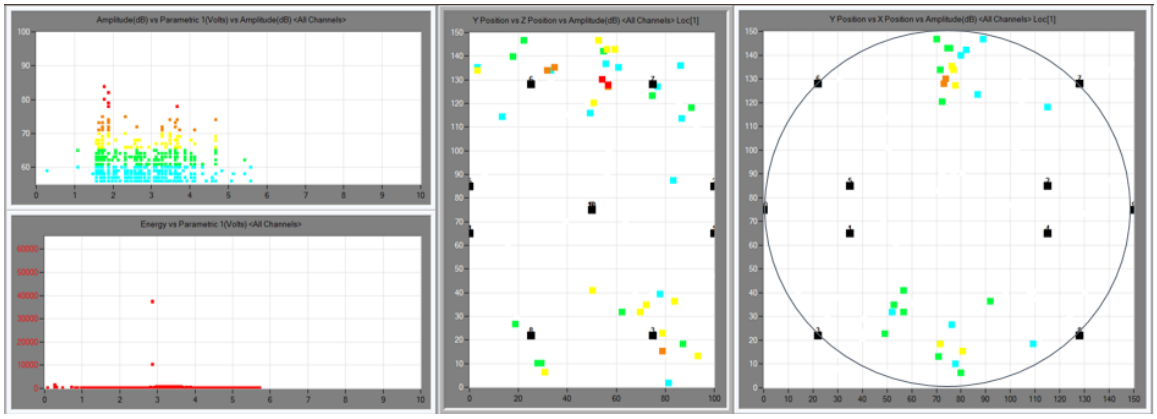
a)


Amplitude(dB) vs Parametric 1(Volts) vs Amplitude(dB) <All Channels>
Energy vs Parametric 1(Volts) <All Channels>
Y Position vs Z Position vs Amplitude(dB) <All Channels> Loc[1]
Y Position vs X Position vs Amplitude(dB) <All Channels> Loc[1]

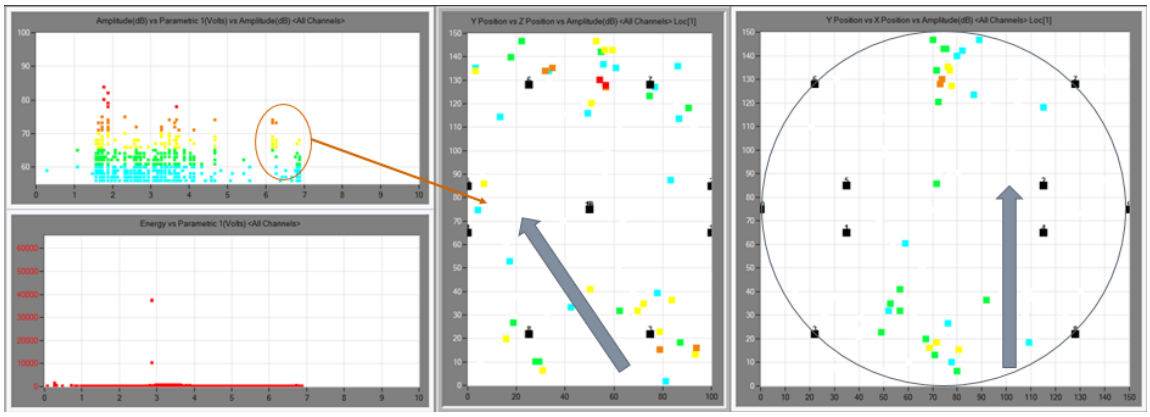
b)


Amplitude(dB) vs Parametric 1(Volts) vs Amplitude(dB) <All Channels>
Energy vs Parametric 1(Volts) <All Channels>
Y Position vs Z Position vs Amplitude(dB) <All Channels> Loc[1]
Y Position vs X Position vs Amplitude(dB) <All Channels> Loc[1]

c)


Amplitude(dB) vs Parametric 1(Volts) vs Amplitude(dB) <All Channels>
Energy vs Parametric 1(Volts) <All Channels>
Y Position vs Z Position vs Amplitude(dB) <All Channels> Loc[1]
Y Position vs X Position vs Amplitude(dB) <All Channels> Loc[1]

d)



e)

Figure 5.2.10: Hit parameters and event localization for disk specimen, 24-month, 5% sodium sulphate cyclic transport regimen up to a) 20% of failure load b) 40% of failure load, c) 60% of failure load d) 80% of failure load and e) 100% of failure load.

5.2.2.3 Results of Acoustic Emission Monitoring for Wicking Transport Regimens

Looking at the activity graphs in Appendix C and the results in Table 5.2.8, the failure process for the limewater specimen is similar to that reported for the limewater diffusion regimen in Section 5.2.2.1. It seems that the failure process initiated in the top section of the disk, the surface exposed to ambient conditions. This would be consistent with the results of the load test where, the ultimate strength measured for the D24LW0W specimen was considered to be the same than its control, D24LW0A. The difference in maturity caused by the presence of an evaporative front may have also influenced the fracture process thus initiating in this zone.

On the other hand, from the tabulated results, there are no noticeable trends for the sulphate specimens. The emission recorded and located for the 2% regimen were distributed across the mid-section of the samples leading to no preferential failure direction. As for the 5% sulphate samples, the first two samples located multiple events near the exposure face post-failure and the third, the failure initiated from the top. Therefore, the significant drop in strength recorded may have been associated with

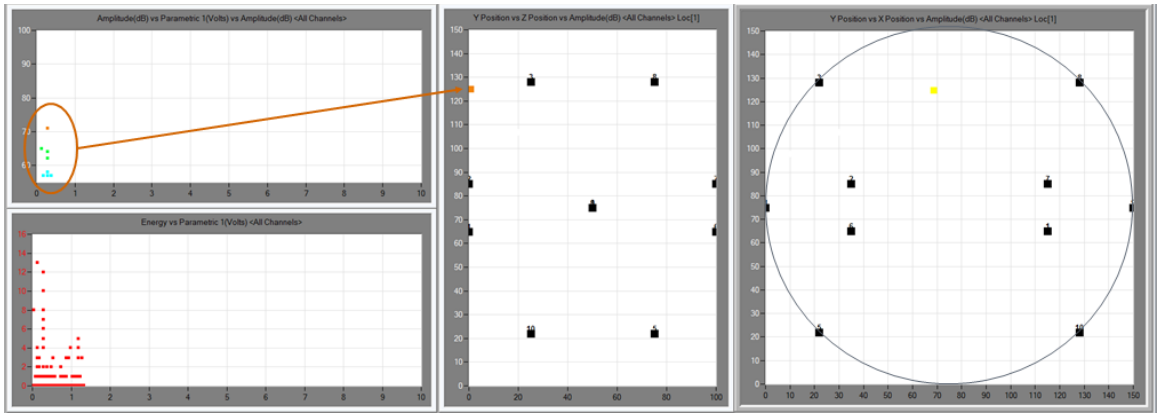
sulphate ingress. Further supporting the latter, looking at the energy and amplitude activity graphs presented in Appendix C, there was a difference in the level of activity between the sulphate specimens and their limewater companions. The energy level associated with the recorded peaks is greater for the limewater specimens than those acquired for the sulphate samples. As previously discussed in Section 5.2.1, the significant loss in strength for both sulphate specimens could account for the lower energy level associated with the failure process under splitting tension. This can be seen in Figure 5.2.11.

Table 5.2.8: Qualification and Quantification of AE hit and event parameters recorded during splitting tensile test for disk specimens exposed to wicking transport regimens.

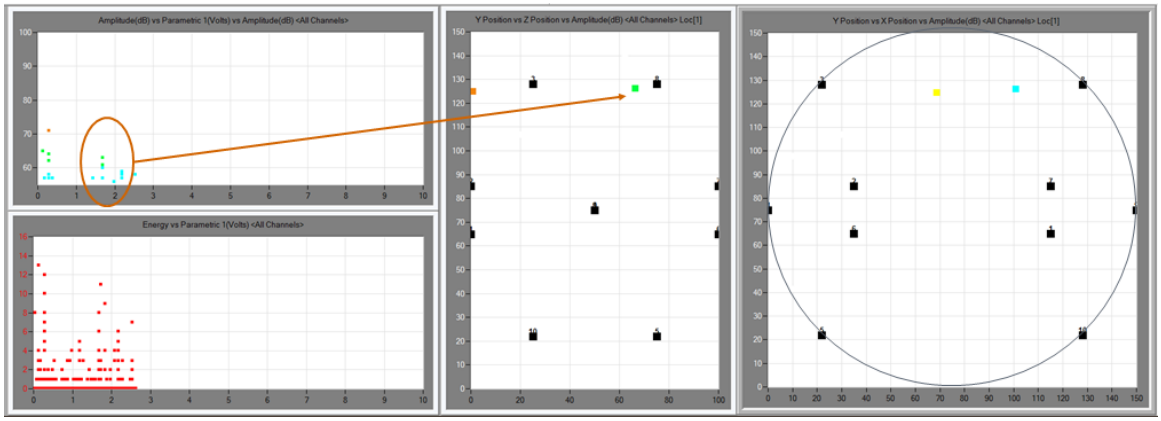
Specimens		D24LW0W			D24SS2W			D24SS5W		
		1	3	4	1	2	3	1	2	3
Location of AE Events										
Ultimate Strength	20%	-	-	-	B	-	M	M	B	T
	40%	-	M	T	M	-	-	M	M	M
	60%	-	M	B	T	-	T	M	T	B
	80%	-	M	T	M	-	M	M	T	-
	100%	-	T	B	M	-	M	B	B	T
Total Number of AE Events Above 55 dB Amplitude										
Event Count		-	37	25	108	-	15	62	21	17
Percent of Ultimate Strength at Peaks in AE Hits (%)										
Peak 1		-	34.3	33.3	31.3	-	40.0	48.5	27.9	4.6
Peak 2		-	38.3	37.5	42.2	-	44.6	77.3	55.7	98.5
Peak 3		-	44.8	43.1	95.3	-	53.8	98.5	96.7	99.5
Peak 4		-	94.0	98.6	98.4	-	89.2	99.5	99.5	-

Looking at the AE activity graphs for sample D24SS5W3 in Figures 5.2.11a to 5.2.11d (from 0% to 80% of applied load), there were very few hits recorded above 55dB. Moreover, the energy computed from each hit is approximately twenty times less (below 50aJ) than that computed for the limewater companions (1000 aJ). Consequently very few events were located. As presented in the Litreature Review Chapter, locability is

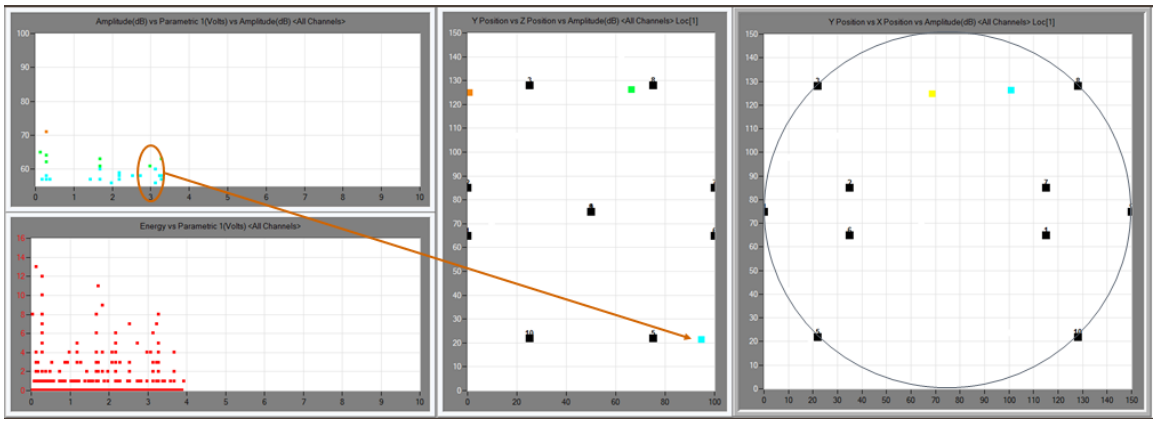
increased with an increase in the arrival signal's strength. As the incident pulse travels, its waveform characteristics degrade. Aggelis et al. (2013) found that only a few centimetres is sufficient to change the signal's characteristics which are important to compute the location of the source pulse. Here attenuation of wave properties may have influenced the results in such a manner that low level signals, at low stress and strain levels, did not permit location computations. Only near failure did the material start emitting considerable signals which enabled the location of multiple events prior to final fracture of the sample. As seen in Figure 5.2.11e, the events were clustered in an area near the top of the sample.



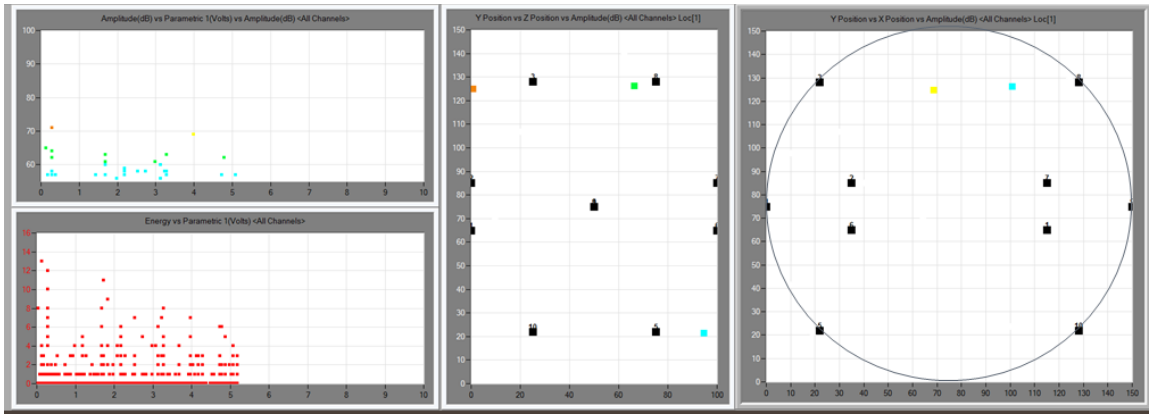
a)



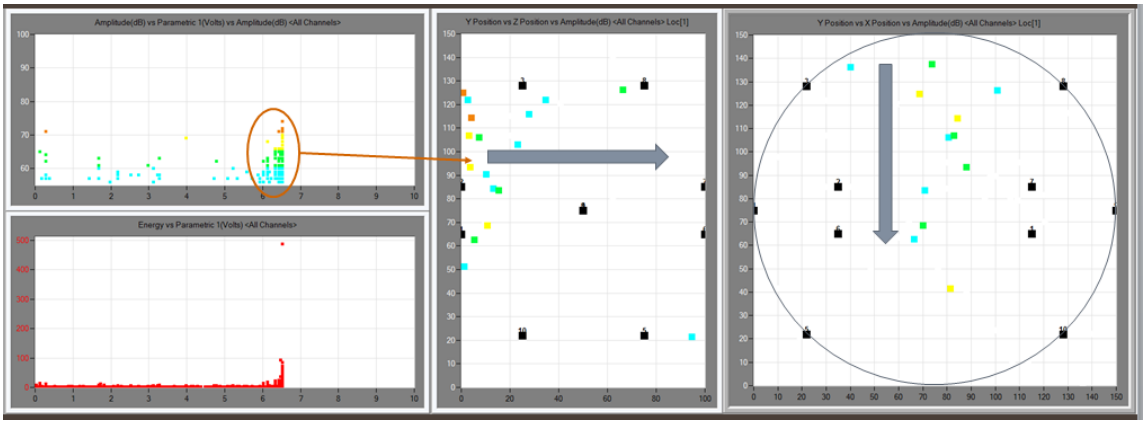
b)



c)



d)



e)

Figure 5.2.11: Hit parameters and event localization for disk specimen, 24-month, 5% sodium sulphate wicking transport regimen up to a) 20% of failure load b) 40% of failure load, c) 60% of failure load d) 80% of failure load and e) 100% of failure load.

5.2.2.4 Results of Acoustic Emission Monitoring for Field Transport Regimens

As previously discussed for the cyclic and wicking regimens, the presence of an evaporation front and a cyclic solution exposure had an effect on the emissions recorded and the samples performance to resist a splitting tensile load. Looking at the results in Table 5.2.9 for the limewater specimen (also illustrated in Appendix C), there was little activity at the beginning of the load tests until 80% of the ultimate load was reached. Here, the sensor configuration used (Type 1) may have influenced the accuracy in locability of the events recorded. Still, it would seem that the effects of cyclic exposure may have caused sufficient damage to the surface of the material since most events localized prior to failure originated from that surface. This would be consistent with the drop in strength noticed in comparison with the diffusion regimen (control) and wicking regimen. Here the effects related to cyclic wetting and drying of the concrete surface would have caused sufficient surface damage (microcracking) to initiate failure of the sample under splitting tensile tension.

As for the sulphate specimens, the presence of multiple deterioration mechanisms had various effects on the failure process. Again, there were no discernable patterns for the 2% regimen. The acoustic activity was low and varied for all three specimens; therefore, there no clear analyzable distinctions can be made. However, the increase in solution concentration had a measurable effect not only on the strength lost, but the failure pattern also.

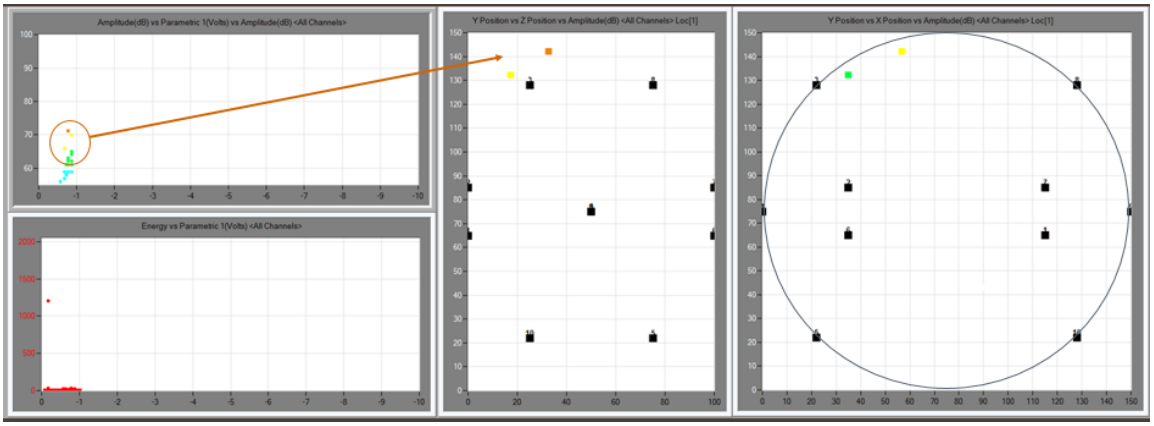
Looking at the event count and peaks in recorded hits for the 5% sulphate specimens, the majority of the acoustic activity was produced between 20% and 70% of the applied load. All samples exhibited acoustic activity in the mid to upper section of the sample near the compression zones. From 80% until failure, the samples recorded events from the mid to bottom section of the samples. Observable on Figure 5.2.12e, the events located in the compression zones near the bottom section of the disk (exposure face)

lead to the final fracture of the specimen. The fracture propagated from the sulphated zone towards the top of the disk, exposed to ambient conditions. It can therefore be assumed that the combined effects of cyclic sorption and evaporation and sulphate attack weakened the sample at its exposure face.

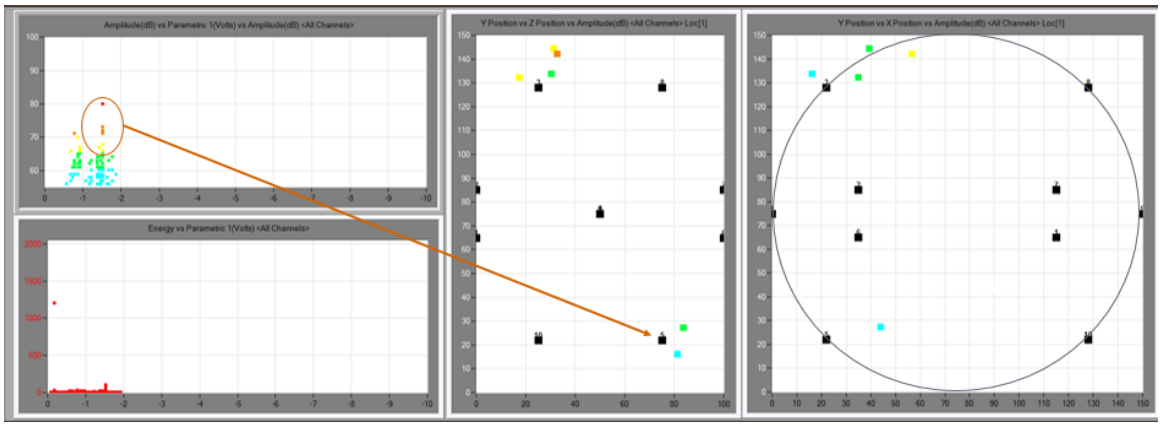
Table 5.2.9: Qualification and Quantification of AE hit and event parameters recorded during splitting tensile test for disk specimens exposed to field transport regimens.

Specimens		D24LW0F			D24SS2F			D24SS5F		
		1	2	3	1	2	3	1	2	3
Location of AE Events										
Ultimate Strength	20%	-	-	B	-	-	-	-	-	M
	40%	-	B	-	M	M	-	-	M	M
	60%	-	M	M	-	M	T	-	M	B
	80%	M	T	-	-	T	-	-	-	B
	100%	T	T	B	B	B	T	-	B	B
Total Number of AE Events Above 55 dB Amplitude										
Event Count		8	32	8	8	17	10	-	25	24
Percent of Ultimate Strength at Peaks in AE Hits (%)										
Peak 1		59.7	28.2	55.6	21.9	38.5	42.4	-	40.0	33.3
Peak 2		89.5	39.0	99.4	26.6	50.7	99.5	-	43.3	52.9
Peak 3		98.5	43.8	-	84.4	99.5	-	-	50.0	70.6
Peak 4		-	99.5	-	95.3	-	-	-	99.5	94.1

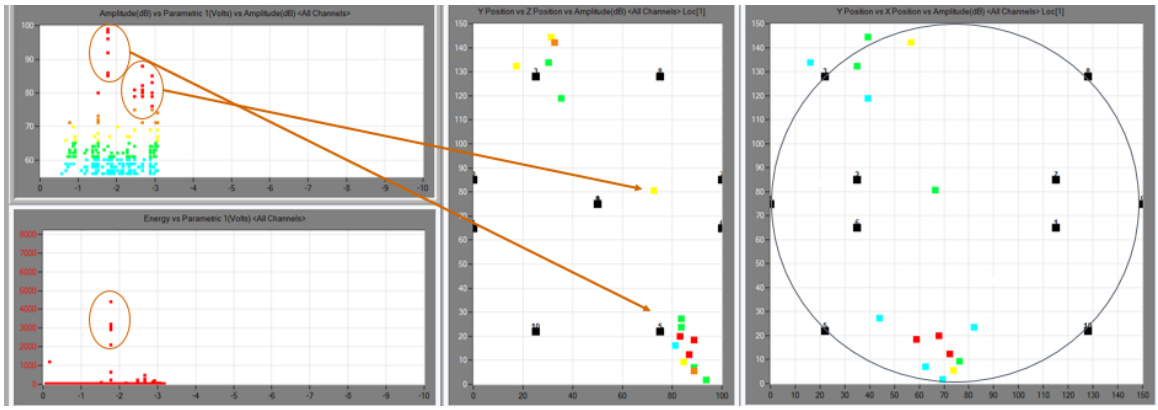
Nonetheless, even if the sulphate exposure conditions resulted in a substantial diminished strength, the fracture process depicted using acoustic emission techniques was sensitive enough to differentiate degraded zones. But, the technique could not distinguish with accuracy the effects of absorption and evaporation combined with sulphate exposure. However, from this condition assessment study, it is clear that the sulphates alone had a role to play in diminishing the mechanical properties of the material. Perhaps, a different loading scheme may be more appropriate for differentiating both deteriorative processes.


Amplitude(dB) vs Parametric 1(Volts) vs Amplitude(dB) <All Channels>
Energy vs Parametric 1(Volts) <All Channels>
Y Position vs Z Position vs Amplitude(dB) <All Channels> Loc[1]
Y Position vs X Position vs Amplitude(dB) <All Channels> Loc[1]

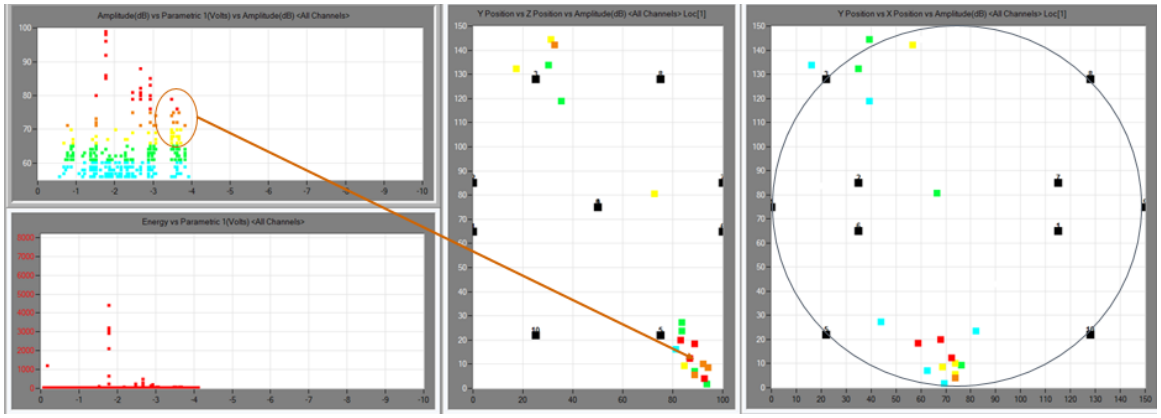
a)


Amplitude(dB) vs Parametric 1(Volts) vs Amplitude(dB) <All Channels>
Energy vs Parametric 1(Volts) <All Channels>
Y Position vs Z Position vs Amplitude(dB) <All Channels> Loc[1]
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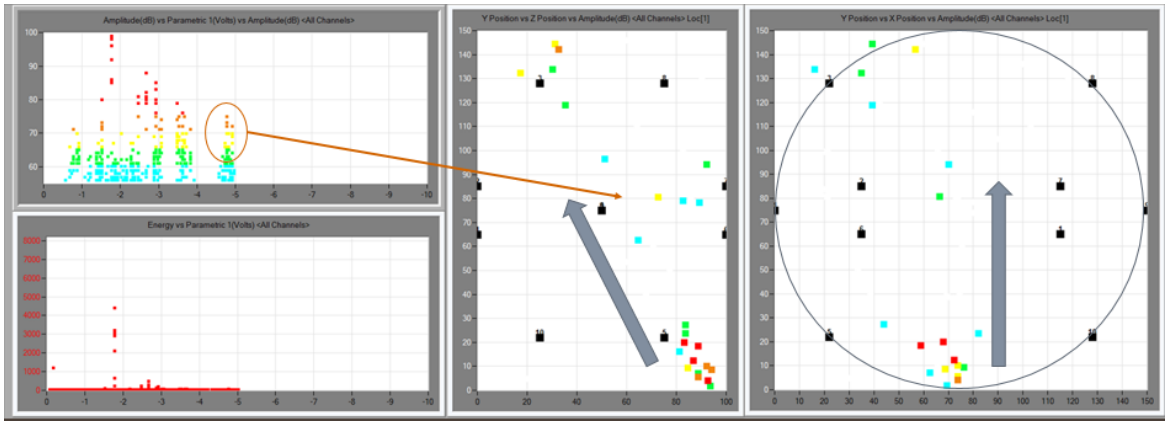
b)


Amplitude(dB) vs Parametric 1(Volts) vs Amplitude(dB) <All Channels>
Energy vs Parametric 1(Volts) <All Channels>
Y Position vs Z Position vs Amplitude(dB) <All Channels> Loc[1]
Y Position vs X Position vs Amplitude(dB) <All Channels> Loc[1]

c)



d)



e)

Figure 5.2.12: Hit parameters and event localization for disk specimen, 24-month, 5% sodium sulphate field transport regimen up to a) 20% of failure load b) 40% of failure load, c) 60% of failure load d) 80% of failure load and e) 100% of failure load.

5.3 Condition Assessment of Prism Samples

Finally, the last test performed to determine the response of a prism under tensile loading was the third-point bending test. Standard 75 mm x 75 mm x 280 mm prismatic samples were subjected to third-point bending in order to help assess the influence of solution concentration along with wet dry cycling on flexural strength properties. Only two transport mechanisms where evaluated, the diffusion mechanism and the cyclic absorption/ evaporation mechanism. The samples were exposed to the solution bi-dimensionally, i.e. only two faces of the prisms were in contact with solution. These two faces were exposed to tensile and compressive stresses according to the mechanical principles of bending theory as described in the literature review.

5.3.1 Comparative Study of Third-Point Bending Test

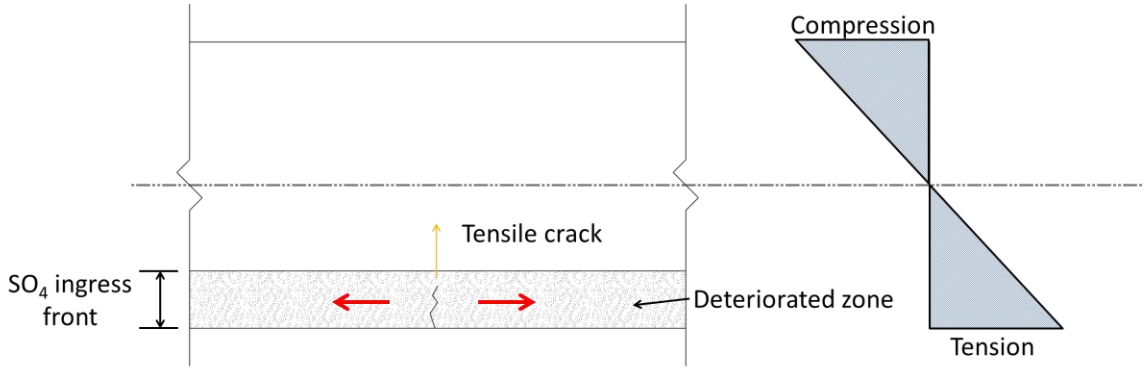


Figure 5.3.1: Tensile crack initiating and propagating under flexural stress for concrete prisms subjected to external sulphate attack.

The flexural test is considered to be particularly sensitive to surficial damage caused by external sulphate attack; the migrating sulphate compounds will alter the material's microstructure starting with the outer surface and gradually move inward toward the bulk material, known as the ingress front. As illustrated in Figure 5.3.1, the outer surface of the prism is subjected to the maximal tensile stress. It is assumed that the surface and ingress front has sustained microstructural changes in comparison to the bulk material;

therefore the development of a tension crack starting at the face of the prism should be indicative of the affected material's mechanical condition as the ingress front grows with exposure time.

The same analytical procedure as described in Section 5.1 was used to study the effects of the exposure regimes over a two year exposure period. Here, only two transport mechanisms were studied for the three solutions of interest; diffusion and cyclic absorption/evaporation. The averages of the flexural strength results for three replicates are presented in Figures 5.3.2 through 5.3.5. The details of the samples' statistical study are provided in Appendix D. The individual standard deviations are depicted in the figures alongside the control's 95% confidence interval and the results of the F-test and t-test are tabulated in Tables 5.3.1 to 5.3.4. From these, the reliability of the method to detect ongoing deterioration and its level of damage is evaluated.

5.3.1.1 Flexural Strength Results after 6 Months of Solution Exposures

The flexural experimental program carried out for the first exposure term was considered successful. The coefficients of variation were considered to be adequately below 16%, the prescribed value for concrete prisms made from the same concrete batch tested by a single operator. (ASTM C78) According to the F-test performed on the samples, the variances were considered to be equal; further implying the adequacy of the test procedure and reliability of the test results.

After 6 months of solution exposure, it can be seen in Figure 5.3.2 that the specimens exposed to both concentrations of sulphate solutions have experienced an increase in flexural strength. However, according to the t-test results presented in Table 5.3.1, all but the P06SS5A specimen were considered to be statistically different from the limewater control, though the average result of the diffusion specimens did fall outside

the range of values corresponding to the control's 95% level of confidence (Figure 5.3.2).

The observed increase in strength for both corrosive solutions (12.2% for P06SS2A, 19.0% for P06SS2C, 8.9% for P06SS5A and 20.1% for P06SS5C) may be due to the early densification process of the concrete matrix as previously mentioned in previous sections. However, for the first time, the tensile stresses for both cyclic exposures were actually higher than that of their companion diffusion specimens. This strength gain was consistent with past experimental studies using combined cyclic sulphate exposure and sustained flexural loading to evaluate ESA durability of various concrete mixes. (Gao et al. 2013)

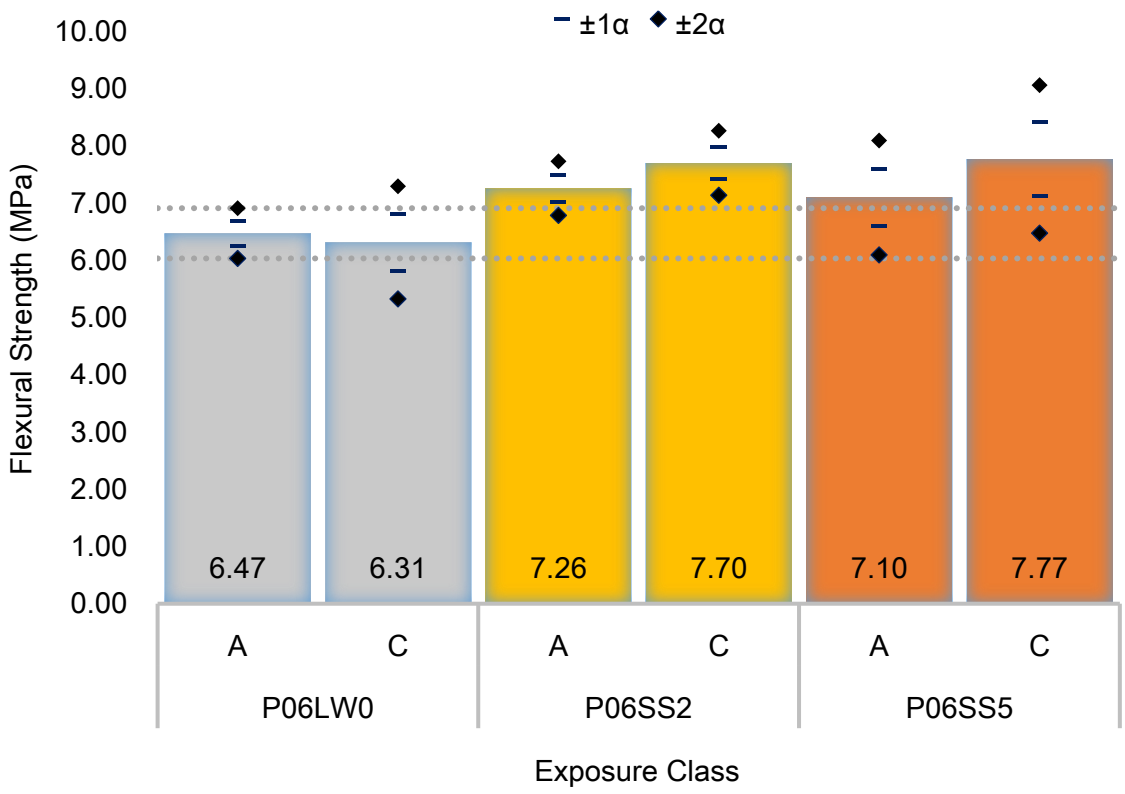


Figure 5.3.2: Flexural strength results and sample statistics: prismatic specimens, 6-month exposure regimens.

Table 5.3.1: Results of F-test and t-test for verification of equality of two sample variances and means: prismatic specimens, 6-month solution exposure period.

Specimen Exposure	t-Test					
	P06LW0A	P06LW0C	P06SS2A	P06SS2C	P06SS5A	P06SS5C
P06LW0A	1.000	0.629	0.013	0.004	0.120	0.030
P06LW0C	0.332	1.000	0.040	0.013	0.125	0.036
P06SS2A	0.928	0.374	1.000	0.105	0.635	0.268
P06SS2C	0.754	0.494	0.823	1.000	0.142	0.875
P06SS5A	0.322	0.982	0.363	0.481	1.000	0.226
P06SS5C	0.206	0.733	0.235	0.319	0.749	1.000
F-Test						

5.3.1.2 Flexural Strength Results after 12 Months of Solution Exposures

The same trend was noticed after one year of exposure (Figure 5.3.3). Again, the increase in strength was not sufficiently significant to statistically determine an observable level of degradation as seen at 6 months of exposure. Only the P12SS5C specimen satisfied the t-test level of significance set at 5%. In this case, the sample failed at 7.47 MPa, which corresponds to a difference of 25.3% in flexural strength from the control value. On the other hand, the other sulphate specimens were under the 10% level of significance and outside the first standard deviation value range of the control specimen. The P12SS2A, P12SS2C and P12SS5A specimens also recorded increases in strength equivalent to 8.1%, 20.8% and 11.2% respectively. These facts are not negligible considering the coefficients of variation range between 2.72% and 10.44%. Therefore, degradation process continued but at a lower rate.

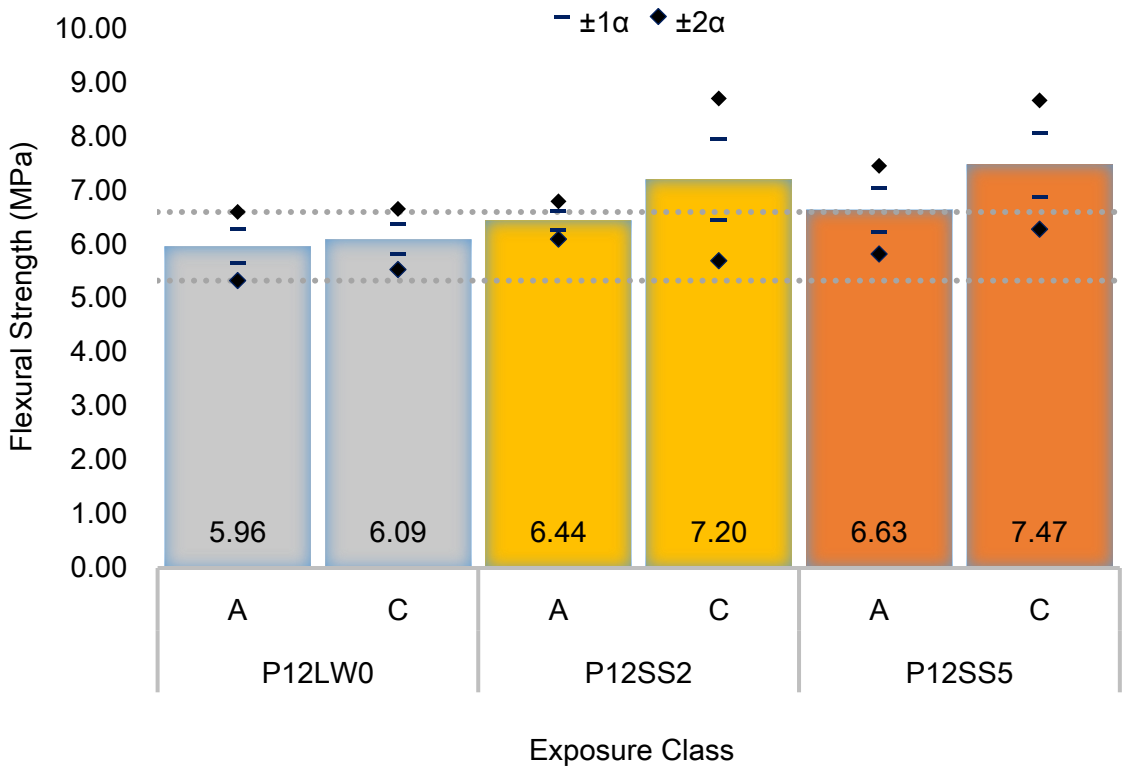


Figure 5.3.3: Flexural strength results and sample statistics: prismatic specimens, 12-month solution exposure period.

Table 5.3.2: Results of F-test and t-test for verification of equality of two sample variances and means: prismatic specimens, 12-month solution exposure period.

Specimen Exposure	t-Test					
	P12LW0A	P12LW0C	P12SS2A	P12SS2C	P12SS5A	P12SS5C
P12LW0A	1.000	0.623	0.083	0.059	0.088	0.018
P12LW0C	0.876	1.000	0.139	0.075	0.131	0.022
P12SS2A	0.466	0.561	1.000	0.166	0.499	0.046
P12SS2C	0.303	0.244	0.103	1.000	0.317	0.647
P12SS5A	0.754	0.641	0.311	0.456	1.000	0.115
P12SS5C	0.442	0.362	0.159	0.773	0.638	1.000
F-Test						

5.3.1.3 Flexural Strength Results after 18 Months of Solution Exposures

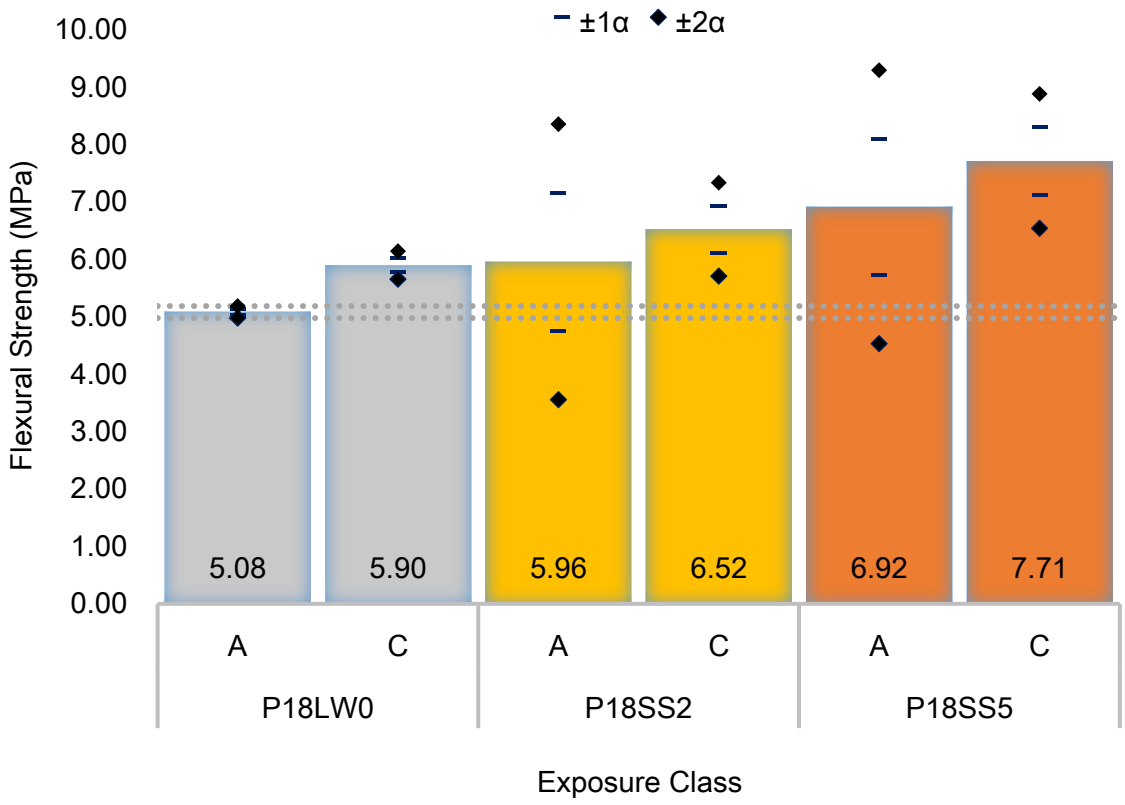


Figure 5.3.4: Flexural strength results and sample statistics: prismatic specimens, 18-month exposure regimens.

After 18 months of exposure, the ultimate strengths continued to increase and the P18SS2C and P18S5C specimens failed at ultimate strengths of 6.52 MPa and 7.71 MPa; making these samples 28.3% and 51.8% stronger than their control specimen. The values obtained for the t-test were within the level of significance making this marked increase quite substantial. However, even a similarly extensive increase in strength (17.3% and 36.2%) was exhibited for both the 2% and 5% sulphate diffusion specimens, they did not satisfy the statistical conditions. Illustrated by the spread in standard deviation in Figure 5.3.4, the coefficients of variation obtained for the two specimens were larger than that stipulated in the standard, 20.2% and 17.2% respectively. In both instances, there was one sample out of the three replicates which

failed at record high strengths. These values would be consistent with the results obtained from the F-test where the sample variances were not considered to be equal (Table 5.3.3). Therefore, there was either variance in the test procedure or between the samples causing the increase in coefficient of variation. With good control in the experimental test conditions, after 18 months in corrosive solution, it is possible that the replicates suffered unequal levels of deterioration. In this case, the replicates were reaching their ultimate densification limits at various stages.

Table 5.3.3: Results of F-test and t-test for verification of equality of two sample variances and means: prismatic specimens, 18-month solution exposure period.

	t-Test					
Specimen Exposure	P18LW0A	P18LW0C	P18SS2A	P18SS2C	P18SS5A	P18SS5C
P18LW0A	1.000	0.000	0.334	0.024	0.116	0.016
P18LW0C	0.307	1.000	0.942	0.064	0.277	0.029
P18SS2A	0.004	0.020	1.000	0.482	0.382	0.085
P18SS2C	0.032	0.165	0.206	1.000	0.618	0.045
P18SS5A	0.004	0.021	0.992	0.209	1.000	0.357
P18SS5C	0.016	0.083	0.384	0.652	0.389	1.000
F-Test						

5.3.1.4 Flexural Strength Results after 24 Months of Solution Exposures

It needs to be addressed that after 2 years of exposure, the concrete samples did not demonstrate any significant visual signs of degradation, such as macrocracking or surface scaling. The epoxy coating surrounding the four sides of the prism acted as a form of confinement which prevented any measurable expansion. This may be representative of field exposure where a sulphate exposed portion of a concrete member may not necessarily be free to expand.

Now, according to the statistical results shown in Figure 5.3.5 and Table 5.3.4, all but the P24SS2C specimens were significantly different from the control specimen. With a probability of 6.9%, the results may still be considerable since the coefficient of variation calculated for the limewater control (8.29%) was the highest of this experimental test for this regime type.

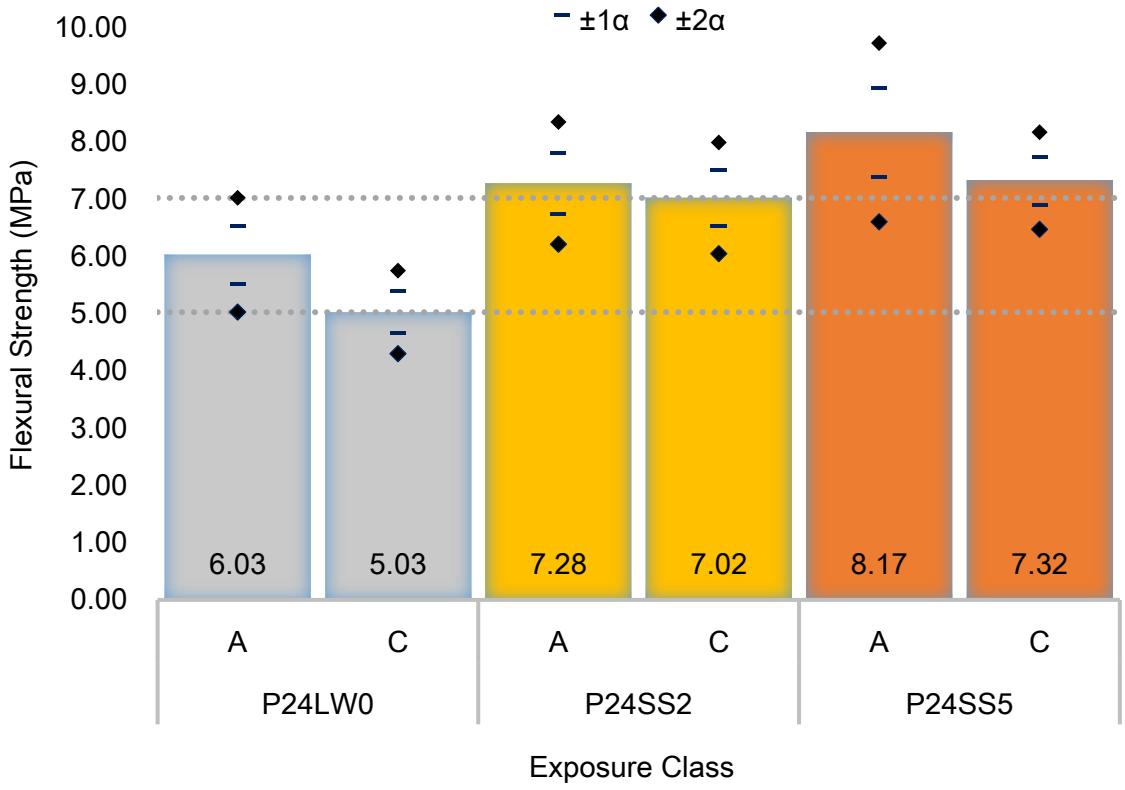


Figure 5.3.5: Flexural strength results and sample statistics: prismatic specimens, 24-month solution exposure period.

At the end of the 2-year exposure term, the sulphate specimens were still failing at higher strengths than their limewater companions. However, for the first time of the full exposure term, the diffusion regimens were producing higher flexural strengths than their cyclic companions. In comparison to the P24LW0A control, the samples were continuing to gain strength with a percent difference of 20.7% and 35.5% for the P24SS2A and P24SS5A specimens, respectively. Meanwhile, the cyclic exposures

seem to have failed at lower values than their 18-month companions. In order to appropriately compare the effects of the cyclic exposure in time, a comparative analysis with respect to the cyclic limewater regimen may provide further insight.

Table 5.3.4: Results of F-test and t-test for verification of equality of two sample variances and means: prismatic specimens, 24-month solution exposure period.

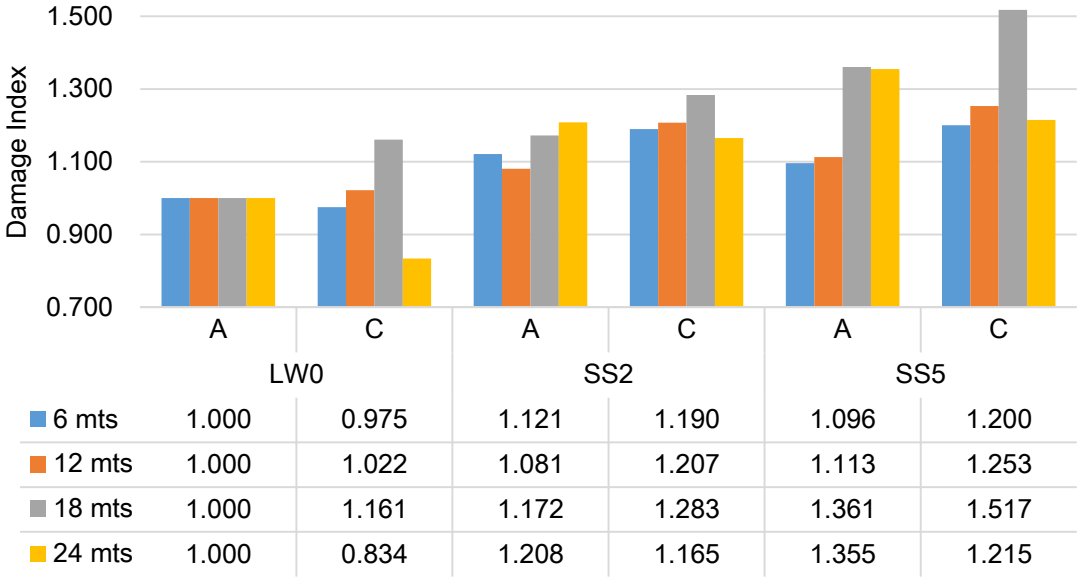
Specimen Exposure	t-Test					
	P24LW0A	P24LW0C	P24SS2A	P24SS2C	P24SS5A	P24SS5C
P24LW0A	1.000	0.048	0.041	0.069	0.016	0.027
P24LW0C	0.690	1.000	0.004	0.005	0.003	0.002
P24SS2A	0.933	0.631	1.000	0.565	0.181	0.923
P24SS2C	0.972	0.716	0.905	1.000	0.097	0.464
P24SS5A	0.581	0.355	0.637	0.558	1.000	0.176
P24SS5C	0.837	0.845	0.773	0.865	0.455	1.000
F-Test						

5.3.1.5 Flexural Strength Damage Index

As previously performed in the previous sections, a damage rating index was calculated and plotted for each regime type with respect to their exposure term's limewater diffusion control. This enabled a better comparison between mechanical strengths obtained and helped in determining the flexural behaviour of the prisms over time.

First, it was observed in the above figures that there was a general increasing trend for all four sulphate regimes up to 18 months of solution exposure, more pronounced in the 5% sulphate solution than the 2% sulphate solution. This was consistent with that observed in Figure 5.3.6. However, at the end of the exposure term, the cyclic exposures seemed to drop, while the positive trend remained for the diffusion specimens. From the observed trend, it could be determined that the cyclic exposures

peaked and reached ultimate densification before the diffusion regimes. Therefore, it could be assumed that the cyclic regimen accelerated the degradation mechanisms caused by ESA. Taking a closer look at the flexural strength for the P24LW0C specimen, there was also a drop in strength recorded. Therefore, in order to truly assess the damage caused by sulphate solution only, a damage index profile was also calculated against the cyclic control only.



	LW0		SS2		SS5	
6 mts	1.000	0.975	1.121	1.190	1.096	1.200
12 mts	1.000	1.022	1.081	1.207	1.113	1.253
18 mts	1.000	1.161	1.172	1.283	1.361	1.517
24 mts	1.000	0.834	1.208	1.165	1.355	1.215

Figure 5.3.6: Flexural strength damage index: comparison between exposure regimens.

Looking at the results illustrated in Figure 5.3.7, up to 18 months of exposure, what was thought to be an increasing trend for the 2% sulphate solution was actually a decreasing trend with respect to the cyclic control. Although, the strengths were still higher than their controls, the mechanical behaviour did not peak until 24 months of exposure. This is also valid for the 5% sulphate solution regime. For the latter, the trend was continuously positive across the exposure term. Contrary to the damage index in Figure 5.3.6, both 24 months specimens actually recorded their highest factor, 1.397 and 1.457 (2% and 5% Na_2SO_4 respectively).



	C		
6 mts	1.000	1.220	1.231
12 mts	1.000	1.182	1.226
18 mts	1.000	1.106	1.307
24 mts	1.000	1.397	1.457

Figure 5.3.7: Flexural strength damage index: comparison between sulphate concentrations for the cyclic exposure regimens.

Therefore, it can be assumed that the cyclic exposure caused a form of damage which was altering the flexural behaviour of the concrete prisms; the sulphate exposure seems to counteract the effects of microcracking related to wetting and drying cycles and aids the material by improving its mechanical properties. This is consistent with the Bassuoni and Mehdi (2009) study where wetting and drying cycles in combination with sustained flexural loading (at low levels) permitted an increased amount of sulphate penetration, thus fortifying the porous microstructure with gypsum and ettringite. In turn, the same experimental procedure produced similar results where the microstructural process was also well explained in Gao et al. 2013.

With a push from industry toward performance testing, and to provide standard methods of testing more realistic to field conditions where the results will be available in a shorter time, accelerated testing methods have become a popular research subject in the last decade. Sustained flexural loading in combination with cyclic wetting and drying exposure proved to be promising as a chemo-mechanical way of accelerating the degradation process. However, does flexural testing truly represent a valid method for

evaluating the mechanical response of concrete subjected to an external source of sulphate? The next section attempts to compare the three methods of tensile testing to help understand the change in engineering behaviour and assess the level of degradation the samples have sustained.

CONCLUSIONS

Currently, there is a movement for change in our current means of assessing material compliance from prescriptive based to performance based specifications. Moreover, standard test methods have often been criticised for not being representative of actual service conditions: either being too severe or not severe enough for that matter. In addition to lengthy test procedures, there is a push to accelerate standard methods of testing while maintaining high accuracy, reliability, reproducibility all in a realistic manner.

While respecting traditional means of inducing an external sulphate attack in the laboratory (complete immersion in a 5% sodium sulphate solution), this experimental study proposed a different methodology for evaluating the extent of sulphate degraded concrete in the laboratory. Over a 2-year exposure term, the extent of degradation of various specimens types, replicating transport mechanisms reminiscent of those seen in the field, were evaluated using novel test procedures. The changes in tensile strength were monitored in three different ways: gas pressure tension testing, splitting tensile testing and flexural testing. Furthermore, ultrasonic pulse velocity was used to further characterise the deterioration processes in conjunction with acoustic emission monitoring during splitting tensile loading. Through statistical analyses, the results discussed in Chapter 4 demonstrated that the test procedures conducted were reliable for assessing the changes in mechanical behaviour observed. This enabled a comparative analysis of the results over the exposure term.

First, the nondestructive and destructive analysis conducted on the cylindrical samples were successful in differentiating the different regimens by using a novel methodology. From the results obtained in this condition assessment, it is important to consider multiple factors before taking any decisive conclusions. Here, ultrasonic testing was

determined to be a viable method for detecting differences in material properties throughout the cylinder. Two different test frequencies were used, 54 kHz and 300 kHz. The change in wave velocity through the longitudinal axis of the concrete cylinders provided conclusive information due to the sensitivity of the test method. Overall, the coefficients of variation were less than 2%; therefore, a comparative analysis between the means of the specimens was possible as early as 6 months into the exposure term. The results demonstrate significant differences in wave velocity when compared to the control specimen, complete immersion in limewater. However, the effects of an evaporation front (partial immersive exposure) were not discernable until 24 months of exposure. Only then do the results obtained for the 5% sodium sulphate regimens demonstrated a statistically important loss in wave velocity due to sulphate exposure. Here, the diminished wave velocities measured for the 2% sodium sulphate exposures was not as significant. Thereafter, the 300 kHz diametral velocity profiles provided further information by detecting the wave velocity (i.e. material property) changes along the path travelled by the sulphate ions. However, the higher variations obtained within the test measurements did not permit conclusive interpretations as early as the 54 kHz assessment. Only after 18 months of exposure was the loss in wave properties sufficiently significant to differentiate the influence of sulphate exposure on certain parts of the cylinder. Nonetheless, it was determined that degradation due to sulphates may not be the primary player in the degradation mechanisms associated with wicking and cyclic exposures. The effects of partial curing and cyclic wetting and drying also had a significant effect on the concrete properties. It would seem that apart from the physically degraded zone, the effects of sulphate exposure could have played a secondary role. Further analysis is required to determine the full extent of their interaction with the cementitious phases. The results of the destructive analysis also support these findings.

The results obtained from the gas pressure tension study demonstrated similar trends to that observed in past investigations for completely immersed specimens where there is

an initial increase in strength followed by a drop in strength as the deterioration mechanisms progresses. This trend in results differs from that obtained for the UPV study where the velocity continuously drops from the beginning of sulphate exposure. For the diffusion mechanism, tensile testing demonstrated substantial differences between the control exposure and the 5% sodium sulphate regimen. On the other hand, the 2% sodium sulphate exposure, representative of severe exposure conditions in the field, was not as distinguishable as the control exposure and the 5% solution exposure for that matter. As for the partially immersed regimens, the failure values recorded were significantly lesser than their diffusion companion regimens. However, it is unclear whether the presence of an evaporation front is actually accelerating the degradation processes in the immersed portion of the cylinder since the above section (never receiving appropriate curing) dictated the failure mechanism under load. The degree in curing or the concrete's maturity overshadowed any changes exhibited in sulphated regions.

The second methodology devised to assess the effects of sulphate exposure under various transport mechanism (diffusion, cyclic sorption and evaporation, wicking and a combination of wicking and cyclic sorption and evaporation) was considered to be successful. Significant conclusions could be achieved only after 24 months of 5% sodium sulphate exposure. Again, the differences in concrete maturity within the specimens themselves and the deteriorative effects related cyclic sorption and evaporation exposure to overshadow the effects of sulphate penetration. Here, splitting tensile testing was not considered to be an efficient means to assess the loss in tensile properties of sulphated concrete. However, combined with acoustic emission monitoring techniques such as event location, the fracture process under load offered further information on the deteriorative process. Again, it was found that the effects related to cyclic exposure appeared to have caused sufficient damage to the exposure face initiating failure of the specimens and this was also illustrated in the decrease in

strength. Although the consequences of wave attenuation, which were clearly increased with deterioration level, diminished the efficiency of the AE method to accurately compute the location of the acoustic events emitted during loading. Nonetheless, amplitude and energy attenuation was an indication of an ongoing deteriorative process changing the characteristics of the materials, such as density and modulus of elasticity. The latter helped distinguish failure modes between limewater regimens and sulphate regimens.

Third, the standard method for determining the bending strength of concrete prisms under four point bending was considered to be successful in assessing early on the influence of sulphate ingress through wetting and drying cycles on tensile strength properties of concrete. Although the significance in results differed for the diffusion regimen due to the variability in the method, there is still a continuous upward trend in tensile strength observed for the 5% solution exposure. The drop in strength seen for the other two test programs was not exhibited here. In comparison to the diffusion mechanism, the effects of a cyclic exposure seemed to have increased the strength properties throughout the exposure term; however the latter was not significant in comparison to that of the diffusion exposure. Nonetheless, the secondary effects of wetting and drying cycles had an influence on the strength properties but to what extent? It is still unclear what role the sulphate ion plays within these chemical and physical processes. As for the other two test methods, microscopic analysis would be necessary to correlate the changes in microstructural properties and engineering properties.

Finally, out of all test methods used to evaluate the extent of degradation, the diffusion based transport mechanisms has proven to be the only method capable of producing consistent and conclusive results for all three destructive methods. Herein, the creation of an evaporation front or a cyclic condition to potentially draw “more” sulphates into the matrix and accelerate the deterioration process may have engendered other physical-chemical processes (realistic to field exposures) which influenced result interpretation.

Although ultrasonic testing combined with pressure tension testing offered a viable method for assessing the effects of an evaporation front and cyclic solution exposure, it is important to separate the effects of moisture exposure and the effects of sulphate exposure causing distinct deterioration processes to the concrete's microstructure if one wants to truly evaluate the behaviour of concrete material in the field under external sulphate attack. By comparing companion exposure conditions, the multi-deterioration mechanisms at play through distinct parts of the concrete specimens was difficult to assess with a certain degree of accuracy. Thus, determining which mechanism was prevalent was not possible.

Moreover, all three test tensile methods exhibited the standard trend in property changes with respect to exposure time. The initial strength gain followed by a latent period before exhibiting a drop may be misleading if these procedures are used to evaluate in-situ conditions. In practice, the misinterpretation of strength gain may be dangerous if no continuous monitoring is conducted with comparable healthy concrete sections. Opposed to ultrasonic testing, the comparison between mature healthy concrete and degraded concrete was possible due to the sensitivity of the method to microstructural changes and its low variability. The early and continuous loss in wave velocity characteristics, regardless of the exposure condition, may provide the NDT tool an edge to strength testing in detecting degraded concrete in the field. Moreover, it should be further evaluated as a potential standard mean for determining the resistance of a concrete mixture (or cement type) to sulphate attack. It may offer an alternative to standard expansion based testing.

The outcome of this study does provide insight on how to properly assess a deteriorating structure with regards to its ambient environment in the field. In reference to the diametral ultrasonic testing method, extrapolating the results on a large scale structural member emphasises the importance of considering a structure in its entirety not only small portions showing visual signs of damage. Material auscultation must be

considered as a whole when evaluating a deteriorating structure in the presence of an external source of sulphates.

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APPENDIX A

MATERIALS

APPENDIX B

RESULTS FOR CYLINDRICAL SPECIMENS

APPENDIX C

RESULTS FOR DISK SPECIMENS

APPENDIX D

RESULTS FOR PRISM SPECIMENS

Appendix A

Materials

LAFARGE CEMENT

Cement Mill Test Report

Month of Issue: May 2012

Plant:	**St-Constant, Quebec**
Product:	**Portland Cement Type GU (GU-P)**
Silo:	**4, 5 and 8**
Manufactured:	**April 2012**

CSA A3001-10 Standard Requirements

CHEMICAL REQUIREMENTS

	Spec limit	Test Result
Rapid Method, X-Ray *(A3003-08)*		
SiO2 (%)	---	19.9
Al2O3 (%)	---	4.3
Fe2O3 (%)	---	2.7
CaO (%)	---	62.3
MgO (%)	5 max	2.8
SO3 (%)*	3.0 max	3.8
Loss on ignition (%)**	3.0 max	0.5
Insoluble residue (%)	1.5 max	0.53
Na2O (%)	---	0.31
K2O (%)	---	0.78
Na2Oeq (%)	---	0.82
Potential Phase Composition *(A3003-08)*		
C3S (%)	---	59
C2S (%)	---	13
C3A (%)	---	7
C4AF (%)	---	8

PHYSICAL REQUIREMENTS

	Spec limit	Test Result
Air content of mortar (%) *(A3004-A5)*	---	8
Fineness by air permeability (Blaine) (m2/kg)	---	395
Retained 325 mesh (%) *(A3004-A3)*	28 max	4.9
Autoclave expansion (%) *(A3004-B5)*	1.0 max	0.03
Compressive strength (MPa) *(A3004-C2)*		
1 day	---	17.8
3 days	14.5 min	27.9
7 days	20.0 min	33.4
28 days (reflects previous month's data)	26.5 min	41.1
Time of setting (minutes) Vicat Initial *(A3004-B2)*	45 - 375	99
Heat of Hydration (KJ/Kg) *(A3004-B7)* 7 days (for information only)	---	292
Mortar Bar Expansion (%) *(A3004-C5)***	0.020 max	0.005

* If exceeds 3.0%, must comply with a maximum expansion limit of 0.020% at 14 days when tested in accodance with CSA A3004-C5.

** A loss on ignition of 3.5% maximum is allowed for designated portland cements, provided that such cements, when tested in accordance with CSA A3003, but at a furnace tempreature of 550+/- 25C, show a loss in mass of no more than 3.0%.

*** Current Production run not available - most recent provided.

We hereby certify that the cement represented by the above chemical and physical analyses meets the requirements of CSA A3001-10 including the maximum sulphate expansion limit at 14 days (CSA A3004-C5).

For additional information on this cement test report, please contact our technical representative Danielle Palardy at 514-895-1876.

ECAN BU - St-Constant Plant
1 Chemin Lafarge, St-Constant
Phone: 450-632-7750 #218

Certified By:

Pascale Poulin

Pascale Poulin - Quality Supervisor
May 15, 2012

BAUVAL
LABORATOIRE CENTRAL

FICHE TECHNIQUE DES GRANULATS
(COMPILATION QUALITATIVE)

Type de matériaux :	**Pierre concassée**	Calibre:	**5-14 mm**	Date:	**2011 05 02**
Provenance :	Sables L.G.	Classe granulaire:		Usages prévus:	Béton de ciment
	St-Hippolyte, Québec	Classement :	1A		

Granulométrie (LC 21-040)		***% passant en mm***														***% passant en um***			
	Nombre d'éch.	*112*	*80*	*56*	*40*	*31,5*	*28*	*20*	*16*	*14*	*12,5*	*10*	*5*	*2,5*	*1,25*	*630*	*315*	*160*	*80*
Saison 2011	3							100		98		63	10	4					1,4
Norme	Limite inf							100		90		45	0	0					0,0
5-14 mm	Limite sup							100		100		75	15	5					1,5

Caractéristiques intrinsèques	*Norme d'essai*	*Résultats*	*Exigences*	*Normes*	*Date*	*Effectué par*
Micro-Deval (MD) (%)	LC 21-070	5,6	≤15%	NQ 2560-114-1/2002	02 05 11	Inspec-Sol inc.
Micro-Deval (MD) (%)	CSA A23.2-29A	5,7	≤14	CSA A.23.1-00	02 05 11	Inspec-Sol inc.
Los Angeles (LA) (%)	LC 21-400	23,6	≤ 35%	NQ 2560-114-1/2002	02 05 11	Inspec-Sol inc.
Los Angeles (LA) (%)	CSA A23.2-16A	23,1	≤50	CSA A.23.1-01	02 05 11	Inspec-Sol inc.
Micro + Los Angeles (MD + LA) (%)	NA	29,2	≤ 40%	NQ 2560-114-1/2002	02 05 11	Inspec-Sol inc.

Caractéristiques fabrications	*Norme d'essai*	*Résultats*	*Exigences*	*Normes*	*Date*	*Effectué par*
% de particules plates	LC 21-265	20	≤25	NQ 2560-114-1/2002	02 05 11	Laboratoire central
% de particules allongées	LC 21-265	35	≤40	NQ 2560-114-1/2002	02 05 11	Laboratoire central
% de particules fracturées	LC 21-100	100	100	NQ 2560-114-1/2002	02 05 11	Laboratoire central

Caractéristiques complémentaires	*Norme d'essai*	*Résultats*	*Exigences*	*Normes*	*Date*	*Effectué par*
*Mottes d'argiles et part friables (%)	CSA A23.2-3A	0,1	≤ 0,25	NQ 2560-114-IV/2002	02 05 11	Inspec-Sol inc.
Propreté (particules < 80 um) (%)	CSA A23.2-5A	1,4	< 1,5	NQ 2560-114-IV/2002	02 05 11	Laboratoire central
Densité relative Séche/SSS	CSA A23.2-12A	2,729/2,741	NA	Aucune	02 05 11	Inspec-Sol inc.
Absorption (%)	CSA A23.2-12A	0,47	NA	Aucune	02 05 11	Inspec-Sol inc.
Perte au MgSO4 (%)	CSA A.23.2-9A	0,9	< 12	CSA A.23.1-00	02 05 11	Inspec-Sol inc.
Masse volumique tassée & non tassée	CSA A.23.2-10A	1609/1511	NA	Aucune	02 05 11	Inspec-Sol inc.
Potentiel de réactivité alcalis granulats	CSA A.23.2-14A	0,006	< 0,040%	CSA A.23.2-27A	27 05 10	Qualitas
Gel-Dégel granulats non confinés (%)	CSA A.23.2-24A	0,9	< 6	CSA A.23.1-00	02 05 11	Inspec-Sol inc.
Coefficient Polissage par Projection	LC 21-102	0,49	>0,45	NQ 2560-114-IV/2002	11 05 11	MTQ

Préparé par: Samira Bakhty; Chef de laboratoire Central

Signature: _____

ASPHALTE HI TECH
10/09/2009 12:47 5143427653

BAUVAL

FICHE TECHNIQUE DES GRANULATS (COMPILATION QUALITATIVE)

Type de matériaux :	Pierre concassée	Calibre:	5-14 mm	Date:	1 mai 2009
Provenance :	Sables L.G. St-Hippolyte, Québec	Classe granulaire:		Usages prévus:	Béton de ciment
		Classement :	1A		

Granulométrie (A 23.2-2A)		% passant en mm														% passant en um			
	Nombre d'éch.	112	80	56	40	31,5	28	20	16	14	12,5	10	5	2,5	1,25	630	315	160	80
Saison 2009								100		100		68	10	5					1,4
Norme 5-14 mm	Limite inf							100		90		45	0	0					
	Limite sup							100		100		75	15	5					1,5

Caractéristiques intrinsèques	Norme d'essai	Résultats	Exigences	Normes	Date	Effectué par
Micro-Deval (MD) (%)	LC 21-070	7,3	</= 15%	NQ 2560-114-1/2002	29 04 09	Inspect-Sol inc.
Los Angeles (LA) (%)	LC 21-400	24,5	</= 35%	NQ 2560-114-1/2002	29 04 09	Inspect-Sol inc.
Micro + Los Angeles (MD + LA) (%)	NA	31,8	</= 40%	NQ 2560-114-1/2002	29 04 09	Inspect-Sol inc.
Micro-Deval (%)	CSA A23.2-29A	6	</= 14%	CSA A.23.1-00	29 04 09	Inspect-Sol inc.
Los Angeles (%)	CSA A23.2-16A	27,9	</= 50%	CSA A.23.1-01	29 04 09	Inspect-Sol inc.

Caractéristiques fabrications	Norme d'essai	Résultats	Exigences	Normes	Date	Effectué par
% de particules plates	LC 21-265	18	</= 25	NQ 2560-114-1/2002	28 04 09	Laboratoire Central
% de particules allongées	LC 21-265	37	</= 40	NQ 2560-114-1/2002	28 04 09	Laboratoire Central
% de particules fracturées	LC 21-100	100	100	NQ 2560-114-1/2002	28 04 09	Laboratoire Central

Caractéristiques complémentaires	Norme d'essai	Résultats	Exigences	Normes	Date	Effectué par
*Mottes d'argiles et part friables (%)	CSA A23.2-3A	0,1	</= 0,25	NQ 2560-114-IV/2002	29 04 09	Inspect-Sol inc.
Propreté (particules < 80 um) (%)	CSA A23.2-5A	0,9	< 1,5 *	NQ 2560-114-IV/2002	29 04 09	Inspect-Sol inc.
Densité relative SSS/séche.	CSA A23.2-12A	2,730/2,715	NA	Aucune	29 04 09	Inspect-Sol inc.
Absorption (%)	CSA A23.2-12A	0,64	NA	Aucune	29 04 09	Inspect-Sol inc.
Perte au MgSO4 (%)	CSA A.23.2-9A	1,1	< 12	CSA A.23.1-00	29 04 09	Inspect-Sol inc.
Masse volumique tassée & non tassée	CSA A.23.2-10A	1600/1436	NA	Aucune	29 04 09	Inspect-Sol inc.
Potentiel de réactivité alcalis granulats	CSA A.23.2-14A	0,019	< 0,040%	CSA A.23.2-27A	10 05 08	Qualitas
Gel-Dégel granulats non confinés (%)	CSA A.23.2-24A	2,0	< 6	CSA A.23.1-00	29 04 09	Inspect-Sol inc.

Préparé par: Aziz.Amimi, Technicien contrôle qualité

Signature:

BAUVAL
LABORATOIRE CENTRAL

FICHE TECHNIQUE DES GRANULATS
(COMPILATION QUALITATIVE)

ISO 9001:2000 CERTIFICATION Intertek

Type de matériaux :	**Pierre concassée**	Calibre:	**10-14 mm**	Date:	**2011 05 02**
Provenance :	Sables L.G.	Classe granulaire:		Usages prévus:	Enrobés bitumineux
	St-Hippolyte, Québec	Classement :	1A		

Granulométrie (LC 21-040)		*% passant en mm*													*% passant en um*			
	Nombre d'éch.	*112*	*80*	*56*	*40*	*31,5*	*28*	*20*	*16*	*14*	*12,5*	*10*	*5*	*2,5*	*1,25*	*630*	*315*	*160*	*80*
Saison 2011	3							100		98		18	1						0,6
Norme	Limite inf							100		80		0	0						0,0
10-14 mm	Limite sup							100		100		20	5						1,5

Caractéristiques intrinsèques	*Norme d'essai*	*Résultats*	*Exigences*	*Normes*	*Date*	*Effectué par*
Micro-Deval (MD) (%)	LC 21-070	6,9	≤15%	NQ 2560-114-1/2002	02 05 11	Inspec-Sol inc.
Micro-Deval (MD) (%)	CSA A23.2-29A	4,9	≤14	CSA A.23.1-00	02 05 11	Inspec-Sol inc.
Los Angeles (LA) (%)	LC 21-400	19,3	≤35%	NQ 2560-114-1/2002	02 05 11	Inspec-Sol inc.
Los Angeles (LA) (%)	CSA A23.2-16A	19,5	≤50	CSA A.23.1-01	02 05 11	Inspec-Sol inc.
Micro + Los Angeles (MD + LA) (%)	NA	26,2	≤ 40%	NQ 2560-114-1/2002	02 05 11	Inspec-Sol inc.

Caractéristiques fabrications	*Norme d'essai*	*Résultats*	*Exigences*	*Normes*	*Date*	*Effectué par*
% de particules plates	LC 21-265	21	≤25	NQ 2560-114-1/2002	02 05 11	Laboratoire central
% de particules allongées	LC 21-265	36	≤40	NQ 2560-114-1/2002	02 05 11	Laboratoire central
% de particules fracturées	LC 21-100	100	100	NQ 2560-114-1/2002	02 05 11	Laboratoire central

Caractéristiques complémentaires	*Norme d'essai*	*Résultats*	*Exigences*	*Normes*	*Date*	*Effectué par*
*Mottes d'argiles et part friables (%)	CSA A23.2-3A	0,2	≤ 0,25	NQ 2560-114-IV/2002	02 05 11	Inspec-Sol inc.
Propreté (particules < 80 um) (%)	CSA A23.2-5A	1,4	< 1,5	NQ 2560-114-IV/2002	02 05 11	Laboratoire central
Densité relative SSS/Séche	LC 21-065	2,739/2,726	NA	Aucune	02 05 11	Inspec-Sol inc.
Absorption (%)	CSA A23.2-12A	0,47	NA	Aucune	02 05 11	Inspec-Sol inc.
Perte au MgSO4 (%)	CSA A.23.2-9A	0,5	< 12	CSA A.23.1-00	02 05 11	Inspec-Sol inc.
Masse volumique tassée & non tassée	CSA A.23.2-10A	1575/1473	NA	Aucune	02 05 11	Inspec-Sol inc.
Potentiel de réactivité alcalis granulats	CSA A.23.2-14A	0,006	< 0,040%	CSA A.23.2-27A	27 05 10	Qualitas
Gel-Dégel granulats non confinés (%)	CSA A.23.2-24A	0,8	< 6	CSA A.23.1-00	02 05 11	Inspec-Sol inc.
Coefficient Polissage par Projection	LC 21-102	0,50	>0,45	NQ 2560-114-IV/2002	01 06 10	MTQ

Préparé par: Samira Bakhty; Chef de laboratoire Central

Signature: _____

BAUVAL CMM

SOLS ET GRANULATS
Compilation granulométrique

Fournisseur : L.G - St-Hippolyte | Projet : Tous | Période : De 2011-02-01 À 2011-05-24

Calibre : 10-14mm LG Pierre granitique | Description du contrôle : | Endroit prélevé : Tous

Site : Tous | Imprimer les 5 | Séquence : Toutes

Granulométrie

N° éch.	Date	Contrat	20	14	10	5.0	2.5	1.25	0.630	0.315	0.160	0.080	COLO	ES	MF
GR-0186	2011-05-11	CONTRÔLE INTER	100	99	39*	6*	4					1,5			
GR-0186R	2011-05-11	CONTRÔLE INTER	100	100	39*	6*	4					1,6*			
GR-0221	2011-05-13	CONTRÔLE INTER	100	100	35*	5	3					1,7*			
GR-0225	2011-05-16	CONTRÔLE INTER	100	100	31*	3	2					1,2			
GR-0260	2011-05-24	CONTRÔLE INTER	100	99	24*	3	2					1,1			

Interprétation des résultats

Observations	5 / 5													
Moyenne		100	100	34*	5	3					1,4			
Valeur minimum		100	99	24	3	2					1,1			
Valeur maximum		100	100	39	6	4					1,7			
Étendue			1	15	3	2					0,6			
Écart type			0,5	6,3	1,5	1,0					0,26			
Variation				40	2	1					0,1			
Exigences normalisées	Min	100	80											
	Max	100	100	20	5						1,5			

* = Non-conforme

Préparé par: Samira Bakhty Date : 2011-05-24 Vérifié par: _____

SG037

BAUVAL

FICHE TECHNIQUE DES GRANULATS (COMPILATION QUALITATIVE)

Type de matériaux :	Pierre concassée	Calibre:	10 mm	Date:	8 mai 2009
Provenance :	Sables L.G.	Classe granulaire:		Usages prévus:	Béton de ciment
	St-Hippolyte, Québec	Classement :	1A		Enrobés Bitumineux

Granulométrie (A 23.2-2A)		*% passant en mm*													*% passant en um*			
Saison 2009	Nombre d'éch.	*112*	*80*	*56*	*40*	*31.5*	*28*	*20*	*16*	*14*	*12.5*	*10*	*5*	*3.15*	*2.5*	*1.25*			*80*
										100	100	90	13	3	3	2			1.4

Caractéristiques intrinsèques	*Norme d'essai*	*Résultats*	*Exigences*	*Normes*	*Date*	*Effectué par*
Micro-Deval (MD) (%)	LC 21-070	8.9	≤15%	NQ 2560-114-1/2002	29 04 09	Inspec-Sol inc.
Los Angeles (LA) (%)	LC 21-400	25.4	≤35%	NQ 2560-114-1/2002	29 04 09	Inspec-Sol inc.
Micro + Los Angeles (MD + LA) (%)	NA	34.3	≤40%	NQ 2560-114-1/2002	29 04 09	Inspec-Sol inc.
Micro-Deval (%)	CSA A23.2-29A	7.5	≤ 14%	CSA A.23.1-00	29 04 09	Inspec-Sol inc.
Los Angeles (%)	CSA A23.2-16A	25.9	≤50%	CSA A.23.1-01	29 04 09	Inspec-Sol inc.
Caractéristiques fabrications	***Norme d'essai***	***Résultats***	***Exigences***	***Normes***	***Date***	***Effectué par***
% de particules plates	LC 21-265	23	≤ 25	NQ 2560-114-1/2002	12 05 09	Laboratoire Central
% de particules allongées	LC 21-265	34	≤ 40	NQ 2560-114-1/2002	12 05 09	Laboratoire Central
% de particules fracturées	LC 21-100	100	100	NQ 2560-114-1/2002	02 05 09	Laboratoire Central
Caractéristiques complémentaires	***Norme d'essai***	***Résultats***	***Exigences***	***Normes***	***Date***	***Effectué par***
*Mottes d'argiles et part friables (%)	CSA A23.2-3A	0	≤0,25	NQ 2560-114-IV/2002	29 04 09	Inspec-Sol inc.
Propreté (particules < 80 um) (%)	CSA A23.2-5A	0.8	< 1,5	NQ 2560-114-IV/2002	29 04 09	Laboratoire Central
Densité relative sss/séche	CSA A23.2-12A	2,725/2,700	NA	Aucune	29 04 09	Inspec-Sol inc.
Absorption (%)	CSA A23.2-12A	0.94	NA	Aucune	29 04 09	Inspec-Sol inc.
Perte au MgSO4 (%)	CSA A.23.2-9A	1.4	< 12	CSA A.23.1-00	29 04 09	Inspec-Sol inc.
Masse volumique tassée & non tassée	CSA A.23.2-10A	1564/1513	NA	Aucune	29 04 09	Inspec-Sol inc.
Potentiel de réactivité alcalis granulats	CSA A.23.2-14A	0.019	< 0,040%	CSA A.23.2-27A	10 05 08	Qualitas
Gel-Dégel granulats non confinés (%)	CSA A.23.2-24A	0.9	< 6	CSA A.23.1-00	29 04 09	Inspec-Sol inc.
Coefficient polissage par projection	LC 21-102	0.50	>0,45	NQ 2560-114-IV/2002	08 08 08	MTQ

Préparé par:, Aziz.Amimi, Technicien contrôle qualité

Signature :

BAUVAL
LABORATOIRE CENTRAL

FICHE TECHNIQUE DES GRANULATS (COMPILATION QUALITATIVE)

Type de matériaux :	**Pierre concassée**	Calibre:	**10 mm**	Date:	**2011 05 02**
Provenance :	Sables L.G.	Classe granulaire:		Usages prévus:	Béton de ciment
	St-Hippolyte, Québec	Classement :	1A		Enrobés Bitumineux

Granulométrie (A 23.2-2A)		***% passant en mm***													***% passant en um***			
	Nombre d'éch.	*112*	*80*	*56*	*40*	*31,5*	*28*	*20*	*16*	*14*	*12,5*	*10*	*5*	*3,15*	*2,5*	*1,25*			*80*
Saison 2011	3									100	100	91	13	2					1,2

Caractéristiques intrinsèques	***Norme d'essai***	***Résultats***	***Exigences***	***Normes***	***Date***	***Effectué par***
Micro-Deval (MD) (%)	LC 21-070	8,4	≤15%	NQ 2560-114-1/2002	02 05 11	Inspec-Sol inc.
Los Angeles (LA) (%)	LC 21-400	21,2	≤35%	NQ 2560-114-1/2002	02 05 11	Inspec-Sol inc.
Micro + Los Angeles (MD + LA) (%)	NA	29,6	≤40%	NQ 2560-114-1/2002	02 05 11	Inspec-Sol inc.
Micro-Deval (%)	CSA A23.2-29A	6,1	≤ 14%	CSA A.23.1-00	02 05 11	Inspec-Sol inc.
Los Angeles (%)	CSA A23.2-16A	23,2	≤50%	CSA A.23.1-01	02 05 11	Inspec-Sol inc.
Caractéristiques fabrications	***Norme d'essai***	***Résultats***	***Exigences***	***Normes***	***Date***	***Effectué par***
% de particules plates	LC 21-265	23	≤ 25	NQ 2560-114-1/2002	02 05 11	Laboratoire Central
% de particules allongées	LC 21-265	33	≤ 40	NQ 2560-114-1/2002	02 05 11	Laboratoire Central
% de particules fracturées	LC 21-100	100	100	NQ 2560-114-1/2002	02 05 11	Laboratoire Central
Caractéristiques complémentaires	***Norme d'essai***	***Résultats***	***Exigences***	***Normes***	***Date***	***Effectué par***
*Mottes d'argiles et part friables (%)	CSA A23.2-3A	0,1	≤0,25	NQ 2560-114-IV/2002	02 05 11	Inspec-Sol inc.
Propreté (particules < 80 um) (%)	CSA A23.2-5A	1,2	< 1,5	NQ 2560-114-IV/2002	02 05 11	Laboratoire Central
Densité relative sss/séche	CSA A23.2-12A	2,734/2,718	NA	Aucune	02 05 11	Inspec-Sol inc.
Absorption (%)	CSA A23.2-12A	0,62	NA	Aucune	02 05 11	Inspec-Sol inc.
Perte au MgSO4 (%)	CSA A.23.2-9A	0,8	< 12	CSA A.23.1-00	02 05 11	Inspec-Sol inc.
Masse volumique tassée & non tassée	CSA A.23.2-10A	1639/1536	NA	Aucune	02 05 11	Inspec-Sol inc.
Potentiel de réactivité alcalis granulats	CSA A.23.2-14A	0,006	< 0,040%	CSA A.23.2-27A	27 05 10	Qualitas
Gel-Dégel granulats non confinés (%)	CSA A.23.2-24A	2,6	< 6	CSA A.23.1-00	02 05 11	Inspec-Sol inc.
Coefficient polissage par projection	LC 21-102	0,49	>0,45	NQ 2560-114-IV/2002	11 05 11	MTQ

Préparé par: Samira Bakhty; Chef de laboratoire Central

Signature :

BAUVAL

FICHE TECHNIQUE DES GRANULATS
(COMPILATION QUALITATIVE)

Type de matériaux :	Sable manufacturé	Calibre:	0-2,5 mm	Date:	1 mai 2009
Provenance :	Sables L.G.	Classe granulaire:		Usages prévus:	Lit de pose
	St-Hippolyte, Québec	Classement :	1		Autre

Granulométrie (A 23.2-2A)		% passant en mm													% passant en um			
	Nombre d'éch.	112	80	56	40	31,5	28	20	16	14	12,5	10	5	2,5	1,25	630	315	160	80
Saison 2009												100	100	85	57	36	18	9	2,6
												100	95	80	50	25	10	5	0,0
Norme	Limite inf																		
	Limite sup												100	100	85	60	30	15	5,0

Caractéristiques intrinsèques	Norme d'essai	Résultats	Exigences	Normes	Date	Effectué par
Micro-Deval (MD)	LC 21-101	18..4%	≤ 30	NQ 2560-114-1/2002	01 05 09	Inspect-Sol inc.
Friabilité	LC 21-080	24,3%	≤ 40	NQ 2560-114-1/2002	01 05 09	Inspect-Sol inc.

Caractéristiques complémentaires	Norme d'essai	Résultats	Exigences	Normes	Date	Effectué par
Mottes d'argiles et part friables (%)	CSA A23.2-3A	0,1	≤ 2,0	NQ 2560-114-V/2002	01 05 09	Inspect-Sol inc.
Coefficient d'écoulement	LC 21-075	98	≥ 80	NQ 2560-114-V/2002	01 05 09	Inspect-Sol inc.
Densité relative brut SSS (fin).	LC 21-065	2,724	NA	-	01 05 09	Inspect-Sol inc.
Absorption	LC 21-065	0,35	NA	-	01 05 09	Inspect-Sol inc.
*Sédimentométrie au 5 um (%)	NQ 2501-025	0,3	≤ 4	NQ 2560-114-V/2002	01 05 09	Inspect-Sol inc.

Préparé par: Aziz Amimi, Technicien contrôle qualité

Signature:

ASPHALTE HI TECH 5143427653 10/09/2009 12:47

GRACE

DARATARD® 17

Set retarding admixture

ASTM C494 Type B and D

Product Description

Daratard® 17 admixture is a ready-to-use aqueous solution of hydroxylated organic compounds. Ingredients are factory pre-mixed in exact proportions to minimize handling, eliminate mistakes and guesswork. Daratard 17 admixture weighs approximately 10.2 lbs/gal (1.17 kg/L).

Uses

Daratard 17 retards the initial and final set of concrete. At the usual addition rate of 3 fl oz/100 lbs (195 mL/100 kg) cement, it will extend the initial setting time of Portland cement concrete by 2 to 3 hours at 70°F (21°C). Daratard 17 is used wherever a delay in setting time will insure sufficient delivery, placement, vibration or compaction time, such as in:

- Hot weather concreting
- Transit mix concrete
- Prestressed concrete

Daratard 17 is also used in special applications, as in bridge decks where it extends plastic characteristics of the concrete until progressive deflection resulting from increasing loads is completed.

Product Advantages

- Provides ≥5% water reduction
- Increases compressive strengths and reduces permeability
- Delays time of set to accommodate long haul times, or facilitate placement and finishing during hot weather concreting

Addition Rates

Addition rates for Daratard 17 will range from 2 to 8 fl oz/100 lbs (130 to 520 mL/100 kg) of cement. The amount to be used will depend upon the degree of retardation required under job conditions. Longer setting times or higher temperatures will require higher addition rates. Conversely, the addition rate will be lower for shorter extensions of time.

Compatibility with Other Admixtures and Batch Sequencing

Daratard 17 is compatible with most Grace admixtures as long as they are added separately to the concrete mix, usually through the water holding tank discharge line. In general, it is recommended that Daratard 17 be added to the concrete mix near the beginning of the batch sequence but after the cement and water is combined for optimum performance. Different sequencing may be used if local testing shows better performance. Please see Grace Technical Bulletin TB-0110, *Admixture Dispenser Discharge Line Location and Sequencing for Concrete Batching Operations* for further recommendations. Daratard 17



should not come in contact with any other admixture before or during the batching process, even if diluted in mix water.

Pretesting of the concrete mix should be performed before use, and as conditions and materials change in order to assure compatibility, and to optimize dosage rates, addition times in the batch sequencing and concrete performance. For concrete that requires air entrainment, the use of an ASTM C260 air-entraining agent (such as Daravair® or Darex® product lines) is recommended to provide suitable air void parameters for freeze-thaw resistance. Please consult your Grace representative for guidance.

Packaging & Handling

Daratard 17 is available in bulk, delivered by metered tank trucks, and 55 gal (210 L) drums. Daratard 17 will freeze at about 28°F (-2°C), but will return to full strength after thawing and thorough agitation.

Dispensing Equipment

A complete line of accurate, automatic dispensing equipment is available. Daratard 17 may be introduced to the mix with the sand or with the water.

Specifications

Concrete shall be designed in accordance with *Standard Recommended Practice for Selecting Proportions for Concrete*, ACI 211.1.

The set-retarding/water-reducing admixture shall comply with ASTM Designation C494, Type D admixture, and shall be Daratard 17, as manufactured by Grace Construction Products, or equal. Certification of compliance shall be made available on request. It shall be used in strict accordance with the manufacturers' recommendations.

The addition rate shall be adjusted to produce the specified retardation of the concrete mix at all temperatures.

www.graceconstruction.com

North American Customer Service: 1-877-4AD-MIX1 (1-877-423-6491)

Daratard, Daravair and Darex are registered trademarks of W. R. Grace & Co.–Conn.

We hope the information here will be helpful. It is based on data and knowledge considered to be true and accurate and is offered for the users' consideration, investigation and verification, but we do not warrant the results to be obtained. Please read all statements, recommendations or suggestions in conjunction with our conditions of sale, which apply to all goods supplied by us. No statement, recommendation or suggestion is intended for any use which would infringe any patent or copyright. W. R. Grace & Co.–Conn., 62 Whittemore Avenue, Cambridge, MA 02140. In Canada, Grace Canada, Inc., 294 Clements Road, West, Ajax, Ontario, Canada L1S 3C6.

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RT-4H Printed in U.S.A. 11/07 FA/LI/1M

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Appendix B

Results for Cylindrical Specimens

Cylinders - 3 Months Limewater Solution Exposure: Complete Immersion

Sample: C03LW0A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.6	23.98	4.2786	66.5	12.8	102.75	23.12	4.4442	75.3	40.6
50	102.74	23.57	4.3589	72.3	69	102.66	23.39	4.3891	72.5	61.3
75	102.73	25.89	3.9679	59.4	10.4	102.78	24.16	4.2541	64.8	23.7
100	102.57	25.9	3.9602	58.2	7.8	102.83	23.92	4.2989	59.6	12.6
125	102.45	23.63	4.3356	66	22.5	102.79	24.56	4.1853	60.1	8.7
150	102.55	25.45	4.0295	65.7	13.5	102.68	24.14	4.2535	62.5	13.5
175	102.46	23.77	4.3105	76.2	66.7	102.68	23.71	4.3307	67.4	36.6

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
201.78	201.68	201.73	42.5	42.4	42.45	4.7522	5.64999	10.0 cm from top

Sample: C03LW0A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.76	23.92	4.2960	60.1	9.5	102.59	23.86	4.2997	67	19.1
50	102.65	23.74	4.3239	65.5	31.4	102.62	23.73	4.3245	77.5	82.2
75	102.78	23.59	4.3569	63.5	26.3	102.63	23.74	4.3231	61.4	22.2
100	102.67	23.43	4.3820	69.7	48.2	102.64	24	4.2767	63.8	15.5
125	102.65	23.95	4.2860	62.5	8.4	102.66	23.82	4.3098	63.3	19.1
150	102.69	23.85	4.3057	73.5	61.4	102.77	23.54	4.3658	76.4	75.2
175	102.79	23.57	4.3611	73.4	42.6	102.66	23.59	4.3518	68	27

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
203.27	204.04	203.655	41.6	41.7	41.65	4.8897	6.02293	7.4 cm from bottom

Sample: C03LW0A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.54	23.59	4.3468	63.7	10	102.48	23.35	4.3889	65.1	9.4
50	102.62	23.88	4.2973	66.5	32.5	102.44	23.35	4.3872	70.5	59.3
75	102.41	23.49	4.3597	65.8	22.2	102.55	25.02	4.0987	59.8	11.3
100	102.36	23.86	4.2900	62.8	13.9	102.54	23.95	4.2814	65.6	20.9
125	102.49	23.57	4.3483	63.8	15.8	102.43	23.42	4.3736	67	27.7
150	102.5	23.19	4.4200	74.5	63.3	102.47	23.8	4.3055	70.9	57.5
175	102.33	23.71	4.3159	71	38.6	102.37	23.82	4.2976	65.6	28.1

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.45	195.57	195.51	39.9	39.7	39.8	4.9123	6.00251	5.2 cm from top

Notes:

Cylinders - 3 Months 2% Sodium Sulphate Solution Exposure: Complete Immersion

Sample: C03SS2A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.39	23.77	4.3075	67.7	23.1	102.58	24.21	4.2371	66	12.3
50	102.44	23.64	4.3333	72.5	70.1	102.58	23.68	4.3319	72.3	59.4
75	102.52	23.9	4.2895	71.9	41.6	102.59	23.86	4.2997	70.6	33.1
100	102.57	24.09	4.2578	68.8	29.4	102.63	23.76	4.3194	65.8	21.7
125	102.63	24.00	4.2762	62.1	12.2	102.61	23.74	4.3222	71.9	25.3
150	102.67	23.64	4.3431	68.7	49.5	102.56	23.88	4.2948	76.1	74.9
175	102.62	23.97	4.2812	71.8	30.5	102.6	24	4.2750	69	40.2

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.97	199.32	199.145	42.4	42.4	42.4	4.6968	5.67449	8.9 cm from bottom

Sample: C03SS2A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.66	23.62	4.3463	69.2	22.5	102.61	23.81	4.3095	60.7	6.8
50	102.7	24.97	4.1129	64.5	23	102.7	23.72	4.3297	69.5	58.6
75	102.72	24.15	4.2534	69.6	23.8	102.6	23.7	4.3291	67	23.4
100	102.6	24.71	4.1522	59.1	8.8	102.58	24.26	4.2284	60.9	15.2
125	102.5	24.16	4.2425	58.9	10.4	102.52	24.78	4.1372	59.1	8
150	102.46	24.28	4.2199	69.5	32.6	102.53	24.39	4.2038	65.5	19.2
175	102.42	24.06	4.2569	64	20.5	102.43	23.9	4.2858	66.4	29.7

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.17	198.02	198.095	40.9	40.9	40.9	4.8434	6.08411	2.6 cm from top

Sample: C03SS2A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.91	22.88	4.4104	69.3	33.3	100.73	23.36	4.3121	71	26.7
50	100.53	23.42	4.2925	74.5	70.5	100.56	23.62	4.2574	77.5	85
75	100.61	23.58	4.2668	73	77.4	100.65	23.83	4.2237	74.5	40.9
100	100.58	23.63	4.2565	64.4	17.4	100.56	23.62	4.2574	68.5	25.6
125	100.56	23.58	4.2646	66.8	22.9	100.49	23.13	4.3446	76.2	39.3
150	100.39	23.55	4.2628	68.1	32.2	100.35	23.27	4.3124	69.6	46.7
175	100.25	23.25	4.3118	78	95.6	100.22	23.56	4.2538	69.8	26.4

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.84	200.08	199.96	41.9	42	41.95	4.7666	6.88687	9.6 cm from bottom

Notes:

Cylinders - 3 Months 5% Sodium Sulphate Solution Exposure: Complete Immersion

Sample: C03SS5A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.41	23.77	4.3084	64.1	15.9	102.44	23.38	4.3815	66	23.2
50	102.51	24.14	4.2465	63.5	25	102.4	23.77	4.3080	74.5	66.5
75	102.32	24.14	4.2386	63.9	30.8	102.4	23.93	4.2791	70.4	41.6
100	102.3	24.25	4.2186	66.9	24.2	102.43	24.52	4.1774	69.6	29.1
125	102.29	24.03	4.2568	60.6	12.5	102.38	24.09	4.2499	60.9	13.1
150	102.2	23.67	4.3177	71.5	48.7	102.31	24.17	4.2329	67.5	31.3
175	102.14	23.64	4.3206	65.2	34.2	102.23	25.33	4.0359	64.5	17.3

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
201.7	201.86	201.78	41.9	42	41.95	4.8100	7.10372	3.0 cm from top

Sample: C03SS5A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.61	24.46	4.1950	64	8.2	102.5	23.92	4.2851	66	23.5
50	102.53	24.81	4.1326	63.5	20	102.53	23.68	4.3298	76.5	100
75	102.55	23.87	4.2962	70	32.1	102.46	23.68	4.3269	68.9	38.4
100	102.53	24.16	4.2438	64.7	19.2	102.46	23.85	4.2960	65	33
125	102.53	23.83	4.3026	59.3	14.6	102.44	24.17	4.2383	62.3	9.2
150	102.46	23.92	4.2834	72.4	63.4	102.38	24.19	4.2323	66.5	40
175	102.38	23.88	4.2873	73	49.5	102.45	24.36	4.2057	61.1	13.5

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
202.55	202.51	202.53	42.2	42.3	42.25	4.7936	7.10714	4.9 cm from top

Sample: C03SS5A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.17	23.24	4.3102	72.5	35.2	100.17	23.63	4.2391	65.8	12.2
50	100.18	23.59	4.2467	68	35.3	100.17	23.11	4.3345	68.5	55
75	100.33	23.6	4.2513	68.7	31.1	100.26	23.56	4.2555	69.6	31.3
100	100.44	24.07	4.1728	64.4	17.6	100.36	23.97	4.1869	70.8	33.5
125	100.6	23.64	4.2555	64	22.4	100.42	23.81	4.2176	64.8	16
150	100.5	23.97	4.1927	71.1	57.7	100.28	23.74	4.2241	76.5	63.7
175	100.62	23.70	4.2456	71.5	34.6	100.26	24.56	4.0822	63.5	21.6

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.78	195.77	195.775	41.3	41.3	41.3	4.7403	6.82058	8.9 cm from top

Notes:

Cylinders - 3 Months Limewater Solution Exposure: Partial Immersion

Sample: C03LW0W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.71	22.84	4.4969	78.6	52.1	102.73	22.93	4.4802	73.2	33.9
50	102.58	23.15	4.4311	80.5	88.5	102.66	23.08	4.4480	81	135.2
75	102.45	23.24	4.4083	73.7	62.5	102.73	23.38	4.3939	71.5	44.5
100	102.43	23.82	4.3002	71.5	48.4	102.62	23.4	4.3855	75.9	66.6
125	102.53	24.24	4.2298	63.3	12.7	102.66	24.42	4.2039	59.4	11
150	102.28	23.89	4.2813	71.4	52.1	102.43	26.77	3.8263	58.5	22.9
175	102.26	26.49	3.8603	60.3	10.9	102.38	23.89	4.2855	69.8	45.3

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.79	196.47	196.13	40.5	40.5	40.5	4.8427	4.71422	4.3 cm from top

Sample: C03LW0W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.7	24.13	4.2561	62.4	13.5	102.67	23.98	4.2815	71	28.2
50	102.86	25.77	3.9915	60	10.1	102.66	24.26	4.2317	62.9	15.5
75	102.72	23.82	4.3123	66.7	26.6	102.61	23.38	4.3888	65.7	22.5
100	102.73	23.94	4.2911	65.1	19.5	102.64	23.98	4.2802	65.1	18.5
125	102.78	24.14	4.2577	69.1	33	102.43	23.91	4.2840	69.4	38
150	102.74	24.69	4.1612	73.5	64.7	102.38	26.33	3.8883	55.8	12.2
175	102.72	24.74	4.1520	64.5	25.2	102.49	24.94	4.1095	66.1	24.5

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
201.45	200.04	200.745	43.3	43	43.15	4.6523	5.31695	7.0 cm from top

Sample: C03LW0W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.72	23.44	4.3823	63	11.4	102.7	23.75	4.3242	65	18
50	102.74	24.03	4.2755	72.6	55.3	102.78	23.52	4.3699	74.5	70.8
75	102.73	23.71	4.3328	73.6	44.3	102.65	23.42	4.3830	67.9	37
100	102.64	24.23	4.2361	68.1	23.3	102.82	23.93	4.2967	67.2	23.5
125	102.69	24.13	4.2557	64.4	15.6	102.75	24.02	4.2777	68.6	21.5
150	102.53	24.22	4.2333	74.3	72.6	102.52	24.28	4.2224	72.5	57.5
175	102.47	24.42	4.1962	64.8	31.2	102.48	24.79	4.1339	67	38

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
202.11	201.41	201.76	41.9	41.8	41.85	4.8210	4.49812	9.1 cm from bottom

Notes:

Cylinders - 3 Months 2% Sodium Sulphate Solution Exposure: Partial Immersion

Sample: C03SS2W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.69	23.88	4.3003	61.9	11.2	102.58	23.32	4.3988	71.8	29
50	102.65	24	4.2771	71.4	69.6	102.58	23.68	4.3319	71.5	36.5
75	102.61	24.18	4.2436	72.2	43.2	102.65	23.64	4.3422	69.9	41
100	102.85	23.73	4.3342	68.5	28.5	102.92	24.28	4.2389	63	13.5
125	102.58	24.47	4.1921	56.1	5.6	102.58	24.58	4.1733	59	12.3
150	102.58	24.73	4.1480	67.5	42.1	102.42	24.6	4.1634	68.5	44.4
175	102.72	24.86	4.1319	65.5	18.2	102.4	24.89	4.1141	67.7	27

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
202.48	202.24	202.36	42.5	42.4	42.45	4.7670	5.14404	3.8 cm from top

Sample: C03SS2W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.4	26.05	3.9309	56.3	4.5	102.45	23.7	4.3228	71.3	26.1
50	102.48	24.86	4.1223	58.5	12.9	102.39	24.34	4.2067	66.8	27.8
75	102.52	28.44	3.6048	59.8	7.7	102.28	24.35	4.2004	64.4	20.7
100	102.45	24.32	4.2126	63.4	18	102.2	26.68	3.8306	56.9	5.8
125	102.62	24.13	4.2528	65.9	14.9	102.11	26.78	3.8129	50.8	4.1
150	102.37	24.82	4.1245	64.6	18	102.09	24.63	4.1449	67.5	37
175	102.34	25.16	4.0676	62.4	14.2	102.02	24.37	4.1863	69	31.7

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.11	199.5	199.305	42.1	42	42.05	4.7397	5.19136	7.0 cm from top

Sample: C03SS2W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.79	25.94	3.9626	58	4.5	102.65	23.76	4.3203	66	15.6
50	102.79	24.04	4.2758	62.5	26.5	102.69	23.82	4.3111	69.5	43.7
75	102.74	26.15	3.9289	54	6.6	102.65	23.98	4.2807	63.7	18.4
100	102.69	26.97	3.8076	54.8	5.4	102.49	25.95	3.9495	55.5	6.1
125	102.68	24.55	4.1825	62.6	20.4	102.49	25.18	4.0703	61.2	11.4
150	102.74	24.77	4.1478	67.5	36.3	102.6	24.8	4.1371	66.5	30.7
175	102.74	24.97	4.1145	60.7	23.3	102.37	26.28	3.8954	59	12.2

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
204.04	203.92	203.98	44.5	44.3	44.4	4.5941	6.34352	3.3 cm from top

Notes:

Cylinders - 3 Months 5% Sodium Sulphate Solution Exposure: Partial Immersion

Sample: C03SS5W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.15	23.52	4.2581	72.1	34.5	100.12	23.59	4.2442	71.9	36.1
50	100.42	23.94	4.1947	71.3	74.2	100.25	23.59	4.2497	71.5	74.9
75	100.78	24.28	4.1507	62.4	21.5	100.23	23.93	4.1885	70.5	44.1
100	100.54	25.64	3.9212	58.8	6.1	100.28	23.47	4.2727	68.5	34.8
125	100.63	24.61	4.0890	57.5	6.9	100.21	24.61	4.0719	57.5	6.9
150	100.52	24.10	4.1710	69.5	51.6	100.35	24.1	4.1639	69.5	51.6
175	100.75	24.57	4.1005	71.9	48.2	100.19	24.57	4.0777	71.9	48.2

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.32	197.22	197.27	43	43.1	43.05	4.5823	6.22052	3.7 cm from top

Sample: C03SS5W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.14	24.22	4.1346	64	14.6	100.4	23.45	4.2814	68	31.4
50	100.42	23.48	4.2768	72.5	61.4	100.34	24.22	4.1429	67.5	22.3
75	100.49	26.28	3.8238	54.8	10.4	100.53	24.22	4.1507	66.2	37.2
100	100.61	24.67	4.0782	59.1	8.8	100.65	24.38	4.1284	66	21.9
125	100.89	24.72	4.0813	61	9.8	100.58	27.16	3.7032	53.3	3.7
150	100.8	24.26	4.1550	67.4	29.6	100.54	24.11	4.1701	69.4	44.5
175	100.85	24.46	4.1231	68.4	43.7	100.28	26.75	3.7488	54.7	5.1

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
201.63	202.23	201.93	43.3	43	43.15	4.6797	5.98337	2.0 cm from top

Sample: C03SS5W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.54	23.82	4.3048	70	19.2	102.5	24.02	4.2673	66	25.4
50	102.48	23.59	4.3442	75.7	88.2	102.49	23.68	4.3281	73.5	57
75	102.38	24.1	4.2481	71.1	32.6	102.42	24.18	4.2357	65.5	23.5
100	102.37	24.7	4.1445	63.1	11.7	102.46	24.38	4.2026	66.4	23.2
125	101.94	27.57	3.6975	48.7	2	102.208	24.48	4.1752	61.3	9.4
150	102.31	24.12	4.2417	64.5	27	102.26	24.19	4.2274	70.9	50.2
175	102.09	24.68	4.1365	61.5	10.5	102.09	24.56	4.1568	68.1	29.1

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
201.54	201.98	201.76	42.2	42.4	42.3	4.7697	5.59192	4.6 cm from top

Notes:

Cylinders - 3 Months Limewater Solution Exposure: Cyclical Partial Immersion

Sample: C03LW0F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.45	23.67	4.3283	66	21.1	102.48	23.77	4.3113	69	23.5
50	102.43	23.6	4.3403	76.5	93.4	102.55	23.75	4.3179	69.5	48.5
75	102.42	24.03	4.2622	71	52	102.45	23.85	4.2956	68.5	38.3
100	102.43	23.8	4.3038	69.5	29.4	102.38	24.52	4.1754	62.9	13.3
125	102.36	24.12	4.2438	59	10.7	102.37	24.24	4.2232	64	17
150	102.33	24.57	4.1648	71.5	58.9	102.27	23.83	4.2916	72.4	59.8
175	102.24	24.11	4.2406	65.2	34.3	102.23	24.33	4.2018	63.9	27.2

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.93	200.29	200.11	41.7	41.8	41.75	4.7931	5.8825	5.3 cm from top

Sample: C03LW0F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.44	24.12	4.2471	60.9	10.6	102.62	23.89	4.2955	60.1	7
50	102.36	23.42	4.3706	73.5	74.5	102.66	23.64	4.3426	70.4	64.5
75	102.31	23.62	4.3315	70.8	36	102.65	23.67	4.3367	68	30.9
100	102.35	23.51	4.3535	67	21.7	102.71	23.77	4.3210	63.7	16.4
125	102.23	23.74	4.3062	65.6	20.9	102.5	23.72	4.3212	69	29.6
150	102.19	24.01	4.2561	72.3	62.1	102.54	24.18	4.2407	65.8	29.5
175	102.13	24.16	4.2272	66.2	30.6	102.42	24.38	4.2010	70.6	43.8

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.92	199.59	199.755	42.6	42.9	42.75	4.6726	4.75458	5.6 cm from top

Sample: C03LW0F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.27	23.6	4.2487	67	20.9	100.18	23.61	4.2431	62.4	9.5
50	100.41	23.48	4.2764	71.5	48.9	100.24	23.77	4.2171	66.5	22
75	100.55	23.56	4.2678	71.4	47.3	100.36	23.89	4.2009	66.4	30.5
100	100.58	23.77	4.2314	71.3	37.7	100.4	23.79	4.2203	66.8	27.3
125	100.67	23.77	4.2352	67.7	19.8	100.55	23.93	4.2018	62.4	11.4
150	100.67	24.17	4.1651	76.1	95.3	100.49	24.31	4.1337	72.7	67.6
175	100.48	24.29	4.1367	67.8	28.7	100.46	24.42	4.1138	64.4	17.8

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.34	196.75	196.545	42.7	42.6	42.65	4.6083	6.41954	6.3 cm from top

Notes:

Cylinders - 3 Months 2% Sodium Sulphate Solution Exposure: Cyclical Partial Immersion

Sample: C03SS2F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.47	26.14	3.9200	52.6	3	102.52	23.81	4.3058	70.5	17.4
50	102.4	26.45	3.8715	54.3	6.3	102.46	24	4.2692	69.5	37
75	102.41	25.7	3.9848	58.7	9.6	102.58	23.89	4.2938	63.8	21.9
100	102.39	26.37	3.8828	54.1	3.2	102.55	24.21	4.2359	68.2	25.3
125	102.37	24.26	4.2197	56.5	6.7	102.43	23.58	4.3439	68.5	35.8
150	102.12	27.00	3.7822	52	5.9	102.4	24.59	4.1643	58.5	7.4
175	102.19	26.80	3.8131	57	5.4	102.65	25.58	4.0129	57.6	10

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
203.13	203.05	203.09	43.4	43.1	43.25	4.6957	5.76164	3.0 cm from top

Sample: C03SS2F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.78	23.4	4.3923	70.2	31.6	102.63	23.59	4.3506	69.5	23.9
50	102.65	23.19	4.4265	73.4	57.7	102.79	23.91	4.2990	73.5	53.4
75	102.5	23.55	4.3524	68.6	41.6	102.7	23.48	4.3739	66.3	31.3
100	102.45	26.14	3.9193	56.6	4.7	102.5	23.74	4.3176	69.2	28.7
125	102.37	23.84	4.2940	63.6	22.3	102.48	24.19	4.2365	61.2	13.9
150	102.22	27.04	3.7803	56.1	6.5	102.47	25.6	4.0027	62.5	23.1
175	102.29	24.70	4.1413	68.9	28.9	102.39	24.64	4.1554	68.3	31.4

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
201.12	200.63	200.875	41.8	41.8	41.8	4.8056	6.5457	3.6 cm from top

Sample: C03SS2F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.6	24.15	4.2484	66	17.3	102.48	24	4.2700	67	20.3
50	102.43	24.1	4.2502	64.5	28.5	102.47	24.12	4.2483	67	28
75	102.45	24.37	4.2039	60.9	12.3	102.49	24.09	4.2545	64.3	19.6
100	102.38	24.39	4.1976	69.7	22.7	102.37	24.31	4.2110	57.9	6.9
125	102.42	26.10	3.9241	52.9	3.5	102.38	23.75	4.3107	61.6	14.7
150	102.4	24.29	4.2157	69.5	49.5	102.27	24.73	4.1355	67.4	31.4
175	102.35	24.42	4.1912	64.5	34.4	102.25	24.44	4.1837	67.8	34.7

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
201.31	201.22	201.265	41.5	41.8	41.65	4.8323	5.10675	3.1 cm from top

Notes:

Cylinders - 3 Months 5% Sodium Sulphate Solution Exposure: Cyclical Partial Immersion

Sample: C03SS5F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.19	23.41	4.2798	65.2	20.3	100.22	23.8	4.2109	66	14.8
50	100.33	23.72	4.2298	74.5	61	100.23	23.98	4.1797	66	21.2
75	100.56	23.59	4.2628	70.2	28	100.32	23.98	4.1835	73.7	60.7
100	100.5	23.74	4.2334	64	19.8	104.7	23.72	4.4140	64.1	18.4
125	100.5	31.97	3.1436	56.6	4	100.62	25.04	4.0184	61	10.5
150	100.4	24.51	4.0963	70.5	55	100.48	24.17	4.1572	71.5	66.1
175	100.39	24.02	4.1794	74	53.6	100.56	24.21	4.1537	69.3	38.2

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.6	197.52	197.56	41.9	42.2	42.05	4.6982	4.91199	2.8 cm from top

Sample: C03SS5F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.19	23.71	4.3100	64.3	24	102.24	23.42	4.3655	71.4	38.5
50	102.17	23.39	4.3681	68.9	48.5	102.18	23.6	4.3297	69.7	65
75	102.4	23.72	4.3170	67.5	28.4	102.14	23.81	4.2898	66.4	16.7
100	102.18	24.31	4.2032	67	23.2	102.11	23.79	4.2921	67.8	38.1
125	102.13	24.28	4.2063	62.9	14.4	101.85	30.24	3.3681	48.9	1
150	101.62	26.18	3.8816	55.6	19.1	101.98	24.42	4.1761	68.5	48
175	102.02	25.23	4.0436	63.1	17	101.97	24.15	4.2224	69.3	35.8

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.39	197.92	198.155	41.6	41.5	41.55	4.7691	4.94456	2.6 cm from bottom

Sample: C03SS5F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.45	23.48	4.2781	66	19.2	100.17	23.04	4.3477	68.4	19
50	100.23	23.54	4.2579	68	31.8	100.2	23.22	4.3152	68.5	42.6
75	100.38	23.66	4.2426	76	51.6	100.25	23.88	4.1981	73.5	48.1
100	100.47	23.95	4.1950	64.9	20.2	100.43	23.9	4.2021	68	23.6
125	100.29	25.96	3.8633	54.3	3.5	100.29	24.3	4.1272	60.7	10.3
150	100.51	23.30	4.3137	72.5	66.2	100.32	26.34	3.8087	58.6	8.2
175	100.55	23.87	4.2124	71.1	51.3	100.36	23.8	4.2168	67.1	23.5

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.73	198.8	198.765	41.8	41.7	41.75	4.7608	4.85111	2.4 cm from top

Notes:

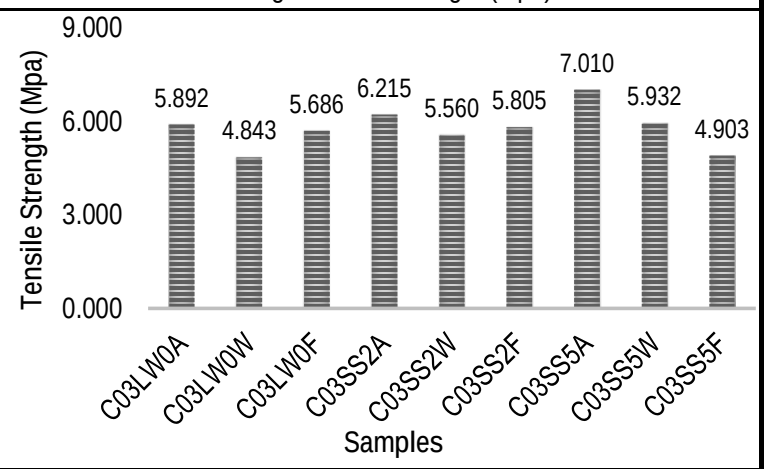
Cylinders - 3 Months Solution Exposure

Statistical Evaluation for Difference Between Samples

Ultimate Tensile Strength (Mpa) - Gas Pressure Tension Test

Samples	Sample Statistics			
	Average	Standard Deviation	Coeff. of Variation	Confi-dence
C03LW0A	5.892	0.210	3.559	0.015
C03LW0W	4.843	0.424	8.762	0.031
C03LW0F	5.686	0.850	14.946	0.062
C03SS2A	6.215	0.617	9.923	0.045
C03SS2W	5.560	0.679	12.218	0.049
C03SS2F	5.805	0.720	12.411	0.052
C03SS5A	7.010	0.164	2.346	0.012
C03SS5W	5.932	0.317	5.351	0.023
C03SS5F	4.903	0.047	0.968	0.003

Average Tensile Strength (Mpa)

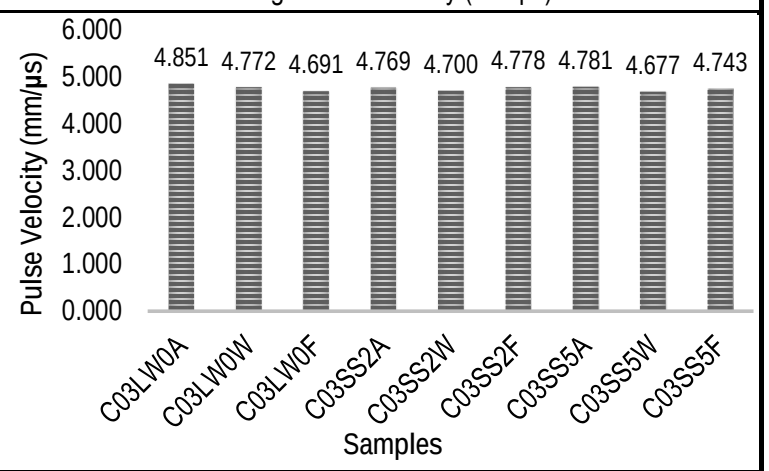


Samples	C03LW0A	C03LW0W	C03LW0F	C03SS2A	C03SS2W	C03SS2F	C03SS5A	C03SS5W	C03SS5F	
C03LW0A	1.000	0.018	0.704	0.438	0.464	0.850	0.002	0.864	0.012	T-Test
C03LW0W	0.392	1.000	0.199	0.034	0.196	0.117	0.001	0.024	0.831	
C03LW0F	0.115	0.399	1.000	0.432	0.851	0.862	0.109	0.663	0.251	
C03SS2A	0.207	0.643	0.690	1.000	0.284	0.495	0.097	0.518	0.066	
C03SS2W	0.174	0.561	0.780	0.904	1.000	0.690	0.023	0.438	0.235	
C03SS2F	0.156	0.515	0.836	0.846	0.941	1.000	0.095	0.793	0.162	
C03SS5A	0.762	0.261	0.072	0.133	0.111	0.099	1.000	0.006	0.000	
C03SS5W	0.608	0.718	0.245	0.419	0.358	0.325	0.423	1.000	0.028	
C03SS5F	0.097	0.025	0.006	0.012	0.010	0.009	0.154	0.044	1.000	
	f-Test									

Longitudinal Pulse Velocity (mm/µs) - 54 kHz Ultrasonic Pulse VelocityTest

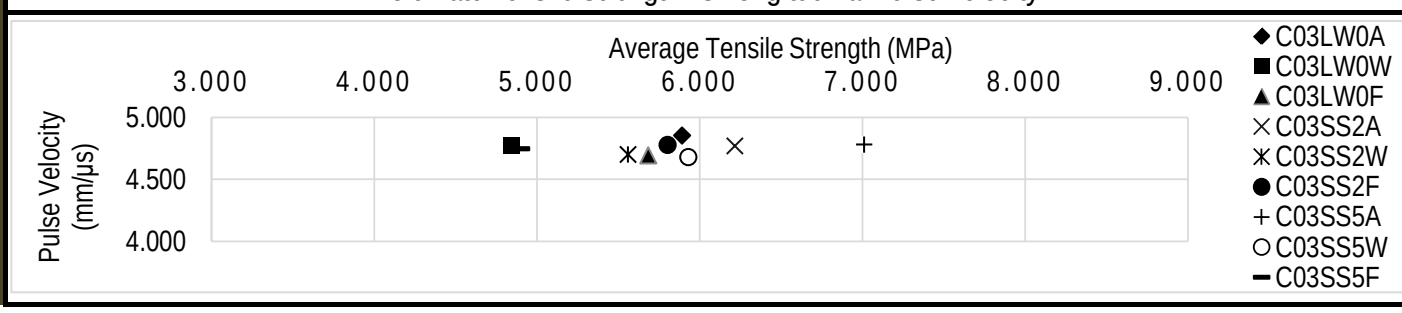
Samples	Sample Statistics			
	Average	Standard Deviation	Coeff. of Variation	Confi-dence
C03LW0A	4.851	0.087	1.786	0.006
C03LW0W	4.772	0.104	2.185	0.008
C03LW0F	4.691	0.094	1.999	0.007
C03SS2A	4.769	0.073	1.537	0.005
C03SS2W	4.700	0.093	1.977	0.007
C03SS2F	4.778	0.072	1.515	0.005
C03SS5A	4.781	0.036	0.762	0.003
C03SS5W	4.677	0.094	2.004	0.007
C03SS5F	4.743	0.039	0.817	0.003

Average Pulse Velocity (mm/µs)



Samples	C03LW0A	C03LW0W	C03LW0F	C03SS2A	C03SS2W	C03SS2F	C03SS5A	C03SS5W	C03SS5F	
C03LW0A	1.000	0.368	0.096	0.277	0.109	0.323	0.266	0.077	0.118	T-Test
C03LW0W	0.817	1.000	0.375	0.969	0.424	0.940	0.891	0.307	0.672	
C03LW0F	0.921	0.894	1.000	0.322	0.912	0.274	0.196	0.863	0.430	
C03SS2A	0.834	0.662	0.759	1.000	0.372	0.888	0.807	0.253	0.613	
C03SS2W	0.930	0.885	0.991	0.767	1.000	0.318	0.233	0.778	0.506	
C03SS2F	0.822	0.650	0.747	0.987	0.755	1.000	0.945	0.215	0.499	
C03SS5A	0.300	0.218	0.262	0.396	0.267	0.404	1.000	0.148	0.277	
C03SS5W	0.922	0.894	0.999	0.759	0.992	0.747	0.263	1.000	0.326	
C03SS5F	0.333	0.243	0.292	0.437	0.296	0.445	0.939	0.292	1.000	
	f-Test									

Ultimate Tensile Strength vs Longitudinal Pulse Velocity



Cylinders - 3 Months Limewater Solution Exposure: Partial Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C03LW0A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C03LW0W	C03LW0F	C03SS2A	C03SS5A	C03LW0W	C03LW0F	C03SS2A	C03SS5A
25	4.342	0.064	1.478	0.003	0.339	0.259	0.792	0.996	0.582	0.063	0.546	0.164
50	4.347	0.037	0.863	0.002	0.005	0.407	0.095	0.145	0.466	0.218	0.107	0.043
75	4.227	0.160	3.786	0.008	0.007	0.024	0.006	0.003	0.081	0.447	0.484	0.503
100	4.248	0.146	3.444	0.008	0.031	0.122	0.049	0.028	0.456	0.776	0.965	0.626
125	4.306	0.067	1.548	0.003	0.106	0.480	0.850	0.081	0.095	0.157	0.324	0.118
150	4.280	0.135	3.165	0.007	0.446	0.116	0.065	0.031	0.096	0.269	0.908	0.594
175	4.328	0.025	0.570	0.001	0.002	0.141	0.750	0.004	0.016	0.000	0.003	0.036

Amplitude

25	66.283	5.063	7.638	0.260	0.665	0.475	0.491	0.314	0.299	0.438	0.694	0.963
50	70.800	4.398	6.211	0.226	0.122	0.601	0.979	0.651	0.851	0.825	0.704	0.561
75	62.450	2.656	4.253	0.136	0.426	0.558	0.996	0.817	0.004	0.000	0.000	0.002
100	63.283	4.158	6.571	0.213	0.889	0.596	0.916	0.376	0.063	0.127	0.591	0.105
125	63.783	2.478	3.885	0.127	0.283	0.416	0.037	0.737	0.323	0.653	0.529	0.206
150	70.583	5.422	7.681	0.278	0.283	0.313	0.366	0.391	0.216	0.650	0.713	0.903
175	70.267	4.017	5.717	0.206	0.574	0.322	0.693	0.734	0.036	0.070	0.869	0.164

Energy

25	16.900	12.182	72.081	0.625	0.622	0.269	0.625	0.628	0.273	0.804	0.554	0.669
50	55.950	20.257	36.206	1.039	0.089	0.678	0.940	0.404	0.761	0.841	0.675	0.711
75	19.350	6.758	34.927	0.347	0.122	0.580	0.033	0.422	0.011	0.001	0.052	0.001
100	19.817	14.539	73.367	0.746	0.520	0.316	0.168	0.124	0.207	0.535	0.984	0.361
125	17.033	7.661	44.975	0.393	0.426	0.844	0.358	0.257	0.394	0.783	0.656	0.522
150	47.400	26.915	56.783	1.381	0.812	0.601	0.483	0.145	0.979	0.313	0.726	0.787
175	39.933	14.448	36.181	0.741	0.687	0.276	0.178	0.883	0.190	0.195	0.967	0.185

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C03LW0W	C03LW0F	C03SS2A	C03SS5A	C03LW0W	C03LW0F	C03SS2A	C03SS5A	C03LW0W	C03LW0F	C03SS2A	C03SS5A
25	0.994	1.015	1.005	1.013	0.949	1.032	0.985	0.998	0.645	1.095	0.813	0.858
50	1.013	1.008	1.016	1.019	1.012	0.993	0.986	1.025	0.894	0.954	0.916	1.112
75	0.967	0.987	0.988	0.989	0.899	0.901	0.878	0.911	0.489	0.494	0.483	0.566
100	0.000	0.000	0.000	0.000	0.924	0.946	0.980	0.946	0.595	0.816	1.007	0.759
125	1.013	1.012	1.010	1.012	0.969	0.987	0.969	1.029	0.775	0.934	0.865	1.164
150	1.043	1.017	1.002	1.008	1.088	0.983	1.014	0.995	1.009	0.762	1.115	0.933
175	1.050	1.034	1.012	1.031	1.077	1.059	1.006	1.057	1.368	1.314	0.986	1.404

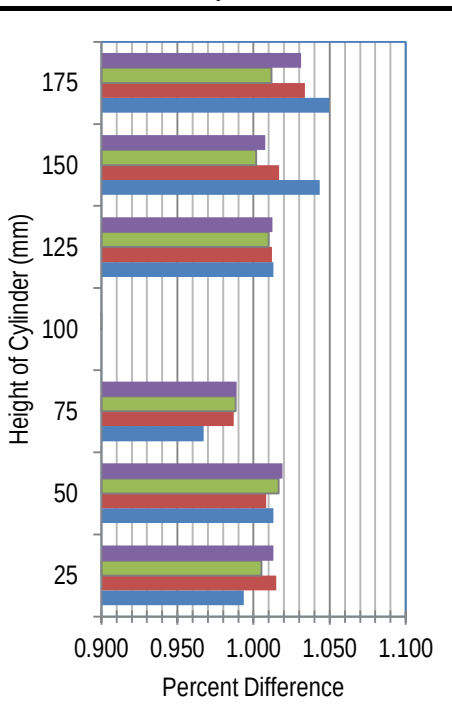
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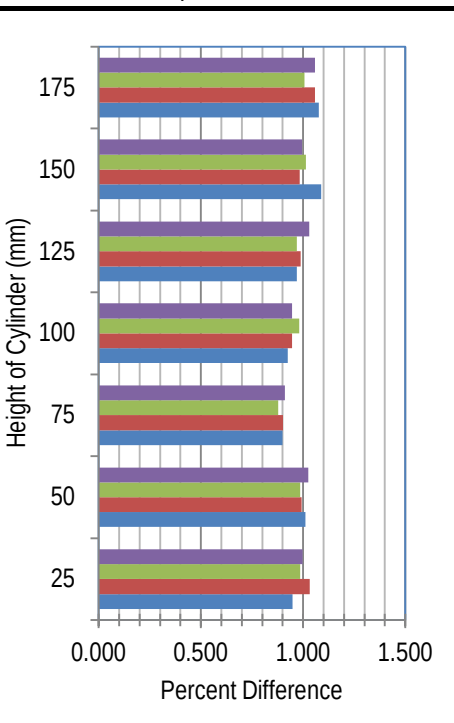
C03SS5A

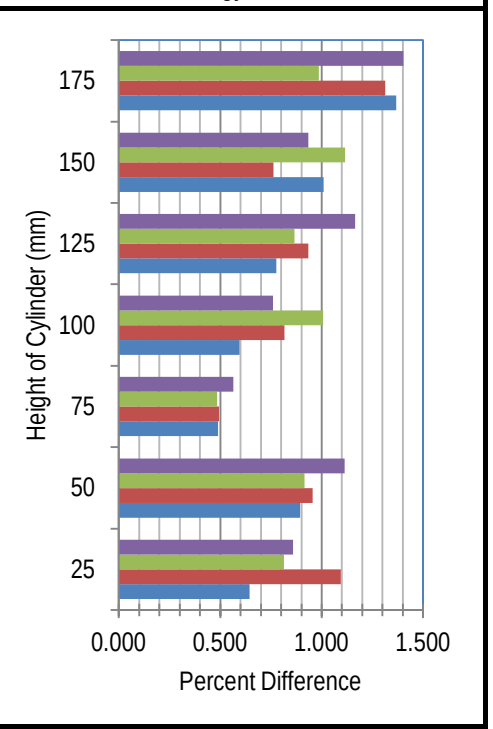
C03SS2A

C03LW0F

C03LW0W







Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C03LW0W				f-Test				T-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C03LW0A	C03LW0F	C03SS2W	C03SS5W	C03LW0A	C03LW0F	C03SS2W	C03SS5W
25	4.370	0.101	2.318	0.005	0.339	0.047	0.151	0.268	0.582	0.082	0.108	0.029
50	4.291	0.170	3.955	0.009	0.005	0.029	0.110	0.110	0.466	0.798	0.636	0.654
75	4.370	0.038	0.873	0.002	0.007	0.551	0.000	0.008	0.081	0.007	0.066	0.013
100	4.298	0.049	1.133	0.002	0.031	0.468	0.004	0.070	0.456	0.392	0.051	0.015
125	4.251	0.030	0.708	0.002	0.106	0.335	0.002	0.001	0.095	0.873	0.088	0.022
150	4.102	0.194	4.740	0.010	0.446	0.027	0.000	0.002	0.096	0.248	0.619	0.333
175	4.123	0.143	3.462	0.007	0.002	0.040	0.459	0.876	0.016	0.339	0.606	0.461

Amplitude

25	69.867	6.211	8.889	0.319	0.665	0.258	0.898	0.185	0.299	0.084	0.158	0.684
50	69.983	9.368	13.387	0.481	0.122	0.046	0.230	0.017	0.851	0.754	0.471	0.631
75	69.483	3.877	5.580	0.199	0.426	0.177	0.264	0.360	0.004	0.942	0.111	0.162
100	68.467	4.441	6.486	0.228	0.889	0.504	0.662	0.836	0.063	0.492	0.018	0.077
125	65.833	4.147	6.299	0.213	0.283	0.785	0.602	0.748	0.323	0.601	0.038	0.005
150	64.883	9.068	13.976	0.465	0.283	0.047	0.001	0.009	0.216	0.128	0.592	0.378
175	65.267	3.079	4.718	0.158	0.574	0.660	0.586	0.110	0.036	0.519	0.567	0.793

Energy

25	26.183	15.373	58.713	0.789	0.622	0.119	0.426	0.234	0.273	0.152	0.178	0.926
50	62.567	46.982	75.092	2.410	0.089	0.183	0.074	0.138	0.761	0.860	0.246	0.984
75	39.567	14.413	36.427	0.739	0.122	0.300	0.836	0.716	0.011	0.955	0.087	0.171
100	33.300	19.710	59.189	1.011	0.520	0.110	0.120	0.217	0.207	0.333	0.044	0.121
125	21.967	11.187	50.925	0.574	0.426	0.324	0.200	0.013	0.394	0.504	0.070	0.018
150	47.000	24.070	51.212	1.235	0.812	0.774	0.062	0.121	0.979	0.271	0.287	0.682
175	29.183	11.947	40.937	0.613	0.687	0.482	0.341	0.320	0.190	0.843	0.192	0.865

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C03LW0A	C03LW0F	C03SS2W	C03SS5W	C03LW0A	C03LW0F	C03SS2W	C03SS5W	C03LW0A	C03LW0F	C03SS2W	C03SS5W
25	1.006	1.021	1.039	1.029	1.054	1.088	1.088	1.017	1.549	1.697	1.728	0.975
50	0.987	0.995	1.009	1.008	0.988	0.981	1.049	0.972	1.118	1.067	1.730	0.993
75	1.034	1.020	1.066	1.057	1.113	1.002	1.086	1.068	2.045	1.010	1.725	1.402
100	0.000	0.000	0.000	0.000	1.082	1.024	1.134	1.076	1.680	1.370	2.585	1.876
125	0.987	0.999	1.033	1.071	1.032	1.019	1.111	1.164	1.290	1.205	1.918	3.406
150	0.958	0.975	0.990	0.979	0.919	0.904	0.968	0.947	0.992	0.756	1.353	1.108
175	0.953	0.985	1.009	1.016	0.929	0.984	1.019	0.988	0.731	0.960	1.383	0.948

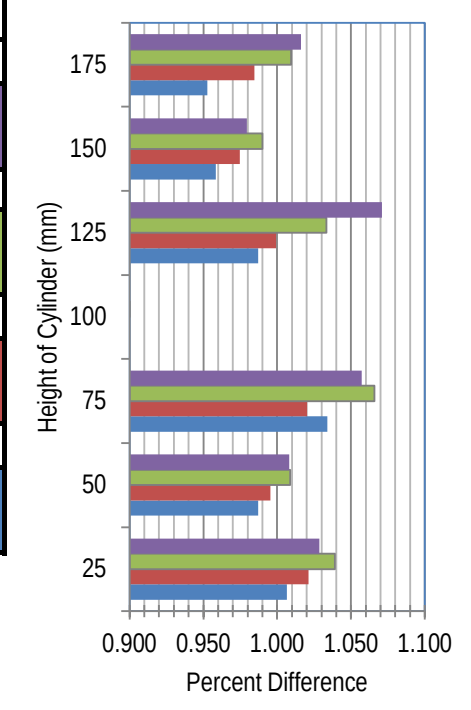
Graph Legend

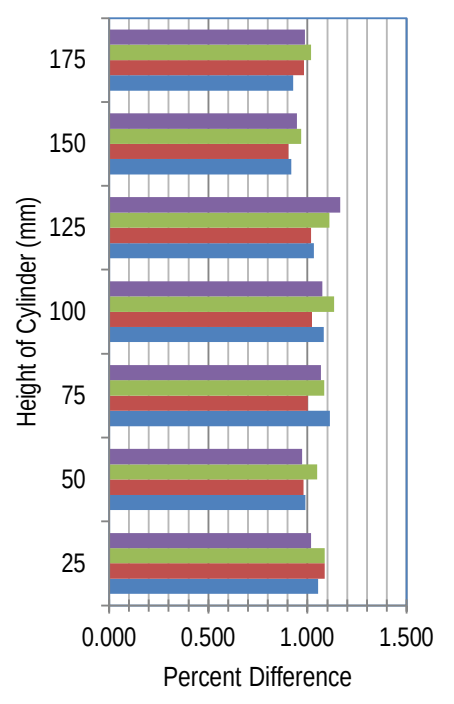
C03SS5W

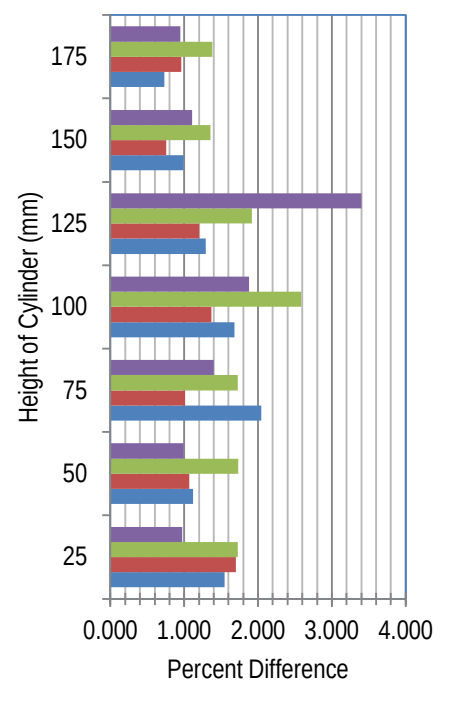
C03SS2W

C03LW0F

C03LW0A







Cylinders - 3 Months Limewater Solution Exposure: Partial Cyclic Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Cylinders - 3 Months Limewater Solution Exposure: Partial Cyclic Immersion

Velocity

	Sample Statistics - C03LW0F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C03LW0A	C03LW0W	C03SS2F	C03SS5F	C03LW0A	C03LW0W	C03SS2F	C03SS5F
25	4.279	0.037	0.872	0.002	0.259	0.047	0.005	0.402	0.063	0.082	0.676	0.489
50	4.311	0.056	1.291	0.003	0.407	0.029	0.019	0.625	0.218	0.798	0.336	0.419
75	4.282	0.051	1.181	0.003	0.024	0.551	0.041	0.960	0.447	0.007	0.552	0.284
100	4.268	0.069	1.610	0.004	0.122	0.468	0.054	0.650	0.776	0.392	0.123	0.812
125	4.255	0.048	1.121	0.002	0.480	0.335	0.023	0.000	0.157	0.873	0.624	0.046
150	4.209	0.063	1.488	0.003	0.116	0.027	0.027	0.029	0.269	0.248	0.056	0.147
175	4.187	0.051	1.208	0.003	0.141	0.040	0.035	0.533	0.000	0.339	0.152	0.664

Amplitude

25	64.233	3.607	5.616	0.185	0.475	0.258	0.191	0.489	0.438	0.084	0.593	0.303
50	71.317	3.435	4.817	0.176	0.601	0.046	0.132	0.691	0.825	0.754	0.216	0.861
75	69.350	2.014	2.904	0.103	0.558	0.177	0.233	0.189	0.000	0.942	0.008	0.452
100	66.867	3.236	4.840	0.166	0.596	0.504	0.107	0.244	0.127	0.492	0.214	0.232
125	64.617	3.648	5.645	0.187	0.416	0.785	0.398	0.449	0.653	0.601	0.176	0.011
150	71.800	3.347	4.661	0.172	0.313	0.047	0.151	0.116	0.650	0.128	0.006	0.787
175	66.350	2.503	3.772	0.128	0.322	0.660	0.115	0.415	0.070	0.519	0.361	0.087

Energy

25	15.433	7.166	46.432	0.403	0.269	0.119	0.559	0.753	0.804	0.152	0.488	0.630
50	58.633	24.635	42.015	1.384	0.678	0.183	0.570	0.422	0.841	0.860	0.093	0.409
75	39.167	8.776	22.406	0.493	0.580	0.300	0.508	0.173	0.001	0.955	0.022	0.944
100	24.300	8.997	37.025	0.506	0.316	0.110	0.601	0.648	0.535	0.333	0.160	0.298
125	18.233	6.982	38.292	0.392	0.844	0.324	0.284	0.531	0.783	0.504	0.715	0.015
150	62.200	21.027	33.806	1.182	0.601	0.774	0.705	0.741	0.313	0.271	0.004	0.823
175	30.400	8.564	28.171	0.481	0.276	0.482	0.382	0.267	0.195	0.843	0.347	0.360

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C03LW0A	C03LW0W	C03SS2F	C03SS5F	C03LW0A	C03LW0W	C03SS2F	C03SS5F	C03LW0A	C03LW0W	C03SS2F	C03SS5F
25	0.985	0.979	1.007	0.995	0.969	0.919	0.974	0.960	0.913	0.589	0.816	0.682
50	0.992	1.005	1.020	1.007	1.007	1.019	1.064	1.030	1.048	0.937	1.668	1.302
75	1.013	0.980	1.009	1.008	1.110	0.998	1.088	0.974	2.024	0.990	1.724	1.006
100	0.000	0.000	0.000	0.000	1.057	0.977	1.068	1.014	1.226	0.730	1.593	1.017
125	0.988	1.001	1.008	1.123	1.013	0.982	1.064	1.126	1.070	0.830	1.129	2.503
150	0.983	1.026	1.049	1.033	1.017	1.107	1.177	1.085	1.312	1.323	3.015	1.421
175	0.967	1.016	1.025	1.004	0.944	1.017	1.036	0.962	0.761	1.042	1.260	0.831

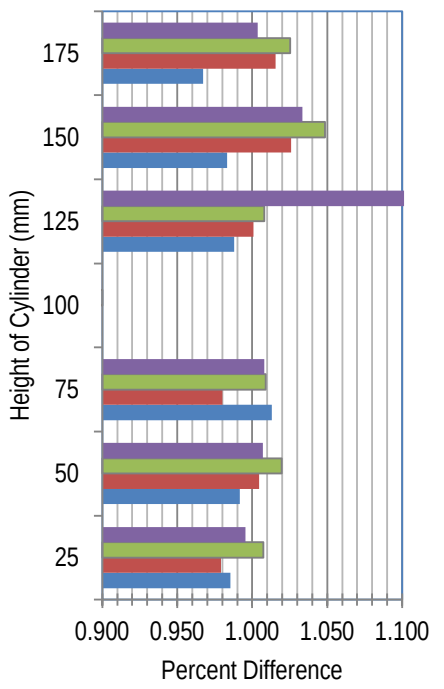
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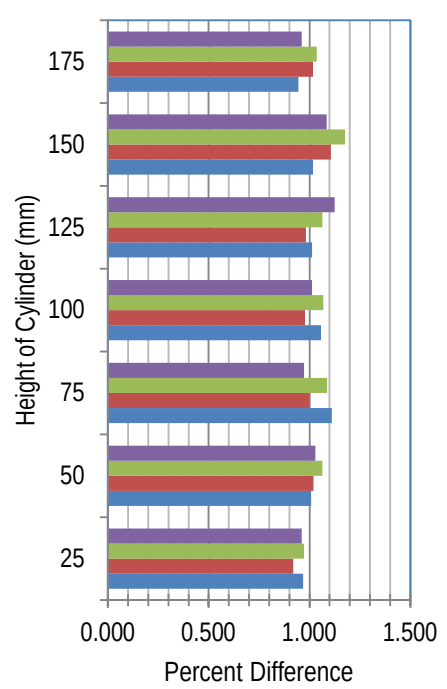
C03SS5F

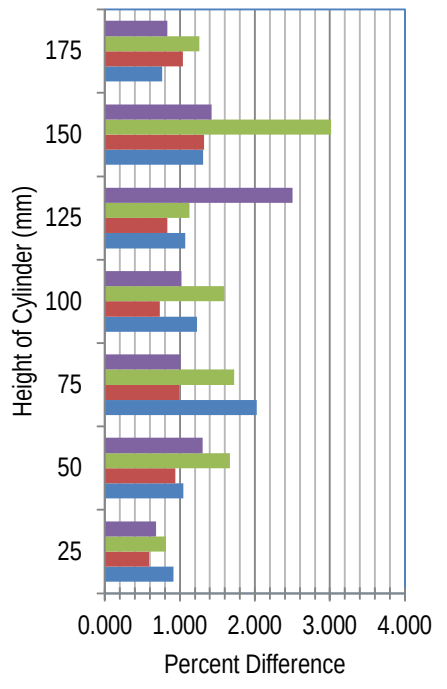
C03SS2F

C03LW0W

C03LW0A







Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Cylinders - 3 Months Limewater Solution Exposure: Partial Cyclic Immersion

Velocity

	Sample Statistics - C03SS2A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C03SS2W	C03SS2F	C03LW0A	C03SS5A	C03SS2W	C03SS2F	C03LW0A	C03SS5A
25	4.320	0.057	1.312	0.003	0.014	0.032	0.792	0.788	0.235	0.356	0.546	0.355
50	4.276	0.085	1.998	0.004	0.833	0.111	0.095	0.809	0.648	0.573	0.107	0.836
75	4.277	0.037	0.868	0.002	0.000	0.011	0.006	0.799	0.186	0.600	0.484	0.907
100	4.245	0.055	1.285	0.003	0.007	0.020	0.049	0.776	0.108	0.177	0.965	0.345
125	4.265	0.073	1.709	0.004	0.113	0.130	0.850	0.057	0.061	0.547	0.324	0.738
150	4.273	0.054	1.267	0.003	0.007	0.014	0.065	0.702	0.002	0.020	0.908	0.395
175	4.277	0.021	0.496	0.001	0.004	0.001	0.750	0.002	0.005	0.023	0.003	0.143

Amplitude

25	67.317	3.653	5.426	0.187	0.220	0.199	0.491	0.742	0.338	0.677	0.694	0.651
50	71.800	4.452	6.201	0.228	0.726	0.319	0.979	0.670	0.100	0.197	0.704	0.366
75	71.100	2.650	3.728	0.136	0.065	0.527	0.996	0.821	0.047	0.002	0.000	0.114
100	64.583	3.956	6.126	0.203	0.497	0.220	0.916	0.434	0.155	0.569	0.591	0.265
125	65.833	7.107	10.796	0.365	0.536	0.576	0.037	0.019	0.100	0.192	0.529	0.251
150	69.583	3.525	5.066	0.181	0.054	0.182	0.366	0.963	0.143	0.020	0.713	0.532
175	69.833	4.839	6.929	0.248	0.680	0.808	0.693	0.956	0.047	0.078	0.869	0.250

Energy

25	20.783	9.669	46.525	0.496	0.856	0.960	0.625	0.996	0.357	0.742	0.554	0.850
50	61.100	20.982	34.341	1.076	0.867	0.818	0.940	0.446	0.058	0.048	0.675	0.488
75	40.033	19.939	49.805	1.023	0.630	0.290	0.033	0.006	0.131	0.098	0.052	0.514
100	19.683	7.446	37.831	0.382	0.655	0.360	0.168	0.860	0.189	0.447	0.984	0.151
125	19.683	11.878	60.343	0.609	0.162	0.969	0.358	0.050	0.161	0.614	0.656	0.365
150	42.517	19.305	45.405	0.990	0.146	0.843	0.483	0.426	0.397	0.067	0.726	0.406
175	40.483	27.754	68.558	1.424	0.013	0.121	0.178	0.139	0.152	0.220	0.967	0.362

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C03SS2W	C03SS2F	C03LW0A	C03SS5A	C03SS2W	C03SS2F	C03LW0A	C03SS5A	C03SS2W	C03SS2F	C03LW0A	C03SS5A
25	1.027	1.017	0.995	1.008	1.048	1.020	1.016	1.014	1.372	1.099	1.230	1.055
50	1.005	1.012	0.984	1.002	1.076	1.071	1.014	1.039	1.689	1.738	1.092	1.215
75	1.043	1.008	1.012	1.001	1.111	1.115	1.139	1.037	1.746	1.762	2.069	1.170
100	0.000	0.000	0.000	0.000	1.070	1.031	1.021	0.965	1.528	1.291	0.993	0.754
125	1.037	1.010	0.990	1.003	1.111	1.084	1.032	1.062	1.719	1.219	1.156	1.345
150	1.031	1.065	0.998	1.006	1.038	1.141	0.986	0.981	1.224	2.061	0.897	0.837
175	1.047	1.048	0.988	1.019	1.090	1.091	0.994	1.051	1.919	1.677	1.014	1.423

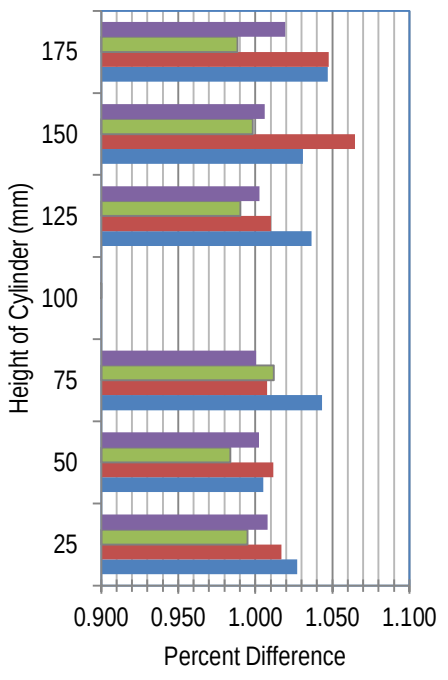
Graph Legend

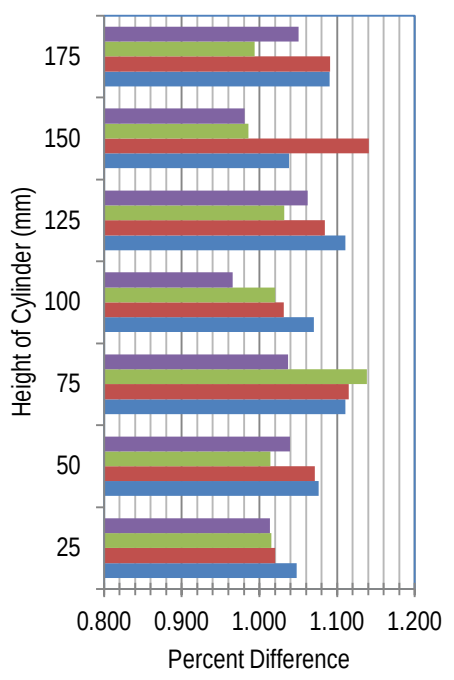
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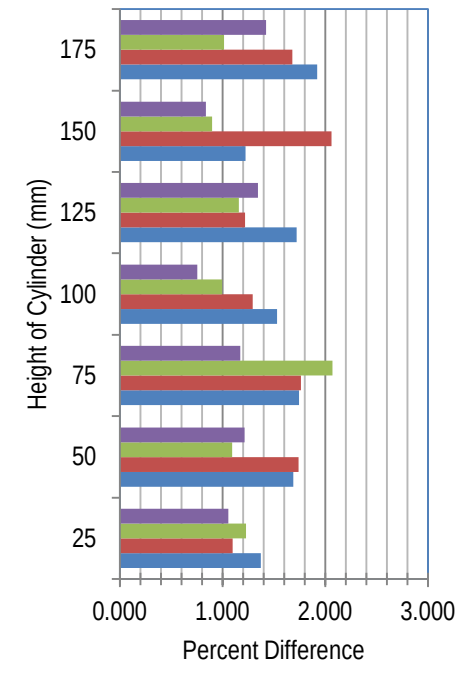
C03LW0A

C03SS2F

C03SS2W







Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Cylinders - 3 Months Limewater Solution Exposure: Partial Cyclic Immersion

Velocity

	Sample Statistics - C03SS2W				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C03SS2A	C03SS2F	C03LW0W	C03SS5W	C03SS2A	C03SS2F	C03LW0W	C03SS5W
25	4.206	0.204	4.846	0.010	0.014	0.691	0.151	0.017	0.235	0.706	0.108	0.642
50	4.254	0.077	1.819	0.004	0.833	0.076	0.110	0.997	0.648	0.756	0.636	0.967
75	4.100	0.282	6.868	0.014	0.000	0.157	0.000	0.225	0.186	0.290	0.066	0.808
100	4.062	0.228	5.603	0.012	0.007	0.624	0.004	0.186	0.108	0.595	0.051	0.566
125	4.114	0.159	3.861	0.008	0.113	0.935	0.002	0.542	0.061	0.260	0.088	0.212
150	4.144	0.013	0.312	0.001	0.007	0.000	0.000	0.039	0.002	0.158	0.619	0.031
175	4.085	0.100	2.459	0.005	0.004	0.422	0.459	0.373	0.005	0.978	0.606	0.719

Amplitude

25	64.217	6.596	10.272	0.338	0.220	0.950	0.898	0.149	0.338	0.660	0.158	0.169
50	66.700	5.251	7.872	0.269	0.726	0.511	0.230	0.177	0.100	0.929	0.471	0.053
75	64.000	6.632	10.363	0.340	0.065	0.201	0.264	0.831	0.047	0.941	0.111	0.773
100	60.350	5.458	9.045	0.280	0.497	0.568	0.662	0.521	0.155	0.551	0.018	0.261
125	59.267	5.303	8.948	0.272	0.536	0.952	0.602	0.840	0.100	0.651	0.038	0.375
150	67.017	1.342	2.003	0.069	0.054	0.003	0.001	0.273	0.143	0.081	0.592	0.189
175	64.050	3.984	6.221	0.204	0.680	0.515	0.586	0.272	0.047	0.991	0.567	0.539

Energy

25	15.150	10.530	69.503	0.540	0.856	0.817	0.426	0.679	0.357	0.529	0.178	0.062
50	36.167	19.388	53.607	0.995	0.867	0.950	0.074	0.731	0.058	0.928	0.246	0.053
75	22.933	15.884	69.262	0.815	0.630	0.554	0.836	0.570	0.131	0.979	0.087	0.532
100	12.883	9.194	71.362	0.472	0.655	0.633	0.120	0.723	0.189	0.702	0.044	0.422
125	11.450	6.016	52.543	0.309	0.162	0.172	0.200	0.170	0.161	0.401	0.070	0.100
150	34.750	9.503	27.348	0.488	0.146	0.203	0.062	0.717	0.397	0.114	0.287	0.232
175	21.100	7.579	35.922	0.389	0.013	0.262	0.341	0.062	0.152	0.632	0.192	0.291

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C03SS2A	C03SS2F	C03LW0W	C03SS5W	C03SS2A	C03SS2F	C03LW0W	C03SS5W	C03SS2A	C03SS2F	C03LW0W	C03SS5W
25	0.973	0.990	0.962	0.990	0.954	0.973	0.919	0.935	0.729	0.801	0.579	0.564
50	0.995	1.006	0.991	1.000	0.929	0.995	0.953	0.926	0.592	1.029	0.578	0.574
75	0.959	0.966	0.938	0.992	0.900	1.004	0.921	0.983	0.573	1.010	0.580	0.813
100	0.000	0.000	0.000	0.000	0.934	0.964	0.881	0.948	0.655	0.845	0.387	0.726
125	0.965	0.975	0.968	1.036	0.900	0.976	0.900	1.048	0.582	0.709	0.521	1.775
150	0.970	1.033	1.010	0.990	0.963	1.099	1.033	0.978	0.817	1.684	0.739	0.819
175	0.955	1.000	0.991	1.007	0.917	1.001	0.981	0.969	0.521	0.874	0.723	0.685

Graph Legend

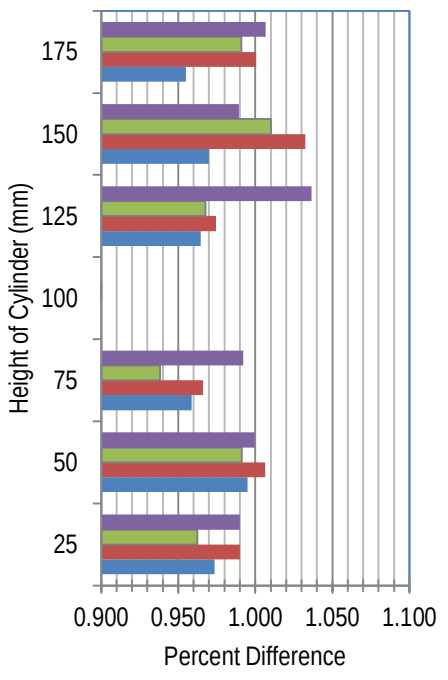
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C03LW0W

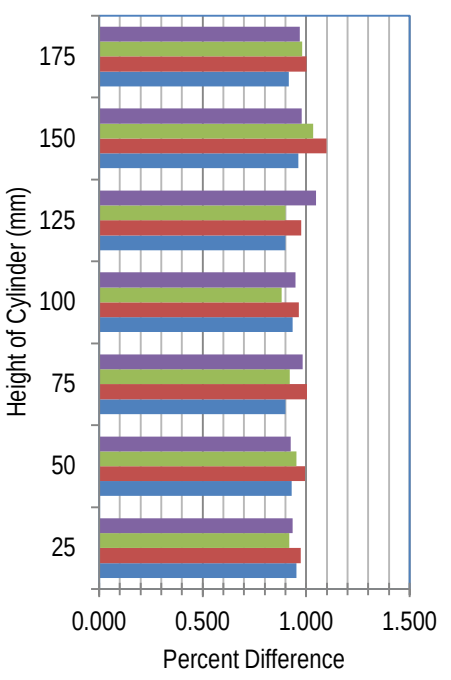
C03SS2F

C03SS2A

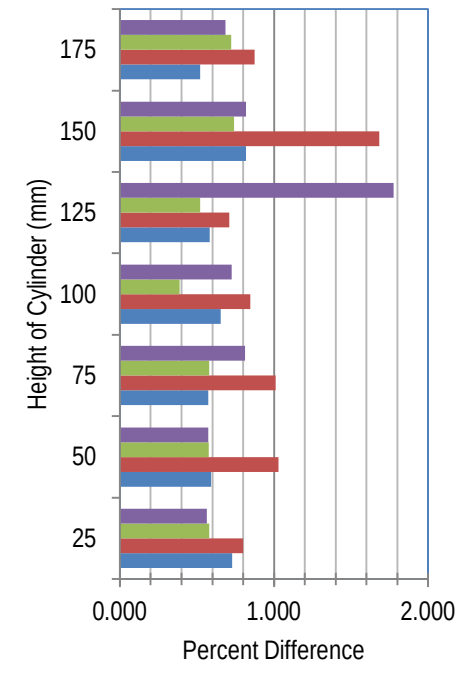
Velocity Index



Amplitude Index



Energy Index



Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Cylinders - 3 Months Limewater Solution Exposure: Partial Cyclic Immersion

Velocity

	Sample Statistics - C24SS2F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C24SS2A	C24SS2W	C24LW0F	C24SS5F	C24SS2A	C24SS2W	C24LW0F	C24SS5F
25	4.248	0.169	3.977	0.009	0.032	0.691	0.005	0.029	0.356	0.706	0.676	0.510
50	4.227	0.187	4.415	0.010	0.111	0.076	0.019	0.051	0.573	0.756	0.336	0.541
75	4.244	0.141	3.333	0.007	0.011	0.157	0.041	0.046	0.600	0.290	0.552	0.937
100	4.127	0.181	4.375	0.009	0.020	0.624	0.054	0.124	0.177	0.595	0.123	0.144
125	4.222	0.153	3.622	0.008	0.130	0.935	0.023	0.039	0.547	0.260	0.624	0.059
150	4.013	0.193	4.812	0.010	0.014	0.000	0.027	0.983	0.020	0.158	0.056	0.608
175	4.083	0.147	3.604	0.008	0.001	0.422	0.035	0.115	0.023	0.978	0.152	0.211

Amplitude

25	65.967	6.793	10.297	0.348	0.199	0.950	0.191	0.055	0.677	0.660	0.593	0.767
50	67.033	7.169	10.695	0.368	0.319	0.511	0.132	0.064	0.197	0.929	0.216	0.503
75	63.767	3.576	5.609	0.183	0.527	0.201	0.233	0.896	0.002	0.941	0.008	0.006
100	62.617	7.151	11.420	0.367	0.220	0.568	0.107	0.010	0.569	0.551	0.214	0.311
125	60.717	5.455	8.984	0.280	0.576	0.952	0.398	0.928	0.192	0.651	0.176	0.307
150	61.000	6.734	11.039	0.345	0.182	0.003	0.151	0.879	0.020	0.081	0.006	0.226
175	64.017	5.425	8.474	0.278	0.808	0.515	0.115	0.417	0.078	0.991	0.361	0.093

Energy

25	18.917	9.443	49.920	0.484	0.960	0.817	0.559	0.786	0.742	0.529	0.488	0.486
50	35.150	18.829	53.568	0.966	0.818	0.950	0.570	0.811	0.048	0.928	0.093	0.361
75	22.717	12.010	52.868	0.616	0.290	0.554	0.508	0.465	0.098	0.979	0.022	0.086
100	15.250	11.521	75.546	0.591	0.360	0.633	0.601	0.333	0.447	0.702	0.160	0.151
125	16.150	11.666	72.233	0.598	0.969	0.172	0.284	0.100	0.614	0.401	0.715	0.133
150	20.633	17.591	85.256	0.902	0.843	0.203	0.705	0.481	0.067	0.114	0.004	0.090
175	24.133	12.987	53.812	0.666	0.121	0.262	0.382	0.805	0.220	0.632	0.347	0.150

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C24SS2A	C24SS2W	C24LW0F	C24SS5F	C24SS2A	C24SS2W	C24LW0F	C24SS5F	C24SS2A	C24SS2W	C24LW0F	C24SS5F
25	0.983	1.010	0.993	0.988	0.980	1.027	1.027	0.986	0.910	1.249	1.226	0.836
50	0.989	0.994	0.981	0.988	0.934	1.005	0.940	0.968	0.575	0.972	0.599	0.781
75	0.992	1.035	0.991	0.999	0.897	0.996	0.919	0.895	0.567	0.991	0.580	0.584
100	5.351	5.592	5.323	5.337	0.970	1.038	0.936	0.949	0.775	1.184	0.628	0.639
125	0.990	1.026	0.992	1.115	0.922	1.024	0.940	1.058	0.820	1.410	0.886	2.217
150	0.939	0.968	0.954	0.986	0.877	0.910	0.850	0.921	0.485	0.594	0.332	0.471
175	0.955	1.000	0.975	0.979	0.917	0.999	0.965	0.928	0.596	1.144	0.794	0.660

Graph Legend

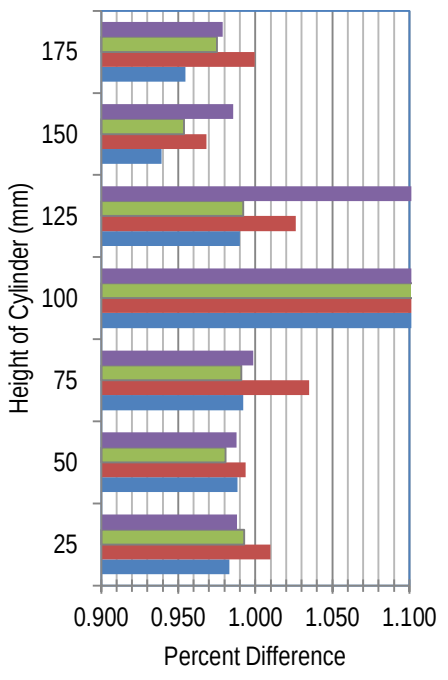
C24SS5F

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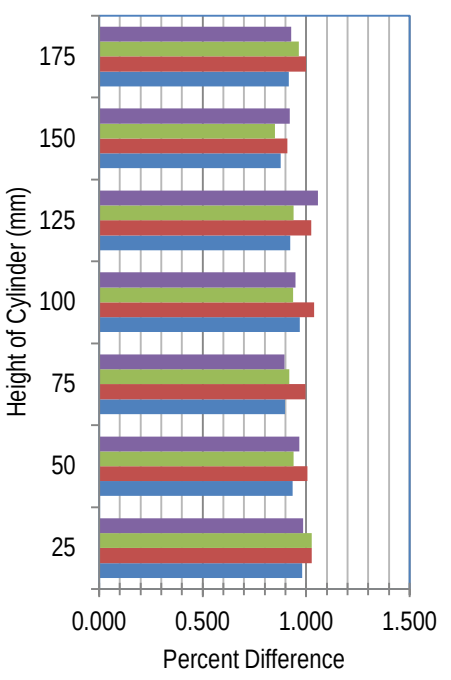
C24SS2W

C24SS2A

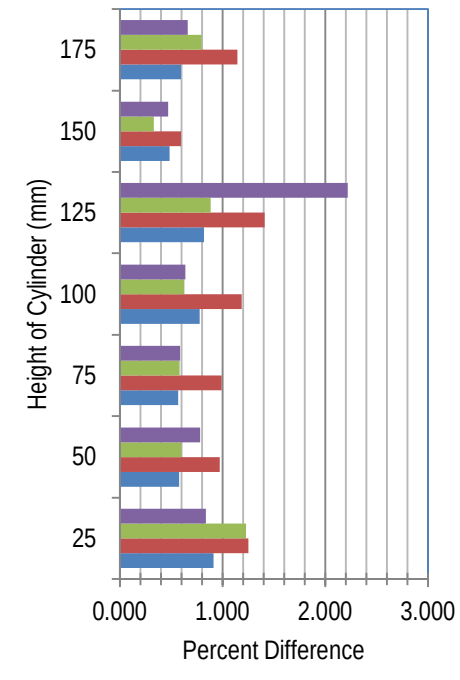
Velocity Index



Amplitude Index



Energy Index



Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Cylinders - 3 Months Limewater Solution Exposure: Partial Cyclic Immersion

Velocity

	Sample Statistics - C03SS5A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C03SS5W	C03SS5F	C03LW0A	C03SS2A	C03SS5W	C03SS5F	C03LW0A	C03SS2A
25	4.287	0.064	1.501	0.003	0.868	0.758	0.996	0.788	0.311	0.735	0.164	0.355
50	4.266	0.076	1.787	0.004	0.973	0.857	0.145	0.809	0.821	0.752	0.043	0.836
75	4.275	0.033	0.770	0.002	0.004	0.343	0.003	0.799	0.078	0.330	0.503	0.907
100	4.216	0.048	1.132	0.002	0.064	0.230	0.028	0.776	0.130	0.331	0.626	0.345
125	4.253	0.028	0.661	0.001	0.000	0.000	0.081	0.057	0.022	0.046	0.118	0.738
150	4.247	0.045	1.064	0.002	0.657	0.007	0.031	0.702	0.032	0.076	0.594	0.395
175	4.196	0.114	2.717	0.006	0.529	0.280	0.004	0.002	0.105	0.656	0.036	0.143

Amplitude

25	66.400	3.129	4.712	0.160	0.927	0.694	0.314	0.742	0.248	0.777	0.963	0.651
50	69.083	5.444	7.881	0.279	0.155	0.181	0.651	0.670	0.268	0.943	0.561	0.366
75	68.583	2.383	3.474	0.122	0.064	0.328	0.817	0.821	0.229	0.181	0.002	0.114
100	66.900	2.728	4.077	0.140	0.412	0.412	0.376	0.434	0.133	0.503	0.105	0.265
125	61.983	2.116	3.414	0.109	0.095	0.069	0.737	0.019	0.040	0.089	0.206	0.251
150	70.917	3.604	5.081	0.185	0.333	0.152	0.391	0.963	0.200	0.183	0.903	0.532
175	66.467	4.714	7.092	0.242	0.450	0.603	0.734	0.956	0.911	0.327	0.164	0.250

Energy

25	19.700	9.694	49.209	0.497	0.812	0.744	0.628	0.996	0.207	0.586	0.669	0.850
50	50.300	30.126	59.892	1.545	0.555	0.227	0.404	0.446	0.429	0.715	0.711	0.488
75	34.217	4.613	13.481	0.237	0.053	0.012	0.422	0.006	0.298	0.538	0.001	0.514
100	26.100	6.853	26.258	0.352	0.335	0.904	0.124	0.860	0.142	0.598	0.361	0.151
125	14.633	4.441	30.349	0.228	0.444	0.741	0.257	0.050	0.004	0.025	0.522	0.365
150	50.800	13.222	26.027	0.678	0.735	0.200	0.145	0.426	0.265	0.551	0.787	0.406
175	28.450	13.481	47.386	0.692	0.455	0.867	0.883	0.139	0.811	0.340	0.185	0.362

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C03SS5W	C03SS5F	C03LW0A	C03SS2A	C03SS5W	C03SS5F	C03LW0A	C03SS2A	C03SS5W	C03SS5F	C03LW0A	C03SS2A
25	1.009	0.997	0.987	0.992	0.967	0.993	1.002	0.986	0.733	0.870	1.166	0.948
50	1.002	0.997	0.981	0.998	0.959	0.997	0.976	0.962	0.798	1.117	0.899	0.823
75	1.034	1.006	1.011	0.999	1.054	0.963	1.098	0.965	1.213	0.879	1.768	0.855
100	0.000	0.000	0.000	0.000	1.051	1.014	1.057	1.036	1.470	1.093	1.317	1.326
125	1.071	1.123	0.988	0.997	1.096	1.080	0.972	0.942	2.269	2.009	0.859	0.743
150	1.014	1.043	0.992	0.994	1.035	1.071	1.005	1.019	1.198	1.161	1.072	1.195
175	1.034	1.006	0.970	0.981	1.006	0.964	0.946	0.952	0.924	0.778	0.712	0.703

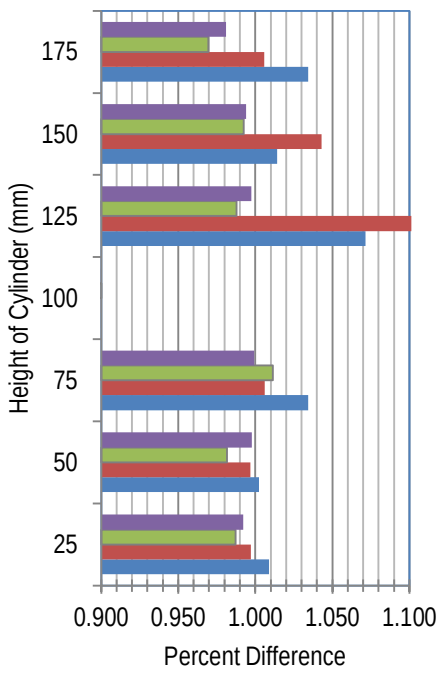
Graph Legend

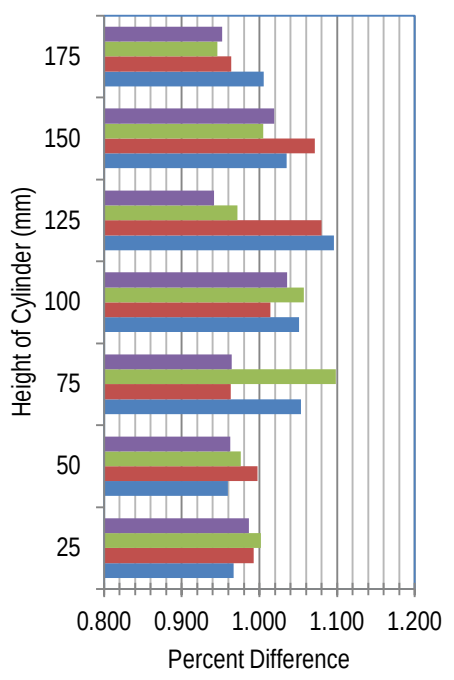
C03SS2A

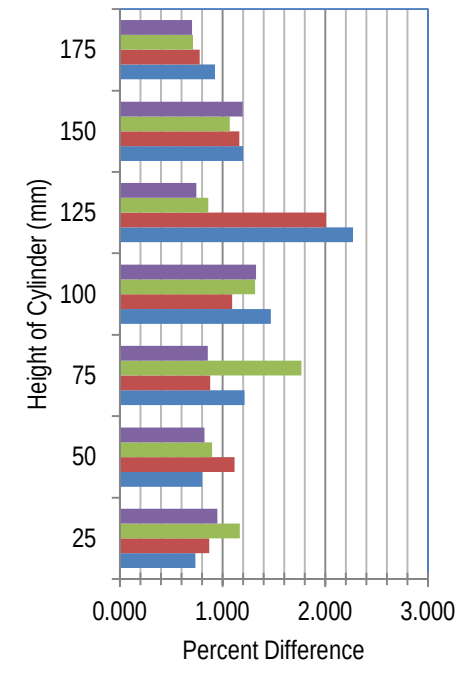
C03LW0A

C03SS5F

C03SS5W







Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C03SS5W				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C03SS5A	C03SS5F	C03LW0W	C03SS2W	C03SS5A	C03SS5F	C03LW0W	C03SS2W
25	4.248	0.059	1.400	0.003	0.868	0.887	0.268	0.017	0.311	0.161	0.029	0.642
50	4.256	0.077	1.821	0.004	0.973	0.830	0.110	0.997	0.821	0.586	0.654	0.967
75	4.133	0.157	3.797	0.008	0.004	0.029	0.008	0.225	0.078	0.136	0.013	0.808
100	4.125	0.120	2.908	0.006	0.064	0.469	0.070	0.186	0.130	0.053	0.015	0.566
125	3.970	0.212	5.337	0.011	0.000	0.142	0.001	0.542	0.022	0.378	0.022	0.212
150	4.188	0.037	0.875	0.002	0.657	0.002	0.002	0.039	0.032	0.201	0.333	0.031
175	4.057	0.154	3.786	0.008	0.529	0.097	0.876	0.373	0.105	0.141	0.461	0.719

Amplitude

25	68.667	3.267	4.757	0.168	0.927	0.628	0.185	0.149	0.248	0.320	0.684	0.169
50	72.000	2.727	3.787	0.140	0.155	0.926	0.017	0.177	0.268	0.120	0.631	0.053
75	65.083	5.998	9.217	0.308	0.064	0.340	0.360	0.831	0.229	0.061	0.162	0.773
100	63.650	4.028	6.329	0.207	0.412	0.112	0.836	0.521	0.133	0.229	0.077	0.261
125	56.550	4.824	8.531	0.247	0.095	0.865	0.748	0.840	0.040	0.776	0.005	0.375
150	68.533	2.270	3.313	0.116	0.333	0.024	0.009	0.273	0.200	0.480	0.378	0.189
175	66.083	6.748	10.212	0.346	0.450	0.211	0.110	0.272	0.911	0.377	0.793	0.539

Energy

25	26.867	8.666	32.255	0.445	0.812	0.929	0.234	0.679	0.207	0.408	0.926	0.062
50	63.000	22.791	36.176	1.169	0.555	0.521	0.138	0.731	0.429	0.151	0.984	0.053
75	28.217	12.141	43.027	0.623	0.053	0.479	0.716	0.570	0.298	0.238	0.171	0.532
100	17.750	10.863	61.202	0.557	0.335	0.396	0.217	0.723	0.142	0.277	0.121	0.422
125	6.450	3.089	47.884	0.158	0.444	0.279	0.013	0.170	0.004	0.742	0.018	0.100
150	42.417	11.274	26.579	0.578	0.735	0.112	0.121	0.717	0.265	0.905	0.682	0.232
175	30.800	19.222	62.409	0.986	0.455	0.560	0.320	0.062	0.811	0.571	0.865	0.291

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C03SS5A	C03SS5F	C03LW0W	C03SS2W	C03SS5A	C03SS5F	C03LW0W	C03SS2W	C03SS5A	C03SS5F	C03LW0W	C03SS2W
25	0.991	0.988	0.972	1.010	1.034	1.027	0.983	1.069	1.364	1.187	1.026	1.773
50	0.998	0.994	0.992	1.000	1.042	1.039	1.029	1.079	1.252	1.399	1.007	1.742
75	0.967	0.973	0.946	1.008	0.949	0.914	0.937	1.017	0.825	0.725	0.713	1.230
100	0.000	0.000	0.000	0.000	0.951	0.965	0.930	1.055	0.680	0.743	0.533	1.378
125	0.933	1.048	0.934	0.965	0.912	0.985	0.859	0.954	0.441	0.886	0.294	0.563
150	0.986	1.028	1.021	1.011	0.966	1.035	1.056	1.023	0.835	0.969	0.902	1.221
175	0.967	0.973	0.984	0.993	0.994	0.958	1.013	1.032	1.083	0.842	1.055	1.460

Graph Legend

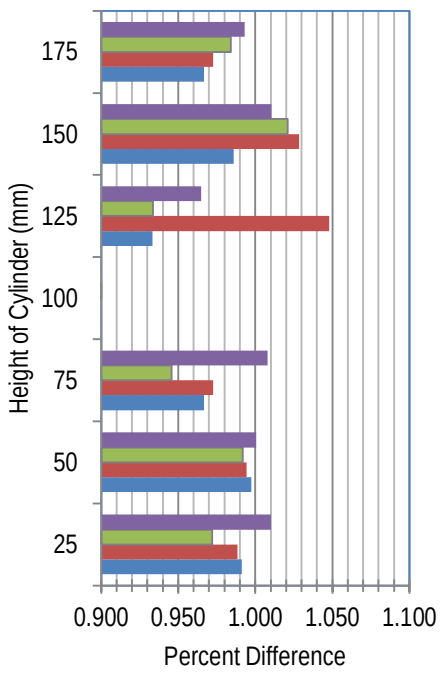
C03SS2W

C03LW0W

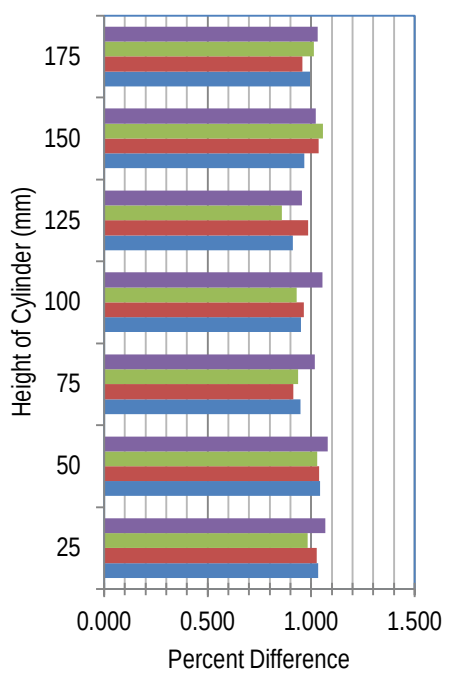
C03SS5F

C03SS5A

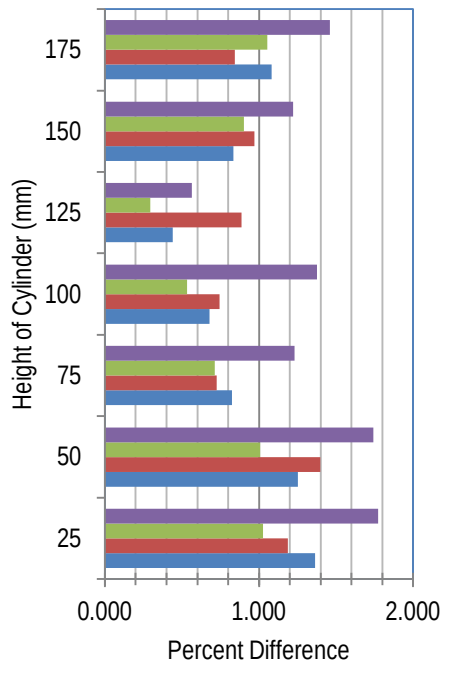
Velocity Index



Amplitude Index



Energy Index



Cylinders - 3 Months Limewater Solution Exposure: Partial Cyclic Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Cylinders - 3 Months Limewater Solution Exposure: Partial Cyclic Immersion

Velocity

	Sample Statistics - C03SS5F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C03SS5A	C03SS5W	C03LW0F	C03SS2F	C03SS5A	C03SS5W	C03LW0F	C03SS2F
25	4.299	0.056	1.294	0.003	0.758	0.887	0.402	0.029	0.735	0.161	0.489	0.510
50	4.280	0.070	1.637	0.004	0.857	0.830	0.625	0.051	0.752	0.586	0.419	0.541
75	4.249	0.052	1.219	0.003	0.343	0.029	0.960	0.046	0.330	0.136	0.284	0.937
100	4.257	0.085	1.999	0.004	0.230	0.469	0.650	0.124	0.331	0.053	0.812	0.144
125	3.788	0.434	11.450	0.022	0.000	0.142	0.000	0.039	0.046	0.378	0.046	0.059
150	4.072	0.191	4.694	0.010	0.007	0.002	0.029	0.983	0.076	0.201	0.147	0.608
175	4.171	0.068	1.628	0.003	0.280	0.097	0.533	0.115	0.656	0.141	0.664	0.211

Amplitude

25	66.883	2.599	3.886	0.133	0.694	0.628	0.489	0.055	0.777	0.320	0.175	0.767
50	69.267	2.849	4.113	0.146	0.181	0.926	0.691	0.064	0.943	0.120	0.287	0.503
75	71.217	3.803	5.340	0.195	0.328	0.340	0.189	0.896	0.181	0.061	0.313	0.006
100	65.967	1.847	2.800	0.095	0.412	0.112	0.244	0.010	0.503	0.229	0.567	0.311
125	57.400	5.227	9.106	0.268	0.069	0.865	0.449	0.928	0.089	0.776	0.020	0.307
150	66.200	7.234	10.928	0.371	0.152	0.024	0.116	0.879	0.183	0.480	0.116	0.226
175	68.983	3.688	5.346	0.189	0.603	0.211	0.415	0.417	0.327	0.377	0.178	0.093

Energy

25	22.633	8.312	36.723	0.426	0.744	0.929	0.753	0.786	0.586	0.408	0.139	0.486
50	45.017	16.821	37.366	0.863	0.227	0.521	0.422	0.811	0.715	0.151	0.290	0.361
75	38.917	16.989	43.654	0.872	0.012	0.479	0.173	0.465	0.538	0.238	0.975	0.086
100	23.883	7.252	30.365	0.372	0.904	0.396	0.648	0.333	0.598	0.277	0.931	0.151
125	7.283	5.190	71.255	0.266	0.741	0.279	0.531	0.100	0.025	0.742	0.012	0.133
150	43.767	24.575	56.149	1.261	0.200	0.112	0.741	0.481	0.551	0.905	0.193	0.090
175	36.567	14.588	39.894	0.748	0.867	0.560	0.267	0.805	0.340	0.571	0.393	0.150

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C03SS5A	C03SS5W	C03LW0F	C03SS2F	C03SS5A	C03SS5W	C03LW0F	C03SS2F	C03SS5A	C03SS5W	C03LW0F	C03SS2F
25	1.003	1.012	1.005	1.012	1.007	0.974	1.041	1.014	1.149	0.842	1.467	1.196
50	1.003	1.006	0.993	1.012	1.003	0.962	0.971	1.033	0.895	0.715	0.768	1.281
75	0.994	1.028	0.992	1.001	1.038	1.094	1.027	1.117	1.137	1.379	0.994	1.713
100	0.000	0.000	0.000	0.000	0.986	1.036	0.987	1.054	0.915	1.346	0.983	1.566
125	0.891	0.954	0.890	0.897	0.926	1.015	0.888	0.945	0.498	1.129	0.399	0.451
150	0.959	0.972	0.968	1.015	0.933	0.966	0.922	1.085	0.862	1.032	0.704	2.121
175	0.994	1.028	0.996	1.022	1.038	1.044	1.040	1.078	1.285	1.187	1.203	1.515

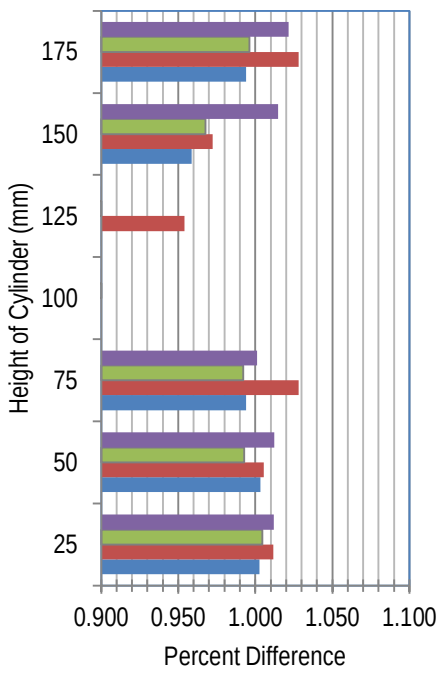
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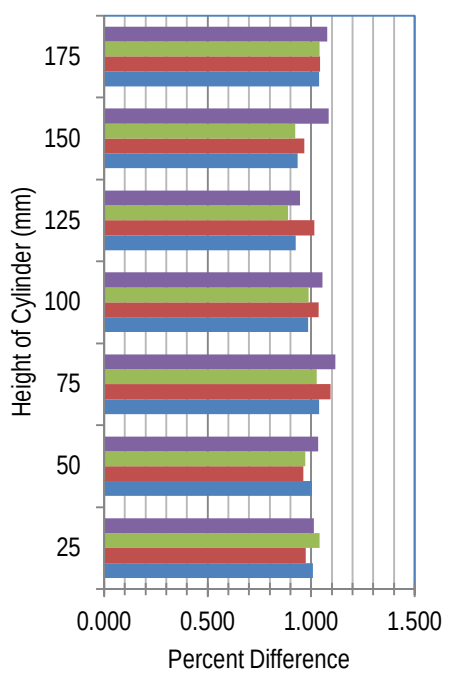
C03SS2F

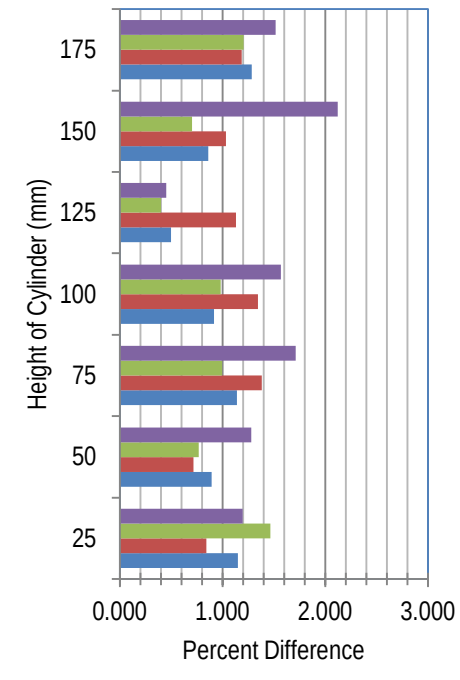
C03LW0F

C03SS5W

C03SS5A







Cylinders - 6 Months Limewater Solution Exposure: Complete Immersion

Sample: C06LW0A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.07	22.81	4.3871	65.9	14	100.19	22.68	4.4175	70	21.1
50	100.14	22.75	4.4018	71.4	42.3	100.33	22.72	4.4159	71.9	54.3
75	100.28	22.84	4.3905	66.5	23.1	100.54	22.96	4.3789	72.6	47.9
100	100.4	23.45	4.2814	64.3	19.2	100.63	23.29	4.3207	63.2	19.5
125	100.45	23.37	4.2982	59.5	11.6	100.65	25.42	3.9595	51.7	3.5
150	100.41	25.50	3.9376	58.7	9	100.65	23.2	4.3384	74.8	61.6
175	100.31	23.59	4.2522	67.1	22.2	100.44	22.92	4.3822	72.5	45.6

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.33	200.02	199.675	41.1	41	41.05	4.8642	7.16511	7.6 cm from top

Sample: C06LW0A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.34	22.68	4.4242	75.7	51.3	100.82	22.91	4.4007	72	46.5
50	100.23	22.96	4.3654	68.8	50.5	100.78	22.59	4.4613	71.9	63.7
75	100.39	23.09	4.3478	66.8	40.7	100.88	23.18	4.3520	69.5	42.5
100	100.26	23.2	4.3216	66.4	22.2	100.75	23.46	4.2945	69	27.9
125	100.25	22.87	4.3835	73.5	58.7	100.61	22.85	4.4031	68.1	44.3
150	100.19	22.81	4.3924	76.5	88.6	100.41	23.65	4.2457	65.7	13.5
175	100.1	23.00	4.3522	78.5	73.1	100.26	22.75	4.4070	76	66.7

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.93	195.66	195.795	39.9	40	39.95	4.9010	6.00246	7.8 cm from top

Sample: C06LW0A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.15	22.98	4.3581	65.6	16.5	100.21	23.04	4.3494	73	28.7
50	100.21	22.89	4.3779	70.5	33.4	100.25	22.68	4.4202	72.5	50.9
75	100.34	23.12	4.3400	69.3	29.8	100.5	23.17	4.3375	70.1	50.6
100	100.52	23	4.3704	67.4	21.9	100.47	23.08	4.3531	70.7	39.9
125	100.51	23.23	4.3267	64.5	17.8	100.62	23.44	4.2927	66	13.3
150	100.54	23.33	4.3095	69.8	47.6	100.55	23.31	4.3136	71.5	52.7
175	100.41	23.08	4.3505	71	44.4	100.55	22.98	4.3755	71.4	39.3

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.38	197.27	197.325	40.2	40.3	40.25	4.9025	6.9376	5.4 cm from top

Notes:

Cylinders - 6 Months 2% Sodium Sulphate Solution Exposure: Complete Immersion

Sample: C06SS2A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.16	23.59	4.2459	62.5	11	100.96	23.18	4.3555	69.7	24.3
50	100.17	23.31	4.2973	70.9	36.5	100.69	23.2	4.3401	72.5	75.7
75	100.33	23.3	4.3060	70.7	49.2	100.69	23.23	4.3345	73.3	72
100	100.5	23.36	4.3022	70.5	29.5	100.67	23.66	4.2549	71.9	28.3
125	100.47	22.97	4.3740	69.5	28.6	100.49	23.26	4.3203	64	19
150	100.35	22.90	4.3821	77.6	77.8	100.3	23.48	4.2717	73.5	54.7
175	100.2	23.02	4.3527	75	63.3	100.17	23	4.3552	72.3	74.1

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.19	196.44	196.315	40.8	40.9	40.85	4.8058	6.18166	9.9 cm from top

Sample: C06SS2A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.86	22.67	4.4049	73.2	32.1	99.9	22.89	4.3644	71	25.2
50	99.9	23.32	4.2839	72.6	43.8	99.97	22.85	4.3751	70.5	83.3
75	100.03	23.34	4.2858	61.7	16.2	100.16	23.4	4.2803	73.7	47.1
100	100.15	23.28	4.3020	65.8	24.9	100.34	23.2	4.3250	69.9	43.5
125	100.16	22.92	4.3700	71	41.1	100.35	23.22	4.3217	70	47.1
150	100.15	23.15	4.3261	76.5	112.1	100.43	23	4.3665	76.5	95
175	100.09	22.90	4.3707	69.4	45.3	100.44	23.22	4.3256	69.8	52.6

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.24	197.71	197.475	40.7	40.8	40.75	4.8460	7.28356	9.9 cm from top

Sample: C06SS2A3

Ultra Sonic Pulse Emission Test (300 kHz)

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
50	100.1	23.16	4.3221	74.5	72.4	100.33	23.17	4.3302	71.5	58.2
75	100.22	23.6	4.2466	68.3	35.4	100.48	23.65	4.2486	69.2	45.9
100	100.05	23.65	4.2304	67.9	28.7	100.29	23.64	4.2424	70	39.8
125	100.08	23.25	4.3045	68.5	19.1	100.3	23.36	4.2937	64.2	23.1
150	100.33	23.18	4.3283	73.5	49.4	100.13	22.86	4.3801	75.5	76.9
175	99.83	23.23	4.2975	72	42.4	99.93	23.27	4.2944	74.4	63.2

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.04	197.28	197.16	41	40.9	40.95	4.8147	7.24807	9.9 cm from top

Notes:

Cylinders - 6 Months 5% Sodium Sulphate Solution Exposure: Complete Immersion

Sample: C06SS5A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.3	24.1	4.1618	63.1	8.5	100.18	23.57	4.2503	67.5	18.2
50	100.39	23.65	4.2448	71.5	71.4	100.23	23.31	4.2999	70.5	46.7
75	100.49	23.95	4.1958	65	25.8	100.51	23.8	4.2231	60.8	27.5
100	100.59	23.63	4.2569	69	29.7	100.57	24.3	4.1387	62.3	10.6
125	100.62	24.31	4.1390	57.8	7.5	100.61	23.39	4.3014	64.1	22.8
150	100.62	23.43	4.2945	73.5	62.9	100.47	23.36	4.3009	68.5	43
175	100.6	23.57	4.2681	69.6	57	100.5	23.85	4.2138	64.9	27.2

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.16	198.6	198.38	41.3	41.4	41.35	4.7976	8.36342	8.0 cm from top

Sample: C06SS5A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.95	23.16	4.3156	71.4	43.2	99.85	23.83	4.1901	58.5	7.7
50	10037	24.02	417.8601	66.5	21.6	100.08	23.49	4.2605	67.4	44.8
75	100.29	23.15	4.3322	66.2	31.4	100.18	23.2	4.3181	62.7	19.9
100	100.4	23.34	4.3016	66	25.1	100.2	23.14	4.3302	66.6	26.1
125	100.5	23.77	4.2280	63.1	13.1	100.32	23.4	4.2872	66	23.5
150	100.46	23.16	4.3377	71	55.5	100.36	23.43	4.2834	71.4	56.5
175	100.42	23.57	4.2605	72.7	41	100.51	23.41	4.2935	73	52.8

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.18	194.94	195.06	40.8	40.7	40.75	4.7867	8.49627	4.8 cm from bottom

Sample: C06SS5A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.09	23.53	4.2537	70.5	27.5	100.07	23.27	4.3004	67	18.4
50	100.25	23.64	4.2407	67.5	40.4	100.31	23.08	4.3462	69.5	42.6
75	100.28	23.57	4.2546	69.7	29.1	100.31	23.64	4.2432	64.5	24
100	100.47	23.88	4.2073	68.1	30	100.49	23.7	4.2401	60.9	15.5
125	100.4	23.18	4.3313	64.6	23.4	100.53	23.49	4.2797	63.2	16.8
150	100.42	23.43	4.2860	71.3	34	100.65	23.57	4.2703	74.6	111.3
175	100.45	23.65	4.2474	70.5	40.2	100.66	24.15	4.1681	67.8	30

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
194.94	194.94	194.94	40.6	40.5	40.55	4.8074	7.54432	5.0 cm from top

Notes:

Cylinders - 6 Months Limewater Solution Exposure: Partial Immersion

Sample: C06LW0W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100	22.94	4.3592	70.5	20.4	99.98	22.69	4.4063	72.9	25.3
50	100.17	23.23	4.3121	71.5	44.9	100.06	23.67	4.2273	64.2	21.3
75	100.04	23.49	4.2588	70.4	37.6	100.27	23.31	4.3016	68.4	32.4
100	100.27	23.87	4.2007	63	15	100.32	23.56	4.2581	66.2	22
125	100.29	23.61	4.2478	74.3	37.5	100.38	23.58	4.2570	67	29.1
150	100.25	24.42	4.1052	66.8	38.5	100.3	23.7	4.2321	72.5	46.6
175	100.16	25.02	4.0032	60.1	14.6	100.37	26.69	3.7606	59.5	18.3

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.55	198.31	198.43	41.6	41.7	41.65	4.7642	4.91523	3.0 cm from top

Sample: C06LW0W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.88	22.53	4.4332	64.6	16.9	99.95	23.12	4.3231	61.9	6.5
50	99.89	23.22	4.3019	66.5	27.6	100.2	23.08	4.3414	67.5	28.4
75	100.01	23.04	4.3407	68.1	31.4	100.18	25.43	3.9394	58.4	8.7
100	100.16	23.48	4.2658	68.6	34.1	100.32	23.33	4.3000	62.4	21.2
125	100.21	23.79	4.2123	67	21.5	100.38	23.97	4.1877	62.8	14.2
150	100.19	24.66	4.0629	68.5	68.7	100.25	24.06	4.1667	72.5	61
175	100.23	24.10	4.1589	70.2	51.1	100.21	24.3	4.1239	66.5	38.5

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.29	197.07	197.18	41.1	41	41.05	4.8034	4.41787	4.2 cm from top

Sample: C06LW0W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.09	22.81	4.3880	70.8	30.3	100.13	23.08	4.3384	68	23.7
50	100.18	22.83	4.3881	72.5	44.4	100.25	23.48	4.2696	64.5	26
75	100.31	23.32	4.3015	69.9	47.2	100.34	23.39	4.2899	66.8	27
100	100.32	23.38	4.2908	68.7	24.3	100.55	24.19	4.1567	57	8.4
125	100.32	24.52	4.0914	63	8.4	100.6	24.39	4.1246	66	14.4
150	100.12	26.00	3.8508	58.4	9.5	100.45	24.09	4.1698	69.5	28.3
175	100.15	24.39	4.1062	67.3	19	100.54	24.8	4.0540	64	19.9

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.59	198.48	198.535	41.6	41.7	41.65	4.7667	5.63191	3.0 cm from top

Notes:

Cylinders - 6 Months 2% Sodium Sulphate Solution Exposure: Partial Immersion

Sample: C06SS2W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.41	23.77	4.3084	65	12.2	102.46	23.31	4.3955	72.2	24
50	102.4	23.45	4.3667	69.5	32.8	102.48	23.82	4.3023	70.2	34.2
75	102.37	23.43	4.3692	70.9	32	102.33	23.68	4.3214	73.2	42.4
100	102.38	23.81	4.2999	71	45.5	102.36	24.21	4.2280	63.1	13.1
125	102.19	23.95	4.2668	64.2	11.8	102.22	24.02	4.2556	66.6	24.8
150	102.22	26.59	3.8443	55.5	6.5	102.07	24.5	4.1661	66.5	41.8
175	102.06	24.94	4.0922	67.6	27	102.1	26.19	3.8984	62.1	10.9

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.82	197.86	197.84	41.5	41.5	41.5	4.7672	6.84193	4.9 cm from top

Sample: C06SS2W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.17	23.23	4.3121	71.1	21.2	100.12	23.76	4.2138	62.6	8.3
50	100.12	23.39	4.2805	71.5	40.6	100.12	23.14	4.3267	76.5	74.1
75	100.26	23.66	4.2375	65.5	20.4	100.28	23.19	4.3243	68.4	47.9
100	100.27	23.39	4.2869	70.4	32	100.38	23.07	4.3511	70.3	37
125	100.17	26.02	3.8497	56.6	6.1	100.04	25.95	3.8551	58.8	5
150	100.11	24.42	4.0995	68.5	44.7	100.14	24.56	4.0774	63.6	43.6
175	100.18	24.62	4.0690	67.1	27.8	100.2	23.98	4.1785	64.2	19.3

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.34	199.38	199.36	42.2	42	42.1	4.7354	4.89107	2.5 cm from top

Sample: C06SS2W3

Ultra Sonic Pulse Emission Test (300 kHz)

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
50	100.35	23.07	4.3498	70.4	42.8	100.34	22.94	4.3740	71.5	51.5
75	100.32	23.11	4.3410	67.3	37.1	100.46	23.03	4.3621	64.1	25.2
100	100.38	23.49	4.2733	70.4	27.6	100.55	23.71	4.2408	70	19.9
125	100.45	24.35	4.1253	55.6	5.4	100.46	25.45	3.9473	55.9	4.1
150	100.3	24.95	4.0200	61.5	27.5	100.52	24	4.1883	67.9	47
175	100.4	24.00	4.1833	69.1	33.8	100.39	24.08	4.1690	73.4	49.6

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
200.44	200.61	200.525	41.8	42	41.9	4.7858	6.42465	9.6 cm from bottom

Notes:

Cylinders - 6 Months 5% Sodium Sulphate Solution Exposure: Partial Immersion

Sample: C06SS5W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.07	23.12	4.3283	71.9	30.3	100.24	23.36	4.2911	69.5	21
50	100.23	23.28	4.3054	66.5	28.5	100.2	23.65	4.2368	72.5	43.8
75	100.29	23.56	4.2568	68.1	43	100.35	23.48	4.2739	67.3	41.3
100	100.44	23.53	4.2686	63	20.2	100.37	23.41	4.2875	68.8	29
125	100.06	24.51	4.0824	57	5.8	100.25	24.51	4.0902	57	5.8
150	100.17	26.22	3.8204	60.4	17	99.98	26.22	3.8131	60.4	17
175	100.26	24.16	4.1498	68.3	41.6	100.34	24.16	4.1531	68.3	41.6

Ultra Sonic Pulse Velocity Test (54 kHz) / Pressure Tension Test

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.77	197.77	197.77	41.8	41.9	41.85	4.7257	5.38348	2.9 cm from top

Sample: C06SS5W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.19	23.3	4.3000	67.9	16.5	100.17	23.45	4.2716	62.7	12.4
50	100.34	23.73	4.2284	68.5	38.5	100.24	23.46	4.2728	66	31.5
75	100.46	23.76	4.2281	67	30.2	100.4	23.21	4.3257	67.5	33.5
100	100.68	26.43	3.8093	51.1	3.1	100.49	23.56	4.2653	75.8	44.8
125	100.49	25.38	3.9594	56.3	5.3	100.43	23.88	4.2056	64.5	15.9
150	100.28	24.00	4.1783	64.5	34.1	100.32	26.13	3.8393	57.1	7.9
175	100.42	24.29	4.1342	72.1	37.8	100.25	24.39	4.1103	62.1	23.8

Ultra Sonic Pulse Velocity Test (54 kHz) / Pressure Tension Test

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.35	196.54	196.445	41.3	41.4	41.35	4.7508	5.57095	2.1 cm from top

Sample: C06SS5W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.12	23.62	4.2388	69.3	25.8	100.26	23.3	4.3030	68.5	20
50	100.25	23.19	4.3230	68.5	37.2	100.41	23.57	4.2601	72.1	38.5
75	100.5	23.83	4.2174	59.7	17.7	100.64	23.92	4.2074	61	14.8
100	100.59	24.14	4.1669	60.3	10	100.62	24.11	4.1734	65.6	19.6
125	100.45	23.86	4.2100	60.9	12	100.48	24.23	4.1469	57	7.3
150	100.45	24.48	4.1033	60.7	12.3	100.28	29.08	3.4484	55.5	11.1
175	100.45	23.76	4.2277	68.3	39	100.32	25.7	3.9035	59.3	14.9

Ultra Sonic Pulse Velocity Test (54 kHz) / Pressure Tension Test

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.92	196.78	196.85	41.6	41.6	41.6	4.7320	7.70434	6.5 cm from top

Notes:

Cylinders - 6 Months Limewater Solution Exposure: Cyclical Partial Immersion

Sample: C06LW0F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.9	23.17	4.3116	73.0	39.8	100.12	23.17	4.3211	74.7	42.4
50	100.03	23.60	4.2386	68.0	40.3	100.31	23.38	4.2904	64.3	20.5
75	100.14	23.87	4.1952	64.1	27.0	100.46	23.83	4.2157	64.5	22.9
100	100.18	24.27	4.1277	62.6	29.4	100.51	24.27	4.1413	63.4	16.1
125	100.17	24.38	4.1087	72.0	35.1	100.48	24.83	4.0467	59.0	12.7
150	100.14	24.91	4.0201	59.5	21.6	100.34	24.70	4.0623	60.0	21.5
175	100.23	25.30	3.9617	62.9	26.4	100.43	27.06	3.7114	59.3	13.1

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.14	199.5	199.32	42.3	42.3	42.3	4.7121	3.84531	5.4 cm from top

Sample: C06LW0F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.1	23.34	4.2888	72.5	51.7	100	22.90	4.3668	72.7	47.5
50	100.32	23.25	4.3148	69.2	40.4	100.24	23.44	4.2755	71.0	47.9
75	100.4	23.45	4.2814	66.7	28.7	100.17	23.68	4.2302	71.2	38.3
100	100.48	24.11	4.1676	65.0	31.2	100.35	23.65	4.2431	63.7	46.5
125	100.42	24.34	4.1257	72.0	38.9	100.29	24.14	4.1545	72.7	40.7
150	100.31	24.18	4.1485	69.9	40.8	100.22	24.42	4.1040	67.5	38.4
175	100.32	25.22	3.9778	65.4	33.3	100.35	24.70	4.0628	64.0	29.8

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.02	197.88	197.95	41.8	41.8	41.8	4.7356	4.79547	2.1 cm from top

Sample: C06LW0F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.04	23.49	4.2588	69.5	39.9	100.21	22.82	4.3913	73.6	41.8
50	100.11	23.23	4.3095	71.8	63.8	100.27	23.51	4.2650	68.5	54.8
75	100.23	23.46	4.2724	70.3	27.6	100.37	23.25	4.3170	73.0	48.8
100	100.3	24.17	4.1498	60.9	18.6	100.42	23.68	4.2407	68.8	64.3
125	100.36	24.16	4.1540	62.0	16.9	100.38	23.85	4.2088	66.7	25.4
150	100.33	24.65	4.0710	69.0	56.8	100.24	24.74	4.0517	68.0	47.1
175	100.48	24.91	4.0337	67.6	36.7	100.24	25.50	3.9310	68.7	42.5

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.59	196.64	196.615	41	41	41	4.7955	4.31366	3.1 cm from top

Notes:

Cylinders - 6 Months 2% Sodium Sulphate Solution Exposure: Cyclical Partial Immersion

Sample: C06SS2F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.02	23.2	4.3112	70	32.6	100.05	22.98	4.3538	71.6	25.1
50	99.98	23	4.3470	78.7	74.6	100.1	23.54	4.2523	69.5	40.3
75	100.18	23.06	4.3443	74.8	64.3	100.35	23.16	4.3329	67.4	27.7
100	100.24	22.95	4.3678	71.7	35	100.35	23.43	4.2830	67.5	30.5
125	100.34	23.47	4.2752	67.7	28.4	100.37	23.45	4.2802	65	19.7
150	100.32	24.60	4.0780	65.4	31.5	100.38	23.71	4.2337	70	38.7
175	100.48	26.24	3.8293	60.4	11.8	100.29	24.2	4.1442	71.2	44.6

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.03	198.13	198.08	41.3	41.2	41.25	4.8019	6.0549	2.2 cm from bottom

Sample: C06SS2F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.22	23.19	4.3217	75.3	33.2	100.24	22.93	4.3716	72.3	31.6
50	100.48	23.36	4.3014	70.5	33.1	100.34	23.13	4.3381	73.5	48.1
75	100.6	23.19	4.3381	71.8	53.3	100.2	23.28	4.3041	67.4	32.7
100	100.59	23.57	4.2677	71.3	41.3	100.17	23.37	4.2863	69.5	35.4
125	100.71	23.66	4.2566	63.5	22.9	100.24	23.31	4.3003	67.8	30.9
150	100.54	32.65	3.0793	65.5	52.8	100.15	24.15	4.1470	66.5	43
175	100.65	24.67	4.0799	66.9	25.5	100.26	24.54	4.0856	64.6	19.5

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.79	199.59	199.69	41.7	41.6	41.65	4.7945	5.77641	3.0 cm from top

Sample: C06SS2F3

Ultra Sonic Pulse Emission Test (300 kHz)

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
50	100.49	23.31	4.3110	70.5	52.2	99.88	23.13	4.3182	73.5	48.1
75	100.48	23.51	4.2739	66.4	29.8	100	23.28	4.2955	67.4	32.7
100	100.35	24	4.1813	63.8	15.4	99.94	23.43	4.2655	67.5	30.5
125	100.27	23.72	4.2272	70.7	23.2	99.95	23.45	4.2623	65	19.7
150	100.09	24.35	4.1105	65.8	22.7	99.92	23.71	4.2143	70	38.7
175	99.91	24.30	4.1115	65.5	16.3	99.76	24.54	4.0652	64.6	19.5

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.42	199.01	198.715	41.2	41.6	41.4	4.7999	5.51537	2.5 cm from top

Notes:

Cylinders - 6 Months 5% Sodium Sulphate Solution Exposure: Cyclical Partial Immersion

Sample: C06SS5F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.02	23.5	4.2562	73.1	32.2	100.02	23.8	4.2025	62.8	10
50	100.07	23.88	4.1905	64.6	18.7	100.16	23.58	4.2477	69.5	52.5
75	100.14	23.62	4.2396	74.7	60.1	100.22	23.66	4.2358	69.5	47.4
100	100.29	23.53	4.2622	69.2	27.9	100.32	24.18	4.1489	64.5	17.5
125	100.24	23.90	4.1941	55.5	8.5	100.44	23.9	4.2025	55.5	8.5
150	99.73	26.34	3.7863	51.3	3.8	99.72	26.34	3.7859	51.3	3.8
175	99.98	26.16	3.8219	55.1	7.5	100.55	26.16	3.8437	55.1	7.5

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.43	198.3	198.365	41.9	42.2	42.05	4.7174	7.41482	2.7 cm from top

Sample: C06SS5F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.1	23.31	4.2943	76.7	50.1	100.08	22.88	4.3741	81	99.4
50	100.21	22.97	4.3626	70.5	61.7	100.32	23	4.3617	73.5	55.5
75	100.36	25.16	3.9889	62.4	14.6	100.35	23.05	4.3536	75.2	87.9
100	100.34	23.29	4.3083	76.5	48.2	100.46	23.57	4.2622	72.9	53.9
125	100.42	25.67	3.9120	57	6.4	100.61	24.58	4.0932	54.5	4.8
150	100.1	25.57	3.9147	58.5	15	100.14	25.57	3.9163	58.5	15
175	100.09	26.23	3.8159	54.3	10.2	100.36	26.42	3.7986	55.3	8

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.63	196.59	196.61	41.8	41.7	41.75	4.7092	5.93947	2.3 cm from top

Sample: C06SS5F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	102.48	23.93	4.2825	68.6	24	102.53	26.07	3.9329	58.1	5.5
50	102.5	24.28	4.2216	60.5	19.8	102.52	23.77	4.3130	75.5	98.4
75	102.47	24.06	4.2589	65.4	26.8	102.5	24.12	4.2496	71.8	36.4
100	102.45	24.02	4.2652	67.7	17.4	102.47	24.59	4.1671	62.8	12.3
125	102.45	26.97	3.7987	55.1	5	102.37	24.06	4.2548	60	14.6
150	102.3	24.16	4.2343	69.4	51.5	102.28	26.77	3.8207	48.6	3
175	102.34	24.43	4.1891	65.3	22.2	102.2	29.77	3.4330	65.7	17.2

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
200.73	201.37	201.05	42.2	42	42.1	4.7755	8.92127	9.1 cm from bottom

Notes:

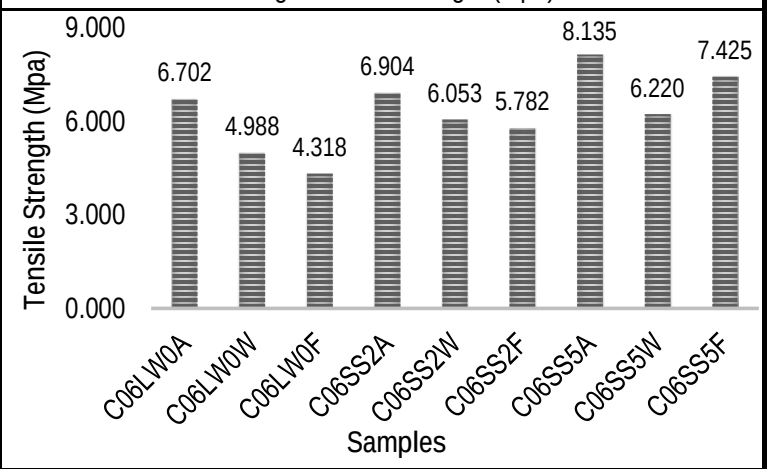
Cylinders - 6 Months Solution Exposure

Statistical Evaluation for Difference Between Samples

Ultimate Tensile Strength (Mpa) - Gas Pressure Tension Test

	Sample Statistics			
Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
C06LW0A	6.702	0.616	9.194	0.045
C06LW0W	4.988	0.610	12.235	0.044
C06LW0F	4.318	0.475	11.002	0.034
C06SS2A	6.904	0.626	9.069	0.045
C06SS2W	6.053	1.027	16.973	0.075
C06SS2F	5.782	0.270	4.666	0.020
C06SS5A	8.135	0.516	6.338	0.037
C06SS5W	6.220	1.289	20.729	0.094
C06SS5F	7.425	1.491	20.079	0.108

Average Tensile Strength (Mpa)



T-Test

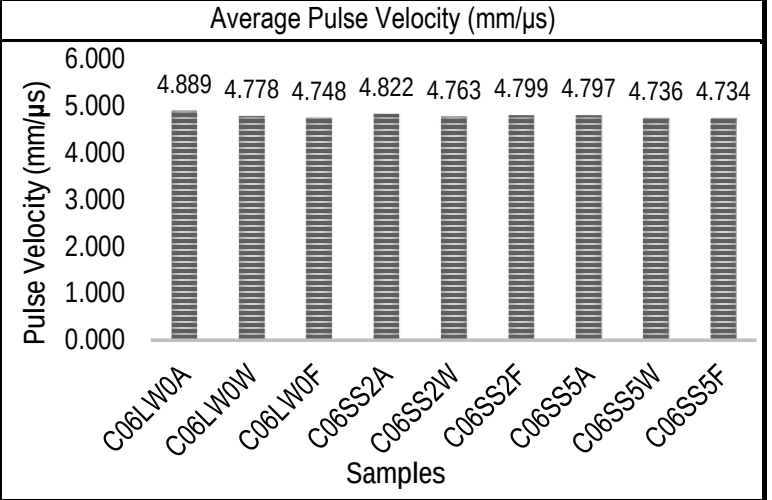
Samples	C06LW0A	C06LW0W	C06LW0F	C06SS2A	C06SS2W	C06SS2F	C06SS5A	C06SS5W	C06SS5F
C06LW0A	1.000	0.027	0.006	0.710	0.401	0.077	0.037	0.590	0.481
C06LW0W	0.990	1.000	0.208	0.019	0.198	0.108	0.002	0.209	0.059
C06LW0F	0.746	0.755	1.000	0.005	0.057	0.010	0.001	0.075	0.026
C06SS2A	0.984	0.974	0.731	1.000	0.287	0.046	0.058	0.454	0.607
C06SS2W	0.529	0.522	0.352	0.542	1.000	0.682	0.035	0.869	0.259
C06SS2F	0.322	0.327	0.488	0.313	0.129	1.000	0.002	0.619	0.193
C06SS5A	0.824	0.833	0.918	0.808	0.402	0.430	1.000	0.075	0.480
C06SS5W	0.372	0.366	0.239	0.382	0.777	0.084	0.276	1.000	0.349
C06SS5F	0.292	0.287	0.184	0.300	0.644	0.063	0.214	0.856	1.000

f-Test

Longitudinal Pulse Velocity (mm/µs) - 54 kHz Ultrasonic Pulse VelocityTest

	Sample Statistics			
Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
C06LW0A	4.889	0.022	0.444	0.002
C06LW0W	4.778	0.022	0.459	0.002
C06LW0F	4.748	0.043	0.906	0.003
C06SS2A	4.822	0.021	0.439	0.002
C06SS2W	4.763	0.025	0.535	0.002
C06SS2F	4.799	0.004	0.080	0.000
C06SS5A	4.797	0.010	0.215	0.001
C06SS5W	4.736	0.013	0.276	0.001
C06SS5F	4.734	0.036	0.764	0.003

Average Pulse Velocity (mm/µs)

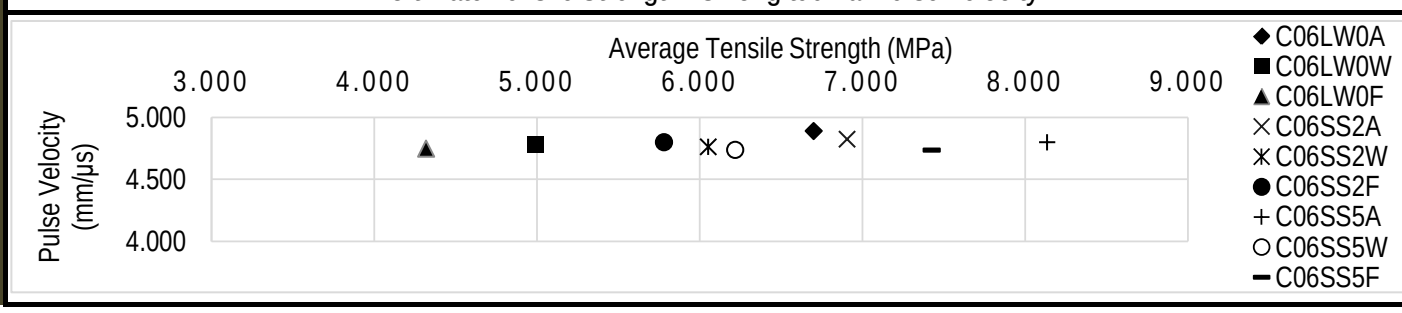


T-Test

Samples	C06LW0A	C06LW0W	C06LW0F	C06SS2A	C06SS2W	C06SS2F	C06SS5A	C06SS5W	C06SS5F
C06LW0A	1.000	0.003	0.007	0.019	0.003	0.016	0.003	0.000	0.003
C06LW0W	0.989	1.000	0.337	0.067	0.474	0.242	0.244	0.046	0.145
C06LW0F	0.406	0.413	1.000	0.055	0.629	0.175	0.125	0.678	0.695
C06SS2A	0.975	0.964	0.389	1.000	0.036	0.192	0.141	0.004	0.022
C06SS2W	0.840	0.851	0.520	0.815	1.000	0.132	0.096	0.182	0.323
C06SS2F	0.061	0.060	0.016	0.064	0.045	1.000	0.823	0.001	0.089
C06SS5A	0.370	0.363	0.109	0.385	0.282	0.244	1.000	0.003	0.044
C06SS5W	0.532	0.524	0.169	0.552	0.416	0.160	0.770	1.000	0.929
C06SS5F	0.529	0.538	0.828	0.510	0.664	0.022	0.151	0.231	1.000

f-Test

Ultimate Tensile Strength vs Longitudinal Pulse Velocity



Cylinders - 6 Months Limewater Solution Exposure: Partial Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C06LW0A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C06LW0W	C06LW0F	C06SS2A	C06SS5A	C06LW0W	C06LW0F	C06SS2A	C06SS5A
25	4.390	0.031	0.699	0.002	0.508	0.328	0.119	0.166	0.502	0.018	0.171	0.000
50	4.407	0.034	0.773	0.002	0.303	0.717	0.911	0.000	0.004	0.000	0.002	0.364
75	4.358	0.022	0.501	0.001	0.001	0.129	0.360	0.071	0.108	0.000	0.001	0.005
100	4.324	0.034	0.781	0.002	0.296	0.389	0.780	0.148	0.015	0.000	0.046	0.031
125	4.277	0.162	3.787	0.008	0.074	0.031	0.004	0.083	0.248	0.083	0.462	0.829
150	4.256	0.163	3.832	0.008	0.681	0.013	0.010	0.001	0.096	0.042	0.259	0.584
175	4.353	0.054	1.235	0.003	0.048	0.088	0.279	0.693	0.002	0.000	0.439	0.003

Amplitude

25	70.367	4.021	5.715	0.206	0.680	0.090	0.728	0.697	0.235	0.241	0.657	0.147
50	71.167	1.338	1.880	0.069	0.085	0.161	0.863	0.410	0.079	0.079	0.282	0.037
75	69.133	2.258	3.266	0.116	0.066	0.298	0.172	0.525	0.200	0.649	0.865	0.019
100	66.833	2.820	4.220	0.145	0.889	0.916	0.570	0.778	0.360	0.112	0.115	0.458
125	63.883	7.520	11.772	0.386	0.280	0.593	0.067	0.050	0.540	0.387	0.270	0.826
150	69.500	6.516	9.375	0.334	0.728	0.476	0.010	0.028	0.787	0.266	0.074	0.458
175	72.750	4.012	5.515	0.206	0.895	0.725	0.245	0.572	0.009	0.004	0.757	0.177

Energy

25	29.683	15.776	53.149	0.809	0.179	0.020	0.367	0.715	0.236	0.081	0.478	0.305
50	49.183	10.374	21.092	0.532	0.943	0.451	0.223	0.366	0.016	0.550	0.183	0.567
75	39.100	10.642	27.218	0.546	0.694	0.825	0.260	0.053	0.246	0.266	0.560	0.031
100	25.100	7.896	31.456	0.405	0.837	0.090	0.888	0.984	0.394	0.292	0.127	0.631
125	24.867	21.627	86.971	1.109	0.155	0.209	0.214	0.021	0.693	0.741	0.644	0.476
150	45.500	30.098	66.149	1.544	0.489	0.119	0.614	0.815	0.827	0.577	0.067	0.384
175	48.550	18.644	38.401	0.956	0.598	0.205	0.370	0.346	0.049	0.061	0.384	0.445

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C06LW0W	C06LW0F	C06SS2A	C06SS5A	C06LW0W	C06LW0F	C06SS2A	C06SS5A	C06LW0W	C06LW0F	C06SS2A	C06SS5A
25	1.003	1.015	1.011	1.034	1.049	0.968	1.018	1.061	1.447	0.677	1.282	1.442
50	1.023	1.029	1.019	0.060	1.042	1.034	0.987	1.034	1.532	1.102	0.798	1.103
75	1.028	1.025	1.017	1.023	1.054	1.012	0.995	1.067	1.273	1.214	0.883	1.488
100	0.000	0.000	0.000	0.000	1.025	1.043	0.964	1.021	1.205	0.731	0.773	1.099
125	1.022	1.035	0.988	1.004	0.966	0.948	0.941	1.012	1.193	0.879	0.838	1.393
150	1.039	1.044	0.980	0.991	1.014	1.059	0.920	0.969	1.081	1.207	0.586	0.752
175	1.079	1.103	1.005	1.026	1.119	1.125	1.008	1.043	1.805	1.602	0.855	1.174

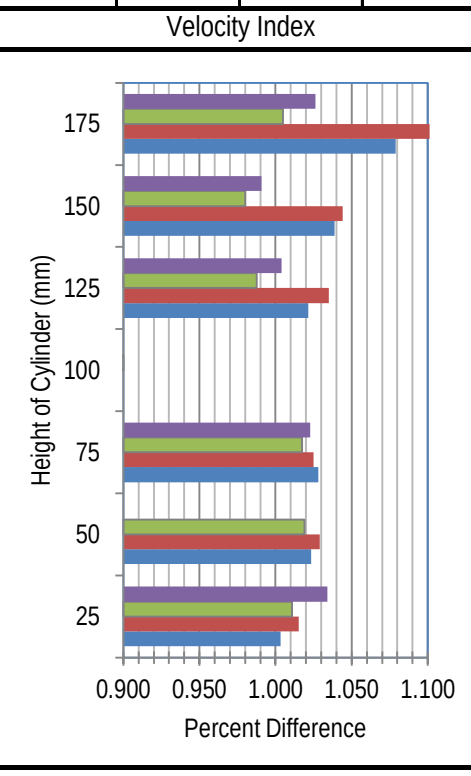
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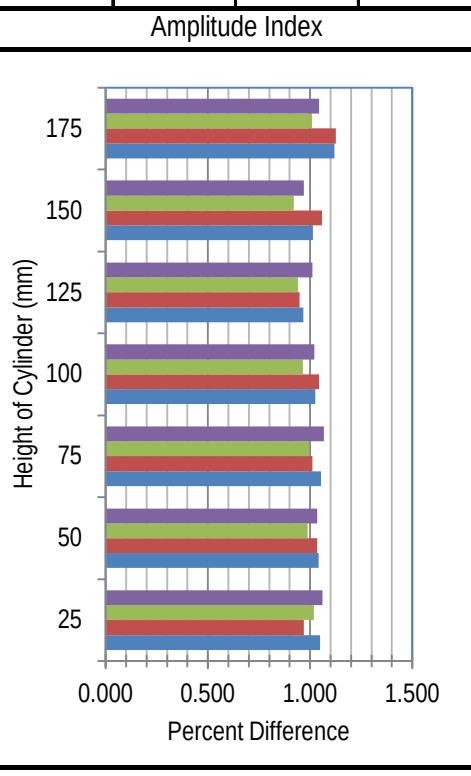
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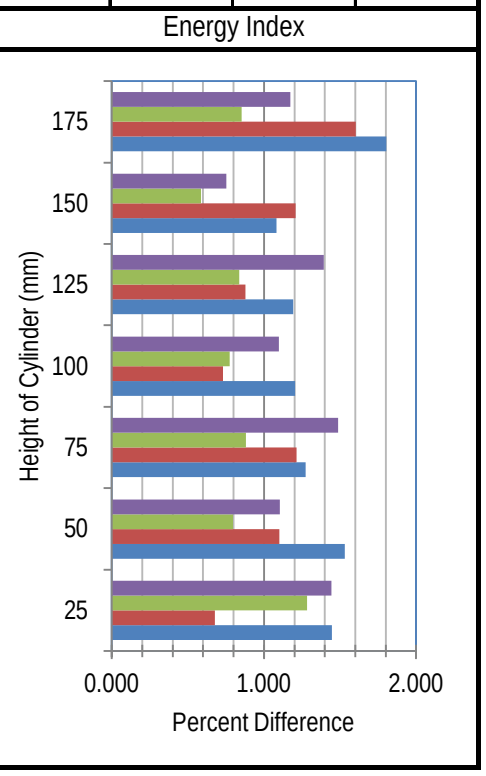
C06SS2A

C06LW0F

C06LW0W







Cylinders - 6 Months Limewater Solution Exposure: Partial Cyclic Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C06LW0W				f-Test				T-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C06LW0A	C06LW0F	C06SS2W	C06SS5W	C06LW0A	C06LW0F	C06SS2W	C06SS5W
25	4.375	0.042	0.960	0.002	0.508	0.743	0.251	0.505	0.502	0.079	0.101	0.002
50	4.307	0.056	1.295	0.003	0.303	0.171	0.388	0.401	0.004	0.363	0.353	0.223
75	4.239	0.149	3.513	0.008	0.001	0.022	0.025	0.018	0.108	0.841	0.220	0.846
100	4.245	0.056	1.311	0.003	0.296	0.849	0.626	0.022	0.015	0.055	0.260	0.320
125	4.187	0.067	1.594	0.003	0.074	0.662	0.037	0.471	0.248	0.157	0.148	0.162
150	4.098	0.134	3.279	0.007	0.681	0.030	0.871	0.177	0.096	0.721	0.678	0.081
175	4.034	0.145	3.592	0.007	0.048	0.751	0.548	0.560	0.002	0.286	0.408	0.315

Amplitude

25	67.100	4.883	7.277	0.251	0.680	0.041	0.998	0.330	0.235	0.038	0.845	0.621
50	68.283	3.137	4.594	0.161	0.085	0.717	0.644	0.775	0.079	0.764	0.071	0.676
75	65.600	5.644	8.604	0.290	0.066	0.381	0.286	0.381	0.200	0.351	0.350	0.860
100	65.217	3.011	4.617	0.154	0.889	0.807	0.997	0.044	0.360	0.501	0.045	0.767
125	66.150	4.477	6.769	0.230	0.280	0.574	0.925	0.500	0.540	0.686	0.033	0.009
150	68.533	5.530	8.069	0.284	0.728	0.712	0.799	0.240	0.787	0.351	0.157	0.007
175	65.017	4.268	6.565	0.219	0.895	0.630	0.861	0.824	0.009	0.873	0.368	0.607

Energy

25	20.517	8.225	40.091	0.422	0.179	0.255	0.918	0.595	0.236	0.000	0.447	0.912
50	32.100	10.029	31.243	0.515	0.943	0.410	0.374	0.212	0.016	0.118	0.093	0.386
75	30.717	12.813	41.715	0.657	0.694	0.540	0.656	0.855	0.246	0.823	0.620	0.931
100	20.833	8.696	41.743	0.446	0.837	0.130	0.533	0.276	0.394	0.132	0.191	0.968
125	20.850	10.831	51.946	0.556	0.155	0.858	0.516	0.065	0.693	0.282	0.066	0.040
150	42.100	21.685	51.508	1.112	0.489	0.361	0.492	0.086	0.827	0.685	0.541	0.034
175	26.900	14.539	54.047	0.746	0.598	0.443	0.835	0.572	0.049	0.648	0.887	0.425

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C06LW0A	C06LW0F	C06SS2W	C06SS5W	C06LW0A	C06LW0F	C06SS2W	C06SS5W	C06LW0A	C06LW0F	C06SS2W	C06SS5W
25	0.997	1.012	1.016	1.020	0.954	0.923	0.991	0.982	0.691	0.468	1.249	0.977
50	0.977	1.006	0.994	1.008	0.959	0.992	0.954	0.989	0.653	0.720	0.698	0.883
75	0.973	0.997	0.980	0.997	0.949	0.960	0.961	1.008	0.786	0.953	0.899	1.021
100	0.000	0.000	0.000	0.000	0.976	1.018	0.942	1.017	0.830	0.607	0.714	0.987
125	0.979	1.013	1.034	1.017	1.035	0.981	1.110	1.125	0.838	0.737	2.187	2.401
150	0.963	1.005	1.008	1.060	0.986	1.044	1.072	1.147	0.925	1.117	1.197	2.541
175	0.927	1.022	0.984	0.981	0.894	1.006	0.967	0.979	0.554	0.888	0.958	0.812

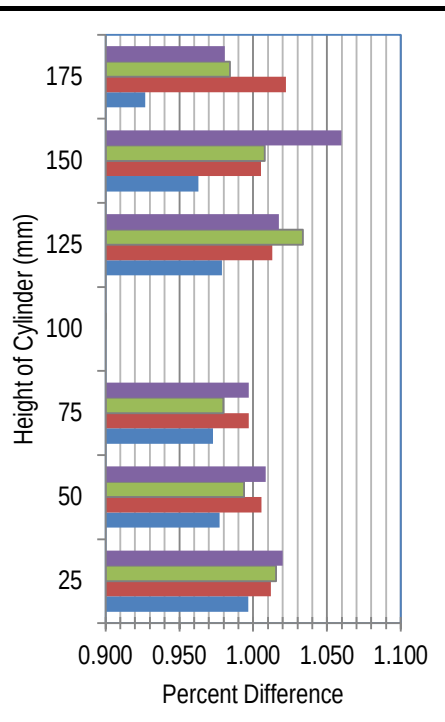
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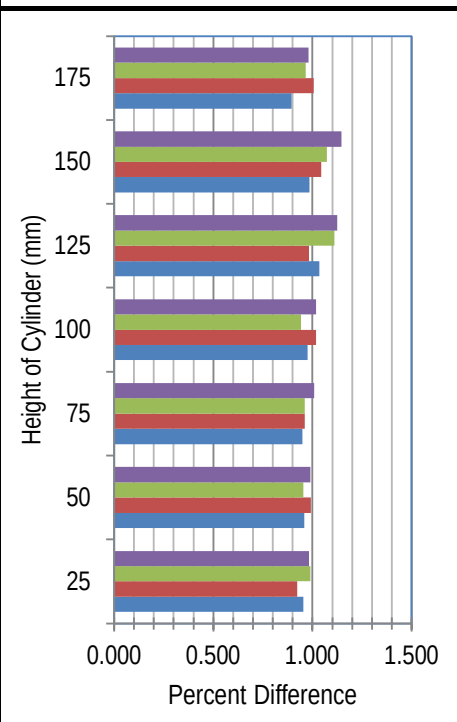
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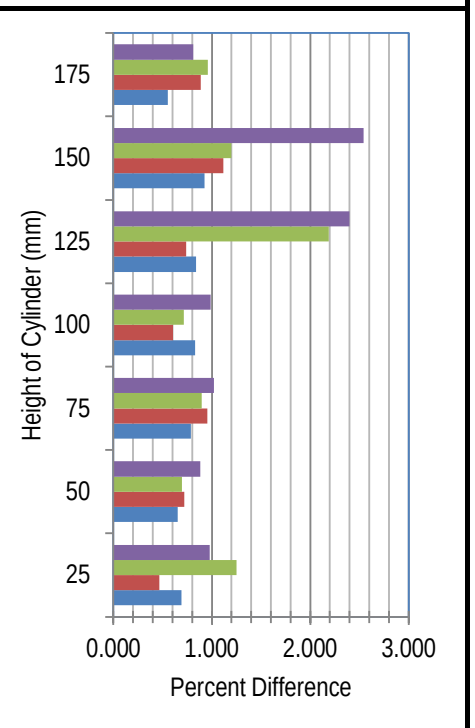
C06SS2W

C06LW0F

C06LW0A







Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Cylinders - 6 Months Limewater Solution Exposure: Partial Cyclic Immersion

Velocity

	Sample Statistics - C06LW0F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C06LW0A	C06LW0W	C06SS2F	C06SS5F	C06LW0A	C06LW0W	C06SS2F	C06SS5F
25	4.323	0.049	1.134	0.003	0.328	0.743	0.385	0.026	0.018	0.079	0.563	0.181
50	4.282	0.029	0.671	0.001	0.717	0.171	0.744	0.060	0.000	0.363	0.138	0.987
75	4.252	0.046	1.079	0.002	0.129	0.022	0.299	0.051	0.000	0.841	0.017	0.581
100	4.178	0.051	1.218	0.003	0.389	0.849	0.739	0.653	0.000	0.055	0.013	0.114
125	4.133	0.054	1.314	0.003	0.031	0.662	0.110	0.019	0.083	0.157	0.000	0.490
150	4.076	0.045	1.095	0.002	0.013	0.030	0.000	0.011	0.042	0.721	0.609	0.061
175	3.946	0.125	3.162	0.006	0.088	0.751	0.832	0.179	0.000	0.286	0.153	0.268

Amplitude

25	72.667	1.742	2.397	0.089	0.090	0.041	0.592	0.003	0.241	0.038	0.777	0.487
50	68.800	2.645	3.844	0.136	0.161	0.717	0.603	0.126	0.079	0.764	0.050	0.785
75	68.300	3.719	5.445	0.191	0.298	0.381	0.818	0.498	0.649	0.351	0.668	0.204
100	64.067	2.685	4.190	0.138	0.916	0.807	0.848	0.181	0.112	0.501	0.020	0.157
125	67.400	5.842	8.667	0.300	0.593	0.574	0.102	0.035	0.387	0.686	0.770	0.002
150	65.650	4.647	7.079	0.238	0.476	0.712	0.127	0.301	0.266	0.351	0.477	0.010
175	64.650	3.399	5.258	0.174	0.725	0.630	0.939	0.321	0.004	0.873	0.668	0.043

Energy

25	43.850	4.759	10.854	0.267	0.020	0.255	0.735	0.001	0.081	0.000	0.002	0.306
50	44.613	14.835	33.252	0.834	0.451	0.410	0.915	0.154	0.550	0.118	0.579	0.168
75	32.217	9.589	29.763	0.539	0.825	0.540	0.346	0.047	0.266	0.823	0.305	0.250
100	34.350	18.222	53.048	1.024	0.090	0.130	0.134	0.933	0.292	0.132	0.724	0.301
125	28.283	11.782	41.657	0.662	0.209	0.858	0.059	0.022	0.741	0.282	0.450	0.032
150	37.692	14.021	37.201	0.788	0.119	0.361	0.503	0.552	0.577	0.685	0.977	0.045
175	30.300	10.100	33.335	0.568	0.205	0.443	0.775	0.304	0.061	0.648	0.263	0.045

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C06LW0A	C06LW0W	C06SS2F	C06SS5F	C06LW0A	C06LW0W	C06SS2F	C06SS5F	C06LW0A	C06LW0W	C06SS2F	C06SS5F
25	0.985	0.988	0.996	1.024	1.033	1.083	1.005	1.037	1.477	2.137	1.432	1.189
50	0.972	0.994	0.993	1.000	0.967	1.008	0.946	0.997	0.907	1.390	0.903	0.873
75	0.976	1.003	0.985	1.007	0.988	1.041	0.987	0.978	0.824	1.049	0.804	0.708
100	0.000	0.000	0.000	0.000	0.959	0.982	0.935	0.929	1.369	1.649	1.096	1.163
125	0.966	0.987	0.969	1.014	1.055	1.019	1.012	1.198	1.137	1.357	1.172	3.550
150	0.958	0.995	1.025	1.043	0.945	0.958	0.977	1.167	0.828	0.895	0.995	2.455
175	0.907	0.978	0.974	1.034	0.889	0.994	0.987	1.106	0.624	1.126	1.325	2.504

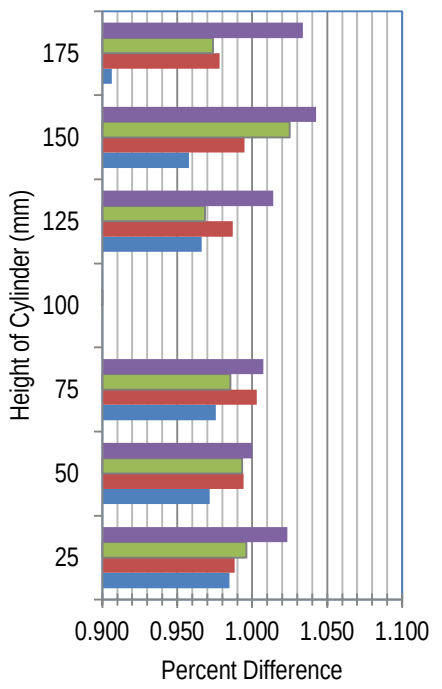
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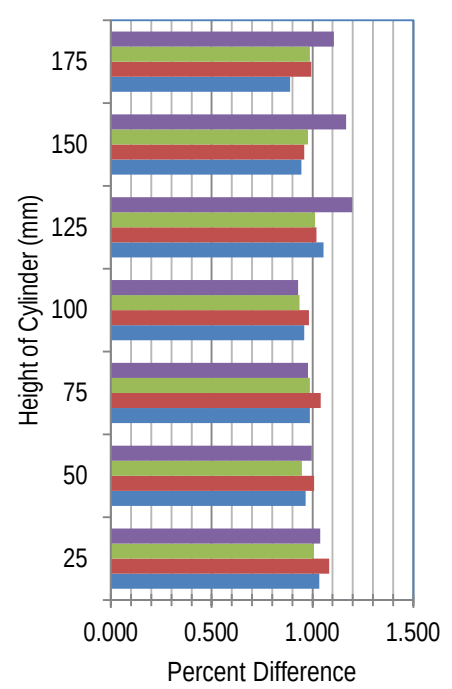
C06SS5F

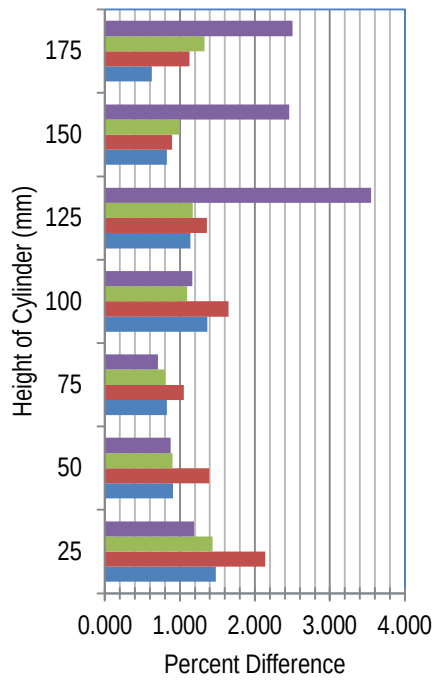
C06SS2F

C06LW0W

C06LW0A







Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Cylinders - 6 Months Limewater Solution Exposure: Partial Cyclic Immersion

Velocity

	Sample Statistics - C06SS2A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C06SS2W	C06SS2F	C06LW0A	C06SS5A	C06SS2W	C06SS2F	C06LW0A	C06SS5A
25	4.343	0.068	1.566	0.003	0.888	0.179	0.119	0.754	0.511	0.936	0.171	0.044
50	4.325	0.032	0.748	0.002	0.774	0.940	0.911	0.000	0.678	0.496	0.002	0.364
75	4.284	0.034	0.788	0.002	0.473	0.687	0.360	0.333	0.106	0.112	0.001	0.405
100	4.276	0.039	0.901	0.002	0.769	0.361	0.780	0.234	0.875	0.976	0.046	0.365
125	4.331	0.034	0.777	0.002	0.002	0.517	0.004	0.144	0.015	0.004	0.462	0.050
150	4.342	0.043	0.979	0.002	0.034	0.000	0.010	0.208	0.002	0.100	0.259	0.039
175	4.333	0.032	0.738	0.002	0.018	0.015	0.279	0.483	0.003	0.001	0.439	0.002
Amplitude												
25	69.100	4.631	6.702	0.238	0.992	0.258	0.728	0.990	0.690	0.259	0.657	0.394
50	72.083	1.451	2.013	0.074	0.250	0.087	0.863	0.511	0.693	0.694	0.282	0.009
75	69.483	4.379	6.303	0.225	0.585	0.565	0.172	0.446	0.592	0.902	0.865	0.058
100	69.333	2.157	3.110	0.111	0.484	0.514	0.570	0.399	0.931	0.610	0.115	0.035
125	67.867	3.028	4.461	0.155	0.361	0.756	0.067	0.880	0.005	0.462	0.270	0.019
150	75.517	1.698	2.248	0.087	0.036	0.581	0.010	0.632	0.001	0.000	0.074	0.007
175	72.150	2.294	3.180	0.118	0.262	0.368	0.245	0.537	0.025	0.003	0.757	0.156
Energy												
25	23.150	8.818	38.089	0.452	0.779	0.193	0.367	0.532	0.287	0.170	0.478	0.745
50	61.650	18.680	30.300	0.958	0.674	0.552	0.223	0.738	0.144	0.229	0.183	0.120
75	44.300	18.279	41.261	0.938	0.240	0.678	0.260	0.005	0.265	0.672	0.560	0.060
100	32.450	7.391	22.776	0.379	0.337	0.716	0.888	0.872	0.576	0.819	0.127	0.055
125	29.667	11.869	40.007	0.609	0.402	0.058	0.214	0.224	0.006	0.325	0.644	0.059
150	77.650	23.720	30.547	1.217	0.383	0.088	0.614	0.785	0.004	0.007	0.067	0.270
175	56.817	12.163	21.408	0.624	0.864	0.913	0.370	0.961	0.003	0.001	0.384	0.050

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C06SS2W	C06SS2F	C06LW0A	C06SS5A	C06SS2W	C06SS2F	C06LW0A	C06SS5A	C06SS2W	C06SS2F	C06LW0A	C06SS5A
25	1.008	1.001	0.989	1.023	1.020	0.956	0.982	1.042	1.409	0.756	0.780	1.125
50	0.998	1.003	0.981	0.059	1.007	0.992	1.013	1.047	1.340	1.248	1.253	1.383
75	0.990	0.993	0.983	1.005	1.018	1.004	1.005	1.072	1.297	1.105	1.133	1.685
100	0.000	0.000	0.000	0.000	1.002	1.011	1.037	1.059	1.112	1.035	1.293	1.421
125	1.069	1.015	1.012	1.016	1.138	1.019	1.062	1.075	3.112	1.229	1.193	1.662
150	1.068	1.092	1.020	1.011	1.181	1.124	1.087	1.053	2.207	2.049	1.707	1.283
175	1.057	1.069	0.995	1.021	1.073	1.101	0.992	1.034	2.024	2.485	1.170	1.373

Graph Legend

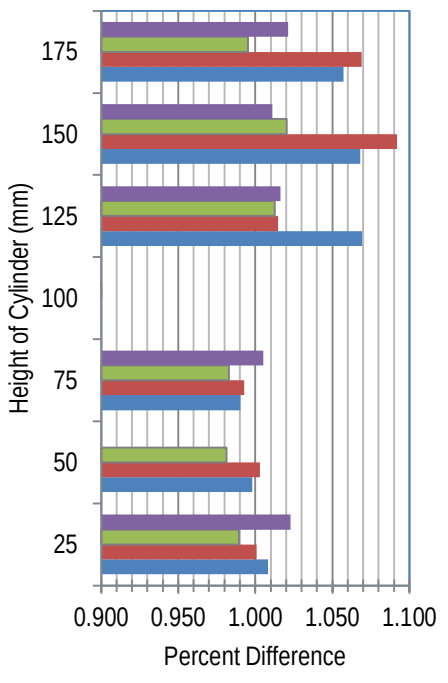
C06SS5A

C06LW0A

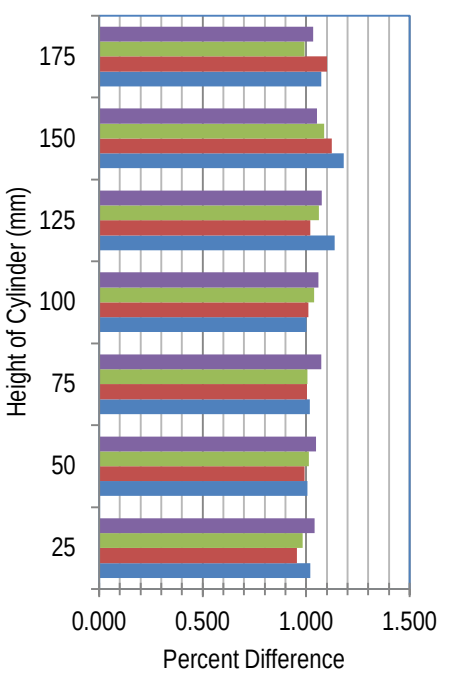
C06SS2F

C06SS2W

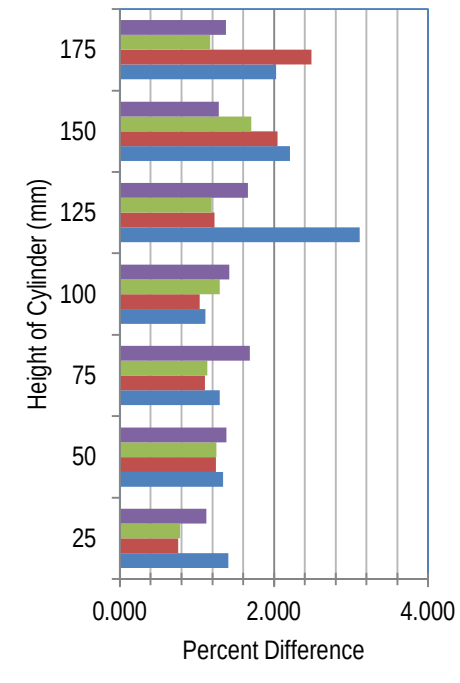
Velocity Index



Amplitude Index



Energy Index



Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C06SS2W				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C06SS2A	C06SS2F	C06LW0W	C06SS5W	C06SS2A	C06SS2F	C06LW0W	C06SS5W
25	4.307	0.074	1.724	0.004	0.888	0.143	0.251	0.086	0.511	0.449	0.101	0.661
50	4.333	0.037	0.854	0.002	0.774	0.833	0.388	0.982	0.678	0.306	0.353	0.016
75	4.326	0.047	1.096	0.002	0.473	0.270	0.025	0.875	0.106	0.632	0.220	0.018
100	4.280	0.044	1.033	0.002	0.769	0.530	0.626	0.008	0.875	0.878	0.260	0.173
125	4.050	0.192	4.731	0.010	0.002	0.000	0.037	0.144	0.015	0.039	0.148	0.468
150	4.066	0.125	3.062	0.006	0.034	0.014	0.871	0.135	0.002	0.654	0.678	0.120
175	4.098	0.109	2.662	0.006	0.018	0.942	0.548	0.986	0.003	0.491	0.408	0.821

Amplitude

25	67.725	4.659	6.879	0.239	0.992	0.255	0.998	0.387	0.690	0.127	0.845	0.818
50	71.600	2.523	3.524	0.129	0.250	0.536	0.644	0.859	0.693	0.537	0.071	0.120
75	68.233	3.383	4.958	0.174	0.585	0.977	0.286	0.840	0.592	0.629	0.350	0.158
100	69.200	3.006	4.344	0.154	0.484	0.961	0.997	0.043	0.931	0.713	0.045	0.205
125	59.617	4.679	7.849	0.240	0.361	0.227	0.925	0.443	0.005	0.010	0.033	0.728
150	63.917	4.906	7.675	0.252	0.036	0.104	0.799	0.351	0.001	0.166	0.157	0.112
175	67.250	3.930	5.844	0.202	0.262	0.817	0.861	0.692	0.025	0.444	0.368	0.742

Energy

25	16.425	7.395	45.021	0.379	0.779	0.293	0.918	0.724	0.287	0.014	0.447	0.327
50	46.000	15.315	33.293	0.786	0.674	0.861	0.374	0.042	0.144	0.698	0.093	0.194
75	34.167	10.389	30.406	0.533	0.240	0.437	0.656	0.792	0.265	0.446	0.620	0.538
100	29.183	11.684	40.038	0.599	0.337	0.544	0.533	0.631	0.576	0.724	0.191	0.317
125	9.533	7.964	83.542	0.409	0.402	0.253	0.516	0.205	0.006	0.003	0.066	0.823
150	35.183	15.663	44.517	0.804	0.383	0.369	0.492	0.276	0.004	0.729	0.541	0.031
175	28.067	13.186	46.980	0.676	0.864	0.779	0.835	0.719	0.003	0.484	0.887	0.490

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C06SS2A	C06SS2F	C06LW0W	C06SS5W	C06SS2A	C06SS2F	C06LW0W	C06SS5W	C06SS2A	C06SS2F	C06LW0W	C06SS5W
25	0.992	0.993	0.985	1.004	0.980	0.937	1.009	0.992	0.710	0.536	0.801	0.782
50	1.002	1.005	1.006	1.015	0.993	0.985	1.049	1.037	0.746	0.931	1.433	1.266
75	1.010	1.003	1.021	1.017	0.982	0.986	1.040	1.048	0.771	0.852	1.112	1.136
100	0.000	0.000	0.000	0.000	0.998	1.009	1.061	1.080	0.899	0.931	1.401	1.382
125	0.935	0.949	0.967	0.984	0.878	0.895	0.901	1.014	0.321	0.395	0.457	1.098
150	0.936	1.022	0.992	1.051	0.846	0.951	0.933	1.069	0.453	0.928	0.836	2.124
175	0.946	1.011	1.016	0.996	0.932	1.026	1.034	1.013	0.494	1.227	1.043	0.848

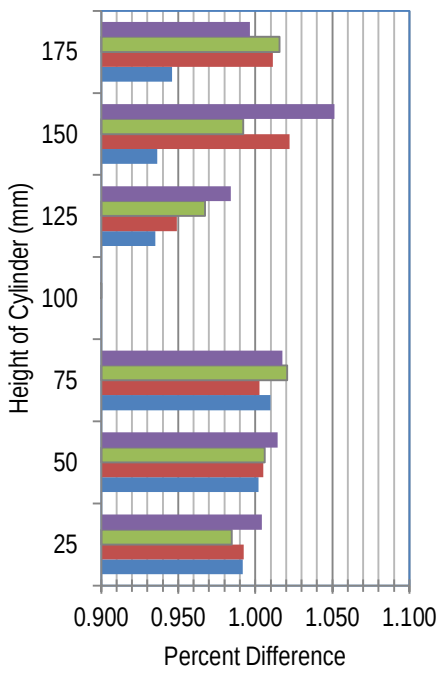
Graph Legend

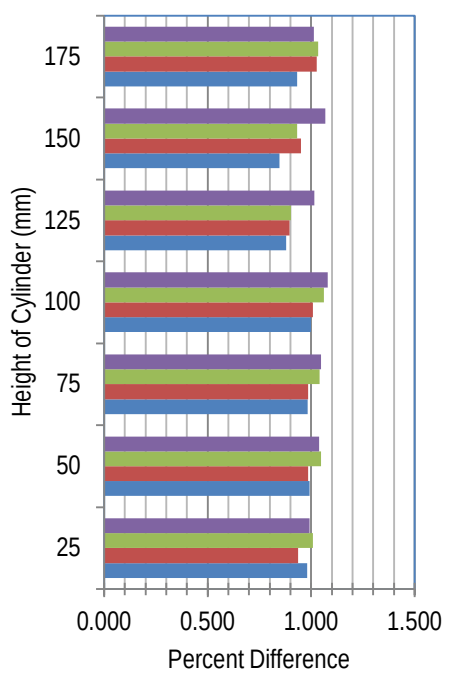
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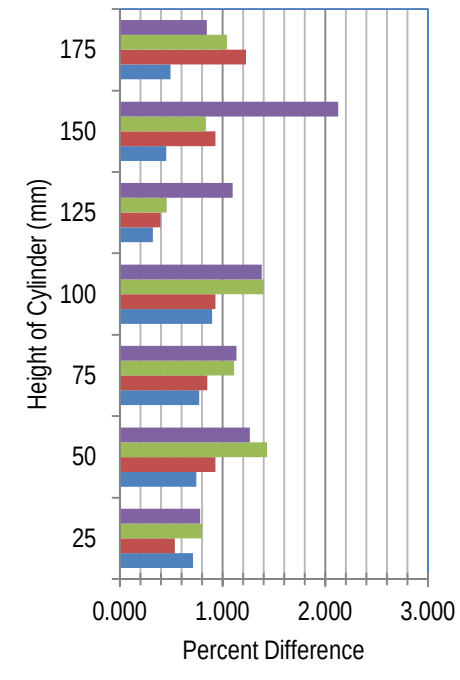
C06LW0W

C06SS2F

C06SS2A







Cylinders - 6 Months Limewater Solution Exposure: Partial Cyclic Immersion

Cylinders - 6 Months Limewater Solution Exposure: Partial Cyclic Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C24SS2F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C24SS2A	C24SS2W	C24LW0F	C24SS5F	C24SS2A	C24SS2W	C24LW0F	C24SS5F
25	4.340	0.028	0.645	0.001	0.179	0.143	0.385	0.018	0.936	0.449	0.563	0.125
50	4.311	0.034	0.777	0.002	0.940	0.833	0.744	0.110	0.496	0.306	0.138	0.408
75	4.315	0.028	0.647	0.001	0.687	0.270	0.299	0.006	0.112	0.632	0.017	0.120
100	4.275	0.060	1.393	0.003	0.361	0.530	0.739	0.907	0.976	0.878	0.013	0.289
125	4.267	0.025	0.580	0.001	0.517	0.000	0.110	0.000	0.004	0.039	0.000	0.050
150	3.977	0.444	11.159	0.023	0.000	0.014	0.000	0.055	0.100	0.654	0.609	0.739
175	4.053	0.113	2.786	0.006	0.015	0.942	0.832	0.124	0.001	0.491	0.153	0.054
Amplitude												
25	72.300	2.220	3.070	0.114	0.258	0.255	0.592	0.049	0.259	0.127	0.777	0.564
50	72.700	3.382	4.652	0.174	0.087	0.536	0.603	0.293	0.694	0.537	0.050	0.198
75	69.200	3.337	4.822	0.171	0.565	0.977	0.818	0.368	0.902	0.629	0.668	0.805
100	68.550	2.938	4.286	0.151	0.514	0.961	0.848	0.246	0.610	0.713	0.020	0.877
125	66.617	2.615	3.925	0.134	0.756	0.227	0.102	0.575	0.462	0.010	0.770	0.000
150	67.200	2.203	3.278	0.113	0.581	0.104	0.127	0.016	0.000	0.166	0.477	0.016
175	65.533	3.523	5.377	0.181	0.368	0.817	0.939	0.358	0.003	0.444	0.668	0.024
Energy												
25	30.625	3.742	12.219	0.192	0.193	0.293	0.735	0.004	0.170	0.014	0.002	0.679
50	49.400	14.105	28.553	0.724	0.552	0.861	0.915	0.128	0.229	0.698	0.579	0.902
75	40.083	15.028	37.493	0.771	0.678	0.437	0.346	0.251	0.672	0.446	0.305	0.667
100	31.350	8.770	27.975	0.450	0.716	0.544	0.134	0.155	0.819	0.724	0.724	0.825
125	24.133	4.598	19.051	0.236	0.058	0.253	0.059	0.616	0.325	0.003	0.450	0.000
150	37.900	10.211	26.941	0.524	0.088	0.369	0.503	0.215	0.007	0.729	0.977	0.026
175	22.867	11.555	50.530	0.593	0.913	0.779	0.775	0.195	0.001	0.484	0.263	0.072

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C24SS2A	C24SS2W	C24LW0F	C24SS5F	C24SS2A	C24SS2W	C24LW0F	C24SS5F	C24SS2A	C24SS2W	C24LW0F	C24SS5F
25	0.999	1.007	1.004	1.027	1.046	1.068	0.995	1.032	1.323	1.865	0.698	0.831
50	0.997	0.995	1.007	1.007	1.009	1.015	1.057	1.053	0.801	1.074	1.107	0.967
75	1.007	0.997	1.015	1.022	0.996	1.014	1.013	0.991	0.905	1.173	1.244	0.880
100	9.374	9.365	9.593	9.463	0.989	0.991	1.070	0.994	0.966	1.074	0.913	1.062
125	0.985	1.054	1.032	1.047	0.982	1.117	0.988	1.184	0.813	2.531	0.853	3.029
150	0.916	0.978	0.976	1.017	0.890	1.051	1.024	1.194	0.488	1.077	1.006	2.469
175	0.935	0.989	1.027	1.062	0.908	0.974	1.014	1.121	0.402	0.815	0.755	1.890

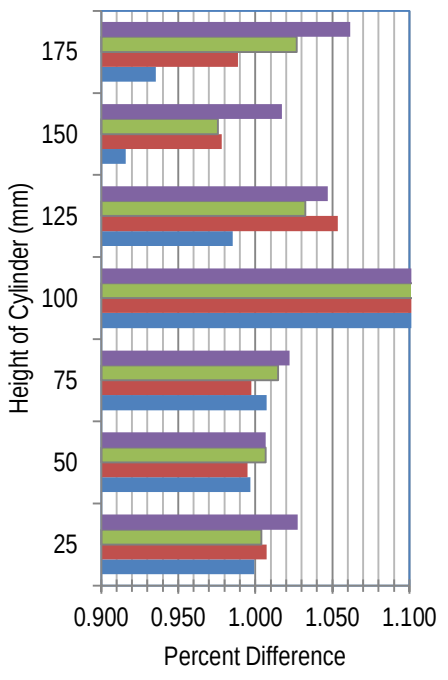
Graph Legend

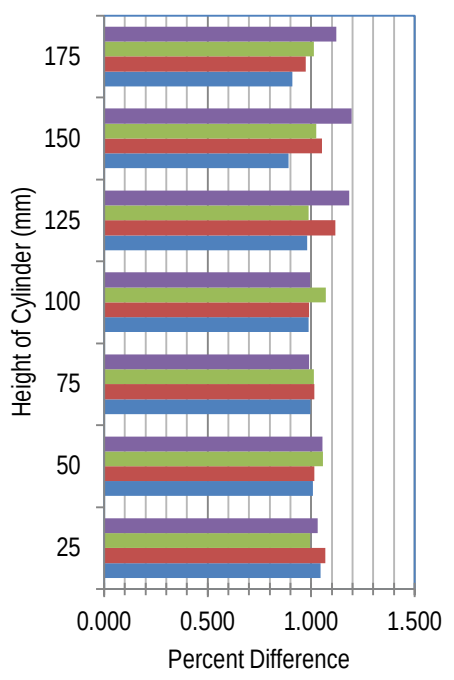
C24SS5F

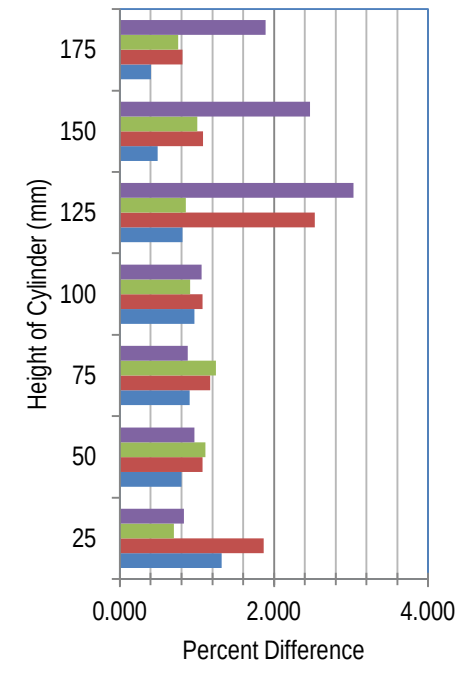
C24LW0F

C24SS2W

C24SS2A







Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C06SS5A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C06SS5W	C06SS5F	C06LW0A	C06SS2A	C06SS5W	C06SS5F	C06LW0A	C06SS2A
25	4.245	0.060	1.417	0.003	0.165	0.061	0.166	0.754	0.146	0.758	0.000	0.044
50	73.209	168.844	230.634	8.662	0.000	0.000	0.000	0.000	0.363	0.363	0.364	0.364
75	4.261	0.054	1.258	0.003	0.677	0.096	0.071	0.333	0.741	0.485	0.005	0.405
100	4.246	0.068	1.609	0.004	0.053	0.860	0.148	0.234	0.324	0.795	0.031	0.365
125	4.261	0.069	1.611	0.004	0.508	0.052	0.083	0.144	0.012	0.056	0.829	0.050
150	4.295	0.023	0.539	0.001	0.000	0.000	0.001	0.208	0.010	0.002	0.584	0.039
175	4.242	0.045	1.052	0.002	0.070	0.002	0.693	0.483	0.034	0.007	0.003	0.002

Amplitude

25	66.333	4.830	7.282	0.248	0.341	0.230	0.697	0.990	0.419	0.378	0.147	0.394
50	68.817	1.980	2.878	0.102	0.492	0.040	0.410	0.511	0.888	0.937	0.037	0.009
75	64.817	3.050	4.705	0.156	0.674	0.279	0.525	0.446	0.888	0.066	0.019	0.058
100	65.483	3.221	4.919	0.165	0.058	0.329	0.778	0.399	0.716	0.193	0.458	0.035
125	63.133	2.820	4.466	0.145	0.762	0.473	0.050	0.880	0.033	0.001	0.826	0.019
150	71.717	2.127	2.966	0.109	0.412	0.014	0.028	0.632	0.000	0.003	0.458	0.007
175	69.750	3.072	4.404	0.158	0.363	0.232	0.572	0.537	0.177	0.001	0.177	0.156

Energy

25	20.583	13.280	64.518	0.681	0.135	0.056	0.715	0.532	0.946	0.320	0.305	0.745
50	44.583	15.958	35.794	0.819	0.035	0.200	0.366	0.738	0.275	0.646	0.567	0.120
75	26.283	4.044	15.388	0.207	0.035	0.001	0.053	0.005	0.482	0.131	0.031	0.060
100	22.833	7.972	34.913	0.409	0.207	0.109	0.984	0.872	0.806	0.414	0.631	0.055
125	17.850	6.603	36.993	0.339	0.372	0.215	0.021	0.224	0.017	0.009	0.476	0.059
150	60.533	26.966	44.548	1.383	0.035	0.433	0.815	0.785	0.009	0.007	0.384	0.270
175	41.367	11.887	28.736	0.610	0.888	0.177	0.346	0.961	0.243	0.000	0.445	0.050

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C06SS5W	C06SS5F	C06LW0A	C06SS2A	C06SS5W	C06SS5F	C06LW0A	C06SS2A	C06SS5W	C06SS5F	C06LW0A	C06SS2A
25	0.990	1.005	0.967	0.978	0.971	0.947	0.943	0.960	0.980	0.558	0.693	0.889
50	17.141	17.093	16.612	16.928	0.997	0.997	0.967	0.955	1.227	0.872	0.906	0.723
75	1.002	1.009	0.978	0.995	0.996	0.928	0.938	0.933	0.874	0.577	0.672	0.593
100	0.000	0.000	0.000	0.000	1.022	0.950	0.980	0.944	1.081	0.773	0.910	0.704
125	1.035	1.045	0.996	0.984	1.074	1.122	0.988	0.930	2.056	2.241	0.718	0.602
150	1.111	1.099	1.009	0.989	1.200	1.275	1.032	0.950	3.654	3.944	1.330	0.780
175	1.031	1.111	0.974	0.979	1.050	1.193	0.959	0.967	1.249	3.419	0.852	0.728

Graph Legend

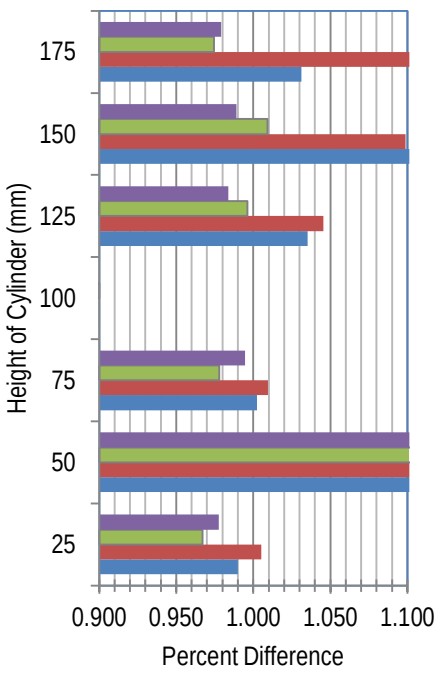
C06SS2A

C06LW0A

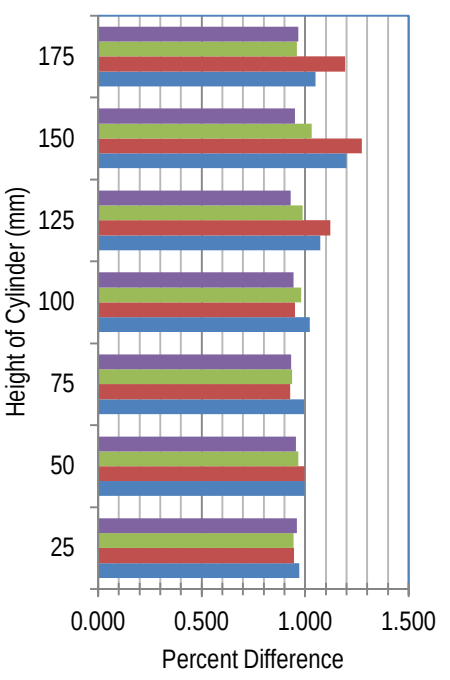
C06SS5F

C06SS5W

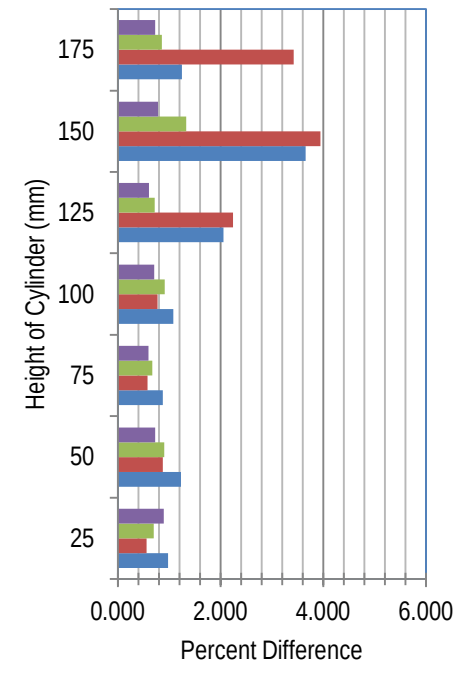
Velocity Index



Amplitude Index



Energy Index



Cylinders - 6 Months Limewater Solution Exposure: Partial Cyclic Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C06SS5W				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C06SS5A	C06SS5F	C06LW0W	C06SS2W	C06SS5A	C06SS5F	C06LW0W	C06SS2W
25	4.289	0.031	0.714	0.002	0.165	0.003	0.505	0.086	0.146	0.351	0.002	0.661
50	4.271	0.037	0.876	0.002	0.000	0.164	0.401	0.982	0.363	0.734	0.223	0.016
75	4.252	0.044	1.036	0.002	0.677	0.043	0.018	0.875	0.741	0.585	0.846	0.018
100	4.162	0.180	4.329	0.009	0.053	0.037	0.022	0.008	0.324	0.379	0.320	0.173
125	4.116	0.094	2.283	0.005	0.508	0.172	0.471	0.144	0.012	0.644	0.162	0.468
150	3.867	0.258	6.682	0.013	0.000	0.377	0.177	0.135	0.010	0.743	0.081	0.120
175	4.113	0.110	2.674	0.006	0.070	0.113	0.560	0.986	0.034	0.020	0.315	0.821

Amplitude

25	68.300	3.065	4.487	0.157	0.341	0.041	0.330	0.387	0.419	0.655	0.621	0.818
50	69.017	2.743	3.974	0.141	0.492	0.144	0.775	0.859	0.888	1.000	0.676	0.120
75	65.100	3.720	5.714	0.191	0.674	0.498	0.381	0.840	0.888	0.097	0.860	0.158
100	64.100	8.317	12.975	0.427	0.058	0.313	0.044	0.043	0.716	0.254	0.767	0.205
125	58.783	3.252	5.532	0.167	0.762	0.313	0.500	0.443	0.033	0.138	0.009	0.728
150	59.767	3.143	5.259	0.161	0.412	0.074	0.240	0.351	0.000	0.335	0.007	0.112
175	66.400	4.738	7.135	0.243	0.363	0.763	0.824	0.692	0.177	0.023	0.607	0.742

Energy

25	21.000	6.399	30.472	0.328	0.135	0.002	0.595	0.724	0.946	0.316	0.912	0.327
50	36.333	5.488	15.106	0.282	0.035	0.002	0.212	0.042	0.275	0.281	0.386	0.194
75	30.083	11.758	39.085	0.603	0.035	0.105	0.855	0.792	0.482	0.215	0.931	0.538
100	21.117	14.659	69.417	0.752	0.207	0.706	0.276	0.631	0.806	0.388	0.968	0.317
125	8.683	4.314	49.685	0.221	0.372	0.714	0.065	0.205	0.017	0.762	0.040	0.823
150	16.567	9.284	56.042	0.476	0.035	0.154	0.086	0.276	0.009	0.889	0.034	0.031
175	33.117	11.128	33.602	0.571	0.888	0.222	0.572	0.719	0.243	0.002	0.425	0.490

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C06SS5A	C06SS5F	C06LW0W	C06SS2W	C06SS5A	C06SS5F	C06LW0W	C06SS2W	C06SS5A	C06SS5F	C06LW0W	C06SS2W
25	1.010	1.015	0.980	0.996	1.030	0.975	1.018	1.008	1.020	0.570	1.024	1.279
50	0.058	0.997	0.992	0.986	1.003	1.000	1.011	0.964	0.815	0.711	1.132	0.790
75	0.998	1.007	1.003	0.983	1.004	0.932	0.992	0.954	1.145	0.661	0.979	0.880
100	0.000	0.000	0.000	0.000	0.979	0.930	0.983	0.926	0.925	0.715	1.014	0.724
125	0.966	1.010	0.983	1.016	0.931	1.045	0.889	0.986	0.486	1.090	0.416	0.911
150	0.900	0.989	0.944	0.951	0.833	1.062	0.872	0.935	0.274	1.079	0.394	0.471
175	0.970	1.078	1.019	1.004	0.952	1.136	1.021	0.987	0.801	2.737	1.231	1.180

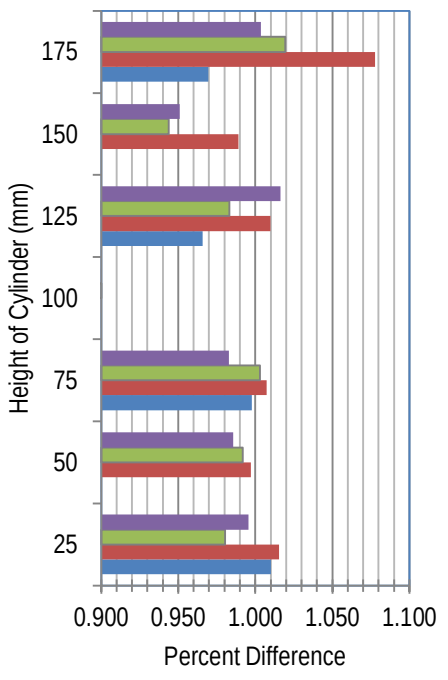
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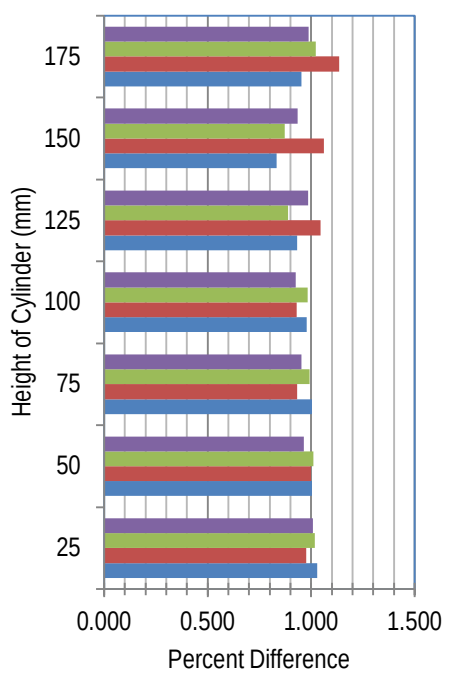
C06SS2W

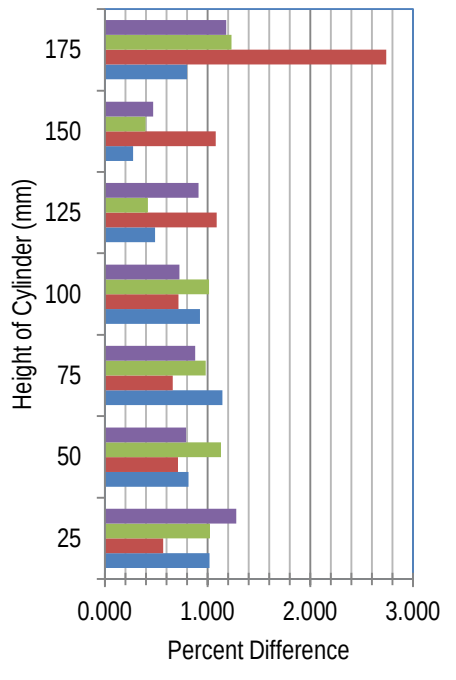
C06LW0W

C06SS5F

C06SS5A







Cylinders - 6 Months Limewater Solution Exposure: Partial Cyclic Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C06SS5F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C06SS5A	C06SS5W	C06LW0F	C06SS2F	C06SS5A	C06SS5W	C06LW0F	C06SS2F
25	4.224	0.153	3.624	0.008	0.061	0.003	0.026	0.018	0.758	0.351	0.181	0.125
50	4.283	0.074	1.716	0.004	0.000	0.164	0.060	0.110	0.363	0.734	0.987	0.408
75	4.221	0.122	2.888	0.006	0.096	0.043	0.051	0.006	0.485	0.585	0.581	0.120
100	4.236	0.063	1.485	0.003	0.860	0.037	0.653	0.907	0.795	0.379	0.114	0.289
125	4.076	0.182	4.471	0.009	0.052	0.172	0.019	0.000	0.056	0.644	0.490	0.050
150	3.910	0.170	4.339	0.009	0.000	0.377	0.011	0.055	0.002	0.743	0.061	0.739
175	3.817	0.240	6.277	0.012	0.002	0.113	0.179	0.124	0.007	0.020	0.268	0.054
Amplitude												
25	70.050	8.613	12.295	0.442	0.230	0.041	0.003	0.049	0.378	0.655	0.496	0.564
50	69.017	5.597	8.109	0.287	0.040	0.144	0.126	0.293	0.937	1.000	0.933	0.198
75	69.833	5.126	7.340	0.263	0.279	0.498	0.498	0.368	0.066	0.097	0.566	0.805
100	68.933	5.135	7.450	0.263	0.329	0.313	0.181	0.246	0.193	0.254	0.067	0.877
125	56.267	2.007	3.566	0.103	0.473	0.313	0.035	0.575	0.001	0.138	0.004	0.000
150	56.267	7.623	13.549	0.391	0.014	0.074	0.301	0.016	0.003	0.335	0.028	0.016
175	58.467	5.460	9.339	0.280	0.232	0.763	0.321	0.358	0.001	0.023	0.040	0.024
Energy												
25	36.867	34.579	93.795	1.774	0.056	0.002	0.001	0.004	0.320	0.316	0.644	0.679
50	51.100	29.666	58.055	1.522	0.200	0.002	0.154	0.128	0.646	0.281	0.642	0.902
75	45.533	26.084	57.285	1.338	0.001	0.105	0.047	0.251	0.131	0.215	0.283	0.667
100	29.533	17.515	59.305	0.899	0.109	0.706	0.933	0.155	0.414	0.388	0.651	0.825
125	7.967	3.629	45.554	0.186	0.215	0.714	0.022	0.616	0.009	0.762	0.007	0.000
150	15.350	18.582	121.053	0.953	0.433	0.154	0.552	0.215	0.007	0.889	0.041	0.026
175	12.100	6.177	51.047	0.317	0.177	0.222	0.304	0.195	0.000	0.002	0.004	0.072

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C06SS5A	C06SS5W	C06LW0F	C06SS2F	C06SS5A	C06SS5W	C06LW0F	C06SS2F	C06SS5A	C06SS5W	C06LW0F	C06SS2F
25	0.995	0.985	0.977	0.973	1.056	1.026	0.964	0.969	1.791	1.756	0.841	1.204
50	0.059	1.003	1.000	0.993	1.003	1.000	1.003	0.949	1.146	1.406	1.145	1.034
75	0.991	0.993	0.993	0.978	1.077	1.073	1.022	1.009	1.732	1.514	1.413	1.136
100	0.000	0.000	0.000	0.000	1.053	1.075	1.076	1.006	1.293	1.399	0.860	0.942
125	0.957	0.990	0.986	0.955	0.891	0.957	0.835	0.845	0.446	0.917	0.282	0.330
150	0.910	1.011	0.959	0.983	0.785	0.941	0.857	0.837	0.254	0.927	0.407	0.405
175	0.900	0.928	0.967	0.942	0.838	0.881	0.904	0.892	0.293	0.365	0.399	0.529

Graph Legend

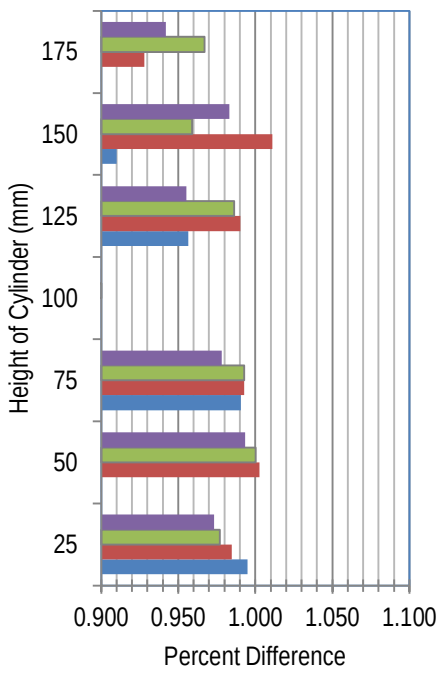
C06SS2F

C06LW0F

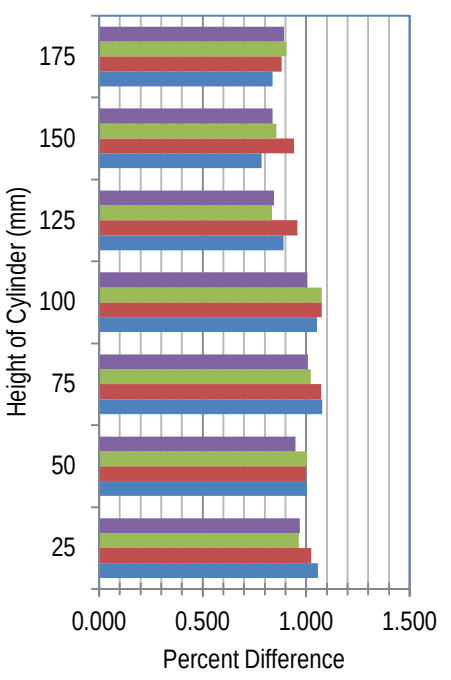
C06SS5W

C06SS5A

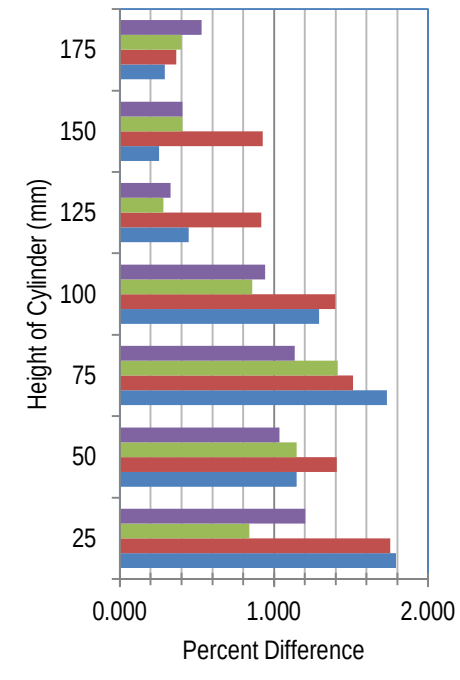
Velocity Index



Amplitude Index



Energy Index



Cylinders - 6 Months Limewater Solution Exposure: Partial Cyclic Immersion

Cylinders - 12 Months Limewater Solution Exposure: Complete Immersion

Sample: C12LW0A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.31	22	4.5595	75.8	78.2	100.11	22.07	4.5360	79.5	91.3
50	100.45	22.43	4.4784	75.8	69.9	100.19	22.75	4.4040	71.1	31.4
75	100.56	22.81	4.4086	75	78.7	100.26	22.95	4.3686	76.7	64.1
100	100.63	22.77	4.4194	74.5	61.2	100.27	22.69	4.4191	74.8	68.7
125	100.86	22.71	4.4412	74.2	59.7	100.44	22.77	4.4111	73.7	36.3
150	100.82	22.45	4.4909	74.8	85.4	100.28	22.56	4.4450	72.5	36.1
175	100.93	22.75	4.4365	77.7	95.5	100.35	22.62	4.4363	75.2	80

Ultra Sonic Pulse Velocity Test (54 kHz)							Gas Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.82	196.36	196.09	40	40.3	40.15	4.8839	6.18116	6.8 cm from top

Sample: C12LW0A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.21	22.31	4.4917	70.1	31.1	99.99	22.35	4.4738	68.5	36.4
50	100.44	22.25	4.5142	74.2	70.7	100.12	22.2	4.5099	73.5	62.9
75	100.66	22.75	4.4246	73.7	62.2	100.26	22.85	4.3877	74.7	73.8
100	100.8	22.8	4.4211	72.6	53	100.25	22.82	4.3931	73.9	90.7
125	100.95	22.86	4.4160	74.9	61.6	100.41	22.64	4.4351	74	75.5
150	100.95	22.67	4.4530	74	70.6	100.36	22.52	4.4565	74.6	100.1
175	101	22.87	4.4163	70.5	30.4	100.45	22.61	4.4427	77.4	123.2

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.97	196.06	196.015	39.8	40.1	39.95	4.9065	7.02398	1.0 cm from top

Sample: C12LW0A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.38	22.27	4.5074	81.6	100.5	100.25	22.32	4.4915	77	56
50	100.51	22.6	4.4473	74.4	47	100.23	22.26	4.5027	75	70
75	100.75	22.76	4.4266	73.9	72.7	100.3	22.67	4.4243	74.7	70.5
100	100.85	22.86	4.4116	76.2	73.1	100.34	22.78	4.4047	73.7	60.4
125	100.99	22.71	4.4469	73.5	56.4	100.19	22.5	4.4529	74.9	46.9
150	101.08	22.59	4.4745	74.1	46.1	99.99	22.4	4.4638	74	83.1
175	101.23	22.44	4.5111	74.9	91.2	99.84	22.16	4.5054	77.5	93.8

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.84	196.96	196.9	40.3	40.4	40.35	4.8798	7.65865	7.0 cm from top

Notes:

Cylinders - 12 Months 2% Sodium Sulphate Solution Exposure: Complete Immersion

Sample: 12SS2A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.13	22.65	4.4208	76.8	95	100.2	22.73	4.4083	77.6	75.3
50	100.33	22.94	4.3736	78.2	119.6	100.38	23	4.3643	74	63.7
75	100.54	23.03	4.3656	75.4	112.8	100.57	23.16	4.3424	79.1	115.8
100	100.6	23.34	4.3102	76	106.2	100.62	23.15	4.3464	75	69.8
125	100.66	22.95	4.3861	77.9	81	100.61	22.86	4.4011	74.2	57.2
150	100.57	22.65	4.4402	78.6	111	100.45	22.68	4.4290	75.5	88
175	100.58	22.92	4.3883	79.2	112.5	100.37	23.04	4.3563	74	64.5

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.57	198.73	198.65	42.7	42.6	42.65	4.6577	8.2569	

Sample: 12SS2A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.12	22.91	4.3701	77	71.5	100.18	22.81	4.3919	77	99.4
50	100.22	22.66	4.4228	79.2	89.1	100.33	22.59	4.4413	76	108.6
75	100.21	22.85	4.3856	72.1	70.3	100.47	22.78	4.4104	75.8	107.7
100	100.21	23.29	4.3027	68.9	23.3	100.71	22.94	4.3901	76.2	108.2
125	100.06	22.97	4.3561	72.9	87.1	100.84	22.92	4.3997	73	76.1
150	99.86	22.88	4.3645	70	41.1	100.85	22.88	4.4078	75	81.8
175	99.69	23.34	4.2712	72.3	54.2	100.95	23.05	4.3796	73.9	91.7

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.15	197.69	197.92	41.6	41.7	41.65	4.7520	7.03963	

Sample: 12SS2A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.2	22.26	4.5013	74.5	76.1	100.17	21.89	4.5761	79	97.9
50	100.33	22.78	4.4043	75.9	68.9	100.28	22.73	4.4118	78	108
75	100.48	23.25	4.3217	76.6	71.8	100.5	23	4.3696	75.8	85.4
100	100.61	23.33	4.3125	75.7	85.6	100.43	23.59	4.2573	75.7	72.7
125	100.83	23.03	4.3782	74	69.9	100.56	23.08	4.3570	73.2	74.8
150	100.77	22.88	4.4043	73	60	100.52	22.8	4.4088	80	105.8
175	100.67	22.94	4.3884	74.4	82.5	100.27	22.89	4.3805	77.1	78

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.57	198.28	197.925	41.5	41.4	41.45	4.7750	6.5669	

Notes:

Cylinders - 12 Months 5% Sodium Sulphate Solution Exposure: Complete Immersion

Sample: C12SS5A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25										
50										
75										
100										
125										
150										
175										

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location

Sample: C12SS5A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.25	22.17	4.5219	78.9	73.1	100.37	22.59	4.4431	71.1	24.2
50	100.34	23.1	4.3437	77	79.2	100.87	22.79	4.4261	80	75.5
75	100.35	22.78	4.4052	73.4	56.9	100.86	22.69	4.4451	69.5	48.9
100	100.43	22.71	4.4223	78.6	87.2	101.58	22.52	4.5107	74	49.7
125	100.47	22.56	4.4535	71.1	44.3	100.95	22.18	4.5514	67.9	34.1
150	100.39	22.55	4.4519	76	80.3	101.15	22.63	4.4697	77.6	87.4
175	100.5	22.65	4.4371	71.7	44.3	100.95	22.72	4.4432	85.1	110.5

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.38	195.93	196.155	40.3	40.3	40.3	4.8674	9.7766	7.4 cm from top

Sample: C12SS5A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.29	23.08	4.3453	76.5	35.9	100.33	23.44	4.2803	69.4	12.9
50	100.63	23.19	4.3394	70	46	100.35	23.37	4.2940	69	25.9
75	100.59	23.64	4.2551	67.4	36.3	100.65	23.6	4.2648	71.9	31.2
100	100.68	23.24	4.3322	68.5	25.6	100.62	23.63	4.2581	71.7	31.4
125	100.71	23.77	4.2369	64	31.2	100.62	23.12	4.3521	70.7	36.7
150	100.53	24.96	4.0276	63.6	18.4	100.61	23.02	4.3705	75	60
175	100.61	24.79	4.0585	61	13.4	100.66	31.28	3.2180	60.3	6.4

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.03	196.87	196.95	41.1	41.2	41.15	4.7861	8.45809	9.8 cm from bottom

Notes:

12SS5A1 used for DRI

Cylinders - 12 Months Limewater Solution Exposure: Partial Immersion

Sample: C12LW0W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.26	22.02	4.5531	69.9	31.8	100.2	22.52	4.4494	68.5	20
50	100.46	22.81	4.4042	70	26	100.26	22.53	4.4501	74.6	38.1
75	100.61	22.71	4.4302	75.5	47	100.3	22.97	4.3666	67.9	27
100	100.68	22.86	4.4042	76.6	61.4	100.4	23.1	4.3463	71.6	39.8
125	100.68	22.81	4.4139	71.2	48.8	100.42	25.43	3.9489	54.4	3.2
150	100.5	23.44	4.2875	67.5	26.9	100.28	24	4.1783	68	30.2
175	100.5	23.51	4.2748	65.7	30.6	100.25	27.16	3.6911	60.2	20.7

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
191.78	191.74	191.76	39.3	39.4	39.35	4.8732	3.71711	3.0 cm from top

Sample: C12LW0W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.46	22.48	4.4689	68.3	21.3	100.77	23.94	4.2093	61.6	8.6
50	100.5	22.64	4.4390	72.5	51.1	101.01	22.72	4.4459	75	58.2
75	100.71	23.23	4.3353	62.9	14.7	100.84	23	4.3843	76.9	54
100	100.91	23.2	4.3496	75.3	32.4	100.67	23.27	4.3262	67.4	24.7
125	101.31	26.00	3.8965	51.8	3	100.56	23.72	4.2395	67	24.7
150	101.65	26.46	3.8416	58.3	15	100.47	26.02	3.8613	58.3	9.6
175	101.38	25.99	3.9007	58.4	7.2	100.08	24.19	4.1372	64.3	21.4

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.65	196.08	196.365	40.7	40.9	40.8	4.8129	5.04534	3.9 cm from top

Sample: C12LW0W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.35	21.85	4.5927	77.6	57.1	100.15	22.07	4.5378	76.7	42.2
50	100.51	22.54	4.4592	80.8	92.5	100.2	22.46	4.4613	77.4	62.1
75	100.68	22.76	4.4236	71.3	40.4	100.27	22.94	4.3710	64.8	15.7
100	100.72	22.81	4.4156	74.4	61	100.29	23.01	4.3585	71.1	46.6
125	100.71	22.81	4.4152	71.2	48.8	100.37	23.02	4.3601	71.4	36.9
150	100.51	23.44	4.2880	67.5	26.9	100.34	23.22	4.3213	71.5	40.4
175	100.59	23.51	4.2786	65.7	30.6	100.39	24.94	4.0253	62.1	15.7

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.37	197.6	197.485	41	41	41	4.8167	4.37582	3.1 cm from top

Notes:

Cylinders - 12 Months 2% Sodium Sulphate Solution Exposure: Partial Immersion

Sample: C12SS2W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.33	23.08	4.3471	68.8	27.9	100.4	23.05	4.3557	71	21
50	100.37	23.18	4.3300	71.1	37.2	100.47	23	4.3683	70.2	49.8
75	100.47	23.19	4.3325	69	33.2	100.48	23.24	4.3236	68.2	22.3
100	100.56	23.43	4.2919	71.4	36.9	100.51	23.22	4.3286	74.5	45.2
125	99.99	27.31	3.6613	46.9	1	100.18		#DIV/0!		
150	100.26	26.45	3.7905	51.6	4	100.01	24.09	4.1515	56	7
175	100.61	23.53	4.2758	68.1	38.8	100.18	24.02	4.1707	62.3	15.6

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.7	198.58	198.64	42.2	42.1	42.15	4.7127	4.56272	4.1 cm from top

Sample: C12SS2W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.42	22.88	4.3890	72	36.9	100.28	22.61	4.4352	64.6	14.8
50	100.58	23.25	4.3260	76	51.6	100.33	22.67	4.4257	71.5	48.8
75	100.91	23.5	4.2940	71.4	34.7	100.37	23.27	4.3133	75.4	57.5
100	100.91	23.33	4.3253	72.1	36.2	100.73	23.54	4.2791	72.4	47.6
125	100.09	29.64	3.3771	49.3	1.4	100.37	26.65	3.7662	49.9	2
150	100.45	26.66	3.7678	53.2	8.5	100.16	26.19	3.8244	53	3.5
175	100.62	27.35	3.6790	58.1	9.7	100.3	23.7	4.2321	67.6	27.6

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
194.81	195.24	195.025	41.3	41.4	41.35	4.7164	4.15404	3.6 cm from top

Sample: C12SS2W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.24	23.69	4.2313	66.4	16.6	100.3	23.37	4.2918	69	17.3
50	100.35	23.02	4.3593	74.6	60	100.38	23.27	4.3137	77.5	68.5
75	100.59	23.52	4.2768	72	50.8	100.61	23.31	4.3162	73.1	66.8
100	100.72	25.33	3.9763	53.3	4.3	100.71	23.9	4.2138	62.7	8.6
125	99.36	24.27	4.0939	52.9	3.3	100.12	24	4.1717	54.5	6
150	100.72	32.99	3.0530	55.5	17	100.16	26.22	3.8200	49	3.5
175	100.71	24.92	4.0413	58.4	10.4	100.18	24.16	4.1465	69.2	28.2

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.12	195.23	195.675	41.3	41.3	41.3	4.7379	3.89423	2.8 cm from top

Notes:

Cylinders - 12 Months 5% Sodium Sulphate Solution Exposure: Partial Immersion

Sample: C12SS5W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.9	22.69	4.4028	76.7	59.2	100.16	22.92	4.3700	78.8	52.1
50	100	22.66	4.4131	76	56.4	100.2	22.54	4.4454	75	64.2
75	100.28	23.19	4.3243	68.8	29.5	100.35	23.02	4.3593	73.5	62
100	100.18	23.35	4.2904	64	14.2	100.31	23.15	4.3330	69.6	27.3
125	100.22	26.08	3.8428	57	6.9	100.32	26.4	3.8000	54.8	3.1
150	100.33	24.03	4.1752	66	24.5	100.3	23.69	4.2339	67.4	27.5
175	100.45	24.43	4.1117	63.6	19.1	100.36	23.52	4.2670	71.3	36.6

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.92	196.52	196.72	41.3	41.3	41.3	4.7632	4.12393	

Sample: C12SS5W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25										
50										
75										
100										
125										
150										
175										

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location

Sample: C12SS5W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.37	22.95	4.3734	72.3	24.9	100.15	22.75	4.4022	73.2	28.3
50	100.57	23.29	4.3182	72.5	47.6	100.14	22.9	4.3729	69.5	28.4
75	100.83	23.36	4.3164	75.8	52.9	100.18	23.35	4.2904	72.4	40.4
100	100.89	24.02	4.2002	64	13.2	99.86	23.75	4.2046	59.1	5.8
125	101.15	28.14	3.5945	48	1	99.74	25.8	3.8659	48.1	2
150	101.12	26.83	3.7689	54	6.6	99.71	26.58	3.7513	48.4	2.5
175	101.25	24.62	4.1125	61.1	15.5	99.61	23.66	4.2101	64.5	19.1

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
194.62	194.79	194.705	41	41	41	4.7489	5.11476	2.5 cm from top

Notes:

12SS5W2 Used for DRI

Cylinders - 12 Months Limewater Solution Exposure: Cyclical Partial Immersion

Sample: C12LW0F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.41	22.61	4.4410	77	53.7	100.17	22.94	4.3666	72	23.8
50	100.28	23	4.3600	73.7	38.8	100.34	23.11	4.3418	66.5	21.3
75	100.37	23.19	4.3282	69.8	21.9	101	23.43	4.3107	66	14.1
100	100.68	23.59	4.2679	73	34.8	101.06	22.97	4.3997	67.7	28.5
125	100.84	23.88	4.2228	64.1	17.7	100.44	23.72	4.2344	65.5	24.8
150	100.62	24.06	4.1820	63.5	15.7	100.67	23.83	4.2245	69.3	35.8
175	100.97	25.11	4.0211	59.3	16	100.33	24.08	4.1665	60.1	13.9

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.8	196.87	196.835	41.1	41.2	41.15	4.7834	4.32399	4.3 cm from top

Sample: C12LW0F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.2	22.85	4.3851	70.1	22.5	100.4	22.65	4.4327	75	32
50	100.43	22.36	4.4915	71.3	45	100.5	23.08	4.3544	64	12.2
75	100.61	23.49	4.2831	67.9	25.9	100.48	23.26	4.3199	69.5	31
100	100.77	23.02	4.3775	66.4	25.6	100.42	23.22	4.3247	67.2	28.7
125	100.9	23.78	4.2431	64.5	21.8	100.21	23.56	4.2534	64	15.5
150	100.95	23.59	4.2794	58.8	10	99.92	23.14	4.3181	68.1	33.2
175	101.12	23.74	4.2595	68.8	32.6	99.76	23.85	4.1828	68.8	40.6

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.14	197.88	198.01	41	41	41	4.8295	4.85316	4.5 cm from top

Sample: C12LW0F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.39	22.71	4.4205	69.3	24.7	100.27	22.26	4.5045	70	23
50	100.32	22.93	4.3751	74.7	52.1	100.45	22.52	4.4605	72	58.2
75	100.48	23.25	4.3217	68.8	31.9	100.66	23.1	4.3576	74.7	56.5
100	100.33	23.19	4.3264	64.3	15.1	100.84	23.38	4.3131	76.5	69.8
125	100.32	23.57	4.2563	65.2	24.3	100.96	23.56	4.2852	70.1	33.1
150	100.08	23.69	4.2246	65	21.6	100.96	23.77	4.2474	63.5	16.2
175	99.89	23.79	4.1988	63.8	22.3	101.01	23.96	4.2158	68.2	28.7

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.08	197.09	197.085	41.2	41.4	41.3	4.7720	4.27088	3.3 cm from top

Notes:

Cylinders - 12 Months 2% Sodium Sulphate Solution Exposure: Cyclical Partial Immersion

Sample: C12SS2F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.01	22.53	4.4390	75	48	100.1	22.53	4.4430	75.1	26.2
50	100.04	22.79	4.3896	71.5	34.6	100.15	22.77	4.3983	72.5	61.9
75	100.13	22.73	4.4052	70.5	34.9	100.33	23.12	4.3395	68.4	21.3
100	100.29	23.34	4.2969	62	10.9	100.39	25.01	4.0140	57	7.3
125	100.23	24.29	4.1264	54.6	6	100.59	24.07	4.1791	59.1	7.1
150	100.08	23.77	4.2103	69.5	38.4	100.65	27.41	3.6720	62.3	20.8
175	100.14	25.57	3.9163	60.7	17.2	100.62	24.47	4.1120	62	16.7

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.32	196.27	196.295	40.6	40.7	40.65	4.8289	4.75752	3.2 cm from top

Sample: C12SS2F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.3	22.55	4.4479	80	58.4	100.09	22.68	4.4131	66.8	22.6
50	100.46	22.36	4.4928	78.5	99.1	100.1	22.65	4.4194	75.5	64
75	100.63	23.16	4.3450	73.1	51.3	100.14	22.86	4.3806	72.6	54.4
100	100.75	23.4	4.3056	69.9	37.3	100.14	23.38	4.2831	69.2	32
125	100.82	24.24	4.1592	60.8	14.8	100	24	4.1667	60.5	12.2
150	100.74	24.73	4.0736	68.7	42.5	99.93	23.48	4.2560	67.7	39.6
175	100.84	23.77	4.2423	71.6	39.5	99.94	23.76	4.2062	69.9	34.4

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.94	198.63	198.785	41.7	41.7	41.7	4.7670	3.61167	5.3 cm from top

Sample: C12SS2F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.28	22.81	4.3963	67.9	16.6	100.31	22.76	4.4073	73.5	25.6
50	100.39	23.05	4.3553	70	39.3	100.47	22.89	4.3893	67.1	24.9
75	100.56	23.45	4.2883	65.6	19.4	100.59	23.17	4.3414	64.2	20.9
100	100.68	23.78	4.2338	68.5	24	100.63	23.78	4.2317	67.2	20.3
125	100.78	46.63	2.1614	47.275	1	100.48	24.63	4.0796	51.2	2.6
150	100.78	23.85	4.2256	65.2	24.1	100.51	24.51	4.1008	51.2	2.6
175	100.86	24.26	4.1575	63	20.6	100.07	23.94	4.1800	51.2	2.6

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.24	195.04	195.14	41.1	41.1	41.1	4.7479	4.89888	4.9 cm from top

Notes:

Cylinders - 12 Months 5% Sodium Sulphate Solution Exposure: Cyclical Partial Immersion

Sample: C12SS5F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.29	23.03	4.3548	65.5	15.9	100.16	22.95	4.3643	64	11.7
50	100.38	22.73	4.4162	68.5	44.7	100.26	23.03	4.3535	64.8	13.8
75	100.54	23.46	4.2856	65.4	16.7	100.36	22.78	4.4056	67.2	28.8
100	100.7	23.2	4.3405	67.9	20.3	100.47	23.21	4.3287	58.5	9
125	100.27	34.49	2.9075	42.333333	0	99.83	32.87	3.0371	48	2
150	100.56	24.05	4.1813	62.1	14	100.29	24.02	4.1753	63.1	15.3
175	100.58	24.03	4.1856	59.2	20.3	100.29	24.01	4.1770	60.5	19.8

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.05	197.23	197.14	41.3	41.4	41.35	4.7676	3.71199	4.6 cm from top

Sample: C12SS5F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25										
50										
75										
100										
125										
150										
175										

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location

Sample: C12SS5F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.04	22.69	4.4090	70.8	33.7	100.28	23	4.3600	70.9	20
50	100.58	22.98	4.3768	74	31.3	100.36	23.28	4.3110	75	59.4
75	100.83	23.2	4.3461	70.7	28.2	100.49	23.22	4.3277	69	25.3
100	100.04	23.3	4.2936	63.4	13.1	100.64	23.41	4.2990	66.6	22.7
125	99.28	28.69	3.4610	54.825	3.375	100.48	26.81	3.7479	57	6
150	99.86	32.36	3.0859	52.3	2	100.44	24.7	4.0664	57.3	8.3
175	99.85	23.85	4.1866	72.4	36.5	100.52	24.17	4.1589	66.7	24.2

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.37	197.5	197.435	41.4	41.3	41.35	4.7747	4.89888	

Notes:

12SS5F2 used for DRI, no tensile strength results

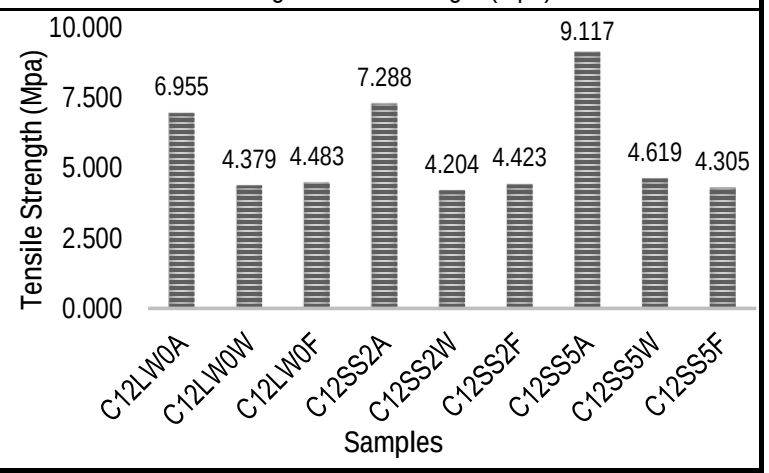
Cylinders - 24 Months Solution Exposure

Statistical Evaluation for Difference Between Samples

Ultimate Tensile Strength (Mpa) - Gas Pressure Tension Test

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
C12LW0A	6.955	0.741	10.657	0.054
C12LW0W	4.379	0.664	15.165	0.048
C12LW0F	4.483	0.322	7.182	0.023
C12SS2A	7.288	0.872	11.964	0.063
C12SS2W	4.204	0.337	8.017	0.024
C12SS2F	4.423	0.706	15.961	0.051
C12SS5A	9.117	0.932	10.226	0.083
C12SS5W	4.619	0.701	15.167	0.062
C12SS5F	4.305	0.839	19.493	0.075

Average Tensile Strength (Mpa)



T-Test

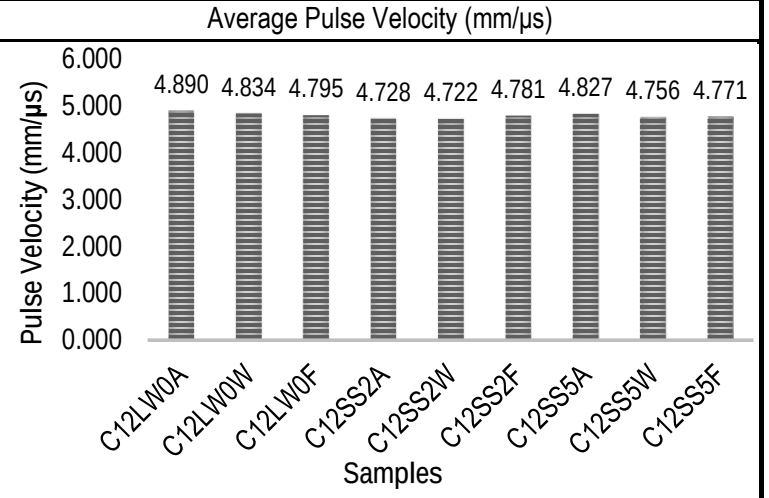
Samples	C12LW0A	C12LW0W	C12LW0F	C12SS2A	C12SS2W	C12SS2F	C12SS5A	C12SS5W	C12SS5F
C12LW0A	1.000	0.011	0.006	0.641	0.004	0.013	0.061	0.039	0.033
C12LW0W	0.891	1.000	0.820	0.010	0.704	0.942	0.007	0.724	0.918
C12LW0F	0.317	0.381	1.000	0.006	0.358	0.900	0.003	0.777	0.748
C12SS2A	0.839	0.734	0.240	1.000	0.005	0.011	0.110	0.038	0.032
C12SS2W	0.343	0.410	0.954	0.260	1.000	0.653	0.003	0.421	0.854
C12SS2F	0.951	0.939	0.344	0.792	0.371	1.000	0.007	0.780	0.875
C12SS5A	0.671	0.591	0.203	0.794	0.219	0.635	1.000	0.032	0.032
C12SS5W	0.889	0.804	0.323	0.988	0.346	0.851	0.821	1.000	0.724
C12SS5F	0.750	0.667	0.242	0.875	0.261	0.713	0.933	0.886	1.000

f-Test

Longitudinal Pulse Velocity (mm/µs) - 54 kHz Ultrasonic Pulse VelocityTest

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
C12LW0A	4.890	0.014	0.294	0.001
C12LW0W	4.834	0.034	0.699	0.002
C12LW0F	4.795	0.030	0.635	0.002
C12SS2A	4.728	0.062	1.315	0.005
C12SS2W	4.722	0.014	0.288	0.001
C12SS2F	4.781	0.042	0.885	0.003
C12SS5A	4.827	0.057	1.190	0.005
C12SS5W	4.756	0.010	0.213	0.001
C12SS5F	4.771	0.005	0.106	0.000

Average Pulse Velocity (mm/µs)

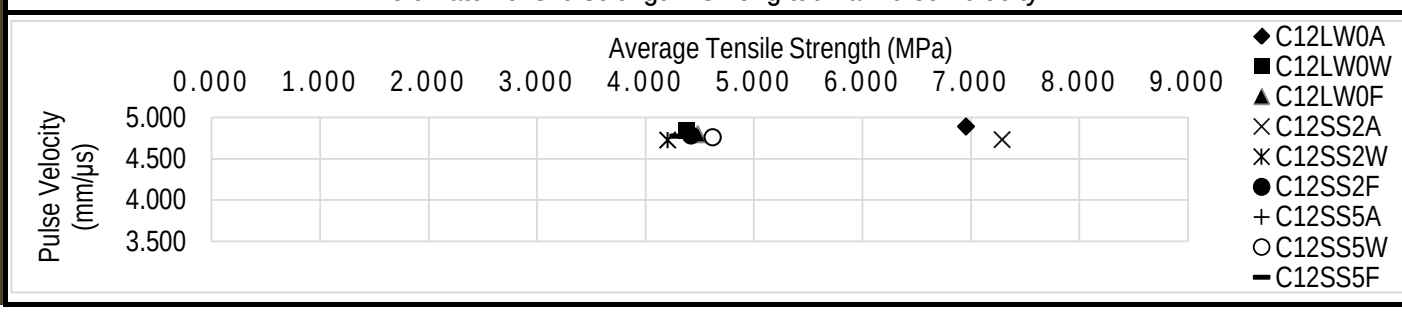


T-Test

Samples	C12LW0A	C12LW0W	C12LW0F	C12SS2A	C12SS2W	C12SS2F	C12SS5A	C12SS5W	C12SS5F
C12LW0A	1.000	0.058	0.008	0.012	0.000	0.014	0.143	0.002	0.002
C12LW0W	0.307	1.000	0.209	0.060	0.006	0.165	0.861	0.056	0.088
C12LW0F	0.365	0.897	1.000	0.170	0.020	0.673	0.462	0.194	0.374
C12SS2A	0.101	0.456	0.387	1.000	0.886	0.289	0.173	0.593	0.423
C12SS2W	0.944	0.279	0.333	0.091	1.000	0.083	0.047	0.060	0.019
C12SS2F	0.207	0.778	0.682	0.633	0.187	1.000	0.375	0.488	0.770
C12SS5A	0.115	0.462	0.400	0.906	0.103	0.615	1.000	0.229	0.306
C12SS5W	0.890	0.414	0.457	0.228	0.931	0.333	0.222	1.000	0.199
C12SS5F	0.482	0.210	0.233	0.115	0.508	0.168	0.112	0.589	1.000

f-Test

Ultimate Tensile Strength vs Longitudinal Pulse Velocity



Cylinders - 12 Months Limewater Solution Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C12LW0A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C12LW0W	C12LW0F	C12SS2A	C12SS5A	C12LW0W	C12LW0F	C12SS2A	C12SS5A
25	4.510	0.032	0.710	0.002	0.006	0.388	0.072	0.024	0.502	0.005	0.103	0.123
50	4.476	0.043	0.965	0.002	0.136	0.433	0.415	0.594	0.125	0.030	0.006	0.004
75	4.407	0.024	0.541	0.001	0.382	0.974	0.566	0.010	0.250	0.000	0.029	0.278
100	4.412	0.011	0.248	0.001	0.022	0.006	0.008	0.000	0.025	0.010	0.003	0.615
125	4.434	0.017	0.381	0.001	0.000	0.607	0.732	0.000	0.068	0.000	0.000	0.637
150	4.464	0.017	0.371	0.001	0.000	0.037	0.345	0.000	0.014	0.000	0.001	0.284
175	4.458	0.040	0.896	0.002	0.002	0.144	0.786	0.000	0.007	0.000	0.003	0.242

Amplitude

25	75.417	5.170	6.856	0.265	0.761	0.291	0.015	0.861	0.042	0.226	0.503	0.662
50	74.000	1.619	2.187	0.083	0.106	0.056	0.718	0.025	0.694	0.093	0.018	1.000
75	74.783	1.067	1.426	0.055	0.002	0.046	0.126	0.079	0.271	0.005	0.341	0.043
100	74.283	1.209	1.628	0.062	0.020	0.011	0.087	0.019	0.252	0.041	0.817	0.650
125	74.200	0.593	0.800	0.030	0.000	0.010	0.024	0.002	0.030	0.000	1.000	0.037
150	74.000	0.807	1.091	0.041	0.001	0.004	0.005	0.000	0.003	0.001	0.413	0.786
175	75.533	2.753	3.645	0.141	0.821	0.326	0.851	0.008	0.000	0.001	0.806	0.380

Energy

25	65.583	28.887	44.046	1.482	0.292	0.080	0.100	0.926	0.028	0.028	0.161	0.145
50	58.650	16.105	27.460	0.826	0.462	0.823	0.456	0.353	0.734	0.061	0.013	0.881
75	70.333	6.207	8.826	0.318	0.051	0.088	0.019	0.205	0.002	0.000	0.037	0.001
100	67.850	13.196	19.449	0.677	0.787	0.455	0.083	0.143	0.016	0.005	0.502	0.171
125	56.067	13.389	23.881	0.687	0.348	0.117	0.570	0.184	0.019	0.000	0.024	0.027
150	70.233	24.638	35.081	1.264	0.102	0.079	0.857	0.609	0.002	0.003	0.474	0.633
175	85.683	30.623	35.739	1.571	0.018	0.031	0.401	0.366	0.003	0.004	0.741	0.124

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C12LW0W	C12LW0F	C12SS2A	C12SS5A	C12LW0W	C12LW0F	C12SS2A	C12SS5A	C12LW0W	C12LW0F	C12SS2A	C12SS5A
25	1.009	1.019	1.015	1.026	1.110	1.044	0.980	1.019	2.174	2.190	0.764	1.796
50	1.007	1.018	1.017	1.029	0.991	1.052	0.962	1.000	1.073	1.546	0.631	1.035
75	1.005	1.020	1.009	1.015	1.040	1.077	0.987	1.060	2.123	2.328	0.748	1.623
100	1.010	1.018	1.021	1.007	1.030	1.074	0.996	1.015	1.531	2.010	0.874	1.400
125	1.053	1.043	1.012	1.008	1.164	1.132	1.000	1.084	2.034	2.452	0.754	1.533
150	1.081	1.051	1.012	1.031	1.175	1.144	0.982	1.013	2.828	3.180	0.864	1.142
175	1.100	1.068	1.022	1.104	1.197	1.165	1.005	1.086	4.074	3.336	1.064	1.963

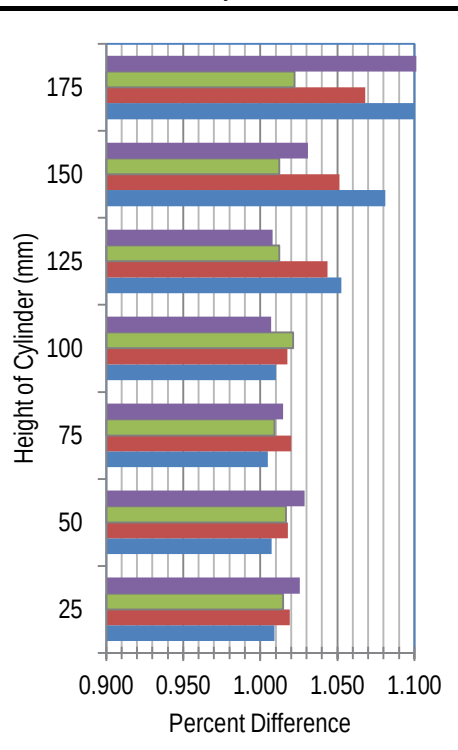
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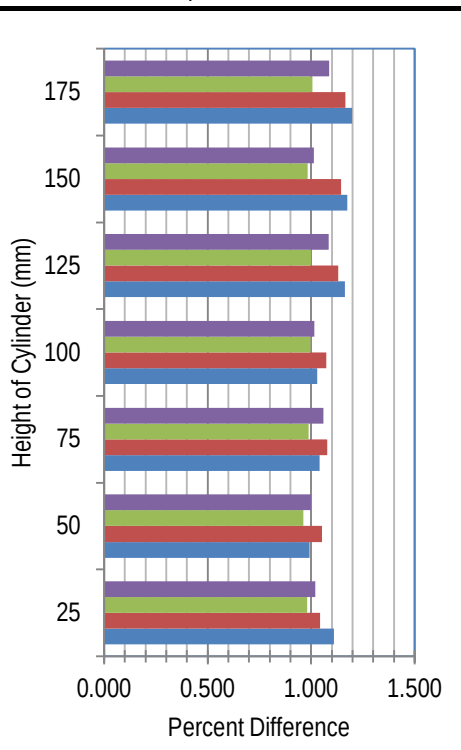
C12SS5A

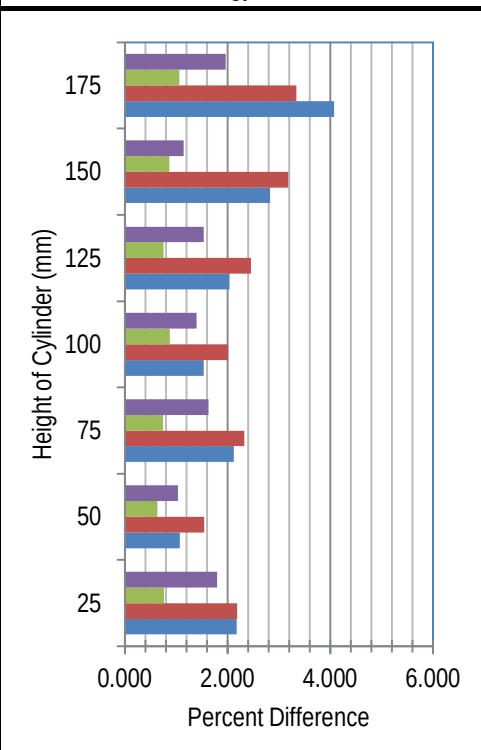
C12SS2A

C12LW0F

C12LW0W







Cylinders - 12 Months Limewater Solution Exposure: Partial Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C12LW0W				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C12LW0A	C12LW0F	C12SS2W	C12SS5W	C12LW0A	C12LW0F	C12SS2W	C12SS5W
25	4.469	0.138	3.084	0.007	0.006	0.038	0.365	0.007	0.502	0.492	0.179	0.210
50	4.443	0.021	0.469	0.001	0.136	0.030	0.131	0.063	0.125	0.138	0.004	0.132
75	4.385	0.036	0.824	0.002	0.382	0.399	0.642	0.735	0.250	0.004	0.027	0.020
100	4.367	0.035	0.807	0.002	0.022	0.537	0.006	0.216	0.025	0.215	0.031	0.008
125	4.212	0.234	5.552	0.012	0.000	0.000	0.504	0.325	0.068	0.716	0.140	0.010
150	4.130	0.221	5.350	0.011	0.000	0.004	0.266	0.710	0.014	0.259	0.047	0.361
175	4.051	0.229	5.651	0.012	0.002	0.041	0.761	0.101	0.007	0.260	0.813	0.334

Amplitude

25	67.917	5.966	8.785	0.306	0.761	0.180	0.524	0.295	0.042	0.147	0.441	0.055
50	74.650	3.587	4.804	0.184	0.106	0.731	0.449	0.772	0.694	0.087	0.697	0.535
75	71.900	5.663	7.876	0.290	0.002	0.171	0.079	0.304	0.271	0.368	0.969	0.822
100	72.117	4.005	5.554	0.205	0.020	0.768	0.172	0.830	0.252	0.266	0.032	0.017
125	63.767	8.513	13.350	0.437	0.000	0.012	0.081	0.343	0.030	0.636	0.030	0.037
150	62.983	5.134	8.151	0.263	0.001	0.509	0.426	0.237	0.003	0.523	0.143	0.396
175	63.100	3.063	4.854	0.157	0.821	0.445	0.369	0.458	0.000	0.447	0.854	0.409

Energy

25	30.167	17.435	57.797	0.894	0.292	0.446	0.571	0.960	0.028	0.981	0.702	0.355
50	54.667	22.839	41.778	1.172	0.462	0.605	0.183	0.549	0.734	0.188	0.968	0.686
75	33.133	16.504	49.809	0.847	0.051	0.776	0.957	0.859	0.002	0.751	0.273	0.233
100	44.317	14.984	33.811	0.769	0.787	0.630	0.687	0.424	0.016	0.307	0.025	0.008
125	27.567	20.949	75.994	1.075	0.348	0.018	0.000	0.006	0.019	1.000	0.042	0.036
150	24.833	11.031	44.420	0.566	0.102	0.889	0.685	0.745	0.002	0.665	0.207	0.239
175	21.033	8.979	42.688	0.461	0.018	0.781	0.818	0.848	0.003	0.422	0.591	0.801

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C12LW0A	C12LW0F	C12SS2W	C12SS5W	C12LW0A	C12LW0F	C12SS2W	C12SS5W	C12LW0A	C12LW0F	C12SS2W	C12SS5W
25	0.991	1.010	1.022	1.019	0.901	0.940	0.965	0.903	0.460	1.007	1.133	0.734
50	0.993	1.010	1.017	1.013	1.009	1.061	1.010	1.019	0.932	1.441	1.008	1.112
75	0.995	1.015	1.014	1.014	0.961	1.035	1.001	0.990	0.471	1.097	0.747	0.717
100	0.990	1.007	1.044	1.026	0.971	1.042	1.140	1.124	0.653	1.313	2.314	2.930
125	0.950	0.991	1.066	1.116	0.859	0.973	1.195	1.227	0.492	1.206	6.411	8.482
150	0.925	0.973	1.109	1.037	0.851	0.973	1.103	1.068	0.354	1.125	1.625	1.626
175	0.909	0.971	1.007	0.970	0.835	0.973	1.007	0.969	0.245	0.819	1.149	0.932

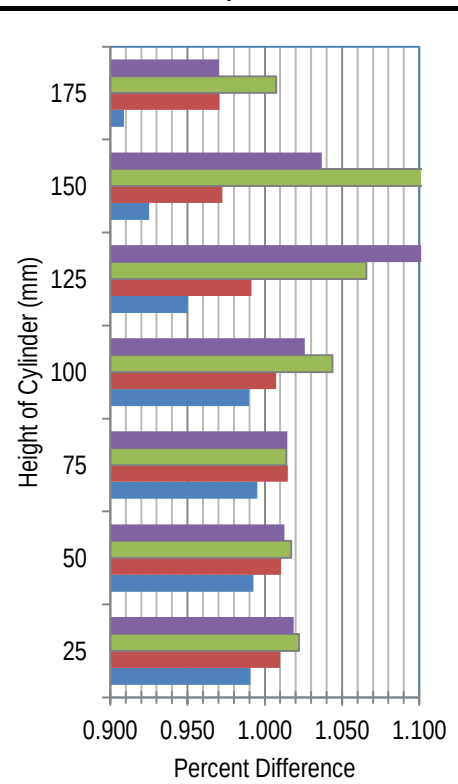
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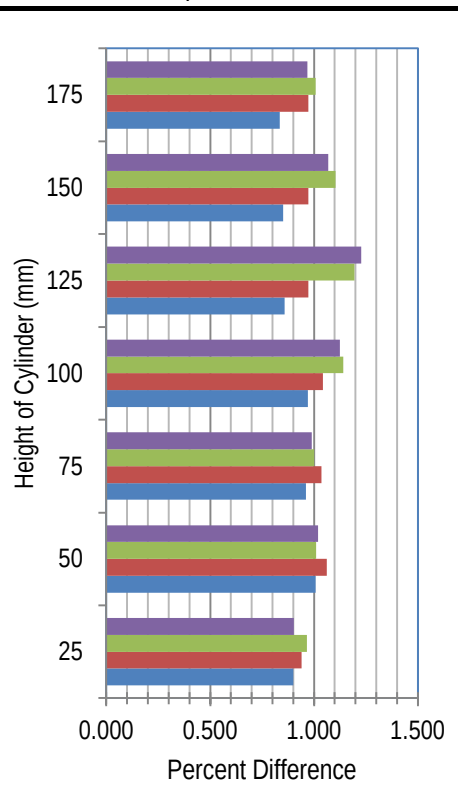
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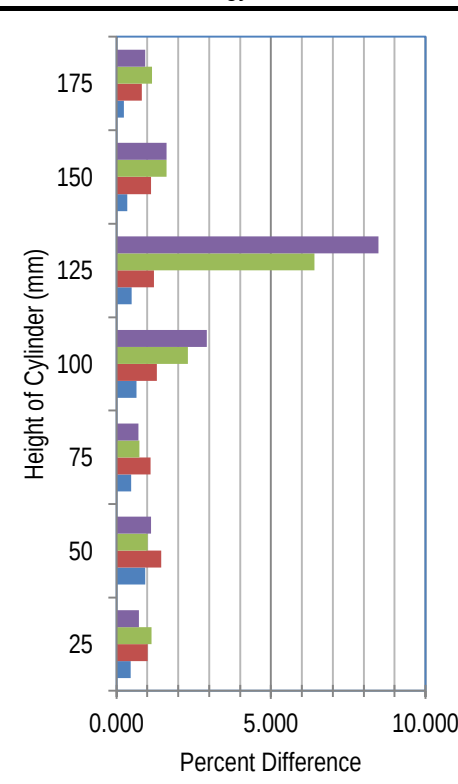
C12SS2W

C12LW0F

C12LW0A







Cylinders - 12 Months Limewater Solution Exposure: Partial Cyclic Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C12LW0F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C12LW0A	C12LW0W	C12SS2F	C12SS5F	C12LW0A	C12LW0W	C12SS2F	C12SS5F
25	4.425	0.048	1.091	0.002	0.388	0.038	0.101	0.307	0.005	0.492	0.977	0.081
50	4.397	0.063	1.426	0.003	0.433	0.030	0.532	0.594	0.030	0.138	0.755	0.394
75	4.320	0.024	0.560	0.001	0.974	0.399	0.294	0.154	0.000	0.004	0.149	0.391
100	4.335	0.047	1.089	0.002	0.006	0.537	0.089	0.259	0.010	0.215	0.064	0.472
125	4.249	0.022	0.507	0.001	0.607	0.000	0.000	0.000	0.000	0.716	0.243	0.016
150	4.246	0.048	1.121	0.002	0.037	0.004	0.005	0.000	0.000	0.259	0.140	0.259
175	4.174	0.081	1.952	0.004	0.144	0.041	0.454	0.012	0.000	0.260	0.523	0.934

Amplitude

25	72.233	3.117	4.315	0.160	0.291	0.180	0.335	0.734	0.226	0.147	0.739	0.973
50	70.367	4.217	5.993	0.216	0.056	0.731	0.925	0.746	0.093	0.087	0.388	0.161
75	69.450	2.913	4.194	0.149	0.046	0.171	0.629	0.732	0.005	0.368	0.845	0.242
100	69.183	4.601	6.650	0.236	0.011	0.768	0.831	0.934	0.041	0.266	0.234	0.016
125	65.567	2.299	3.507	0.118	0.010	0.012	0.077	0.042	0.000	0.636	0.005	0.026
150	64.700	3.755	5.804	0.193	0.004	0.509	0.214	0.546	0.001	0.523	0.854	0.227
175	64.833	4.402	6.790	0.226	0.326	0.445	0.290	0.491	0.001	0.447	0.623	0.592

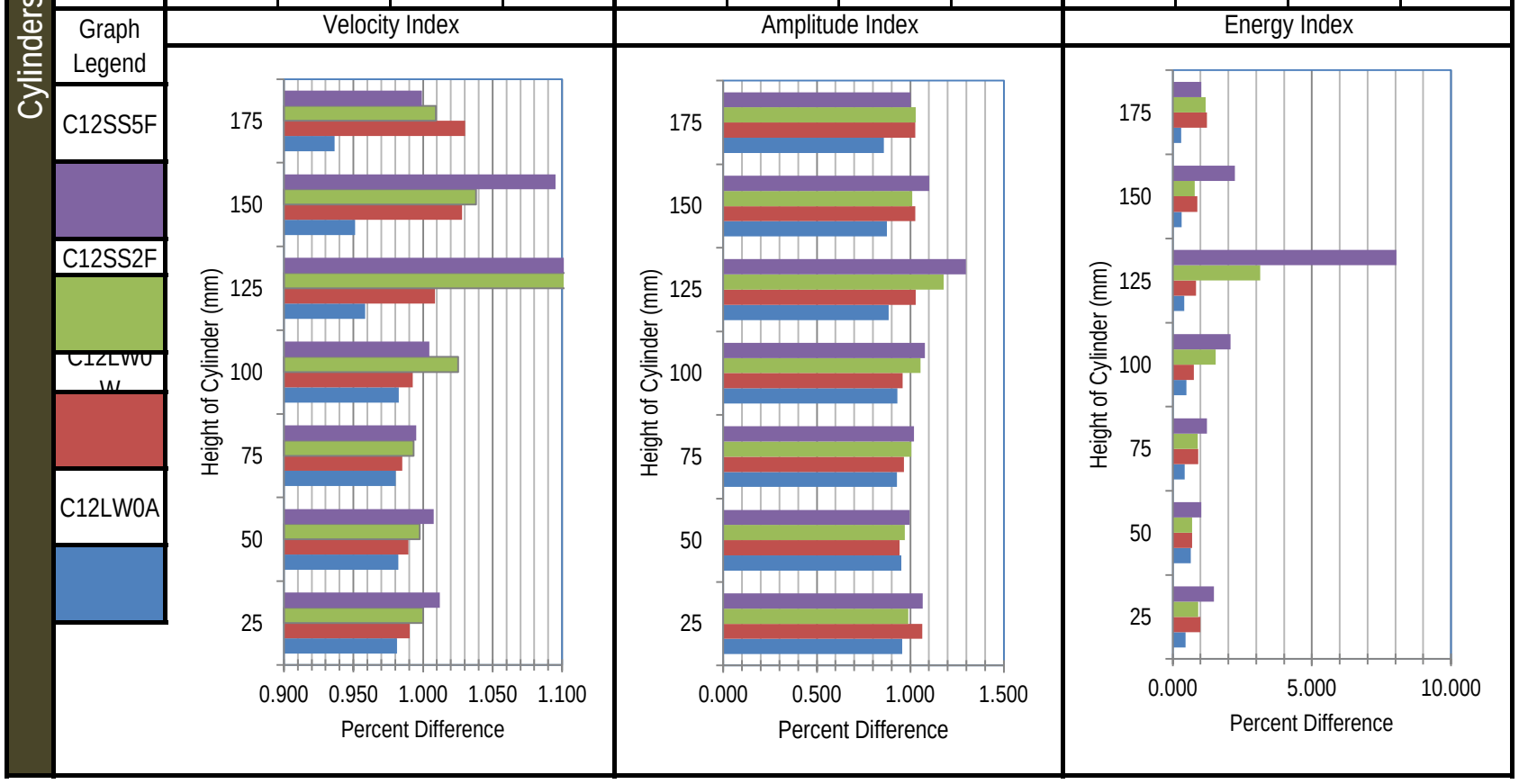
Energy

25	29.950	12.145	40.550	0.623	0.080	0.446	0.524	0.733	0.028	0.981	0.731	0.338
50	37.933	17.894	47.172	0.918	0.823	0.605	0.389	0.812	0.061	0.188	0.253	0.249
75	30.217	14.435	47.771	0.741	0.088	0.776	0.839	0.149	0.000	0.751	0.699	0.364
100	33.750	18.804	55.717	0.965	0.455	0.630	0.318	0.103	0.005	0.307	0.221	0.008
125	22.867	6.207	27.143	0.318	0.117	0.018	0.756	0.169	0.000	1.000	0.001	0.050
150	22.083	10.328	46.768	0.530	0.079	0.889	0.411	0.412	0.003	0.665	0.450	0.041
175	25.683	10.232	39.841	0.525	0.031	0.781	0.575	0.693	0.004	0.422	0.587	0.472

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C12LW0A	C12LW0W	C12SS2F	C12SS5F	C12LW0A	C12LW0W	C12SS2F	C12SS5F	C12LW0A	C12LW0W	C12SS2F	C12SS5F
25	0.981	0.990	1.000	1.012	0.958	1.064	0.989	1.065	0.457	0.993	0.910	1.474
50	0.982	0.990	0.998	1.008	0.951	0.943	0.970	0.997	0.647	0.694	0.703	1.017
75	0.980	0.985	0.993	0.995	0.929	0.966	1.006	1.020	0.430	0.912	0.897	1.221
100	0.983	0.993	1.025	1.005	0.931	0.959	1.054	1.079	0.497	0.762	1.536	2.074
125	0.958	1.009	1.115	1.292	0.884	1.028	1.180	1.297	0.408	0.830	3.140	8.041
150	0.951	1.028	1.038	1.095	0.874	1.027	1.009	1.102	0.314	0.889	0.789	2.231
175	0.936	1.030	1.009	0.999	0.858	1.027	1.028	1.002	0.300	1.221	1.176	1.019



Cylinders - 12 Months 2% Sodium Sulfate Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C12SS2A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C12SS2W	C12SS2F	C12LW0A	C12SS5A	C12SS2W	C12SS2F	C12LW0A	C12SS5A
25	4.445	0.078	1.763	0.004	0.778	0.013	0.072	0.512	0.163	0.564	0.103	0.441
50	4.403	0.029	0.666	0.002	0.405	0.331	0.415	0.209	0.141	0.847	0.006	0.083
75	4.366	0.031	0.716	0.002	0.443	0.602	0.566	0.032	0.092	0.461	0.029	0.669
100	4.320	0.045	1.035	0.002	0.018	0.072	0.008	0.083	0.081	0.099	0.003	0.356
125	4.380	0.020	0.453	0.001	0.000	0.000	0.732	0.001	0.022	0.147	0.000	0.800
150	4.409	0.026	0.589	0.001	0.000	0.000	0.345	0.000	0.007	0.015	0.001	0.499
175	4.361	0.045	1.041	0.002	0.006	0.060	0.786	0.000	0.008	0.004	0.003	0.346
Amplitude												
25	76.983	1.459	1.896	0.075	0.030	0.018	0.015	0.034	0.013	0.112	0.503	0.273
50	76.883	1.919	2.496	0.098	0.574	0.128	0.718	0.050	0.045	0.038	0.018	0.367
75	75.800	2.253	2.972	0.116	0.914	0.311	0.126	0.702	0.013	0.003	0.341	0.010
100	74.583	2.814	3.773	0.144	0.044	0.220	0.087	0.394	0.014	0.004	0.817	0.549
125	74.200	1.890	2.547	0.097	0.185	0.034	0.024	0.267	0.000	0.000	1.000	0.007
150	75.350	3.646	4.839	0.187	0.140	0.193	0.005	0.258	0.000	0.005	0.413	0.484
175	75.150	2.521	3.355	0.129	0.198	0.036	0.851	0.006	0.000	0.008	0.806	0.407
Energy												
25	85.867	12.844	14.958	0.659	0.936	0.603	0.100	0.160	0.000	0.000	0.161	0.004
50	92.983	22.937	24.667	1.177	0.180	0.731	0.456	0.788	0.004	0.022	0.013	0.046
75	93.967	20.712	22.041	1.063	0.668	0.575	0.019	0.377	0.001	0.000	0.037	0.002
100	77.633	31.150	40.125	1.598	0.259	0.050	0.083	0.906	0.003	0.006	0.502	0.170
125	74.350	10.237	13.769	0.525	0.006	0.182	0.570	0.352	0.000	0.000	0.024	0.000
150	81.283	26.822	32.999	1.376	0.152	0.242	0.857	0.723	0.000	0.002	0.474	0.314
175	80.567	20.530	25.482	1.053	0.061	0.366	0.401	0.102	0.000	0.000	0.741	0.124

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C12SS2W	C12SS2F	C12LW0A	C12SS5A	C12SS2W	C12SS2F	C12LW0A	C12SS5A	C12SS2W	C12SS2F	C12LW0A	C12SS5A
25	1.017	1.005	0.986	1.011	1.094	1.054	1.021	1.041	3.224	2.610	1.309	2.351
50	1.008	0.999	0.984	1.012	1.040	1.060	1.039	1.039	1.715	1.723	1.585	1.641
75	1.010	1.004	0.991	1.005	1.056	1.097	1.014	1.074	2.120	2.788	1.336	2.169
100	1.032	1.022	0.979	0.986	1.179	1.136	1.004	1.019	4.054	3.534	1.144	1.602
125	1.108	1.149	0.988	0.996	1.390	1.335	1.000	1.084	17.291	10.208	1.326	2.033
150	1.184	1.078	0.988	1.018	1.320	1.176	1.018	1.031	5.318	2.903	1.157	1.321
175	1.084	1.054	0.978	1.080	1.199	1.192	0.995	1.081	4.403	3.690	0.940	1.846

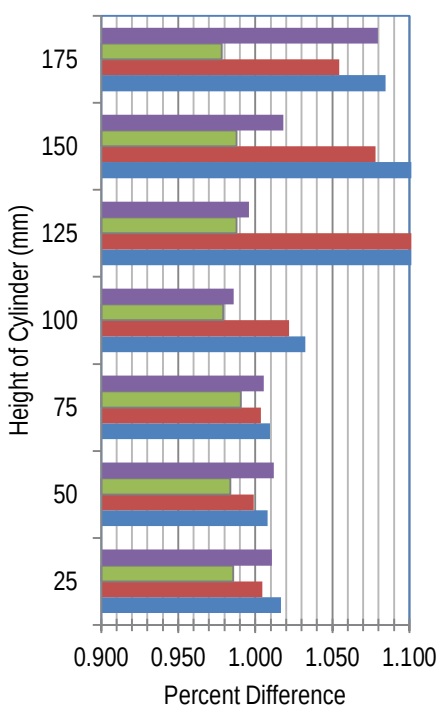
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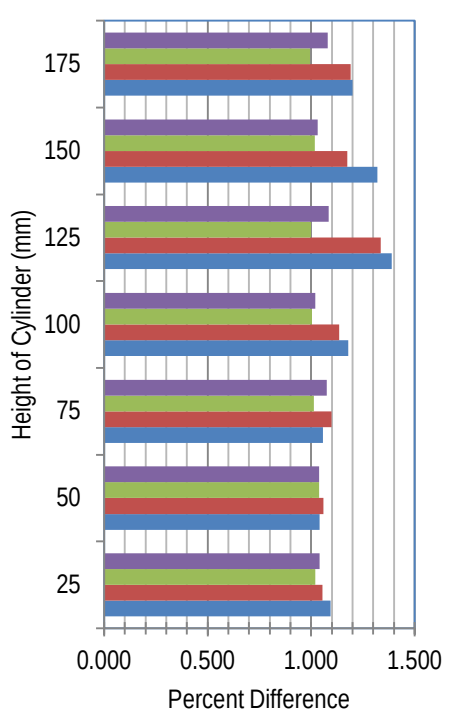
C12SS5A

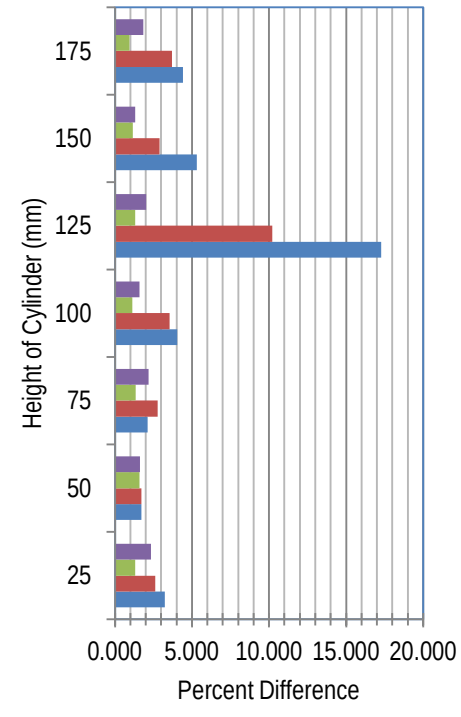
C12LW0A

C12SS2F

C12SS2W







Cylinders - 12 Months 2% Sodium Sulfate Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C12SS2W				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C12SS2A	C12SS2F	C12LW0W	C12SS5W	C12SS2A	C12SS2F	C12LW0W	C12SS5W
25	4.372	0.089	2.047	0.005	0.778	0.007	0.365	0.024	0.163	0.212	0.179	0.694
50	4.369	0.044	0.998	0.002	0.405	0.885	0.131	0.608	0.141	0.168	0.004	0.565
75	4.324	0.045	1.041	0.002	0.443	0.801	0.642	0.479	0.092	0.318	0.027	0.951
100	4.184	0.151	3.620	0.008	0.018	0.490	0.006	0.198	0.081	0.583	0.031	0.398
125	3.952	0.321	8.123	0.016	0.000	0.064	0.504	0.148	0.022	0.706	0.140	0.332
150	3.725	0.377	10.122	0.019	0.000	0.251	0.266	0.565	0.007	0.067	0.047	0.270
175	4.021	0.198	4.935	0.010	0.006	0.265	0.761	0.148	0.008	0.250	0.813	0.183

Amplitude

25	70.350	4.414	6.274	0.226	0.030	0.810	0.524	0.570	0.013	0.342	0.441	0.091
50	73.933	2.503	3.386	0.128	0.574	0.318	0.449	0.720	0.045	0.482	0.697	0.701
75	71.800	2.371	3.302	0.122	0.914	0.363	0.079	0.638	0.013	0.156	0.969	0.635
100	63.250	7.771	12.287	0.399	0.044	0.374	0.172	0.357	0.014	0.544	0.032	0.836
125	53.383	3.590	6.725	0.184	0.185	0.365	0.081	0.580	0.000	0.434	0.030	0.601
150	57.083	7.497	13.133	0.385	0.140	0.846	0.426	0.634	0.000	0.121	0.143	0.733
175	62.667	4.699	7.498	0.241	0.198	0.354	0.369	0.963	0.000	0.912	0.854	0.429

Energy

25	26.633	13.341	50.092	0.684	0.936	0.660	0.571	0.586	0.000	0.485	0.702	0.169
50	54.233	11.979	22.088	0.615	0.180	0.099	0.183	0.580	0.004	0.983	0.968	0.572
75	44.333	16.925	38.176	0.868	0.668	0.893	0.957	0.824	0.001	0.288	0.273	0.861
100	19.150	18.113	94.585	0.929	0.259	0.356	0.687	0.275	0.003	0.755	0.025	0.695
125	4.300	2.380	55.347	0.122	0.006	0.099	0.000	0.814	0.000	0.254	0.042	0.527
150	15.283	13.353	87.367	0.685	0.152	0.776	0.685	0.982	0.000	0.156	0.207	0.999
175	18.300	8.058	44.032	0.413	0.061	0.293	0.818	0.695	0.000	0.591	0.591	0.465

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C12SS2A	C12SS2F	C12LW0W	C12SS5W	C12SS2A	C12SS2F	C12LW0W	C12SS5W	C12SS2A	C12SS2F	C12LW0W	C12SS5W
25	0.984	0.988	0.978	0.996	0.914	0.963	1.036	0.935	0.310	0.810	0.883	0.648
50	0.992	0.991	0.983	0.996	0.962	1.020	0.990	1.009	0.583	1.005	0.992	1.103
75	0.990	0.994	0.986	1.000	0.947	1.040	0.999	0.989	0.472	1.316	1.338	0.960
100	0.969	0.990	0.958	0.983	0.848	0.964	0.877	0.986	0.247	0.872	0.432	1.266
125	0.902	1.037	0.938	1.047	0.719	0.960	0.837	1.027	0.058	0.590	0.156	1.323
150	0.845	0.911	0.902	0.935	0.758	0.891	0.906	0.968	0.188	0.546	0.615	1.001
175	0.922	0.972	0.993	0.963	0.834	0.994	0.993	0.962	0.227	0.838	0.870	0.811

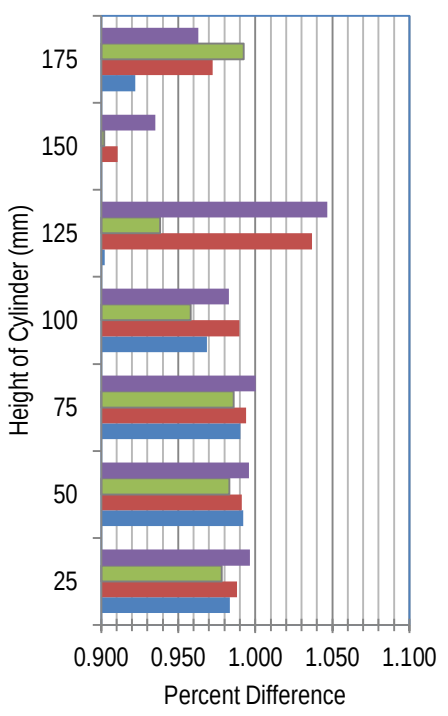
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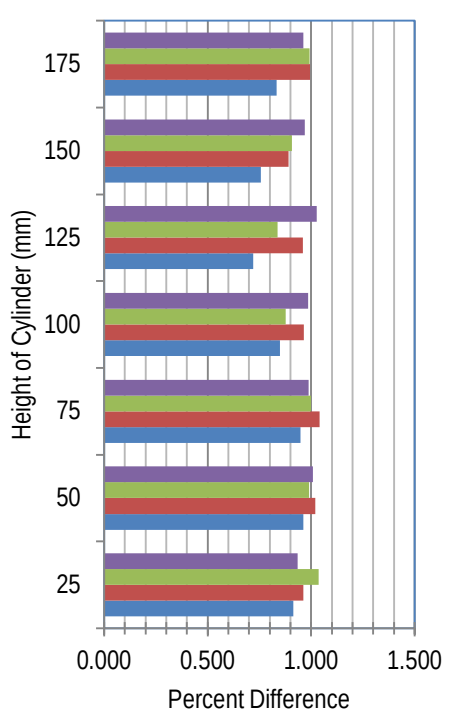
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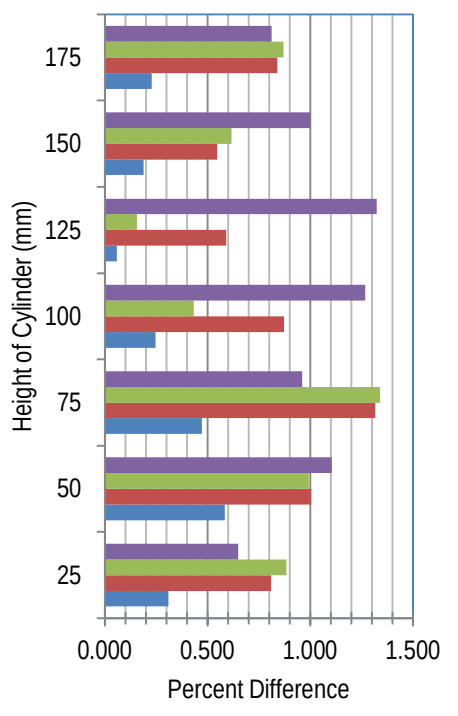
C12LW0W

C12SS2F

C12SS2A







Cylinders - 12 Months 2% Sodium Sulfate Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C12SS2F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C12SS2A	C12SS2W	C12LW0F	C12SS5F	C12SS2A	C12SS2W	C12LW0F	C12SS5F
25	4.424	0.022	0.487	0.001	0.013	0.007	0.101	0.719	0.564	0.212	0.977	0.008
50	4.407	0.047	1.059	0.002	0.331	0.885	0.532	0.986	0.847	0.168	0.755	0.182
75	4.350	0.040	0.920	0.002	0.602	0.801	0.294	0.622	0.461	0.318	0.149	0.766
100	4.228	0.109	2.584	0.006	0.072	0.490	0.089	0.027	0.099	0.583	0.064	0.108
125	3.812	0.809	21.234	0.042	0.000	0.064	0.000	0.254	0.147	0.706	0.243	0.269
150	4.090	0.217	5.307	0.011	0.000	0.251	0.005	0.083	0.015	0.067	0.140	0.493
175	4.136	0.116	2.809	0.006	0.060	0.265	0.454	0.004	0.004	0.250	0.523	0.426

Amplitude

25	73.050	4.942	6.765	0.254	0.018	0.810	0.335	0.630	0.112	0.342	0.739	0.107
50	72.517	4.035	5.564	0.207	0.128	0.318	0.925	0.685	0.038	0.482	0.388	0.507
75	69.067	3.659	5.298	0.188	0.311	0.363	0.629	0.468	0.003	0.156	0.845	0.645
100	65.633	5.086	7.749	0.261	0.220	0.374	0.831	0.795	0.004	0.544	0.234	0.632
125	55.579	5.531	9.952	0.284	0.034	0.365	0.077	0.663	0.000	0.434	0.005	0.229
150	64.100	6.843	10.676	0.351	0.193	0.846	0.214	0.633	0.005	0.121	0.854	0.214
175	63.067	7.309	11.589	0.375	0.036	0.354	0.290	0.812	0.008	0.912	0.623	0.722

Energy

25	32.900	16.421	49.911	0.842	0.603	0.660	0.524	0.400	0.000	0.485	0.731	0.208
50	53.967	26.965	49.967	1.383	0.731	0.099	0.389	0.625	0.022	0.983	0.253	0.321
75	33.700	15.886	47.139	0.815	0.575	0.893	0.839	0.115	0.000	0.288	0.699	0.318
100	21.967	11.664	53.100	0.598	0.050	0.356	0.318	0.344	0.006	0.755	0.221	0.404
125	7.283	5.362	73.623	0.275	0.182	0.099	0.756	0.244	0.000	0.254	0.001	0.166
150	28.000	15.266	54.520	0.783	0.242	0.776	0.411	0.161	0.002	0.156	0.450	0.057
175	21.833	13.336	61.083	0.684	0.366	0.293	0.575	0.405	0.000	0.591	0.587	0.664

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C12SS2A	C12SS2W	C12LW0F	C12SS5F	C12SS2A	C12SS2W	C12LW0F	C12SS5F	C12SS2A	C12SS2W	C12LW0F	C12SS5F
25	0.995	1.012	1.000	1.012	0.949	1.038	1.011	1.077	0.383	1.235	1.098	1.619
50	1.001	1.009	1.002	1.010	0.943	0.981	1.031	1.028	0.580	0.995	1.423	1.447
75	0.996	1.006	1.007	1.002	0.911	0.962	0.994	1.015	0.359	0.760	1.115	1.362
100	0.979	1.010	0.975	0.980	0.880	1.038	0.949	1.024	0.283	1.147	0.651	1.350
125	0.870	0.964	0.897	1.159	0.749	1.041	0.848	1.100	0.098	1.694	0.319	2.561
150	0.928	1.098	0.963	1.055	0.851	1.123	0.991	1.092	0.344	1.832	1.268	2.828
175	0.948	1.028	0.991	0.990	0.839	1.006	0.973	0.975	0.271	1.193	0.850	0.866

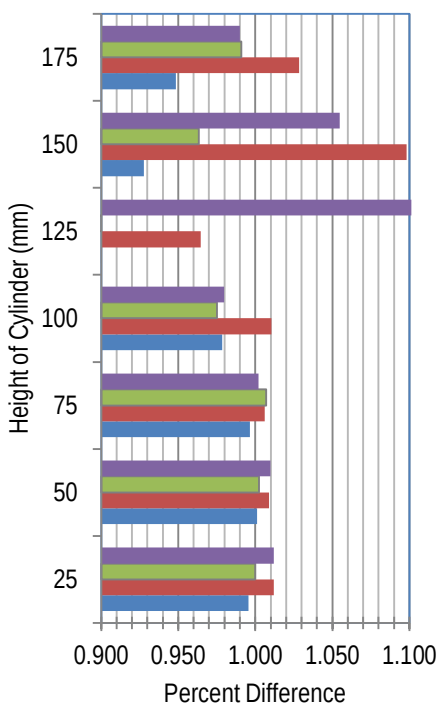
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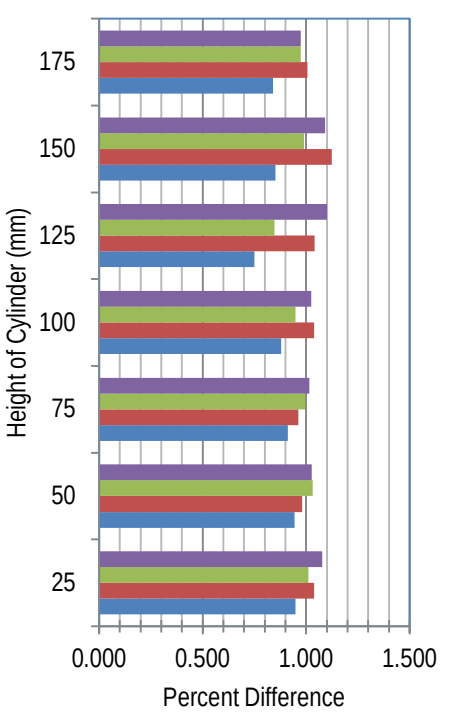
C12SS5F

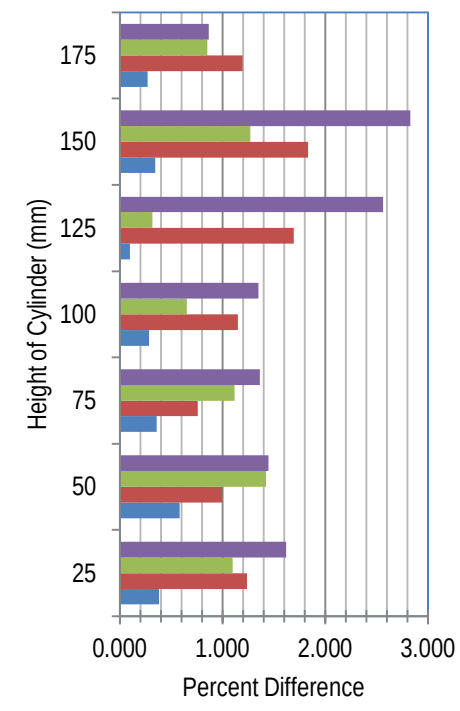
C12LW0F

C12SS2W

C12SS2A







Cylinders - 12 Months 2% Sodium Sulfate Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C12SS5A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C12SS5W	C12SS5F	C12LW0A	C12SS2A	C12SS5W	C12SS5F	C12LW0A	C12SS2A
25	4.398	0.106	2.421	0.007	0.015	0.040	0.024	0.512	0.857	0.668	0.123	0.441
50	4.351	0.055	1.264	0.003	0.997	0.723	0.594	0.209	0.382	0.713	0.004	0.083
75	4.343	0.097	2.230	0.006	0.074	0.304	0.010	0.032	0.715	0.982	0.278	0.669
100	4.381	0.110	2.500	0.007	0.420	0.028	0.000	0.083	0.101	0.321	0.615	0.356
125	4.398	0.135	3.069	0.008	0.891	0.117	0.000	0.001	0.000	0.002	0.637	0.800
150	4.330	0.206	4.760	0.013	0.722	0.155	0.000	0.000	0.080	0.163	0.284	0.499
175	4.039	0.576	14.267	0.036	0.008	0.000	0.000	0.000	0.670	0.665	0.242	0.346

Amplitude

25	73.975	4.466	6.037	0.281	0.542	0.724	0.861	0.034	0.653	0.074	0.662	0.273
50	74.000	5.354	7.235	0.336	0.341	0.860	0.025	0.050	0.814	0.377	1.000	0.367
75	70.550	2.644	3.747	0.166	0.875	0.816	0.079	0.702	0.332	0.206	0.043	0.010
100	73.200	4.248	5.803	0.267	0.987	0.981	0.019	0.394	0.024	0.022	0.650	0.549
125	68.425	3.276	4.787	0.206	0.586	0.272	0.002	0.267	0.001	0.003	0.037	0.007
150	73.050	6.390	8.748	0.402	0.559	0.688	0.000	0.258	0.046	0.012	0.786	0.484
175	69.525	11.620	16.714	0.730	0.142	0.316	0.008	0.006	0.505	0.490	0.380	0.407

Energy

25	36.525	26.129	71.537	1.642	0.503	0.132	0.926	0.160	0.778	0.288	0.145	0.004
50	56.650	25.317	44.690	1.591	0.436	0.674	0.353	0.788	0.631	0.271	0.881	0.046
75	43.325	11.715	27.040	0.736	0.757	0.254	0.205	0.377	0.766	0.029	0.001	0.002
100	48.475	27.785	57.317	1.746	0.095	0.037	0.143	0.906	0.091	0.101	0.171	0.170
125	36.575	5.619	15.362	0.353	0.233	0.221	0.184	0.352	0.000	0.000	0.027	0.000
150	61.525	31.006	50.396	1.948	0.172	0.024	0.609	0.723	0.033	0.042	0.633	0.314
175	43.650	47.511	108.846	2.985	0.025	0.014	0.366	0.102	0.444	0.497	0.124	0.124

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C12SS5W	C12SS5F	C12LW0A	C12SS2A	C12SS5W	C12SS5F	C12LW0A	C12SS2A	C12SS5W	C12SS5F	C12LW0A	C12SS2A
25	1.002	1.006	0.975	0.989	0.983	1.091	0.981	0.961	0.888	1.797	0.557	0.425
50	0.992	0.997	0.972	0.988	1.010	1.049	1.000	0.962	1.153	1.519	0.966	0.609
75	1.005	1.000	0.985	0.995	0.971	1.036	0.943	0.931	0.938	1.751	0.616	0.461
100	1.029	1.015	0.993	1.014	1.141	1.142	0.985	0.981	3.205	2.978	0.714	0.624
125	1.165	1.338	0.992	1.004	1.316	1.354	0.922	0.922	11.254	12.862	0.652	0.492
150	1.087	1.117	0.970	0.982	1.239	1.244	0.987	0.969	4.028	6.215	0.876	0.757
175	0.967	0.967	0.906	0.926	1.068	1.075	0.920	0.925	1.934	1.732	0.509	0.542

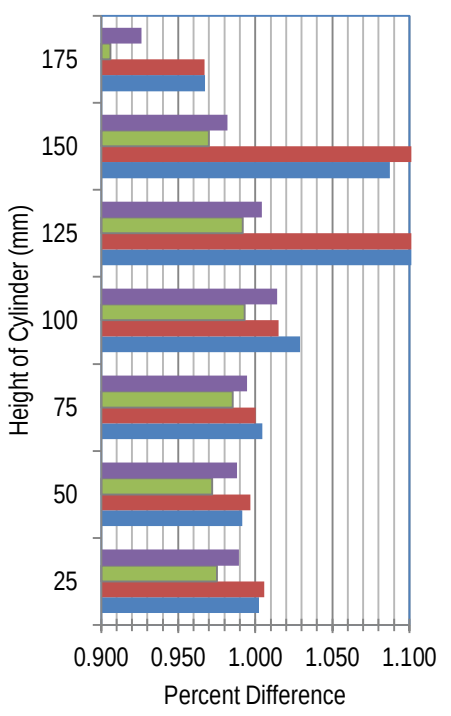
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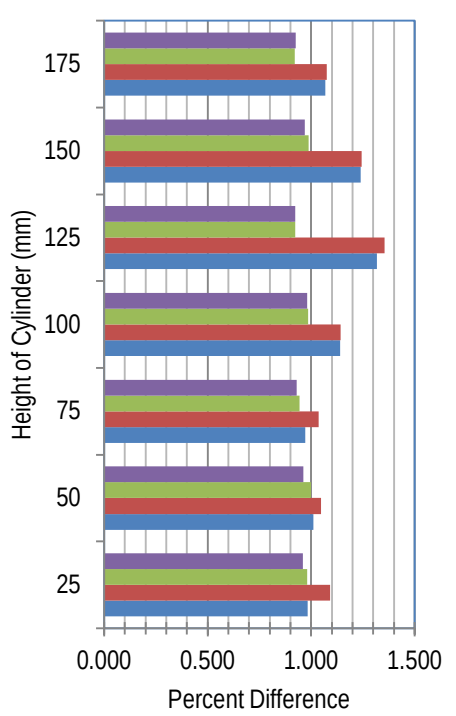
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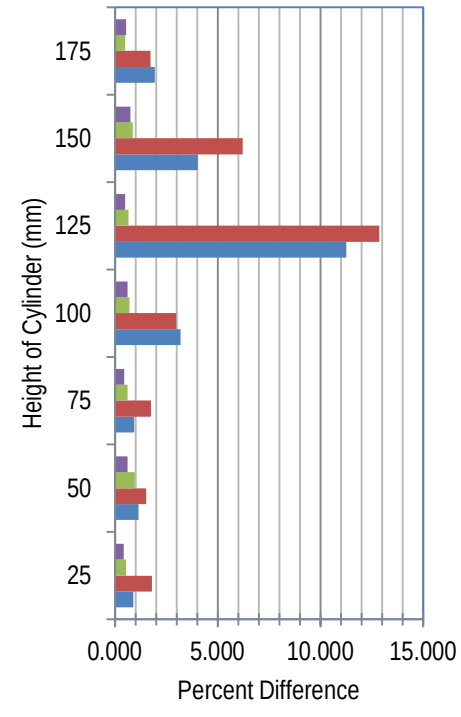
C12LW0A

C12SS5F

C12SS5W







Cylinders - 12 Months 2% Sodium Sulfate Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C12SS5W				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C12SS5A	C12SS5F	C12LW0W	C12SS2W	C12SS5A	C12SS5F	C12LW0W	C12SS2W
25	4.387	0.018	0.407	0.001	0.015	0.595	0.007	0.024	0.857	0.363	0.210	0.694
50	4.387	0.055	1.250	0.003	0.997	0.726	0.063	0.608	0.382	0.537	0.132	0.565
75	4.323	0.028	0.658	0.002	0.074	0.381	0.735	0.479	0.715	0.538	0.020	0.951
100	4.257	0.065	1.538	0.004	0.420	0.116	0.216	0.198	0.101	0.143	0.008	0.398
125	3.776	0.124	3.281	0.008	0.891	0.094	0.325	0.148	0.000	0.081	0.010	0.332
150	3.982	0.258	6.473	0.016	0.722	0.267	0.710	0.565	0.080	0.734	0.361	0.270
175	4.175	0.077	1.834	0.005	0.008	0.015	0.101	0.148	0.670	0.968	0.334	0.183

Amplitude

25	75.250	3.034	4.031	0.191	0.542	0.794	0.295	0.570	0.653	0.019	0.055	0.091
50	73.250	2.901	3.961	0.182	0.341	0.431	0.772	0.720	0.814	0.377	0.535	0.701
75	72.625	2.917	4.017	0.183	0.875	0.698	0.304	0.638	0.332	0.049	0.822	0.635
100	64.175	4.291	6.687	0.270	0.987	0.968	0.830	0.357	0.024	0.981	0.017	0.836
125	51.975	4.621	8.890	0.290	0.586	0.560	0.343	0.580	0.001	0.736	0.037	0.601
150	58.950	9.254	15.698	0.581	0.559	0.333	0.237	0.634	0.046	0.964	0.396	0.733
175	65.125	4.361	6.696	0.274	0.142	0.597	0.458	0.963	0.505	0.913	0.409	0.429

Energy

25	41.125	17.077	41.525	1.073	0.503	0.364	0.960	0.586	0.778	0.078	0.355	0.169
50	49.150	15.406	31.345	0.968	0.436	0.713	0.549	0.580	0.631	0.376	0.686	0.572
75	46.200	14.225	30.790	0.894	0.757	0.159	0.859	0.824	0.766	0.031	0.233	0.861
100	15.125	8.940	59.105	0.562	0.095	0.586	0.424	0.275	0.091	0.841	0.008	0.695
125	3.250	2.580	79.386	0.162	0.233	0.970	0.006	0.814	0.000	0.829	0.036	0.527
150	15.275	12.557	82.204	0.789	0.172	0.265	0.745	0.982	0.033	0.470	0.239	0.999
175	22.575	9.503	42.094	0.597	0.025	0.751	0.848	0.695	0.444	0.684	0.801	0.465

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C12SS5A	C12SS5F	C12LW0W	C12SS2W	C12SS5A	C12SS5F	C12LW0W	C12SS2W	C12SS5A	C12SS5F	C12LW0W	C12SS2W
25	0.998	1.003	0.982	1.004	1.017	1.110	1.108	1.070	1.126	2.023	1.363	1.544
50	1.008	1.005	0.987	1.004	0.990	1.038	0.981	0.991	0.868	1.318	0.899	0.906
75	0.995	0.996	0.986	1.000	1.029	1.067	1.010	1.011	1.066	1.867	1.394	1.042
100	0.972	0.986	0.975	1.017	0.877	1.001	0.890	1.015	0.312	0.929	0.341	0.790
125	0.858	1.148	0.896	0.955	0.760	1.028	0.815	0.974	0.089	1.143	0.118	0.756
150	0.920	1.027	0.964	1.069	0.807	1.004	0.936	1.033	0.248	1.543	0.615	0.999
175	1.034	1.000	1.031	1.038	0.937	1.007	1.032	1.039	0.517	0.896	1.073	1.234

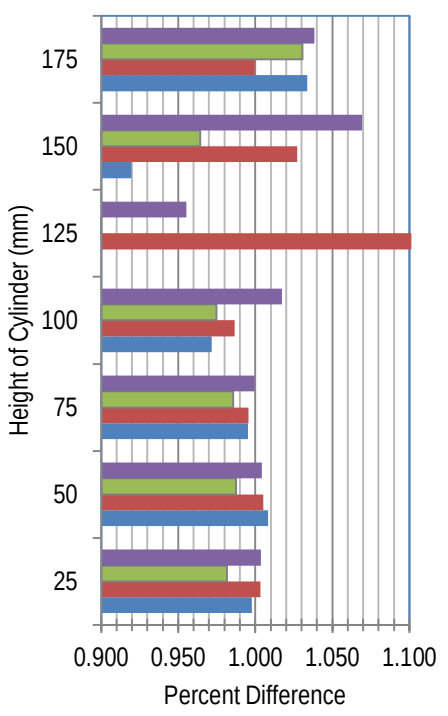
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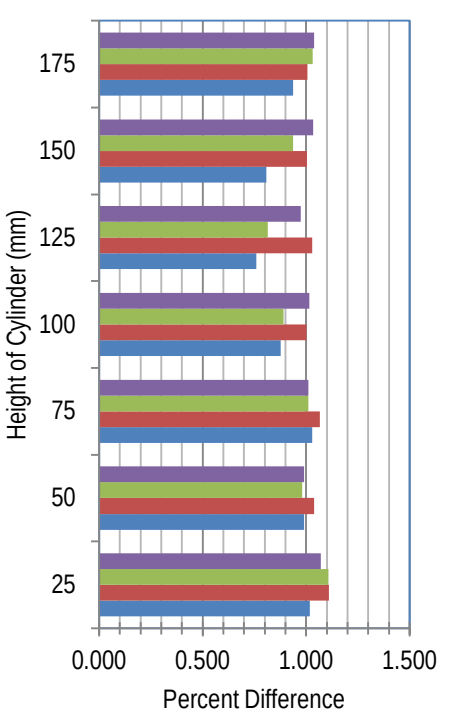
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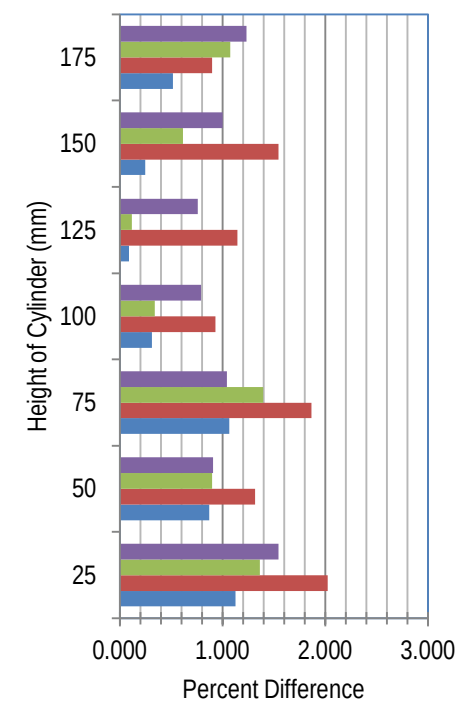
C12LW0W

C12SS5F

C12SS5A







Cylinders - 12 Months 2% Sodium Sulfate Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C12SS5F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C12SS5A	C12SS5W	C12LW0F	C12SS2F	C12SS5A	C12SS5W	C12LW0F	C12SS2F
25	4.372	0.025	0.571	0.002	0.040	0.595	0.307	0.719	0.668	0.363	0.081	0.008
50	4.364	0.044	1.008	0.003	0.723	0.726	0.594	0.986	0.713	0.537	0.394	0.182
75	4.341	0.050	1.148	0.003	0.304	0.381	0.154	0.622	0.982	0.538	0.391	0.766
100	4.315	0.023	0.527	0.001	0.028	0.116	0.259	0.027	0.321	0.143	0.472	0.108
125	3.288	0.387	11.766	0.024	0.117	0.094	0.000	0.254	0.002	0.081	0.016	0.269
150	3.877	0.530	13.674	0.033	0.155	0.267	0.000	0.083	0.163	0.734	0.259	0.493
175	4.177	0.013	0.307	0.001	0.000	0.015	0.012	0.004	0.665	0.968	0.934	0.426
Amplitude												
25	67.800	3.575	5.273	0.225	0.724	0.794	0.734	0.630	0.074	0.019	0.071	0.107
50	70.575	4.795	6.794	0.301	0.860	0.431	0.746	0.685	0.377	0.377	0.944	0.507
75	68.075	2.285	3.357	0.144	0.816	0.698	0.732	0.468	0.206	0.049	0.452	0.645
100	64.100	4.185	6.529	0.263	0.981	0.968	0.934	0.795	0.022	0.981	0.115	0.632
125	50.540	6.681	13.219	0.420	0.272	0.560	0.042	0.663	0.003	0.736	0.017	0.229
150	58.700	4.961	8.452	0.312	0.688	0.333	0.546	0.633	0.012	0.964	0.060	0.214
175	64.700	6.088	9.409	0.382	0.316	0.597	0.491	0.812	0.490	0.913	0.969	0.722
Energy												
25	20.325	9.539	46.931	0.599	0.132	0.364	0.733	0.400	0.288	0.078	0.221	0.208
50	37.300	19.420	52.065	1.220	0.674	0.713	0.812	0.625	0.271	0.376	0.959	0.321
75	24.750	5.580	22.546	0.351	0.254	0.159	0.149	0.115	0.029	0.031	0.497	0.318
100	16.275	6.337	38.939	0.398	0.037	0.586	0.103	0.344	0.101	0.841	0.116	0.404
125	2.844	2.519	88.596	0.158	0.221	0.970	0.169	0.244	0.000	0.829	0.000	0.166
150	9.900	6.081	61.425	0.382	0.024	0.265	0.412	0.161	0.042	0.470	0.069	0.057
175	25.200	7.786	30.896	0.489	0.014	0.751	0.693	0.405	0.497	0.684	0.938	0.664

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C12SS5A	C12SS5W	C12LW0F	C12SS2F	C12SS5A	C12SS5W	C12LW0F	C12SS2F	C12SS5A	C12SS5W	C12LW0F	C12SS2F
25	0.994	0.997	0.988	0.988	0.917	0.901	0.939	0.928	0.556	0.494	0.679	0.618
50	1.003	0.995	0.993	0.990	0.954	0.963	1.003	0.973	0.658	0.759	0.983	0.691
75	1.000	1.004	1.005	0.998	0.965	0.937	0.980	0.986	0.571	0.536	0.819	0.734
100	0.985	1.014	0.996	1.021	0.876	0.999	0.927	0.977	0.336	1.076	0.482	0.741
125	0.748	0.871	0.774	0.863	0.739	0.972	0.771	0.909	0.078	0.875	0.124	0.390
150	0.895	0.974	0.913	0.948	0.804	0.996	0.907	0.916	0.161	0.648	0.448	0.354
175	1.034	1.000	1.001	1.010	0.931	0.993	0.998	1.026	0.577	1.116	0.981	1.154

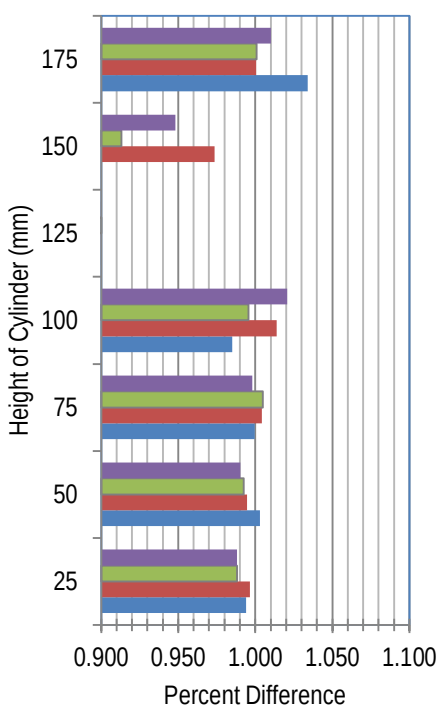
Graph Legend

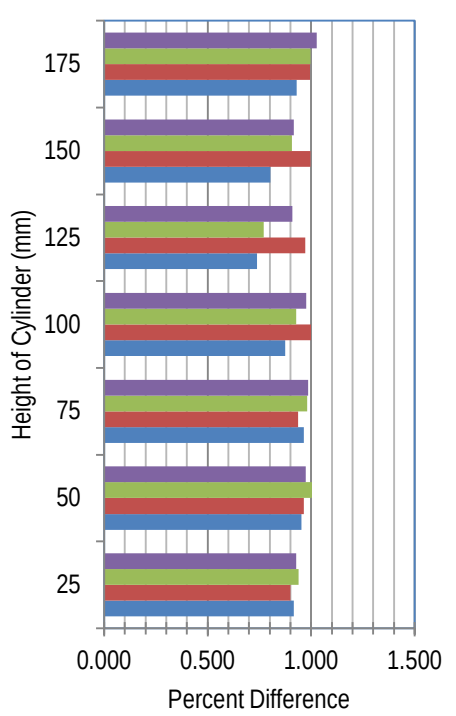
C12SS2F

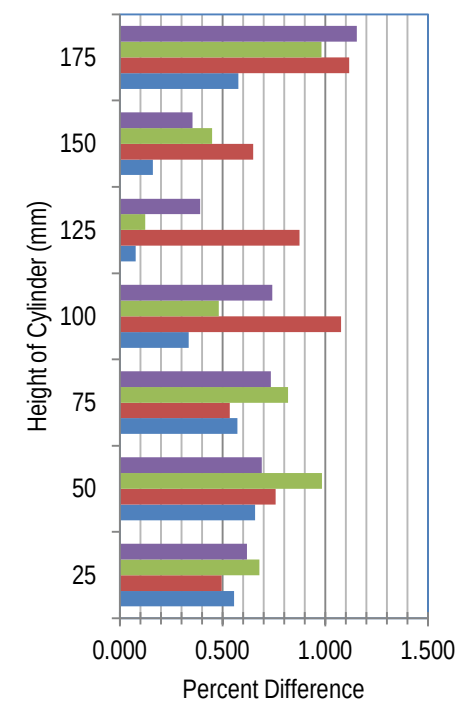
C12LW0F

C12SS5W

C12SS5A







Cylinders - 18 Months Limewater Solution Exposure: Complete Immersion

Sample: C18LW0A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.37	22.99	4.3658	72.5	56.4	100.57	23.3	4.3163	74	55.6
50	100.42	22.9	4.3852	73	56	100.66	23.44	4.2944	74	64.4
75	100.44	23.38	4.2960	75.5	58	100.89	23.78	4.2426	62.3	30.7
100	100.45	23.41	4.2909	73.4	57.4	101.02	23.68	4.2660	73	59.1
125	100.37	23.28	4.3114	69	46.4	100.95	23.55	4.2866	68.8	38.8
150	100.15	23.57	4.2490	76.2	98.1	100.85	23.55	4.2824	72.5	56.8
175	100.19	22.97	4.3618	78.3	136.7	101.03	23.4	4.3175	74.6	85.1

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.02	195.62	195.32	42.7	42.7	42.7	4.5742	5.71191	6.8 cm from top

Sample: C18LW0A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.34	23.36	4.2954	67.8	27.1	100.3	23.08	4.3458	77.4	55.9
50	100.29	23.23	4.3173	73	70.9	100.45	23.29	4.3130	73	65.9
75	100.34	23.35	4.2972	71.1	47.8	100.59	23.48	4.2841	70.7	58.3
100	100.34	23.53	4.2643	72.5	61.1	100.71	23.94	4.2068	75.3	68.8
125	100.32	23.53	4.2635	72	64.3	100.82	23.49	4.2920	71	49.2
150	100.22	23.39	4.2847	73.2	68.2	100.86	23.31	4.3269	72	69.8
175	100.24	23.27	4.3077	74	90.9	101.04	23.64	4.2741	74	94.2

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.34	195.44	195.39	42.8	43	42.9	4.5545	5.6	7.2 cm from bottom

Sample: C18LW0A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.06	23.2	4.3129	69.8	49	99.83	23.11	4.3198	67.7	47.6
50	100.23	23.48	4.2687	72	79.2	100.03	23.66	4.2278	64.3	27.5
75	100.39	23.82	4.2145	68.1	41.2	99.98	23.51	4.2527	67.7	29.3
100	100.5	24	4.1875	66.2	23.4	99.99	23.52	4.2513	69.1	47.3
125	100.6	23.51	4.2790	71	49.8	100.04	23.53	4.2516	66.9	48.2
150	100.56	23.77	4.2305	70.6	51.8	100.02	23.42	4.2707	75.4	66.4
175	100.64	23.23	4.3323	75.4	67.2	100.11	23.49	4.2618	71.6	75.1

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
194.98	194.78	194.88	42.9	43	42.95	4.5374		7.2 cm from bottom

Notes:

Technical problems for A2 and A3. Not able to get accurate failure pressure

Cylinders - 18 Months 2% Sodium Sulphate Solution Exposure: Complete Immersion

Sample: 18SS2A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.16	24.00	4.1733	70.0	33.4	100.21	24.00	4.1754	75.0	48.7
50	100.25	24.14	4.1529	70.1	57.5	100.33	24.08	4.1665	70.0	68.0
75	100.38	23.65	4.2444	70.3	56.0	100.49	24.35	4.1269	63.0	23.3
100	100.42	24.15	4.1582	62.8	32.4	100.5	24.20	4.1529	67.6	59.4
125	100.35	23.94	4.1917	67.7	42.5	100.58	24.11	4.1717	73.0	44.6
150	100.34	23.95	4.1896	73.0	67.4	100.6	23.97	4.1969	69.8	39.5
175	100.33	23.62	4.2477	73.6	53.8	100.65	23.58	4.2684	76.0	95.9

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.37	196.29	196.33	41.9	41.9	41.9	4.6857	8.00124	2.0 cm from bottom

Sample: 18SS2A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.14	23.65	4.2342	69.3	42.3	100.08	23.18	4.3175	77.5	87.4
50	100.23	23.58	4.2506	73.5	85.5	100.24	23.96	4.1836	71.2	74.4
75	100.34	23.98	4.1843	69.6	49.6	100.34	23.87	4.2036	73.0	77.9
100	100.41	24.35	4.1236	69.0	36.2	100.42	23.78	4.2229	68.9	78.9
125	100.47	24.21	4.1499	68.6	28.1	100.55	23.82	4.2212	74.0	48.4
150	100.44	24.13	4.1625	71.3	54.0	100.55	23.51	4.2769	66.3	32.6
175	100.42	23.61	4.2533	78.3	97.3	100.72	24.34	4.1380	72.3	52.4

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.49	195.8	195.645	41.7	41.7	41.7	4.6917	9.98016	7.5 cm from bottom

Sample: 18SS2A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.08	24.13	4.1475	73.8	48.6	100.42	24.19	4.1513	78.0	68.3
50	100.23	24.59	4.0760	74.0	56.8	100.5	24.11	4.1684	75.4	80.3
75	100.42	24.04	4.1772	71.5	49.6	100.71	24.15	4.1702	75.5	99.4
100	100.4	24.25	4.1402	64.5	46.6	100.75	24.21	4.1615	65.9	44.7
125	100.51	23.67	4.2463	73.0	58.7	100.81	24.25	4.1571	67.0	29.0
150	100.52	23.59	4.2611	76.7	108.4	100.67	24.08	4.1806	73.8	58.9
175	100.66	24.06	4.1837	67.9	43.7	100.65	23.84	4.2219	76.1	67.0

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.92	199.5	199.71	42.9	42.9	42.9	4.6552	10.2375	6.5 cm from top

Notes:

Cylinders - 18 Months 5% Sodium Sulphate Solution Exposure: Complete Immersion

Sample: 18SS5A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.26	24.28	4.1293	70.1	39.0	100.32	24.28	4.1318	72.0	37.3
50	100.42	24.98	4.0200	67.8	53.1	100.46	24.35	4.1252	73.5	61.0
75	100.4	24.86	4.0386	65.0	44.2	100.7	24.45	4.1186	70.2	45.1
100	100.37	24.69	4.0652	68.5	27.3	100.78	24.63	4.0918	71.7	83.5
125	100.41	26.81	3.7452	57.0	7.0	100.81	24.84	4.0584	63.0	13.2
150	100.18	24.43	4.1007	63.5	28.5	100.71	24.27	4.1496	69.8	44.7
175	100.19	24.45	4.0978	62.1	28.1	100.82	24.48	4.1185	68.2	48.7

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.04	199.17	199.105	43	43	43	4.6303	10.12832	3.7 cm from top

Sample: 18SS5A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.28	24.45	4.1014	69.9	23.6	100.22	24.36	4.1141	72.0	39.3
50	100.31	23.97	4.1848	75.0	78.4	100.09	24.68	4.0555	69.0	61.7
75	100.51	24.18	4.1567	69.0	44.1	100.17	25.42	3.9406	65.2	31.2
100	100.61	26.25	3.8328	60.4	21.2	100.13	24.41	4.1020	70.7	78.4
125	100.75	24.29	4.1478	67.0	28.5	100.13	24.00	4.1721	69.5	34.0
150	100.86	23.95	4.2113	74.0	69.7	99.83	23.81	4.1928	74.1	70.4
175	100.91	24.16	4.1767	74.5	50.4	99.76	23.70	4.2093	72.6	66.0

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.22	197.75	197.485	42.7	42.7	42.7	4.6249	10.2015	9.5 cm from top

Sample: C18SS5A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.22	24.58	4.0773	64.7	11.6	100.15	24.13	4.1504	72	40
50	100.29	24.41	4.1086	70	34.1	100.32	24.67	4.0665	73	72.4
75	100.26	24.08	4.1636	75.6	82.4	100.46	24.37	4.1223	68.2	50.6
100	100.47	24.35	4.1261	73.7	65.3	100.62	24.39	4.1255	74.5	76
125	100.62	24.35	4.1322	74.4	57.4	100.74	24.15	4.1714	70.2	32.9
150	100.74	24.11	4.1783	72.2	49.7	100.58	24.05	4.1821	75	55
175	100.95	23.81	4.2398	75.2	91.2	100.58	23.66	4.2511	75.3	103.7

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.71	197.37	197.54	44.5	44.6	44.55	4.4341	8.47455	8.1 cm from top

Notes:

Cylinders - 18 Months Limewater Solution Exposure: Partial Immersion

Sample: C18LW0W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.61	23.02	4.3271	74.7	70.6	100.09	23.06	4.3404	78	91.1
50	99.54	23.27	4.2776	78.3	108.3	100.21	23.09	4.3400	80.5	117.2
75	99.52	23.53	4.2295	76.3	83.6	100.32	23.78	4.2187	75.9	53.5
100	99.56	23.44	4.2474	76	92.3	100.39	23.33	4.3030	75.5	87.7
125	99.57	24.01	4.1470	67.4	40.7	100.42	23.84	4.2122	69.6	52.3
150	99.54	24.15	4.1217	70	44.9	100.43	23.7	4.2376	71.7	50.9
175	99.66	23.56	4.2301	70.7	46.4	100.48	24.26	4.1418	71.5	65.8

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.3	198.22	198.26	44	44	44	4.5059	3.90486	3.9 cm fom top

Sample: C18LW0W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.32	23.02	4.3579	73	47	100.33	23.05	4.3527	79.5	95.4
50	100.37	23.26	4.3151	77.5	93.9	100.24	23.2	4.3207	77.5	105.2
75	100.52	23.16	4.3402	75.8	65.6	100.37	23.62	4.2494	74.1	72.7
100	100.59	23.95	4.2000	73	40.5	100.5	23.56	4.2657	71	57.1
125	100.85	24.25	4.1588	68	45.4	100.52	23.76	4.2306	73	54.4
150	100.71	23.81	4.2297	72.5	66.3	100.21	23.76	4.2176	72	51.6
175	100.94	24.21	4.1694	67	36.6	100.6	24.06	4.1812	65.6	31.6

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.18	196.17	196.175	43.7	43.7	43.7	4.4891	4.15495	5.9 cm from bottom

Sample: C18LW0W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.35	23.29	4.3087	74.5	65	100.32	23.5	4.2689	73	51.5
50	100.39	23.5	4.2719	75.3	73.6	100.4	23.5	4.2723	76	72.7
75	100.53	23.53	4.2724	74	65.5	100.46	23.51	4.2731	71.5	61.2
100	100.72	24.13	4.1741	71	41.4	100.53	24.1	4.1714	70.6	51.6
125	100.67	24.25	4.1513	67	44.1	100.53	24.07	4.1766	71.4	44.5
150	100.63	24.17	4.1634	68.3	50.6	100.43	23.89	4.2039	73	56.3
175	100.71	24.55	4.1022	65.4	43.3	100.49	24.67	4.0734	71.1	55

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.19	195.72	195.955	43.8	43.8	43.8	4.4739	3.87093	5.0 cm from top

Notes:

Cylinders - 18 Months 2% Sodium Sulphate Solution Exposure: Partial Immersion

Sample: 18SS2W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.33	23.98	4.1839	72.0	38.7	100.07	24.02	4.1661	74.0	45.2
50	100.35	23.85	4.2075	73.0	54.6	100.19	23.99	4.1763	72.4	47.6
75	100.46	24.36	4.1240	72.5	85.1	100.4	24.74	4.0582	70.3	61.9
100	100.53	24.69	4.0717	64.6	26.6	100.6	24.97	4.0288	64.6	50.4
125	100.48	34.19	2.9389	49.7	2.0	100.4	27.42	3.6616	54.8	4.0
150	100.38	27.44	3.6582	58.0	7.0	99.97	27.61	3.6208	56.8	8.7
175	100.39	26.44	3.7969	63.7	45.6	100.61	26.01	3.8681	63.5	29.8

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
201.14	201.19	201.165	44.5	44.4	44.45	4.5256	3.55154	2.2 cm from top

Sample: 18SS2W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.28	23.60	4.2492	77.0	69.1	100.17	23.68	4.2302	73.0	49.4
50	100.56	24.08	4.1761	73.9	50.4	100.18	24.00	4.1742	73.0	61.0
75	100.55	24.43	4.1158	66.9	41.0	100.19	24.07	4.1624	72.1	61.9
100	100.68	25.26	3.9857	60.6	18.6	100.11	24.89	4.0221	64.2	28.1
125	100.77	27.35	3.6845	58.1	7.0	100.01	24.62	4.0621	62.0	14.9
150	100.74	27.26	3.6955	62.4	20.5	99.7	25.18	3.9595	62.9	21.2
175	100.81	25.46	3.9595	64.6	27.6	99.59	27.37	3.6387	57.4	7.0

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.28	197.18	197.23	43	43.1	43.05	4.5814	4.61443	2.3 cm from top

Sample: 18SS2W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.97	24.08	4.1516	66.0	19.3	99.88	23.54	4.2430	71.2	46.2
50	99.93	24.30	4.1123	75.5	83.2	99.97	24.65	4.0556	69.5	46.3
75	100.01	24.53	4.0770	66.4	31.9	100.1	24.61	4.0675	69.3	41.2
100	100.12	26.67	3.7540	63.1	14.1	100.07	24.60	4.0679	73.0	73.1
125	100.13	26.92	3.7195	53.9	4.0	99.99	29.48	3.3918	51.6	3.6
150	100	25.16	3.9746	64.0	25.5	100.13	31.02	3.2279	51.7	3.8
175	100.18	27.47	3.6469	52.1	3.3	100.24	27.95	3.5864	53.3	7.5

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.49	199.55	199.52	43.6	43.5	43.55	4.5814	4.46459	3.0 cm from top

Notes:

Cylinders - 18 Months 5% Sodium Sulphate Solution Exposure: Partial Immersion

Sample: C18SS5W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.89	23.75	4.2059	75.6	63.6	99.85	23.85	4.1866	74	47.3
50	100.07	23.34	4.2875	74	69.4	100.25	23.87	4.1998	71	56.1
75	100.17	24.02	4.1703	71.4	53	100.07	23.95	4.1783	73	64.5
100	100.58	24.38	4.1255	69.1	39.3	100.14	23.81	4.2058	73.5	47.5
125	99.77	23.95	4.1658	60	24.8	99.74	24.32	4.1012	64.7	25.9
150	100.38	23.94	4.1930	66	31.6	100.12	24.88	4.0241	57.8	9.9
175	100.61	24.22	4.1540	71.2	54.1	100.04	25.2	3.9698	67.4	36.5

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.57	198.24	198.405	45.3	45.3	45.3	4.3798	3.84913	3.8 cm from top

Sample: C18SS5W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.25	23.22	4.3174	73.5	37.9	100.18	23.57	4.2503	73	52.9
50	100.4	23.95	4.1921	77	92.4	100.38	23.95	4.1912	71.4	48.5
75	100.56	24	4.1900	75.8	73.9	100.44	24	4.1850	71	57.4
100	99.95	23.94	4.1750	70	38.7	99.99	24.23	4.1267	65.3	24.8
125	100.02	24.70	4.0494	62.4	14.6	100.33	24.69	4.0636	65.5	29.2
150	100.27	24.52	4.0893	64.7	23.2	100.19	24.91	4.0221	70	30.4
175	100.93	24.64	4.0962	69.5	54.9	100.27	24.57	4.0810	68.1	36.1

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.03	197.2	197.115	44.7	44.7	44.7	4.4097	4.74856	4.0 cm from top

Sample: C18SS5W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.09	23.31	4.2939	79	72.5	100.27	23.68	4.2344	73	40.9
50	100.31	23.55	4.2594	79.2	99.2	100.47	23.5	4.2753	75.8	65
75	100.25	23.85	4.2034	72.7	54.1	100.55	23.78	4.2283	73.1	58.7
100	100.31	25.91	3.8715	52.5	4.7	100.06	24.63	4.0625	66.1	23.9
125	99.31	24.09	4.1225	64.5	26.2	100.12	24.57	4.0749	58.3	10.6
150	99.56	31.04	3.2075	48.1	2.1	100.6	24.65	4.0811	56.6	10.4
175	100.38	24.45	4.1055	67.3	41.3	100.54	24.7	4.0704	60.5	17.7

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.58	195.77	195.675	44.6	44.6	44.6	4.3873	5.19032	3.2 cm from top

Notes:

Cylinders - 18 Months Limewater Solution Exposure: Cyclical Partial Immersion

Sample: C18LW0F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.41	23.48	4.2764	77	71.1	100.04	23.4	4.2752	75	53.9
50	100.5	23.79	4.2245	78.9	99.3	100.09	23.49	4.2610	75.9	79.5
75	100.64	23.97	4.1986	76.8	81.9	100.1	23.95	4.1795	74	84.8
100	100.75	24.02	4.1944	76.3	75.4	100.1	24.28	4.1227	69.2	36.1
125	100.78	24.37	4.1354	72.2	46	100.01	24.45	4.0904	70	35
150	100.63	24.74	4.0675	70	42.4	99.9	24.95	4.0040	71	35.9
175	100.8	24.80	4.0645	67.9	40	100.05	24.95	4.0100	70	54.9

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.18	198.28	198.23	44.5	44.5	44.5	4.4546	3.60447	8.1 cm from top

Sample: C18LW0F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.27	24.05	4.1692	74.7	63.1	100.07	23.8	4.2046	74.3	52
50	100.54	23.8	4.2244	76	69.8	100.14	24	4.1725	74.3	62.9
75	100.63	23.88	4.2140	74.3	69.9	100.19	24	4.1746	68.1	51.3
100	100.71	24.47	4.1157	71.9	48.1	100.21	24.2	4.1409	69.5	42.4
125	100.78	24.37	4.1354	68.3	37.5	100.25	24.65	4.0669	66.6	32.6
150	100.66	25.00	4.0264	71	48.9	100.2	25.07	3.9968	66.1	29.2
175	100.67	24.58	4.0956	72.8	63.2	100.25	24.84	4.0358	72	54.9

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.72	196.6	196.66	44.6	44.6	44.6	4.4094	4.15046	7.9 cm from top

Sample: C18LW0F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.35	23.53	4.2648	75.5	59.3	100.45	23.79	4.2224	69	20.9
50	100.51	23.75	4.2320	78	84.8	100.36	23.65	4.2436	76.5	73.2
75	100.65	24.09	4.1781	74	79	100.44	24.49	4.1013	66	25.3
100	100.74	24.44	4.1219	73.7	62.8	100.39	24.1	4.1656	73	55.8
125	100.81	24.45	4.1231	73.1	60.5	100.41	24.64	4.0751	71	41.9
150	100.68	24.78	4.0630	70	41.3	100.32	24.83	4.0403	68.8	49.2
175	100.65	25.23	3.9893	73.5	58.4	100.48	25.09	4.0048	68.6	45.8

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
194.45	193.68	194.065	43.9	43.9	43.9	4.4206	3.44794	6.1 cm from top

Notes:

Cylinders - 18 Months 2% Sodium Sulphate Solution Exposure: Cyclical Partial Immersion

Sample: 18SS2F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.11	23.75	4.2152	71.2	36.1	100.16	23.79	4.2102	78.8	61.5
50	100.19	24.09	4.1590	67.0	35.6	100.33	24.59	4.0801	66.9	29.8
75	100.27	24.48	4.0960	65.7	30.4	100.44	24.47	4.1046	68.5	37.3
100	100.37	24.51	4.0951	62.5	36.4	100.55	24.97	4.0268	61.8	28.0
125	100.25	47.66	2.1034	45.4	1.0	100.51	26.85	3.7434	55.0	6.6
150	100.15	25.32	3.9554	64.0	19.7	100.42	25.90	3.8772	60.5	18.0
175	100.15	27.00	3.7093	62.2	13.6	100.61	26.78	3.7569	59.2	17.5

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.37	198..48	198.37	43.7	43.8	43.75	4.5342	3.21458	2.1 cm from top

Sample: 18SS2F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.11	23.78	4.2098	75.0	51.2	100.27	23.94	4.1884	75.5	54.1
50	100.25	24.14	4.1529	69.6	46.1	100.49	24.15	4.1611	71.0	50.5
75	100.3	24.23	4.1395	65.6	39.1	100.65	24.38	4.1284	70.5	71.2
100	100.37	24.67	4.0685	65.7	28.9	100.75	25.17	4.0028	65.0	30.4
125	100.23	26.88	3.7288	51.9	3.0	100.74	25.94	3.8836	57.0	7.9
150	100.2	25.35	3.9527	71.0	29.0	100.62	27.71	3.6312	62.0	26.0
175	100.25	25.58	3.9191	69.9	33.7	100.74	27.44	3.6713	64.9	27.0

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.21	199.29	199.25	43.5	43.5	43.5	4.5805	4.22146	3.9 cm from top

Sample: 18SS2F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.31	23.72	4.2289	69.3	29.4	100.39	23.51	4.2701	77.0	70.7
50	100.42	23.75	4.2282	69.8	36.4	100.4	24.38	4.1181	64.8	33.5
75	100.52	24.10	4.1710	68.5	39.7	100.54	24.26	4.1443	72.5	78.6
100	100.53	24.80	4.0536	64.8	45.9	100.56	25.10	4.0064	64.5	31.5
125	100.48	25.04	4.0128	63.0	14.0	100.66	25.06	4.0168	68.4	34.5
150	100.32	24.44	4.1047	68.0	35.1	100.54	24.76	4.0606	67.0	36.5
175	100.23	25.57	3.9198	65.3	33.4	100.72	25.45	3.9576	68.5	57.0

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.79	198.79	198.79	43.8	43.9	43.85	4.5334	4.03989	2.3 cm from top

Notes:

Cylinders - 18 Months 5% Sodium Sulphate Solution Exposure: Cyclical Partial Immersion

Sample: C18SS5F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.04	23.45	4.2661	73.9	50.2	100.3	22.97	4.3666	73.8	49.7
50	100.28	23.68	4.2348	73.1	52.8	100.46	23.28	4.3153	67.4	29.9
75	99.98	23.77	4.2061	67.6	36.3	100.68	23.43	4.2971	68.5	36.2
100	99.99	24	4.1663	66.6	30.3	100.72	23.74	4.2426	71.7	36.6
125	98.76	23.32	4.2350	60	13.1	100.07	24.1	4.1523	59	6.9
150	99.77	24.36	4.0956	66.5	28	100.67	24	4.1946	67	28.4
175	99.86	25.41	3.9299	62.9	17.3	100.84	24.51	4.1142	68	51.1

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.75	198.66	198.705	44.7	44.8	44.75	4.4403	5.12046	8.8 cm from bottom

Sample: 18SS5F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.04	24.07	4.1562	65.0	18.0	100.09	24.30	4.1189	65.0	12.8
50	100.1	24.80	4.0363	62.5	20.6	100.07	24.30	4.1181	74.0	90.7
75	100.26	26.06	3.8473	58.9	12.1	100.17	26.12	3.8350	61.6	12.7
100	100.29	25.23	3.9750	60.2	22.9	100.25	26.80	3.7407	60.3	9.2
125	99.83	27.62	3.6144	60.5	7.7	99.5	27.21	3.6567	53.8	13.0
150	100.03	26.75	3.7394	64.0	20.5	100.32	27.24	3.6828	60.5	31.8
175	100.31	29.56	3.3934	52.2	4.5	100.48	27.01	3.7201	56.3	5.5

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
199.68	199.87	199.775	43.8	43.8	43.8	4.5611	4.24725	3.4 cm from top

Sample: C18SS5F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.12	24	4.1717	68.4	16.9	99.85	23.47	4.2544	74	58.8
50	100.33	23.84	4.2085	72	45.1	99.87	23.79	4.1980	75.5	60.3
75	100.41	23.71	4.2349	73.7	80.5	100.04	24.08	4.1545	66.4	42
100	100.54	23.97	4.1944	73.5	52.9	100.03	24.01	4.1662	70.3	31.9
125	100.22	24.14	4.1516	60.8	8.7	99.67	23.81	4.1861	65.9	22.5
150	100.39	24.95	4.0236	58.3	9.9	99.33	24.92	3.9860	62.9	13.9
175	100.42	24.67	4.0705	68.4	34	100.31	24.72	4.0578	69.9	40.1

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.17	198.33	198.25	45	44.9	44.95	4.4105	4.60098	2.8 cm from top

Notes:

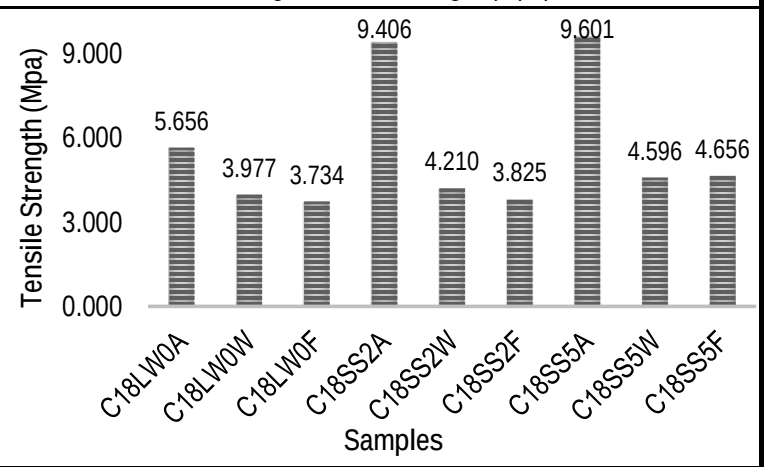
Cylinders - 18 Months Solution Exposure

Statistical Evaluation for Difference Between Samples

Ultimate Tensile Strength (Mpa) - Gas Pressure Tension Test

Samples	Sample Statistics: Average	Standard Deviation	Coeff. of Variation	Confi-dence
C18LW0A	5.656	0.079	1.399	0.006
C18LW0W	3.977	0.155	3.900	0.011
C18LW0F	3.734	0.369	9.876	0.027
C18SS2A	9.406	1.224	13.008	0.089
C18SS2W	4.210	0.575	13.665	0.042
C18SS2F	3.825	0.537	14.029	0.039
C18SS5A	9.601	0.977	10.172	0.071
C18SS5W	4.596	0.683	14.871	0.050
C18SS5F	4.656	0.439	9.433	0.032

Average Tensile Strength (Mpa)



T-Test

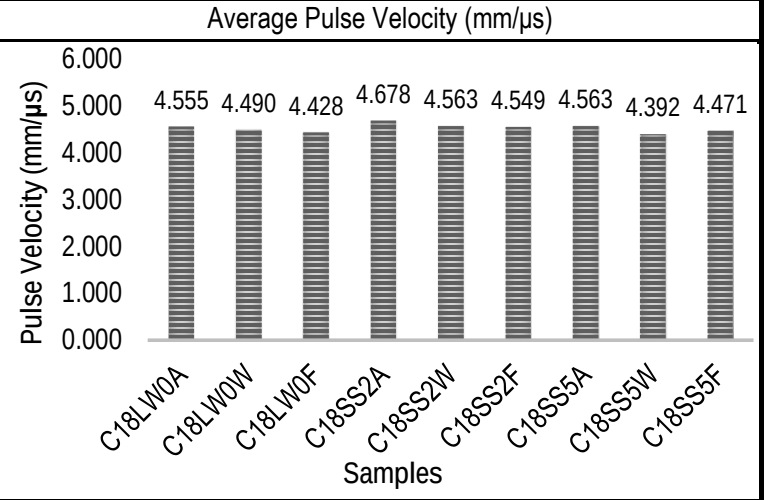
Samples	C18LW0A	C18LW0W	C18LW0F	C18SS2A	C18SS2W	C18SS2F	C18SS5A	C18SS5W	C18SS5F
C18LW0A	1.000	0.001	0.006	0.033	0.044	0.020	0.012	0.130	0.056
C18LW0W	0.679	1.000	0.353	0.015	0.535	0.663	0.009	0.254	0.065
C18LW0F	0.300	0.301	1.000	0.002	0.294	0.821	0.001	0.127	0.050
C18SS2A	0.091	0.032	0.167	1.000	0.003	0.002	0.840	0.004	0.003
C18SS2W	0.194	0.136	0.583	0.362	1.000	0.445	0.001	0.496	0.346
C18SS2F	0.207	0.154	0.642	0.323	0.931	1.000	0.001	0.199	0.107
C18SS5A	0.114	0.049	0.250	0.778	0.515	0.464	1.000	0.002	0.001
C18SS5W	0.163	0.098	0.451	0.476	0.829	0.763	0.658	1.000	0.904
C18SS5F	0.253	0.222	0.827	0.228	0.736	0.802	0.336	0.585	1.000

f-Test

Longitudinal Pulse Velocity (mm/µs) - 54 kHz Ultrasonic Pulse VelocityTest

Samples	Sample Statistics: Average	Standard Deviation	Coeff. of Variation	Confi-dence
C18LW0A	4.555	0.018	0.405	0.001
C18LW0W	4.490	0.016	0.357	0.001
C18LW0F	4.428	0.024	0.531	0.002
C18SS2A	4.678	0.020	0.418	0.001
C18SS2W	4.563	0.032	0.706	0.002
C18SS2F	4.549	0.027	0.592	0.002
C18SS5A	4.563	0.112	2.449	0.008
C18SS5W	4.392	0.016	0.354	0.001
C18SS5F	4.471	0.080	1.784	0.006

Average Pulse Velocity (mm/µs)

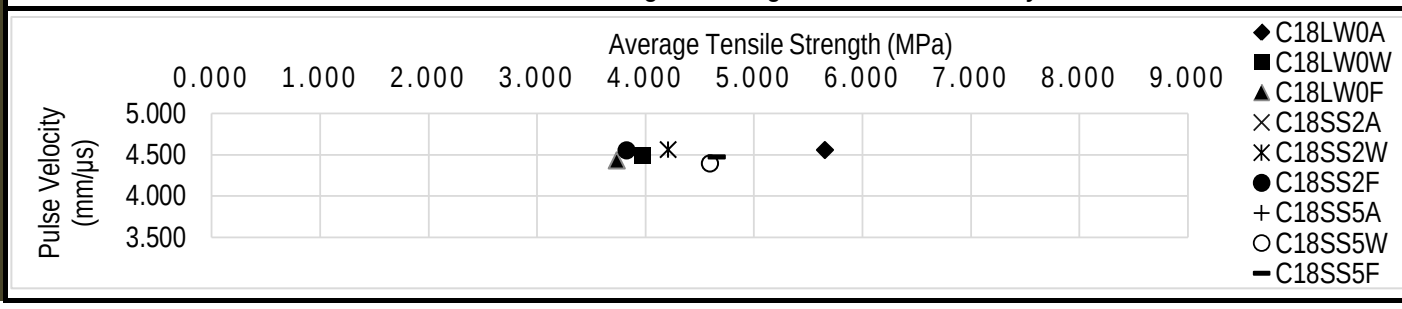


T-Test

Samples	C18LW0A	C18LW0W	C18LW0F	C18SS2A	C18SS2W	C18SS2F	C18SS5A	C18SS5W	C18SS5F
C18LW0A	1.000	0.010	0.002	0.001	0.746	0.765	0.916	0.000	0.147
C18LW0W	0.860	1.000	0.020	0.000	0.024	0.030	0.373	0.002	0.722
C18LW0F	0.761	0.634	1.000	0.000	0.004	0.004	0.167	0.092	0.427
C18SS2A	0.942	0.804	0.817	1.000	0.006	0.003	0.216	0.000	0.012
C18SS2W	0.494	0.397	0.697	0.539	1.000	0.608	0.996	0.001	0.137
C18SS2F	0.638	0.523	0.865	0.690	0.824	1.000	0.846	0.001	0.181
C18SS5A	0.053	0.040	0.085	0.059	0.153	0.110	1.000	0.115	0.308
C18SS5W	0.832	0.971	0.609	0.776	0.379	0.501	0.038	1.000	0.228
C18SS5F	0.102	0.078	0.160	0.113	0.280	0.205	0.675	0.073	1.000

f-Test

Ultimate Tensile Strength vs Longitudinal Pulse Velocity



Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Cylinders - 18 Months Limewater Solution Exposure: Complete Immersion

Velocity

	Sample Statistics - C18LW0A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confidence	C18LW0W	C18LW0F	C18SS2A	C18SS5A	C18LW0W	C18LW0F	C18SS2A	C18SS5A
25	4.326	0.025	0.586	0.001	0.571	0.254	0.058	0.974	0.999	0.001	0.004	0.000
50	4.301	0.053	1.227	0.003	0.224	0.235	0.897	0.825	0.954	0.013	0.002	0.000
75	4.265	0.033	0.782	0.002	0.576	0.746	0.748	0.059	0.978	0.002	0.003	0.003
100	4.244	0.039	0.926	0.002	0.515	0.607	0.750	0.038	0.532	0.001	0.003	0.008
125	4.281	0.021	0.496	0.001	0.308	0.435	0.230	0.000	0.000	0.000	0.000	0.026
150	4.274	0.033	0.776	0.002	0.531	0.799	0.478	0.726	0.006	0.000	0.023	0.001
175	4.309	0.037	0.859	0.002	0.374	0.853	0.539	0.264	0.000	0.000	0.005	0.002

Amplitude

25	71.533	3.823	5.344	0.196	0.520	0.481	0.931	0.525	0.027	0.187	0.293	0.482
50	71.550	3.608	5.042	0.185	0.118	0.108	0.322	0.617	0.003	0.011	0.648	0.931
75	69.233	4.396	6.349	0.226	0.008	0.914	0.934	0.798	0.022	0.258	0.626	0.882
100	71.583	3.320	4.638	0.170	0.457	0.653	0.549	0.361	0.440	0.703	0.013	0.519
125	69.783	1.885	2.701	0.097	0.436	0.588	0.295	0.022	0.933	0.747	0.617	0.305
150	73.317	2.119	2.890	0.109	0.563	0.770	0.275	0.146	0.067	0.007	0.398	0.359
175	74.650	2.192	2.937	0.112	0.627	0.913	0.284	0.079	0.001	0.014	0.731	0.196

Energy

25	48.600	11.194	23.033	0.574	0.231	0.360	0.241	0.930	0.044	0.583	0.519	0.029
50	60.650	17.952	29.599	0.921	0.940	0.476	0.381	0.764	0.008	0.079	0.292	0.957
75	44.217	12.771	28.882	0.655	0.645	0.220	0.139	0.522	0.007	0.078	0.235	0.553
100	52.850	16.002	30.278	0.821	0.456	0.814	0.887	0.265	0.451	0.948	0.749	0.665
125	49.450	8.307	16.798	0.426	0.344	0.670	0.466	0.120	0.540	0.209	0.226	0.028
150	68.517	16.113	23.517	0.827	0.106	0.131	0.287	0.979	0.063	0.004	0.527	0.124
175	91.533	24.294	26.542	1.246	0.169	0.038	0.916	0.742	0.002	0.010	0.121	0.109

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C18LW0W	C18LW0F	C18SS2A	C18SS5A	C18LW0W	C18LW0F	C18SS2A	C18SS5A	C18LW0W	C18LW0F	C18SS2A	C18SS5A
25	1.000	1.021	1.030	1.051	0.935	0.963	0.968	1.020	0.693	0.910	0.887	1.528
50	1.000	1.018	1.032	1.051	0.920	0.934	0.989	1.002	0.637	0.775	0.861	1.009
75	1.000	1.022	1.019	1.043	0.923	0.959	0.982	1.005	0.660	0.676	0.746	0.891
100	1.004	1.024	1.020	1.046	0.982	0.991	1.077	1.024	0.856	0.989	1.063	0.902
125	1.024	1.043	1.022	1.051	1.002	0.994	0.989	1.044	1.054	1.170	1.181	1.715
150	1.019	1.060	1.015	1.025	1.031	1.055	1.021	1.026	1.282	1.665	1.139	1.293
175	1.038	1.068	1.021	1.030	1.104	1.054	1.008	1.047	1.971	1.731	1.339	1.415

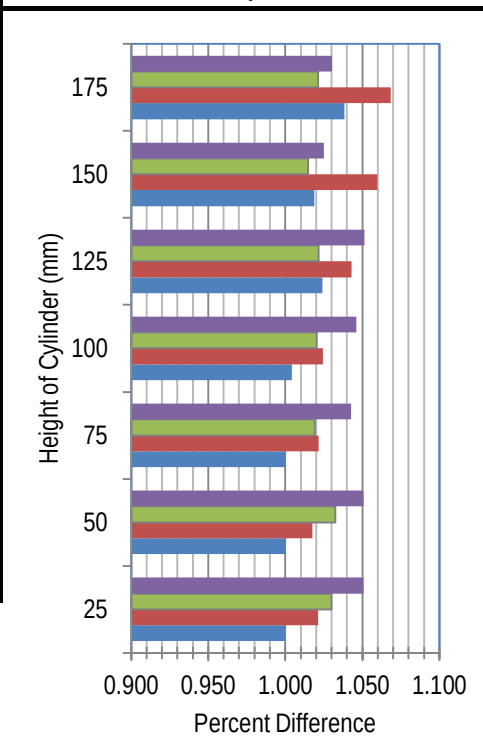
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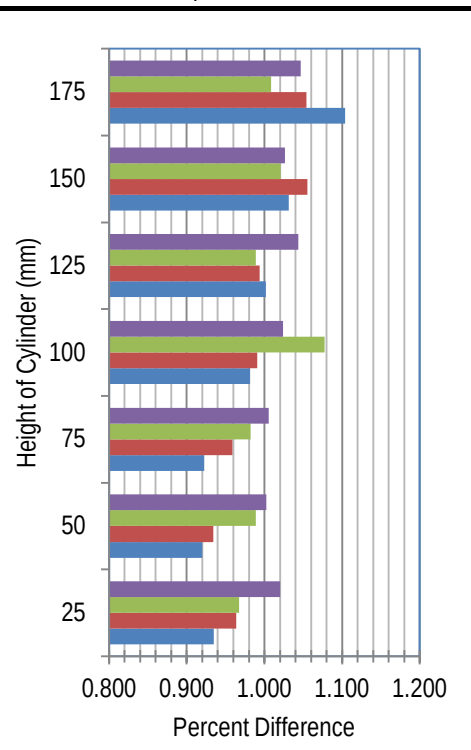
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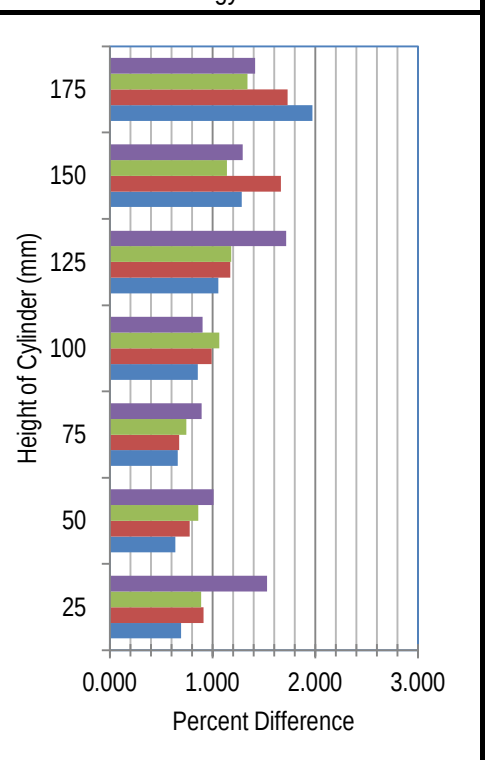
C18SS2A

C18LW0F

C18LW0W







Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Cylinders - 18 Months Limewater Solution Exposure: Partial Immersion

Velocity

Height (mm)	Sample Statistics - C18LW0W				F-Test				t-Test			
	Average	Standard Deviation	Coefficient of Variation	Confidence	C18LW0A	C18LW0F	C18SS2W	C18SS5W	C18LW0A	C18LW0F	C18SS2W	C18SS5W
25	4.326	0.033	0.767	0.002	0.571	0.554	0.616	0.381	0.999	0.002	0.000	0.010
50	4.300	0.029	0.683	0.002	0.224	0.976	0.184	0.379	0.954	0.002	0.000	0.013
75	4.264	0.043	1.018	0.002	0.576	0.813	0.867	0.132	0.978	0.004	0.000	0.005
100	4.227	0.054	1.266	0.003	0.515	0.252	0.104	0.102	0.532	0.008	0.001	0.033
125	4.179	0.035	0.827	0.002	0.308	0.805	0.000	0.642	0.000	0.003	0.011	0.004
150	4.196	0.045	1.064	0.002	0.531	0.382	0.001	0.000	0.006	0.000	0.006	0.140
175	4.150	0.057	1.362	0.003	0.374	0.478	0.054	0.871	0.000	0.002	0.001	0.066

Amplitude

Height (mm)	Sample Statistics - C18LW0W				F-Test				t-Test			
	Average	Standard Deviation	Coefficient of Variation	Confidence	C18LW0A	C18LW0F	C18SS2W	C18SS5W	C18LW0A	C18LW0F	C18SS2W	C18SS5W
25	76.533	2.819	3.683	0.145	0.520	0.950	0.587	0.682	0.027	0.185	0.044	0.243
50	77.767	1.677	2.156	0.086	0.118	0.960	0.724	0.178	0.003	0.251	0.001	0.068
75	75.033	1.073	1.430	0.055	0.008	0.010	0.079	0.339	0.022	0.162	0.002	0.023
100	72.917	2.333	3.199	0.120	0.457	0.765	0.224	0.026	0.440	0.664	0.002	0.071
125	69.667	2.730	3.918	0.140	0.436	0.809	0.305	0.904	0.933	0.728	0.000	0.001
150	71.083	1.612	2.267	0.083	0.563	0.773	0.035	0.003	0.067	0.141	0.001	0.022
175	67.633	2.757	4.077	0.141	0.627	0.705	0.147	0.550	0.001	0.056	0.007	0.876

Energy

Height (mm)	Sample Statistics - C18LW0W				F-Test				t-Test			
	Average	Standard Deviation	Coefficient of Variation	Confidence	C18LW0A	C18LW0F	C18SS2W	C18SS5W	C18LW0A	C18LW0F	C18SS2W	C18SS5W
25	70.100	19.934	28.437	1.023	0.231	0.766	0.654	0.404	0.044	0.152	0.035	0.103
50	95.150	18.602	19.550	0.954	0.940	0.432	0.530	0.871	0.008	0.097	0.002	0.063
75	67.017	10.278	15.336	0.527	0.645	0.100	0.184	0.562	0.007	0.876	0.175	0.229
100	61.767	22.790	36.898	1.169	0.456	0.331	0.972	0.403	0.451	0.466	0.069	0.017
125	46.900	5.286	11.270	0.271	0.344	0.178	0.799	0.470	0.540	0.343	0.000	0.000
150	53.433	7.272	13.609	0.373	0.106	0.902	0.649	0.282	0.063	0.018	0.000	0.000
175	46.450	12.450	26.803	0.639	0.169	0.422	0.526	0.831	0.002	0.322	0.012	0.422

Damage Rating Index Along Transverse Axis

Percent Difference

Height (mm)	Velocity				Amplitude				Energy			
	C18LW0A	C18LW0F	C18SS2W	C18SS5W	C18LW0A	C18LW0F	C18SS2W	C18SS5W	C18LW0A	C18LW0F	C18SS2W	C18SS5W
25	1.000	1.021	1.029	1.018	1.070	1.031	1.060	1.025	1.442	1.313	1.570	1.335
50	1.000	1.017	1.036	1.015	1.087	1.015	1.067	1.041	1.569	1.216	1.664	1.326
75	1.000	1.021	1.040	1.017	1.084	1.039	1.078	1.030	1.516	1.025	1.245	1.112
100	0.996	1.020	1.060	1.032	1.019	1.009	1.122	1.103	1.169	1.156	1.757	2.072
125	0.976	1.018	1.169	1.020	0.998	0.992	1.266	1.113	0.948	1.110	7.927	2.143
150	0.982	1.040	1.137	1.066	0.970	1.023	1.199	1.174	0.780	1.299	3.698	2.980
175	0.963	1.029	1.107	1.017	0.906	0.955	1.144	1.004	0.507	0.879	2.307	1.158

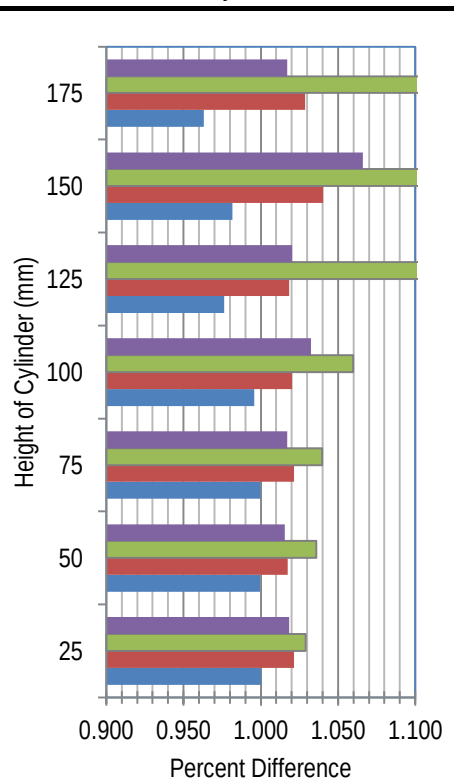
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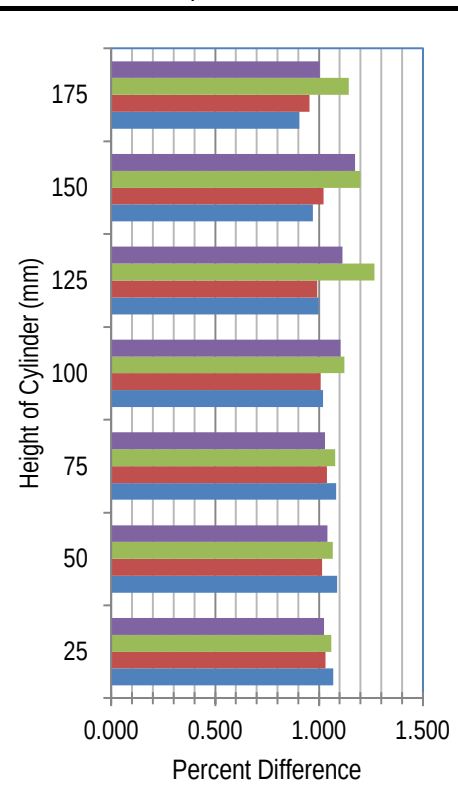
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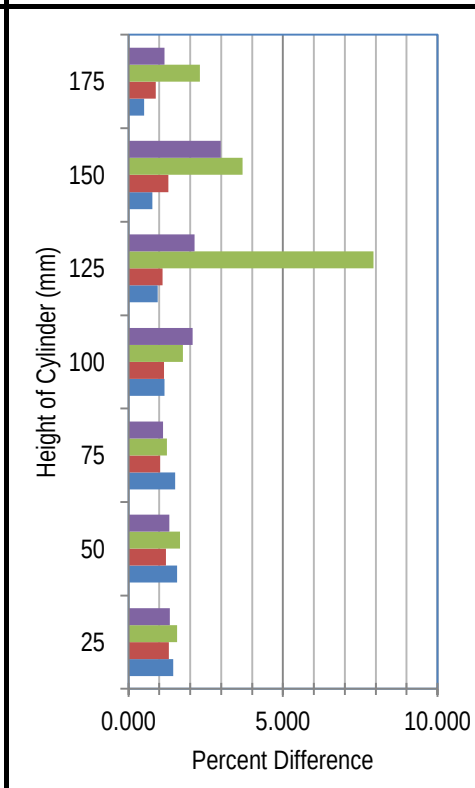
C18SS2W

C18LW0F

C18LW0A







Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Cylinders - 18 Months Limewater Solution Exposure: Partial Cyclic Immersion

Velocity

	Sample Statistics - C18LW0F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confidence	C18LW0A	C18LW0W	C18SS2F	C18SS5F	C18LW0A	C18LW0W	C18SS2F	C18SS5F
25	4.235	0.044	1.036	0.002	0.254	0.554	0.332	0.135	0.001	0.002	0.495	0.757
50	4.226	0.030	0.705	0.002	0.235	0.976	0.290	0.022	0.013	0.002	0.009	0.358
75	4.174	0.039	0.930	0.002	0.746	0.813	0.465	0.002	0.002	0.004	0.048	0.391
100	4.144	0.031	0.745	0.002	0.607	0.252	0.718	0.001	0.001	0.008	0.000	0.460
125	4.104	0.031	0.750	0.002	0.435	0.805	0.000	0.000	0.000	0.003	0.142	0.408
150	4.033	0.029	0.730	0.002	0.799	0.382	0.002	0.001	0.000	0.000	0.197	0.383
175	4.033	0.040	1.001	0.002	0.853	0.478	0.028	0.001	0.000	0.002	0.007	0.240

Amplitude

25	74.250	2.737	3.686	0.140	0.481	0.950	0.572	0.314	0.187	0.185	0.909	0.012
50	76.600	1.637	2.137	0.084	0.108	0.960	0.459	0.031	0.011	0.251	0.000	0.015
75	72.200	4.179	5.787	0.214	0.914	0.010	0.357	0.628	0.258	0.162	0.102	0.002
100	72.267	2.685	3.716	0.138	0.653	0.765	0.248	0.119	0.703	0.664	0.000	0.045
125	70.200	2.436	3.469	0.125	0.588	0.809	0.019	0.331	0.747	0.728	0.009	0.001
150	69.483	1.847	2.658	0.095	0.770	0.773	0.120	0.209	0.007	0.141	0.046	0.000
175	70.800	2.307	3.259	0.118	0.913	0.705	0.264	0.025	0.014	0.056	0.011	0.187

Energy

25	53.383	17.324	32.453	0.889	0.360	0.766	0.809	0.714	0.583	0.152	0.767	0.012
50	78.250	12.807	16.367	0.657	0.476	0.432	0.317	0.174	0.079	0.097	0.000	0.005
75	65.367	23.068	35.290	1.183	0.220	0.100	0.776	0.863	0.078	0.876	0.230	0.020
100	53.433	14.328	26.815	0.735	0.814	0.331	0.123	0.979	0.948	0.466	0.012	0.018
125	42.250	10.154	24.033	0.521	0.670	0.178	0.687	0.244	0.209	0.343	0.001	0.000
150	41.150	7.705	18.724	0.395	0.131	0.902	0.993	0.778	0.004	0.018	0.011	0.000
175	52.867	8.499	16.076	0.436	0.038	0.422	0.217	0.097	0.010	0.322	0.011	0.053

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C18LW0A	C18LW0W	C18SS2F	C18SS5F	C18LW0A	C18LW0W	C18SS2F	C18SS5F	C18LW0A	C18LW0W	C18SS2F	C18SS5F
25	0.979	0.979	1.004	1.003	1.038	0.970	0.997	1.060	1.098	0.762	1.057	1.552
50	0.983	0.983	1.018	1.010	1.071	0.985	1.123	1.083	1.290	0.822	2.025	1.568
75	0.979	0.979	1.011	1.019	1.043	0.962	1.053	1.092	1.478	0.975	1.324	1.784
100	0.976	0.980	1.025	1.015	1.010	0.991	1.128	1.077	1.011	0.865	1.594	1.744
125	0.959	0.982	1.146	1.026	1.006	1.008	1.236	1.170	0.854	0.901	3.784	3.526
150	0.944	0.961	1.026	1.020	0.948	0.977	1.062	1.099	0.601	0.770	1.503	1.863
175	0.936	0.972	1.055	1.039	0.948	1.047	1.089	1.125	0.578	1.138	1.741	2.080

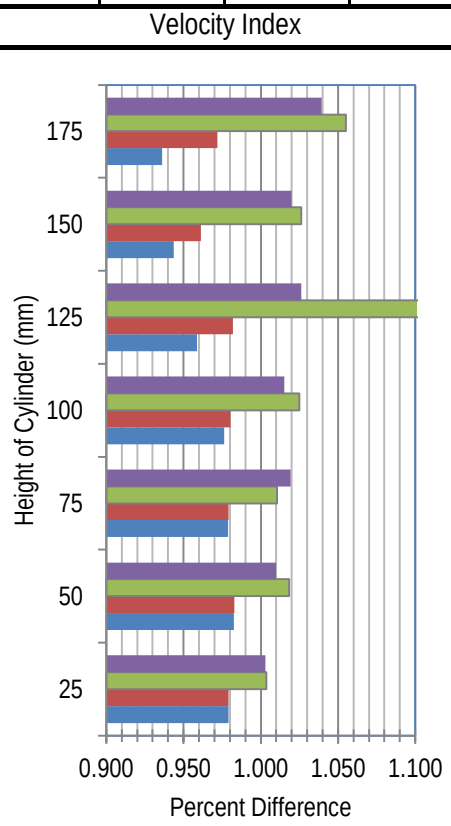
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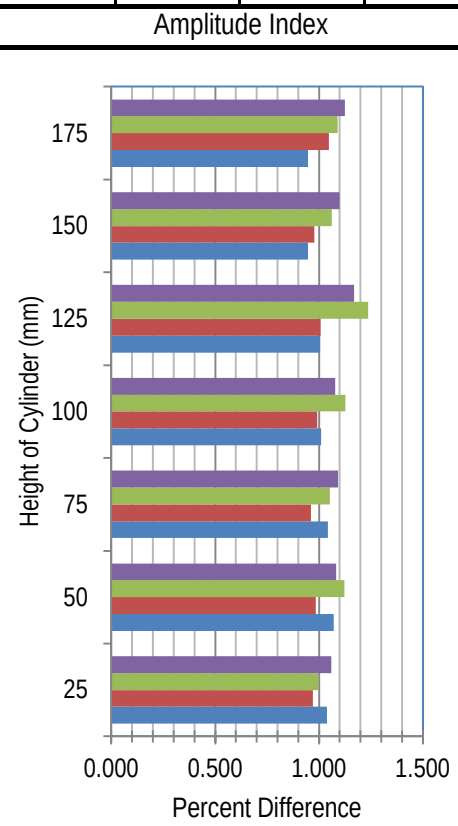
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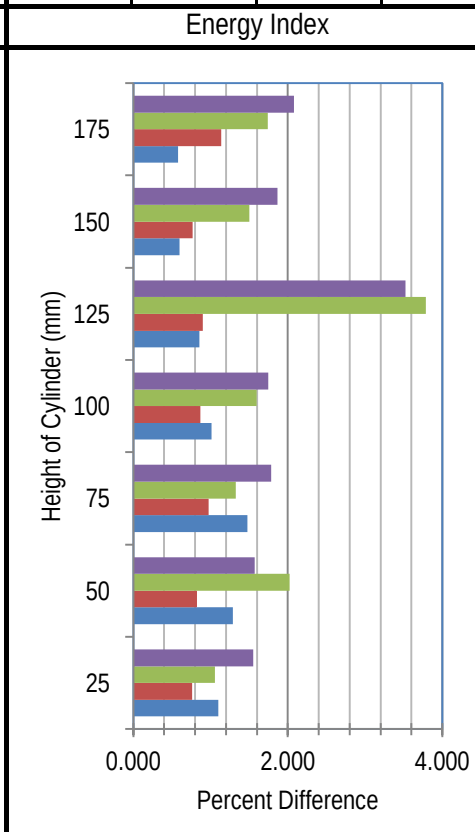
C18SS2F

C18LW0W

C18LW0A







Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Cylinders - 18 Months 2% Sodium Sulfate Exposure: Complete Immersion

Velocity

	Sample Statistics - C18SS2A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confidence	C18SS2W	C18SS2F	C18LW0A	C18SS5A	C18SS2W	C18SS2F	C18LW0A	C18SS5A
25	4.200	0.065	1.559	0.003	0.353	0.081	0.974	0.061	0.900	0.503	0.000	0.026
50	4.166	0.056	1.347	0.003	0.992	0.788	0.825	0.928	0.631	0.602	0.000	0.052
75	4.184	0.039	0.927	0.002	0.943	0.466	0.059	0.107	0.004	0.020	0.003	0.034
100	4.160	0.034	0.813	0.002	0.015	0.868	0.038	0.020	0.015	0.000	0.008	0.076
125	4.190	0.038	0.904	0.002	0.000	0.000	0.000	0.006	0.010	0.098	0.026	0.142
150	4.211	0.046	1.103	0.002	0.001	0.014	0.726	0.715	0.005	0.008	0.001	0.120
175	4.219	0.049	1.173	0.003	0.031	0.065	0.264	0.603	0.000	0.000	0.002	0.290

Amplitude

25	73.933	3.670	4.964	0.188	0.988	0.956	0.931	0.582	0.431	0.804	0.293	0.071
50	72.367	2.247	3.106	0.115	0.787	0.942	0.322	0.615	0.682	0.010	0.648	0.522
75	70.483	4.227	5.998	0.217	0.295	0.344	0.934	0.863	0.665	0.367	0.626	0.507
100	66.450	2.500	3.763	0.128	0.281	0.311	0.549	0.140	0.489	0.073	0.013	0.168
125	70.550	3.112	4.412	0.160	0.448	0.055	0.295	0.164	0.000	0.007	0.617	0.216
150	71.817	3.576	4.980	0.183	0.564	0.831	0.275	0.694	0.000	0.015	0.398	0.870
175	74.033	3.665	4.950	0.188	0.375	0.875	0.284	0.451	0.000	0.002	0.731	0.323

Energy

25	54.783	19.672	35.908	1.009	0.674	0.610	0.241	0.276	0.352	0.684	0.519	0.034
50	70.417	11.825	16.793	0.607	0.741	0.402	0.381	0.559	0.105	0.000	0.292	0.226
75	59.300	26.264	44.290	1.347	0.533	0.577	0.139	0.380	0.691	0.480	0.235	0.467
100	49.700	17.105	34.416	0.877	0.567	0.062	0.887	0.326	0.235	0.071	0.749	0.514
125	41.883	11.739	28.027	0.602	0.065	0.924	0.466	0.383	0.000	0.001	0.226	0.164
150	60.133	26.853	44.656	1.378	0.032	0.016	0.287	0.275	0.007	0.029	0.527	0.588
175	68.350	23.120	33.826	1.186	0.501	0.394	0.916	0.664	0.002	0.007	0.121	0.811

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C18SS2W	C18SS2F	C18LW0A	C18SS5A	C18SS2W	C18SS2F	C18LW0A	C18SS5A	C18SS2W	C18SS2F	C18LW0A	C18SS5A
25	0.999	0.995	0.971	1.020	1.024	0.993	1.034	1.054	1.227	1.085	1.127	1.723
50	1.004	1.004	0.969	1.018	0.993	1.061	1.011	1.014	1.231	1.822	1.161	1.171
75	1.020	1.013	0.981	1.023	1.013	1.028	1.018	1.023	1.102	1.201	1.341	1.196
100	1.043	1.029	0.980	1.025	1.022	1.037	0.928	0.950	1.414	1.483	0.940	0.848
125	1.171	1.170	0.979	1.029	1.282	1.242	1.011	1.055	7.079	3.751	0.847	1.453
150	1.141	1.071	0.985	1.010	1.211	1.098	0.980	1.005	4.161	2.196	0.878	1.135
175	1.125	1.104	0.979	1.009	1.253	1.139	0.992	1.038	3.395	2.251	0.747	1.057

Graph Legend

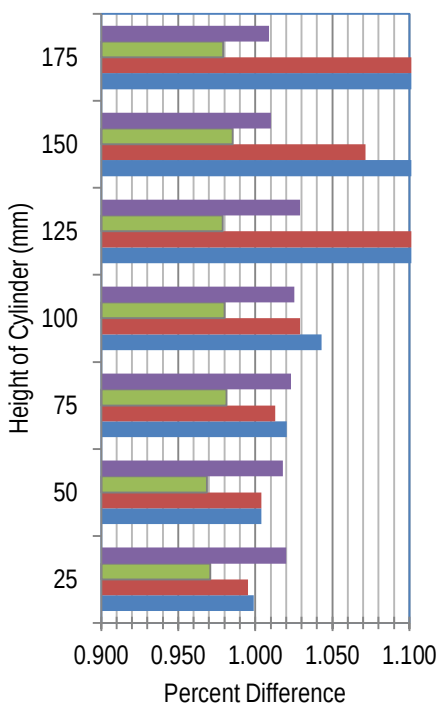
C18SS5A

C18LW0A

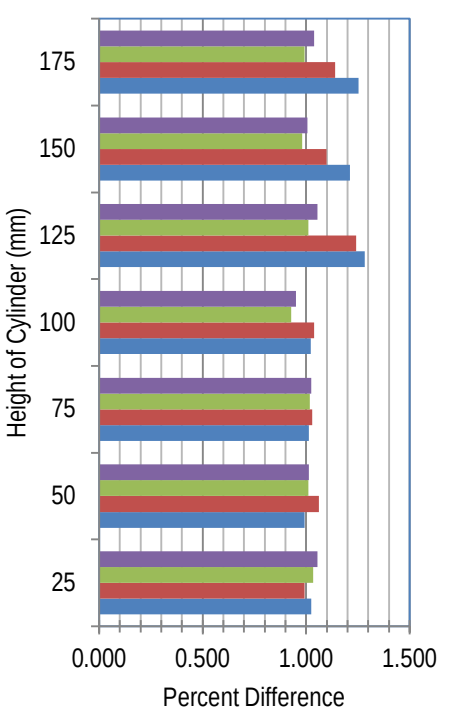
C18SS2F

C18SS2W

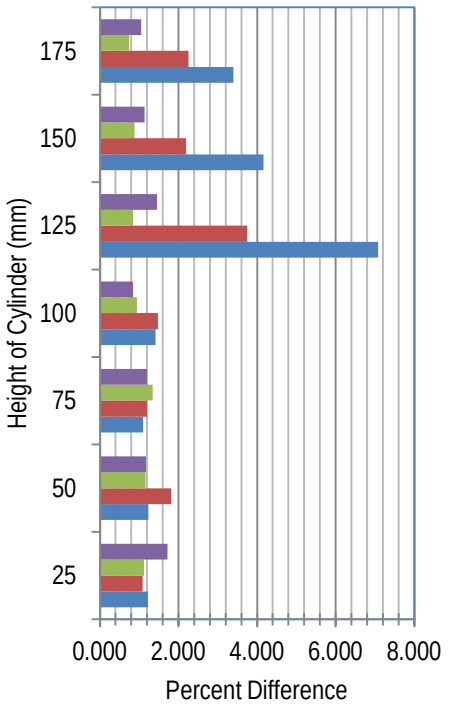
Velocity Index



Amplitude Index



Energy Index



Cylinders - 18 Months 2% Sodium Sulfate Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C18SS2W				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confidence	C18SS2A	C18SS2F	C18LW0W	C18SS5W	C18SS2A	C18SS2F	C18LW0W	C18SS5W
25	4.204	0.042	1.000	0.002	0.353	0.378	0.616	0.703	0.900	0.442	0.000	0.130
50	4.150	0.056	1.346	0.003	0.992	0.796	0.184	0.635	0.631	0.989	0.000	0.017
75	4.101	0.040	0.979	0.002	0.943	0.425	0.867	0.175	0.004	0.164	0.000	0.001
100	3.988	0.119	2.987	0.006	0.015	0.022	0.104	0.992	0.015	0.331	0.001	0.155
125	3.576	0.378	10.580	0.019	0.000	0.172	0.000	0.000	0.010	0.988	0.011	0.020
150	3.689	0.273	7.403	0.014	0.001	0.309	0.001	0.550	0.005	0.095	0.006	0.212
175	3.749	0.148	3.953	0.008	0.031	0.706	0.054	0.074	0.000	0.377	0.001	0.002

Amplitude

25	72.200	3.644	5.047	0.187	0.988	0.968	0.587	0.346	0.431	0.302	0.044	0.190
50	72.883	1.979	2.716	0.102	0.787	0.732	0.724	0.309	0.682	0.004	0.001	0.258
75	69.583	2.560	3.679	0.131	0.295	0.915	0.079	0.385	0.665	0.511	0.002	0.027
100	65.017	4.194	6.450	0.215	0.281	0.046	0.224	0.252	0.489	0.614	0.002	0.762
125	55.017	4.461	8.109	0.229	0.448	0.214	0.305	0.362	0.000	0.651	0.000	0.006
150	59.300	4.698	7.923	0.241	0.564	0.715	0.035	0.275	0.000	0.035	0.001	0.750
175	59.100	5.591	9.460	0.287	0.375	0.463	0.147	0.374	0.000	0.061	0.007	0.013

Energy

25	44.650	16.131	36.128	0.828	0.674	0.928	0.654	0.694	0.352	0.536	0.035	0.380
50	57.183	13.816	24.161	0.709	0.741	0.249	0.530	0.431	0.105	0.017	0.002	0.174
75	53.833	19.561	36.336	1.003	0.533	0.947	0.184	0.065	0.691	0.706	0.175	0.480
100	35.150	22.417	63.775	1.150	0.567	0.020	0.972	0.423	0.235	0.870	0.069	0.641
125	5.917	4.689	79.249	0.241	0.065	0.054	0.799	0.333	0.000	0.363	0.000	0.001
150	14.450	9.014	62.380	0.462	0.032	0.732	0.649	0.525	0.007	0.023	0.000	0.586
175	20.133	16.812	83.503	0.862	0.501	0.853	0.526	0.671	0.002	0.297	0.012	0.048

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C18SS2A	C18SS2F	C18LW0W	C18SS5W	C18SS2A	C18SS2F	C18LW0W	C18SS5W	C18SS2A	C18SS2F	C18LW0W	C18SS5W
25	1.001	0.996	0.972	0.990	0.977	0.970	0.943	0.967	0.815	0.884	0.637	0.850
50	0.996	1.000	0.965	0.980	1.007	1.069	0.937	0.975	0.812	1.480	0.601	0.797
75	0.980	0.993	0.962	0.978	0.987	1.015	0.927	0.955	0.908	1.090	0.803	0.893
100	0.959	0.987	0.944	0.974	0.978	1.015	0.892	0.984	0.707	1.049	0.569	1.179
125	0.854	0.999	0.856	0.873	0.780	0.969	0.790	0.879	0.141	0.530	0.126	0.270
150	0.876	0.939	0.879	0.937	0.826	0.906	0.834	0.980	0.240	0.528	0.270	0.806
175	0.889	0.981	0.904	0.919	0.798	0.909	0.874	0.878	0.295	0.663	0.433	0.502

Graph Legend

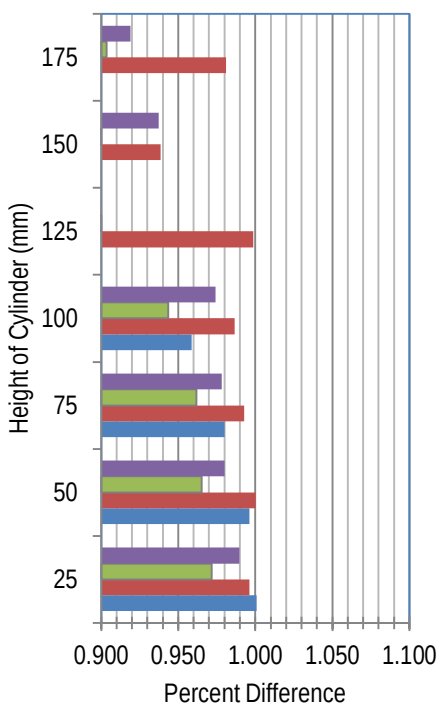
C18SS5W

C18LW0W

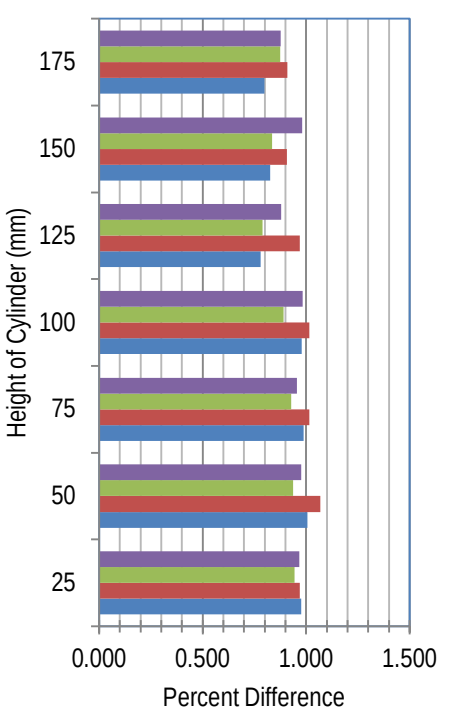
C18SS2F

C18SS2A

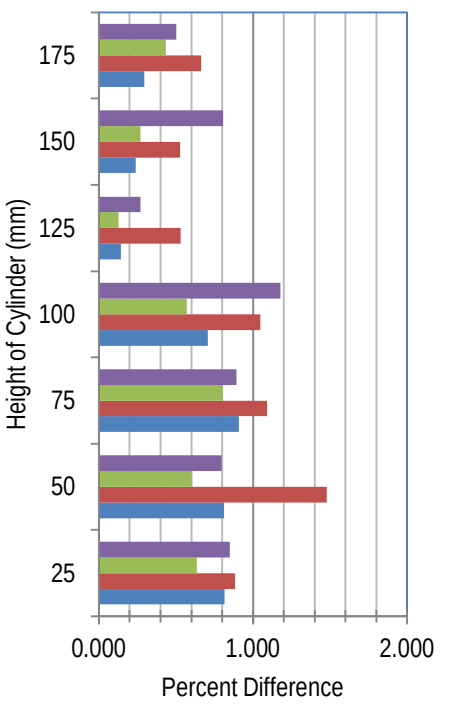
Velocity Index



Amplitude Index



Energy Index



Cylinders - 18 Months 2% Sodium Sulfate Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C18SS2F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confidence	C18SS2A	C18SS2W	C18LW0F	C18SS5F	C18SS2A	C18SS2W	C18LW0F	C18SS5F
25	4.220	0.028	0.654	0.001	0.081	0.378	0.332	0.020	0.503	0.442	0.495	0.963
50	4.150	0.049	1.192	0.003	0.788	0.796	0.290	0.167	0.602	0.989	0.009	0.445
75	4.131	0.027	0.665	0.001	0.466	0.425	0.465	0.000	0.020	0.164	0.048	0.693
100	4.042	0.037	0.905	0.002	0.868	0.022	0.718	0.003	0.000	0.331	0.000	0.644
125	3.581	0.735	20.515	0.038	0.000	0.172	0.000	0.057	0.098	0.988	0.142	0.238
150	3.930	0.168	4.270	0.009	0.014	0.309	0.002	0.696	0.008	0.095	0.197	0.832
175	3.822	0.124	3.247	0.006	0.065	0.706	0.028	0.101	0.000	0.377	0.007	0.647

Amplitude

25	74.467	3.575	4.801	0.183	0.956	0.968	0.572	0.649	0.804	0.302	0.909	0.085
50	68.183	2.326	3.411	0.119	0.942	0.732	0.459	0.129	0.010	0.004	0.000	0.272
75	68.550	2.692	3.927	0.138	0.344	0.915	0.357	0.169	0.367	0.511	0.102	0.336
100	64.050	1.540	2.404	0.079	0.311	0.046	0.248	0.012	0.073	0.614	0.000	0.260
125	56.783	8.127	14.312	0.417	0.055	0.214	0.019	0.130	0.007	0.651	0.009	0.402
150	65.417	3.955	6.046	0.203	0.831	0.715	0.120	0.742	0.015	0.035	0.046	0.322
175	65.000	3.946	6.070	0.202	0.875	0.463	0.264	0.207	0.002	0.061	0.011	0.557

Energy

25	50.500	15.460	30.614	0.793	0.610	0.928	0.809	0.544	0.684	0.536	0.767	0.157
50	38.650	7.939	20.541	0.407	0.402	0.249	0.317	0.026	0.000	0.017	0.000	0.330
75	49.383	20.177	40.857	1.035	0.577	0.947	0.776	0.649	0.480	0.706	0.230	0.354
100	33.517	6.741	20.112	0.346	0.062	0.020	0.123	0.118	0.071	0.870	0.012	0.668
125	11.167	12.280	109.975	0.630	0.924	0.054	0.687	0.125	0.001	0.363	0.001	0.886
150	27.383	7.672	28.016	0.394	0.016	0.732	0.993	0.771	0.029	0.023	0.011	0.292
175	30.367	15.412	50.753	0.791	0.394	0.853	0.217	0.639	0.007	0.297	0.011	0.633

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C18SS2A	C18SS2W	C18LW0F	C18SS5F	C18SS2A	C18SS2W	C18LW0F	C18SS5F	C18SS2A	C18SS2W	C18LW0F	C18SS5F
25	1.005	1.004	0.996	1.000	1.007	1.031	1.003	1.064	0.922	1.131	0.946	1.468
50	0.996	1.000	0.982	0.992	0.942	0.936	0.890	0.964	0.549	0.676	0.494	0.775
75	0.987	1.007	0.990	1.008	0.973	0.985	0.949	1.037	0.833	0.917	0.755	1.348
100	0.972	1.013	0.976	0.991	0.964	0.985	0.886	0.955	0.674	0.954	0.627	1.094
125	0.855	1.001	0.873	0.896	0.805	1.032	0.809	0.946	0.267	1.887	0.264	0.932
150	0.933	1.065	0.975	0.994	0.911	1.103	0.941	1.035	0.455	1.895	0.665	1.240
175	0.906	1.019	0.948	0.985	0.878	1.100	0.918	1.033	0.444	1.508	0.574	1.195

Graph Legend

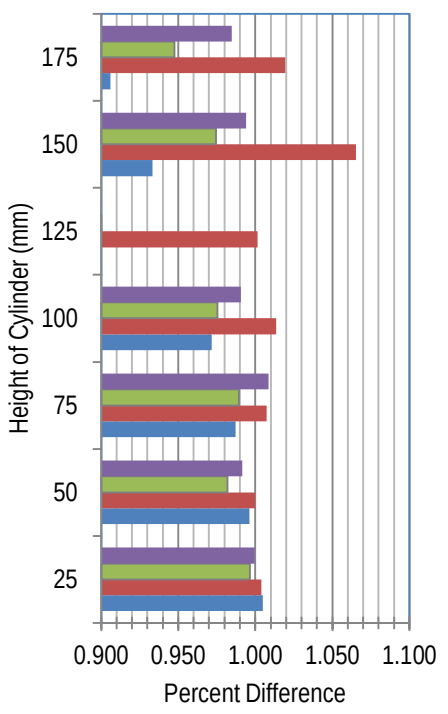
C18SS5F

C18LW0F

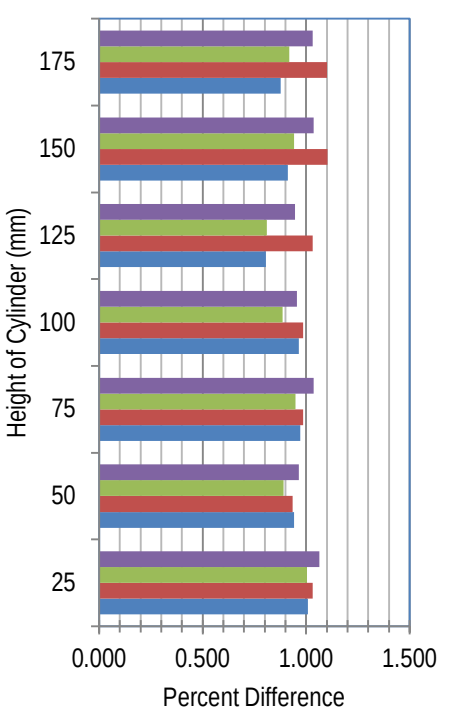
C18SS2W

C18SS2A

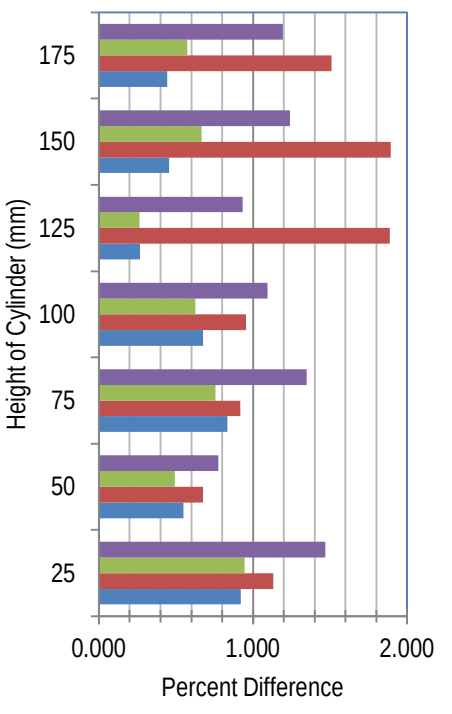
Velocity Index



Amplitude Index



Energy Index



Cylinders - 18 Months 2% Sodium Sulfate Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Velocity

	Sample Statistics - C18SS5A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confidence	C18SS5W	C18SS5F	C18LW0A	C18SS2A	C18SS5W	C18SS5F	C18LW0A	C18SS2A
25	4.117	0.026	0.625	0.001	0.168	0.015	0.974	0.061	0.000	0.036	0.000	0.026
50	4.093	0.059	1.431	0.003	0.566	0.295	0.825	0.928	0.001	0.075	0.000	0.052
75	4.090	0.086	2.095	0.004	0.007	0.082	0.059	0.107	0.032	0.951	0.003	0.034
100	4.057	0.112	2.768	0.006	0.892	0.273	0.038	0.020	0.590	0.798	0.008	0.076
125	4.071	0.165	4.054	0.008	0.010	0.260	0.000	0.006	0.732	0.604	0.026	0.142
150	4.169	0.039	0.939	0.002	0.000	0.003	0.726	0.715	0.177	0.047	0.001	0.120
175	4.182	0.063	1.513	0.003	0.938	0.006	0.264	0.603	0.017	0.045	0.002	0.290
Amplitude												
25	70.117	2.829	4.035	0.145	0.676	0.347	0.525	0.582	0.012	0.964	0.482	0.071
50	71.383	2.850	3.992	0.146	0.796	0.261	0.617	0.615	0.085	0.790	0.931	0.522
75	68.867	3.898	5.660	0.200	0.091	0.529	0.798	0.863	0.057	0.327	0.882	0.507
100	69.917	5.132	7.340	0.263	0.462	0.803	0.361	0.140	0.316	0.393	0.519	0.168
125	66.850	6.117	9.151	0.314	0.125	0.339	0.022	0.164	0.152	0.043	0.305	0.216
150	71.433	4.304	6.025	0.221	0.206	0.612	0.146	0.694	0.014	0.004	0.359	0.870
175	71.317	5.242	7.350	0.269	0.449	0.492	0.079	0.451	0.158	0.045	0.196	0.323
Energy												
25	31.800	11.669	36.696	0.599	0.769	0.238	0.930	0.276	0.017	0.793	0.029	0.034
50	60.117	15.586	25.926	0.800	0.592	0.333	0.764	0.559	0.288	0.412	0.957	0.226
75	49.600	17.292	34.863	0.887	0.106	0.437	0.522	0.380	0.199	0.321	0.553	0.467
100	58.617	27.343	46.647	1.403	0.229	0.190	0.265	0.326	0.048	0.051	0.665	0.514
125	28.833	17.779	61.662	0.912	0.079	0.028	0.120	0.383	0.408	0.069	0.028	0.164
150	53.000	15.910	30.019	0.816	0.572	0.220	0.979	0.275	0.002	0.002	0.124	0.588
175	64.683	28.372	43.864	1.456	0.138	0.413	0.742	0.664	0.085	0.019	0.109	0.811

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C18SS5W	C18SS5F	C18LW0A	C18SS2A	C18SS5W	C18SS5F	C18LW0A	C18SS2A	C18SS5W	C18SS5F	C18LW0A	C18SS2A
25	0.969	0.975	0.952	0.980	0.939	1.001	0.980	0.948	0.606	0.924	0.654	0.580
50	0.967	0.978	0.952	0.982	0.955	1.009	0.998	0.986	0.838	1.205	0.991	0.854
75	0.976	0.999	0.959	0.977	0.946	1.042	0.995	0.977	0.823	1.354	1.122	0.836
100	16.327	16.381	15.750	16.070	1.058	1.042	0.977	1.052	1.966	1.913	1.109	1.179
125	0.994	1.018	0.951	0.972	1.068	1.114	0.958	0.948	1.318	2.406	0.583	0.688
150	1.059	1.054	0.975	0.990	1.180	1.130	0.974	0.995	2.955	2.400	0.774	0.881
175	1.025	1.078	0.971	0.991	1.059	1.133	0.955	0.963	1.613	2.545	0.707	0.946

Graph Legend

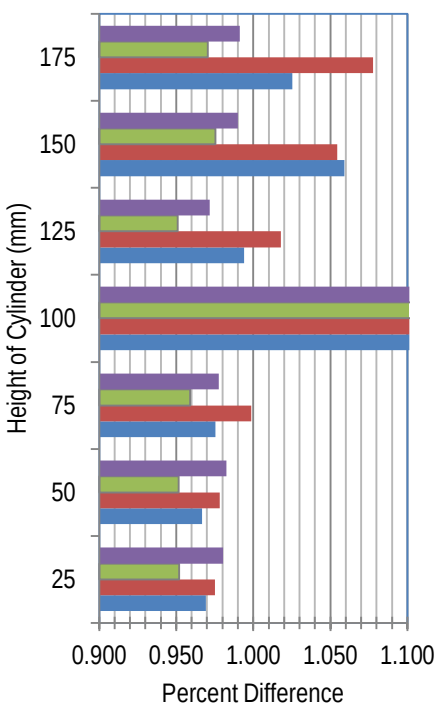
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C18LW0A

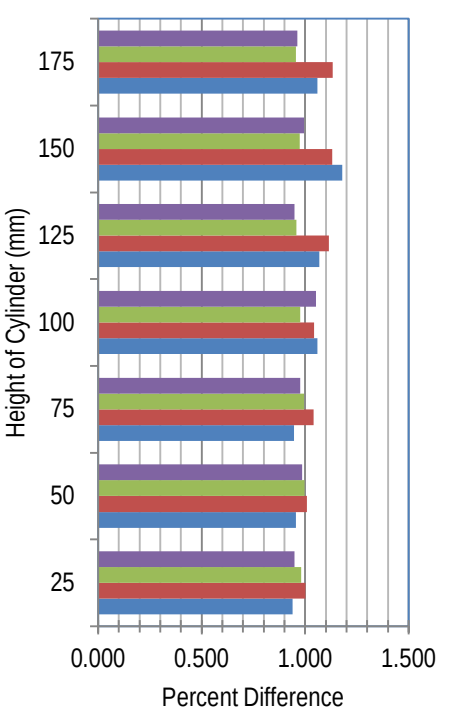
C18SS5F

C18SS5W

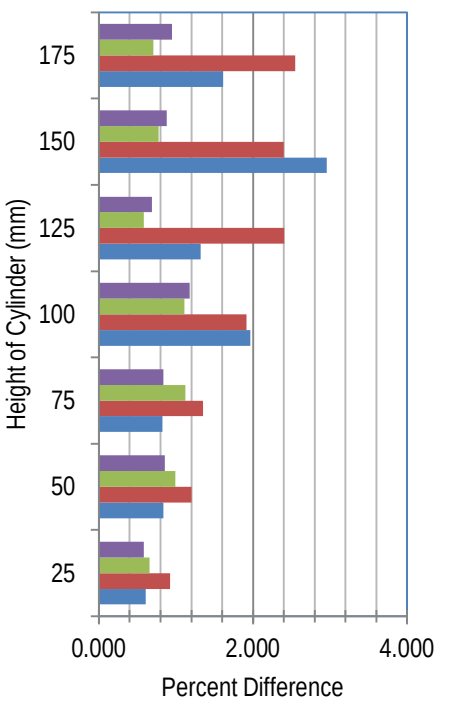
Velocity Index



Amplitude Index



Energy Index



Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Cylinders - 18 Months 2% Sodium Sulfate Exposure: Complete Immersion

Velocity

	Sample Statistics - C18SS5W				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confidence	C18SS5A	C18SS5F	C18LW0W	C18SS2W	C18SS5A	C18SS5F	C18LW0W	C18SS2W
25	4.248	0.050	1.184	0.003	0.168	0.220	0.381	0.703	0.000	0.557	0.010	0.130
50	4.234	0.045	1.055	0.002	0.566	0.115	0.379	0.635	0.001	0.285	0.013	0.017
75	4.193	0.021	0.496	0.001	0.007	0.000	0.132	0.175	0.032	0.296	0.005	0.001
100	4.095	0.120	2.923	0.006	0.892	0.333	0.102	0.992	0.590	0.885	0.033	0.155
125	4.096	0.043	1.051	0.002	0.010	0.001	0.642	0.000	0.732	0.444	0.004	0.020
150	3.936	0.362	9.206	0.019	0.000	0.224	0.000	0.550	0.177	0.920	0.140	0.212
175	4.079	0.061	1.496	0.003	0.938	0.005	0.871	0.074	0.017	0.144	0.066	0.002

Amplitude

25	74.683	2.324	3.112	0.119	0.676	0.183	0.682	0.346	0.012	0.045	0.243	0.190
50	74.733	3.219	4.307	0.165	0.796	0.380	0.178	0.309	0.085	0.126	0.068	0.258
75	72.833	1.693	2.325	0.087	0.091	0.027	0.339	0.385	0.057	0.024	0.023	0.027
100	66.083	7.274	11.008	0.373	0.462	0.624	0.026	0.252	0.316	0.794	0.071	0.762
125	62.567	2.888	4.616	0.148	0.125	0.534	0.904	0.362	0.152	0.223	0.001	0.006
150	60.533	7.930	13.100	0.407	0.206	0.085	0.003	0.275	0.014	0.474	0.022	0.750
175	67.333	3.659	5.434	0.188	0.449	0.159	0.550	0.374	0.158	0.216	0.876	0.013

Energy

25	52.517	13.402	25.520	0.688	0.769	0.367	0.404	0.694	0.017	0.101	0.103	0.380
50	71.767	20.082	27.983	1.030	0.592	0.658	0.871	0.431	0.288	0.124	0.063	0.174
75	60.267	7.814	12.966	0.401	0.106	0.023	0.562	0.065	0.199	0.069	0.229	0.480
100	29.817	15.314	51.360	0.786	0.229	0.908	0.403	0.423	0.048	0.926	0.017	0.641
125	21.883	7.445	34.023	0.382	0.079	0.595	0.470	0.333	0.408	0.028	0.000	0.001
150	17.933	12.181	67.925	0.625	0.572	0.493	0.282	0.525	0.002	0.514	0.000	0.586
175	40.100	13.764	34.323	0.706	0.138	0.481	0.831	0.671	0.085	0.159	0.422	0.048

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C18SS5A	C18SS5F	C18LW0W	C18SS2W	C18SS5A	C18SS5F	C18LW0W	C18SS2W	C18SS5A	C18SS5F	C18LW0W	C18SS2W
25	1.032	1.006	0.982	1.010	1.065	1.067	0.976	1.034	1.651	1.527	0.749	1.176
50	1.034	1.012	0.985	1.020	1.047	1.056	0.961	1.025	1.194	1.438	0.754	1.255
75	1.025	1.024	0.983	1.022	1.058	1.102	0.971	1.047	1.215	1.645	0.899	1.120
100	1.009	1.003	0.969	1.027	0.945	0.985	0.906	1.016	0.509	0.973	0.483	0.848
125	1.006	1.024	0.980	1.145	0.936	1.043	0.898	1.137	0.759	1.826	0.467	3.699
150	0.944	0.996	0.938	1.067	0.847	0.958	0.852	1.021	0.338	0.812	0.336	1.241
175	0.975	1.051	0.983	1.088	0.944	1.070	0.996	1.139	0.620	1.578	0.863	1.992

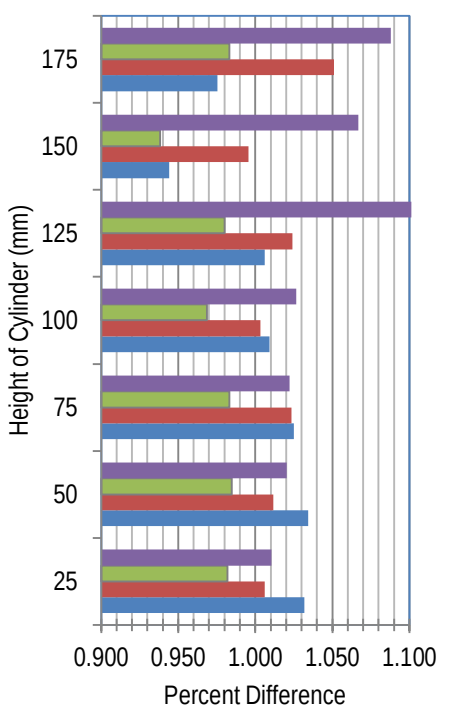
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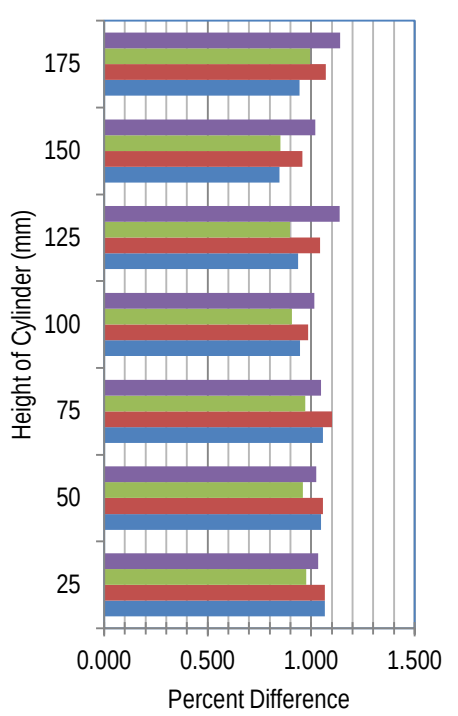
C18SS2W

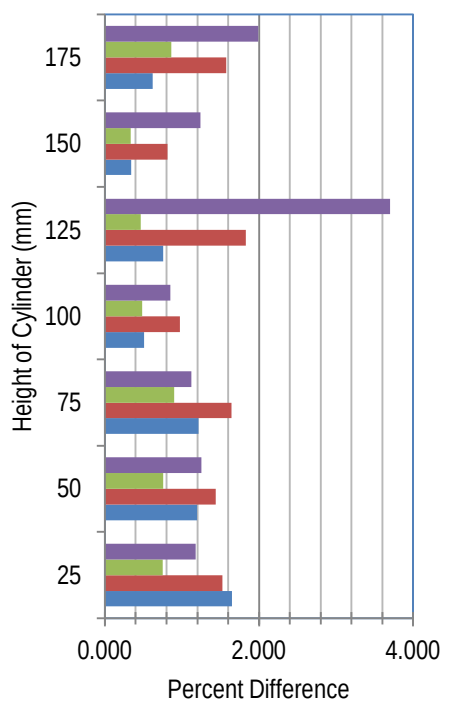
C18LW0W

C18SS5F

C18SS5A







Statistical Evaluation for Difference Between Samples

Wave Parameters of Ultra Sonic Pulse Emission Test (300 kHz)

Cylinders - 18 Months 2% Sodium Sulfate Exposure: Complete Immersion

Velocity

	Sample Statistics - C18SS5F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confidence	C18SS5A	C18SS5W	C18LW0F	C18SS2F	C18SS5A	C18SS5W	C18LW0F	C18SS2F
25	4.222	0.091	2.154	0.005	0.015	0.220	0.135	0.020	0.036	0.557	0.757	0.963
50	4.185	0.097	2.311	0.005	0.295	0.115	0.022	0.167	0.075	0.285	0.358	0.445
75	4.096	0.203	4.947	0.010	0.082	0.000	0.002	0.000	0.951	0.296	0.391	0.693
100	4.081	0.190	4.657	0.010	0.273	0.333	0.001	0.003	0.798	0.885	0.460	0.644
125	3.999	0.284	7.094	0.015	0.260	0.001	0.000	0.057	0.604	0.444	0.408	0.238
150	3.954	0.202	5.101	0.010	0.003	0.224	0.001	0.696	0.047	0.920	0.383	0.832
175	3.881	0.278	7.174	0.014	0.006	0.005	0.001	0.101	0.045	0.144	0.240	0.647

Amplitude

25	70.017	4.432	6.330	0.227	0.347	0.183	0.314	0.649	0.964	0.045	0.075	0.085
50	70.750	4.889	6.910	0.251	0.261	0.380	0.031	0.129	0.790	0.126	0.031	0.272
75	66.117	5.253	7.944	0.269	0.529	0.027	0.628	0.169	0.327	0.024	0.051	0.336
100	67.100	5.770	8.599	0.296	0.803	0.624	0.119	0.012	0.393	0.794	0.075	0.260
125	60.000	3.877	6.461	0.199	0.339	0.534	0.331	0.130	0.043	0.223	0.000	0.402
150	63.200	3.387	5.359	0.174	0.612	0.085	0.209	0.742	0.004	0.474	0.003	0.322
175	62.950	7.257	11.528	0.372	0.492	0.159	0.025	0.207	0.045	0.216	0.045	0.557

Energy

25	34.400	20.595	59.870	1.057	0.238	0.367	0.714	0.544	0.793	0.101	0.115	0.157
50	49.900	24.750	49.599	1.270	0.333	0.658	0.174	0.026	0.412	0.124	0.032	0.330
75	36.633	25.012	68.277	1.283	0.437	0.023	0.863	0.649	0.321	0.069	0.065	0.354
100	30.633	14.507	47.358	0.744	0.190	0.908	0.979	0.118	0.051	0.926	0.021	0.668
125	11.983	5.794	48.350	0.297	0.028	0.595	0.244	0.125	0.069	0.028	0.000	0.886
150	22.083	8.800	39.851	0.451	0.220	0.493	0.778	0.771	0.002	0.514	0.003	0.292
175	25.417	19.230	75.659	0.987	0.413	0.481	0.097	0.639	0.019	0.159	0.015	0.633

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C18SS5A	C18SS5W	C18LW0F	C18SS2F	C18SS5A	C18SS5W	C18LW0F	C18SS2F	C18SS5A	C18SS5W	C18LW0F	C18SS2F
25	1.025	0.994	0.997	1.000	0.999	0.938	0.943	0.940	1.082	0.655	0.644	0.681
50	1.022	0.988	0.990	1.008	0.991	0.947	0.924	1.038	0.830	0.695	0.638	1.291
75	1.001	0.977	0.981	0.992	0.960	0.908	0.916	0.965	0.739	0.608	0.560	0.742
100	1.006	0.997	0.985	1.010	0.960	1.015	0.929	1.048	0.523	1.027	0.573	0.914
125	0.982	0.976	0.974	1.117	0.898	0.959	0.855	1.057	0.416	0.548	0.284	1.073
150	0.948	1.004	0.980	1.006	0.885	1.044	0.910	0.966	0.417	1.231	0.537	0.806
175	0.928	0.951	0.962	1.015	0.883	0.935	0.889	0.968	0.393	0.634	0.481	0.837

Graph Legend

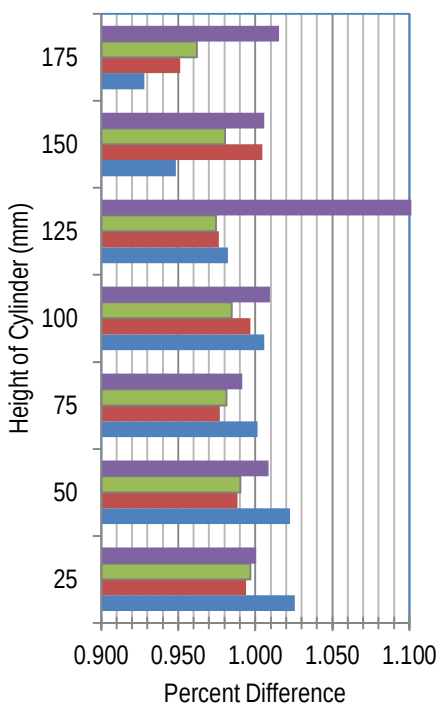
C18SS2F

C18LW0F

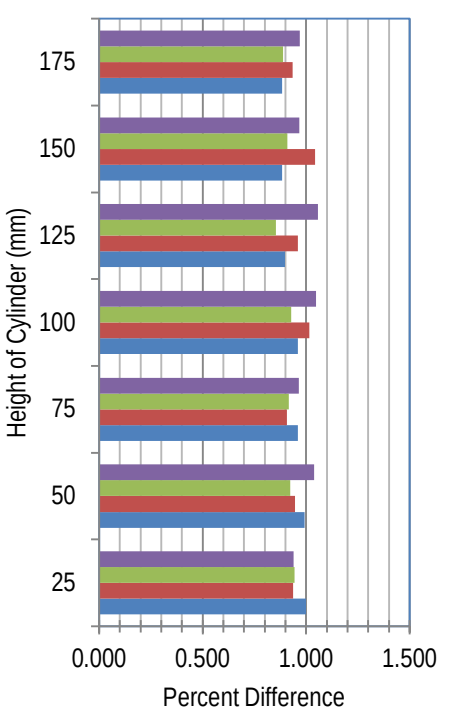
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C18SS5A

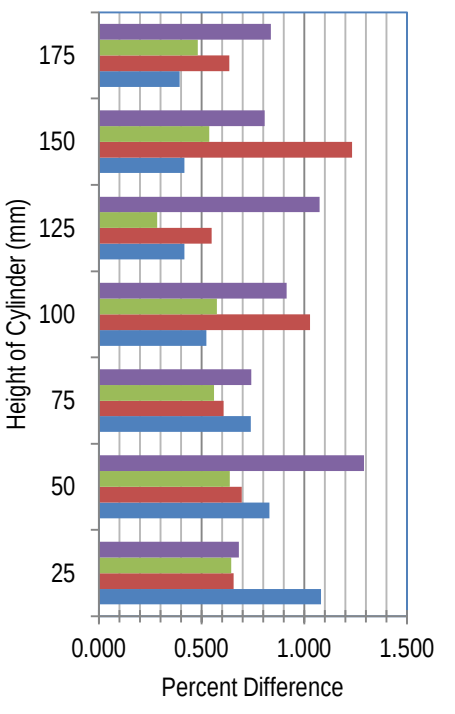
Velocity Index



Amplitude Index



Energy Index



Cylinders - 24 Months Limewater Solution Exposure: Complete Immersion

Sample: C24LW0A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.24	22.54	4.4472	71.2	35.1	100.21	22.59	4.4360	66.2	21.6
50	100.37	23.1	4.3450	70	48.1	100.26	23.22	4.3178	61.8	12.9
75	100.5	23.25	4.3226	74.5	55.2	100.32	23.45	4.2780	71	38.1
100	100.54	23.13	4.3467	69	45.8	100.27	23.34	4.2961	65.3	24.5
125	100.62	23.14	4.3483	69.8	21.8	100.22	23.02	4.3536	60.1	10.5
150	100.54	23.18	4.3374	66.5	24.4	100.01	23.17	4.3164	64.1	15.5
175	100.8	23.13	4.3580	69.7	40.6	99.95	22.69	4.4050	66.2	23.1

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.83	195.4	195.615	41.1	41.2	41.15	4.7537	7.18	4.5

Sample: C24LW0A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.34	22.9	4.3817	72.1	30.6	100.33	23.01	4.3603	69.7	22.3
50	100.44	23.22	4.3256	69	36	100.45	23.25	4.3204	67.6	20.5
75	100.63	23.31	4.3170	66.3	29	100.51	23.26	4.3212	70.3	44.2
100	100.67	23.49	4.2857	70.5	35.6	100.53	23.5	4.2779	63.7	16.1
125	100.82	23.51	4.2884	63.4	17.8	100.53	23.5	4.2779	67	23.6
150	100.83	22.89	4.4050	69	30.6	100.35	22.98	4.3668	66.5	26.1
175	100.98	23.15	4.3620	71.7	36	100.38	23.09	4.3473	72.2	40.7

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
194.26	194.57	194.415	40.8	41	40.9	4.7534	6.33593	8.5 cm from bottom

Sample: C24LW0A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.15	22.78	4.3964	75.3	64.6	100.34	22.66	4.4281	75.5	74.1
50	100.15	22.38	4.4750	74.2	72.9	100.55	22.85	4.4004	73.9	63.4
75	100.14	22.87	4.3787	72.7	76.9	100.71	22.65	4.4464	75.4	89
100	100.15	23.09	4.3374	68.9	35.9	100.87	23.13	4.3610	74.4	64.2
125	100.17	22.84	4.3857	71	58.9	101.04	23.18	4.3589	72	58
150	100.02	22.77	4.3926	73.2	78.6	101.07	22.83	4.4271	76	73.5
175	100.01	22.20	4.5050	75.8	136.3	101.27	22.84	4.4339	78.8	122.2

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.02	196.6	196.81	41.3	41.3	41.3	4.7654	6.20887	

Notes:

C24LWA3 might be C24x

Cylinders - 24 Months 2% Sodium Sulphate Solution Exposure: Complete Immersion

Sample: C24SS2A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.23	23.12	4.3352	74.3	46.6	100.29	23	4.3604	73	49.9
50	100.3	23.2	4.3233	74.6	72.8	100.57	23.27	4.3219	74.8	53.5
75	100.3	23.65	4.2410	70.3	66.5	100.47	23.77	4.2268	70.7	40.6
100	100.38	23.43	4.2843	70	48.2	100.74	23.91	4.2133	76.4	58.6
125	100.2	23.24	4.3115	73	69.7	100.72	23.29	4.3246	68.5	48.6
150	99.96	23.34	4.2828	66.5	37	100.5	23.18	4.3356	75	69.1
175	99.98	23.00	4.3470	78.7	136.6	100.88	23.43	4.3056	70.5	49.4

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.2	197.55	197.375	42.4	42.4	42.4	4.6551	7.30105	5.4 cm from bottom

Sample: C24SS2A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.99	22.62	4.4204	77	112.2	100.29	23.03	4.3548	77.8	106
50	100.24	22.77	4.4023	77.6	90.3	100.57	23	4.3726	79	123.7
75	100.25	22.9	4.3777	75	87.3	100.47	23.2	4.3306	76.8	99.9
100	100.31	23.24	4.3163	78.4	116	100.74	22.83	4.4126	78.3	150.2
125	100.37	22.65	4.4313	74	94.7	100.72	22.76	4.4253	78.1	99.8
150	100.29	22.35	4.4872	76	94.6	100.5	22.6	4.4469	79.8	135.8
175	100.26	22.57	4.4422	79.2	116.1	100.88	22.76	4.4323	79.4	151.2

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.79	197.74	197.765	41.5	41.8	41.65	4.7483	6.20129	

Sample: C24SS2A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.23	23.22	4.3165	72.3	32.6	99.91	22.95	4.3534	70.1	28.8
50	100.45	23.18	4.3335	68.3	37.7	100.06	23.13	4.3260	68.1	35.4
75	100.65	23.61	4.2630	65.4	17.3	100.21	23.17	4.3250	73.1	51.4
100	100.74	23.66	4.2578	68.4	23.1	100.33	23.37	4.2931	71.8	45.8
125	100.87	23.51	4.2905	67.8	16	100.45	23.29	4.3130	65.9	29.8
150	100.82	23.00	4.3835	70.7	33.1	100.5	23	4.3696	74.3	56.1
175	100.85	23.00	4.3848	71	41.4	100.67	23.17	4.3448	71.3	32.7

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.39	195.28	195.335	41.5	41.6	41.55	4.7012	7.49185	

Notes:

A2 and A3 loaded to over 10Mpa and did not fail on first trial. Failures are for the second trial.

Cylinders - 24 Months 5% Sodium Sulphate Solution Exposure: Complete Immersion

Sample: C24SS5A1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.5	23.7	4.2405	62	10.2	100.2	23.4	4.2821	67	23.8
50	100.58	23.9	4.2084	68.3	19.7	100.25	23.82	4.2086	59	10.4
75	100.7	23.69	4.2507	59.6	14	100.35	24.56	4.0859	64.6	17.2
100	100.76	25.31	3.9810	60.4	8.4	100.37	23.79	4.2190	63.1	17.1
125	100.94	24.38	4.1403	56.5	8.2	100.39	24.04	4.1760	60.9	10.9
150	100.9	24.37	4.1403	57.8	7.3	100.34	24.07	4.1687	63.3	14.6
175	101.08	24.59	4.1106	66.3	20.8	100.46	23.75	4.2299	62.5	17.7

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.13	194.89	195.01	42.1	42.3	42.2	4.6211	7.6785	

Sample: C24SS5A2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.31	23.41	4.2849	70.3	30.2	100.4	23.25	4.3183	72.6	54.8
50	100.27	24.19	4.1451	58.2	7.7	100.25	23.55	4.2569	72.2	71.4
75	100.4	23.77	4.2238	68.5	49.4	100.45	23.88	4.2064	71.9	62.4
100	100.68	24.36	4.1330	65.3	19	100.55	24.04	4.1826	67.5	30.9
125	100.35	23.42	4.2848	69.4	57.5	100.66	24.05	4.1854	63.2	15.3
150	100.32	23.79	4.2169	72.9	58.5	100.46	23.7	4.2388	70	69.4
175	100.33	23.33	4.3005	73.7	56.8	100.3	23.08	4.3458	73.9	49.1

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.86	196.83	196.845	42.9	43	42.95	4.5831	8.10086	

Sample: C24SS5A3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location

Notes:

DRI Performed on C24SS5A3

Cylinders - 24 Months Limewater Solution Exposure: Partial Immersion

Sample: C24LW0W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.82	22.77	4.3838	71.5	73.3	99.88	22.46	4.4470	78.5	115.2
50	99.93	22.97	4.3505	79.5	89.7	99.98	23.1	4.3281	77.3	71.3
75	100.01	23.37	4.2794	76.5	76.9	100.1	23.38	4.2814	73	82.2
100	100.01	23.08	4.3332	76.7	73.1	100.23	23.16	4.3277	78.3	70.3
125	99.97	23.60	4.2360	68.7	50.5	100.27	23.96	4.1849	70.8	47.5
150	99.82	24.61	4.0561	65.7	23.3	100.34	24.12	4.1600	70.3	50
175	99.91	24.71	4.0433	70.8	46.9	100.62	25.14	4.0024	67.5	24.9

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.24	194.75	194.995	41.7	41.7	41.7	4.6761	3.9937	4.3 cm from top

Sample: C24LW0W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.99	22.5	4.4440	82	95.3	100.07	23.03	4.3452	81	94.2
50	99.97	22.93	4.3598	81	116	100.22	22.92	4.3726	78.4	95.3
75	100.07	22.92	4.3661	74.6	77.1	100.34	23.08	4.3475	77.1	102.1
100	100.07	23.32	4.2912	78.4	99.4	100.44	23.9	4.2025	74.9	70.1
125	99.85	23.46	4.2562	74.3	56.5	100.31	23.82	4.2112	74.4	78.1
150	99.71	23.86	4.1790	67	22.7	100.19	23.82	4.2061	69	39.5
175	99.82	24.39	4.0927	67.3	28.2	100.34	24.48	4.0989	68.6	47.5

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
198.49	198.44	198.465	43.1	43.3	43.2	4.5941	4.94335	

Sample: C24LW0W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.43	22.91	4.3837	71	30.1	100.25	22.91	4.3758	69.3	26
50	100.49	23.05	4.3597	73.2	55.5	100.24	23.13	4.3338	71.6	39.3
75	100.64	23.48	4.2862	68.1	30.7	100.28	23.56	4.2564	69.2	36.8
100	100.69	23.66	4.2557	67.2	33	100.3	23.89	4.1984	68.1	27.9
125	100.73	24.21	4.1607	63	18.7	100.26	24.08	4.1636	63.6	22.6
150	100.75	24.62	4.0922	62	14.5	100.07	24.14	4.1454	60.4	13.4
175	100.87	25.11	4.0171	64.3	24.1	100.12	24.59	4.0716	63	16.3

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
194.88	194.98	194.93	41.9	42.1	42	4.6412	3.57799	

Notes:

Cylinders - 24 Months 2% Sodium Sulphate Solution Exposure: Partial Immersion

Sample: C24SS2W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.34	22.81	4.3989	71.3	19.3	100.1	22.84	4.3827	71.2	25.2
50	100.49	23.21	4.3296	73.7	31.7	100.18	23.1	4.3368	76.4	75.8
75	100.69	23.24	4.3326	68.4	33	100.26	22.94	4.3705	68.4	30.4
100	100.82	23.48	4.2939	67.2	23.2	100.31	22.84	4.3919	68.7	41.1
125	100.48	25.80	3.8946	48	2.1	100.29	24.46	4.1002	50.3	2
150	100.79	26.34	3.8265	51.7	2	100.03	27.04	3.6993	51.5	2.5
175	100.91	25.92	3.8931	59.7	7.1	100.36	27.03	3.7129	45.7	1.8

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
200.05	199.53	199.79	42.9	42.9	42.9	4.6571	5.05277	

Sample: C24SS2W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.92	23.19	4.3088	70	24.9	100.1	23.38	4.2814	69	18
50	99.98	23.59	4.2382	65.5	15.3	100.18	23.54	4.2557	70.5	34.3
75	100.06	23.79	4.2060	65.2	17	100.26	23.21	4.3197	68.3	33.3
100	100.24	23.84	4.2047	70.5	28.4	100.31	23.78	4.2183	73.8	44.4
125	100.28	25.08	3.9984	52.9	3.4	100.29	24.82	4.0407	61.5	8.5
150	100.18	24.83	4.0346	59.2	16.9	100.03	24.24	4.1267	59.6	11.8
175	100.35	24.50	4.0959	65.1	27.5	100.36	25.33	3.9621	54.1	8.9

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.99	197.01	197	43.2	43.4	43.3	4.5497	5.44429	

Sample: C24SS2W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.09	22.49	4.4504	71	27.2	100.09	23.02	4.3480	74.3	39.4
50	100.13	23.7	4.2249	66.5	19.9	100.28	23.13	4.3355	71.8	36.7
75	100.2	23.97	4.1802	65.4	14.9	100.4	23.98	4.1868	65.9	18.5
100	110.34	24.14	4.5708	65.2	13.2	100.62	24.11	4.1734	64.4	13.4
125	100.26	24.15	4.1516	56.8	9.3	100.64	25.47	3.9513	47.6	2
150	100.14	24.37	4.1092	53	5	100.58	26.43	3.8055	46.2	1
175	100.18	27.31	3.6683	49.6	4.1	100.65	23.97	4.1990	62.2	15.6

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
193.82	193.55	193.685	41.9	42.1	42	4.6115	6.20033	

Notes:

Cylinders - 24 Months 5% Sodium Sulphate Solution Exposure: Partial Immersion

Sample: C24SS5W1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.07	23.95	4.1783	66.9	12.7	99.83	23.58	4.2337	66.2	21.4
50	100.2	24.34	4.1167	67.6	22.9	99.88	23.77	4.2019	68.1	34.6
75	100.37	25.21	3.9814	55.8	11	99.95	24.03	4.1594	67.6	32.1
100	100.61	24.44	4.1166	63.3	11.3	100.32	25.61	3.9172	68	17.6
125	100.04	24.37	4.1050	58	12	99.33	24.8	4.0052	62.4	19.2
150	98.46	23.58	4.1756	61	18.7	99.68	25.05	3.9792	63.9	9.8
175	100.5	24.98	4.0232	60.1	9.1	100.11	24.59	4.0712	63.5	25.8

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
194.03	194.04	194.035	42.9	43.1	43	4.5124	5.12865	

Sample: C24SS5W2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.1	23.15	4.3240	74.2	37.1	100.37	23.37	4.2948	73.6	33.7
50	100.04	23.57	4.2444	69.6	32.8	100.57	23.86	4.2150	68.2	27.6
75	100.03	23.63	4.2332	70.8	42.1	100.73	23.64	4.2610	70.2	45
100	99.53	24.35	4.0875	61.2	10.3	100.95	24.78	4.0738	57.8	9.4
125	99.51	23.50	4.2345	36		99.47	56.5	1.7605	49.5	
150	99.86	64.00	1.5603	42.5		101.04	25.29	3.9953	56.5	5.5
175	99.75	24.09	4.1407	64	24.2	101.21	25.03	4.0435	63.7	22.5

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
193.61	194.12	193.865	42.9	42.9	42.9	4.5190	5.01481	

Sample: C24SS5W3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location

Notes:

DRI Performed on C24SS5W3

Cylinders - 24 Months Limewater Solution Exposure: Cyclical Partial Immersion

Sample: C24LW0F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.24	23.26	4.3095	79.9	98.1	100.27	23	4.3596	80	
50	100.39	23.61	4.2520	78	113.2	100.37	24	4.1821	78	
75	100.37	23.8	4.2172	75.9	76.1	100.53	23.5	4.2779	77	
100	100.4	24.11	4.1642	73	56.3	100.63	24	4.1929	77.5	
125	100.4	23.50	4.2723	70.5		100.73	24.03	4.1918	71.9	73.2
150	100.31	24.50	4.0943	68		100.68	23.98	4.1985	75.1	69.6
175	100.33	25.00	4.0132	68		100.77	25.23	3.9941	58.8	24.6

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.61	197.77	197.69	43	43.1	43.05	4.5921	3.94364	3.4 cm from top

Sample: C24LW0F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	99.98	23.13	4.3225	74.2	32.7	99.93	23.32	4.2852	73.9	45.2
50	100.05	23.65	4.2304	69	54	100.04	23.52	4.2534	70.5	43.3
75	100.17	24	4.1737	67.5	27.8	100.17	23.96	4.1807	66.8	24.3
100	100.22	23.89	4.1951	69.4	33.6	100.34	24.36	4.1190	69.5	40.9
125	100.04	26.74	3.7412	54.9	3.1	100.26	24.48	4.0956	59	7
150	100.34	24.13	4.1583	68	26	100.26	24.15	4.1516	66	22
175	99.94	24.49	4.0808	62.9	18.6	100.27	24.86	4.0334	60.1	11.7

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
196.12	196.26	196.19	42.4	42.6	42.5	4.6162	4.21555	5.5 cm from top

Sample: C24LW0F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.26	23.41	4.2828	73	40.3	100.33	23.34	4.2986	75	57.9
50	100.43	23.74	4.2304	74.3	61.1	100.51	23.78	4.2267	72.5	55.3
75	100.49	24.05	4.1784	72.6	66	100.61	23.89	4.2114	74	71.6
100	100.55	24.09	4.1739	69.5	34.6	100.71	23.83	4.2262	72	49.5
125	100.62	24.17	4.1630	63	22.6	100.76	24.32	4.1431	66	18.6
150	100.49	24.40	4.1184	69.6	35.6	100.59	24.07	4.1791	69.3	38.9
175	100.55	25.36	3.9649	61.6	14.5	100.61	24.96	4.0308	64.7	24.9

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)	Pressure Tension Test	
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
191.87	192.63	192.25	41.5	41.7	41.6	4.6214	4.93402	

Notes:

Cylinders - 24 Months 2% Sodium Sulphate Solution Exposure: Cyclical Partial Immersion

Sample: C24SS2F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.46	23.02	4.3640	77	72.6	100.24	23	4.3583	74.1	54.3
50	100.31	23.67	4.2379	77.6	72.2	100.29	23.39	4.2877	76.5	53.9
75	100.41	24	4.1837	69	31.4	100.43	23.79	4.2215	69.8	42.4
100	100.37	24.03	4.1769	72.9	49.6	100.52	24.42	4.1163	70.7	34.3
125	99.65	24.57	4.0558	59.7	13	100.65	24.7	4.0749	59.4	8.9
150	100.17	25.03	4.0020	59.2	13.6	100.65	24.68	4.0782	62.3	17.5
175	100.19	24.83	4.0350	65	25	100.84	24.85	4.0579	66.9	35.6

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
192.84	192.98	192.91	41.2	42.2	41.7	4.6261	4.32723	4.0 cm from top

Sample: C24SS2F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.12	22.65	4.4203	75	72.9	100.24	22.58	4.4393	74	48.6
50	100.18	23.13	4.3312	77.5	80.5	100.45	23.19	4.3316	78.4	81.6
75	100.14	23.41	4.2777	76.7	75.2	100.69	23.48	4.2883	71.1	46.4
100	100.01	23.19	4.3126	70	40.2	100.84	23.49	4.2929	72.3	50
125	99.63	23.94	4.1617	61	8.2	100.92	23.81	4.2386	66.1	30.6
150	99.81	23.92	4.1727	69.5	36.4	100.95	23.79	4.2434	72	51
175	99.82	24.50	4.0743	70.6	40.6	101.06	24.65	4.0998	65.5	22.4

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
195.77	195.69	195.73	42.7	42.7	42.7	4.5838	4.76732	3.2 cm from top

Sample: C24SS2F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.41	23.22	4.3243	79.8	86	100.23	23.28	4.3054	73.1	40
50	100.55	23.1	4.3528	75.5	80.9	100.14	23.02	4.3501	75.7	57.3
75	100.73	23.21	4.3399	74.1	77.7	100.16	23.52	4.2585	73.2	62.9
100	100.87	23.72	4.2525	78.5	76.3	100.1	23.75	4.2147	72.8	47.9
125	100.48	24.34	4.1282	58.1	20	100	23.66	4.2265	68.2	39.2
150	100.95	24.52	4.1170	68.5	38.7	99.98	23.97	4.1710	71.8	46.1
175	101.1	24.87	4.0651	72.2	58.2	99.94	24.38	4.0993	67.4	46.4

Ultra Sonic Pulse Velocity Test (54 kHz)							Pressure Tension Test	
Lenght (mm)			Time (µs)			Velocity (mm/µs)		
Axis 1-3	Axis 2-4	Average	1	2	Average		Pressure (MPa)	Failure Location
197.45	197.28	197.365	43.4	43.3	43.35	4.5528	4.02199	5.3 cm from top

Notes:

Cylinders - 24 Months 5% Sodium Sulphate Solution Exposure: Cyclical Partial Immersion

Sample: C24SS5F1

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.2	23	4.3565	71		100.33	23	4.3622	65	
50	100.14	24	4.1725	69.5		100.45	23.5	4.2745	75	
75	100.04	24	4.1683	69		100.69	24	4.1954	70.5	
100	100.23	27	3.7122	58.5		101.04	33.5	3.0161	52	
125	99.76	24.00	4.1567	67.5		98.42	29	3.3938	56.5	
150	99.47	24.00	4.1446	65		100.84	24	4.2017	67.5	
175	99.75	24.00	4.1563	70.5		101.03	25.5	3.9620	58	

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)
Axis 1-3	Axis 2-4	Average	1	2	Average	
198.79	199.04	198.915	43.7	43.9	43.8	4.5414

Pressure Tension Test

Pressure (MPa)	Failure Location
3.38304	2.1 cm from top

Sample: C24SS5F2

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy
25	100.3	22.94	4.3723	75.7	53.2	100.17	23.4	4.2808	78.3	70.7
50	100.56	23.51	4.2773	70.6	48.5	100.29	23.47	4.2731	75.5	79.9
75	100.63	23.71	4.2442	75.5	69.6	100.43	23.74	4.2304	74.5	58.4
100	100.83	25.02	4.0300	65.4	13.7	100.57	26.3	3.8240	58.2	7.4
125	98.27	26.83	3.6627	49.4	3	100.29	24.39	4.1119	60.3	9.5
150	100.72	25.00	4.0288	63.9	15.3	100.55	24.53	4.0991	63.3	14.6
175	100.81	25.56	3.9441	62	19.4	100.65	24.56	4.0981	68	47.1

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)
Axis 1-3	Axis 2-4	Average	1	2	Average	
194.98	194.94	194.96	43.7	43.6	43.65	4.4664

Pressure Tension Test

Pressure (MPa)	Failure Location
3.51892	3.3 cm from top

Sample: C24SS5F3

Ultra Sonic Pulse Emission Test (300 kHz)

	Axis 1-3					Axis 2-4				
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy

Ultra Sonic Pulse Velocity Test (54 kHz)

Lenght (mm)			Time (µs)			Velocity (mm/µs)
Axis 1-3	Axis 2-4	Average	1	2	Average	

Pressure Tension Test

Pressure (MPa)	Failure Location

Notes:

DRI Performed on C24SS5F3

AST results not from file C24SS5F1

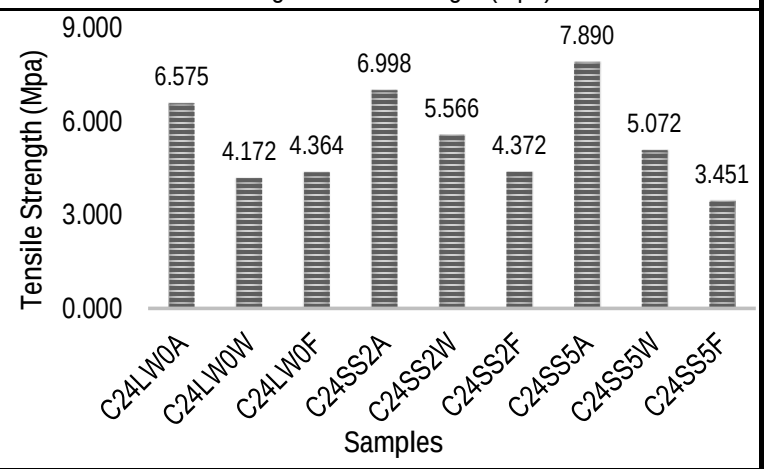
Cylinders - 24 Months Solution Exposure

Statistical Evaluation for Difference Between Samples

Ultimate Tensile Strength (Mpa) - Gas Pressure Tension Test

Samples	Sample Statistics			
	Average	Standard Deviation	Coeff. of Variation	Confi-dence
C24LW0A	6.575	0.528	8.028	0.038
C24LW0W	4.172	0.700	16.777	0.051
C24LW0F	4.364	0.512	11.724	0.037
C24SS2A	6.998	0.697	9.954	0.051
C24SS2W	5.566	0.583	10.481	0.042
C24SS2F	4.372	0.375	8.570	0.027
C24SS5A	7.890	0.299	3.785	0.027
C24SS5W	5.072	0.080	1.587	0.007
C24SS5F	3.451	0.096	2.784	0.009

Average Tensile Strength (Mpa)

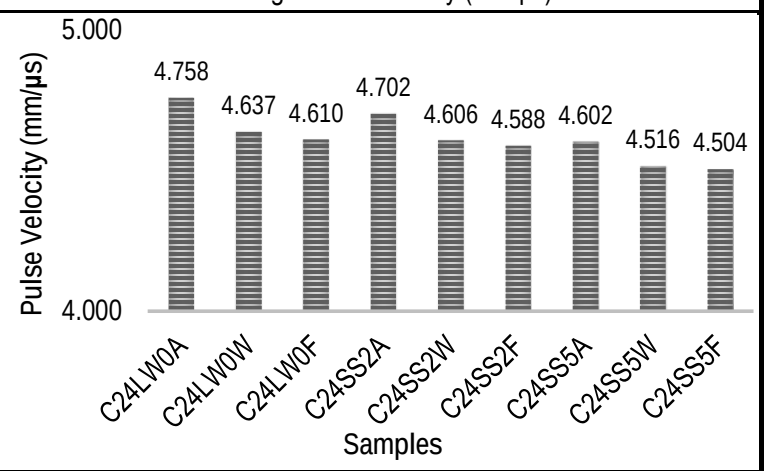


Samples	C24LW0A	C24LW0W	C24LW0F	C24SS2A	C24SS2W	C24SS2F	C24SS5A	C24SS5W	C24SS5F	
C24LW0A	1.000	0.009	0.006	0.449	0.090	0.004	0.053	0.032	0.004	T-Test
C24LW0W	0.725	1.000	0.720	0.008	0.057	0.684	0.006	0.184	0.263	
C24LW0F	0.969	0.697	1.000	0.006	0.055	0.984	0.003	0.163	0.098	
C24SS2A	0.730	0.995	0.701	1.000	0.052	0.005	0.199	0.034	0.007	
C24SS2W	0.900	0.820	0.870	0.824	1.000	0.041	0.015	0.340	0.017	
C24SS2F	0.670	0.446	0.698	0.449	0.584	1.000	0.002	0.090	0.048	
C24SS5A	0.743	0.578	0.763	0.580	0.681	0.982	1.000	0.006	0.002	
C24SS5W	0.214	0.162	0.221	0.163	0.194	0.300	0.335	1.000	0.003	
C24SS5F	0.255	0.193	0.263	0.194	0.231	0.357	0.396	0.888	1.000	
	f-Test									

Longitudinal Pulse Velocity (mm/µs) - 54 kHz Ultrasonic Pulse VelocityTest

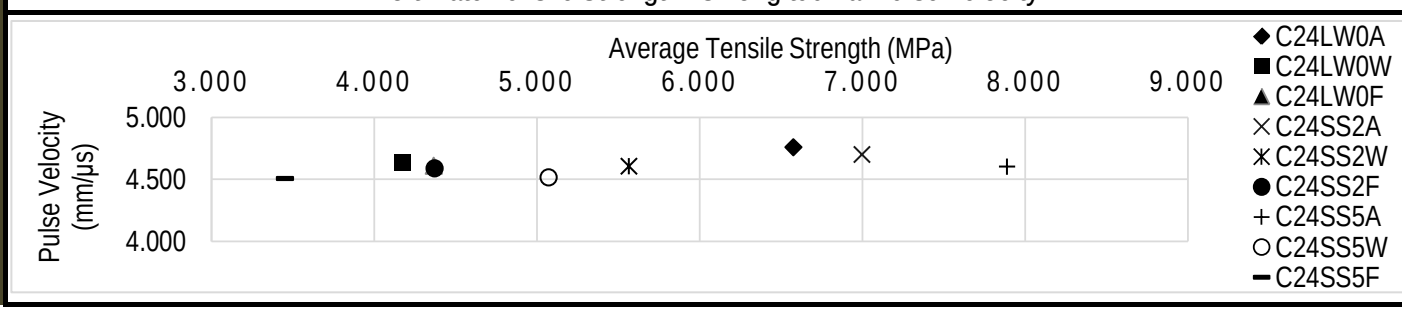
Samples	Sample Statistics			
	Average	Standard Deviation	Coeff. of Variation	Confi-dence
C24LW0A	4.758	0.007	0.143	0.000
C24LW0W	4.637	0.041	0.888	0.003
C24LW0F	4.610	0.016	0.339	0.001
C24SS2A	4.702	0.047	0.991	0.003
C24SS2W	4.606	0.054	1.171	0.004
C24SS2F	4.588	0.037	0.802	0.003
C24SS5A	4.602	0.027	0.583	0.002
C24SS5W	4.516	0.005	0.103	0.000
C24SS5F	4.504	0.053	1.177	0.005

Average Pulse Velocity (mm/µs)



Samples	C24LW0A	C24LW0W	C24LW0F	C24SS2A	C24SS2W	C24SS2F	C24SS5A	C24SS5W	C24SS5F	
C24LW0A	1.000	0.034	0.000	0.170	0.038	0.013	0.002	0.000	0.090	T-Test
C24LW0W	0.053	1.000	0.344	0.147	0.473	0.195	0.376	0.029	0.049	
C24LW0F	0.320	0.252	1.000	0.032	0.912	0.389	0.699	0.004	0.040	
C24SS2A	0.042	0.877	0.202	1.000	0.081	0.029	0.077	0.013	0.021	
C24SS2W	0.031	0.736	0.155	0.855	1.000	0.649	0.931	0.111	0.128	
C24SS2F	0.066	0.888	0.306	0.768	0.635	1.000	0.670	0.080	0.122	
C24SS5A	0.118	0.838	0.456	0.755	0.664	0.917	1.000	0.046	0.145	
C24SS5W	0.866	0.159	0.410	0.140	0.121	0.177	0.218	1.000	0.784	
C24SS5F	0.032	0.653	0.154	0.746	0.858	0.573	0.597	0.111	1.000	
	f-Test									

Ultimate Tensile Strength vs Longitudinal Pulse Velocity



Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Cylinders - 24 Months Limewater Solution Exposure: Complete Immersion

Velocity

	Sample Statistics - C24LW0A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C24LW0W	C24LW0F	C24SS2A	C24SS5A	C24LW0W	C24LW0F	C24SS2A	C24SS5A
25	4.408	0.034	0.775	0.002	0.718	0.709	0.953	0.970	0.601	0.000	0.028	0.000
50	4.364	0.062	1.431	0.003	0.012	0.075	0.193	0.648	0.633	0.002	0.559	0.002
75	4.344	0.060	1.371	0.003	0.505	0.385	0.993	0.646	0.202	0.001	0.176	0.007
100	4.317	0.035	0.815	0.002	0.275	0.956	0.183	0.038	0.111	0.000	0.508	0.032
125	4.335	0.043	0.984	0.002	0.853	0.006	0.429	0.436	0.000	0.026	0.661	0.003
150	4.374	0.042	0.961	0.002	0.546	0.847	0.240	0.838	0.000	0.000	0.778	0.000
175	4.402	0.060	1.369	0.003	0.386	0.372	0.806	0.283	0.000	0.000	0.453	0.016
Amplitude												
25	71.667	3.523	4.916	0.181	0.466	0.799	0.690	0.562	0.041	0.048	0.225	0.187
50	69.417	4.578	6.596	0.235	0.255	0.681	0.992	0.393	0.003	0.106	0.134	0.203
75	71.700	3.291	4.589	0.169	0.903	0.580	0.666	0.333	0.198	0.791	0.933	0.072
100	68.633	3.805	5.544	0.195	0.853	0.699	0.767	0.755	0.019	0.147	0.051	0.081
125	67.217	4.672	6.950	0.240	0.954	0.468	0.972	0.730	0.193	0.384	0.166	0.178
150	69.217	4.536	6.553	0.233	0.390	0.423	0.979	0.403	0.378	0.960	0.118	0.390
175	72.400	4.445	6.139	0.228	0.134	0.540	0.984	0.597	0.047	0.002	0.334	0.330
Energy												
25	41.383	22.453	54.256	1.152	0.302	0.750	0.300	0.809	0.109	0.379	0.255	0.418
50	42.300	23.641	55.889	1.213	0.718	0.735	0.441	0.604	0.039	0.168	0.147	0.400
75	55.400	23.294	42.046	1.195	0.702	0.857	0.568	0.893	0.429	0.881	0.752	0.232
100	37.017	16.814	45.422	0.863	0.320	0.316	0.036	0.355	0.081	0.503	0.131	0.087
125	31.767	21.155	66.596	1.085	0.921	0.542	0.314	0.797	0.293	0.655	0.119	0.552
150	41.450	27.294	65.848	1.400	0.194	0.486	0.455	0.745	0.286	0.839	0.159	0.835
175	66.483	49.244	74.069	2.526	0.011	0.001	0.887	0.163	0.144	0.064	0.484	0.282

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C24LW0W	C24LW0F	C24SS2A	C24SS5A	C24LW0W	C24LW0F	C24SS2A	C24SS5A	C24LW0W	C24LW0F	C24SS2A	C24SS5A
25	1.003	1.023	1.012	1.030	0.925	0.943	0.967	1.054	0.572	0.755	0.660	1.391
50	1.003	1.032	1.004	1.038	0.890	0.942	0.941	1.077	0.543	0.647	0.614	1.549
75	1.010	1.033	1.012	1.036	0.964	0.992	0.997	1.084	0.819	1.042	0.916	1.550
100	1.012	1.033	1.005	1.046	0.914	0.956	0.929	1.071	0.594	0.861	0.503	1.964
125	1.032	1.057	0.997	1.033	0.948	1.047	0.944	1.075	0.696	1.276	0.532	1.383
150	1.057	1.054	0.998	1.044	1.031	0.998	0.939	1.049	1.522	1.079	0.584	1.107
175	1.086	1.095	1.006	1.037	1.067	1.155	0.965	1.048	2.123	3.525	0.756	1.842

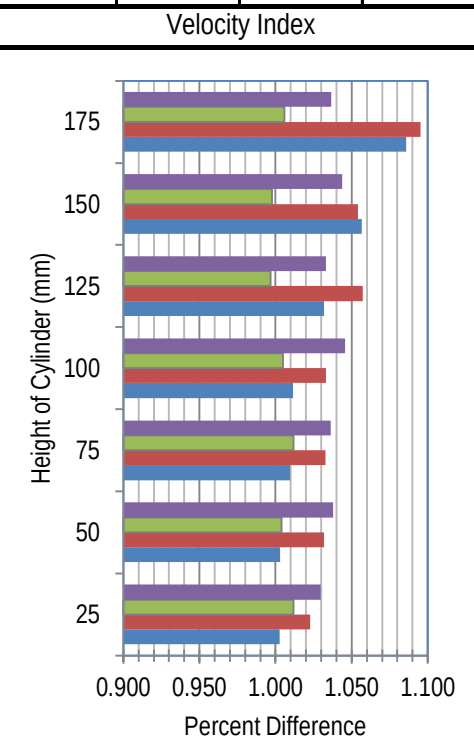
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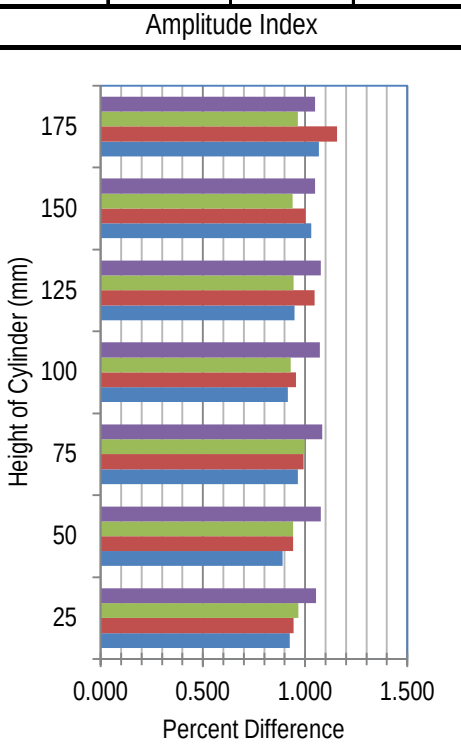
C24SS5A

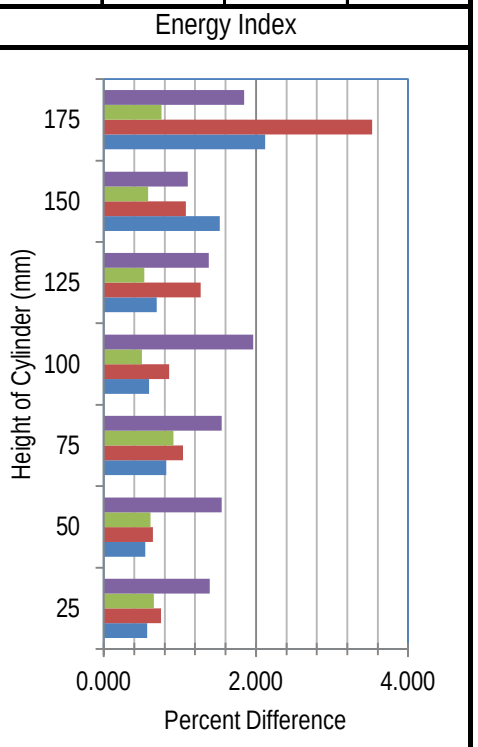
C24SS2A

C24LW0F

C24LW0W







Cylinders - 24 Months Limewater Solution Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C24LW0W				f-Test				T-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C24LW0A	C24LW0F	C24SS2W	C24SS5W	C24LW0A	C24LW0F	C24SS2W	C24SS5W
25	4.397	0.040	0.921	0.002	0.718	0.466	0.373	0.334	0.601	0.002	0.274	0.003
50	4.351	0.017	0.390	0.001	0.012	0.377	0.027	0.027	0.633	0.000	0.030	0.008
75	4.303	0.043	1.009	0.002	0.505	0.836	0.172	0.043	0.202	0.002	0.363	0.102
100	4.268	0.059	1.391	0.003	0.275	0.298	0.062	0.396	0.111	0.010	0.559	0.002
125	4.202	0.039	0.931	0.002	0.853	0.004	0.074	0.000	0.000	0.245	0.004	0.336
150	4.140	0.056	1.351	0.003	0.546	0.428	0.023	0.000	0.000	0.720	0.036	0.337
175	4.054	0.040	0.984	0.002	0.386	0.978	0.002	0.581	0.000	0.160	0.183	0.608
Amplitude												
25	77.500	4.980	6.426	0.255	0.466	0.330	0.042	0.848	0.041	0.546	0.024	0.044
50	77.967	2.649	3.398	0.136	0.255	0.457	0.339	0.093	0.003	0.047	0.005	0.000
75	74.400	3.484	4.682	0.179	0.903	0.665	0.109	0.167	0.198	0.373	0.001	0.036
100	75.067	4.151	5.530	0.213	0.853	0.569	0.717	0.890	0.019	0.159	0.012	0.002
125	70.933	4.546	6.408	0.233	0.954	0.434	0.703	0.070	0.193	0.067	0.000	0.038
150	67.167	3.014	4.487	0.155	0.390	0.953	0.272	0.030	0.378	0.248	0.000	0.096
175	67.850	2.138	3.151	0.110	0.134	0.354	0.015	0.848	0.047	0.009	0.011	0.005
Energy												
25	72.350	36.809	50.876	1.888	0.302	0.514	0.004	0.079	0.109	0.395	0.026	0.027
50	77.850	28.032	36.007	1.438	0.718	0.998	0.569	0.020	0.039	0.478	0.015	0.007
75	67.633	27.894	41.243	1.431	0.702	0.858	0.022	0.357	0.429	0.393	0.011	0.053
100	62.300	27.055	43.426	1.388	0.320	0.071	0.148	0.008	0.081	1.000	0.017	0.006
125	45.650	22.160	48.543	1.137	0.921	0.606	0.001	0.345	0.293	0.204	0.006	0.120
150	27.233	14.549	53.422	0.746	0.194	0.587	0.096	0.371	0.286	0.293	0.016	0.123
175	31.317	12.909	41.221	0.662	0.011	0.155	0.508	0.419	0.144	0.079	0.011	0.170

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C24LW0A	C24LW0F	C24SS2W	C24SS5W	C24LW0A	C24LW0F	C24SS2W	C24SS5W	C24LW0A	C24LW0F	C24SS2W	C24SS5W
25	0.997	1.020	1.008	1.033	1.081	1.020	1.090	1.104	1.748	1.319	2.819	2.759
50	0.997	1.029	1.015	1.037	1.123	1.058	1.102	1.140	1.840	1.191	2.186	2.641
75	0.991	1.023	1.009	1.035	1.038	1.029	1.112	1.126	1.221	1.272	2.759	2.078
100	0.989	1.021	0.991	1.054	1.094	1.045	1.099	1.200	1.683	1.450	2.283	5.128
125	0.969	1.025	1.045	1.192	1.055	1.105	1.342	1.378	1.437	1.833	10.033	2.926
150	0.946	0.998	1.052	1.208	0.970	0.969	1.255	1.200	0.657	0.709	4.168	2.403
175	0.921	1.009	1.034	0.996	0.937	1.082	1.210	1.080	0.471	1.660	2.891	1.535

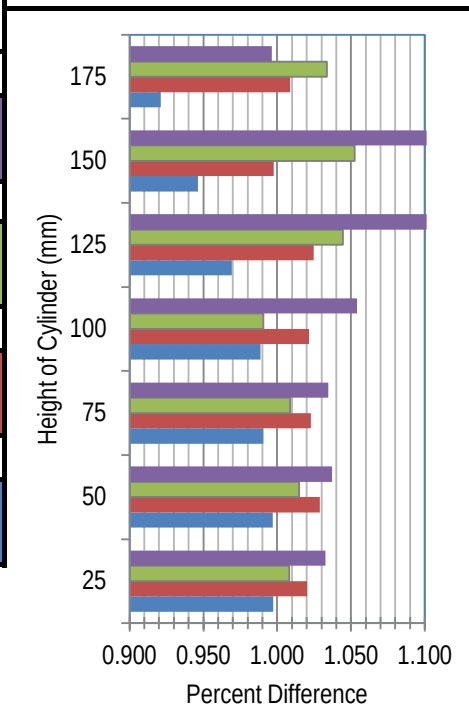
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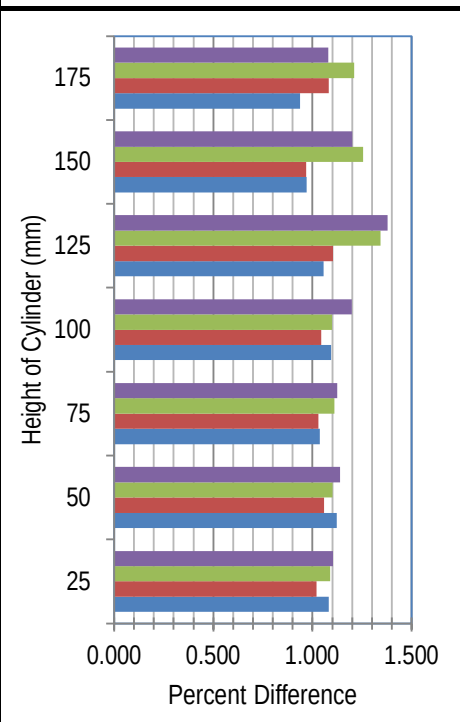
C24SS5W

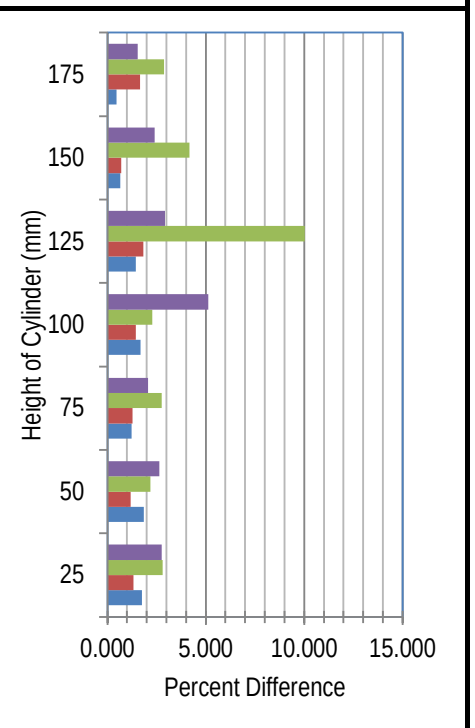
C24SS2W

C24LW0F

C24LW0A







Cylinders - 24 Months Limewater Solution Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C24LW0F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C24LW0A	C24LW0W	C24SS2F	C24SS5F	C24LW0A	C24LW0W	C24SS2F	C24SS5F
25	4.310	0.029	0.664	0.001	0.709	0.466	0.210	0.426	0.000	0.002	0.036	0.171
50	4.229	0.026	0.611	0.001	0.075	0.377	0.258	0.174	0.002	0.000	0.002	0.428
75	4.207	0.039	0.937	0.002	0.385	0.836	0.496	0.873	0.001	0.002	0.072	0.903
100	4.179	0.036	0.864	0.002	0.956	0.298	0.142	0.000	0.000	0.010	0.174	0.094
125	4.101	0.186	4.532	0.010	0.006	0.004	0.071	0.177	0.026	0.245	0.590	0.158
150	4.150	0.038	0.925	0.002	0.847	0.428	0.109	0.200	0.000	0.720	0.621	0.393
175	4.020	0.039	0.980	0.002	0.372	0.978	0.342	0.063	0.000	0.160	0.020	0.726
Amplitude												
25	76.000	3.126	4.113	0.160	0.799	0.330	0.629	0.212	0.048	0.546	0.765	0.183
50	73.717	3.771	5.116	0.193	0.681	0.457	0.021	0.769	0.106	0.047	0.099	0.019
75	72.300	4.274	5.911	0.219	0.580	0.665	0.414	0.641	0.791	0.373	0.994	0.377
100	71.817	3.172	4.417	0.163	0.699	0.569	0.905	0.270	0.147	0.159	0.569	0.001
125	64.217	6.591	10.263	0.338	0.468	0.434	0.317	0.736	0.384	0.067	0.516	0.011
150	69.333	3.098	4.469	0.159	0.423	0.953	0.267	0.428	0.960	0.248	0.417	0.225
175	62.683	3.326	5.306	0.171	0.540	0.354	0.754	0.280	0.002	0.009	0.015	0.232
Energy												
25	54.840	25.862	47.158	1.453	0.750	0.514	0.413	0.685	0.379	0.395	0.578	0.721
50	65.380	27.494	42.053	1.545	0.735	0.998	0.114	0.929	0.168	0.478	0.659	0.561
75	53.160	25.036	47.095	1.407	0.857	0.858	0.543	0.465	0.881	0.393	0.834	0.868
100	42.980	9.778	22.751	0.550	0.316	0.071	0.472	0.655	0.503	1.000	0.399	0.043
125	24.900	28.167	113.120	1.583	0.542	0.606	0.107	0.243	0.655	0.204	0.708	0.055
150	38.420	18.737	48.768	1.053	0.486	0.587	0.647	0.040	0.839	0.293	0.667	0.094
175	18.860	5.911	31.343	0.332	0.001	0.155	0.137	0.059	0.064	0.079	0.016	0.913

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C24LW0A	C24LW0W	C24SS2F	C24SS5F	C24LW0A	C24LW0W	C24SS2F	C24SS5F	C24LW0A	C24LW0W	C24SS2F	C24SS5F
25	0.978	0.980	0.987	0.992	1.060	0.981	1.007	1.048	1.325	0.758	0.879	0.885
50	0.969	0.972	0.980	0.995	1.062	0.945	0.959	1.015	1.546	0.840	0.920	1.018
75	0.968	0.978	0.987	0.999	1.008	0.972	1.000	0.999	0.960	0.786	0.949	0.831
100	0.968	0.979	0.988	1.146	1.046	0.957	0.986	1.227	1.161	0.690	0.864	4.074
125	0.946	0.976	0.989	1.070	0.955	0.905	1.034	1.099	0.784	0.545	1.246	3.984
150	0.949	1.002	1.005	1.008	1.002	1.032	1.031	1.068	0.927	1.411	1.134	2.570
175	0.913	0.991	0.987	0.995	0.866	0.924	0.923	0.970	0.284	0.602	0.496	0.567

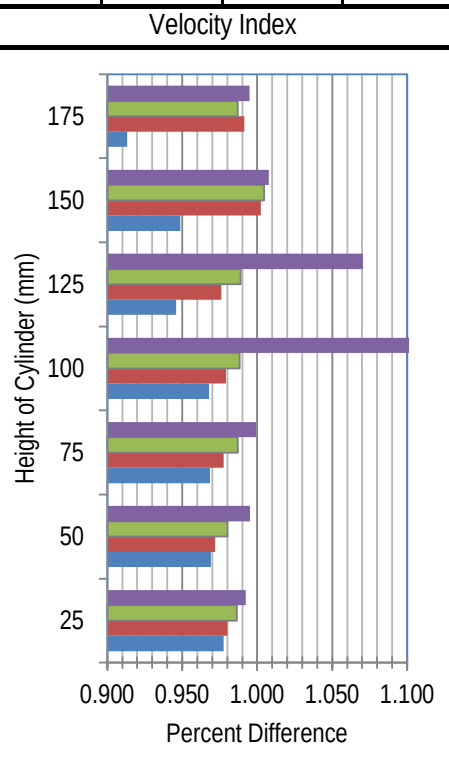
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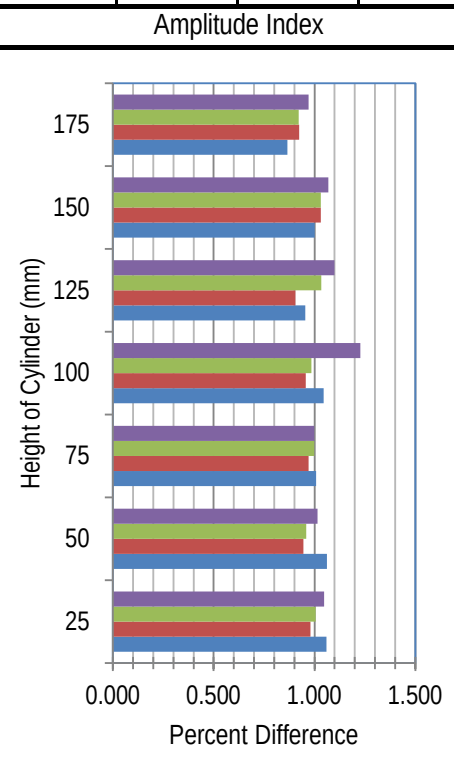
C24SS5F

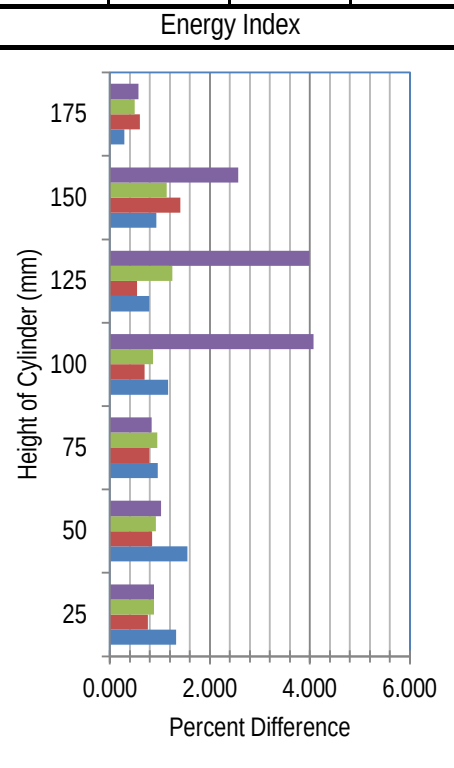
C24SS2F

C24LW0W

C24LW0A







Cylinders - 24 Months Limewater Solution Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C24SS2A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C24SS2W	C24SS2F	C24LW0A	C24SS5A	C24SS2W	C24SS2F	C24LW0A	C24SS5A
25	4.357	0.035	0.806	0.002	0.239	0.399	0.953	0.931	0.869	0.656	0.028	0.009
50	4.347	0.033	0.765	0.002	0.336	0.538	0.193	0.495	0.041	0.197	0.559	0.000
75	4.294	0.059	1.382	0.003	0.460	0.853	0.993	0.641	0.520	0.347	0.176	0.040
100	4.296	0.067	1.560	0.003	0.100	0.837	0.183	0.359	0.855	0.123	0.508	0.014
125	4.349	0.062	1.429	0.003	0.374	0.672	0.429	0.935	0.000	0.001	0.661	0.005
150	4.384	0.074	1.689	0.004	0.074	0.781	0.240	0.438	0.001	0.000	0.778	0.002
175	4.376	0.054	1.226	0.003	0.010	0.119	0.806	0.198	0.002	0.000	0.453	0.029

Amplitude

25	74.083	2.919	3.939	0.150	0.304	0.735	0.690	0.351	0.061	0.387	0.225	0.032
50	73.733	4.601	6.240	0.236	0.839	0.009	0.992	0.398	0.265	0.160	0.134	0.033
75	71.883	4.033	5.610	0.207	0.062	0.486	0.666	0.556	0.029	0.835	0.933	0.086
100	73.883	4.376	5.922	0.224	0.636	0.427	0.767	0.582	0.035	0.649	0.051	0.005
125	71.217	4.596	6.454	0.236	0.720	0.802	0.972	0.707	0.000	0.005	0.166	0.025
150	73.717	4.591	6.228	0.236	0.820	0.768	0.979	0.416	0.000	0.046	0.118	0.062
175	75.017	4.486	5.980	0.230	0.277	0.349	0.984	0.609	0.000	0.009	0.334	0.101

Energy

25	62.683	36.887	58.847	1.892	0.004	0.127	0.300	0.291	0.057	0.987	0.255	0.142
50	68.900	34.085	49.471	1.749	0.331	0.046	0.441	0.880	0.070	0.888	0.147	0.083
75	60.500	30.501	50.415	1.565	0.015	0.312	0.568	0.730	0.033	0.765	0.752	0.211
100	73.650	48.700	66.124	2.498	0.013	0.018	0.036	0.021	0.067	0.293	0.131	0.039
125	59.767	34.234	57.280	1.756	0.000	0.047	0.314	0.555	0.011	0.035	0.119	0.099
150	70.950	38.920	54.856	1.997	0.001	0.059	0.455	0.754	0.009	0.069	0.159	0.189
175	87.900	52.660	59.909	2.702	0.002	0.009	0.887	0.137	0.015	0.068	0.484	0.101

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C24SS2W	C24SS2F	C24LW0A	C24SS5A	C24SS2W	C24SS2F	C24LW0A	C24SS5A	C24SS2W	C24SS2F	C24LW0A	C24SS5A
25	0.999	0.997	0.988	1.018	1.041	0.981	1.034	1.090	2.442	1.005	1.515	2.107
50	1.014	1.007	0.996	1.034	1.042	0.959	1.062	1.144	1.934	0.970	1.629	2.524
75	1.007	1.008	0.989	1.024	1.074	0.994	1.003	1.087	2.468	1.080	1.092	1.692
100	0.997	1.016	0.995	1.041	1.082	1.014	1.076	1.153	2.699	1.481	1.990	3.907
125	1.081	1.049	1.003	1.036	1.348	1.147	1.060	1.139	13.136	2.991	1.881	2.601
150	1.115	1.061	1.002	1.046	1.377	1.097	1.065	1.117	10.860	2.094	1.712	1.895
175	1.116	1.075	0.994	1.030	1.338	1.104	1.036	1.086	8.114	2.311	1.322	2.435

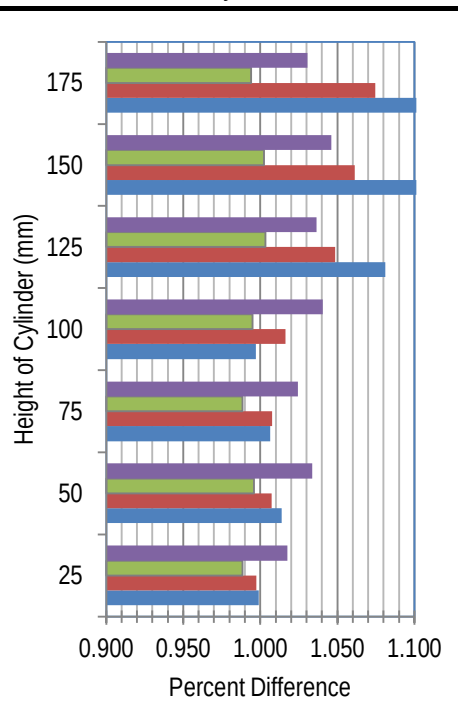
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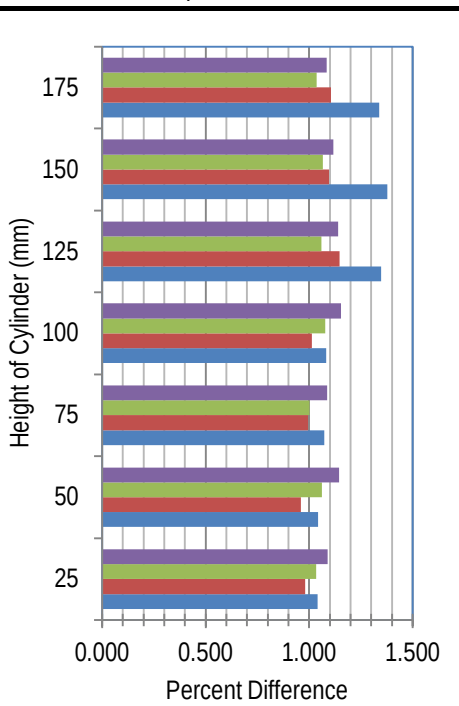
C24SS5A

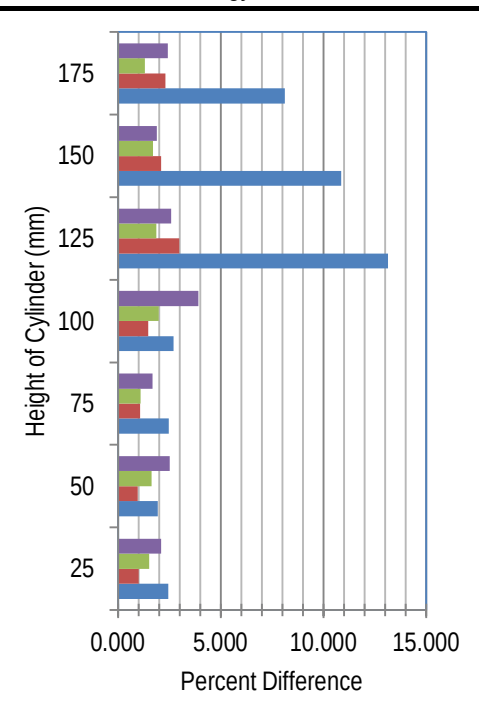
C24LW0A

C24SS2F

C24SS2W







Cylinders - 24 Months Limewater Solution Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C24SS2W				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C24SS2A	C24SS2F	C24LW0W	C24SS5W	C24SS2A	C24SS2F	C24LW0W	C24SS5W
25	4.362	0.062	1.418	0.003	0.239	0.726	0.373	0.859	0.869	0.839	0.274	0.034
50	4.287	0.053	1.228	0.003	0.336	0.721	0.027	0.871	0.041	0.336	0.030	0.028
75	4.266	0.084	1.975	0.004	0.460	0.359	0.172	0.405	0.520	0.917	0.363	0.141
100	4.309	0.150	3.491	0.008	0.100	0.144	0.062	0.422	0.855	0.263	0.559	0.015
125	4.023	0.095	2.359	0.005	0.374	0.636	0.074	0.000	0.000	0.031	0.004	0.463
150	3.934	0.179	4.562	0.009	0.074	0.123	0.023	0.001	0.001	0.035	0.036	0.478
175	3.922	0.209	5.318	0.011	0.010	0.000	0.002	0.043	0.002	0.139	0.183	0.149
Amplitude												
25	71.133	1.784	2.508	0.092	0.304	0.483	0.042	0.091	0.061	0.006	0.024	0.709
50	70.733	4.181	5.911	0.215	0.839	0.013	0.339	0.026	0.265	0.014	0.005	0.232
75	66.933	1.587	2.371	0.081	0.062	0.212	0.109	0.007	0.029	0.003	0.001	0.829
100	68.300	3.501	5.126	0.180	0.636	0.743	0.717	0.650	0.035	0.036	0.012	0.048
125	52.850	5.441	10.295	0.279	0.720	0.545	0.703	0.136	0.000	0.008	0.000	0.804
150	53.533	5.108	9.542	0.262	0.820	0.945	0.272	0.216	0.000	0.001	0.000	0.607
175	56.067	7.557	13.479	0.388	0.277	0.053	0.015	0.041	0.000	0.010	0.011	0.082
Energy												
25	25.667	7.630	29.727	0.391	0.004	0.093	0.004	0.418	0.057	0.002	0.026	0.927
50	35.617	21.414	60.123	1.099	0.331	0.263	0.569	0.044	0.070	0.006	0.015	0.527
75	24.517	8.590	35.036	0.441	0.015	0.110	0.022	0.241	0.033	0.004	0.011	0.315
100	27.283	13.363	48.980	0.686	0.013	0.873	0.148	0.061	0.067	0.019	0.017	0.039
125	4.550	3.420	75.173	0.175	0.000	0.012	0.001	0.394	0.011	0.029	0.006	0.011
150	6.533	6.403	98.005	0.328	0.001	0.081	0.096	0.801	0.009	0.005	0.016	0.331
175	10.833	9.435	87.094	0.484	0.002	0.456	0.508	0.776	0.015	0.002	0.011	0.131

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C24SS2A	C24SS2F	C24LW0W	C24SS5W	C24SS2A	C24SS2F	C24LW0W	C24SS5W	C24SS2A	C24SS2F	C24LW0W	C24SS5W
25	1.001	0.998	0.992	1.024	0.960	0.942	0.918	1.013	0.409	0.411	0.355	0.979
50	0.986	0.993	0.985	1.022	0.959	0.920	0.907	1.034	0.517	0.501	0.458	1.208
75	0.993	1.001	0.991	1.026	0.931	0.926	0.900	1.013	0.405	0.438	0.362	0.753
100	1.003	1.019	1.010	1.064	0.924	0.937	0.910	1.091	0.370	0.549	0.438	2.246
125	0.925	0.970	0.957	1.141	0.742	0.851	0.745	1.027	0.076	0.228	0.100	0.292
150	0.897	0.952	0.950	1.148	0.726	0.796	0.797	0.956	0.092	0.193	0.240	0.576
175	0.896	0.963	0.967	0.964	0.747	0.825	0.826	0.892	0.123	0.285	0.346	0.531

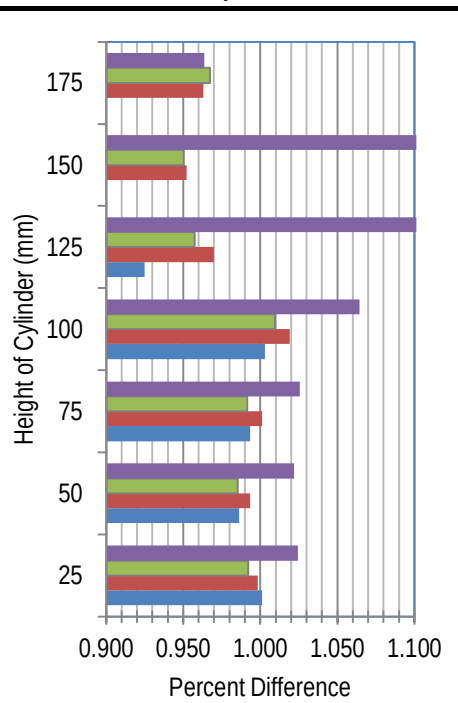
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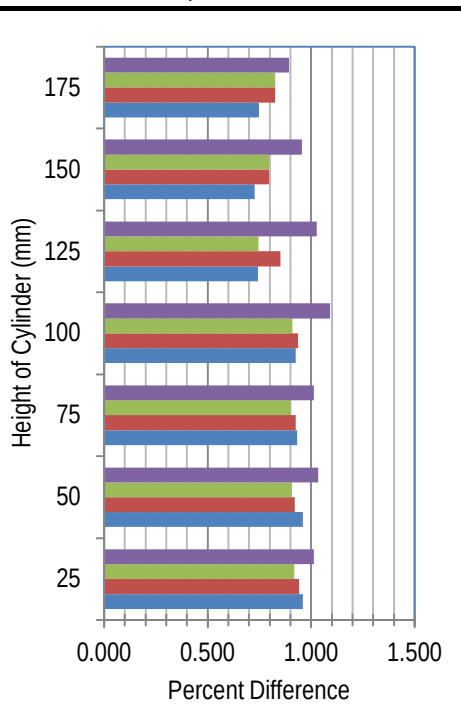
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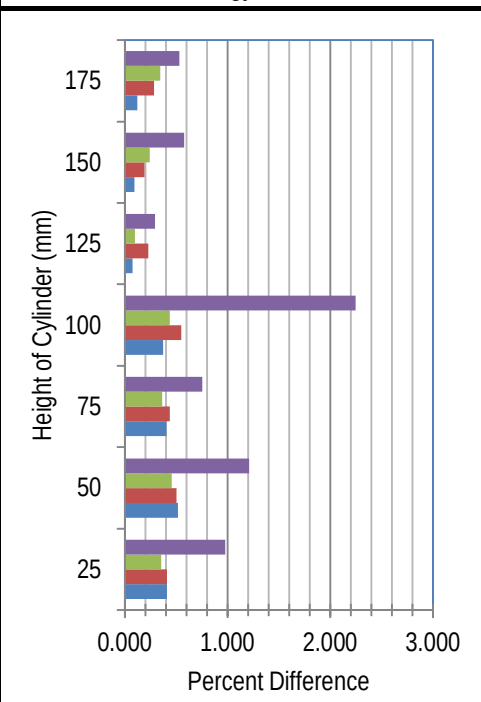
C24LW0W

C24SS2F

C24SS2A







Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Cylinders - 24 Months Limewater Solution Exposure: Complete Immersion

Velocity

	Sample Statistics - C24SS2F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C24SS2A	C24SS2W	C24LW0F	C24SS5F	C24SS2A	C24SS2W	C24LW0F	C24SS5F
25	4.369	0.052	1.201	0.003	0.399	0.726	0.210	0.757	0.656	0.839	0.036	0.439
50	4.315	0.044	1.031	0.002	0.538	0.721	0.258	0.727	0.197	0.336	0.002	0.062
75	4.262	0.054	1.276	0.003	0.853	0.359	0.496	0.479	0.347	0.917	0.072	0.131
100	4.228	0.074	1.746	0.004	0.837	0.144	0.142	0.002	0.123	0.263	0.174	0.076
125	4.148	0.076	1.830	0.004	0.672	0.636	0.071	0.005	0.001	0.031	0.590	0.183
150	4.131	0.084	2.043	0.004	0.781	0.123	0.109	0.865	0.000	0.035	0.621	0.820
175	4.072	0.025	0.615	0.001	0.119	0.000	0.342	0.009	0.000	0.139	0.020	0.586
Amplitude												
25	75.500	2.488	3.296	0.128	0.735	0.483	0.629	0.097	0.387	0.006	0.765	0.391
50	76.867	1.154	1.501	0.059	0.009	0.013	0.021	0.062	0.160	0.014	0.099	0.064
75	72.317	2.898	4.007	0.149	0.486	0.212	0.414	0.824	0.835	0.003	0.994	0.977
100	72.867	2.999	4.116	0.154	0.427	0.743	0.905	0.228	0.649	0.036	0.569	0.001
125	62.083	4.086	6.581	0.210	0.802	0.545	0.317	0.219	0.005	0.008	0.516	0.344
150	67.217	5.276	7.849	0.271	0.768	0.945	0.267	0.116	0.046	0.001	0.417	0.435
175	67.933	2.870	4.225	0.147	0.349	0.053	0.754	0.176	0.009	0.010	0.015	0.252
Energy												
25	62.400	17.487	28.025	0.897	0.127	0.093	0.413	0.978	0.987	0.002	0.578	0.975
50	71.067	12.507	17.599	0.642	0.046	0.263	0.114	0.272	0.888	0.006	0.659	0.585
75	56.000	18.812	33.593	0.965	0.312	0.110	0.543	0.618	0.765	0.004	0.834	0.595
100	49.717	14.410	28.985	0.739	0.018	0.873	0.472	0.461	0.293	0.019	0.399	0.011
125	19.983	12.589	62.999	0.646	0.047	0.012	0.107	0.540	0.035	0.029	0.708	0.199
150	33.883	15.176	44.790	0.779	0.059	0.081	0.647	0.050	0.069	0.005	0.667	0.028
175	38.033	13.442	35.343	0.690	0.009	0.456	0.137	0.410	0.068	0.002	0.016	0.703

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C24SS2A	C24SS2W	C24LW0F	C24SS5F	C24SS2A	C24SS2W	C24LW0F	C24SS5F	C24SS2A	C24SS2W	C24LW0F	C24SS5F
25	1.003	1.002	1.014	1.006	1.019	1.061	0.993	1.041	0.995	2.431	1.138	1.007
50	0.993	1.007	1.020	1.016	1.042	1.087	1.043	1.058	1.031	1.995	1.087	1.107
75	0.992	0.999	1.013	1.012	1.006	1.080	1.000	0.999	0.926	2.284	1.053	0.875
100	13.035	12.997	13.402	15.361	0.986	1.067	1.015	1.245	0.675	1.822	1.157	4.712
125	0.954	1.031	1.011	1.083	0.872	1.175	0.967	1.063	0.334	4.392	0.803	3.197
150	0.942	1.050	0.995	1.003	0.912	1.256	0.969	1.035	0.478	5.186	0.882	2.266
175	0.930	1.038	1.013	1.008	0.906	1.212	1.084	1.051	0.433	3.511	2.017	1.144

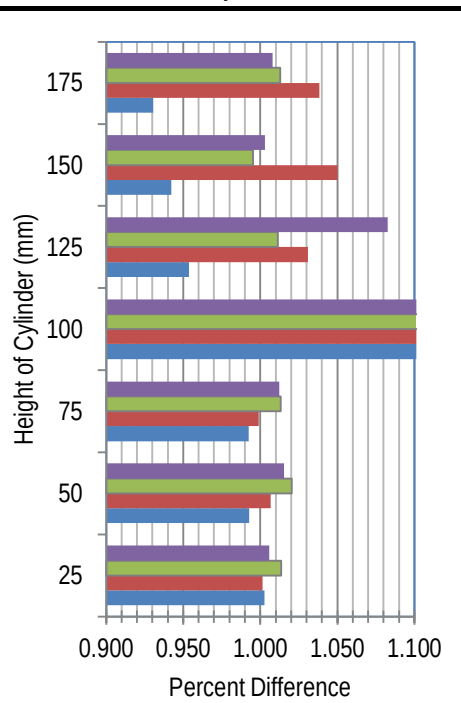
Graph Legend

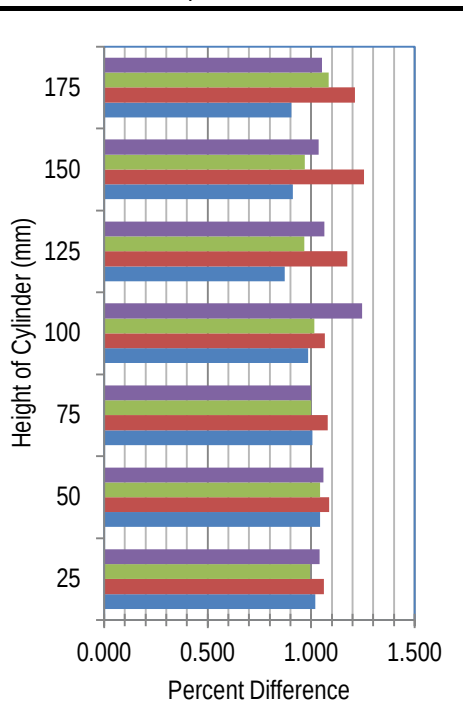
C24SS5F

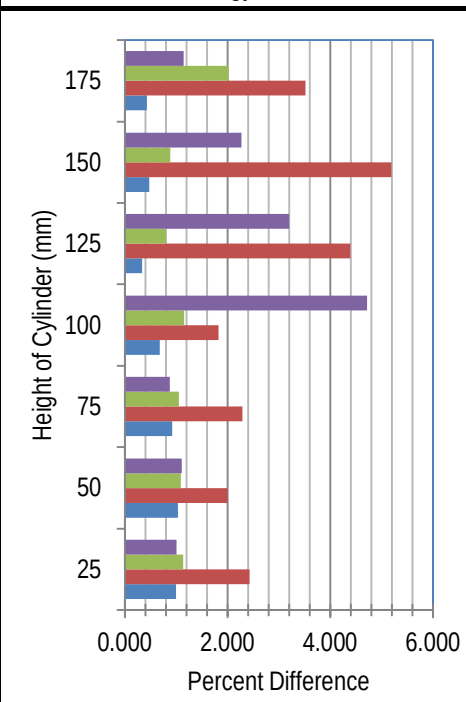
C24LW0F

C24SS2W

C24SS2A







Cylinders - 24 Months Limewater Solution Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C24SS5A				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C24SS5W	C24SS5F	C24LW0A	C24SS2A	C24SS5W	C24SS5F	C24LW0A	C24SS2A
25	4.281	0.032	0.744	0.002	0.273	0.662	0.970	0.931	0.536	0.058	0.000	0.009
50	4.205	0.046	1.090	0.003	0.776	0.859	0.648	0.495	0.784	0.242	0.002	0.000
75	4.192	0.073	1.738	0.005	0.394	0.248	0.646	0.641	0.666	0.673	0.007	0.040
100	4.129	0.105	2.536	0.007	0.803	0.041	0.038	0.359	0.289	0.113	0.032	0.014
125	4.197	0.062	1.475	0.004	0.000	0.015	0.436	0.935	0.339	0.140	0.003	0.005
150	4.191	0.045	1.069	0.003	0.000	0.443	0.838	0.438	0.308	0.141	0.000	0.002
175	4.247	0.102	2.413	0.006	0.285	0.986	0.283	0.198	0.021	0.030	0.016	0.029

Amplitude

25	67.975	4.599	6.765	0.289	0.903	0.704	0.562	0.351	0.500	0.269	0.187	0.032
50	64.425	6.920	10.741	0.435	0.006	0.210	0.393	0.398	0.337	0.072	0.203	0.033
75	66.150	5.288	7.994	0.332	0.655	0.409	0.333	0.556	0.991	0.089	0.072	0.086
100	64.075	3.038	4.741	0.191	0.591	0.359	0.755	0.582	0.588	0.127	0.081	0.005
125	62.500	5.375	8.599	0.338	0.237	0.591	0.730	0.707	0.136	0.413	0.178	0.025
150	66.000	6.786	10.281	0.426	0.596	0.061	0.403	0.416	0.136	0.777	0.390	0.062
175	69.100	5.645	8.169	0.355	0.096	0.993	0.597	0.609	0.109	0.306	0.330	0.101

Energy

25	29.750	18.666	62.744	1.173	0.428	0.890	0.809	0.291	0.757	0.098	0.418	0.142
50	27.300	29.846	109.326	1.875	0.018	0.978	0.604	0.880	0.894	0.204	0.400	0.083
75	35.750	23.901	66.855	1.502	0.489	0.476	0.893	0.730	0.829	0.197	0.232	0.211
100	18.850	9.264	49.148	0.582	0.168	0.673	0.355	0.021	0.228	0.314	0.087	0.039
125	22.975	23.202	100.988	1.458	0.319	0.289	0.797	0.555	0.696	0.394	0.552	0.099
150	37.450	31.065	82.950	1.952	0.090	0.023	0.745	0.754	0.191	0.243	0.835	0.189
175	36.100	19.750	54.708	1.241	0.154	0.789	0.163	0.137	0.189	0.875	0.282	0.101

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C24SS5W	C24SS5F	C24LW0A	C24SS2A	C24SS5W	C24SS5F	C24LW0A	C24SS2A	C24SS5W	C24SS5F	C24LW0A	C24SS2A
25	1.006	0.986	0.971	0.983	0.968	0.938	0.948	0.918	1.134	0.480	0.719	0.475
50	1.002	0.990	0.963	0.967	0.942	0.887	0.928	0.874	0.926	0.425	0.645	0.396
75	1.008	0.996	0.965	0.976	1.001	0.914	0.923	0.920	1.098	0.559	0.645	0.591
100	1.020	1.133	0.956	0.961	1.024	1.095	0.934	0.867	1.551	1.787	0.509	0.256
125	1.190	1.095	0.968	0.965	1.214	1.070	0.930	0.878	1.473	3.676	0.723	0.384
150	1.223	1.018	0.958	0.956	1.179	1.017	0.954	0.895	3.304	2.505	0.903	0.528
175	1.043	1.051	0.965	0.970	1.100	1.069	0.954	0.921	1.770	1.086	0.543	0.411

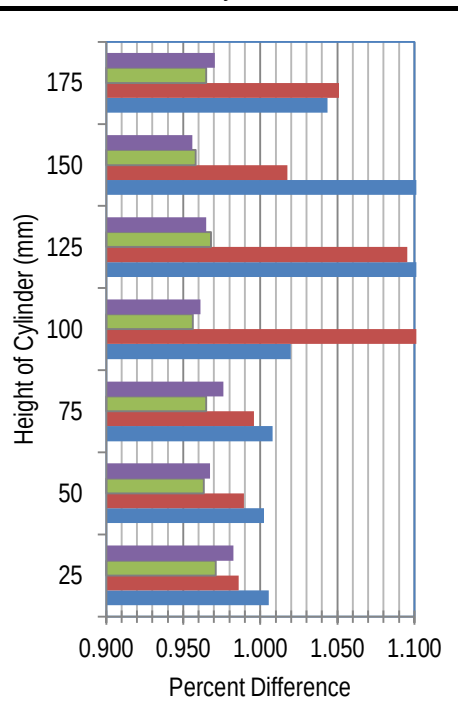
Graph Legend

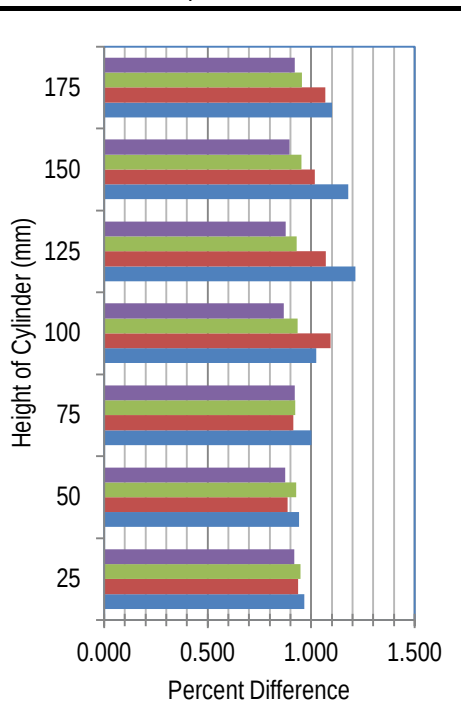
C24SS2A

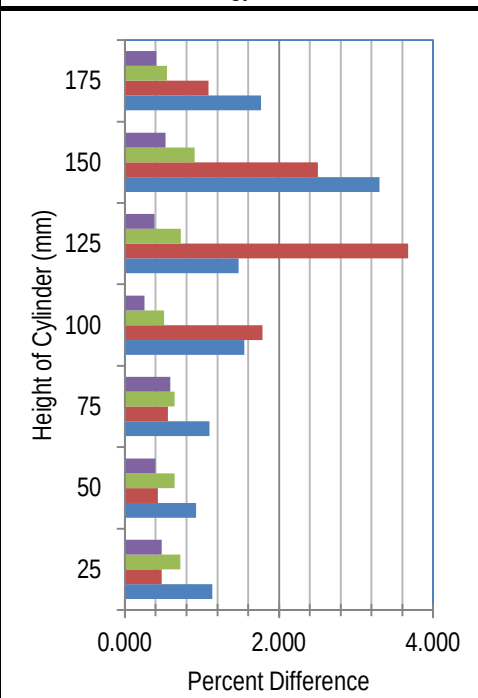
C24LW0A

C24SS5F

C24SS5W







Cylinders - 24 Months Limewater Solution Exposure: Complete Immersion

Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Velocity

	Sample Statistics - C24SS5W				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C24SS5A	C24SS5F	C24LW0W	C24SS2W	C24SS5A	C24SS5F	C24LW0W	C24SS2W
25	4.258	0.065	1.525	0.004	0.273	0.492	0.334	0.859	0.536	0.070	0.003	0.034
50	4.194	0.055	1.307	0.003	0.776	0.915	0.027	0.871	0.784	0.194	0.008	0.028
75	4.159	0.126	3.025	0.008	0.394	0.061	0.043	0.405	0.666	0.485	0.102	0.141
100	4.049	0.090	2.211	0.006	0.803	0.027	0.396	0.422	0.289	0.163	0.002	0.015
125	3.526	1.181	33.489	0.074	0.000	0.086	0.000	0.000	0.339	0.651	0.336	0.463
150	3.428	1.248	36.411	0.078	0.000	0.001	0.000	0.001	0.308	0.349	0.337	0.478
175	4.070	0.051	1.260	0.003	0.285	0.278	0.581	0.043	0.021	0.627	0.608	0.149

Amplitude

25	70.225	4.260	6.066	0.268	0.903	0.617	0.848	0.091	0.500	0.552	0.044	0.709
50	68.375	0.858	1.255	0.054	0.006	0.066	0.093	0.026	0.337	0.063	0.000	0.232
75	66.100	7.006	10.599	0.440	0.655	0.217	0.167	0.007	0.991	0.153	0.036	0.829
100	62.575	4.268	6.821	0.268	0.591	0.692	0.890	0.650	0.588	0.288	0.002	0.048
125	51.475	11.623	22.581	0.730	0.237	0.497	0.070	0.136	0.136	0.355	0.038	0.804
150	55.975	9.485	16.945	0.596	0.596	0.024	0.030	0.216	0.136	0.155	0.096	0.607
175	62.825	1.828	2.910	0.115	0.096	0.095	0.848	0.041	0.109	0.582	0.005	0.082

Energy

25	26.225	11.260	42.935	0.707	0.428	0.704	0.079	0.418	0.757	0.023	0.027	0.927
50	29.475	5.294	17.960	0.333	0.018	0.049	0.020	0.044	0.894	0.263	0.007	0.527
75	32.550	15.393	47.290	0.967	0.489	0.715	0.357	0.241	0.829	0.059	0.053	0.315
100	12.150	3.715	30.578	0.233	0.168	0.633	0.008	0.061	0.228	0.661	0.006	0.039
125	15.600	5.091	32.636	0.452	0.319	0.935	0.345	0.394	0.696	0.194	0.120	0.011
150	11.333	6.732	59.402	0.488	0.090	0.104	0.371	0.801	0.191	0.524	0.123	0.331
175	20.400	7.653	37.514	0.481	0.154	0.167	0.419	0.776	0.189	0.278	0.170	0.131

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C24SS5A	C24SS5F	C24LW0W	C24SS2W	C24SS5A	C24SS5F	C24LW0W	C24SS2W	C24SS5A	C24SS5F	C24LW0W	C24SS2W
25	0.994	0.980	0.968	0.976	1.033	0.969	0.906	0.987	0.882	0.423	0.362	1.022
50	0.998	0.987	0.964	0.978	1.061	0.941	0.877	0.967	1.080	0.459	0.379	0.828
75	0.992	0.988	0.967	0.975	0.999	0.913	0.888	0.988	0.910	0.509	0.481	1.328
100	0.981	1.111	0.949	0.940	0.977	1.069	0.834	0.916	0.645	1.152	0.195	0.445
125	0.840	0.920	0.839	0.877	0.824	0.881	0.726	0.974	0.679	2.496	0.342	3.429
150	0.818	0.832	0.828	0.871	0.848	0.862	0.833	1.046	0.303	0.758	0.416	1.735
175	0.958	1.007	1.004	1.038	0.909	0.972	0.926	1.121	0.565	0.614	0.651	1.883

Graph Legend

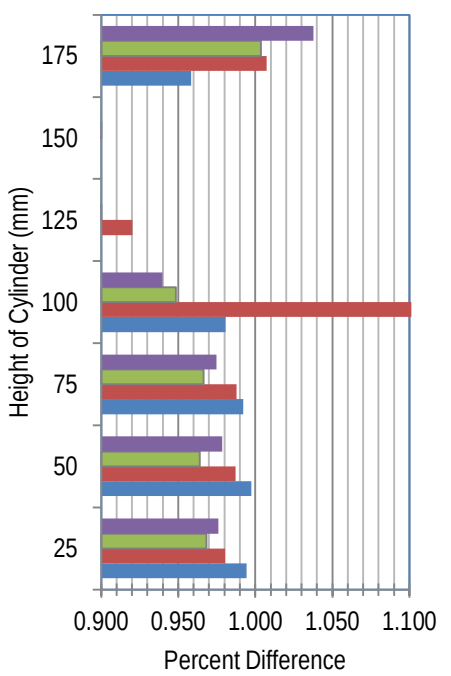
C24SS2W

C24LW0W

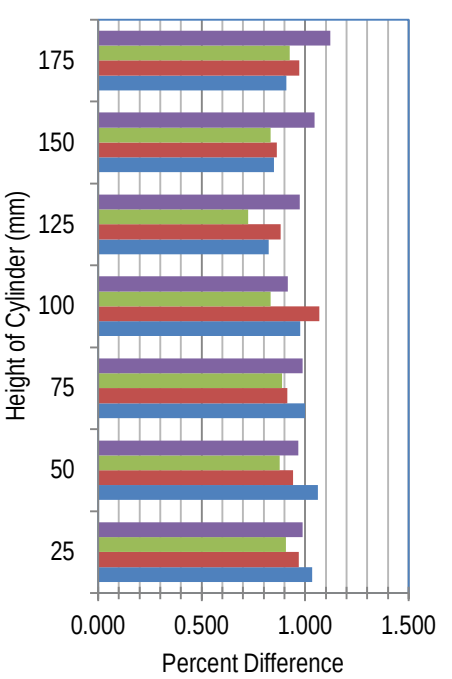
C24SS5F

C24SS5A

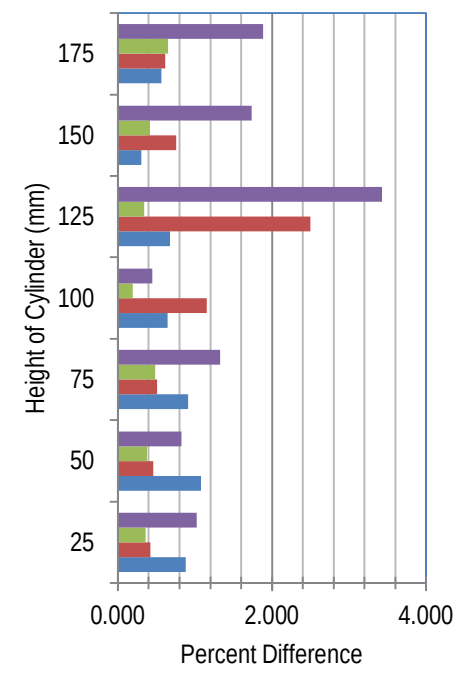
Velocity Index



Amplitude Index



Energy Index



Statistical Evaluation for Difference Between Samples

Wave Parameters of 300 kHz Diametral Ultra Sonic Pulse Emission Test

Cylinders - 24 Months Limewater Solution Exposure: Complete Immersion

Velocity

	Sample Statistics - C24SS5F				F-Test				t-Test			
Height (mm)	Average	Standard Deviation	Coefficient of Variation	Confi-dence	C24SS5A	C24SS5W	C24LW0F	C24SS2F	C24SS5A	C24SS5W	C24LW0F	C24SS2F
25	4.343	0.042	0.966	0.003	0.662	0.492	0.426	0.757	0.058	0.070	0.171	0.439
50	4.249	0.051	1.206	0.003	0.859	0.915	0.174	0.727	0.242	0.194	0.428	0.062
75	4.210	0.034	0.815	0.002	0.248	0.061	0.873	0.479	0.673	0.485	0.903	0.131
100	3.646	0.440	12.064	0.028	0.041	0.027	0.000	0.002	0.113	0.163	0.094	0.076
125	3.831	0.367	9.584	0.023	0.015	0.086	0.177	0.005	0.140	0.651	0.158	0.183
150	4.119	0.073	1.774	0.005	0.443	0.001	0.200	0.865	0.141	0.349	0.393	0.820
175	4.040	0.104	2.564	0.007	0.986	0.278	0.063	0.009	0.030	0.627	0.726	0.586

Amplitude

25	72.500	5.842	8.058	0.367	0.704	0.617	0.212	0.097	0.269	0.552	0.248	0.391
50	72.650	3.042	4.188	0.191	0.210	0.066	0.769	0.062	0.072	0.063	0.651	0.064
75	72.375	3.119	4.310	0.196	0.409	0.217	0.641	0.824	0.089	0.153	0.977	0.977
100	58.525	5.476	9.356	0.344	0.359	0.692	0.270	0.228	0.127	0.288	0.001	0.001
125	58.425	7.550	12.923	0.474	0.591	0.497	0.736	0.219	0.413	0.355	0.234	0.344
150	64.925	1.855	2.858	0.117	0.061	0.024	0.428	0.116	0.777	0.155	0.035	0.435
175	64.625	5.677	8.785	0.357	0.993	0.095	0.280	0.176	0.306	0.582	0.510	0.252

Energy

25	61.950	12.374	19.975	1.100	0.890	0.704	0.685	0.978	0.098	0.023	0.735	0.975
50	64.200	22.203	34.584	1.973	0.978	0.049	0.929	0.272	0.204	0.263	0.960	0.585
75	64.000	7.920	12.374	0.704	0.476	0.715	0.465	0.618	0.197	0.059	0.592	0.595
100	10.550	4.455	42.225	0.396	0.673	0.633	0.655	0.461	0.314	0.661	0.008	0.011
125	6.250	4.596	73.539	0.408	0.289	0.935	0.243	0.540	0.394	0.194	0.418	0.199
150	14.950	0.495	3.311	0.044	0.023	0.104	0.040	0.050	0.243	0.524	0.049	0.028
175	33.250	19.587	58.908	1.740	0.789	0.167	0.059	0.410	0.875	0.278	0.484	0.703

Damage Rating Index Along Transverse Axis

Percent Difference

	Velocity				Amplitude				Energy			
Height (mm)	C24SS5A	C24SS5W	C24LW0F	C24SS2F	C24SS5A	C24SS5W	C24LW0F	C24SS2F	C24SS5A	C24SS5W	C24LW0F	C24SS2F
25	1.014	1.020	1.008	0.994	1.067	1.032	0.954	0.960	2.082	2.362	1.130	0.993
50	1.011	1.013	1.005	0.985	1.128	1.063	0.986	0.945	2.352	2.178	0.982	0.903
75	1.004	1.012	1.001	0.988	1.094	1.095	1.001	1.001	1.790	1.966	1.204	1.143
100	0.883	0.900	0.872	0.862	0.913	0.935	0.815	0.803	0.560	0.868	0.245	0.212
125	0.913	1.086	0.934	0.924	0.935	1.135	0.910	0.941	0.272	0.401	0.251	0.313
150	0.983	1.202	0.992	0.997	0.984	1.160	0.936	0.966	0.399	1.319	0.389	0.441
175	0.951	0.993	1.005	0.992	0.935	1.029	1.031	0.951	0.921	1.630	1.763	0.874

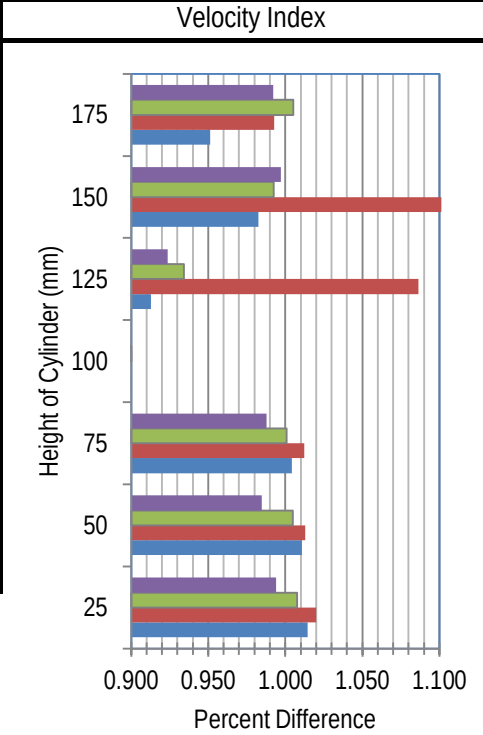
Graph Legend

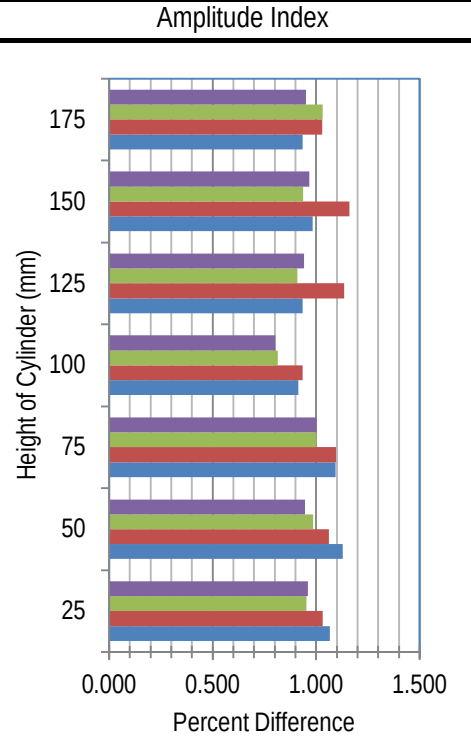
C24SS2F

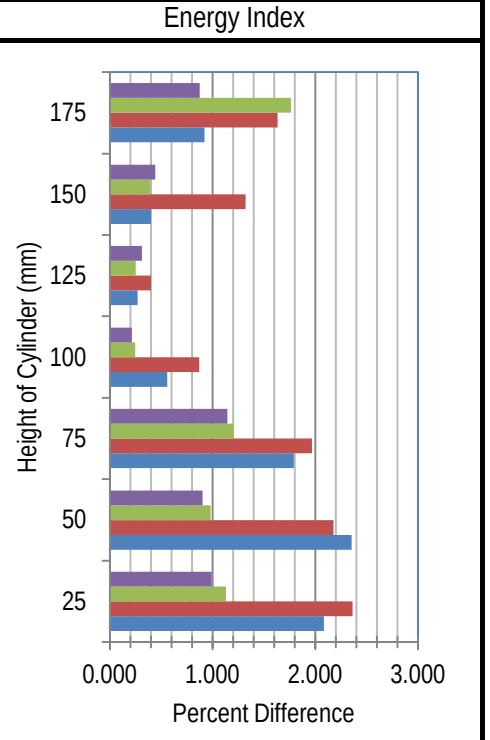
C24LW0F

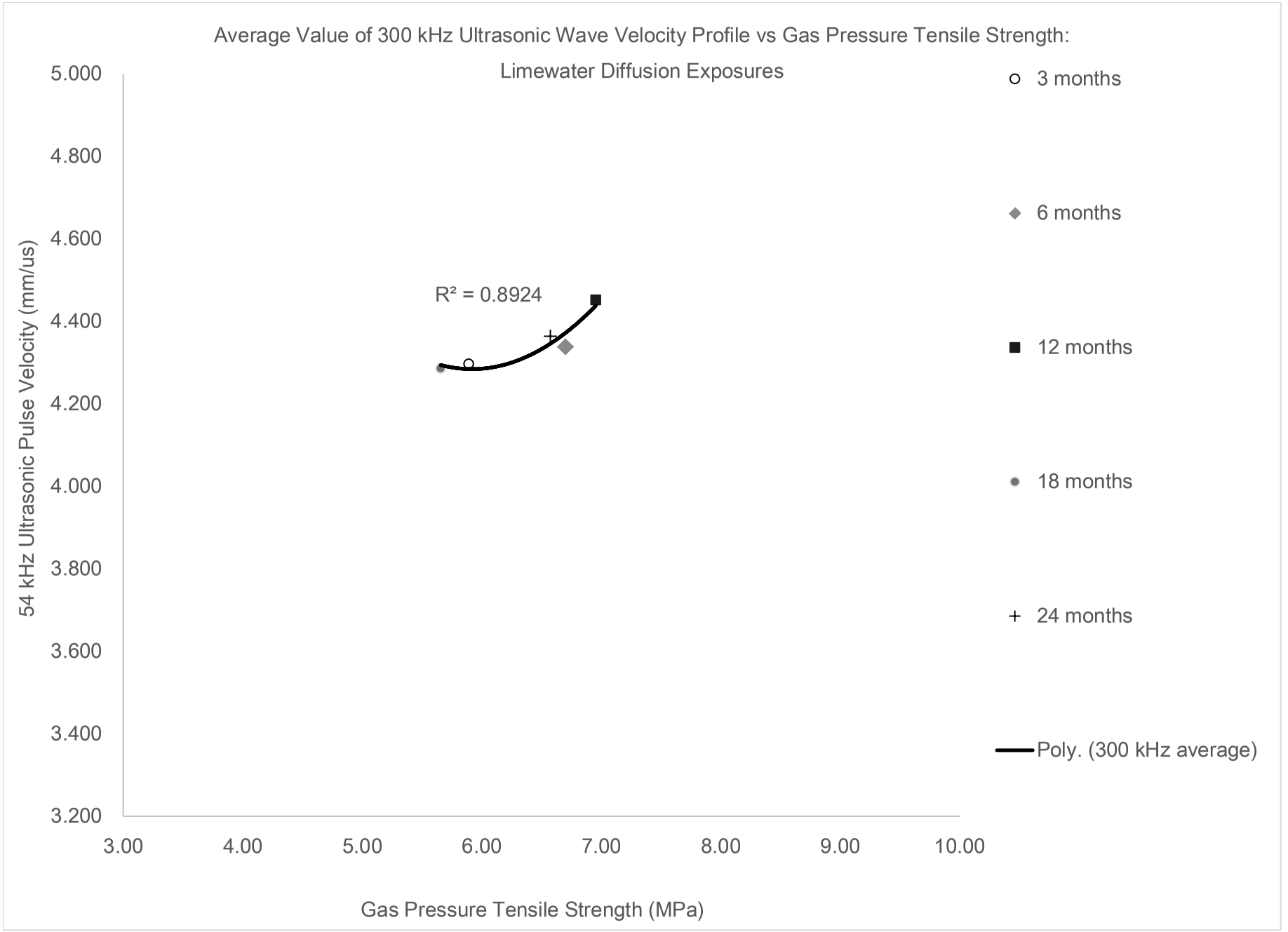
C24SS5W

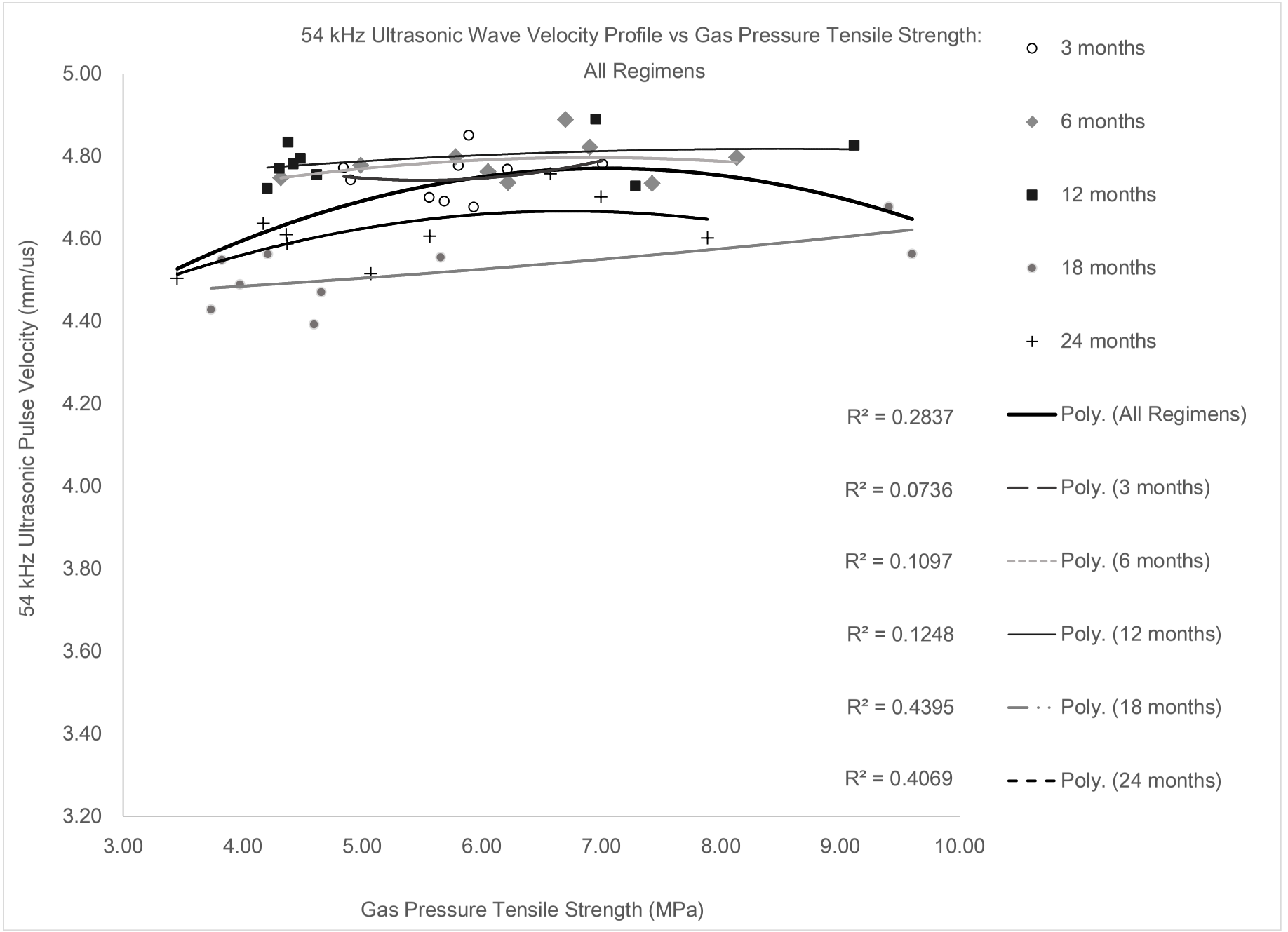
C24SS5A

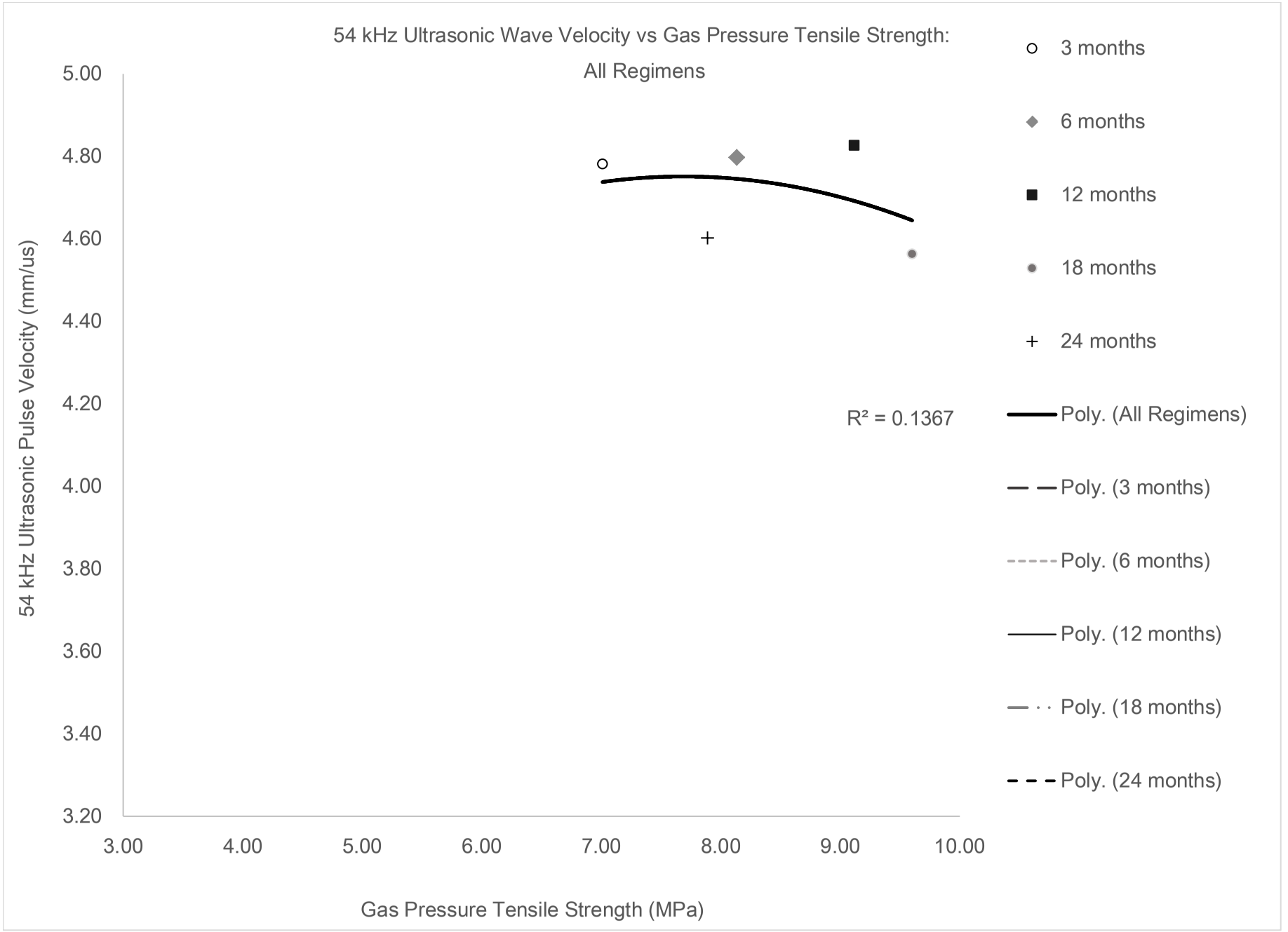


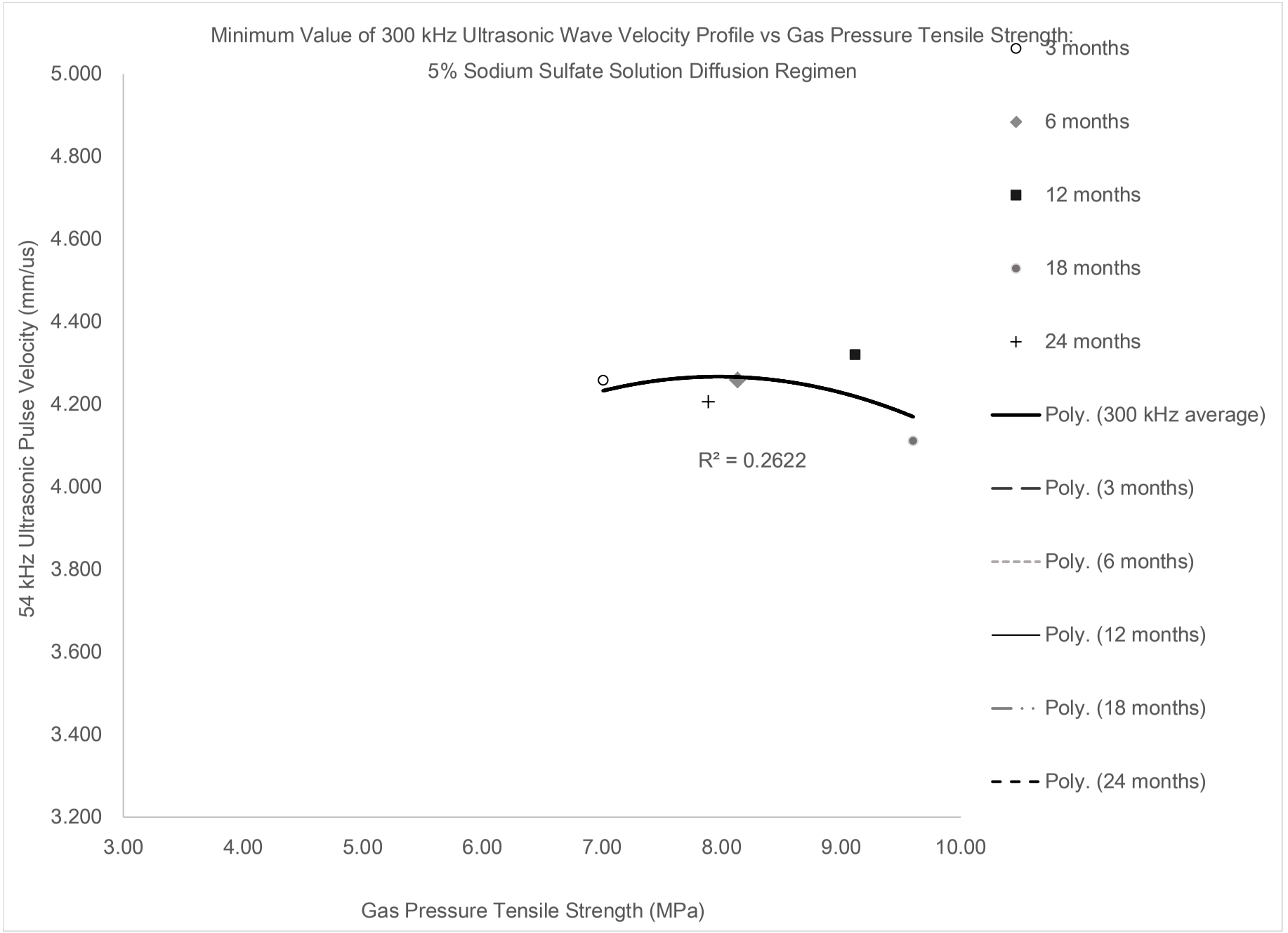


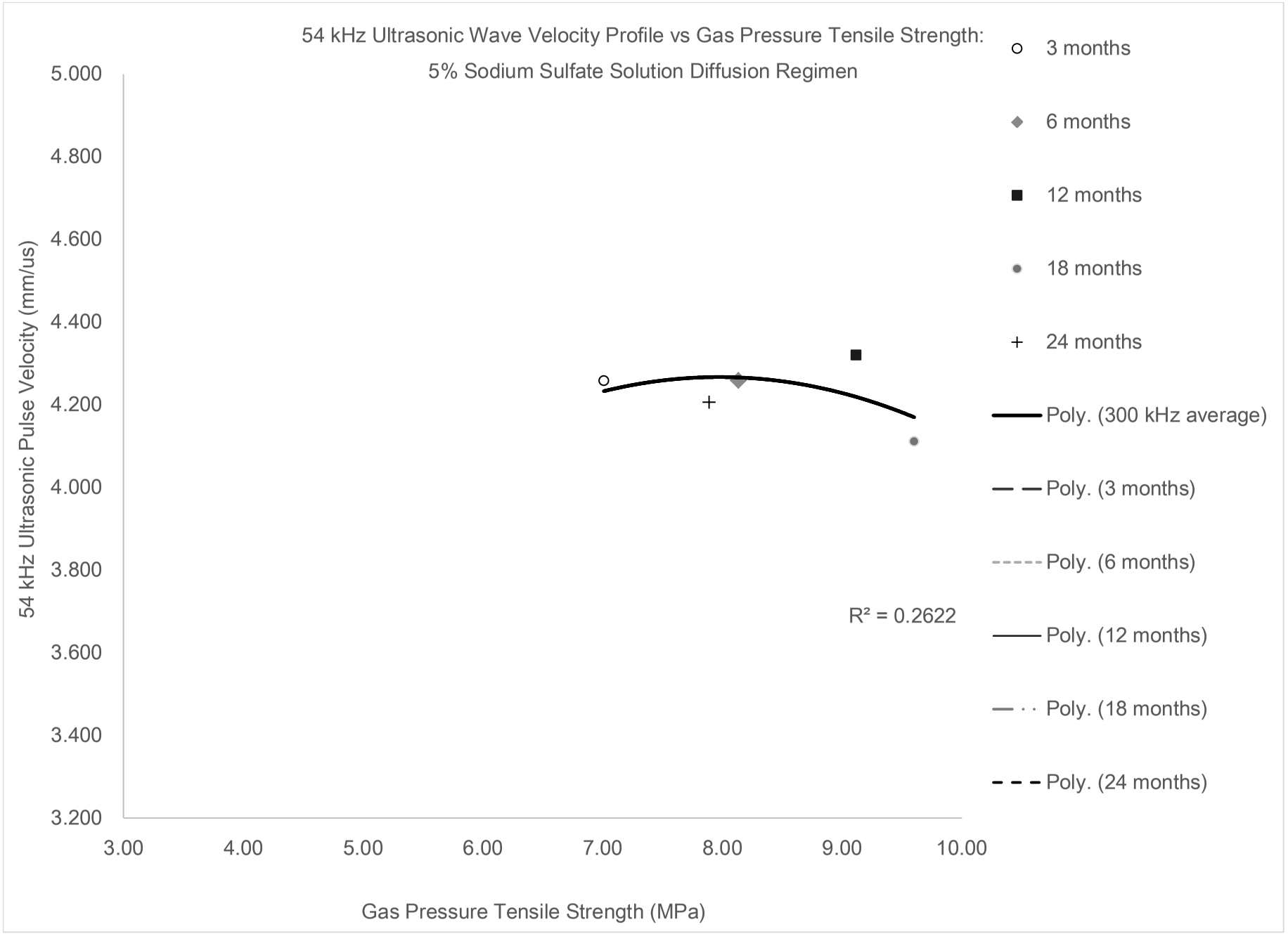


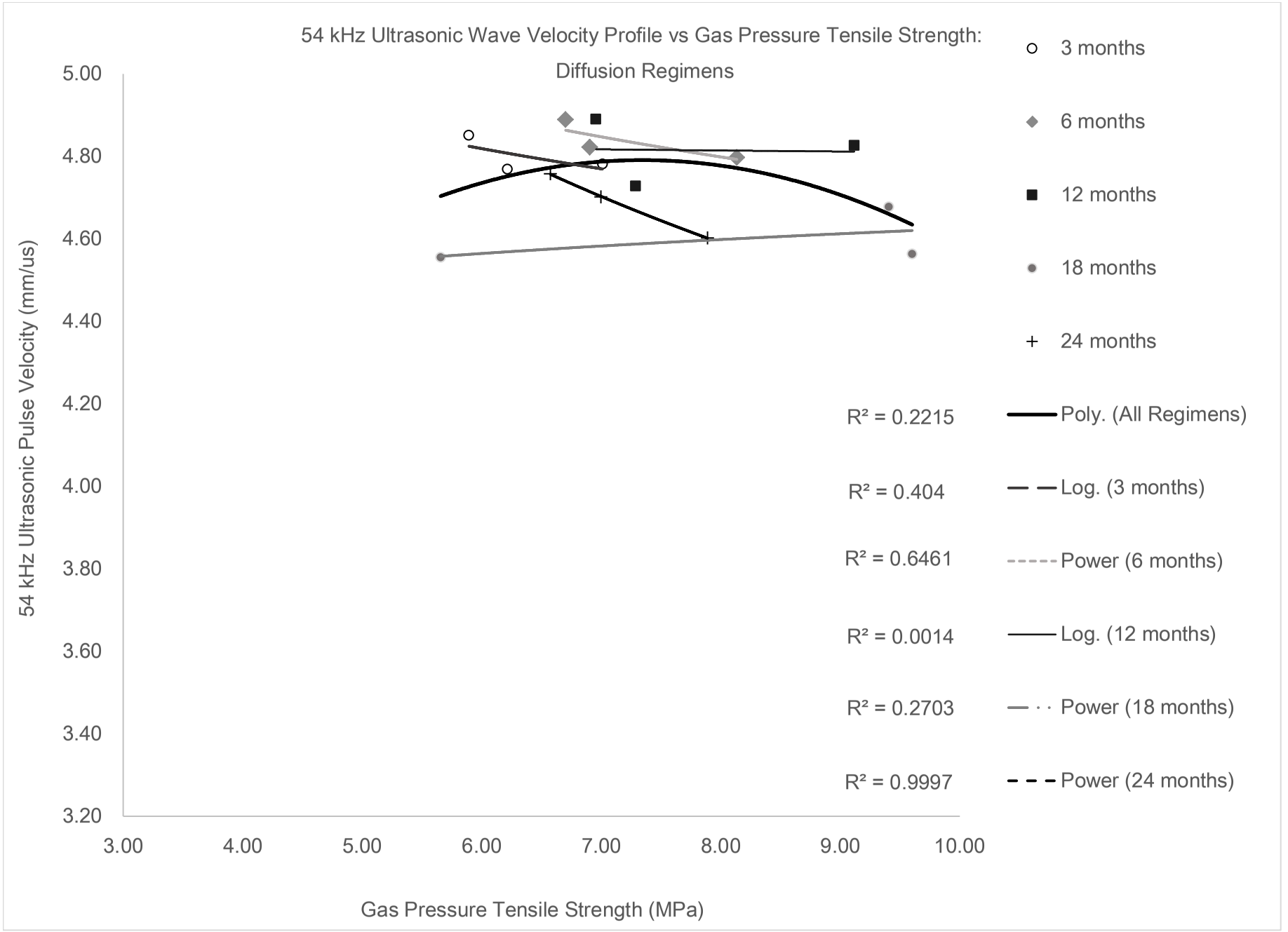

Average Value of 300 kHz Ultrasonic Wave Velocity Profile vs Gas Pressure Tensile Strength:
Limewater Diffusion Exposures
54 kHz Ultrasonic Pulse Velocity (mm/us)
5.000
4.800
4.600
4.400
4.200
4.000
3.800
3.600
3.400
3.200
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strength (MPa)
R² = 0.8924
3 months
6 months
12 months
18 months
24 months
Poly. (300 kHz average)

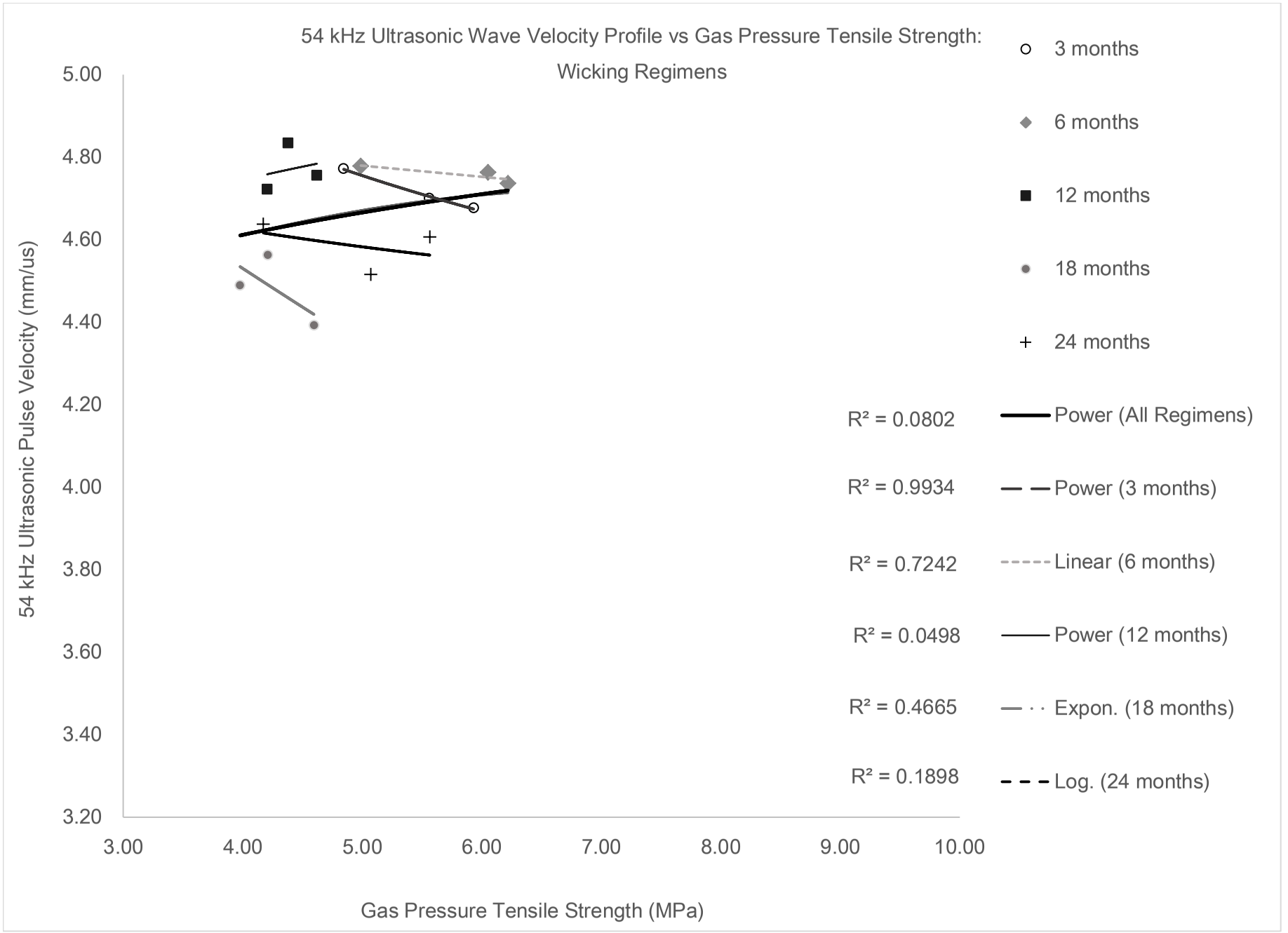

54 kHz Ultrasonic Wave Velocity Profile vs Gas Pressure Tensile Strength: All Regimens
54 kHz Ultrasonic Pulse Velocity (mm/us)
5.00
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strength (MPa)
3 months
6 months
12 months
18 months
24 months
R² = 0.2837
Poly. (All Regimens)
R² = 0.0736
Poly. (3 months)
R² = 0.1097
Poly. (6 months)
R² = 0.1248
Poly. (12 months)
R² = 0.4395
Poly. (18 months)
R² = 0.4069
Poly. (24 months)

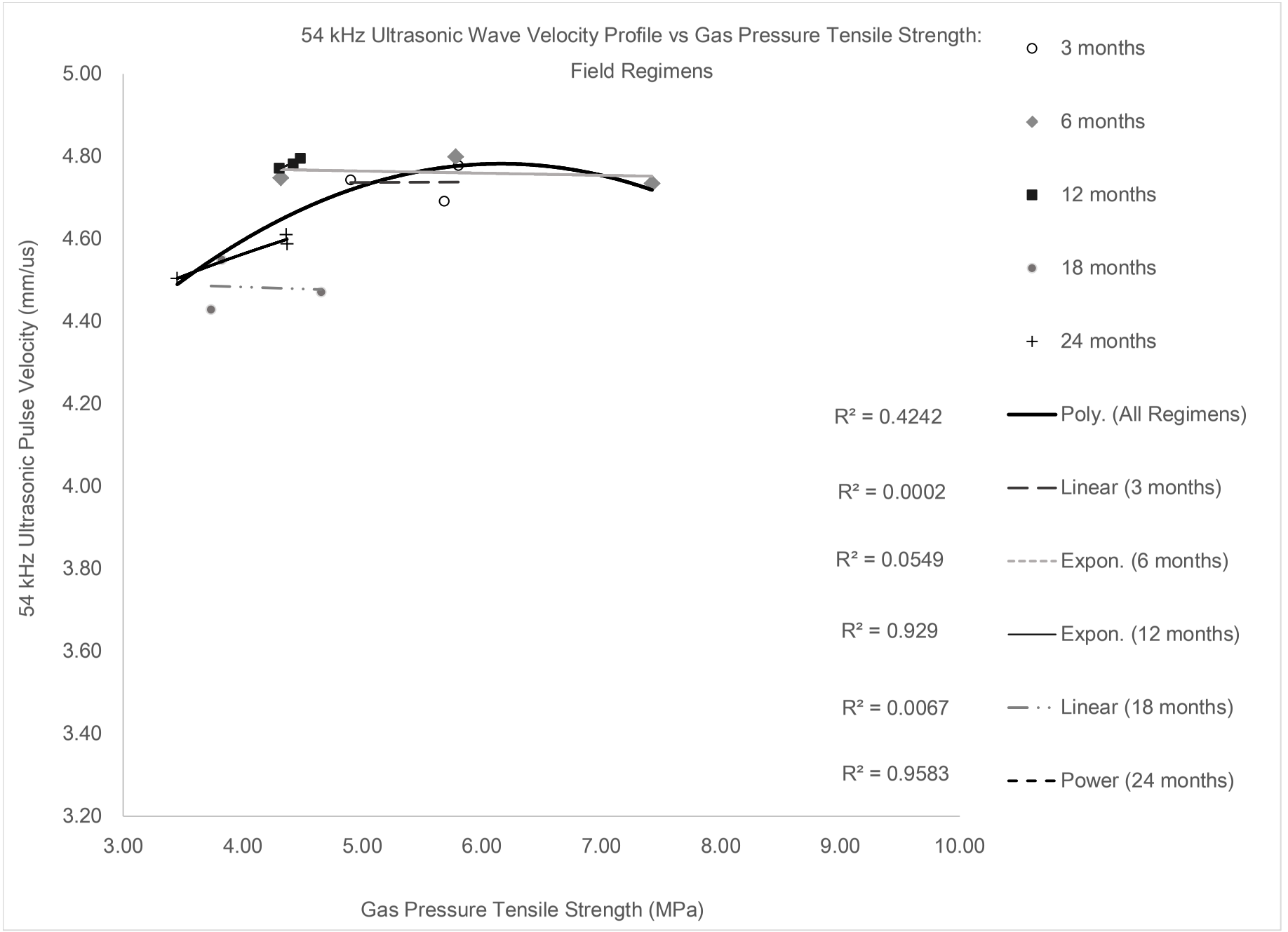

54 kHz Ultrasonic Wave Velocity vs Gas Pressure Tensile Strength: All Regimens
54 kHz Ultrasonic Pulse Velocity (mm/us)
5.00
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strength (MPa)
R² = 0.1367
3 months
6 months
12 months
18 months
24 months
Poly. (All Regimens)
Poly. (3 months)
Poly. (6 months)
Poly. (12 months)
Poly. (18 months)
Poly. (24 months)

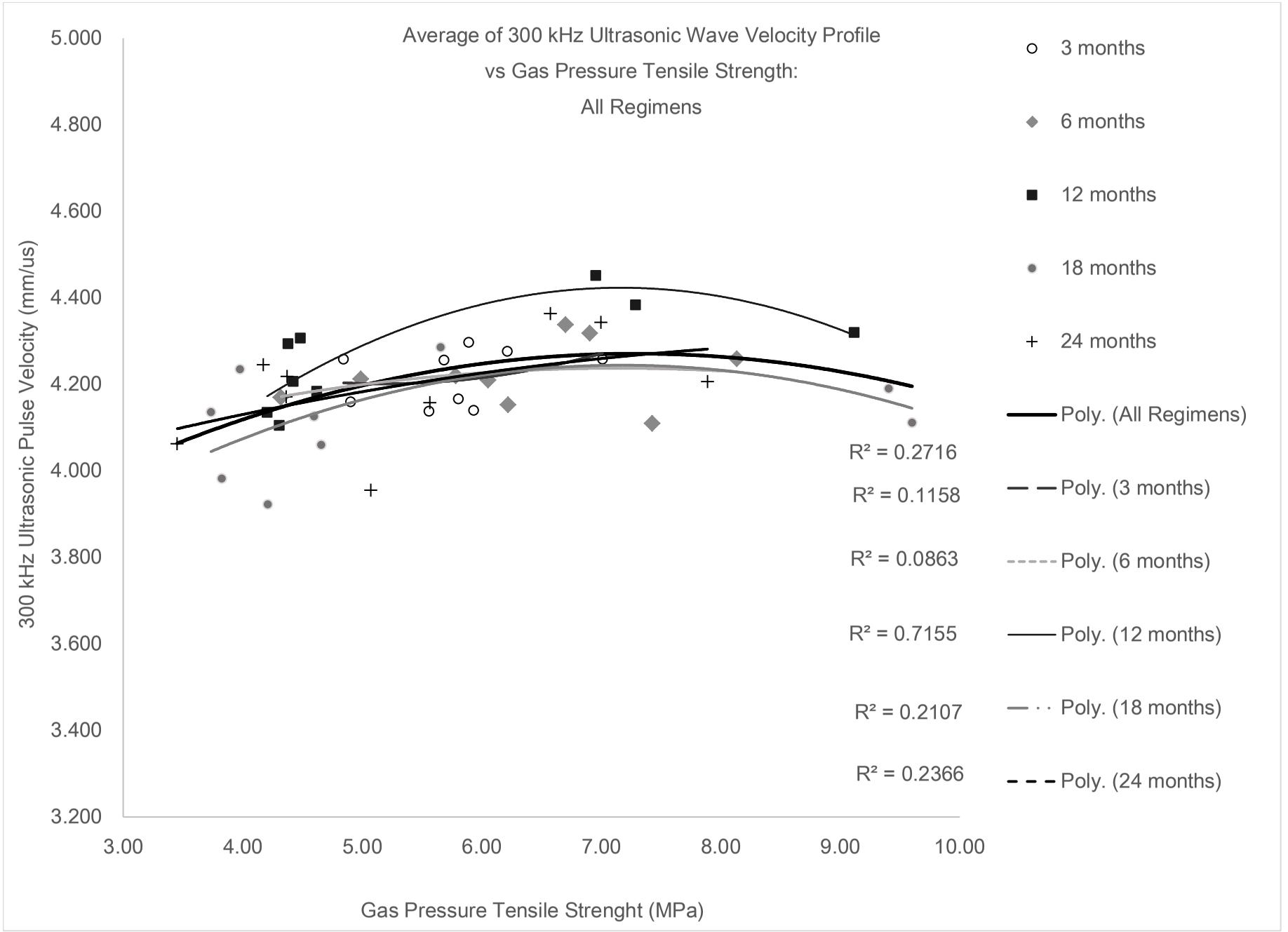

Minimum Value of 300 kHz Ultrasonic Wave Velocity Profile vs Gas Pressure Tensile Strength:
5% Sodium Sulfate Solution Diffusion Regimen
54 kHz Ultrasonic Pulse Velocity (mm/us)
5.000
4.800
4.600
4.400
4.200
4.000
3.800
3.600
3.400
3.200
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strength (MPa)
R² = 0.2622
3 months
6 months
12 months
18 months
24 months
Poly. (300 kHz average)
Poly. (3 months)
Poly. (6 months)
Poly. (12 months)
Poly. (18 months)
Poly. (24 months)

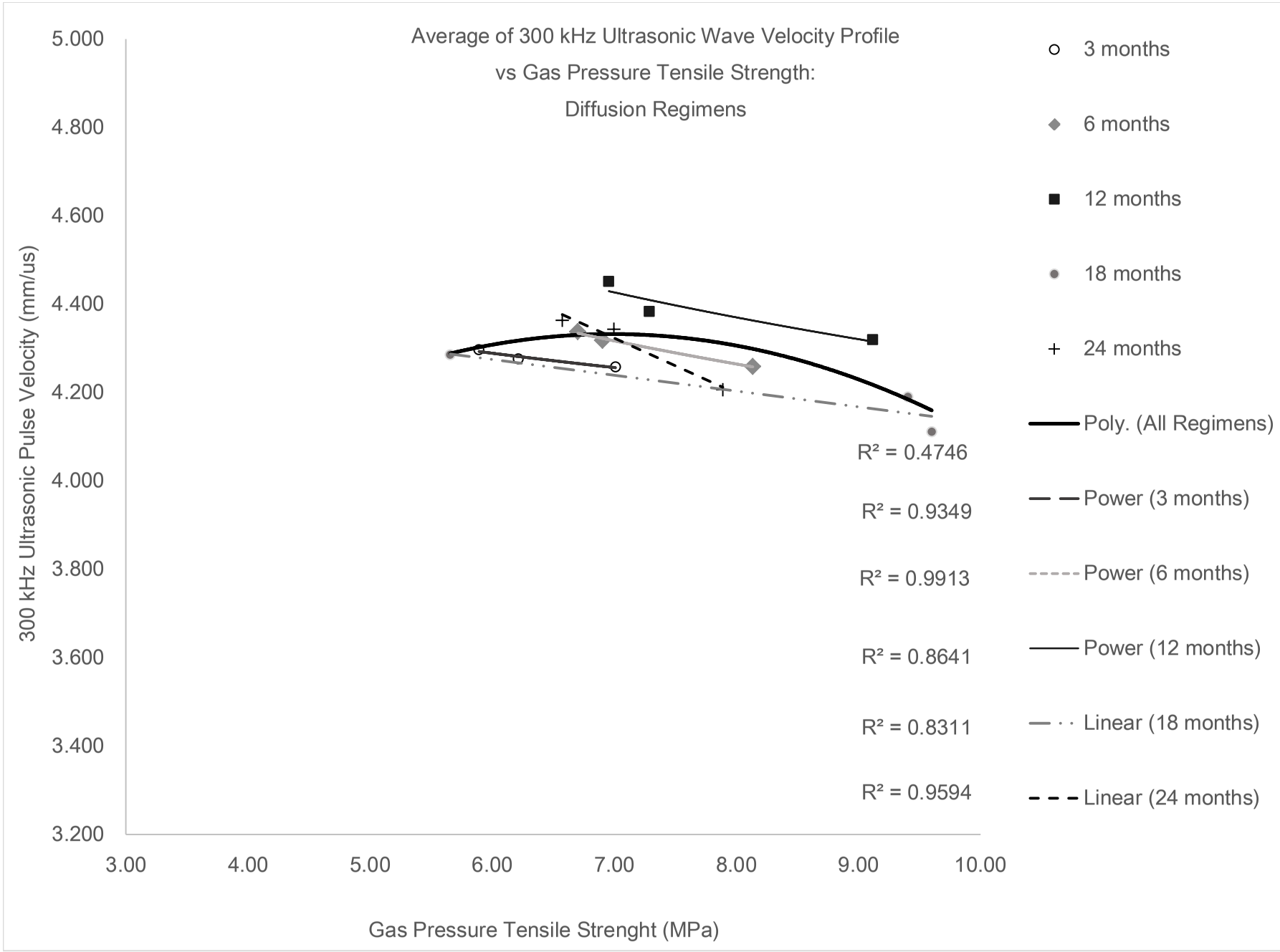

54 kHz Ultrasonic Wave Velocity Profile vs Gas Pressure Tensile Strength:
5% Sodium Sulfate Solution Diffusion Regimen
54 kHz Ultrasonic Pulse Velocity (mm/us)
5.000
4.800
4.600
4.400
4.200
4.000
3.800
3.600
3.400
3.200
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strength (MPa)
R² = 0.2622
3 months
6 months
12 months
18 months
24 months
Poly. (300 kHz average)
Poly. (3 months)
Poly. (6 months)
Poly. (12 months)
Poly. (18 months)
Poly. (24 months)

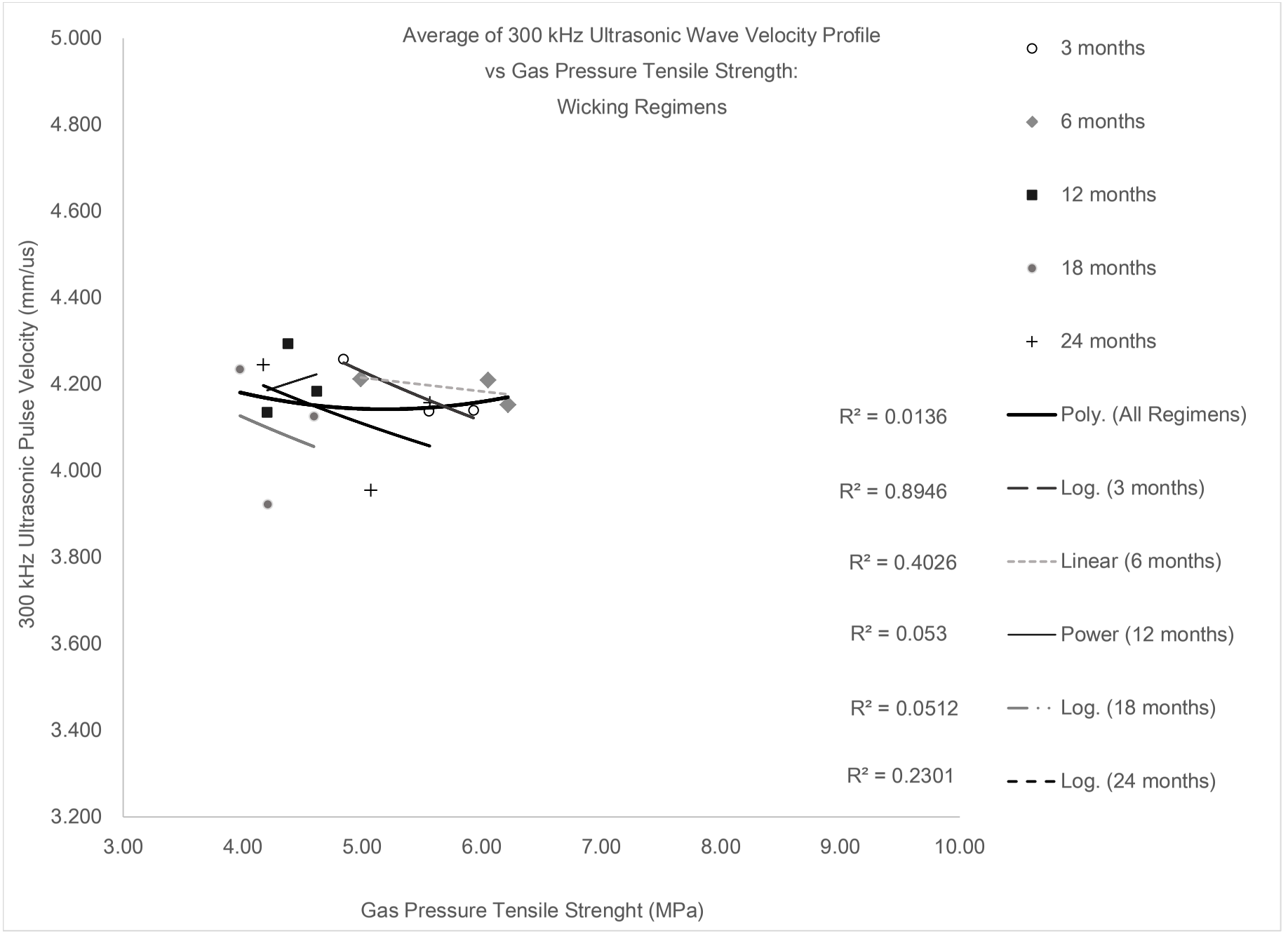

54 kHz Ultrasonic Wave Velocity Profile vs Gas Pressure Tensile Strength: Diffusion Regimens
54 kHz Ultrasonic Pulse Velocity (mm/us)
5.00
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strength (MPa)
3 months
6 months
12 months
18 months
24 months
R² = 0.2215
Poly. (All Regimens)
R² = 0.404
Log. (3 months)
R² = 0.6461
Power (6 months)
R² = 0.0014
Log. (12 months)
R² = 0.2703
Power (18 months)
R² = 0.9997
Power (24 months)

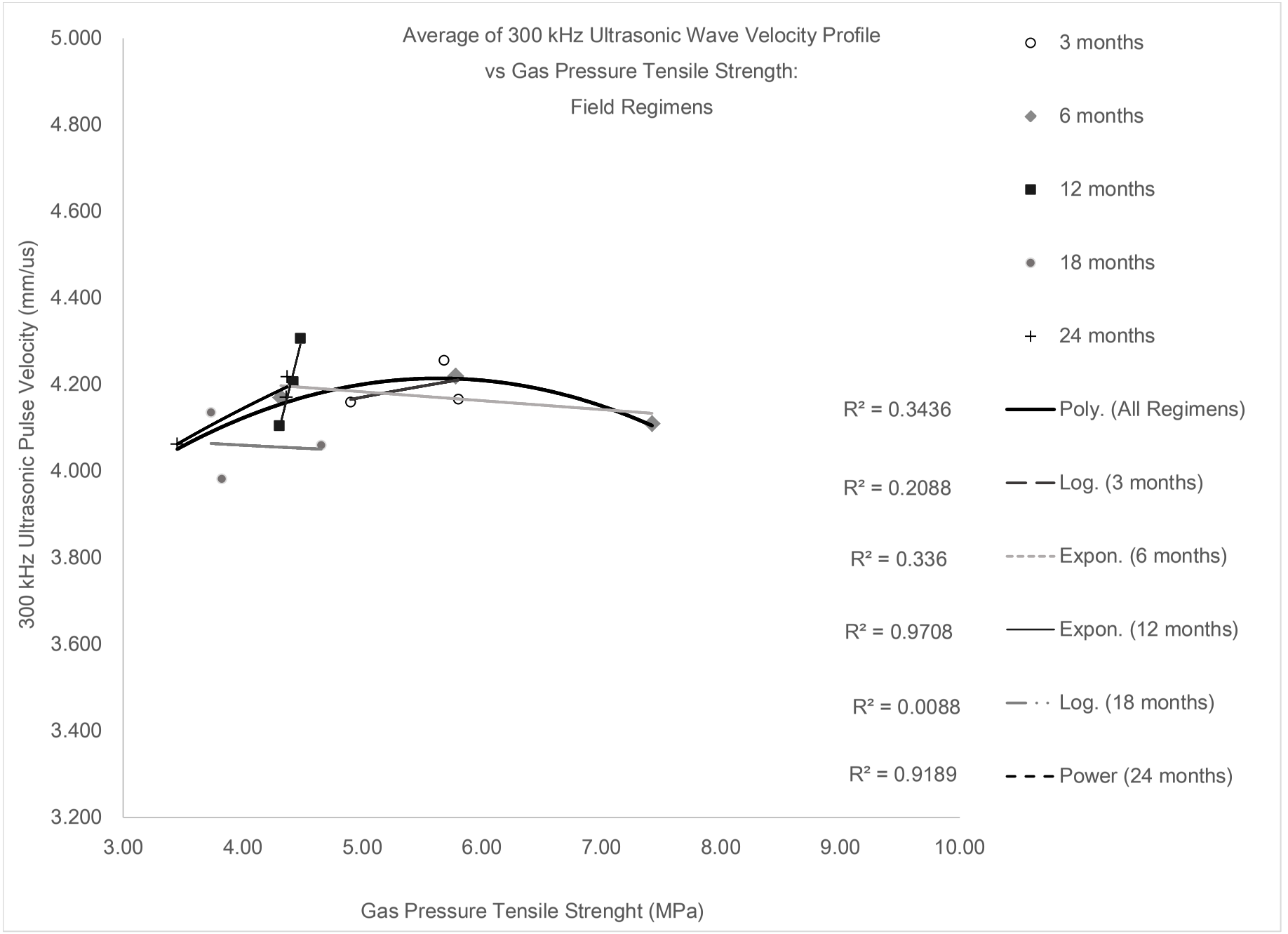

54 kHz Ultrasonic Wave Velocity Profile vs Gas Pressure Tensile Strength: Wicking Regimens
54 kHz Ultrasonic Pulse Velocity (mm/us)
5.00
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strength (MPa)
3 months
6 months
12 months
18 months
24 months
R² = 0.0802
Power (All Regimens)
R² = 0.9934
Power (3 months)
R² = 0.7242
Linear (6 months)
R² = 0.0498
Power (12 months)
R² = 0.4665
Expon. (18 months)
R² = 0.1898
Log. (24 months)

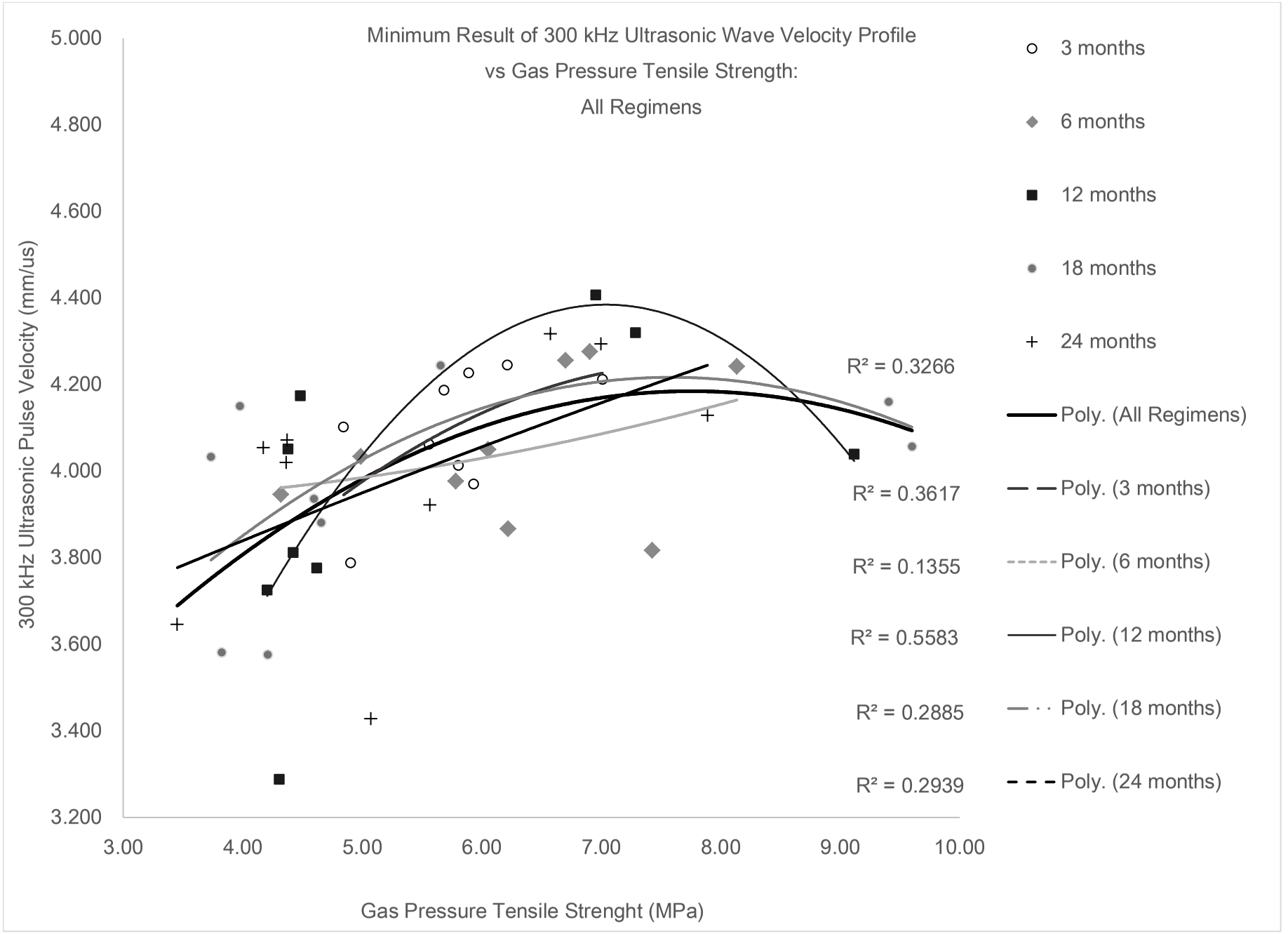

54 kHz Ultrasonic Wave Velocity Profile vs Gas Pressure Tensile Strength: Field Regimens
54 kHz Ultrasonic Pulse Velocity (mm/us)
5.00
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strength (MPa)
3 months
6 months
12 months
18 months
24 months
R² = 0.4242
Poly. (All Regimens)
R² = 0.0002
Linear (3 months)
R² = 0.0549
Expon. (6 months)
R² = 0.929
Expon. (12 months)
R² = 0.0067
Linear (18 months)
R² = 0.9583
Power (24 months)

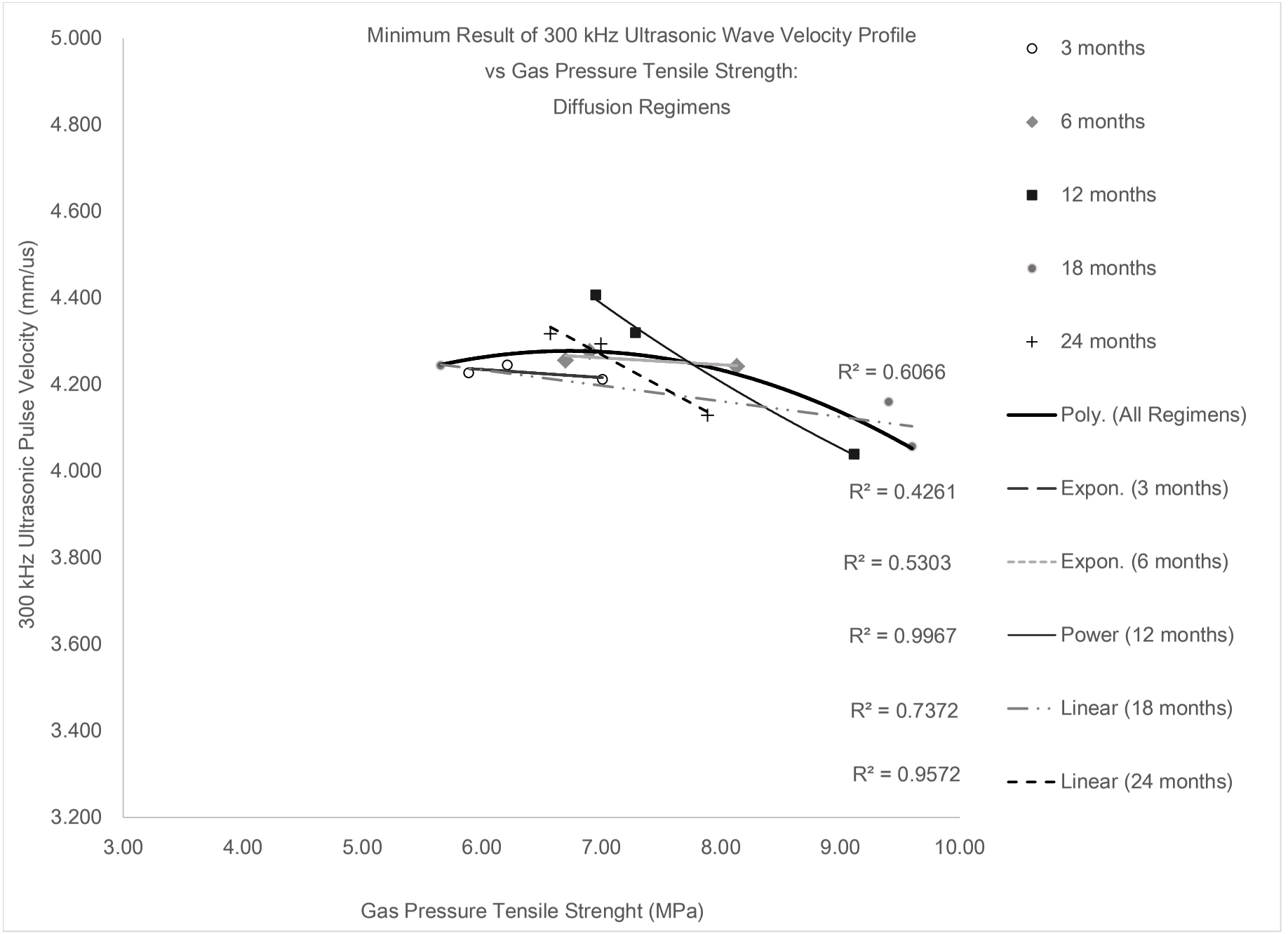

Average of 300 kHz Ultrasonic Wave Velocity Profile
vs Gas Pressure Tensile Strength:
All Regimens
300 kHz Ultrasonic Pulse Velocity (mm/us)
5.000
4.800
4.600
4.400
4.200
4.000
3.800
3.600
3.400
3.200
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strenght (MPa)
3 months
6 months
12 months
18 months
24 months
Poly. (All Regimens)
Poly. (3 months)
Poly. (6 months)
Poly. (12 months)
Poly. (18 months)
Poly. (24 months)
R² = 0.2716
R² = 0.1158
R² = 0.0863
R² = 0.7155
R² = 0.2107
R² = 0.2366

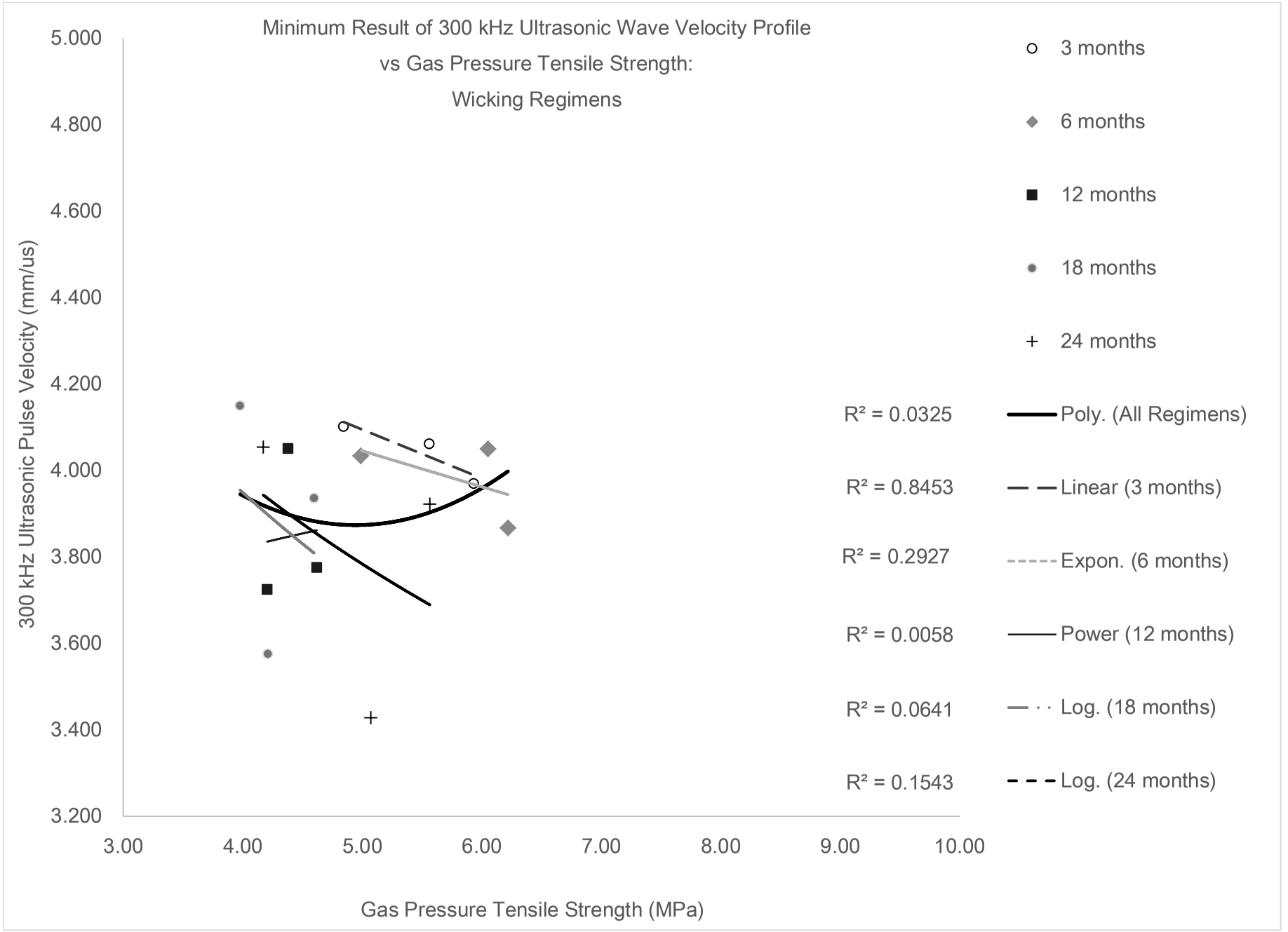

Average of 300 kHz Ultrasonic Wave Velocity Profile
vs Gas Pressure Tensile Strength:
Diffusion Regimens
300 kHz Ultrasonic Pulse Velocity (mm/us)
5.000
4.800
4.600
4.400
4.200
4.000
3.800
3.600
3.400
3.200
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strenght (MPa)
3 months
6 months
12 months
18 months
24 months
Poly. (All Regimens)
Power (3 months)
Power (6 months)
Power (12 months)
Linear (18 months)
Linear (24 months)
R² = 0.4746
R² = 0.9349
R² = 0.9913
R² = 0.8641
R² = 0.8311
R² = 0.9594

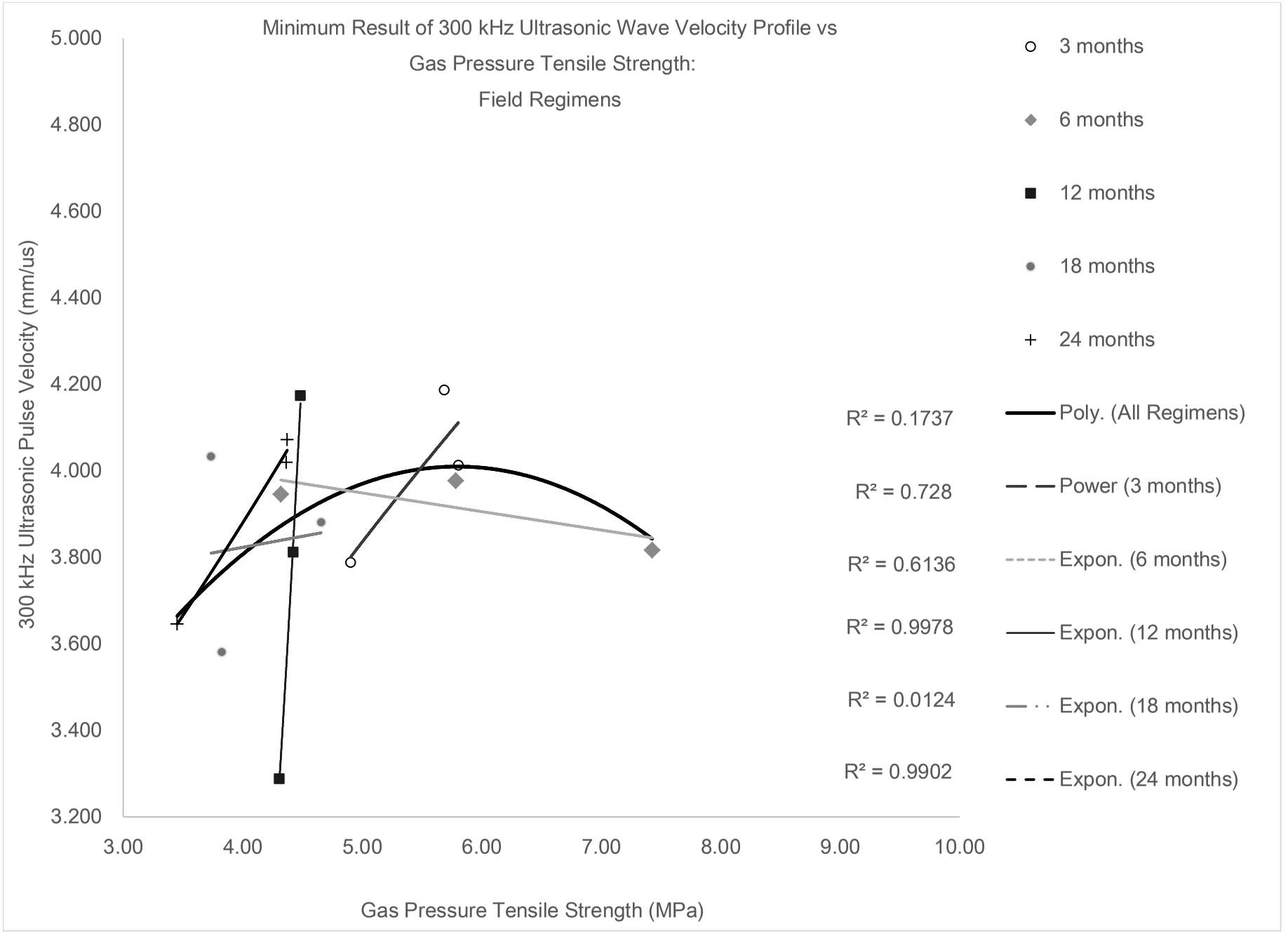

Average of 300 kHz Ultrasonic Wave Velocity Profile
vs Gas Pressure Tensile Strength:
Wicking Regimens
300 kHz Ultrasonic Pulse Velocity (mm/us)
5.000
4.800
4.600
4.400
4.200
4.000
3.800
3.600
3.400
3.200
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strenght (MPa)
3 months
6 months
12 months
18 months
24 months
R² = 0.0136
Poly. (All Regimens)
R² = 0.8946
Log. (3 months)
R² = 0.4026
Linear (6 months)
R² = 0.053
Power (12 months)
R² = 0.0512
Log. (18 months)
R² = 0.2301
Log. (24 months)

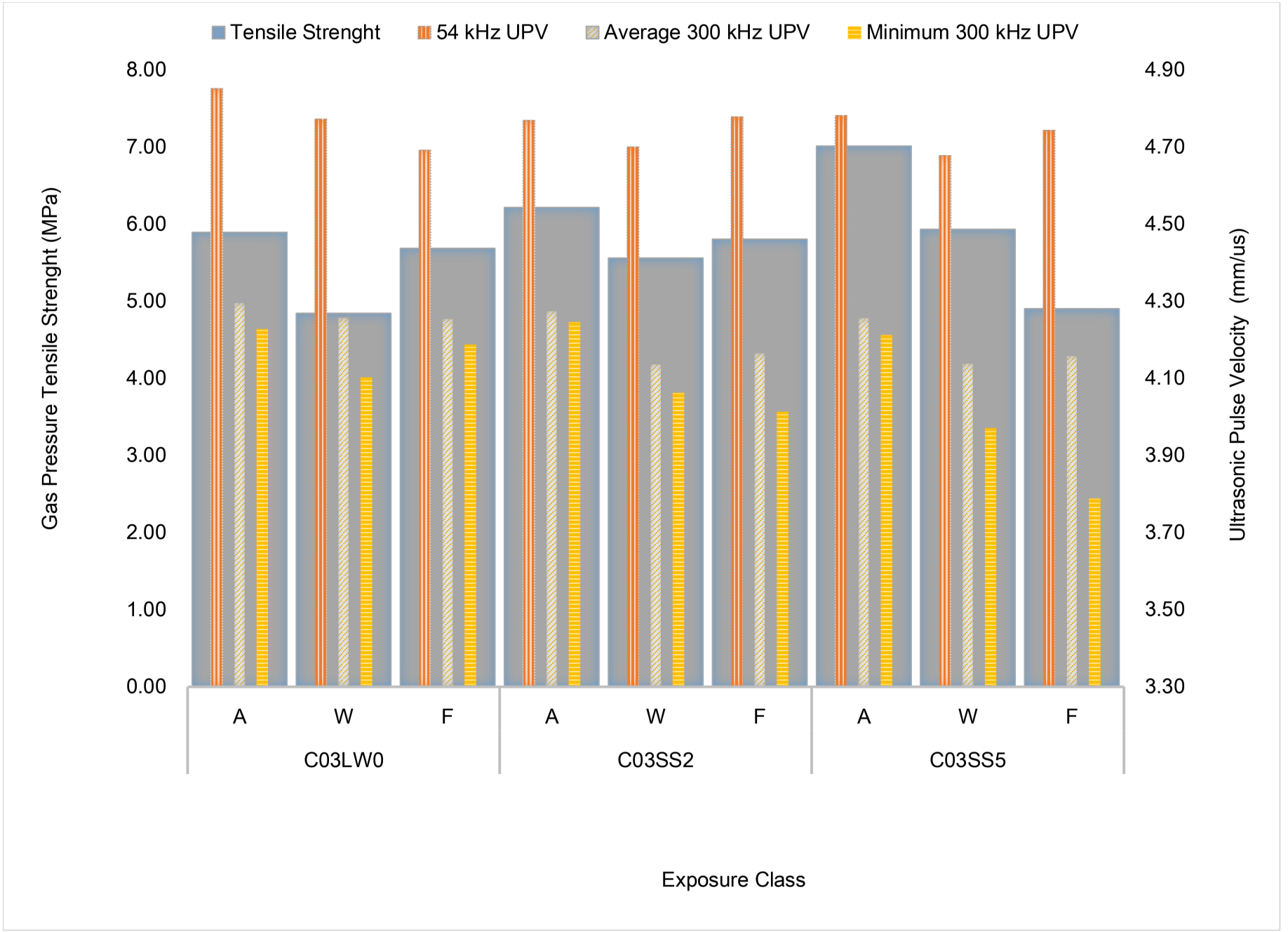

Average of 300 kHz Ultrasonic Wave Velocity Profile
vs Gas Pressure Tensile Strength:
Field Regimens
300 kHz Ultrasonic Pulse Velocity (mm/us)
5.000
4.800
4.600
4.400
4.200
4.000
3.800
3.600
3.400
3.200
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strenght (MPa)
3 months
6 months
12 months
18 months
24 months
R² = 0.3436
Poly. (All Regimens)
R² = 0.2088
Log. (3 months)
R² = 0.336
Expon. (6 months)
R² = 0.9708
Expon. (12 months)
R² = 0.0088
Log. (18 months)
R² = 0.9189
Power (24 months)

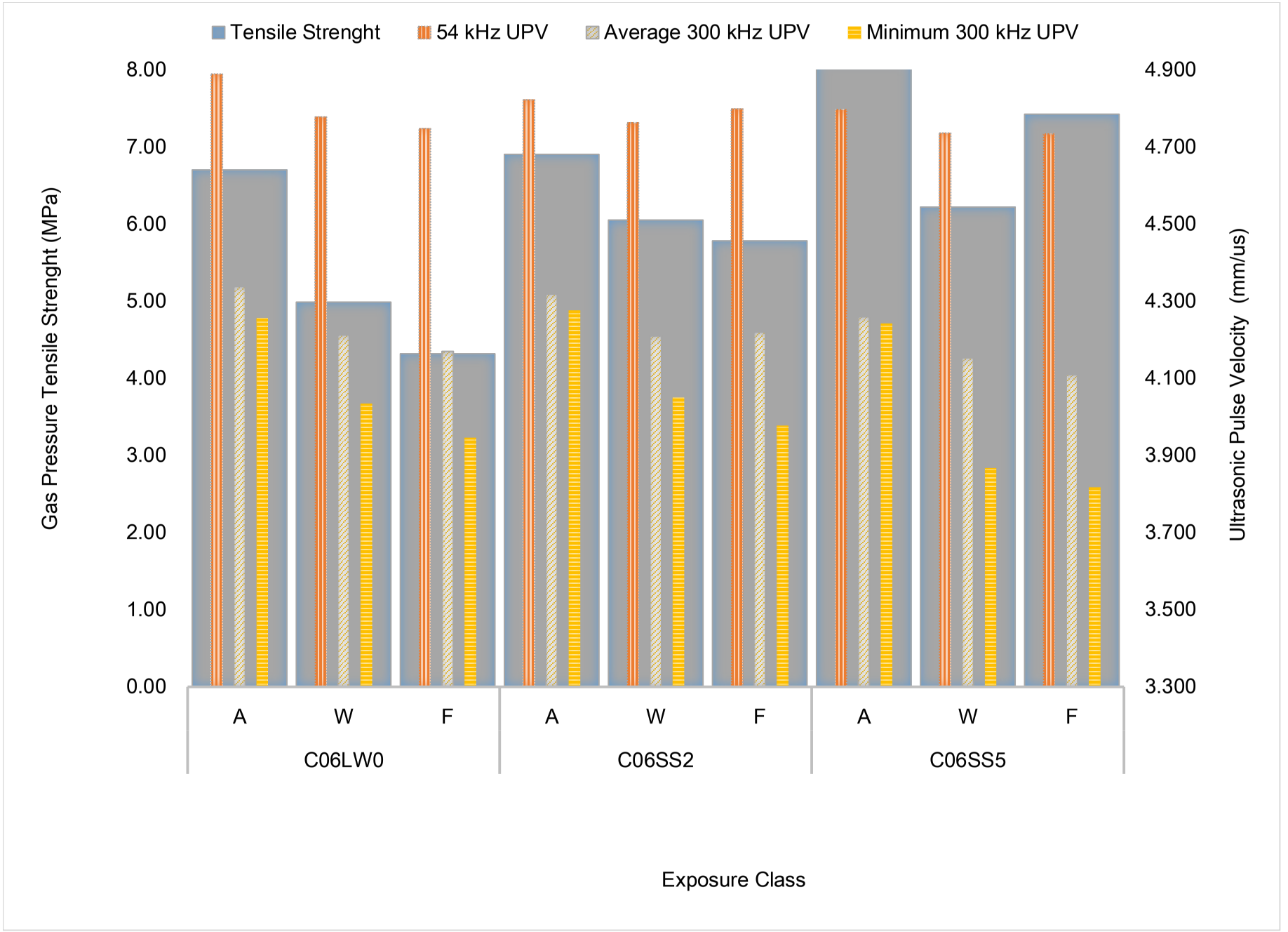

Minimum Result of 300 kHz Ultrasonic Wave Velocity Profile
vs Gas Pressure Tensile Strength:
All Regimens
300 kHz Ultrasonic Pulse Velocity (mm/us)
5.000
4.800
4.600
4.400
4.200
4.000
3.800
3.600
3.400
3.200
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strenght (MPa)
3 months
6 months
12 months
18 months
24 months
Poly. (All Regimens)
Poly. (3 months)
Poly. (6 months)
Poly. (12 months)
Poly. (18 months)
Poly. (24 months)
R² = 0.3266
R² = 0.3617
R² = 0.1355
R² = 0.5583
R² = 0.2885
R² = 0.2939

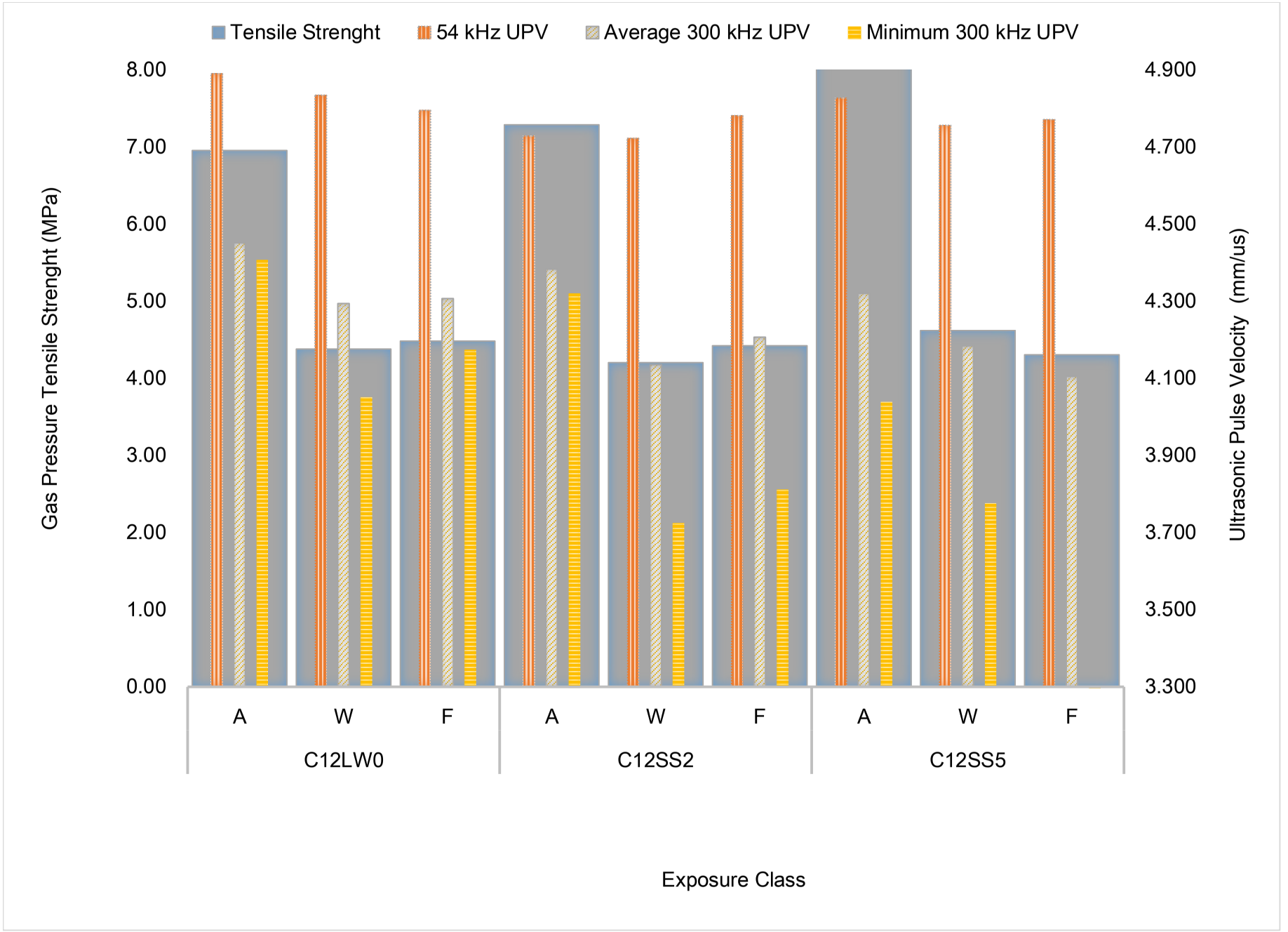

Minimum Result of 300 kHz Ultrasonic Wave Velocity Profile
vs Gas Pressure Tensile Strength:
Diffusion Regimens
300 kHz Ultrasonic Pulse Velocity (mm/us)
5.000
4.800
4.600
4.400
4.200
4.000
3.800
3.600
3.400
3.200
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strenght (MPa)
3 months
6 months
12 months
18 months
24 months
Poly. (All Regimens)
Expon. (3 months)
Expon. (6 months)
Power (12 months)
Linear (18 months)
Linear (24 months)
R² = 0.6066
R² = 0.4261
R² = 0.5303
R² = 0.9967
R² = 0.7372
R² = 0.9572

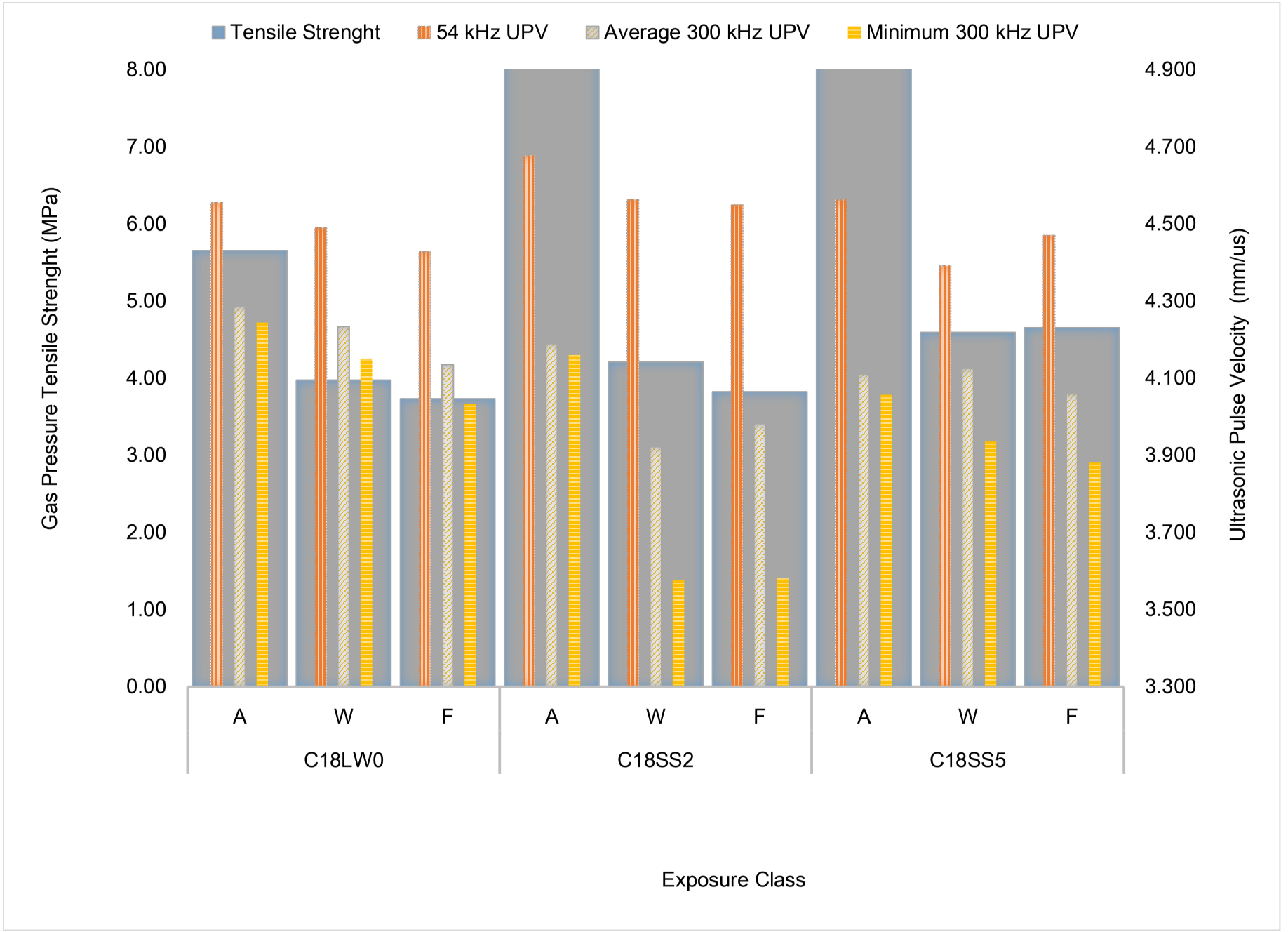

Minimum Result of 300 kHz Ultrasonic Wave Velocity Profile
vs Gas Pressure Tensile Strength:
Wicking Regimens
300 kHz Ultrasonic Pulse Velocity (mm/us)
5.000
4.800
4.600
4.400
4.200
4.000
3.800
3.600
3.400
3.200
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strength (MPa)
3 months
6 months
12 months
18 months
24 months
R² = 0.0325
Poly. (All Regimens)
R² = 0.8453
Linear (3 months)
R² = 0.2927
Expon. (6 months)
R² = 0.0058
Power (12 months)
R² = 0.0641
Log. (18 months)
R² = 0.1543
Log. (24 months)

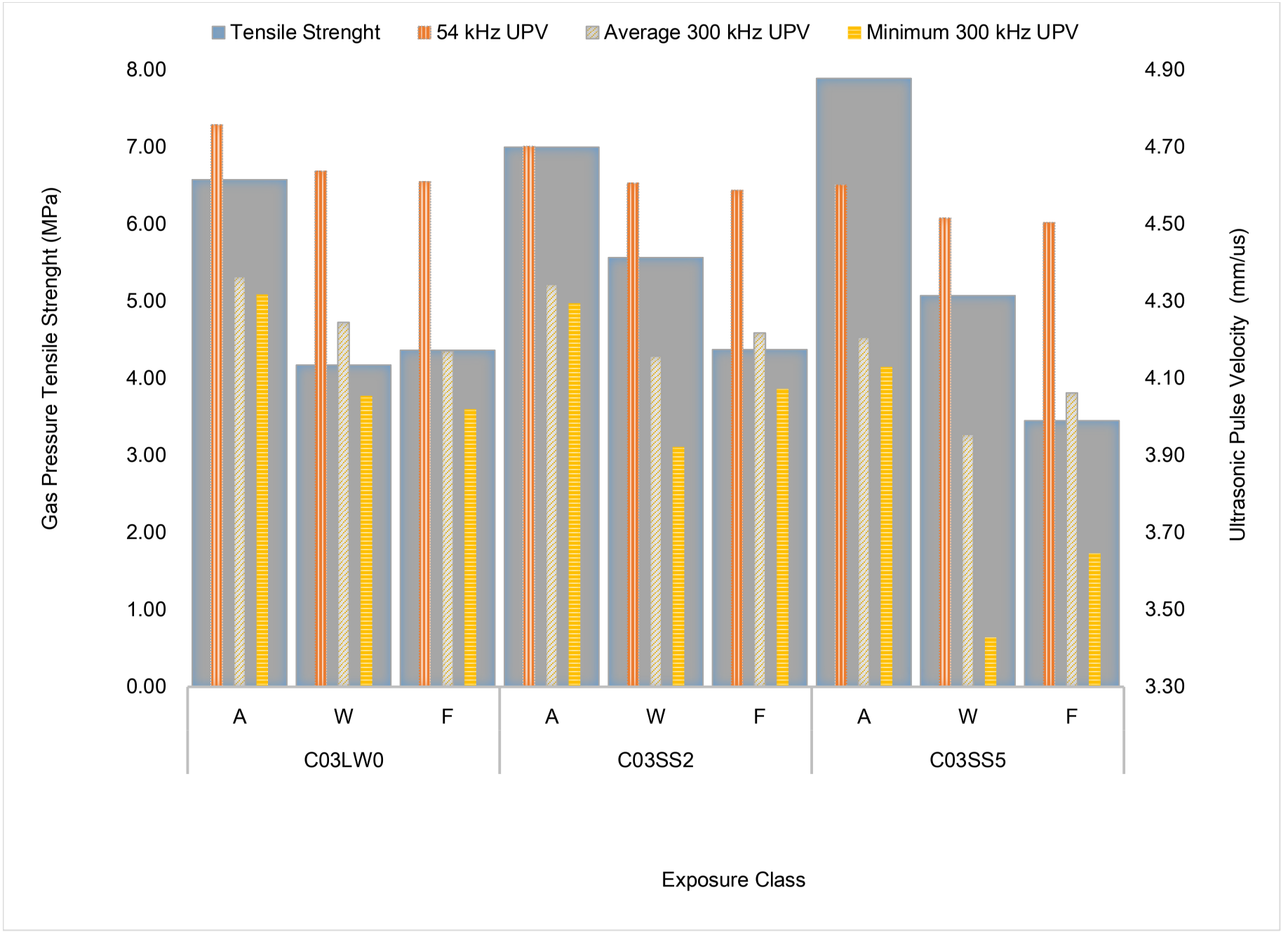

Minimum Result of 300 kHz Ultrasonic Wave Velocity Profile vs
Gas Pressure Tensile Strength:
Field Regimens
300 kHz Ultrasonic Pulse Velocity (mm/us)
5.000
4.800
4.600
4.400
4.200
4.000
3.800
3.600
3.400
3.200
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Gas Pressure Tensile Strength (MPa)
3 months
6 months
12 months
18 months
24 months
R² = 0.1737
Poly. (All Regimens)
R² = 0.728
Power (3 months)
R² = 0.6136
Expon. (6 months)
R² = 0.9978
Expon. (12 months)
R² = 0.0124
Expon. (18 months)
R² = 0.9902
Expon. (24 months)


Tensile Strenght
54 kHz UPV
Average 300 kHz UPV
Minimum 300 kHz UPV
Gas Pressure Tensile Strenght (MPa)
Ultrasonic Pulse Velocity (mm/us)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4.90
4.70
4.50
4.30
4.10
3.90
3.70
3.50
3.30
A
W
F
A
W
F
A
W
F
C03LW0
C03SS2
C03SS5
Exposure Class


Tensile Strenght
54 kHz UPV
Average 300 kHz UPV
Minimum 300 kHz UPV
Gas Pressure Tensile Strenght (MPa)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4.900
4.700
4.500
4.300
4.100
3.900
3.700
3.500
3.300
Ultrasonic Pulse Velocity (mm/us)
A
W
F
A
W
F
A
W
F
C06LW0
C06SS2
C06SS5
Exposure Class


Tensile Strenght
54 kHz UPV
Average 300 kHz UPV
Minimum 300 kHz UPV
Gas Pressure Tensile Strenght (MPa)
Ultrasonic Pulse Velocity (mm/us)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4.900
4.700
4.500
4.300
4.100
3.900
3.700
3.500
3.300
A
W
F
A
W
F
A
W
F
C12LW0
C12SS2
C12SS5
Exposure Class


Tensile Strenght
54 kHz UPV
Average 300 kHz UPV
Minimum 300 kHz UPV
Gas Pressure Tensile Strenght (MPa)
Ultrasonic Pulse Velocity (mm/us)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4.900
4.700
4.500
4.300
4.100
3.900
3.700
3.500
3.300
A
W
F
A
W
F
A
W
F
C18LW0
C18SS2
C18SS5
Exposure Class


Tensile Strenght
54 kHz UPV
Average 300 kHz UPV
Minimum 300 kHz UPV
Gas Pressure Tensile Strenght (MPa)
Ultrasonic Pulse Velocity (mm/us)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4.90
4.70
4.50
4.30
4.10
3.90
3.70
3.50
3.30
A
W
F
A
W
F
A
W
F
C03LW0
C03SS2
C03SS5
Exposure Class

Appendix C

Results for Disk Specimens

Disks - 03 Months Limewater Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D03LW0A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Axis	Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.29	36.38	4.13	49.00	3.70	1.00	103.16	22.10			
50.00	150.19	35.90	4.18	60.10	13.00	2.00	103.09	22.00			
75.00	150.03	41.63	3.60	51.40	3.00	Average	103.13	22.05	4.6769	78.49	3.23

Sample: D03LW0A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.41	35.48	4.24	59.50	17.10	Axis 1-3	103.42	21.60			
50	150.31	34.79	4.32	63.00	19.40	Axis 2-4	103.71	21.70			
75	150.27	33.33	4.51	61.80	32.60	Average	103.57	21.65	4.7836	87.66	3.58

Sample: D03LW0A3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.44	51.34	2.93	50.70	3.00	Axis 1-3	103.88	22.30			
50	150.6	36.96	4.07	53.30	4.50	Axis 2-4	103.77	22.40			
75	150.44	39.97	3.76	51.60	5.30	Average	103.83	22.35	4.6454	84.63	3.45

Sample: D03LW0C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.28					Axis 1-3	104.25	22.30			
50.00		37.13	4.05	51.3	3.0	Axis 2-4	104.05	22.30			
75.00	150.58					Average	104.15	22.30	4.6704	105.00	4.27

Sample: D03LW0C2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.88					Axis 1-3	105.54	22.60			
50.00		36.53	4.13	63.3	15.0	Axis 2-4	105.47	22.60			
75.00	150.64					Average	105.51	22.60	4.6684	99.58	3.99

Sample: D03LW0C4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.82	39.63	3.81	56.50	12.40	Axis 1-3	101.79	21.70			
50.00	150.80	42.67	3.53	52.60	3.00	Axis 2-4	101.66	21.60			
75.00	149.56	42.49	3.52	54.50	13.00	Average	101.73	21.65	4.6986	96.25	4.01

Disks - 03 Months Limewater Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D03LW0W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.21	35.42	4.24	64.00	24.00	Axis 1-3	102.35	21.40			
50.00	150.12					Axis 2-4	102.47	21.40			
75.00	149.72	33.60	4.46	61.50	16.80	Average	102.41	21.40	4.7855	74.42	3.08

Sample: D03LW0W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.04	35.91	4.18	68.50	28.70	Axis 1-3	101.19	21.50			
50.00	149.84					Axis 2-4	101.18	21.60			
75.00	149.91	34.36	4.36	67.00	35.70	Average	101.19	21.55	4.6954	74.48	3.13

Sample: D03LW0W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.63	35.99	4.16	66.60	33.70	Axis 1-3	104.03	21.90			
50.00	143.73					Axis 2-4	104.08	21.90			
75.00	143.70	33.60	4.28	72.50	77.70	Average	104.06	21.90	4.7514	74.94	3.15

Sample: D03LW0F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.76	35.95	4.17	65.50	26.40	Axis 1-3	104.65	22.10			
50.00	149.49					Axis 2-4	104.63	22.20			
75.00	149.33	33.86	4.41	70.50	59.00	Average	104.64	22.15	4.7242	82.33	3.35

Sample: D03LW0F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.34	37.35	4.03	53.50	7.00	Axis 1-3	103.44	22.20			
50.00	150.01					Axis 2-4	103.53	22.30			
75.00	150.14	33.85	4.44	60.30	27.30	Average	103.49	22.25	4.6510	92.25	3.78

Sample: D03LW0F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.02	35.89	4.18	61.50	25.40	Axis 1-3	101.36	21.50			
50.00	150.14					Axis 2-4	101.41	21.50			
75.00	150.10	33.51	4.48	73.50	95.50	Average	101.39	21.50	4.7156	88.71	3.71

Disks - 03 Months 2% Sodium Sulfate Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D03SS2A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.23	37.20	4.04	61.00	20.10	Axis 1-3	104.81	23.00			
50.00	150.25					Axis 2-4	104.81	23.00			
75.00	150.12	34.16	4.39	67.50	41.00	Average	104.81	23.00	4.5570	105.01	4.25

Sample: D03SS2A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.34	36.68	4.10	60.90	14.90	Axis 1-3	104.63	23.10			
50	150.43					Axis 2-4	104.61	23.20			
75	150.13	34.34	4.37	65.50	42.50	Average	104.62	23.15	4.5192	93.02	3.77

Sample: D03SS2A3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.18	36.10	4.16	66.00	29.50	Axis 1-3	103.55	23.10			
50	150.27					Axis 2-4	103.54	23.10			
75	150.02	34.21	4.39	74.50	111.30	Average	103.55	23.10	4.4825	85.00	3.48

Sample: D03SS2C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.13	35.76	4.20	63.00	21.00	Axis 1-3	105.20	23.20			
50.00	150.30					Axis 2-4	105.22	23.30			
75.00	150.09	33.70	4.45	71.50	66.70	Average	105.21	23.25	4.5252	95.61	3.85

Sample: D03SS2C2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.25	36.77	4.09	63.50	23.90	Axis 1-3	102.68	22.30			
50.00	150.23					Axis 2-4	102.65	22.30			
75.00	150.20	34.58	4.34	70.00	71.80	Average	102.67	22.30	4.6038	97.45	4.02

Sample: D03SS2C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.93	36.96	4.06	63.10	22.30	Axis 1-3	104.33	22.90			
50.00	149.95					Axis 2-4	104.31	22.90			
75.00	149.77	34.09	4.39	62.90	21.80	Average	104.32	22.90	4.5555	107.05	4.36

Disks - 03 Months 2% Sodium Sulfate Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D03SS2W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.05	36.18	4.15	66.50	26.00	Axis 1-3	96.26	21.50			
50.00	150.12					Axis 2-4	96.30	21.50			
75.00	149.87	33.65	4.45	73.00	72.80	Average	96.28	21.50	4.4781	90.12	3.97

Sample: D03SS2W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.08	36.05	4.16	67.00	29.00	Axis 1-3	96.76	21.50			
50.00	150.12					Axis 2-4	96.76	21.50			
75.00	150.00	34.45	4.35	71.50	64.70	Average	96.76	21.50	4.5005	85.99	3.77

Sample: D03SS2W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.42	36.78	4.09	64.00	25.00	Axis 1-3	99.05	22.20			
50.00	150.24					Axis 2-4	99.07	22.30			
75.00	150.32	34.33	4.38	64.50	37.40	Average	99.06	22.25	4.4521	82.64	3.53

Sample: D03SS2F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.39	35.82	4.20	69.50	33.20	Axis 1-3	100.43	22.40			
50.00	150.47					Axis 2-4	100.43	22.40			
75.00	150.07	34.49	4.35	64.50	33.50	Average	100.43	22.40	4.4835	104.29	4.40

Sample: D03SS2F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.23	36.13	4.16	65.20	27.50	Axis 1-3	98.32	21.20			
50.00	150.29					Axis 2-4	98.27	21.20			
75.00	149.93	33.71	4.45	69.50	86.00	Average	98.30	21.20	4.6366	86.38	3.73

Sample: D03SS2F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.46	36.39	4.13	68.00	46.50	Axis 1-3	100.13	22.00			
50.00	150.35					Axis 2-4	100.10	22.10			
75.00	150.34	34.40	4.37	66.50	56.50	Average	100.12	22.05	4.5404	87.90	3.72

Disks - 03 Months 5% Sodium Sulfate Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D03SS5A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.46					Axis 1-3	106.75	23.10			
50.00	150.36	37.59	4.00	56.40	7.20	Axis 2-4	106.59	23.00			
75.00	150.08	36.75	4.08	57.00	11.50	Average	106.67	23.05	4.6278	89.06	3.54

Sample: D03SS5A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	151.03	38.16	3.96	56.90	7.00	Axis 1-3	102.78	21.60			
50	151.15	1241.54	0.12	61.50	17.50	Axis 2-4	102.58	21.70			
75	151.2	36.62	4.13	52.50	7.50	Average	102.68	21.65	4.7427	88.65	3.64

Sample: D03SS5A3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.56	38.68	3.89	48.70	6.00	Axis 1-3	104.23	22.30			
50	150.75	36.86	4.09	56.90	9.70	Axis 2-4	104.29	22.30			
75	150.53	36.61	4.11	54.50	11.50	Average	104.26	22.30	4.6753	89.20	3.62

Sample: D03SS5C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.64					Axis 1-3	106.10	23.20			
50.00		37.18	4.05	58.8	6.1	Axis 2-4	106.10	23.30			
75.00	150.63					Average	106.10	23.25	4.5634	83.19	3.31

Sample: D03SS5C4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.40					Axis 1-3	104.50	22.50			
50.00		37.01	4.05	50.3	2.3	Axis 2-4	104.52	22.60			
75.00	149.69					Average	104.51	22.55	4.6346	92.74	3.77

Sample: D03SS5C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.48	36.44	4.13	52.7	8.2	Axis 1-3	102.02	22.00			
50.00		73.27	2.05	45.6	1.0	Axis 2-4	102.27	22.10			
75.00	150.07	37.22	4.03	61.0	23.0	Average	102.15	22.05	4.6324	85.49	3.55

Disks - 03 Months 5% Sodium Sulfate Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D03SS5W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.84					Axis 1-3	103.83	22.50			
50.00		55.19	2.73	51.0	2.5	Axis 2-4	104.00	22.70			
75.00	150.84					Average	103.92	22.60	4.5980	78.97	3.21

Sample: D03SS5W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.70					Axis 1-3	105.00	23.40			
50.00		37.20	4.05	60.2	10.0	Axis 2-4	104.86	23.40			
75.00	150.84					Average	104.93	23.40	4.4842	89.74	3.61

Sample: D03SS5W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.33	36.64	4.10	63.30	17.60	Axis 1-3	97.37	21.10			
50.00	150.37					Axis 2-4	97.33	21.10			
75.00	150.30	34.26	4.39	63.00	32.50	Average	97.35	21.10	4.6137	88.39	3.84

Sample: D03SS5F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.50	36.52	4.12	60.0	13.5	Axis 1-3	103.67	23.30			
50.00		37.63	4.00	54.9	10.9	Axis 2-4	103.09	23.30			
75.00	150.29	37.56	4.00	63.2	22.2	Average	103.38	23.30	4.4369	87.71	3.59

Sample: D03SS5F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.80					Axis 1-3	100.40	22.10			
50.00		37.36	4.03	51.4	2.5	Axis 2-4	100.40	22.00			
75.00	150.00					Average	100.40	22.05	4.5533	87.88	3.71

Sample: D03SS5F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.29	36.66	4.10	63.60	17.50	Axis 1-3	102.85	22.80			
50.00	150.33					Axis 2-4	102..85	22.90			
75.00	150.21	34.21	4.39	69.50	37.10	Average	102.85	22.85	4.5011	97.86	4.03

Disks - 24 Months Solution Exposure

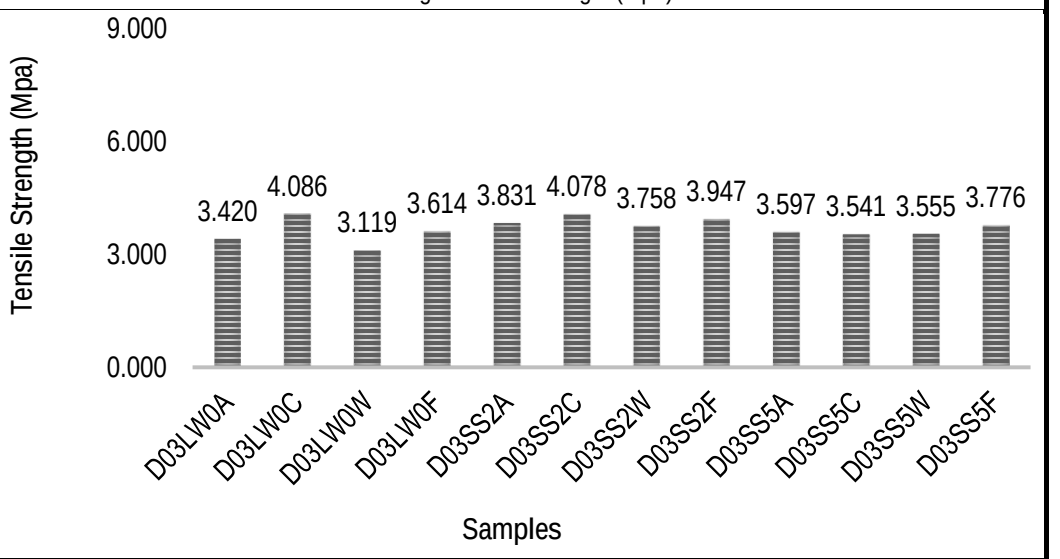
Statistical Evaluation for Difference Between Samples Variances and Means

Tensile Strength (Mpa) - Splitting Tensile Test

Sample Statistics

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
D03LW0A	3.420	0.181	5.280	0.013
D03LW0C	4.086	0.157	3.838	0.011
D03LW0W	3.119	0.032	1.032	0.002
D03LW0F	3.614	0.231	6.389	0.017
D03SS2A	3.831	0.387	10.105	0.028
D03SS2C	4.078	0.258	6.317	0.019
D03SS2W	3.758	0.220	5.850	0.016
D03SS2F	3.947	0.391	9.901	0.028
D03SS5A	3.597	0.053	1.476	0.004
D03SS5C	3.541	0.226	6.373	0.016
D03SS5W	3.555	0.323	9.075	0.023
D03SS5F	3.776	0.228	6.039	0.017

Average Tensile Strength (Mpa)



f-Test

Samples	D03LW0A	D03LW0C	D03LW0W	D03LW0F	D03SS2A	D03SS2C	D03SS2W	D03SS2F	D03SS5A	D03SS5C	D03SS5W	D03SS5F
D03LW0A	1.000	0.008	0.098	0.316	0.171	0.022	0.108	0.101	0.179	0.506	0.562	0.101
D03LW0C	0.860	1.000	0.007	0.043	0.350	0.965	0.111	0.599	0.007	0.027	0.062	0.124
D03LW0W	0.062	0.081	1.000	0.063	0.085	0.022	0.035	0.066	0.000	0.080	0.143	0.036
D03LW0F	0.759	0.631	0.038	1.000	0.450	0.081	0.476	0.272	0.907	0.719	0.809	0.436
D03SS2A	0.357	0.282	0.014	0.525	1.000	0.410	0.791	0.733	0.405	0.326	0.396	0.842
D03SS2C	0.659	0.541	0.031	0.891	0.614	1.000	0.178	0.654	0.078	0.053	0.093	0.203
D03SS2W	0.806	0.674	0.042	0.951	0.488	0.843	1.000	0.506	0.283	0.299	0.417	0.929
D03SS2F	0.352	0.277	0.013	0.517	0.990	0.606	0.481	1.000	0.259	0.194	0.251	0.547
D03SS5A	0.159	0.206	0.538	0.100	0.037	0.081	0.110	0.036	1.000	0.702	0.843	0.256
D03SS5C	0.781	0.651	0.040	0.977	0.507	0.869	0.974	0.500	0.105	1.000	0.957	0.275
D03SS5W	0.477	0.382	0.020	0.677	0.820	0.779	0.634	0.810	0.053	0.657	1.000	0.387
D03SS5F	0.771	0.642	0.039	0.987	0.515	0.879	0.964	0.508	0.103	0.990	0.666	1.000

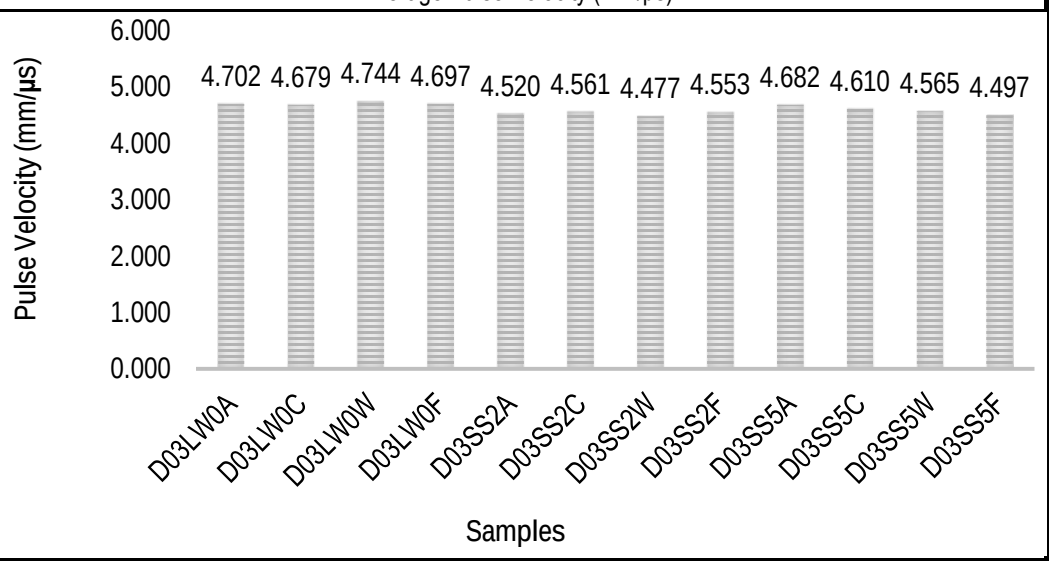
T-Test

Longitudinal Pulse Velocity (mm/µs) - 54 kHz Ultrasonic Pulse VelocityTest

Sample Statistics

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
D03LW0A	4.702	0.072	1.540	0.005
D03LW0C	4.679	0.017	0.361	0.001
D03LW0W	4.744	0.046	0.959	0.003
D03LW0F	4.697	0.040	0.851	0.003
D03SS2A	4.520	0.037	0.824	0.003
D03SS2C	4.561	0.040	0.870	0.003
D03SS2W	4.477	0.024	0.540	0.002
D03SS2F	4.553	0.077	1.699	0.006
D03SS5A	4.682	0.058	1.234	0.004
D03SS5C	4.610	0.040	0.878	0.003
D03SS5W	4.565	0.071	1.549	0.005
D03SS5F	4.497	0.058	1.296	0.004

Average Pulse Velocity (mm/µs)



f-Test

Samples	D03LW0A	D03LW0C	D03LW0W	D03LW0F	D03SS2A	D03SS2C	D03SS2W	D03SS2F	D03SS5A	D03SS5C	D03SS5W	D03SS5F
D03LW0A	1.000	0.623	0.442	0.921	0.018	0.042	0.007	0.072	0.727	0.128	0.080	0.019
D03LW0C	0.103	0.000	0.081	0.517	0.003	0.009	0.000	0.100	0.939	0.053	0.053	0.007
D03LW0W	0.566	0.242	0.000	0.249	0.003	0.006	0.001	0.021	0.217	0.019	0.021	0.004
D03LW0F	0.467	0.303	0.871	0.000	0.005	0.014	0.001	0.046	0.731	0.057	0.048	0.008
D03SS2A	0.418	0.342	0.802	0.929	0.000	0.253	0.172	0.531	0.015	0.046	0.377	0.604
D03SS2C	0.461	0.307	0.863	0.992	0.937	0.000	0.034	0.881	0.041	0.211	0.939	0.189
D03SS2W	0.201	0.656	0.440	0.536	0.593	0.542	0.000	0.177	0.005	0.008	0.110	0.609
D03SS2F	0.934	0.091	0.514	0.422	0.376	0.416	0.178	0.000	0.083	0.324	0.854	0.371
D03SS5A	0.778	0.158	0.766	0.648	0.587	0.641	0.298	0.716	0.000	0.153	0.091	0.018
D03SS5C	0.476	0.297	0.883	0.988	0.917	0.980	0.526	0.430	0.658	0.000	0.394	0.051
D03SS5W	0.976	0.108	0.586	0.485	0.435	0.479	0.210	0.910	0.801	0.494	0.000	0.267
D03SS5F	0.786	0.155	0.758	0.640	0.580	0.633	0.294	0.724	0.991	0.650	0.809	0.000

T-Test

Disks - 6 Months Limewater Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D06LW0A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Axis	Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.79	35.07	4.27	59.00	19.50	Axis 1-3	101.63	20.80			
50.00	149.96	36.84	4.07	56.20	6.00	Axis 2-4	101.90	20.80			
75.00	149.10	34.31	4.35	61.50	15.00	Average	101.77	20.80	4.8925	98.19	4.11

Sample: D06LW0A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.83	38.54	3.91	58.00	17.50	Axis 1-3	96.15	19.60			
50	150.88	35.50	4.25	66.00	23.00	Axis 2-4	95.52	19.60			
75	150.17	34.13	4.40	57.60	20.40	Average	95.84	19.60	4.8895	107.10	4.72

Sample: D06LW0A4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.72	37.82	3.99	52.10	7.50	Axis 1-3	99.24	20.50			
50	150.75	36.93	4.08	59.50	10.00	Axis 2-4	99.69	20.60			
75	149.72	34.49	4.34	58.90	16.00	Average	99.47	20.55	4.8401	107.80	4.59

Sample: D06LW0C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00						Axis 1-3					
50.00						Axis 2-4					
75.00						Average					#DIV/0!

Sample: D06LW0C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00						Axis 1-3					
50.00						Axis 2-4					
75.00						Average					#DIV/0!

Sample: D06LW0C4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00						Axis 1-3					
50.00						Axis 2-4					
75.00						Average					#DIV/0!

Disks - 6 Months Limewater Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D06LW0W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.43	35.15	4.28	62.30	21.60	Axis 1-3	100.11	20.80			
50.00	150.44					Axis 2-4	100.09	20.70			
75.00	149.98	35.82	4.19	57.70	12.20	Average	100.10	20.75	4.8241	108.13	4.58

Sample: D06LW0W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.93	35.72	4.20	61.20	22.50	Axis 1-3	102.27	21.20			
50.00	150.07					Axis 2-4	102.24	21.30			
75.00	150.60	34.38	4.38	68.00	40.10	Average	102.26	21.25	4.8120	99.52	4.13

Sample: D06LW0W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.27	35.01	4.29	70.00	32.70	Axis 1-3	96.20	20.20			
50.00	150.46					Axis 2-4	96.22	20.20			
75.00	150.05	33.79	4.44	67.30	32.70	Average	96.21	20.20	4.7629	121.67	5.36

Sample: D06LW0F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00						Axis 1-3					
50.00						Axis 2-4					
75.00						Average					#DIV/0!

Sample: D06LW0F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00						Axis 1-3					
50.00						Axis 2-4					
75.00						Average					#DIV/0!

Sample: D06LW0F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00						Axis 1-3					
50.00						Axis 2-4					
75.00						Average					#DIV/0!

Disks - 6 Months 2% Sodium Sulfate Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D06SS2A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.34	73.79	2.02	48.2	1.2	Axis 1-3	94.82	20.00			
50.00		36.77	4.07	58.5	12.4	Axis 2-4	94.78	20.10			
75.00	149.68	38.31	3.91	57.5	12.1	Average	94.80	20.05	4.7282	109.76	4.93

Sample: D06SS2A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	149.92	35.50	4.22	57.1	7.1	Axis 1-3	101.20	20.70			
50		38.89	3.86	50.1	3.8	Axis 2-4	101.20	20.70			
75	150.24	37.06	4.05	58.7	18.0	Average	101.20	20.70	4.8889	124.96	5.24

Sample: D06SS2A4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150	118.81	1.26	41.8	0.0	Axis 1-3	99.18	20.60			
50		36.69	4.09	59.1	14.0	Axis 2-4	99.72	20.60			
75	150.16	39.02	3.85	56.0	9.5	Average	99.45	20.60	4.8277	119.41	5.09

Sample: D06SS2C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.14	35.10	4.28	67.50	31.00	Axis 1-3	100.39	21.00			
50.00	150.26					Axis 2-4	100.32	21.10			
75.00	149.97	33.56	4.47	68.00	51.60	Average	100.36	21.05	4.7675	101.01	4.27

Sample: D06SS2C2D

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.67	36.44	4.13	61.00	22.60	Axis 1-3	96.53	20.30			
50.00	150.65					Axis 2-4	96.43	20.30			
75.00	150.49	33.65	4.47	65.00	40.60	Average	96.48	20.30	4.7527	111.11	4.87

Sample: D06SS2C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.28	36.36	4.13	63.20	14.50	Axis 1-3	100.80	21.20			
50.00	150.24					Axis 2-4	100.81	21.30			
75.00	150.10	34.43	4.36	63.50	20.90	Average	100.81	21.25	4.7438	101.59	4.27

Disks - 6 Months 2% Sodium Sulfate Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D06SS2W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.40	36.75	4.09	57.3	7.7	Axis 1-3	100.74	21.20			
50.00		37.12	4.06	53.0	5.9	Axis 2-4	100.68	21.20			
75.00	151.00	37.45	4.03	63.0	22.8	Average	100.71	21.20	4.7505	114.07	4.78

Sample: D06SS2W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.21	36.89	4.07	55.6	11.4	Axis 1-3	98.74	21.30			
50.00		36.69	4.09	55.5	5.8	Axis 2-4	98.31	21.40			
75.00	150.18	37.27	4.03	62.0	21.5	Average	98.53	21.35	4.6148	103.05	4.43

Sample: D06SS2W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.56					Axis 1-3	100.00	21.80			
50.00		35.70	4.22	63.5	16.6	Axis 2-4	100.20	21.80			
75.00	150.58					Average	100.10	21.80	4.5917	108.72	4.59

Sample: D06SS2F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.97	35.24	4.26	64.50	33.00	Axis 1-3	99.19	21.00			
50.00	149.91					Axis 2-4	99.13	21.00			
75.00	149.97	34.19	4.39	61.00	24.60	Average	99.16	21.00	4.7219	100.78	4.32

Sample: D06SS2F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy					Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00						Axis 1-3					
50.00						Axis 2-4					
75.00						Average					

Sample: D06SS2F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.26	36.00	4.17	65.60	26.50	Axis 1-3	102.61	21.80			
50.00	150.21					Axis 2-4	102.59	21.90			
75.00	150.05	34.87	4.30	64.50	26.00	Average	102.60	21.85	4.6957	104.39	4.31

Disks - 6 Months 5% Sodium Sulfate Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D06SS5A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.38	35.59	4.23	58.2	9.6	Axis 1-3	100.72	21.30			
50.00		37.01	4.07	58.7	23.5	Axis 2-4	101.00	21.40			
75.00	150.52	98.64	1.53	42.6	0.5	Average	100.86	21.35	4.7241	108.83	4.57

Sample: D06SS5A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.04	34.40	4.36	63.4	24.3	Axis 1-3	102.56	21.70			
50		37.04	4.06	59.7	16.4	Axis 2-4	102.84	21.70			
75	150.58	36.89	4.08	63.3	22.8	Average	102.70	21.70	4.7327	107.93	4.45

Sample: D06SS5A4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.08	43.74	3.43	53.20	6.50	Axis 1-3	97.2	20.60			
50	150.76	35.82	4.21	58.50	12.70	Axis 2-4	97.33	20.60			
75	150.42	38.92	3.86	52.10	4.20	Average	97.27	20.60	4.7216	109.93	4.78

Sample: D06SS5C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.17					Axis 1-3	96.71	20.30			
50.00	149.93					Axis 2-4	96.76	20.40			
75.00	150.07					Average	96.74	20.35	4.7536	107.81	4.73

Sample: D06SS5C2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.11	34.99	4.29	67.80	34.00	Axis 1-3	100.65	21.10			
50.00	150.23					Axis 2-4	100.86	21.00			
75.00	150.19	34.71	4.33	66.50	32.50	Average	100.76	21.05	4.7865	108.00	4.54

Sample: D06SS5C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.28					Axis 1-3	102.88	21.80			
50.00	150.05	36.22	4.15	59.00	10.50	Axis 2-4	102.98	21.80			
75.00	150.38					Average	102.93	21.80	4.7216	98.25	4.04

Disks - 6 Months 5% Sodium Sulfate Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D06SS5W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.39	36.69	4.10	59.40	14.40	Axis 1-3	99.54	21.30			
50.00	150.24					Axis 2-4	99.60	21.30			
75.00	150.28	34.85	4.31	72.00	78.40	Average	99.57	21.30	4.6746	101.99	4.34

Sample: D06SS5W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.89	36.00	4.16	67.70	33.50	Axis 1-3	98.94	20.50			
50.00	149.97					Axis 2-4	98.96	20.50			
75.00	149.86	33.80	4.43	70.40	91.60	Average	98.95	20.50	4.8268	106.72	4.58

Sample: D06SS5W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.64	35.87	4.20	66.50	35.60	Axis 1-3	99.63	20.90			
50.00	150.69					Axis 2-4	99.60	20.90			
75.00	150.05	34.29	4.38	65.00	22.00	Average	99.62	20.90	4.7663	101.49	4.31

Sample: D06SS5F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.34	35.32	4.26	63.50	25.00	Axis 1-3	101.65	21.20			
50.00	150.13					Axis 2-4	101.64	21.20			
75.00	149.96	34.42	4.36	66.00	42.50	Average	101.65	21.20	4.7946	103.79	4.33

Sample: D06SS5F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.21	35.51	4.23	62.50	27.70	Axis 1-3	100.30	20.80			
50.00	150.10					Axis 2-4	100.32	20.90			
75.00	150.22	34.21	4.39	70.00	68.50	Average	100.31	20.85	4.8110	107.47	4.54

Sample: D06SS5F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.70	35.60	4.23	63.1	14.1	Axis 1-3	101.18	21.10			
50.00		36.13	4.15	64.6	49.7	Axis 2-4	101.28	21.20			
75.00	149.18	38.55	3.87	58.0	10.0	Average	101.23	21.15	4.7863	109.74	4.60

Disks - 6 Months Solution Exposure

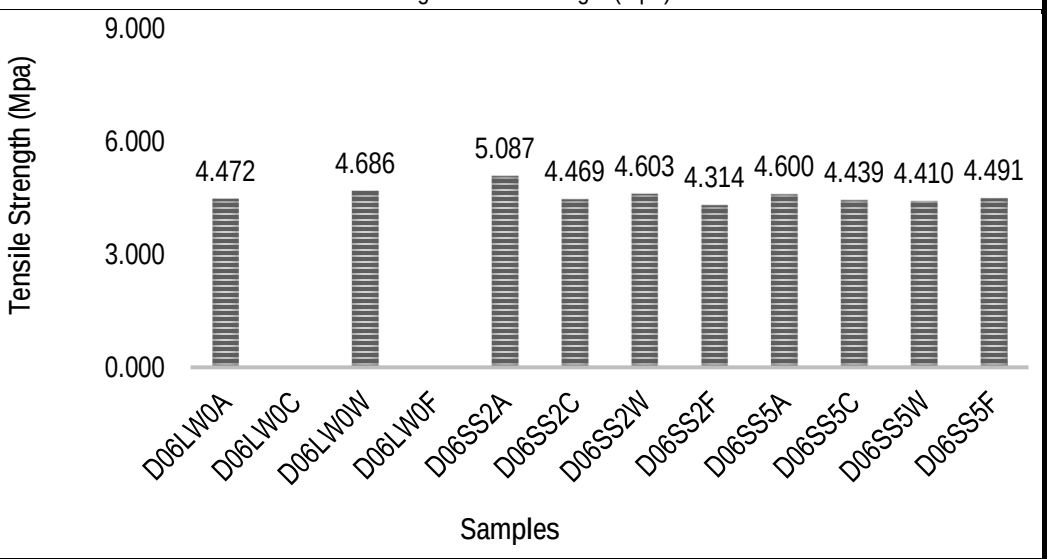
Statistical Evaluation for Difference Between Samples Variances and Means

Tensile Strength (Mpa) - Splitting Tensile Test

Sample Statistics

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
D06LW0A	4.472	0.325	7.261	0.024
D06LW0C				
D06LW0W	4.686	0.624	13.312	0.045
D06LW0F				
D06SS2A	5.087	0.154	3.027	0.011
D06SS2C	4.469	0.346	7.731	0.025
D06SS2W	4.603	0.176	3.824	0.013
D06SS2F	4.314	0.001	0.028	0.000
D06SS5A	4.600	0.169	3.669	0.012
D06SS5C	4.439	0.354	7.966	0.026
D06SS5W	4.410	0.148	3.360	0.011
D06SS5F	4.491	0.143	3.194	0.010

Average Tensile Strength (Mpa)



T-Test

Samples	D06LW0A	D06LW0C	D06LW0W	D06LW0F	D06SS2A	D06SS2C	D06SS2W	D06SS2F	D06SS5A	D06SS5C	D06SS5W	D06SS5F
D06LW0A	1.000		0.626		0.041	0.992	0.572	0.488	0.578	0.910	0.778	0.930
D06LW0C												
D06LW0W	0.426		1.000		0.341	0.626	0.836	0.410	0.829	0.582	0.497	0.626
D06LW0F												
D06SS2A	0.367		0.115		1.000	0.047	0.023	0.013	0.021	0.044	0.005	0.008
D06SS2C	0.938		0.469		0.331	1.000	0.581	0.518	0.587	0.920	0.798	0.924
D06SS2W	0.454		0.147		0.867	0.412	1.000	0.104	0.982	0.511	0.219	0.441
D06SS2F	0.005		0.003		0.011	0.005	0.010	1.000	0.099	0.603	0.380	0.166
D06SS5A	0.425		0.136		0.909	0.385	0.958	0.010	1.000	0.516	0.216	0.443
D06SS5C	0.915		0.486		0.319	0.977	0.397	0.005	0.371	1.000	0.902	0.824
D06SS5W	0.345		0.107		0.961	0.311	0.829	0.012	0.870	0.299	1.000	0.532
D06SS5F	0.327		0.100		0.929	0.294	0.798	0.012	0.839	0.283	0.968	1.000

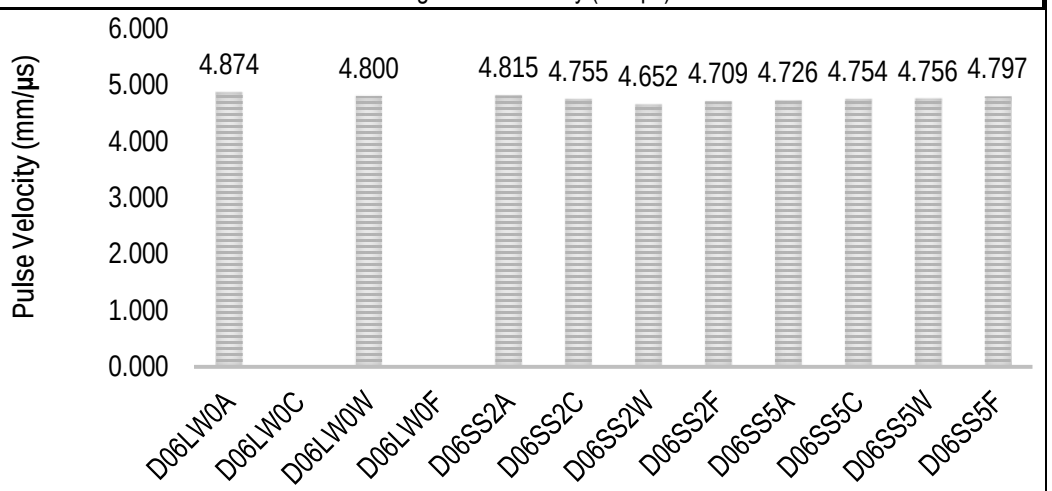
f-Test

Longitudinal Pulse Velocity (mm/µs) - 54 kHz Ultrasonic Pulse VelocityTest

Sample Statistics

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
D06LW0A	4.874	0.029	0.604	0.002
D06LW0C				
D06LW0W	4.800	0.032	0.676	0.002
D06LW0F				
D06SS2A	4.815	0.081	1.685	0.006
D06SS2C	4.755	0.012	0.252	0.001
D06SS2W	4.652	0.086	1.844	0.006
D06SS2F	4.709	0.019	0.394	0.001
D06SS5A	4.726	0.006	0.123	0.000
D06SS5C	4.754	0.032	0.683	0.002
D06SS5W	4.756	0.077	1.611	0.006
D06SS5F	4.797	0.013	0.263	0.001

Average Pulse Velocity (mm/µs)



T-Test

Samples	D06LW0A	D06LW0C	D06LW0W	D06LW0F	D06SS2A	D06SS2C	D06SS2W	D06SS2F	D06SS5A	D06SS5C	D06SS5W	D06SS5F
D06LW0A	1.000		0.042		0.301	0.003	0.013	0.006	0.011	0.009	0.067	0.014
D06LW0C												
D06LW0W	0.903		0.000		0.777	0.087	0.050	0.040	0.055	0.159	0.414	0.912
D06LW0F												
D06SS2A	0.233		0.276		0.000	0.326	0.076	0.182	0.198	0.293	0.412	0.744
D06SS2C	0.284		0.240		0.043	0.000	0.173	0.041	0.021	0.971	0.980	0.013
D06SS2W	0.211		0.250		0.944	0.038	0.000	0.447	0.274	0.128	0.194	0.097
D06SS2F	0.815		0.750		0.320	0.522	0.303	0.000	0.203	0.182	0.475	0.007
D06SS5A	0.076		0.063		0.010	0.384	0.009	0.172	0.000	0.276	0.571	0.001
D06SS5C	0.902		0.999		0.276	0.239	0.250	0.750	0.063	0.000	0.968	0.097
D06SS5W	0.257		0.304		0.943	0.048	0.888	0.338	0.012	0.304	0.000	0.449
D06SS5F	0.310		0.262		0.047	0.949	0.042	0.557	0.353	0.262	0.053	0.000

f-Test

Disks - 12 Months Limewater Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D12LW0A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Axis	Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.58	34.77	4.33	75.00	75.40	Axis 1-3	96.21	20.40			
50.00	150.53					Axis 2-4	96.14	20.40			
75.00	150.13	33.66	4.46	66.00	29.50	Average	96.18	20.40	4.7145	116.02	5.11

Sample: D12LW0A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.75	36.85	4.09	62.00	17.00	Axis 1-3	98.74	21.10			
50	150.67	37.25	4.04	60.80	10.90	Axis 2-4	98.79	21.00			
75	150.32	35.86	4.19	60.50	23.40	Average	98.77	21.05	4.6919	109.27	4.68

Sample: D12LW0A3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.66	35.36	4.26	66.00	40.50	Axis 1-3	98.72	20.20			
50	150.69	35.31	4.27	61.20	14.00	Axis 2-4	98.76	20.20			
75	150.51	33.21	4.53	61.10	26.90	Average	98.74	20.20	4.8881	118.41	5.07

Sample: D12LW0C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.82	38.53	3.91	56.30	13.00	Axis 1-3	99.23	20.6000			
50	150.07	35.63	4.21	62.00	13.50	Axis 2-4	98.98	20.5000			
75	150.47	33.57	4.48	58.00	23.00	Average	99.11	20.55	4.8226	114.66	4.90

Sample: D12LW0C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.58	35.96	4.19	58.50	12.70	Axis 1-3	97.61	20.1000			
50	150.9	35.81	4.21	61.20	12.90	Axis 2-4	97.98	20.1000			
75	150.61	32.98	4.57	63.70	35.00	Average	97.80	20.10	4.8654	108.28	4.68

Sample: D12LW0C4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.58	36.03	4.18	57.00	13.50	Axis 1-3	99.86	20.3000			
50	150.69	37.95	3.97	47.80	2.00	Axis 2-4	99.47	20.3000			
75	150.07	35.25	4.26	50.20	7.90	Average	99.67	20.30	4.9096	106.84	4.54

Field (F) Transport Mechanisms

Disks - 12 Months Limewater Solution Exposure: Wicking (W) and

Sample: D12LW0W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25						Axis 1-3					
50						Axis 2-4					
75						Average					

Sample: D12LW0W4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25						Axis 1-3					
50						Axis 2-4					
75						Average					

Sample: D12LW0W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25						Axis 1-3					
50						Axis 2-4					
75						Average					

Sample: D12LW0F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.24	39.00	3.85	55.20	9.60	Axis 1-3	98.98	21.3000			
50	150.15	36.86	4.07	59.60	10.00	Axis 2-4	98.97	21.3000			
75	150.07	34.56	4.34	63.50	27.70	Average	98.98	21.30	4.6467	100.19	4.29

Sample: D12LW0F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.44	37.17	4.05	61.10	22.00	Axis 1-3	99.58	21.4000			
50	150.58					Axis 2-4	99.59	21.4000			
75	150.31	34.21	4.39	64.00	33.00	Average	99.59	21.40	4.6535	110.80	4.71

Sample: D12LW0F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.34	35.85	4.19	62.50	20.30	Axis 1-3	95.26	20.2000			
50	150.46					Axis 2-4	95.34	20.2000			
75	150.23	33.46	4.49	68.00	53.60	Average	95.30	20.20	4.7178	101.06	4.49

Disks - 12 Months 2% Sodium Sulfate Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D12SS2A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.26	38.54	3.90	58.00	9.50	Axis 1-3	99.66	21.50			
50.00	150.08	37.22	4.03	53.10	4.10	Axis 2-4	99.64	21.50			
75.00	150.08	36.09	4.16	58.50	25.50	Average	99.65	21.50	4.6349	104.17	4.43

Sample: D12SS2A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.66	35.83	4.20	60.50	22.50	Axis 1-3	98.86	21.10			
50	150.86					Axis 2-4	98.85	21.10			
75	150.66	34.22	4.40	57.50	12.00	Average	98.86	21.10	4.6851	103.61	4.43

Sample: D12SS2A3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.86	37.84	3.99	55.20	13.00	Axis 1-3	98.63	20.90			
50	150.81	61.89	2.44	50.50	5.50	Axis 2-4	98.66	21.00			
75	150.2	34.72	4.33	55.90	14.70	Average	98.65	20.95	4.7086	110.60	4.74

Sample: D12SS2C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.30	36.35	4.13	60.90	21.50	Axis 1-3	96.63	20.60			
50.00	150.53					Axis 2-4	96.70	20.70			
75.00	150.09	33.35	4.50	70.10	47.00	Average	96.67	20.65	4.6811	106.90	4.68

Sample: D12SS2C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.28	35.76	4.20	67.00	26.90	Axis 1-3	95.19	20.40			
50.00	150.29					Axis 2-4	95.20	20.40			
75.00	150.23	36.42	4.12	51.50	9.00	Average	95.20	20.40	4.6664	98.40	4.38

Sample: D12SS2C4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	151.17	37.23	4.06	59.50	14.50	Axis 1-3	95.20	19.70			
50.00	151.08	36.91	4.09	58.30	9.50	Axis 2-4	95.11	19.70			
75.00	150.81	35.43	4.26	56.00	14.50	Average	95.16	19.70	4.8302	100.10	4.43

Disks - 12 Months 2% Sodium Sulfate Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D12SS2W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.38	34.99	4.30	68.50	35.20	Axis 1-3	101.16	21.60			
50.00	150.39					Axis 2-4	101.21	21.60			
75.00	149.97	34.16	4.39	66.00	44.80	Average	101.19	21.60	4.6845	117.41	4.92

Sample: D12SS2W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.80	34.97	4.28	69.50	56.10	Axis 1-3	98.77	20.70			
50.00	149.81					Axis 2-4	98.81	20.80			
75.00	149.79	34.33	4.36	60.00	15.50	Average	98.79	20.75	4.7610	88.28	3.80

Sample: D12SS2W4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.46	36.12	4.17	62.80	13.30	Axis 1-3	97.02	20.30			
50.00	150.46	37.23	4.04	48.10	2.90	Axis 2-4	92.02	20.30			
75.00	149.91	37.74	3.97	49.00	5.10	Average	94.52	20.30	4.6562	111.64	5.00

Sample: D12SS2F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.69	36.27	4.15	62.90	22.80	Axis 1-3	98.85	21.00			
50.00	150.57					Axis 2-4	98.89	21.00			
75.00	150.56	34.20	4.40	67.00	31.10	Average	98.87	21.00	4.7081	104.79	4.48

Sample: D12SS2F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.04	38.70	3.88	53.10	11.50	Axis 1-3	99.59	21.00			
50.00	149.84	37.80	3.96	56.30	5.50	Axis 2-4	99.58	21.00			
75.00	149.84	34.72	4.32	64.00	23.20	Average	99.59	21.00	4.7421	113.31	4.83

Sample: D12SS2F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.66	36.04	4.18	65.30	38.50	Axis 1-3	98.19	20.90			
50.00	150.63					Axis 2-4	98.09	20.90			
75.00	150.36	34.23	4.39	64.00	26.00	Average	98.14	20.90	4.6957	110.27	4.75

Disks - 12 Months 5% Sodium Sulfate Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D12SS5A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.80	42.94	3.51	58.00	14.00	Axis 1-3	99.03	20.40			
50.00	150.87	41.43	3.64	56.60	4.90	Axis 2-4	99.02	20.50			
75.00	150.79	35.93	4.20	64.50	34.40	Average	99.03	20.45	4.8423	116.20	4.95

Sample: D12SS5A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.58	43.36	3.47	52.10	6.90	Axis 1-3	98.64	20.50			
50	150.67	59.35	2.54	51.10	2.00	Axis 2-4	98.66	20.60			
75	150.72	40.45	3.73	59.30	19.00	Average	98.65	20.55	4.8005	108.25	4.64

Sample: D12SS5A4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.97	35.85	4.21	62.50	27.00	Axis 1-3	99.2	20.40			
50	150.78	40.09	3.76	57.00	4.00	Axis 2-4	99.24	20.50			
75	150.15	36.28	4.14	54.50	8.60	Average	99.22	20.45	4.8518	111.43	4.75

Sample: D12SS5C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.80	38.46	3.92	54.90	7.00	Axis 1-3	99.73	21.00			
50.00	150.94	39.19	3.85	45.90	1.00	Axis 2-4	99.59	20.80			
75.00	150.85	36.99	4.08	52.70	5.00	Average	99.66	20.90	4.7684	107.44	4.55

Sample: D12SS5C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.90	39.78	3.79	52.00	8.00	Axis 1-3	99.51	21.00			
50.00	150.96	37.15	4.06	57.10	7.00	Axis 2-4	99.50	20.90			
75.00	150.30	36.78	4.09	51.00	12.30	Average	99.51	20.95	4.7496	116.31	4.94

Sample: D12SS5C4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.59	42.81	3.52	49.40	5.50	Axis 1-3	99.97	21.70			
50.00	150.56	37.16	4.05	55.00	6.00	Axis 2-4	99.96	21.80			
75.00	150.36	38.81	3.87	51.50	6.50	Average	99.97	21.80	4.5856	111.09	4.70

Disks - 12 Months 5% Sodium Sulfate Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D12SS5W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00						Axis 1-3					
50.00						Axis 2-4					
75.00						Average					

Sample: D12SS5W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.19	36.81	4.08	60.50	12.00	Axis 1-3	99.27	21.00			
50.00	150.23					Axis 2-4	99.28	20.90			
75.00	150.24	34.02	4.42	66.20	31.50	Average	99.28	20.95	4.7387	116.94	4.99

Sample: D12SS5W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00						Axis 1-3					
50.00						Axis 2-4					
75.00						Average					

Sample: D12SS5F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.08	35.67	4.21	72.50	53.90	Axis 1-3	95.21	20.20			
50.00	150.18					Axis 2-4	95.22	20.30			
75.00	150.06	33.29	4.51	67.00	52.50	Average	95.22	20.25	4.7020	95.97	4.27

Sample: D12SS5F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.28	37.96	3.96	60.80	11.10	Axis 1-3	100.32	21.50			
50.00	150.35	36.76	4.09	53.70	6.40	Axis 2-4	100.33	21.50			
75.00	150.13	34.52	4.35	66.20	19.20	Average	100.33	21.50	4.6663	106.09	4.48

Sample: D12SS5F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.35	42.93	3.50	51.00	3.50	Axis 1-3	98.78	21.20			
50.00	150.37	36.16	4.16	63.30	17.50	Axis 2-4	98.79	21.20			
75.00	150.05					Average	98.79	21.20	4.6597	109.77	4.71

Disks - 12 Months Solution Exposure

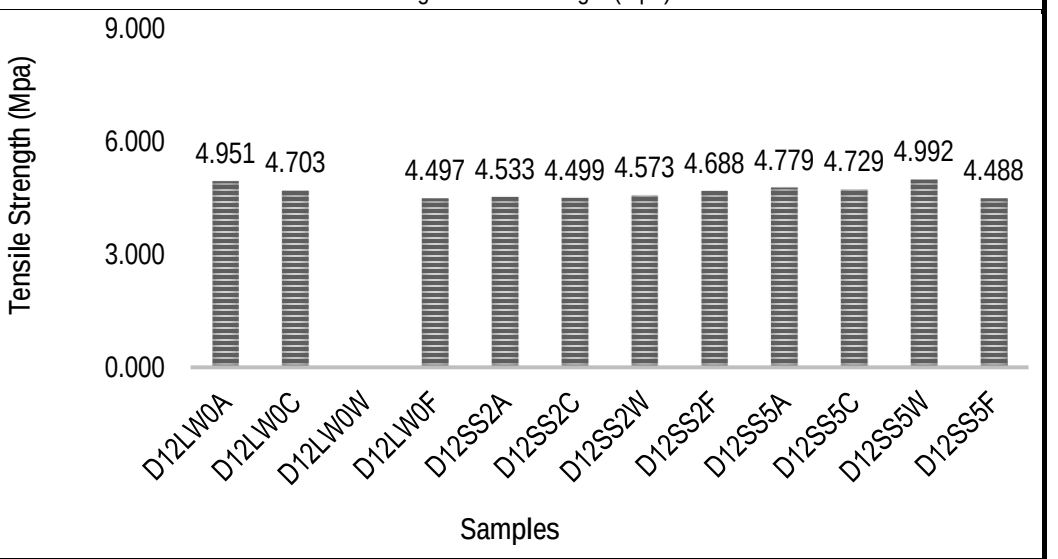
Statistical Evaluation for Difference Between Samples Variances and Means

Tensile Strength (Mpa) - Splitting Tensile Test

Sample Statistics

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
D12LW0A	4.951	0.237	4.794	0.017
D12LW0C	4.703	0.181	3.853	0.013
D12LW0W				
D12LW0F	4.497	0.208	4.631	0.015
D12SS2A	4.533	0.178	3.938	0.013
D12SS2C	4.499	0.162	3.606	0.012
D12SS2W	4.573	0.673	14.710	0.049
D12SS2F	4.688	0.184	3.932	0.013
D12SS5A	4.779	0.161	3.363	0.012
D12SS5C	4.729	0.196	4.135	0.014
D12SS5W	4.992			
D12SS5F	4.488	0.217	4.831	0.016

Average Tensile Strength (Mpa)



f-Test

Samples	D12LW0A	D12LW0C	D12LW0W	D12LW0F	D12SS2A	D12SS2C	D12SS2W	D12SS2F	D12SS5A	D12SS5C	D12SS5W	D12SS5F
D12LW0A	1.000	0.224		0.067	0.071	0.053	0.410	0.204	0.358	0.280		0.067
D12LW0C	0.736	1.000		0.265	0.311	0.220	0.773	0.924	0.617	0.874		0.257
D12LW0W												
D12LW0F	0.870	0.862		1.000	0.832	0.988	0.861	0.300	0.137	0.232		0.961
D12SS2A	0.723	0.985		0.847	1.000	0.822	0.926	0.354	0.151	0.268		0.795
D12SS2C	0.637	0.890		0.755	0.905	1.000	0.863	0.254	0.101	0.192		0.945
D12SS2W	0.221	0.135		0.175	0.132	0.110	1.000	0.789	0.633	0.718		0.845
D12SS2F	0.753	0.983		0.879	0.968	0.873	0.140	1.000	0.554	0.803		0.290
D12SS5A	0.629	0.881		0.746	0.895	0.990	0.108	0.864	1.000	0.751		0.135
D12SS5C	0.809	0.924		0.937	0.909	0.815	0.156	0.941	0.806	1.000		0.225
D12SS5W												
D12SS5F	0.910	0.823		0.960	0.808	0.718	0.188	0.839	0.709	0.897		1.000

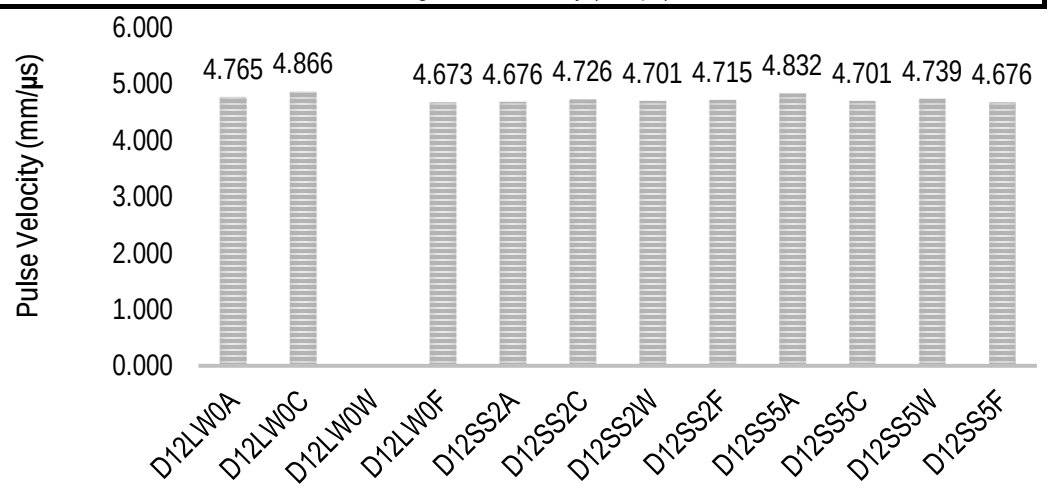
T-Test

Longitudinal Pulse Velocity (mm/µs) - 54 kHz Ultrasonic Pulse VelocityTest

Sample Statistics

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
D12LW0A	4.765	0.107	2.253	0.008
D12LW0C	4.866	0.043	0.894	0.003
D12LW0W				
D12LW0F	4.673	0.039	0.840	0.003
D12SS2A	4.676	0.038	0.805	0.003
D12SS2C	4.726	0.091	1.917	0.007
D12SS2W	4.701	0.054	1.153	0.004
D12SS2F	4.715	0.024	0.510	0.002
D12SS5A	4.832	0.027	0.565	0.002
D12SS5C	4.701	0.101	2.140	0.007
D12SS5W	4.739			
D12SS5F	4.676	0.023	0.487	0.002

Average Pulse Velocity (mm/µs)



f-Test

Samples	D12LW0A	D12LW0C	D12LW0W	D12LW0F	D12SS2A	D12SS2C	D12SS2W	D12SS2F	D12SS5A	D12SS5C	D12SS5W	D12SS5F
D12LW0A	1.000	0.205		0.235	0.248	0.656	0.407	0.511	0.356	0.495		0.286
D12LW0C	0.282	0.000		0.005	0.005	0.073	0.015	0.006	0.311	0.060		0.003
D12LW0W												
D12LW0F	0.236	0.898		0.000	0.917	0.403	0.511	0.184	0.005	0.671		0.906
D12SS2A	0.219	0.857		0.959	0.000	0.430	0.558	0.204	0.004	0.707		0.994
D12SS2C	0.832	0.374		0.316	0.294	0.000	0.699	0.854	0.125	0.768		0.407
D12SS2W	0.406	0.783		0.688	0.651	0.527	0.000	0.688	0.020	0.992		0.509
D12SS2F	0.096	0.468		0.546	0.580	0.132	0.329	0.000	0.005	0.825		0.109
D12SS5A	0.122	0.566		0.653	0.690	0.167	0.405	0.874	0.000	0.096		0.002
D12SS5C	0.935	0.315		0.264	0.246	0.896	0.450	0.108	0.137	0.000		0.710
D12SS5W												
D12SS5F	0.086	0.430		0.503	0.535	0.119	0.300	0.945	0.820	0.097		0.000

T-Test

Disks - 18 Months Limewater Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D18LW0A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Axis	Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.52	36.99	4.07	63.00	26.50	1.00	94.08	19.70			
50.00	150.64	204646.50	0.00	38.00	16.00	2.00	94.09	19.60			
75.00	150.64	34.30	4.39	62.50	33.50	Average	94.09	19.65	4.7880	94.65	4.25

Sample: D18LW0A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.38	39.09	3.85	51.40	4.00	Axis 1-3	98.14	20.70			
50	150.71	36.82	4.09	55.30	6.30	Axis 2-4	97.95	20.50			
75	150.49	36.44	4.13	55.30	13.70	Average	98.05	20.60	4.7595	99.37	4.29

Sample: D18LW0A3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.43	50.72	2.97	50.00	5.50	Axis 1-3	97.74	20.70			
50	150.67					Axis 2-4	97.65	20.50			
75	150.3	36.00	4.18	57.50	15.50	Average	97.70	20.60	4.7425	100.12	4.34

Sample: D18LW0C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.34	37.78	3.98	54.10	12.20	Axis 1-3	101.40	21.70			
50.00	150.25	37.78	3.98	60.00	9.70	Axis 2-4	101.27	21.80			
75.00	150.06	36.82	4.08	59.00	14.40	Average	101.34	21.75	4.6591	109.32	4.57

Sample: D18LW0C2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.34	42.55	3.53	52.20	7.00	Axis 1-3	100.45	21.40			
50.00	150.46	37.69	3.99	54.00	5.50	Axis 2-4	100.27	21.50			
75.00	150.27	36.47	4.12	60.00	18.00	Average	100.36	21.45	4.6788	103.01	4.35

Sample: D18LW0C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.36	38.30	3.93	53.50	6.50	Axis 1-3	99.95	21.00			
50.00	150.23	36.32	4.14	58.50	8.90	Axis 2-4	100.60	21.10			
75.00	150.31	34.06	4.41	65.70	29.00	Average	100.28	21.05	4.7637	103.10	4.35

Disks - 18 Months Limewater Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D18LW0W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.97	37.98	3.95	61.70	27.40	Axis 1-3	94.20	21.10			
50.00	150.02					Axis 2-4	94.22	21.10			
75.00	149.87	34.14	4.39	66.30	25.00	Average	94.21	21.10	4.4649	93.25	4.20

Sample: D18LW0W4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.29	36.63	4.10	63.00	19.50	Axis 1-3	95.51	21.00			
50.00	150.47					Axis 2-4	95.46	21.10			
75.00	150.00	33.99	4.41	65.50	39.50	Average	95.49	21.05	4.5361	102.75	4.56

Sample: D18LW0W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.09	36.64	4.10	64.00	40.00	Axis 1-3	98.19	21.70			
50.00	150.29					Axis 2-4	98.17	21.80			
75.00	150.09	34.17	4.39	69.50	84.30	Average	98.18	21.75	4.5140	91.79	3.96

Sample: D18LW0F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.11	36.95	4.06	66.50	31.00	Axis 1-3	97.95	20.90			
50.00	150.21					Axis 2-4	97.95	21.00			
75.00	150.43	34.46	4.37	69.50	53.00	Average	97.95	20.95	4.6754	82.41	3.56

Sample: D18LW0F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.24	32.03	4.69	60.40	13.00	Axis 1-3	97.63	20.90			
50.00	150.27					Axis 2-4	97.64	20.90			
75.00	149.97	30.41	4.93	58.00	16.20	Average	97.64	20.90	4.6715	98.04	4.26

Sample: D18LW0F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.96	38.46	3.90	58.00	10.50	Axis 1-3	96.64	21.20			
50.00	150.06					Axis 2-4	96.59	21.20			
75.00	150.39	35.00	4.30	66.50	26.00	Average	96.62	21.20	4.5573	77.56	3.40

Disks - 18 Months 2% Sodium Sulfate Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D18SS2A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.07	37.21	4.03	56.80	10.50	Axis 1-3	100.70	22.30			
50.00	150.13					Axis 2-4	100.74	22.30			
75.00	149.97	34.95	4.29	65.00	26.80	Average	100.72	22.30	4.5166	110.95	4.67

Sample: D18SS2A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.35	37.57	4.00	56.50	9.50	Axis 1-3	101.14	22.50			
50	150.18					Axis 2-4	101.04	22.50			
75	149.81	34.90	4.29	66.50	36.70	Average	101.09	22.50	4.4929	96.54	4.05

Sample: D18SS2A3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	149.99	37.04	4.05	58.50	17.00	Axis 1-3	98.55	21.90			
50	150.25					Axis 2-4	98.53	22.00			
75	150.05	34.71	4.32	69.00	47.50	Average	98.54	21.95	4.4893	90.44	3.89

Sample: D18SS2C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.81	37.74	3.97	58.10	13.20	Axis 1-3	95.06	21.40			
50.00	149.68					Axis 2-4	95.05	21.50			
75.00	149.65	35.51	4.21	63.40	19.00	Average	95.06	21.45	4.4315	96.33	4.31

Sample: D18SS2C2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	151.77	42.42	3.58	49.00	4.00	Axis 1-3	97.21	21.30			
50.00	151.85	38.86	3.91	54.90	7.00	Axis 2-4	97.61	21.30			
75.00	151.72	37.39	4.06	60.00	13.50	Average	97.41	21.30	4.5732	92.48	3.98

Sample: D18SS2C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.96	36.96	4.06	65.00	34.50	Axis 1-3	97.51	21.70			
50.00	150.02					Axis 2-4	97.53	21.80			
75.00	149.81	34.77	4.31	66.50	37.80	Average	97.52	21.75	4.4837	95.28	4.15

Disks - 18 Months 2% Sodium Sulfate Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D18SS2W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.02	37.03	4.05	64.50	39.50	Axis 1-3	96.94	21.90			
50.00	150.16					Axis 2-4	96.97	21.90			
75.00	149.83	35.19	4.26	67.00	43.80	Average	96.96	21.90	4.4272	90.51	3.96

Sample: D18SS2W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.22	37.27	4.03	60.70	16.80	Axis 1-3	À	20.90			
50.00	150.25					Axis 2-4	97.42	21.00			
75.00	150.04	34.76	4.32	68.00	43.70	Average	97.42	20.95	4.6501	92.52	4.03

Sample: D18SS2W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.25	36.95	4.07	65.50	25.50	Axis 1-3	100.56	21.50			
50.00	150.48					Axis 2-4	100.58	21.40			
75.00	150.08	35.46	4.23	67.50	41.50	Average	100.57	21.45	4.6886	89.66	3.78

Sample: D18SS2F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.12	36.46	4.12	59.50	15.50	Axis 1-3	97.10	21.60			
50.00	150.19					Axis 2-4	97.05	21.60			
75.00	149.87	34.62	4.33	65.00	37.00	Average	97.08	21.60	4.4942	97.57	4.26

Sample: D18SS2F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.31	38.16	3.94	58.00	15.00	Axis 1-3	97.50	21.60			
50.00	150.06					Axis 2-4	97.52	21.60			
75.00	150.25	34.44	4.36	65.90	36.20	Average	97.51	21.60	4.5144	90.57	3.94

Sample: D18SS2F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.30	39.06	3.85	57.00	6.90	Axis 1-3	99.22	21.30			
50.00	150.22					Axis 2-4	99.20	21.40			
75.00	150.26	37.16	4.04	62.30	23.70	Average	99.21	21.35	4.6468	87.52	3.74

Disks - 18 Months 5% Sodium Sulfate Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D18SS5A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	151.03	37.62	4.01	60.40	15.00	Axis 1-3	97.42	21.30			
50.00	151.27	40.02	3.78	62.00	20.60	Axis 2-4	97.44	21.50			
75.00	151.11	35.84	4.22	65.00	21.00	Average	97.43	21.40	4.5528	109.85	4.75

Sample: D18SS5A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	151.66	41.93	3.62	50.50	3.40	Axis 1-3	98.03	21.30			
50	151.92	37.38	4.06	57.10	7.50	Axis 2-4	97.88	21.20			
75	151.95	36.86	4.12	63.30	16.50	Average	97.96	21.25	4.6096	89.81	3.84

Sample: D18SS5A3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.73	41.58	3.63	51.10	4.00	Axis 1-3	102.54	22.00			
50	150.58	36.93	4.08	62.50	13.80	Axis 2-4	102.40	22.00			
75	150.59	37.18	4.05	59.60	12.30	Average	102.47	22.00	4.6577	104.35	4.30

Sample: D18SS5C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.62	43.38	3.47	50.00	4.90	Axis 1-3	102.25	21.80			
50.00	150.68	36.75	4.10	62.50	18.00	Axis 2-4	102.28	21.80			
75.00	150.47	36.94	4.07	56.40	10.50	Average	102.27	21.80	4.6911	109.55	4.53

Sample: D18SS5C2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.45	38.01	3.96	58.00	11.50	Axis 1-3	98.21	20.80			
50.00	150.56	36.60	4.11	56.90	8.80	Axis 2-4	98.17	20.70			
75.00	150.44	36.91	4.08	54.60	8.50	Average	98.19	20.75	4.7320	105.38	4.54

Sample: D18SS5C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.45	39.04	3.85	50.00	4.30	Axis 1-3	100.48	21.50			
50.00	150.47	36.78	4.09	61.30	10.50	Axis 2-4	100.58	21.60			
75.00	150.19	37.69	3.98	57.50	10.50	Average	100.53	21.55	4.6650	95.83	4.04

Disks - 18 Months 5% Sodium Sulfate Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D18SS5W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.08	36.97	4.06	64.00	23.00	Axis 1-3	97.73	21.80			
50.00	150.24					Axis 2-4	97.69	21.90			
75.00	149.96	35.17	4.26	66.50	46.60	Average	97.71	21.85	4.4719	97.81	4.25

Sample: D18SS5W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00						Axis 1-3					
50.00						Axis 2-4					
75.00						Average					

Sample: D18SS5W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.88	37.67	3.98	57.50	15.70	Axis 1-3	98.34	21.90			
50.00	149.83					Axis 2-4	98.38	22.00			
75.00	150.08	34.62	4.34	67.00	39.30	Average	98.36	21.95	4.4811	98.41	4.25

Sample: D18SS5F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.21	36.83	4.08	61.00	19.00	Axis 1-3	97.62	21.20			
50.00	150.03					Axis 2-4	97.58	21.20			
75.00	150.26	35.27	4.26	58.30	12.50	Average	97.60	21.20	4.6038	92.62	4.02

Sample: D18SS5F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.22	37.85	3.97	62.00	19.00	Axis 1-3	95.01	20.20			
50.00	150.21					Axis 2-4	95.02	20.20			
75.00	150.17	35.29	4.26	58.50	16.50	Average	95.02	20.20	4.7037	78.50	3.50

Sample: D18SS5F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.08	38.03	3.95	58.50	15.50	Axis 1-3	98.11	21.20			
50.00	150.04					Axis 2-4	98.12	21.20			
75.00	150.08	35.29	4.25	66.00	47.90	Average	98.12	21.20	4.6281	89.84	3.88

Disks - 12 Months Solution Exposure

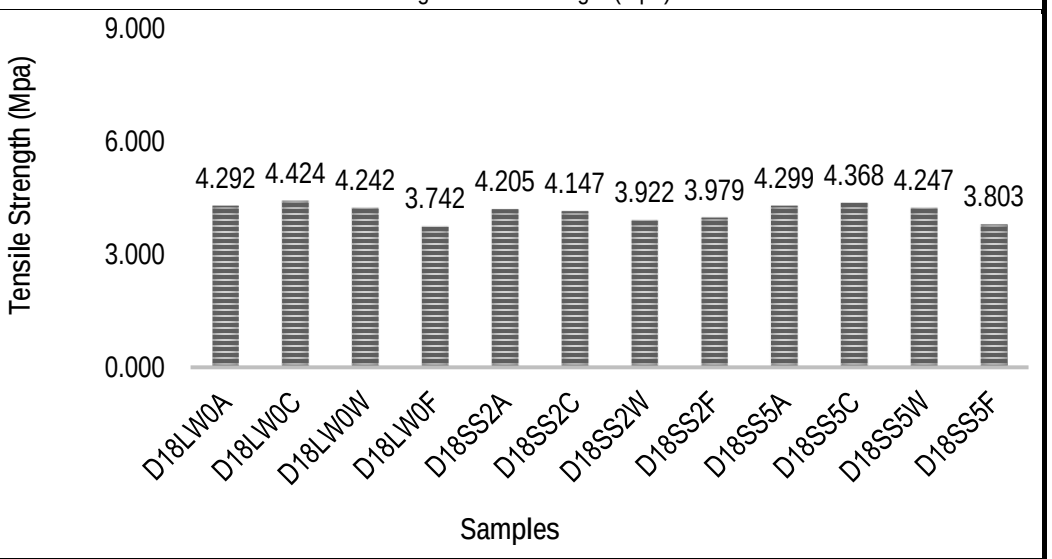
Statistical Evaluation for Difference Between Samples Variances and Means

Tensile Strength (Mpa) - Splitting Tensile Test

Sample Statistics

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
D18LW0A	4.292	0.042	0.977	0.003
D18LW0C	4.424	0.128	2.893	0.009
D18LW0W	4.242	0.300	7.062	0.022
D18LW0F	3.742	0.453	12.116	0.033
D18SS2A	4.205	0.413	9.821	0.030
D18SS2C	4.147	0.164	3.945	0.012
D18SS2W	3.922	0.129	3.300	0.009
D18SS2F	3.979	0.266	6.683	0.019
D18SS5A	4.299	0.453	10.528	0.033
D18SS5C	4.368	0.288	6.593	0.021
D18SS5W	4.247	0.002	0.039	0.000
D18SS5F	3.803	0.270	7.098	0.020

Average Tensile Strength (Mpa)



T-Test

Samples	D18LW0A	D18LW0C	D18LW0W	D18LW0F	D18SS2A	D18SS2C	D18SS2W	D18SS2F	D18SS5A	D18SS5C	D18SS5W	D18SS5F
D18LW0A	1.000	0.163	0.801	0.170	0.753	0.211	0.009	0.176	0.980	0.692	0.206	0.085
D18LW0C	0.194	1.000	0.387	0.066	0.430	0.082	0.009	0.059	0.669	0.773	0.139	0.023
D18LW0W	0.038	0.309	1.000	0.186	0.908	0.654	0.164	0.320	0.864	0.626	0.979	0.133
D18LW0F	0.017	0.148	0.608	1.000	0.261	0.220	0.545	0.478	0.207	0.114	0.193	0.851
D18SS2A	0.020	0.175	0.689	0.907	1.000	0.830	0.320	0.470	0.804	0.605	0.878	0.231
D18SS2C	0.123	0.759	0.459	0.230	0.271	1.000	0.135	0.406	0.613	0.311	0.399	0.133
D18SS2W	0.190	0.989	0.315	0.151	0.179	0.770	1.000	0.752	0.237	0.070	0.049	0.531
D18SS2F	0.049	0.376	0.881	0.512	0.586	0.549	0.383	1.000	0.351	0.161	0.223	0.466
D18SS5A	0.017	0.148	0.609	0.998	0.909	0.231	0.151	0.513	1.000	0.834	0.861	0.179
D18SS5C	0.042	0.330	0.961	0.575	0.654	0.488	0.336	0.920	0.576	1.000	0.542	0.068
D18SS5W	0.056	0.018	0.008	0.005	0.006	0.014	0.018	0.009	0.005	0.008	1.000	0.104
D18SS5F	0.047	0.367	0.896	0.523	0.599	0.537	0.374	0.985	0.525	0.935	0.009	1.000

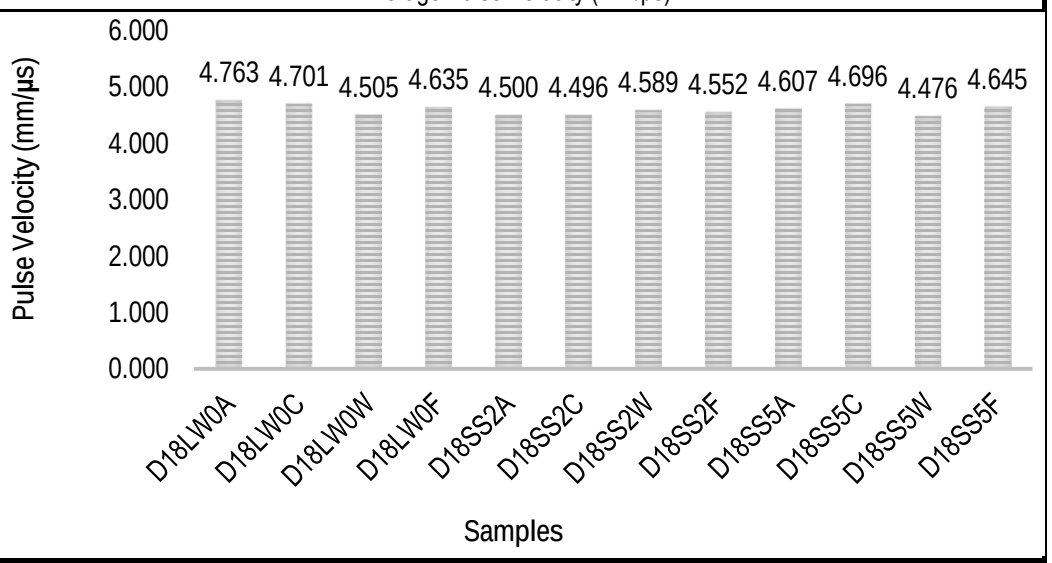
f-Test

Longitudinal Pulse Velocity (mm/µs) - 54 kHz Ultrasonic Pulse VelocityTest

Sample Statistics

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
D18LW0A	4.763	0.023	0.483	0.002
D18LW0C	4.701	0.056	1.182	0.004
D18LW0W	4.505	0.036	0.809	0.003
D18LW0F	4.635	0.067	1.448	0.005
D18SS2A	4.500	0.015	0.330	0.001
D18SS2C	4.496	0.072	1.595	0.005
D18SS2W	4.589	0.141	3.076	0.010
D18SS2F	4.552	0.083	1.822	0.006
D18SS5A	4.607	0.053	1.140	0.004
D18SS5C	4.696	0.034	0.720	0.002
D18SS5W	4.476	0.007	0.146	0.001
D18SS5F	4.645	0.052	1.122	0.004

Average Pulse Velocity (mm/µs)



T-Test

Samples	D18LW0A	D18LW0C	D18LW0W	D18LW0F	D18SS2A	D18SS2C	D18SS2W	D18SS2F	D18SS5A	D18SS5C	D18SS5W	D18SS5F
D18LW0A	1.000	0.145	0.000	0.035	0.000	0.004	0.162	0.013	0.009	0.046	0.000	0.023
D18LW0C	0.293	0.000	0.007	0.261	0.004	0.018	0.270	0.061	0.101	0.911	0.013	0.277
D18LW0W	0.571	0.601	0.000	0.042	0.823	0.857	0.377	0.422	0.051	0.003	0.374	0.019
D18LW0F	0.211	0.814	0.455	0.000	0.067	0.071	0.636	0.249	0.599	0.231	0.051	0.842
D18SS2A	0.586	0.133	0.284	0.093	0.000	0.942	0.389	0.390	0.027	0.001	0.140	0.010
D18SS2C	0.187	0.751	0.410	0.934	0.082	0.000	0.369	0.429	0.097	0.012	0.738	0.044
D18SS2W	0.052	0.268	0.125	0.369	0.022	0.410	0.000	0.717	0.845	0.269	0.302	0.550
D18SS2F	0.143	0.620	0.324	0.791	0.062	0.856	0.513	0.000	0.387	0.049	0.311	0.174
D18SS5A	0.322	0.944	0.650	0.760	0.148	0.698	0.243	0.573	0.000	0.069	0.045	0.419
D18SS5C	0.634	0.540	0.926	0.405	0.323	0.364	0.109	0.285	0.586	0.000	0.003	0.229
D18SS5W	0.393	0.166	0.252	0.137	0.595	0.129	0.065	0.111	0.175	0.271	0.000	0.023
D18SS5F	0.327	0.936	0.656	0.753	0.150	0.691	0.240	0.566	0.992	0.592	0.177	0.000

f-Test

Disks - 24 Months Limewater Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D24LW0A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy	Axis	Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.54	38.32	3.93	55.10	4.50	1.00	100.64	21.60			
50.00	150.95	36.60	4.12	59.90	6.90	2.00	100.78	21.60			
75.00	150.64	35.66	4.22	57.50	9.50	Average	100.71	21.60	4.6625	117.68	4.94

Sample: D24LW0A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.16					Axis 1-3	100.39	22.30			
50		36.72	4.09	60.5	8.3	Axis 2-4	100.49	22.40			
75	150.3					Average	100.44	22.35	4.4940	115.96	4.89

Sample: D24LW0A3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	151.23	31.38	4.82	65.00	22.80	Axis 1-3	98.06	21.30			
50						Axis 2-4	98.20	21.40			
75	151.7	32.98	4.60	58.80	13.50	Average	98.13	21.35	4.5963	109.36	4.68

Sample: D24LW0C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.48					Axis 1-3	98.44	21.60			
50.00		36.62	4.11	58.9	8.5	Axis 2-4	98.44	21.60			
75.00	150.69					Average	98.44	21.60	4.5574	102.02	4.38

Sample: D24LW0C2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.31					Axis 1-3	100.98	21.00			
50.00		37.18	4.04	52.2	3.6	Axis 2-4	101.15	21.00			
75.00	150.25					Average	101.07	21.00	4.8126	105.56	4.42

Sample: D24LW0C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	151.64	37.03	4.10	61.00	17.50	Axis 1-3	99.42	20.90			
50.00	151.60	37.78	4.01	57.10	6.50	Axis 2-4	99.36	21.00			
75.00	151.51	41.96	3.61	52.50	4.30	Average	99.39	20.95	4.7442	87.49	3.70

Disks - 24 Months Limewater Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D24LW0W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	151.47	32.21	4.70	65.50	26.50	Axis 1-3	99.36	21.60			
50.00		110049.15	0.00	46.00	12830.00	Axis 2-4	99.64	21.70			
75.00	151.62	35.77	4.24	58.50	14.50	Average	99.50	21.65	4.5958	112.81	4.76

Sample: D24LW0W4

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.20	36.27	4.14	57.8	7.3	Axis 1-3	99.50	21.80			
50.00		56.42	2.67	48.8	2.3	Axis 2-4	99.40	21.90			
75.00	150.76	45.51	3.31	53.0	5.5	Average	99.45	21.85	4.5515	106.57	4.53

Sample: D24LW0W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.92	37.43	4.03	54.5	10.4	Axis 1-3	98.86	21.20			
50.00		36.44	4.14	61.4	17.2	Axis 2-4	98.84	21.20			
75.00	150.52	37.95	3.97	57.0	11.8	Average	98.85	21.20	4.6627	101.67	4.34

Sample: D24LW0F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.86					Axis 1-3	99.28	21.00			
50.00		38.02	3.97	50.2	2.7	Axis 2-4	99.32	21.10			
75.00	150.74					Average	99.30	21.05	4.7173	100.15	4.26

Sample: D24LW0F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.67					Axis 1-3	100.72	21.40			
50.00		37.74	4.00	56.0	5.5	Axis 2-4	100.68	21.40			
75.00	151.48					Average	100.70	21.40	4.7056	96.26	4.03

Sample: D24LW0F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.58					Axis 1-3	99.35	20.70			
50.00		37.42	4.02	61.4	12.2	Axis 2-4	99.08	20.70			
75.00	150.47					Average	99.22	20.70	4.7930	94.57	4.03

Disks - 24 Months 2% Sodium Sulfate Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D24SS2A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.70					Axis 1-3	95.61	20.50			
50.00		35.54	4.24	62.8	11.3	Axis 2-4	95.80	20.50			
75.00	150.68					Average	95.71	20.50	4.6685	98.89	4.37

Sample: D24SS2A2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150	85.59	1.75	45.1	1.4	Axis 1-3	100.26	21.90			
50		37.65	3.99	54.2	7.3	Axis 2-4	100.15	22.00			
75	150.54	37.53	4.01	59.5	17.5	Average	100.21	21.95	4.5651	98.48	4.16

Sample: D24SS2A3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.48	36.63	4.11	58.8	6.6	Axis 1-3	97.72	20.80			
50		39.98	3.76	51.9	4.8	Axis 2-4	97.46	21.00			
75	150.48	44.33	3.39	57.2	9.9	Average	97.59	20.90	4.6694	88.61	3.84

Sample: D24SS2C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.20	36.40	4.13	61.7	11.7	Axis 1-3	99.12	21.70			
50.00		45.58	3.30	48.8	6.5	Axis 2-4	99.10	21.50			
75.00	150.60	39.71	3.79	55.8	8.7	Average	99.11	21.60	4.5884	111.36	4.76

Sample: D24SS2C2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.99					Axis 1-3	100.74	21.90			
50.00		105.60	1.43	40.0	0.0	Axis 2-4	100.40	22.20			
75.00	150.60					Average	100.57	22.05	4.5610	98.48	4.13

Sample: D24SS2C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.73	35.75	4.19	64.50	20.50	Axis 1-3	100.51	21.70			
50.00	149.69					Axis 2-4	100.51	21.80			
75.00	149.93	34.59	4.33	69.30	51.50	Average	100.51	21.75	4.6211	101.92	4.31

Disks - 24 Months 2% Sodium Sulfate Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D24SS2W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.57	37.17	4.05	51.0	3.1	Axis 1-3	99.25	21.50			
50.00		52.62	2.86	44.6	0.5	Axis 2-4	99.35	21.50			
75.00	150.49	40.06	3.76	54.3	8.5	Average	99.30	21.50	4.6186	96.26	4.10

Sample: D24SS2W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.92	36.25	4.16	61.5	18.9	Axis 1-3	98.74	22.00			
50.00		57.90	2.61	48.7	0.8	Axis 2-4	98.84	22.10			
75.00	151.12	38.58	3.92	54.5	9.0	Average	98.79	22.05	4.4803	94.89	4.05

Sample: D24SS2W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.22	35.08	4.28	65.4	23.0	Axis 1-3	98.29	21.70			
50.00		37.67	3.99	59.8	10.2	Axis 2-4	98.41	21.80			
75.00	150.50	41.29	3.64	52.3	8.5	Average	98.35	21.75	4.5218	97.42	4.19

Sample: D24SS2F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.96					Axis 1-3	97.03	20.90			
50.00		38.19	3.95	52.4	3.3	Axis 2-4	96.99	20.90			
75.00	150.81					Average	97.01	20.90	4.6416	96.69	4.21

Sample: D24SS2F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.40	37.16	4.05	62.0	18.5	Axis 1-3	99.42	22.30			
50.00		37.89	3.96	59.2	12.1	Axis 2-4	99.52	22.50			
75.00	150.00	62.33	2.41	50.8	3.6	Average	99.47	22.40	4.4406	98.92	4.22

Sample: D24SS2F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.82					Axis 1-3	96.76	20.70			
50.00		43.76	3.45	48.5	2.2	Axis 2-4	96.77	20.70			
75.00	151.24					Average	96.77	20.70	4.6746	88.53	3.86

Disks - 24 Months 5% Sodium Sulfate Solution Exposure: Diffusion (A) and Cyclic Sorption and Evaporation (C) Transport Mechanisms

Sample: D24SS5A1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	151.59	38.75	3.91	52.90	7.50	Axis 1-3	100.04	21.70			
50.00	151.82	38.91	3.90	55.20	6.00	Axis 2-4	100.10	21.80			
75.00	151.73	37.18	4.08	61.70	29.20	Average	100.07	21.75	4.6009	106.45	4.46

Sample:

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25						Axis 1-3					
50						Axis 2-4					
75						Average					

Sample: D24SS5A3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25	150.69	40.32	3.74	50.4	2.1	Axis 1-3	100.88	22.00			
50		64.77	2.33	41.8	0.5	Axis 2-4	100.84	22.10			
75	150.95	83.72	1.80	48.5	3.2	Average	100.86	22.05	4.5741	109.63	4.59

Sample: D24SS5C1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.04	36.58	4.10	53.5	3.4	Axis 1-3	101.39	21.80			
50.00		53.94	2.78	47.1	0.5	Axis 2-4	101.53	21.80			
75.00	150.21	37.01	4.06	57.0	9.9	Average	101.46	21.80	4.6541	110.82	4.63

Sample: D24SS5C2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.25	36.49	4.12	53.1	5.8	Axis 1-3	101.59	22.20			
50.00		39.77	3.78	53.8	4.5	Axis 2-4	101.50	22.00			
75.00	150.50	39.28	3.83	51.5	4.0	Average	101.55	22.10	4.5948	103.26	4.31

Sample: D24SS5C3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.32	37.21	4.04	48.6	1.4	Axis 1-3	99.54	21.70			
50.00		62.96	2.39	43.5	0.6	Axis 2-4	99.42	21.80			
75.00	150.44	57.57	2.61	55.0	6.5	Average	99.48	21.75	4.5738	103.41	4.40

Disks - 24 Months 5% Sodium Sulfate Solution Exposure: Wicking (W) and Field (F) Transport Mechanisms

Sample: D24SS5W1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.72	34.95	4.28	62.3	20.0	Axis 1-3	101.48	21.70			
50.00		37.20	4.01	57.4	9.1	Axis 2-4	101.16	21.90			
75.00	148.94	41.05	3.63	53.0	3.5	Average	101.32	21.80	4.6477	99.37	4.18

Sample: D24SS5W2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.24	98.59	1.52	43.2	0.0	Axis 1-3	97.36	21.40			
50.00		142.10	1.06	41.0	0.0	Axis 2-4	97.28	21.50			
75.00	149.92	98.37	1.52	44.0	0.5	Average	97.32	21.45	4.5371	91.36	3.98

Sample: D24SS5W3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	151.21	41.55	3.64	49.10	3.00	Axis 1-3	100.36	22.10			
50.00	151.47	38.77	3.91	53.50	4.20	Axis 2-4	100.54	22.10			
75.00	150.97	36.52	4.13	62.50	15.50	Average	100.45	22.10	4.5452	97.56	4.09

Sample: D24SS5F1

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00						Axis 1-3					
50.00						Axis 2-4					
75.00						Average					

Sample: D24SS5F2

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	150.98	86.34	1.75	44.3	0.4	Axis 1-3	98.00	22.20			
50.00		51.57	2.92	48.5	1.3	Axis 2-4	98.23	22.30			
75.00	150.51	89.65	1.68	42.1	0.0	Average	98.12	22.25	4.4097	90.06	3.88

Sample: D24SS5F3

Ultra Sonic Pulse Emission Test (300 kHz)						Ultra Sonic Pulse Velocity Test (54 kHz)				Splitting Tension Test	
Diametral Axis						Longitudinal Axis					
Height (mm)	Diameter (mm)	Time (µs)	Velocity (mm/µs)	Amplitude (dB)	Energy		Lenght (mm)	Time (µs)	Velocity (mm/µs)	Splitting Tensile Load (kN)	Splitting Tensile Strength (MPa)
25.00	149.82	36.42	4.11	61.50	20.20	Axis 1-3	99.03	22.10			
50.00	149.17					Axis 2-4	99.01	22.20			
75.00	148.96	34.43	4.33	65.50	40.40	Average	99.02	22.15	4.4704	75.62	3.26

Disks - 24 Months Solution Exposure

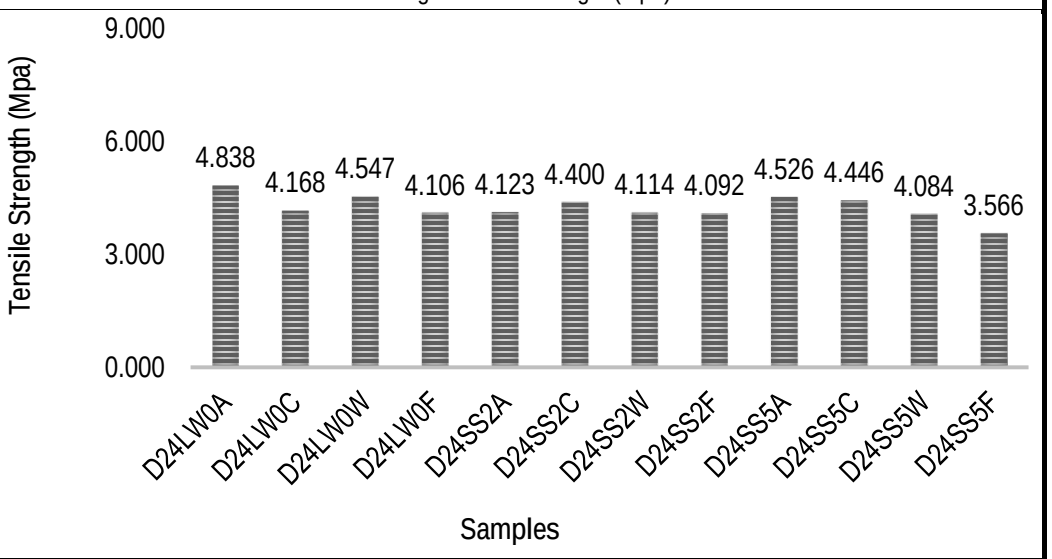
Statistical Evaluation for Difference Between Samples Variances and Means

Tensile Strength (Mpa) - Splitting Tensile Test

Sample Statistics

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
D24LW0A	4.838	0.135	2.783	0.010
D24LW0C	4.168	0.408	9.795	0.030
D24LW0W	4.547	0.210	4.609	0.015
D24LW0F	4.106	0.132	3.207	0.010
D24SS2A	4.123	0.264	6.410	0.019
D24SS2C	4.400	0.321	7.286	0.023
D24SS2W	4.114	0.074	1.787	0.005
D24SS2F	4.092	0.204	4.995	0.015
D24SS5A	4.526	0.088	1.943	0.006
D24SS5C	4.446	0.168	3.779	0.012
D24SS5W	4.084	0.100	2.439	0.007
D24SS5F	3.566	0.439	12.304	0.039

Average Tensile Strength (Mpa)



f-Test

Samples	D24LW0A	D24LW0C	D24LW0W	D24LW0F	D24SS2A	D24SS2C	D24SS2W	D24SS2F	D24SS5A	D24SS5C	D24SS5W	D24SS5F
D24LW0A	1.000	0.054	0.113	0.003	0.014	0.095	0.001	0.006	0.067	0.034	0.001	0.015
D24LW0C	0.196	1.000	0.226	0.815	0.882	0.482	0.834	0.789	0.329	0.336	0.748	0.214
D24LW0W	0.584	0.417	1.000	0.037	0.095	0.543	0.028	0.055	0.906	0.550	0.026	0.039
D24LW0F	0.978	0.188	0.566	1.000	0.923	0.215	0.927	0.928	0.030	0.051	0.831	0.121
D24SS2A	0.412	0.591	0.772	0.398	1.000	0.313	0.957	0.879	0.141	0.149	0.821	0.164
D24SS2C	0.300	0.763	0.599	0.289	0.809	1.000	0.207	0.234	0.641	0.837	0.178	0.087
D24SS2W	0.459	0.063	0.219	0.475	0.144	0.100	1.000	0.869	0.011	0.035	0.694	0.324
D24SS2F	0.605	0.401	0.975	0.587	0.748	0.578	0.229	1.000	0.072	0.082	0.953	0.154
D24SS5A	0.838	0.301	0.569	0.854	0.458	0.381	0.709	0.582	1.000	0.591	0.015	0.094
D24SS5C	0.782	0.290	0.783	0.761	0.576	0.431	0.321	0.806	0.694	1.000	0.033	0.044
D24SS5W	0.707	0.112	0.369	0.728	0.249	0.176	0.705	0.384	0.941	0.520	1.000	0.123
D24SS5F	0.165	0.790	0.343	0.159	0.478	0.609	0.054	0.330	0.252	0.241	0.096	1.000

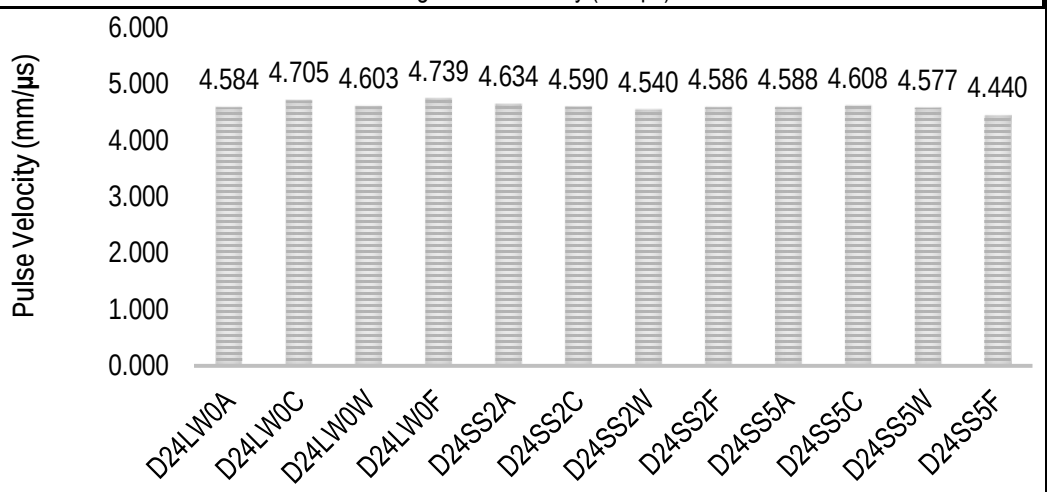
T-Test

Longitudinal Pulse Velocity (mm/µs) - 54 kHz Ultrasonic Pulse VelocityTest

Sample Statistics

Samples	Average	Standard Deviation	Coeff. of Variation	Confi-dence
D24LW0A	4.584	0.085	1.852	0.006
D24LW0C	4.705	0.132	2.808	0.010
D24LW0W	4.603	0.056	1.217	0.004
D24LW0F	4.739	0.047	1.001	0.003
D24SS2A	4.634	0.060	1.293	0.004
D24SS2C	4.590	0.030	0.656	0.002
D24SS2W	4.540	0.071	1.563	0.005
D24SS2F	4.586	0.127	2.762	0.009
D24SS5A	4.588	0.019	0.413	0.001
D24SS5C	4.608	0.042	0.904	0.003
D24SS5W	4.577	0.062	1.347	0.004
D24SS5F	4.440	0.043	0.968	0.004

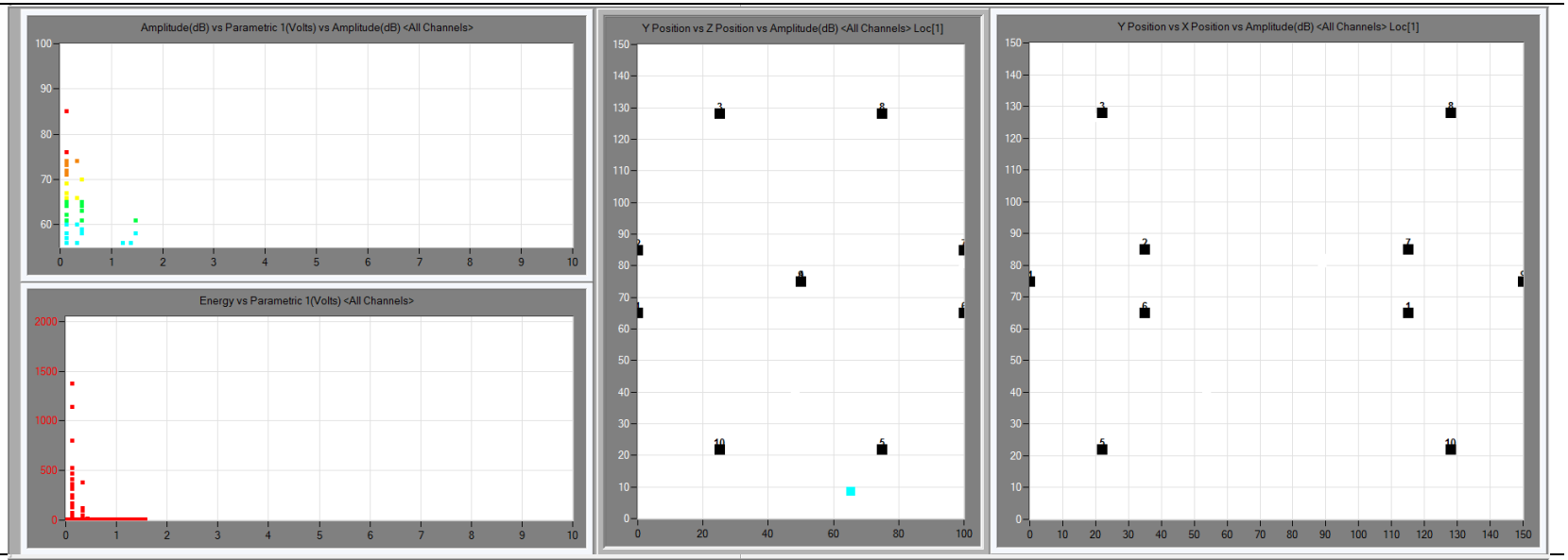
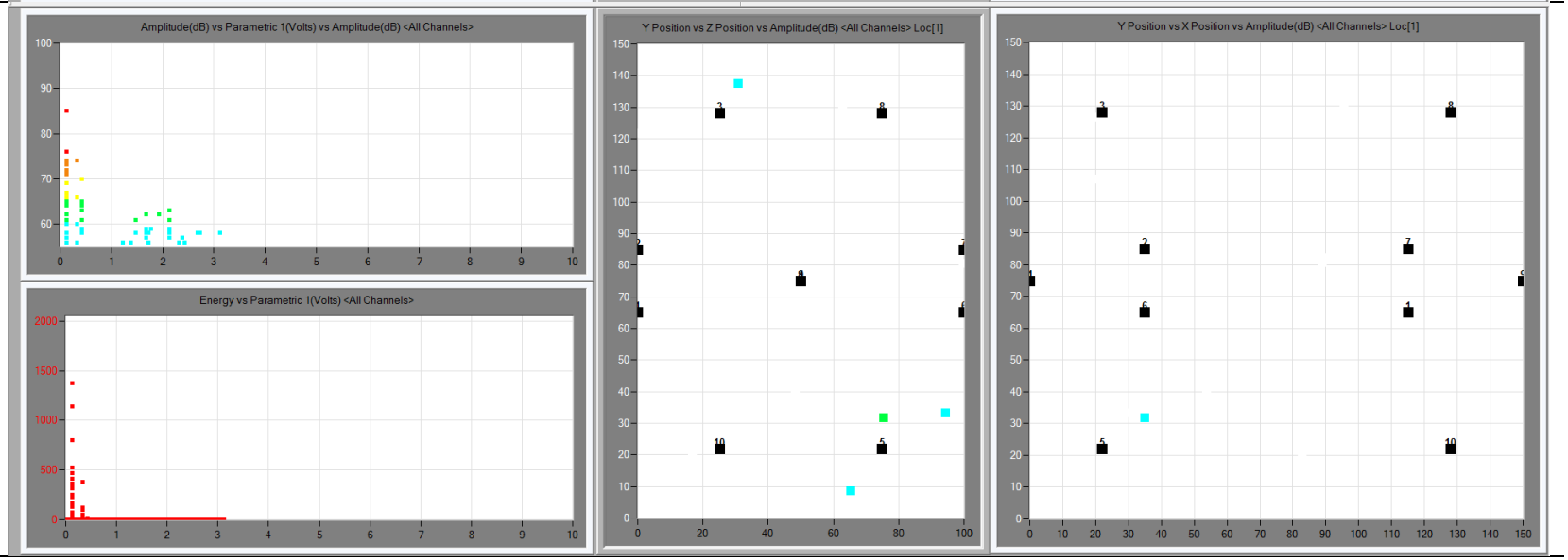
Average Pulse Velocity (mm/µs)

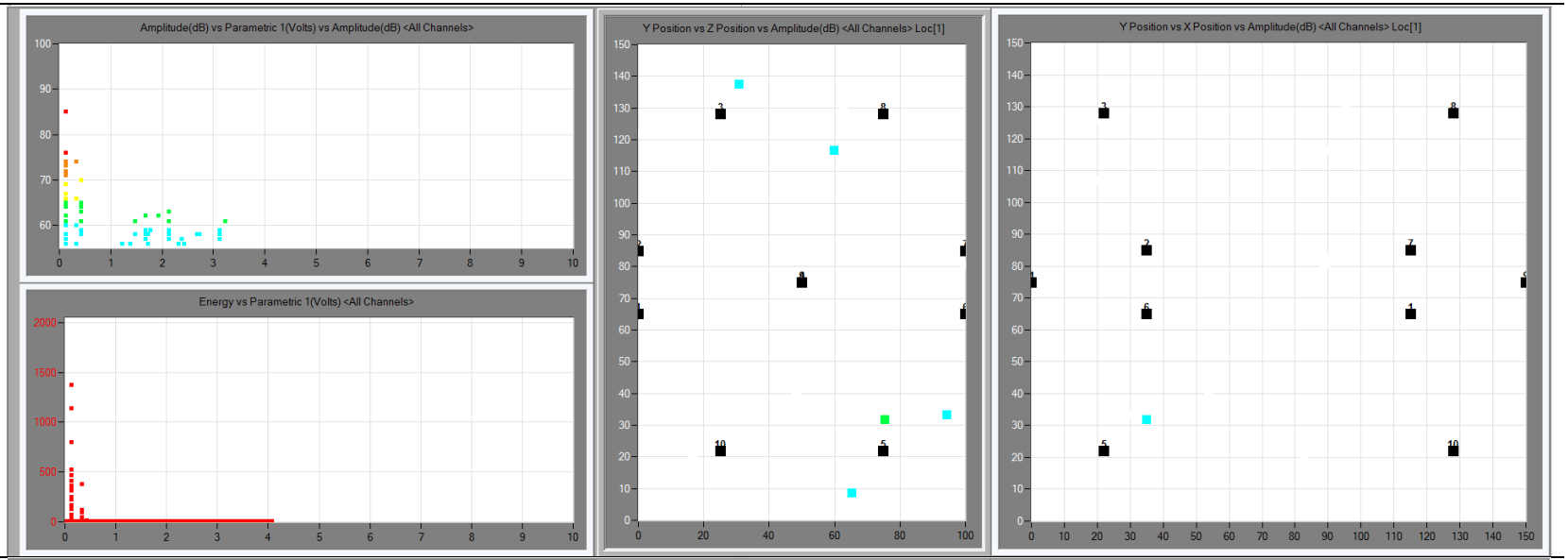
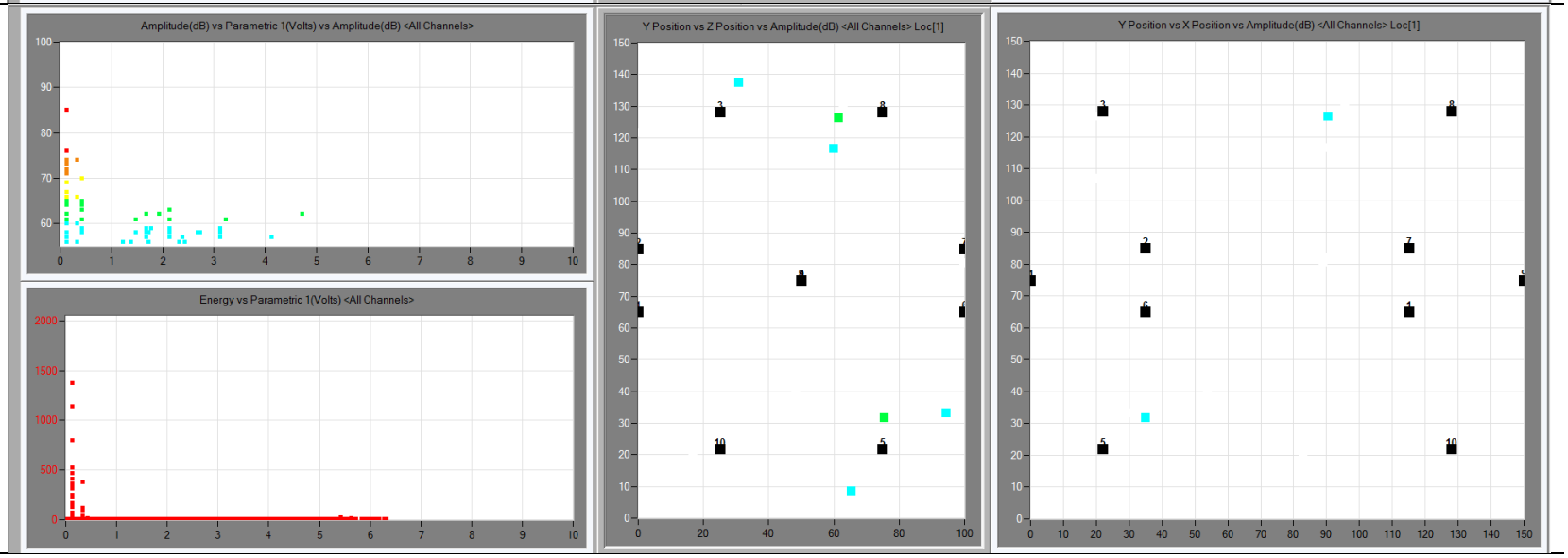


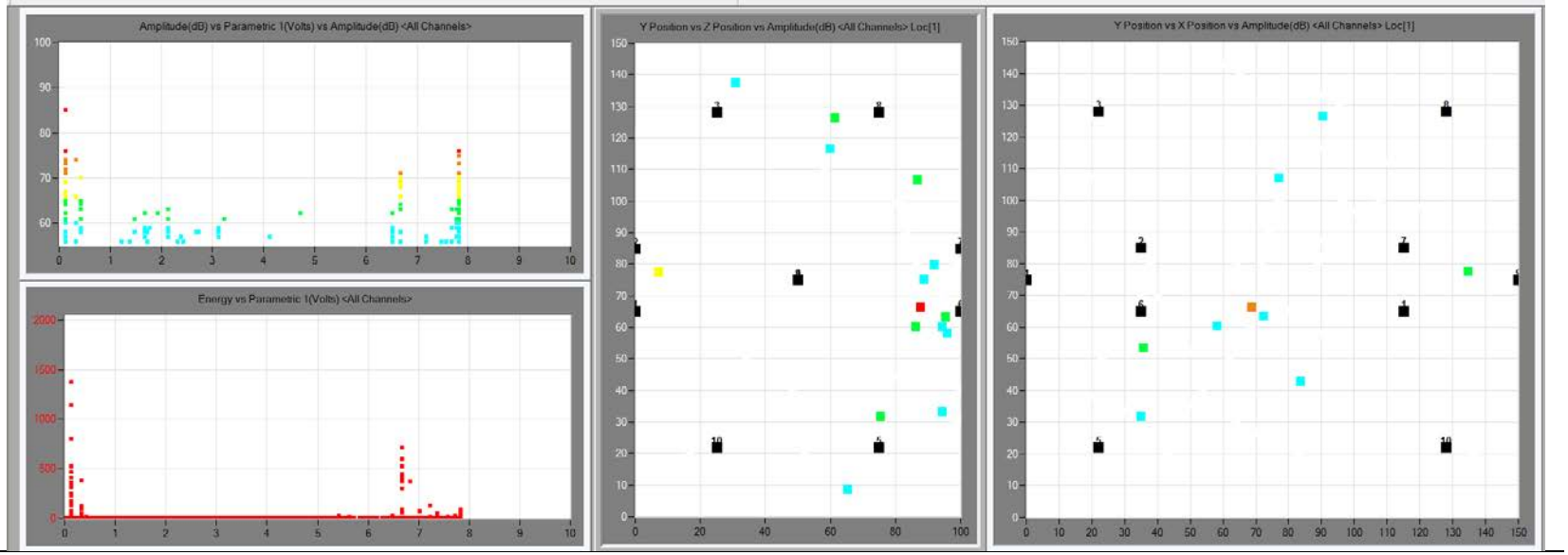
f-Test

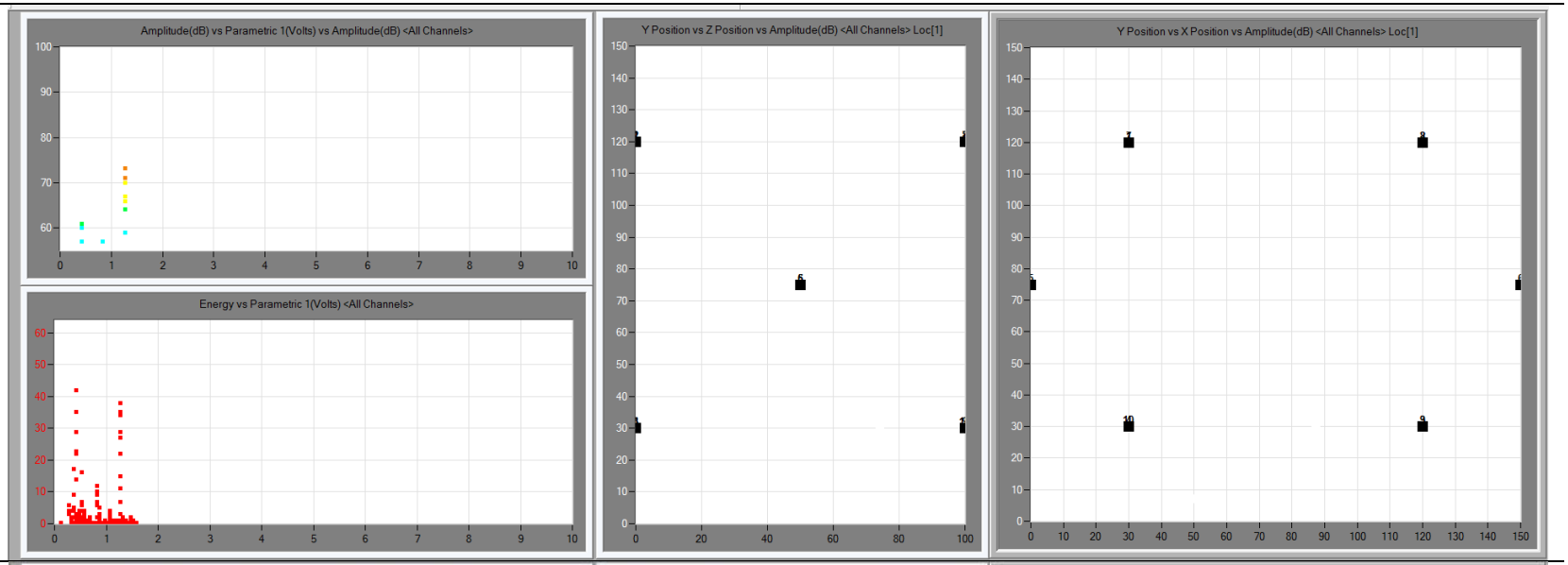
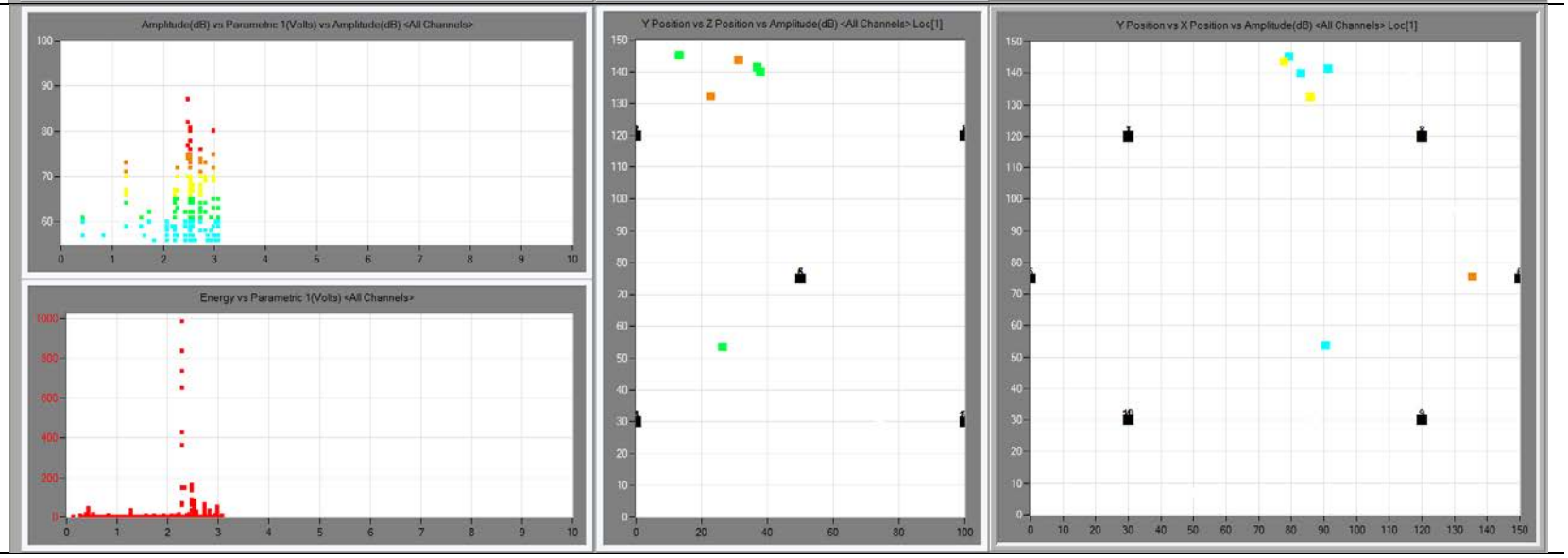
Samples	D24LW0A	D24LW0C	D24LW0W	D24LW0F	D24SS2A	D24SS2C	D24SS2W	D24SS2F	D24SS5A	D24SS5C	D24SS5W	D24SS5F
D24LW0A	1.000	0.255	0.761	0.051	0.451	0.914	0.529	0.988	0.962	0.691	0.907	0.121
D24LW0C	0.585	0.000	0.288	0.697	0.448	0.217	0.130	0.323	0.322	0.291	0.203	0.079
D24LW0W	0.606	0.305	0.000	0.033	0.548	0.738	0.293	0.835	0.737	0.922	0.609	0.041
D24LW0F	0.476	0.228	0.835	0.000	0.077	0.010	0.016	0.122	0.026	0.023	0.023	0.006
D24SS2A	0.665	0.341	0.932	0.770	0.000	0.318	0.154	0.579	0.382	0.560	0.310	0.030
D24SS2C	0.223	0.099	0.449	0.575	0.403	0.000	0.325	0.955	0.921	0.590	0.750	0.018
D24SS2W	0.823	0.448	0.767	0.617	0.832	0.305	0.000	0.617	0.444	0.229	0.539	0.180
D24SS2F	0.620	0.958	0.327	0.246	0.366	0.107	0.478	0.000	0.985	0.790	0.918	0.231
D24SS5A	0.311	0.202	0.465	0.543	0.436	0.812	0.371	0.210	0.000	0.582	0.832	0.047
D24SS5C	0.388	0.181	0.713	0.871	0.652	0.686	0.513	0.195	0.612	0.000	0.512	0.022
D24SS5W	0.690	0.358	0.904	0.744	0.972	0.385	0.860	0.383	0.424	0.627	0.000	0.076
D24SS5F	0.674	0.448	0.954	0.921	0.904	0.580	0.787	0.467	0.528	0.822	0.884	0.000

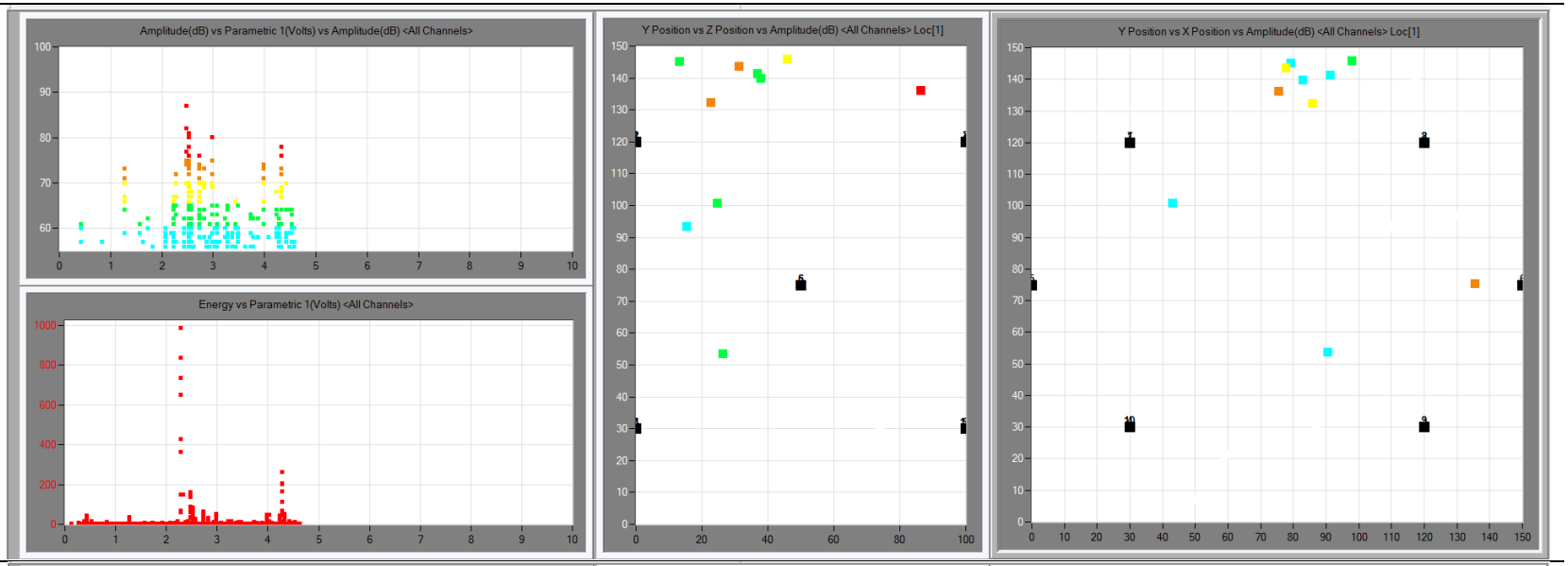
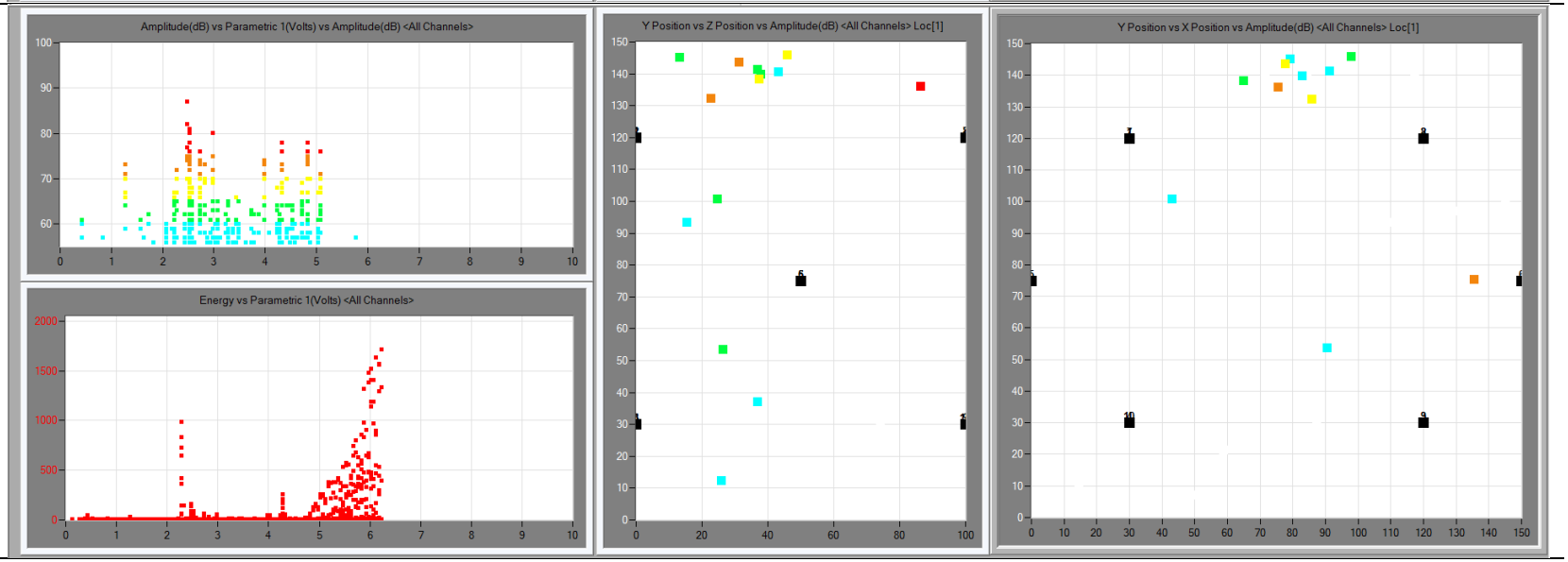
T-Test

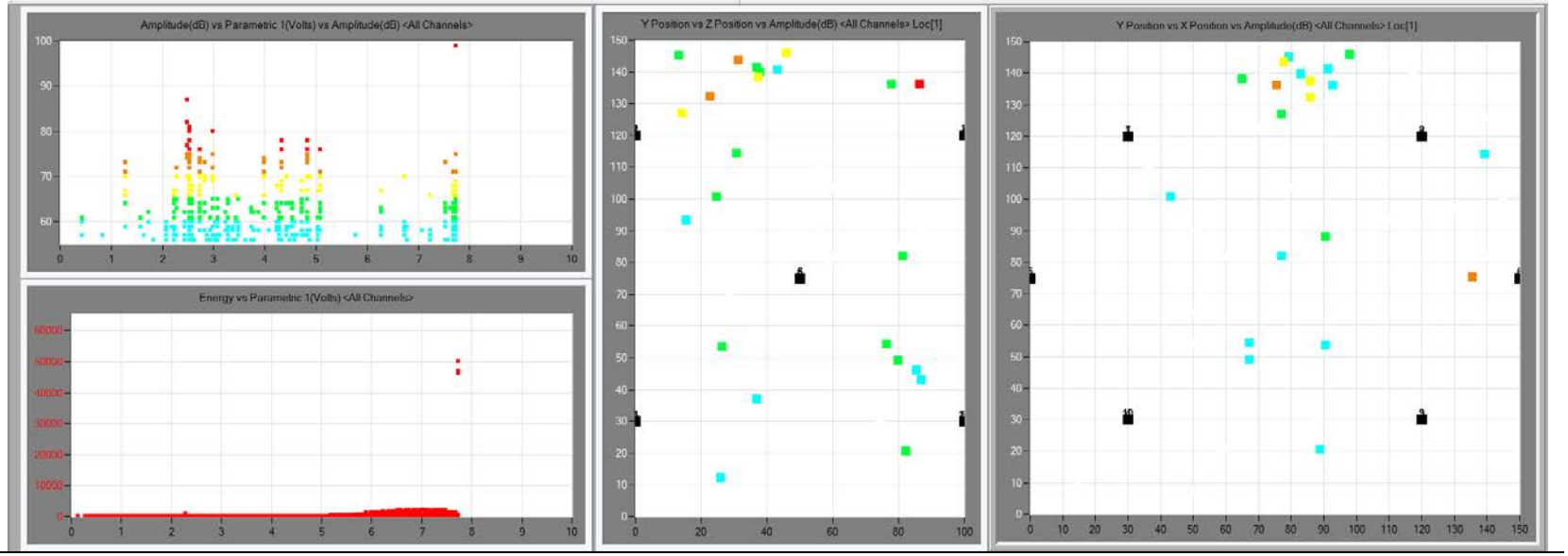
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0A1**
20%	
40%	

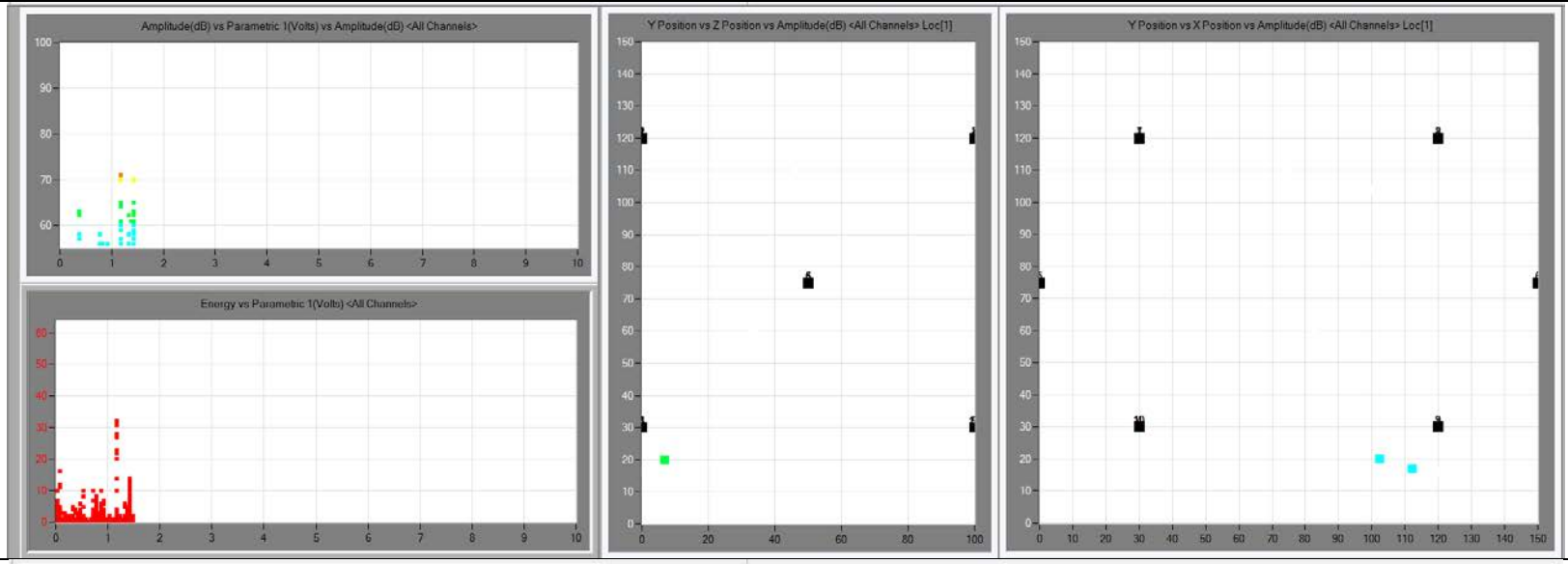
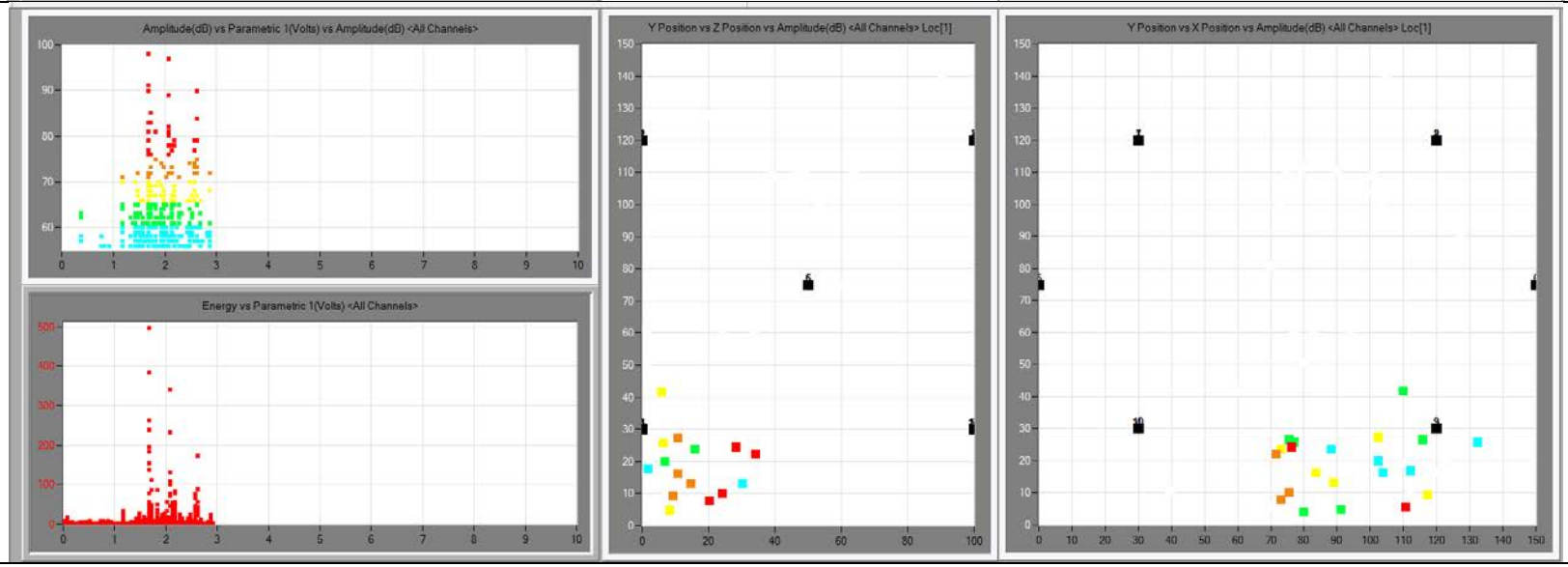
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0A1**
60%	
80%	

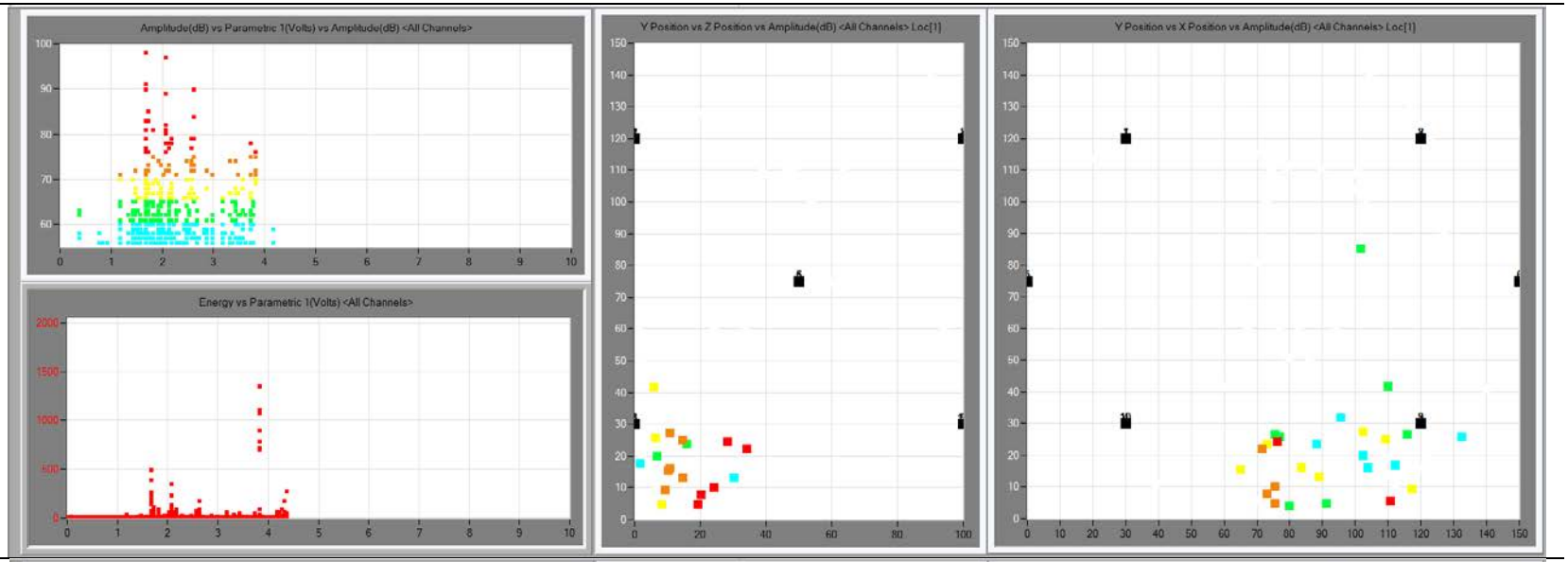
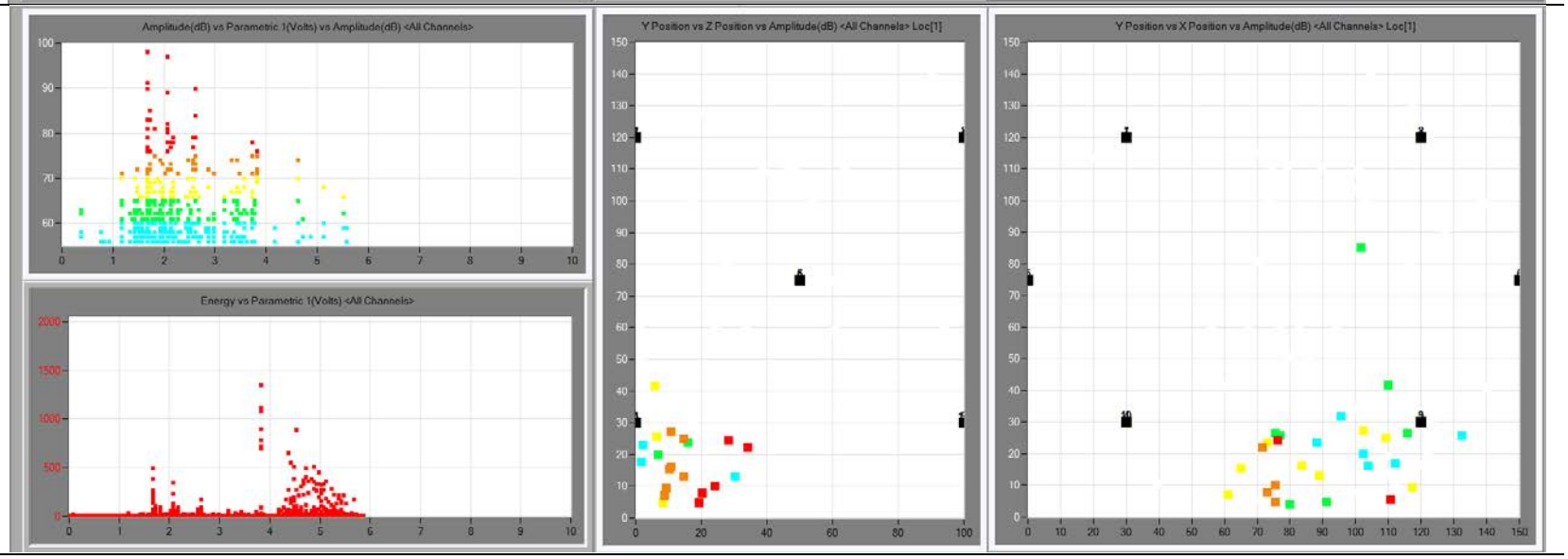
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0A1**
100 %	

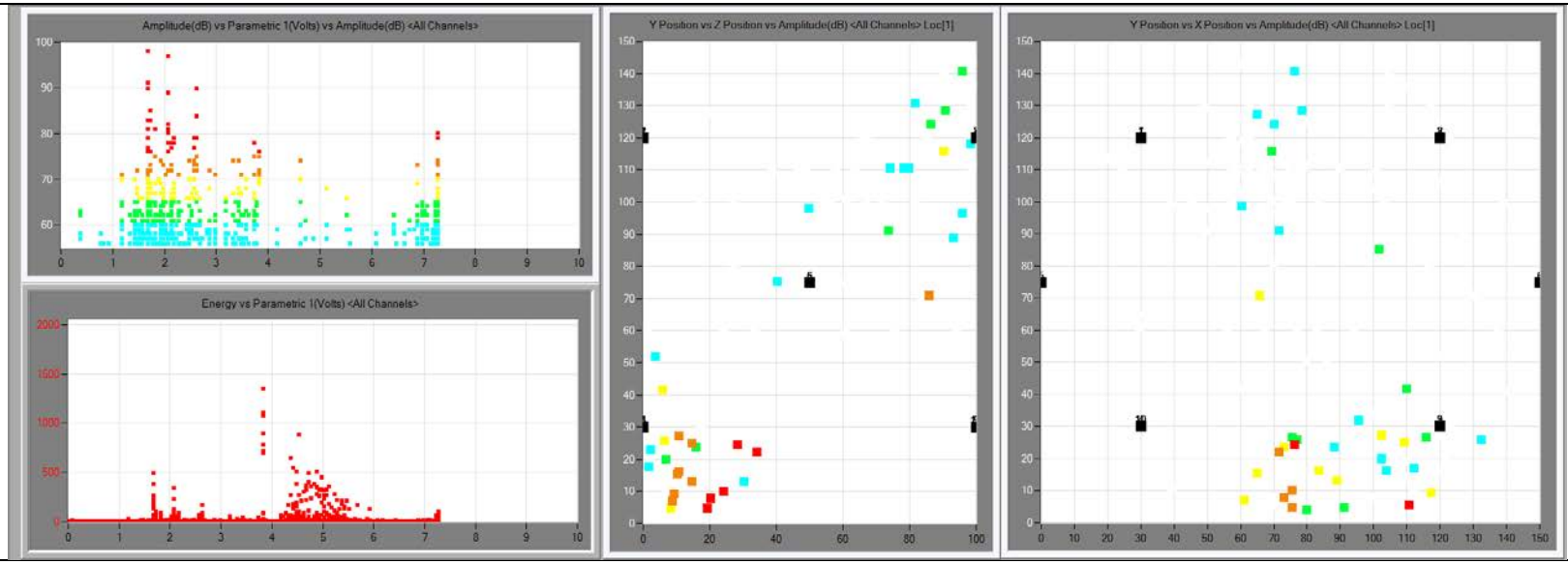
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0A2**
20%	
40%	

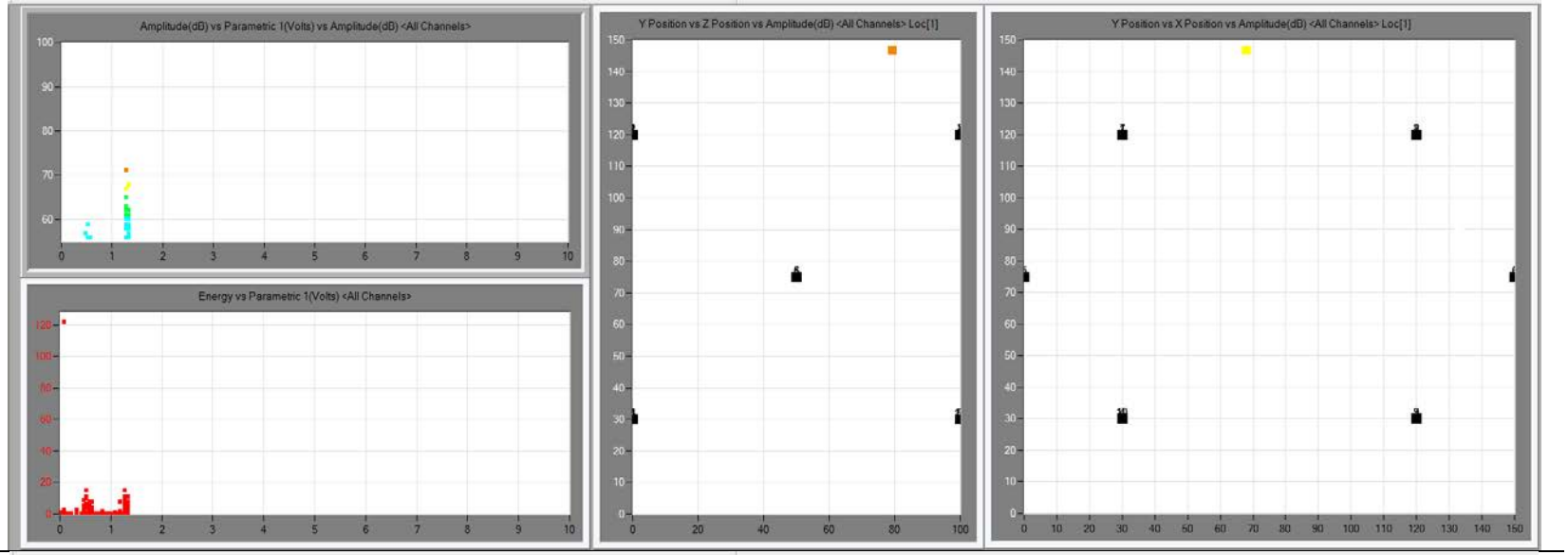
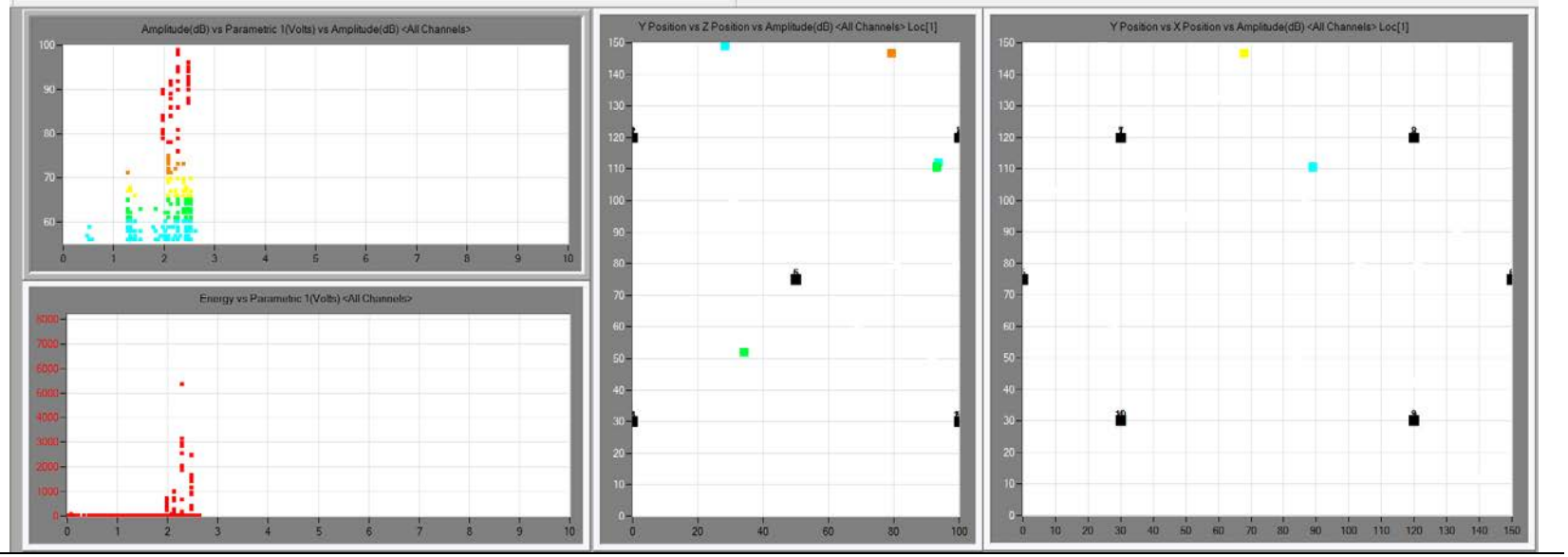
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0A2**
60%	
80%	

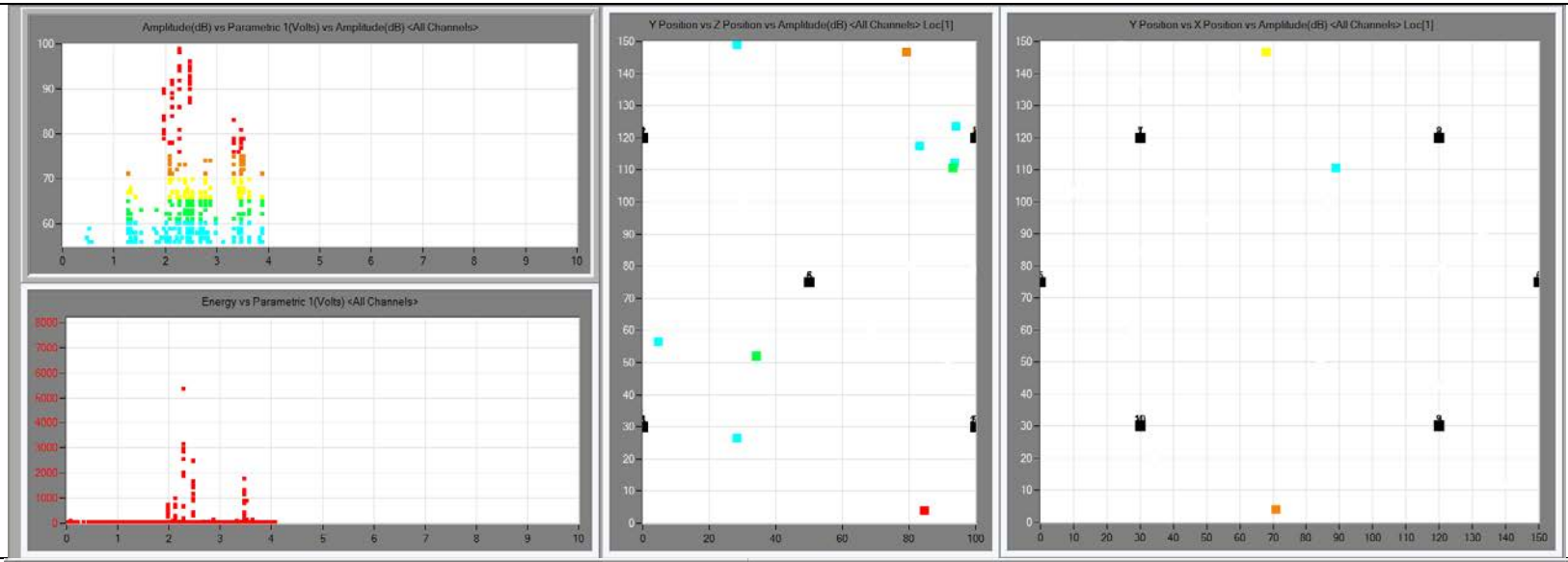
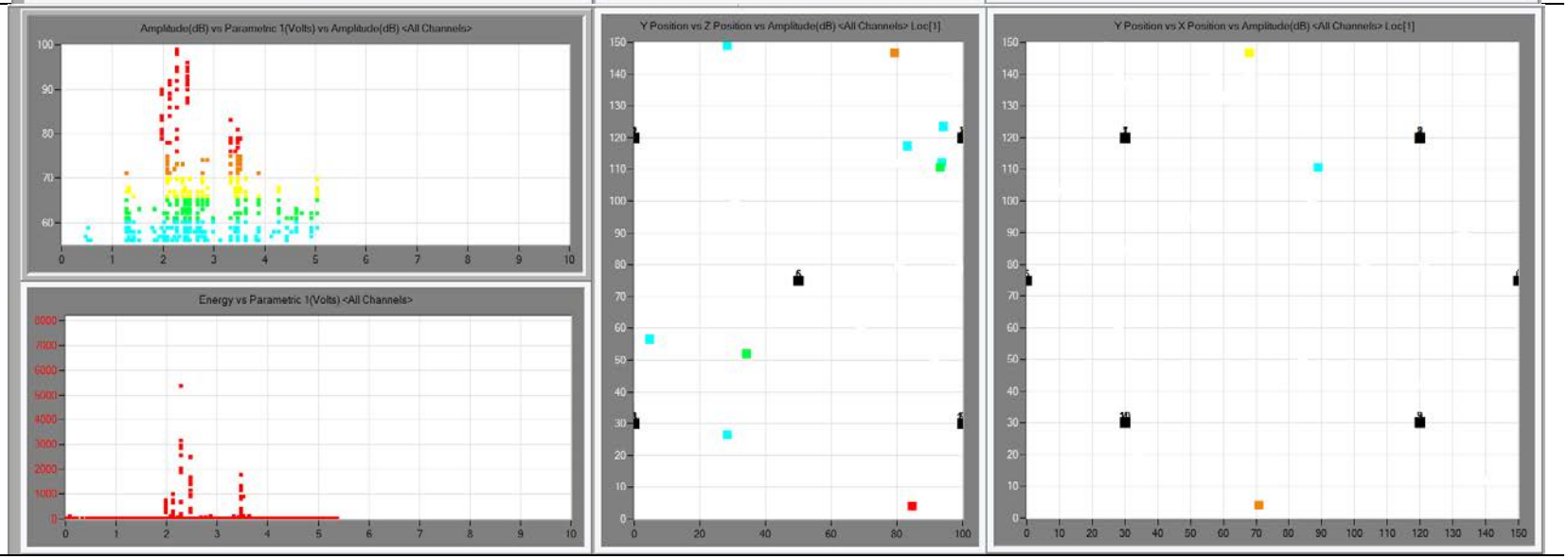
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0A2**
100%	

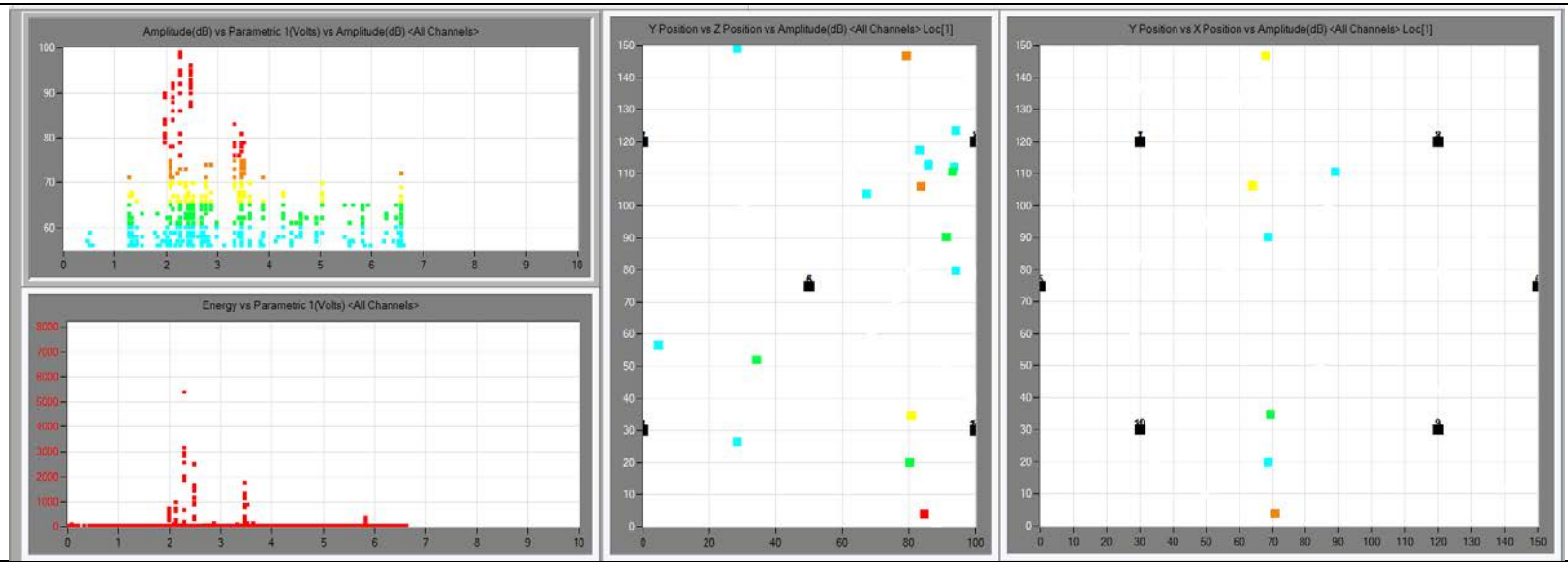
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0A3**
20%	
40%	

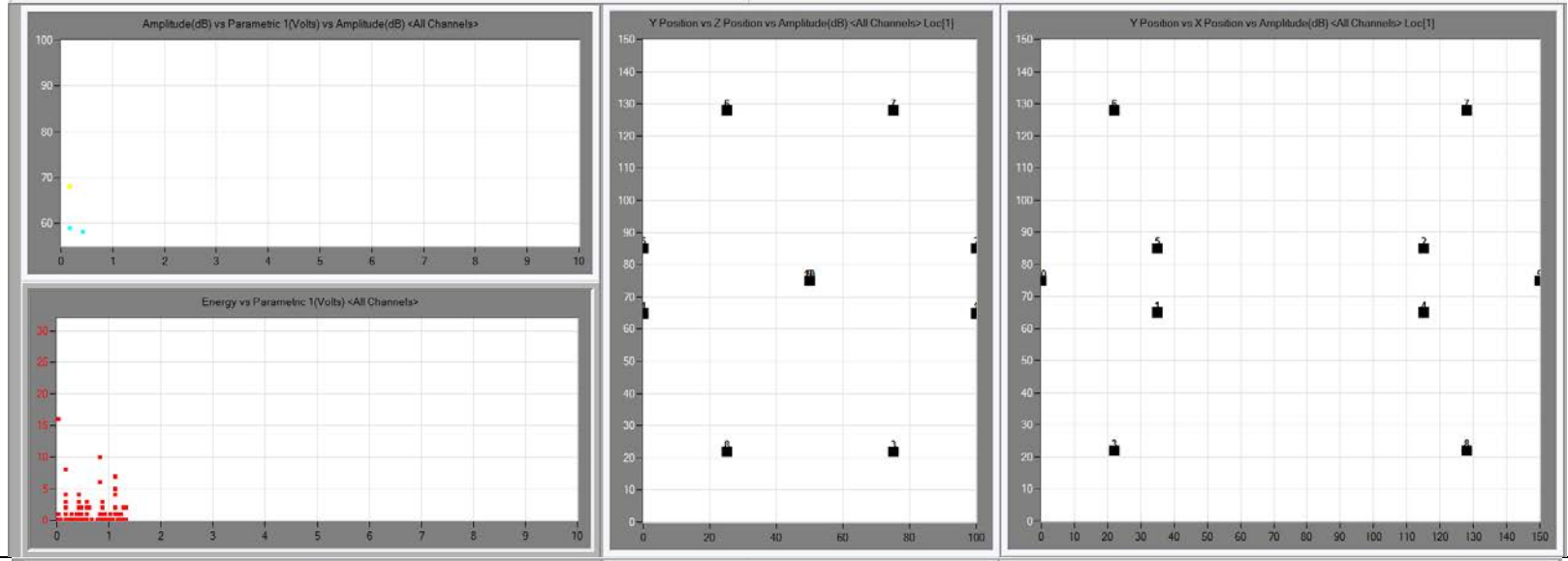
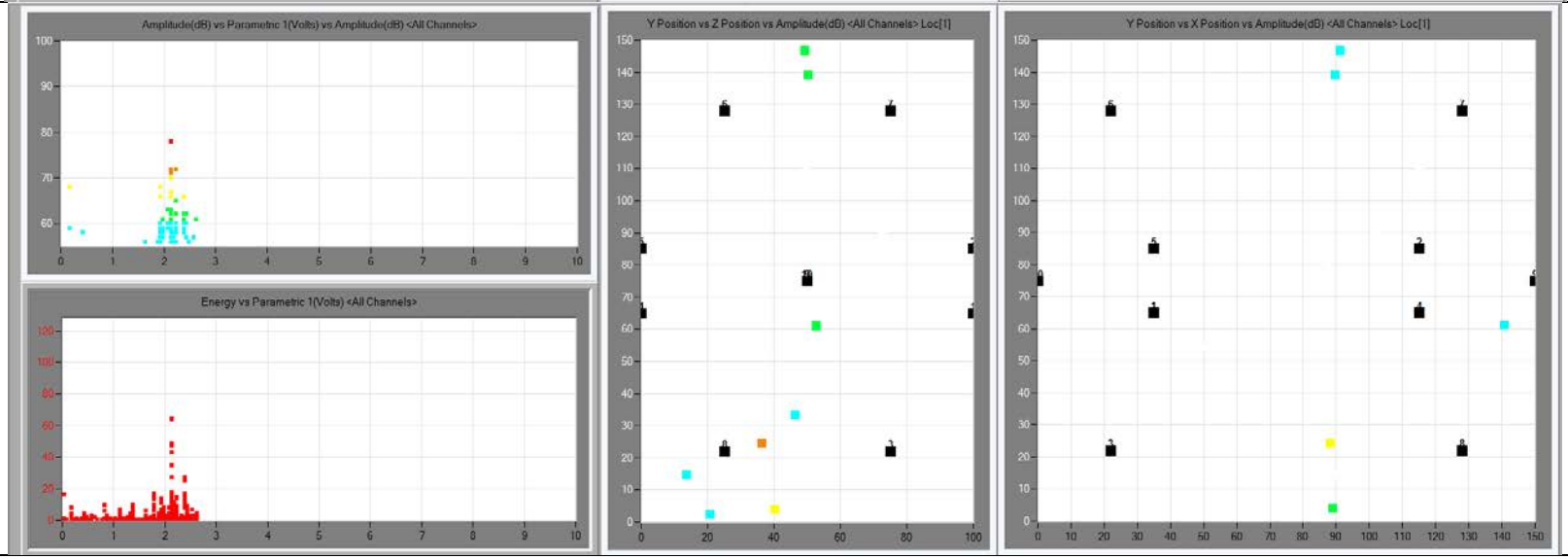
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0A3**
60%	
80%	

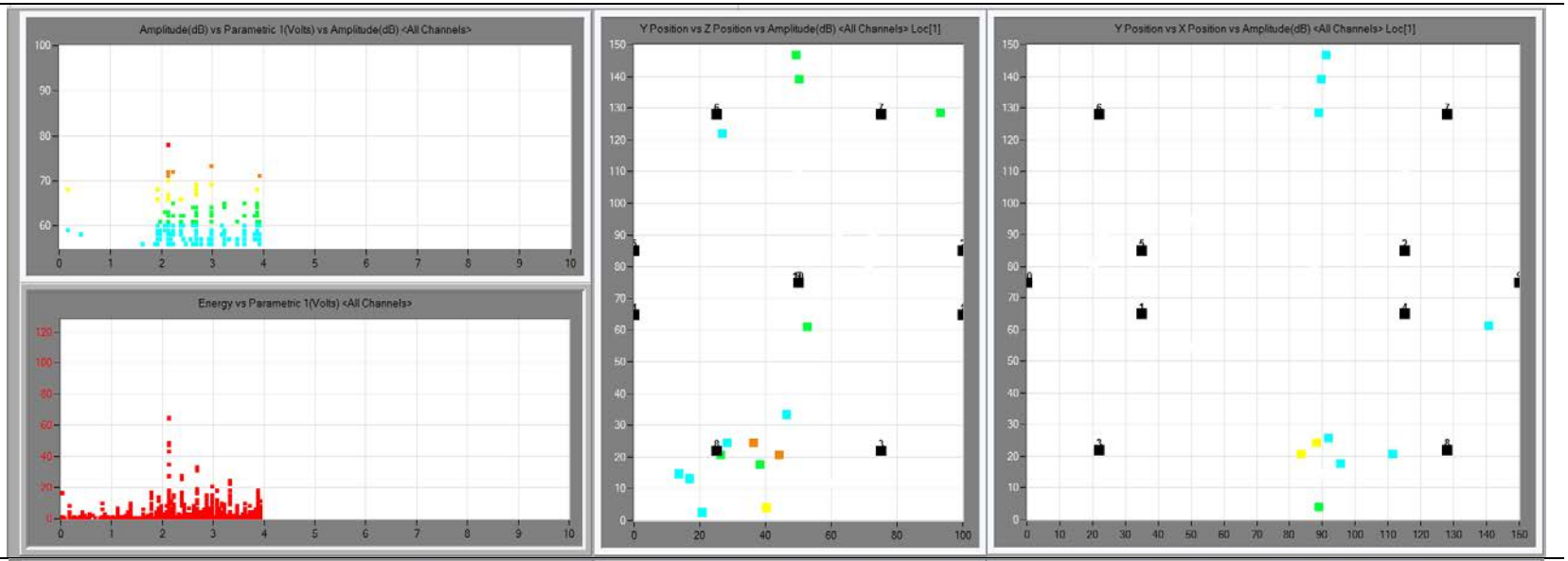
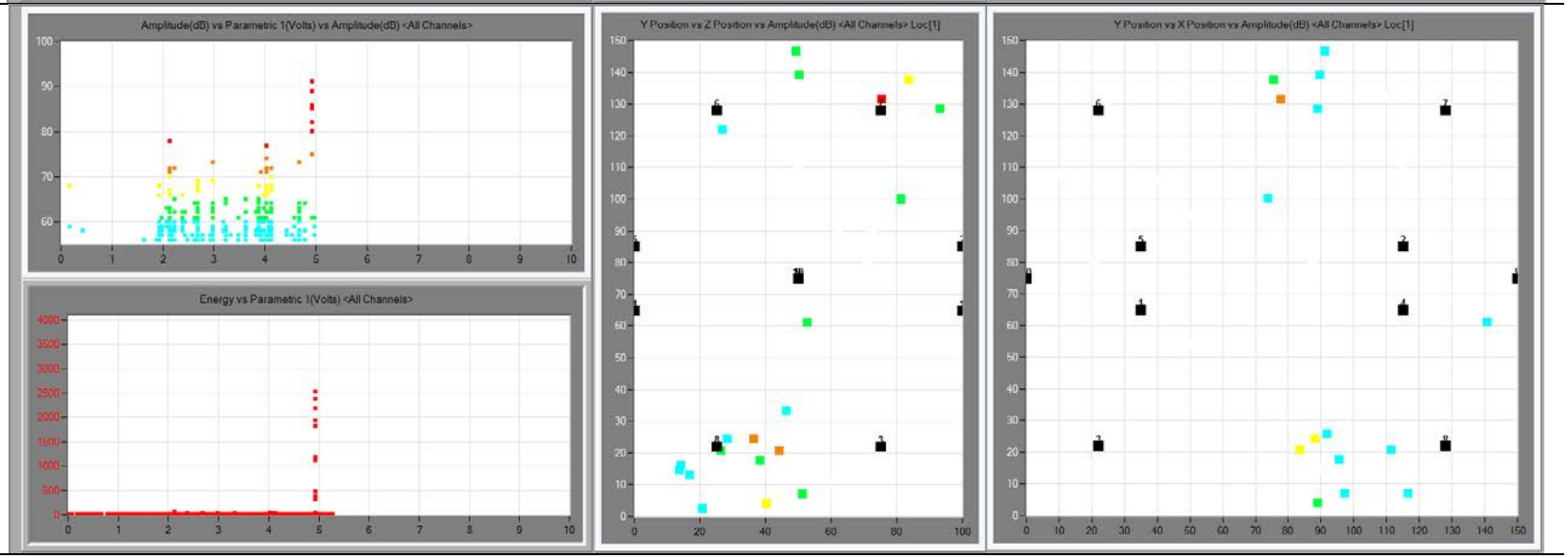
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0A3**
100%	

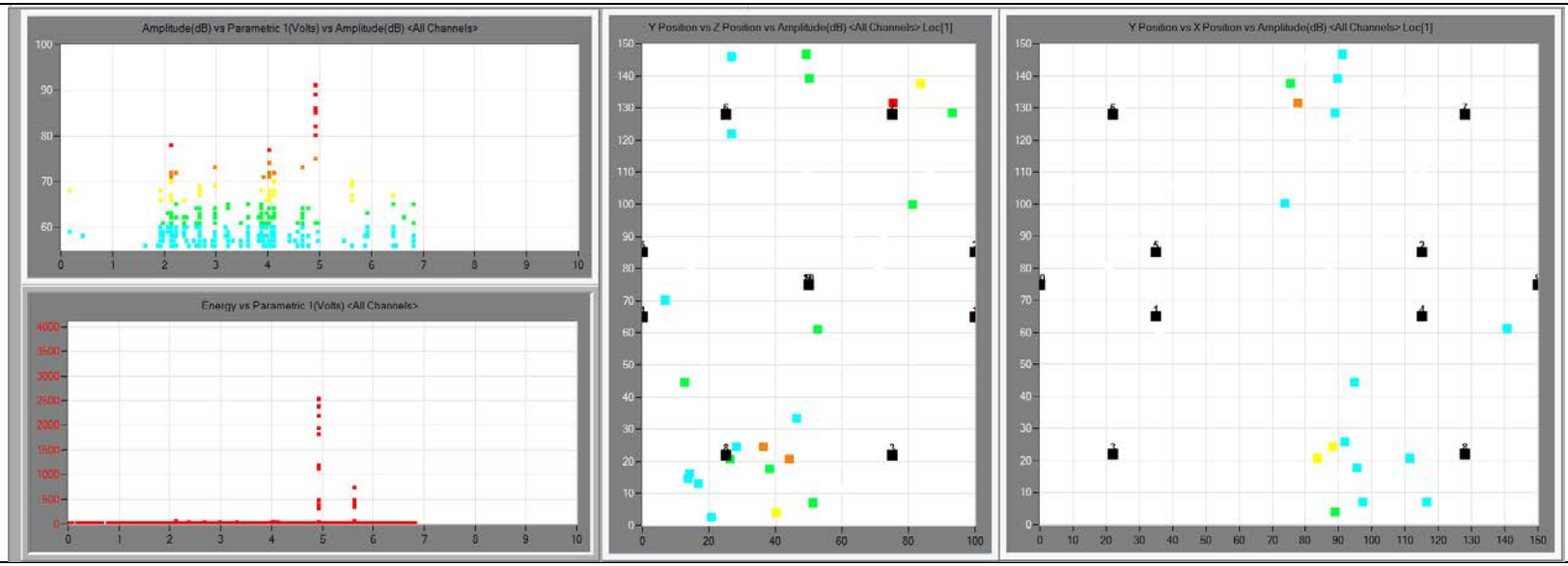
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2A1**
20%	
40%	

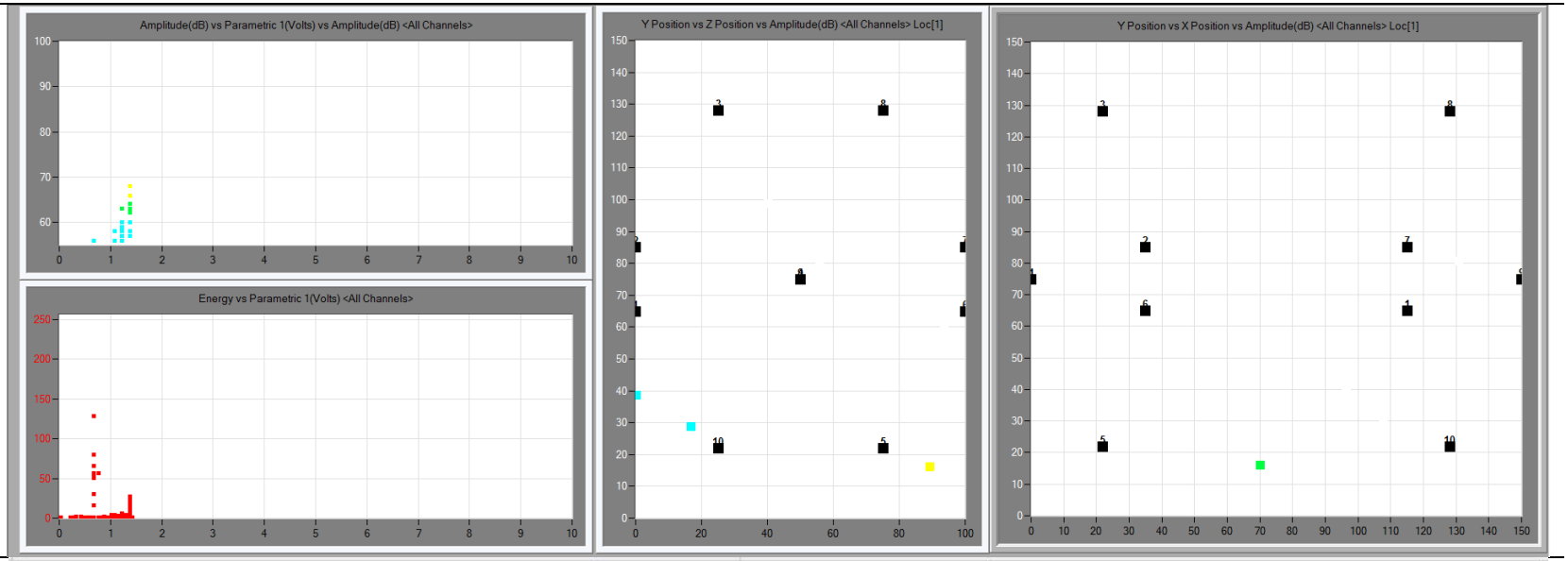
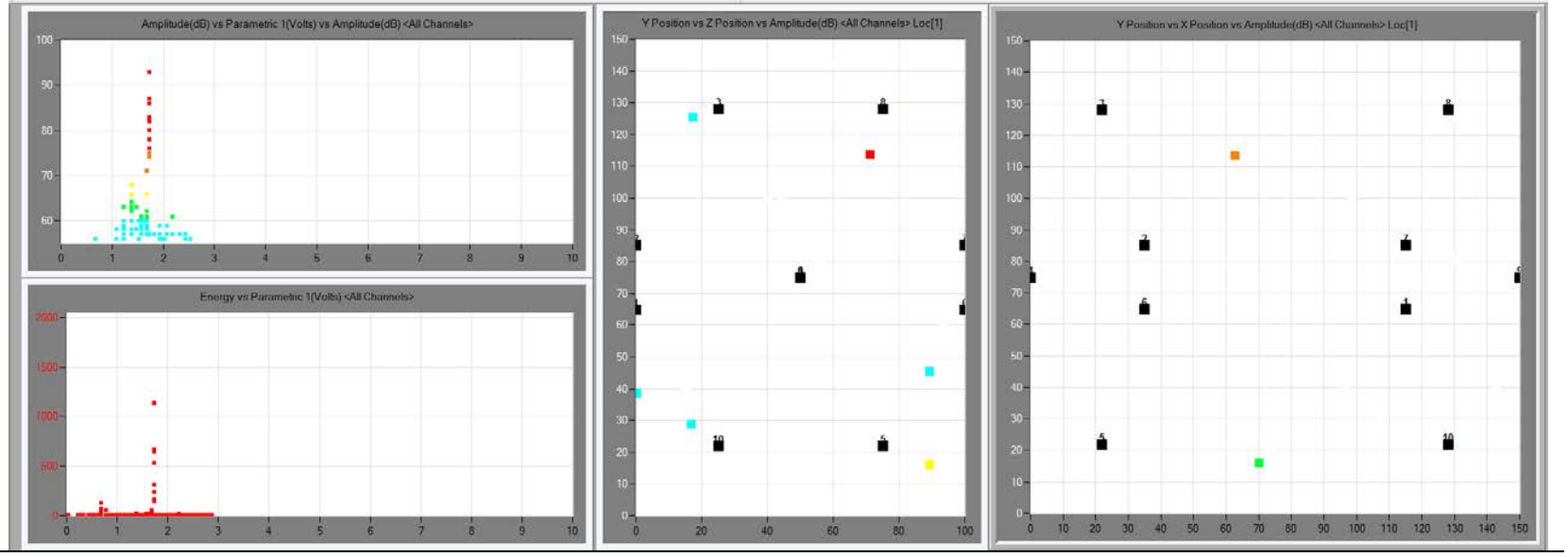
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2A1**
60%	
80%	

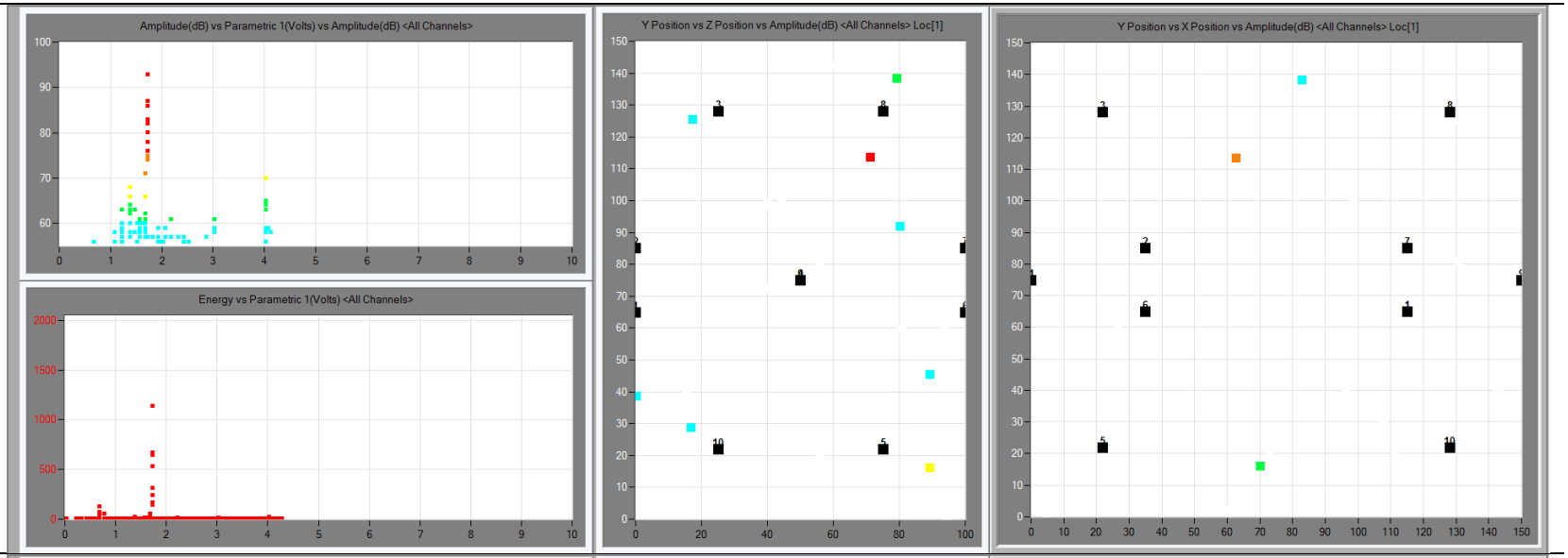
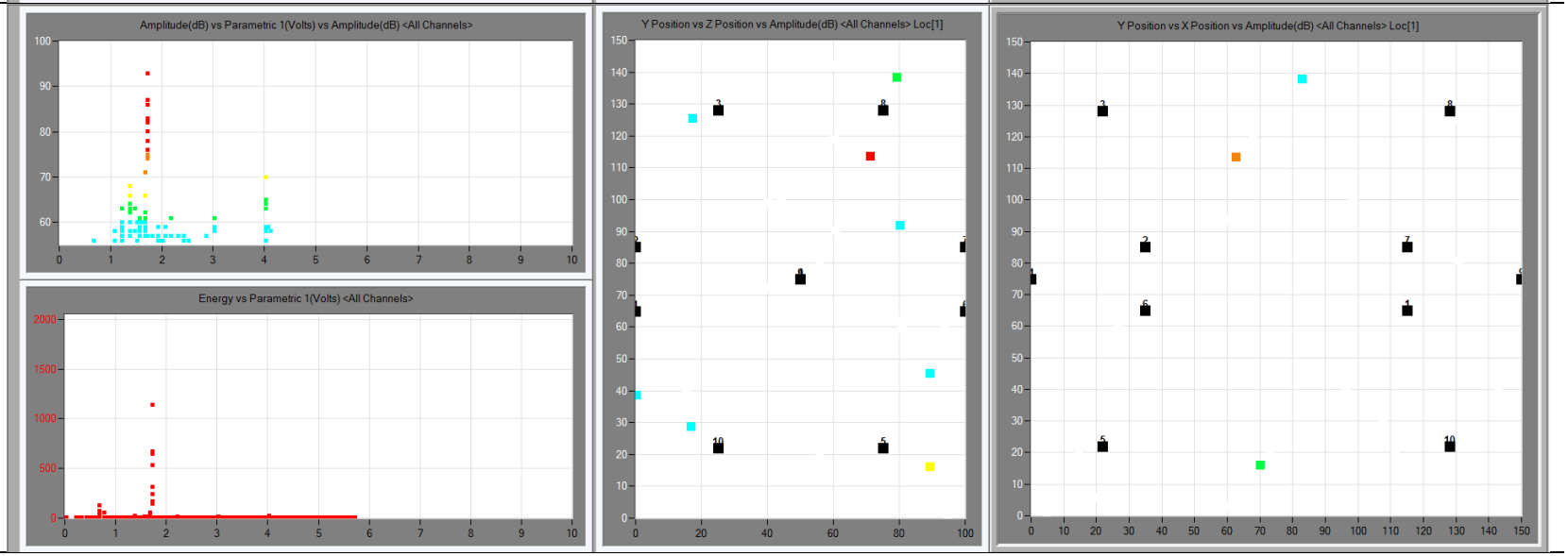
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2A1**
100%	

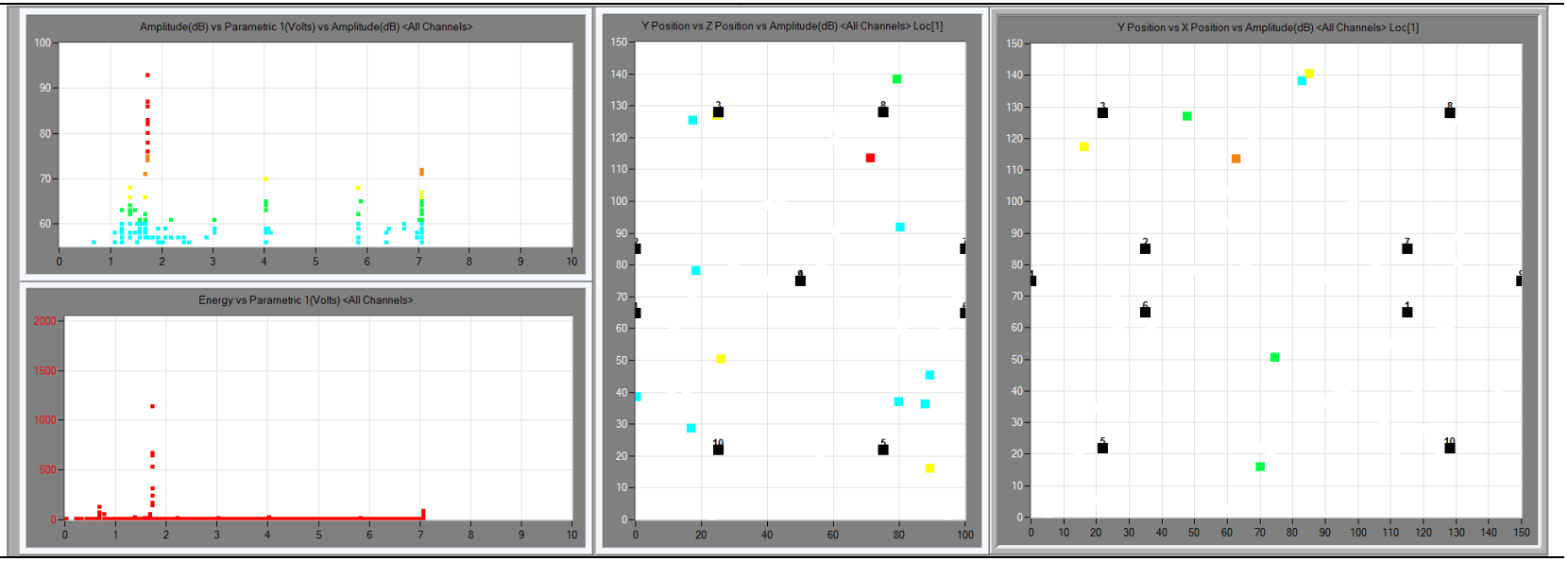
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2A2**
20%	
40%	

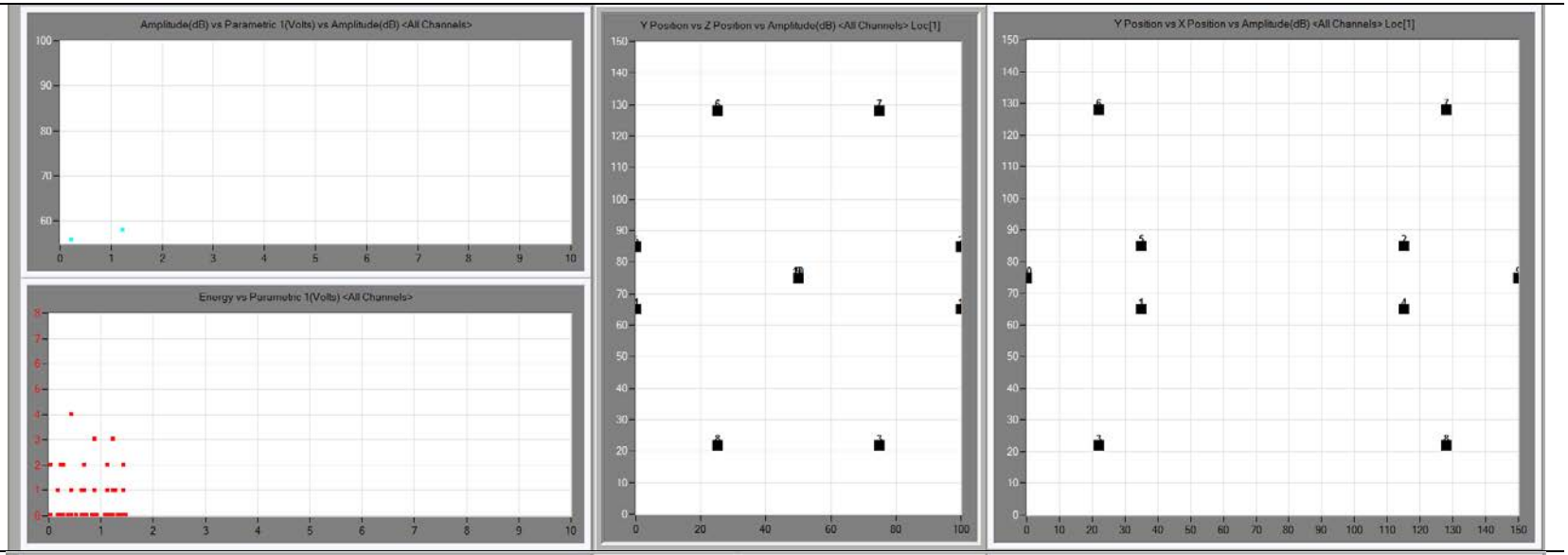
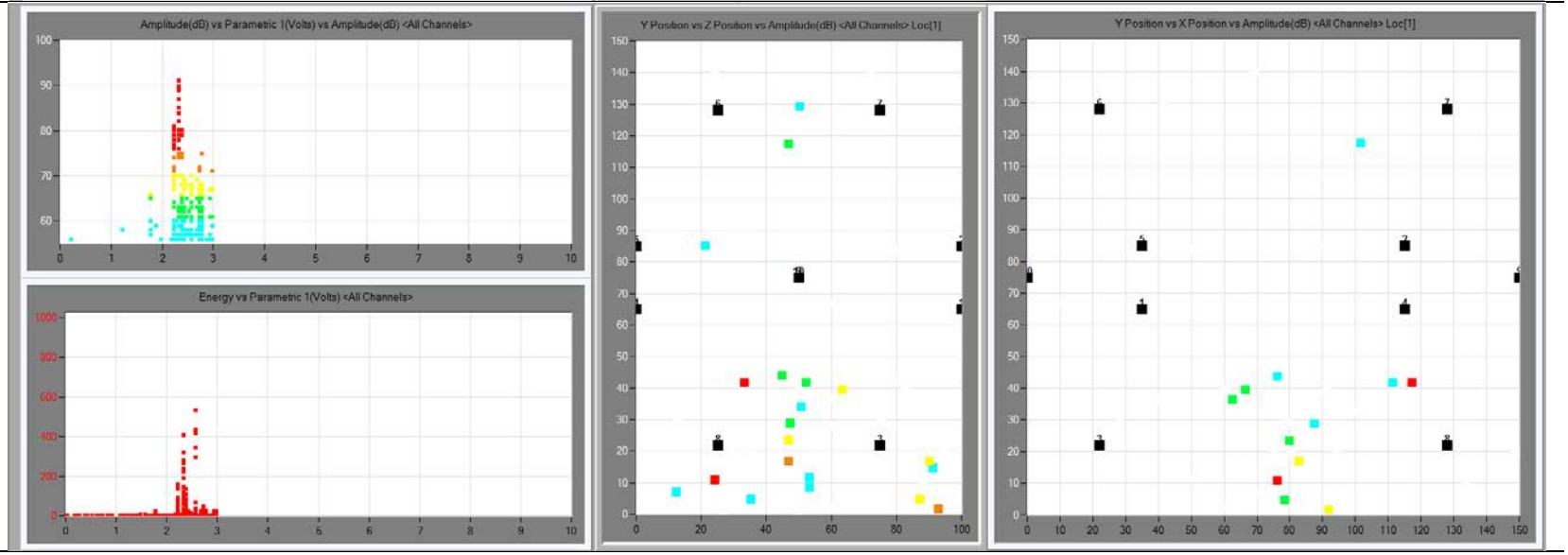
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2A2**
60%	
80%	

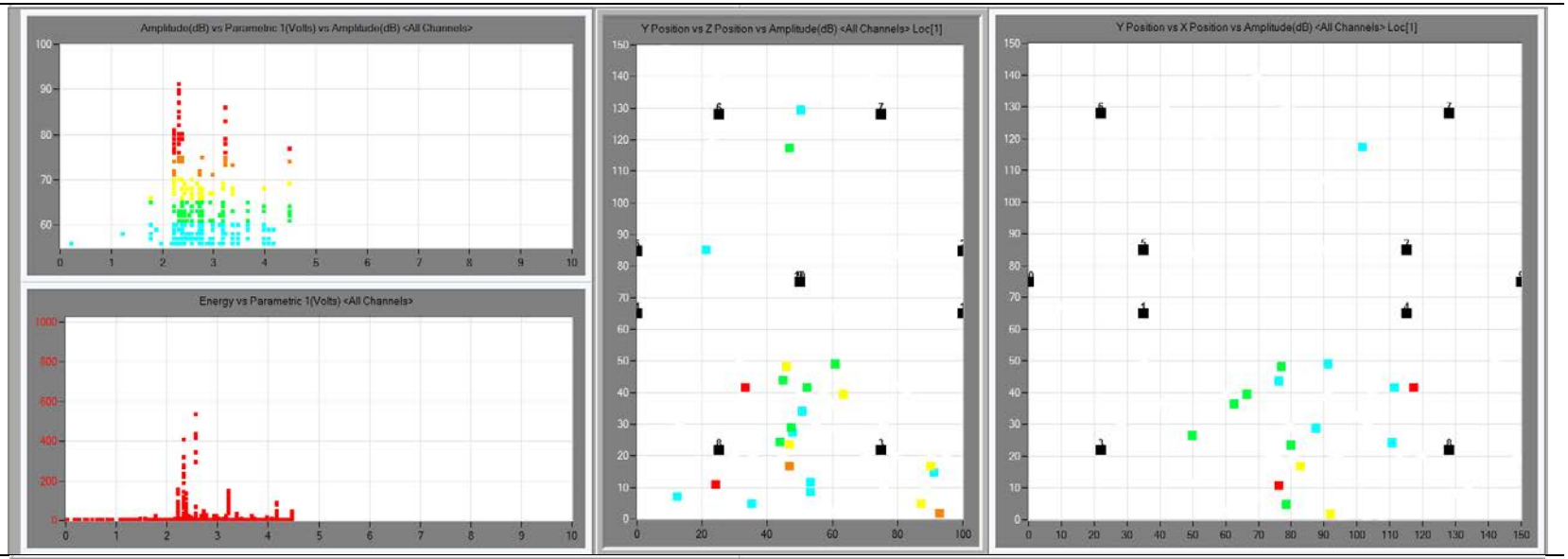
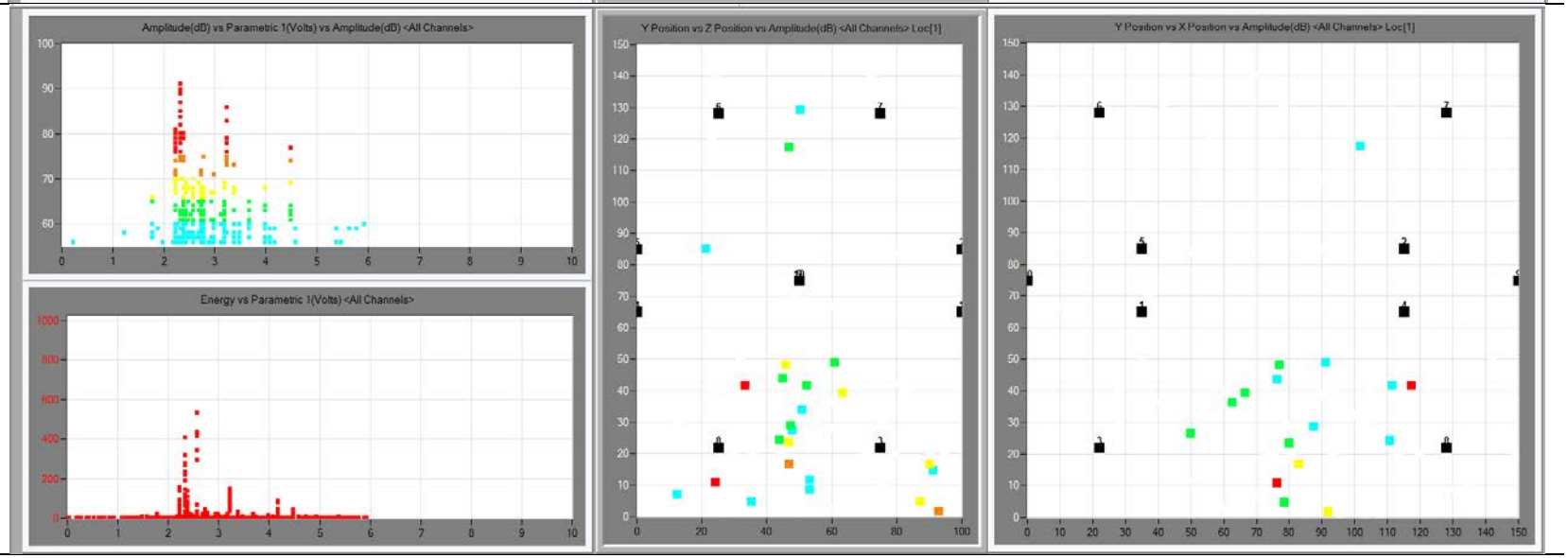
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2A2**
100%	

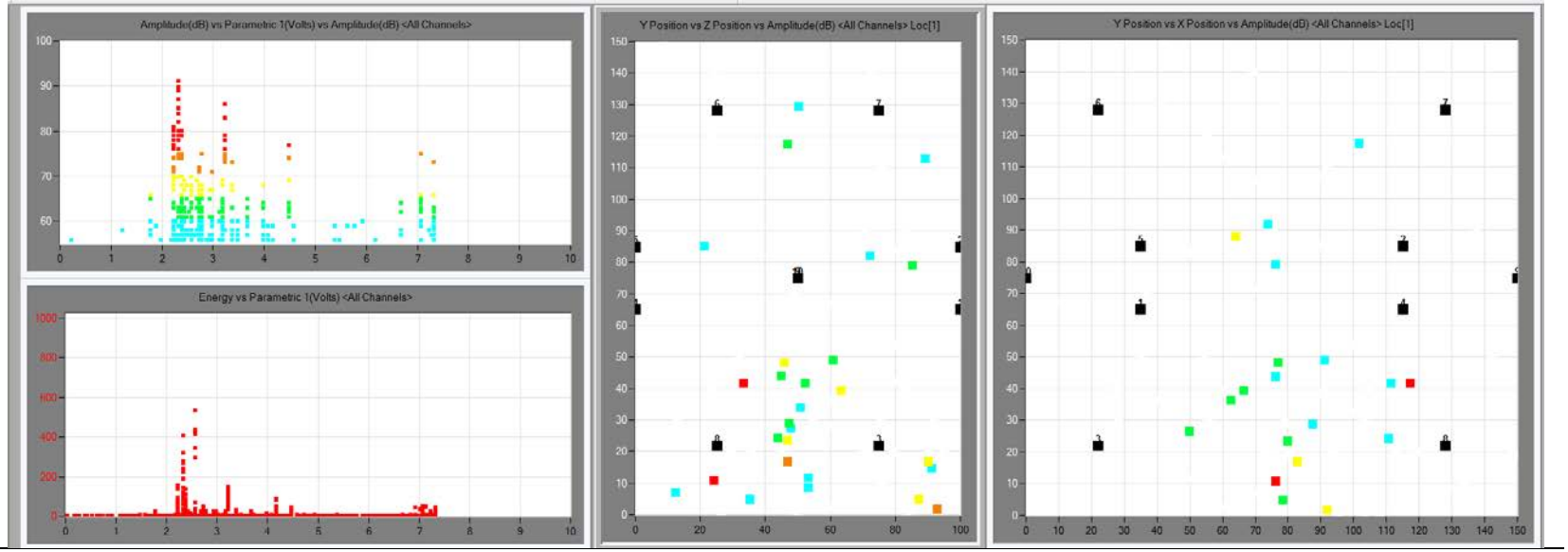
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5A1**
20%	
40%	

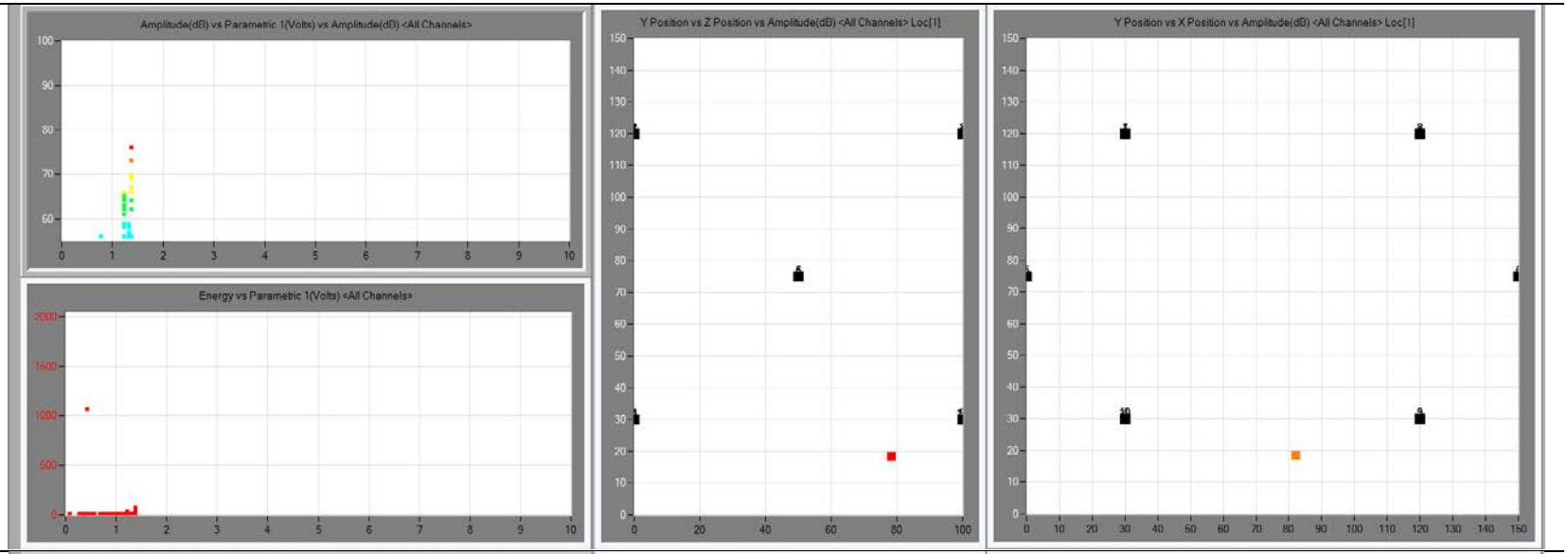
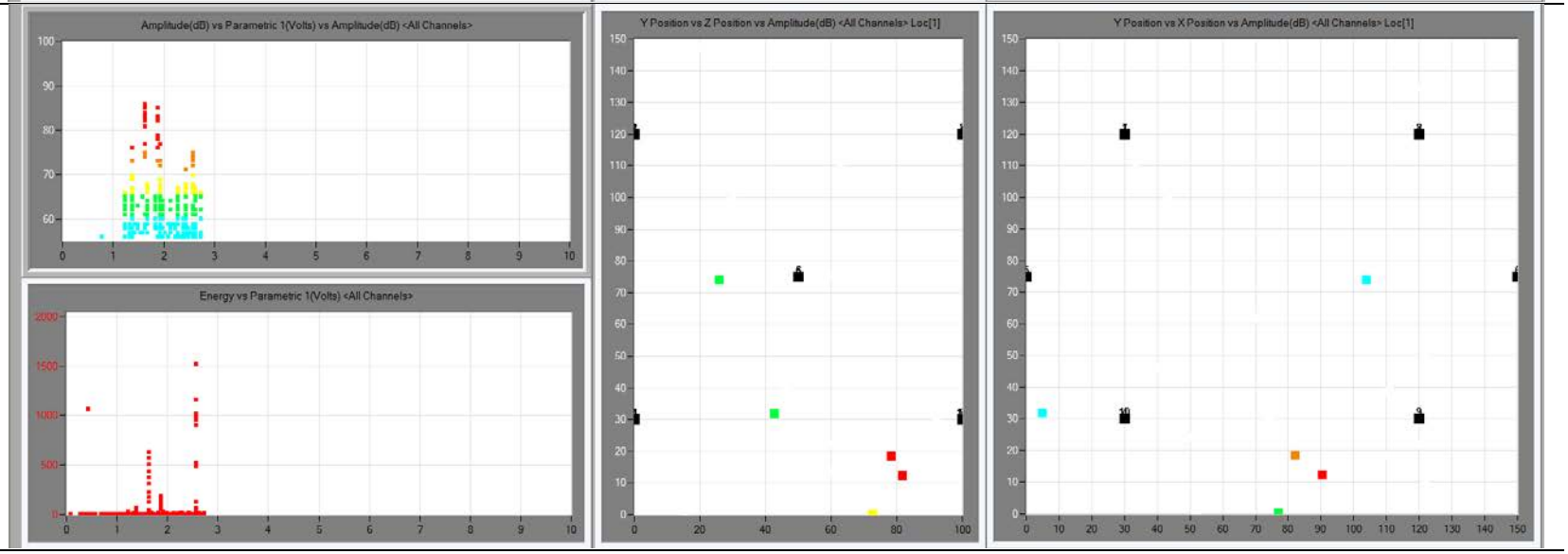
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5A1**
60%	
80%	

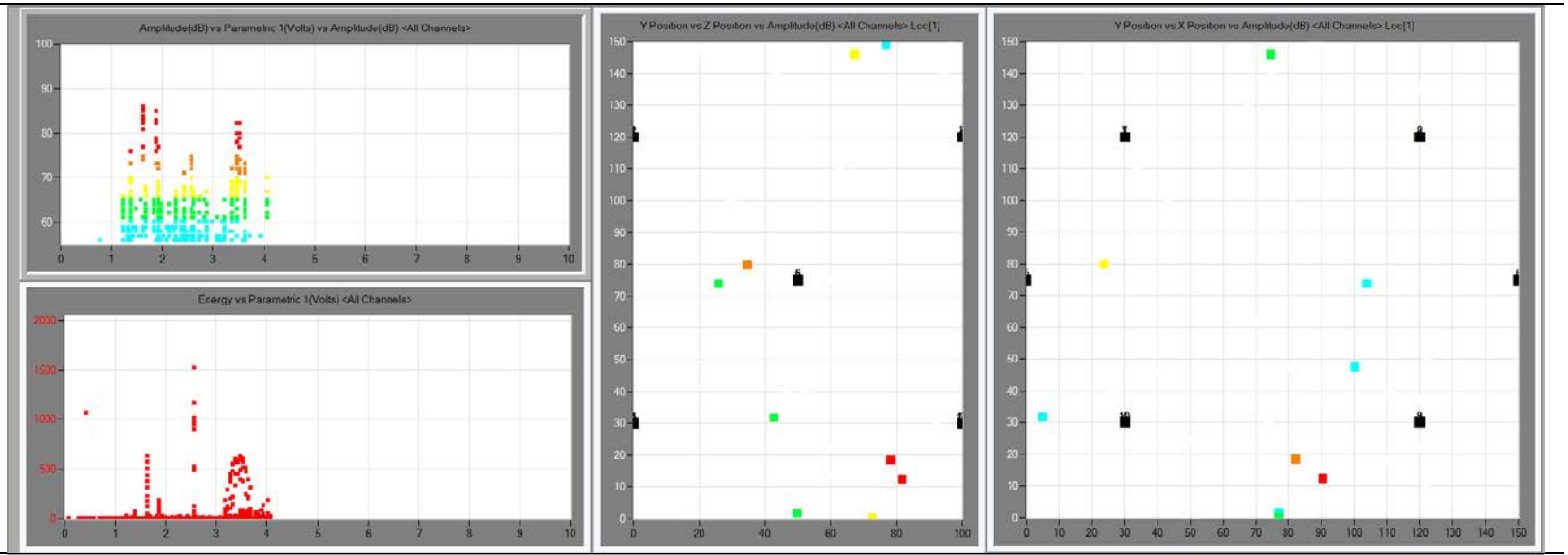
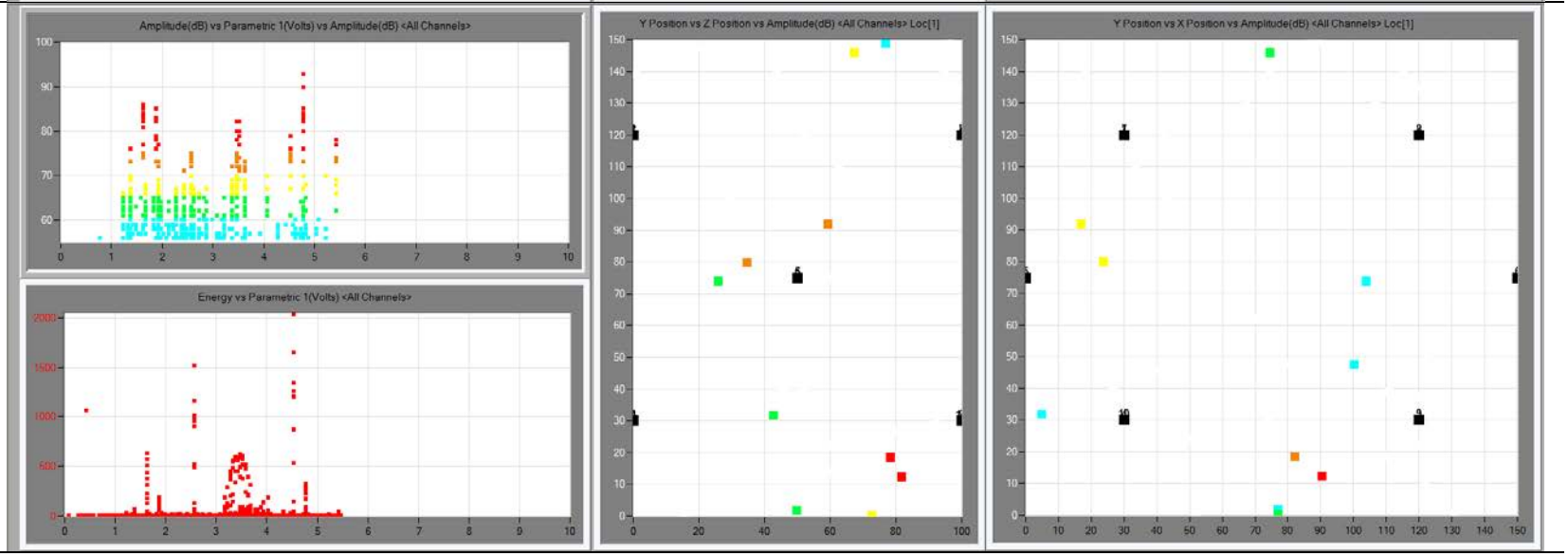
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5A1**
100%	

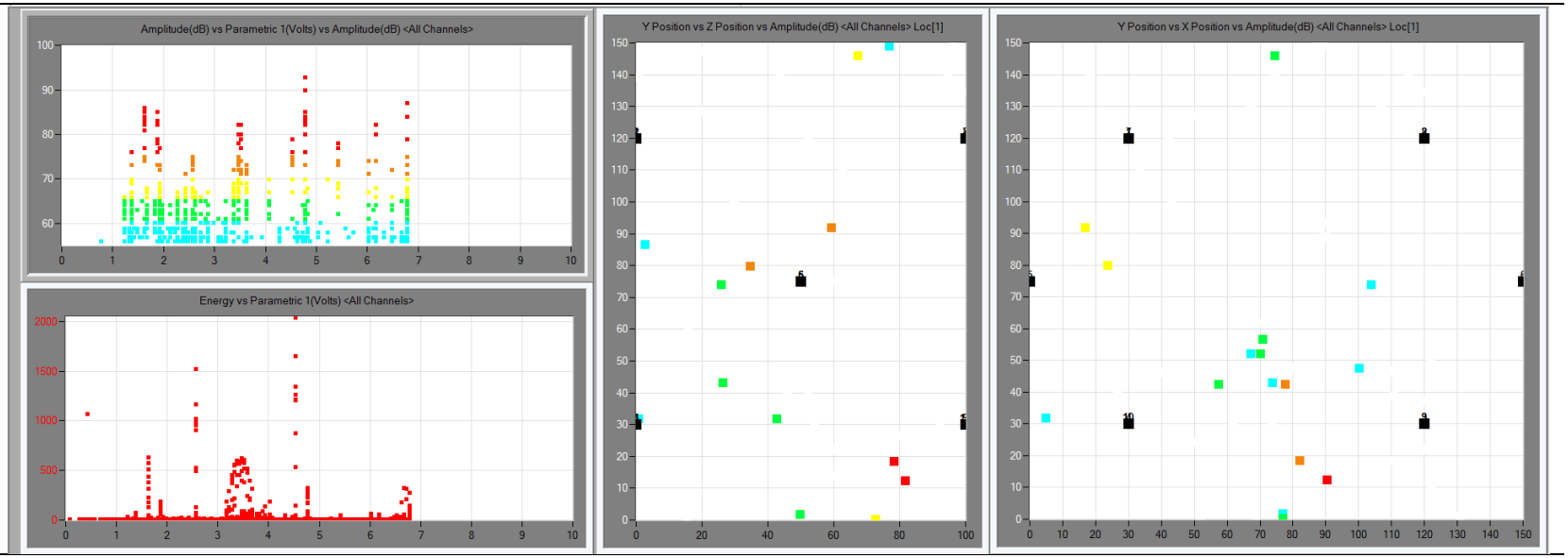
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5A3**
20%	
40%	

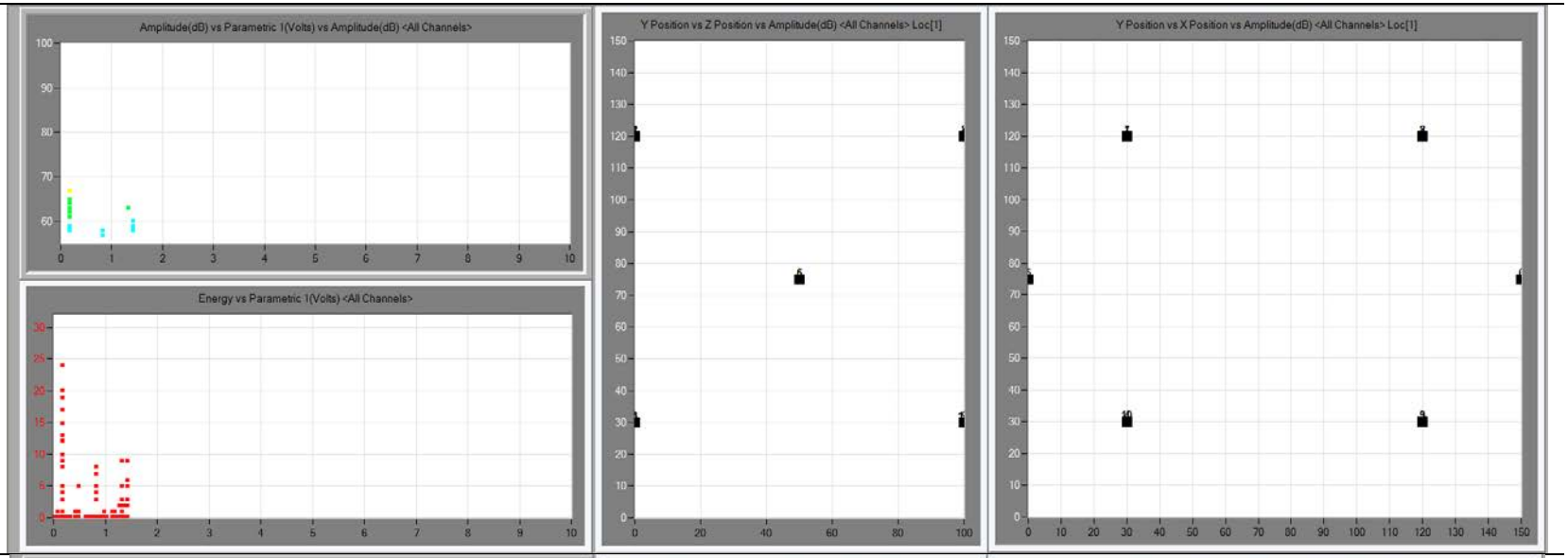
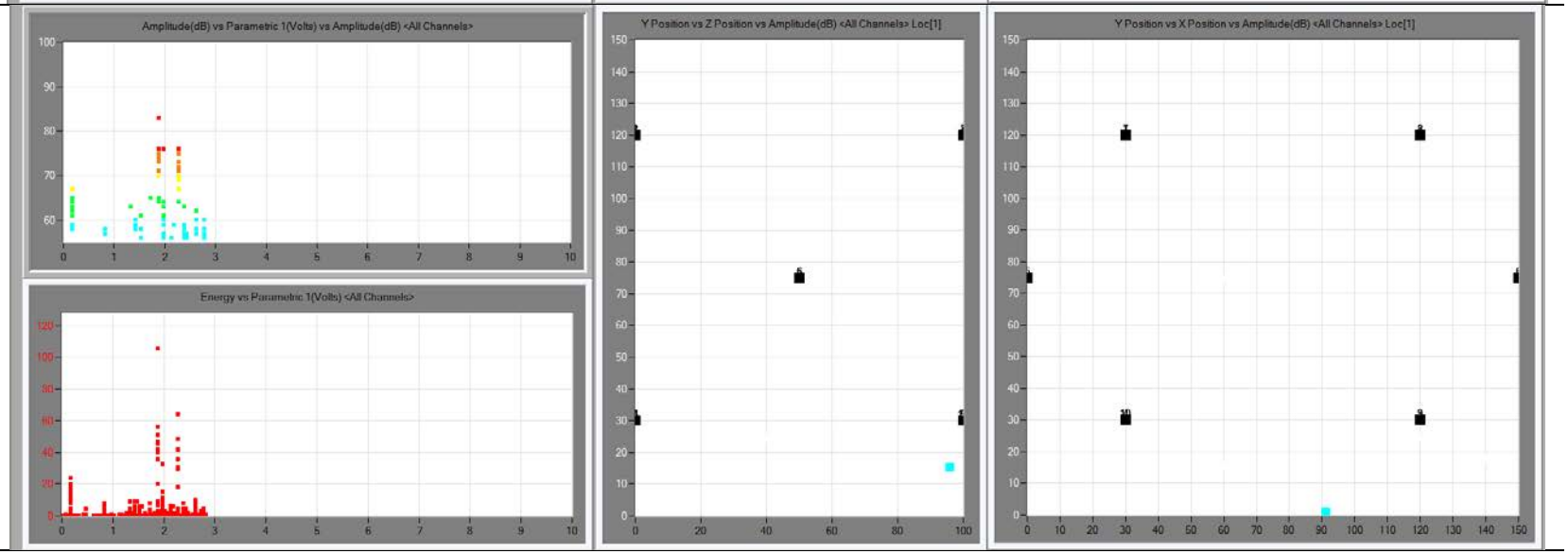
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5A3**
60%	
80%	

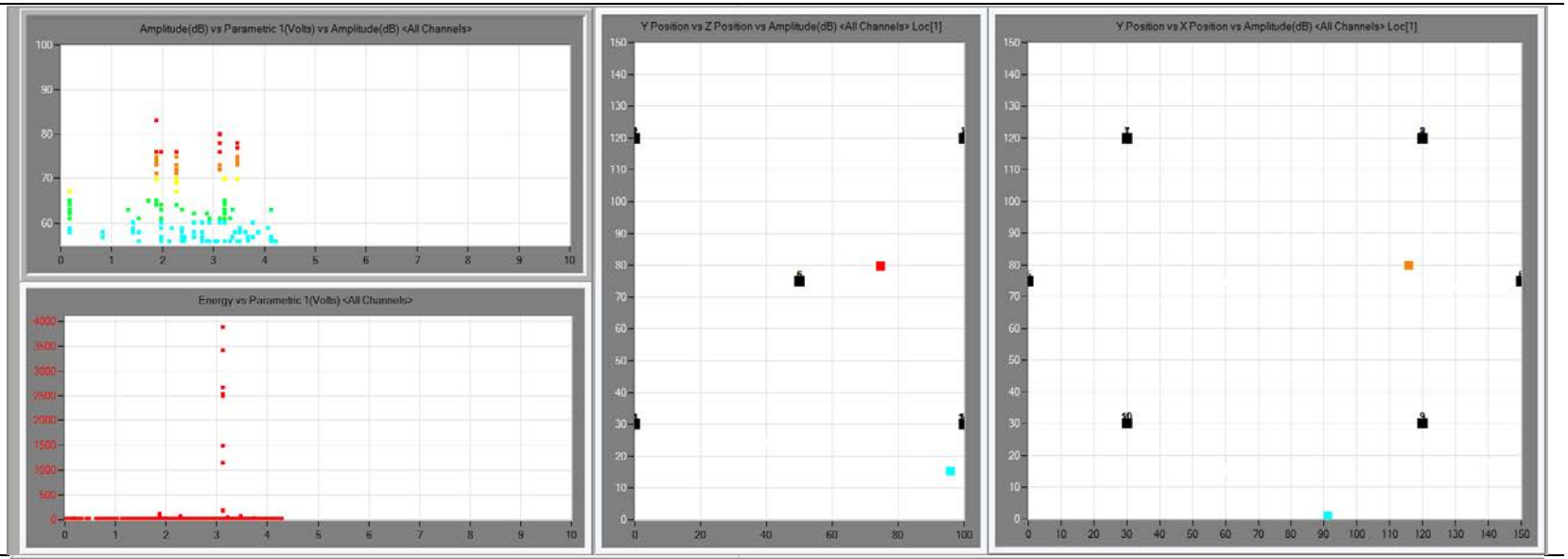
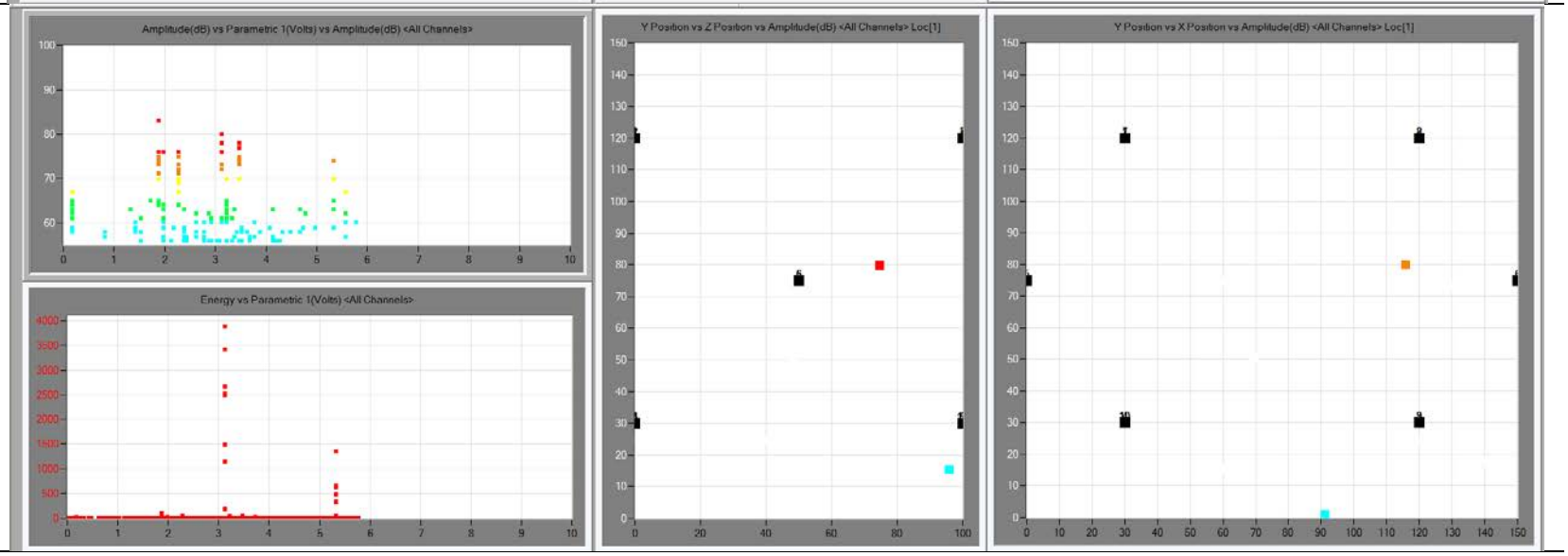
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5A3**
100%	

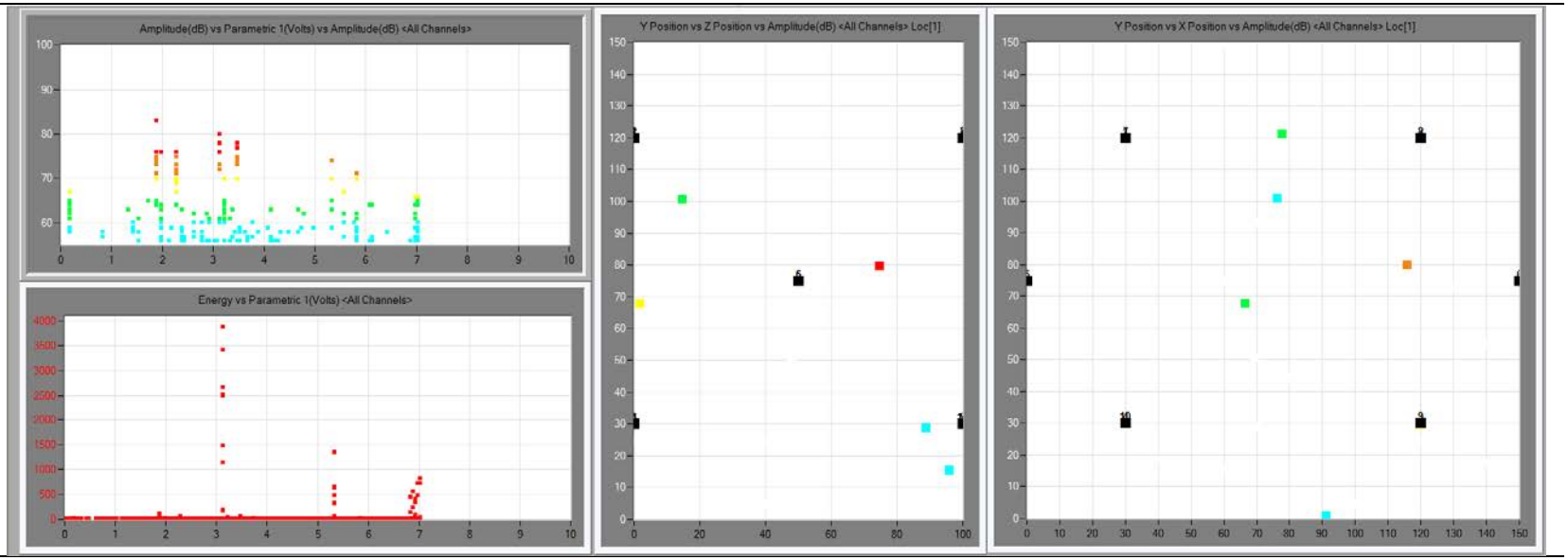
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0C1**
20%	
40%	

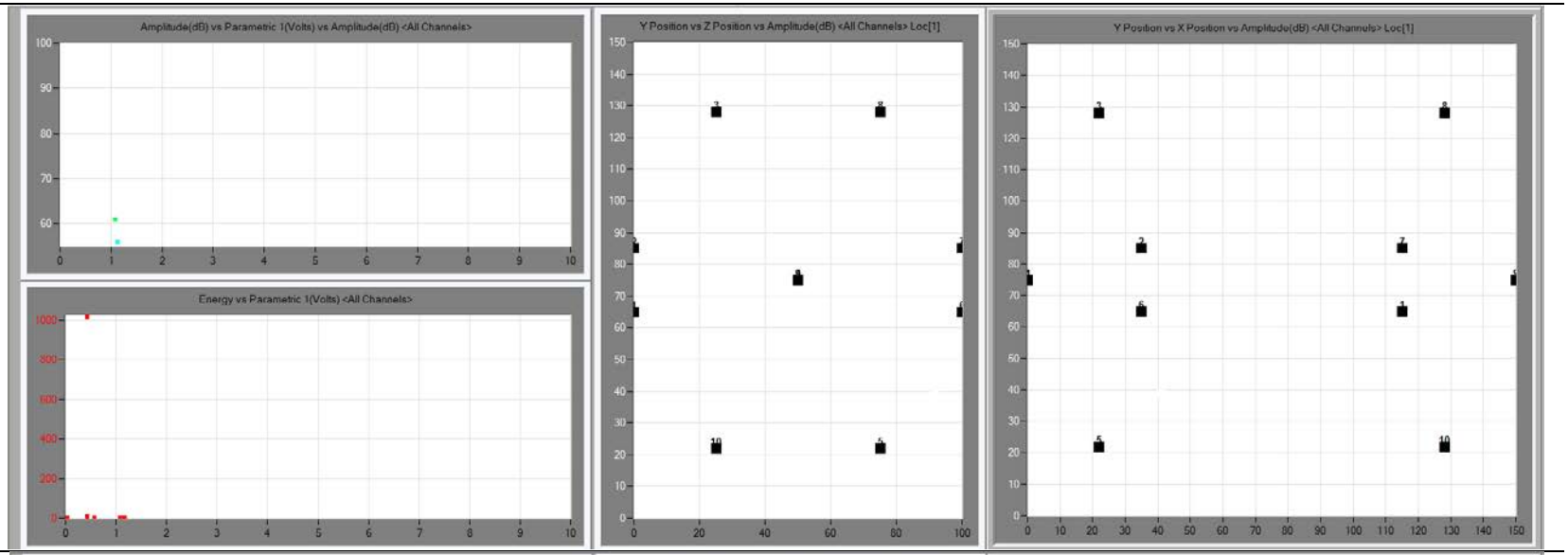
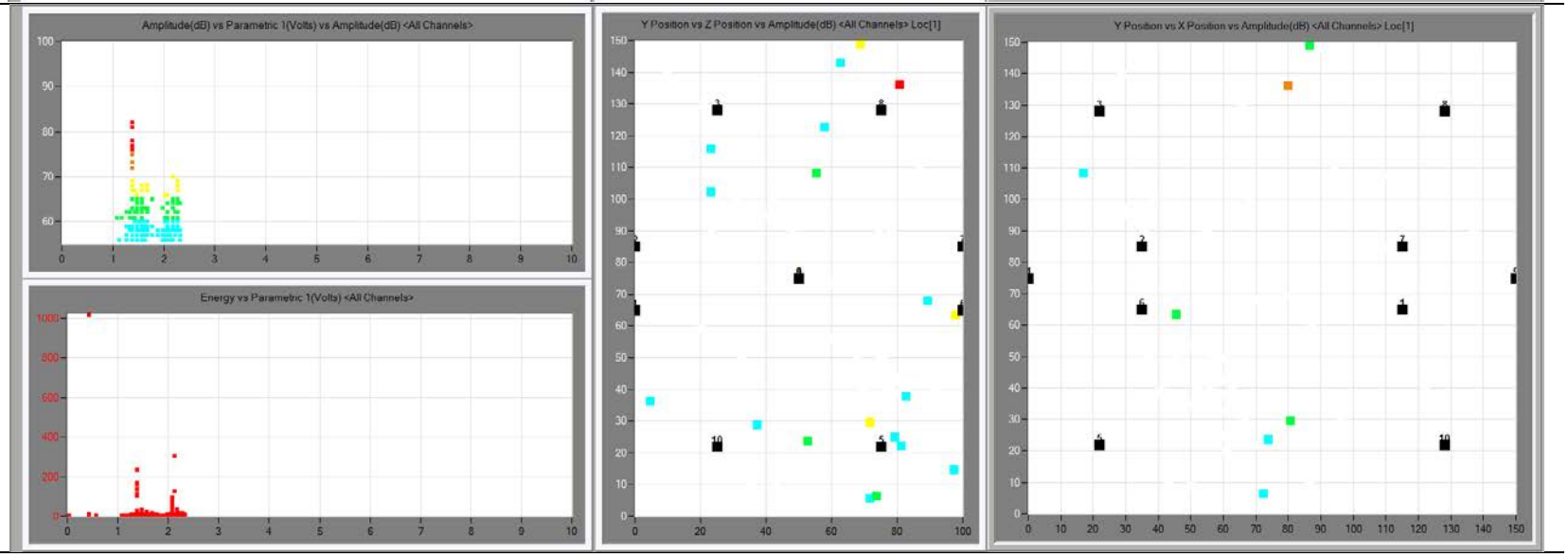
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0C1**
60%	
80%	

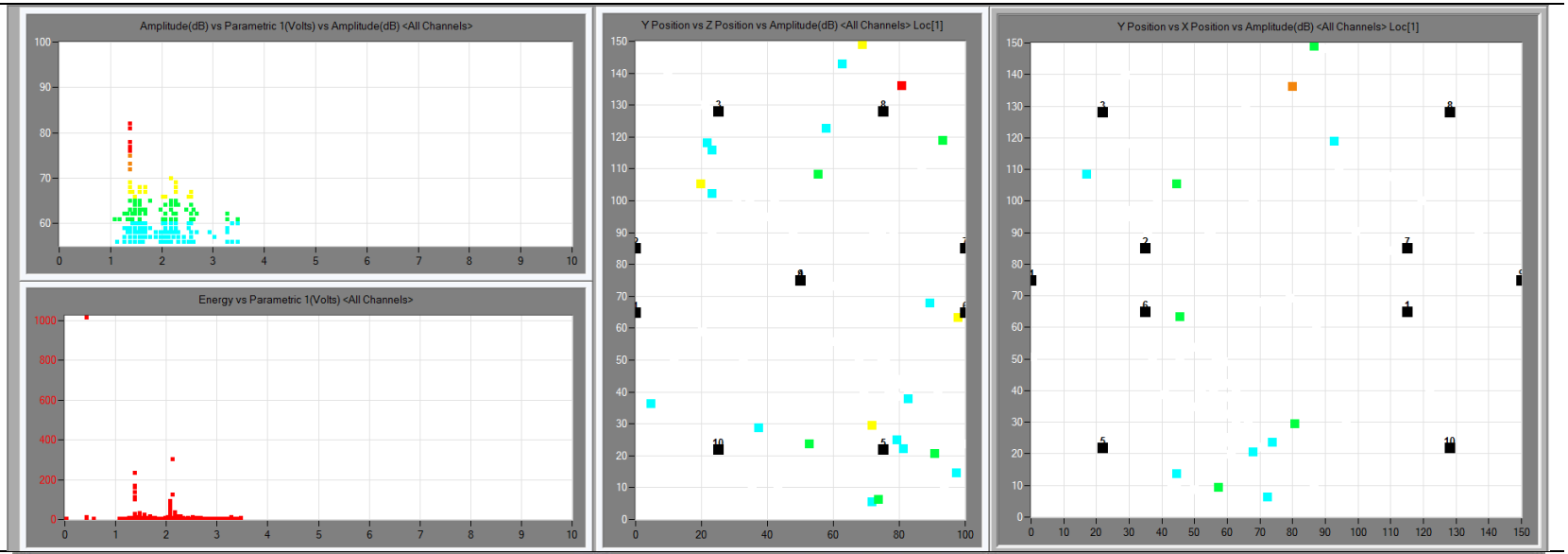
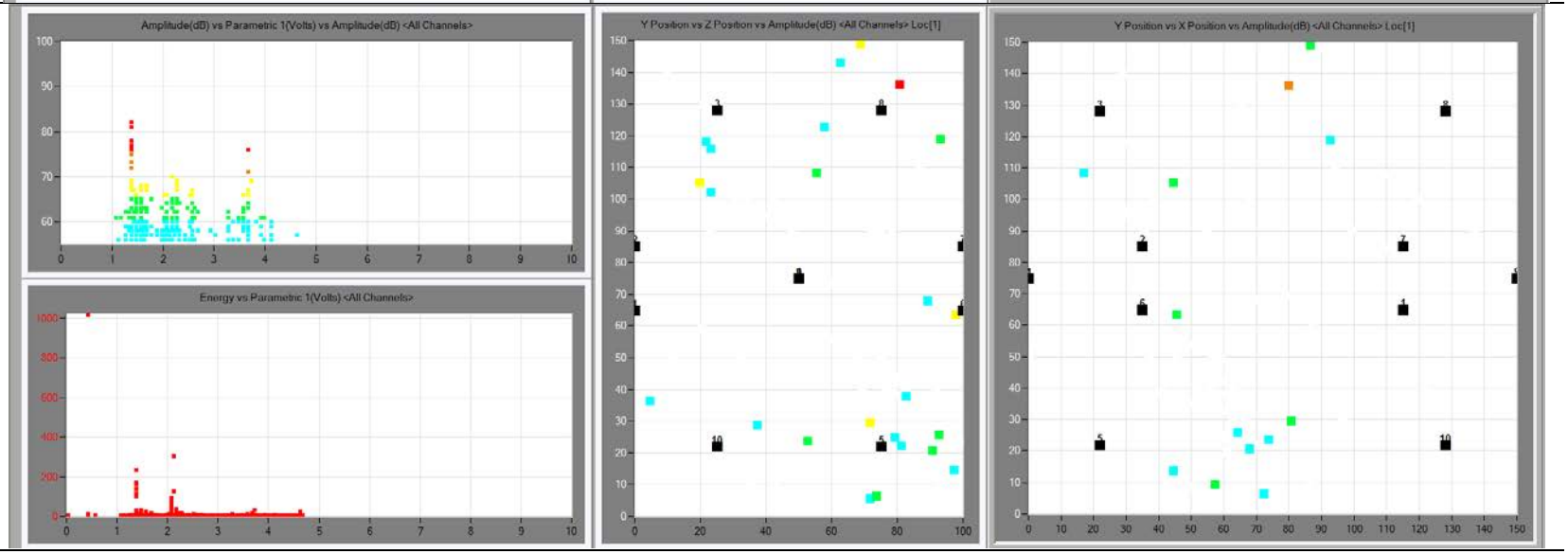
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0C1**
100%	

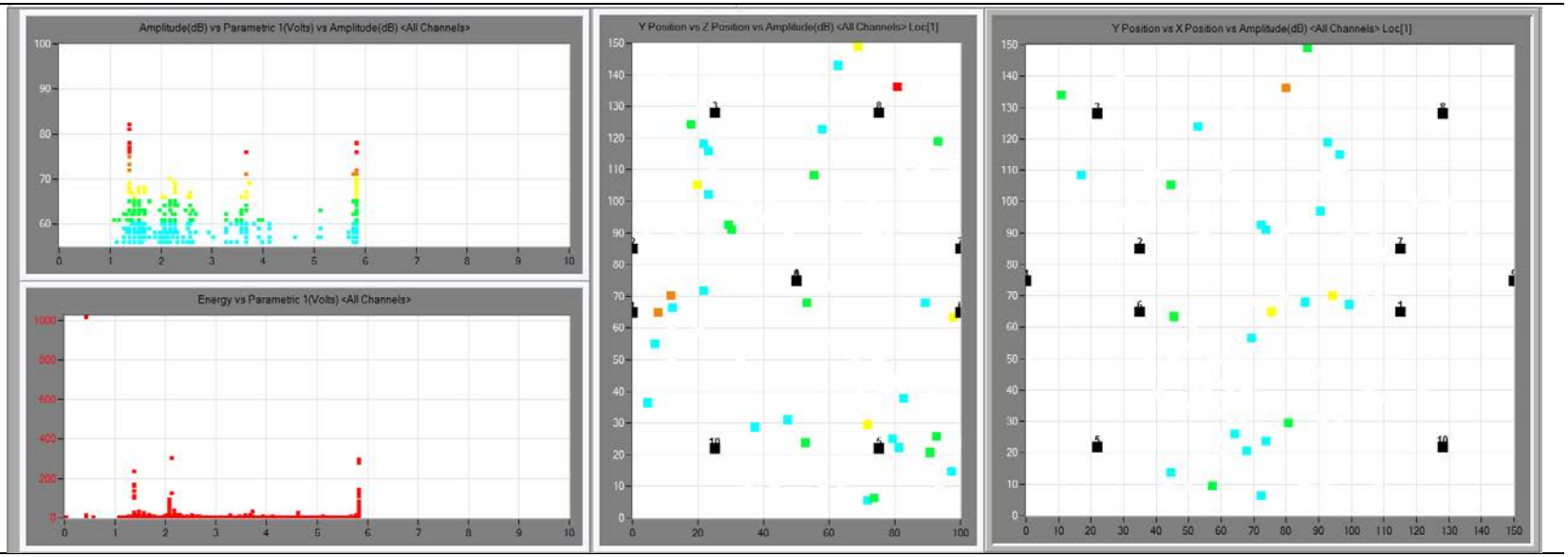
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0C2**
20%	
40%	

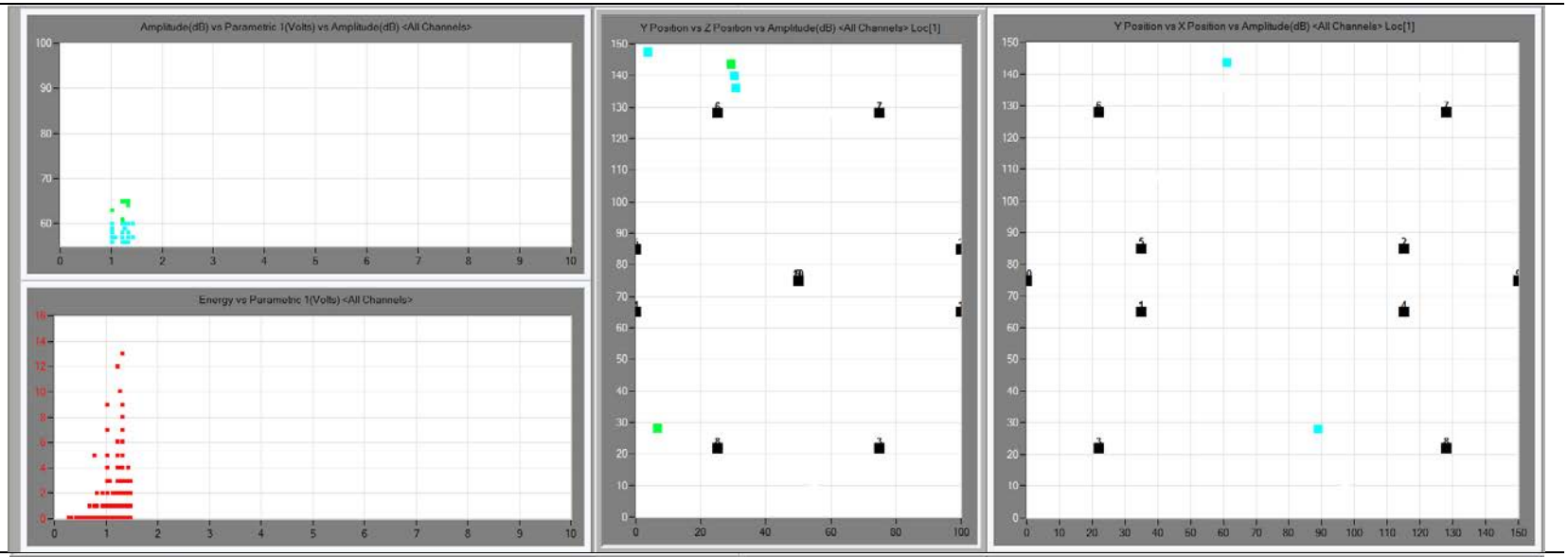
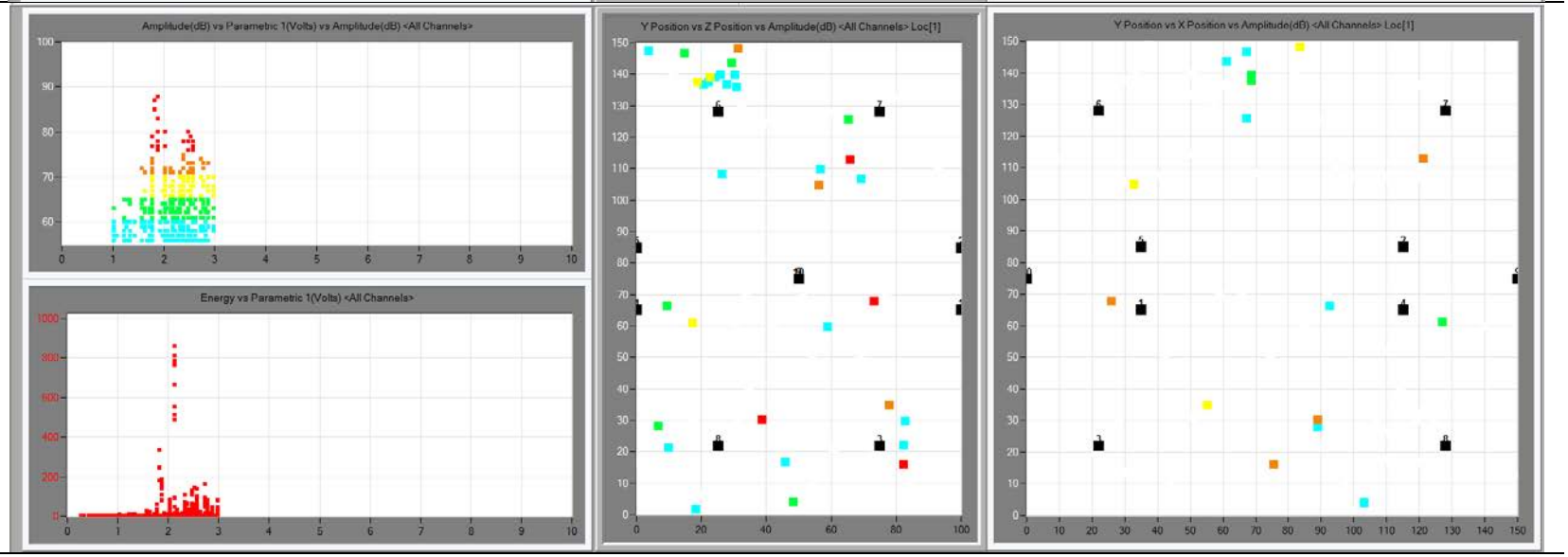
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0C2**
60%	
80%	

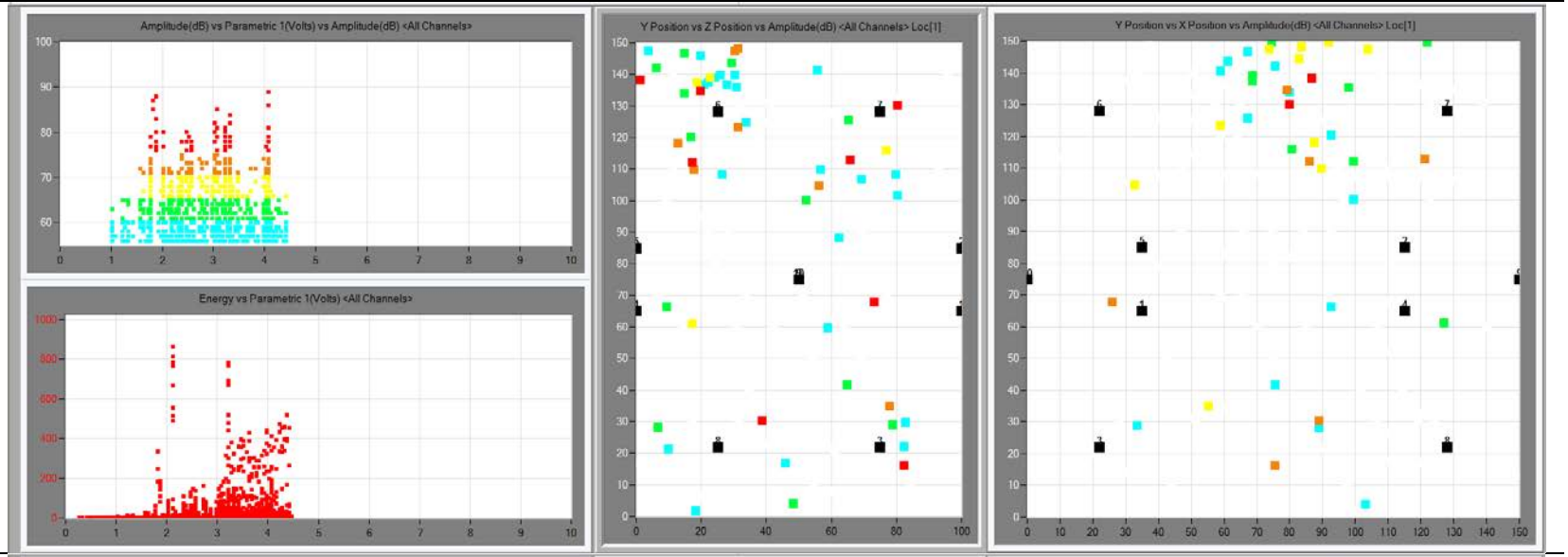
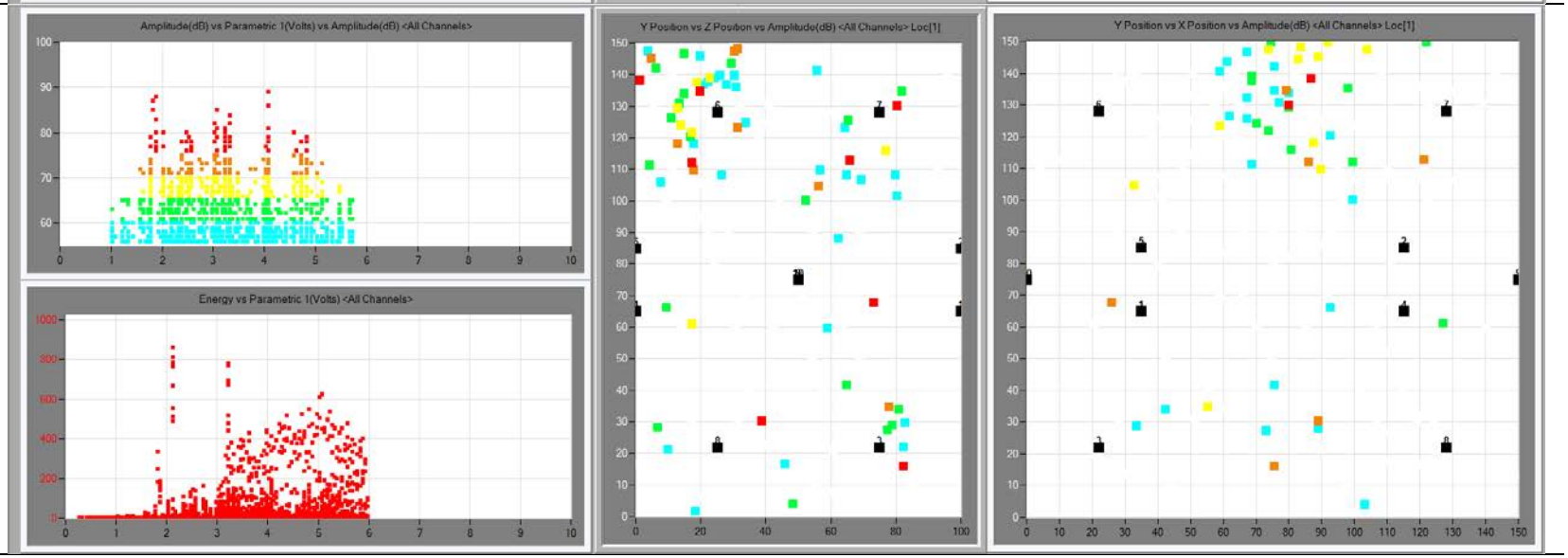
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0C2**
100%	

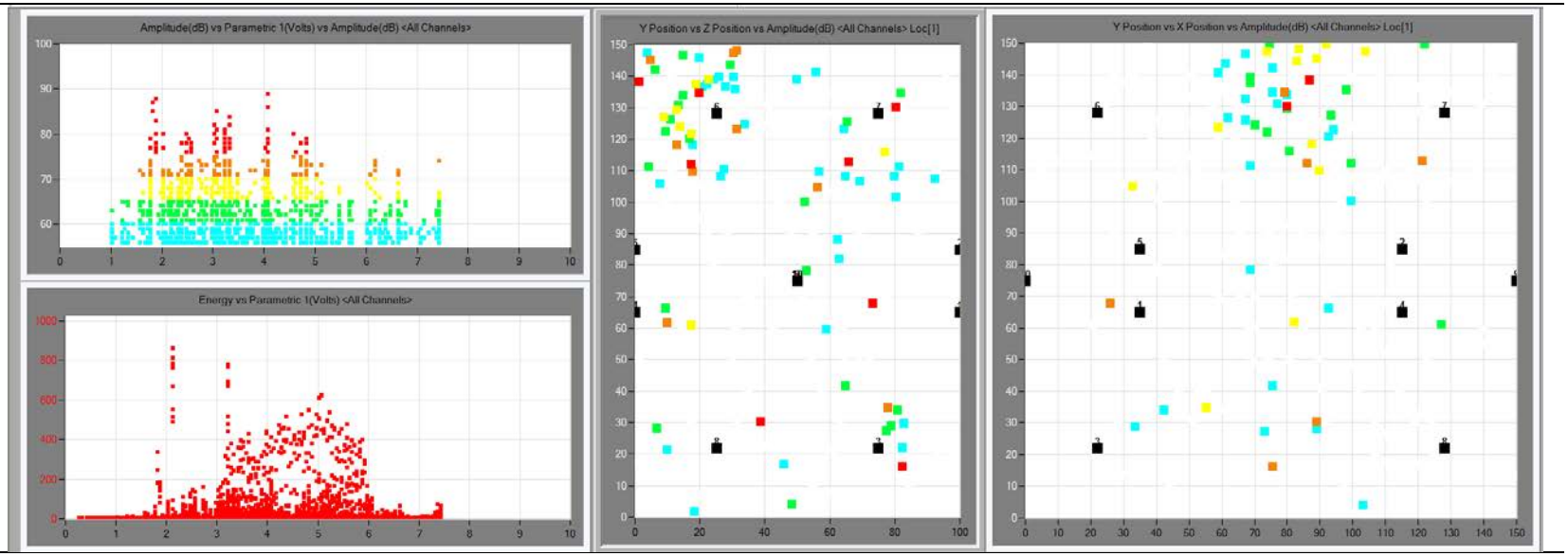
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0C3**
20%	
40%	

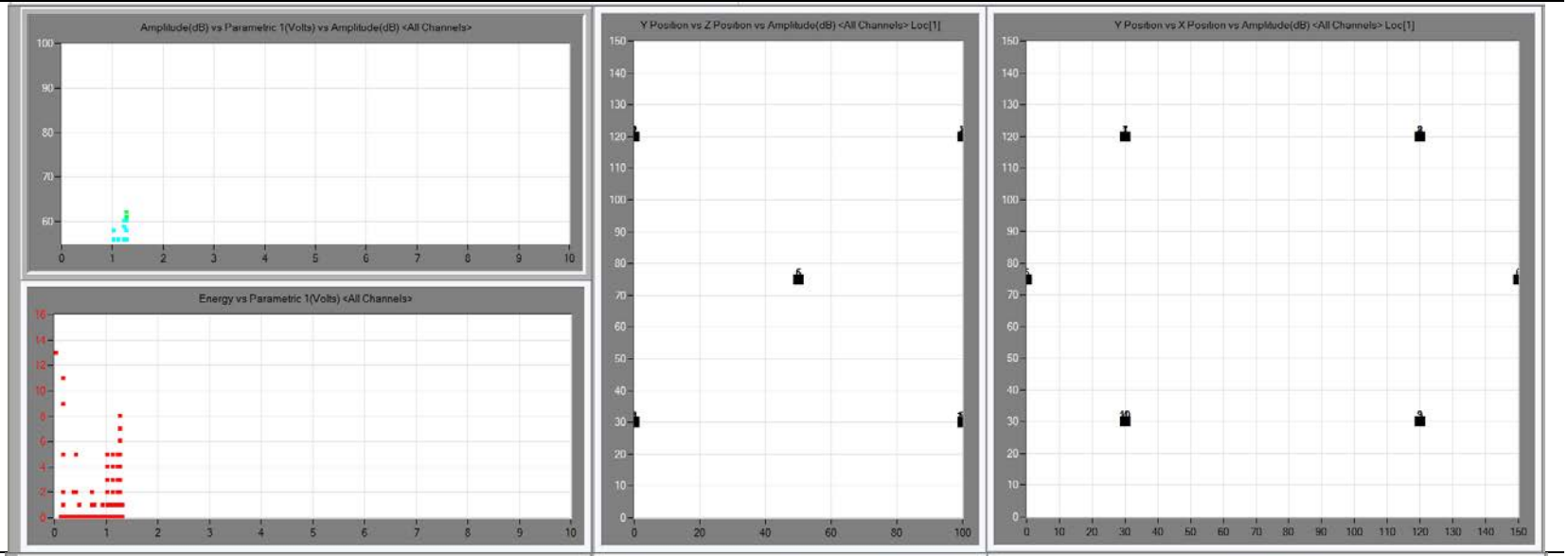
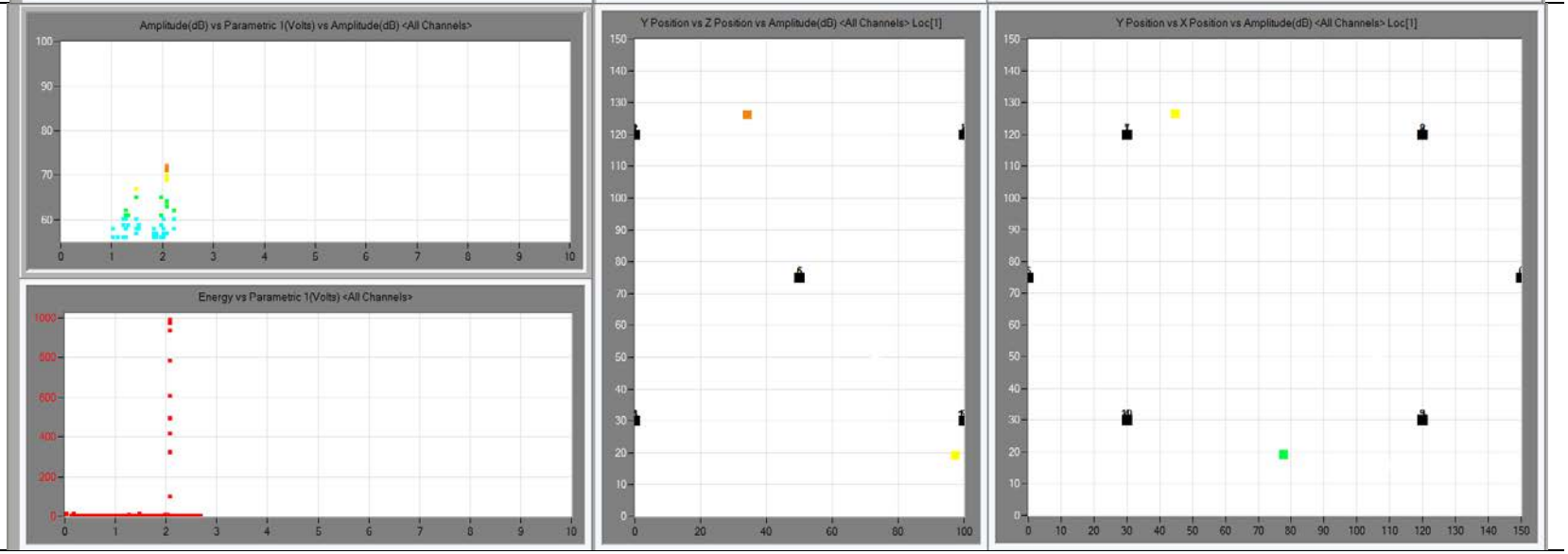
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0C3**
60%	
80%	

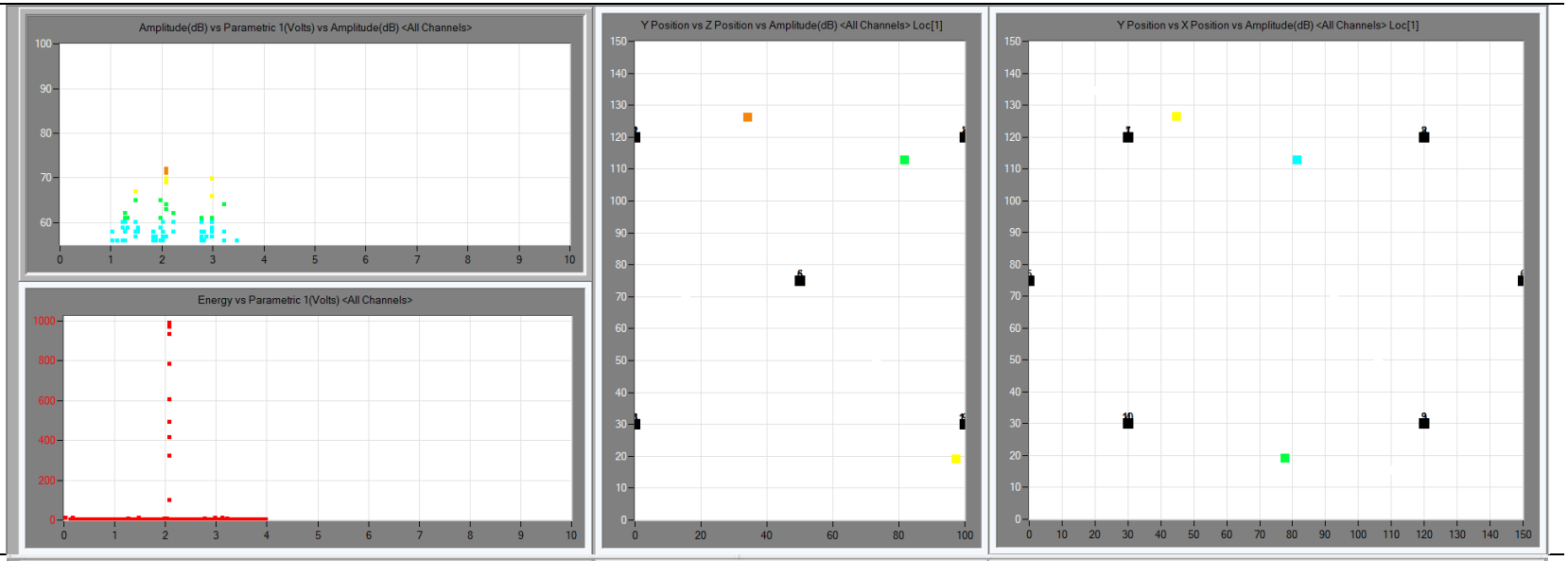
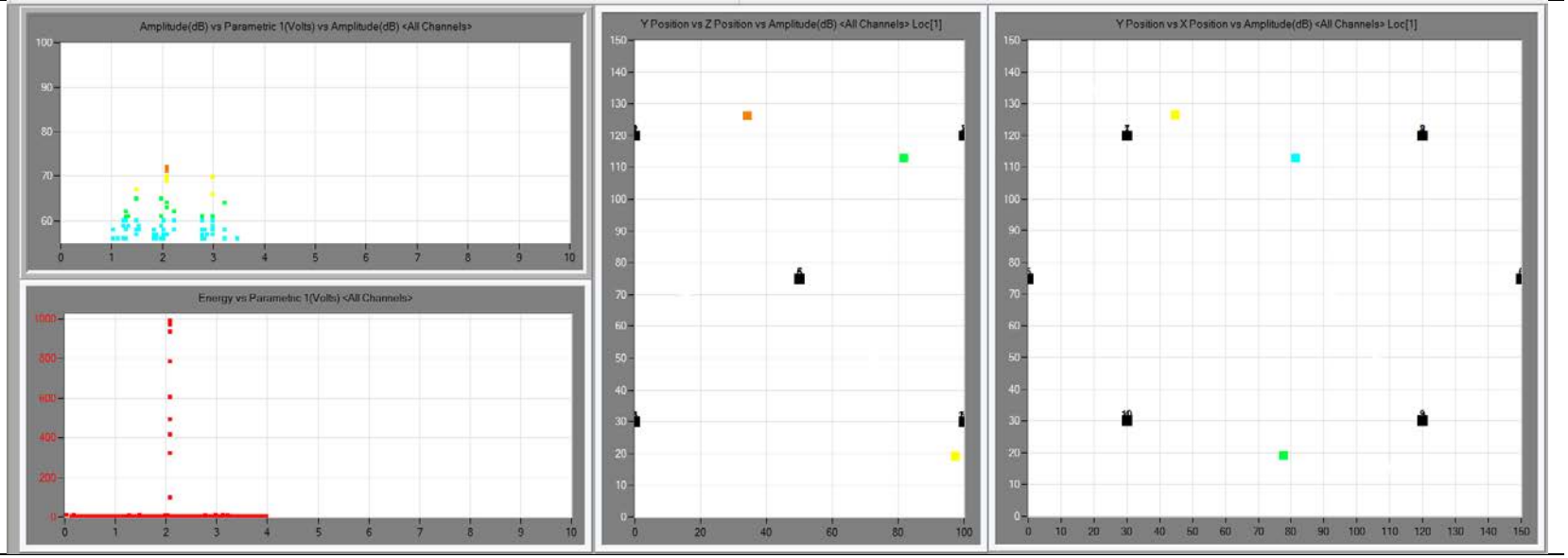
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0C3**
100%	

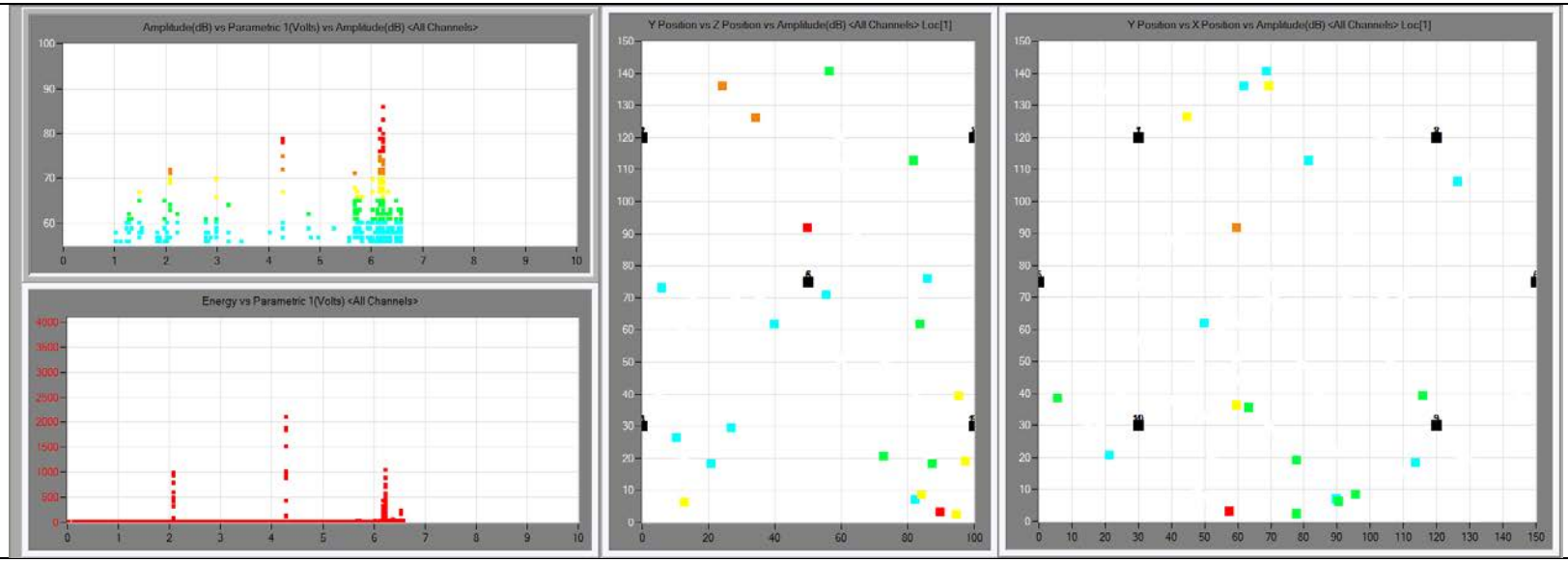
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2C1**
20%	
40%	

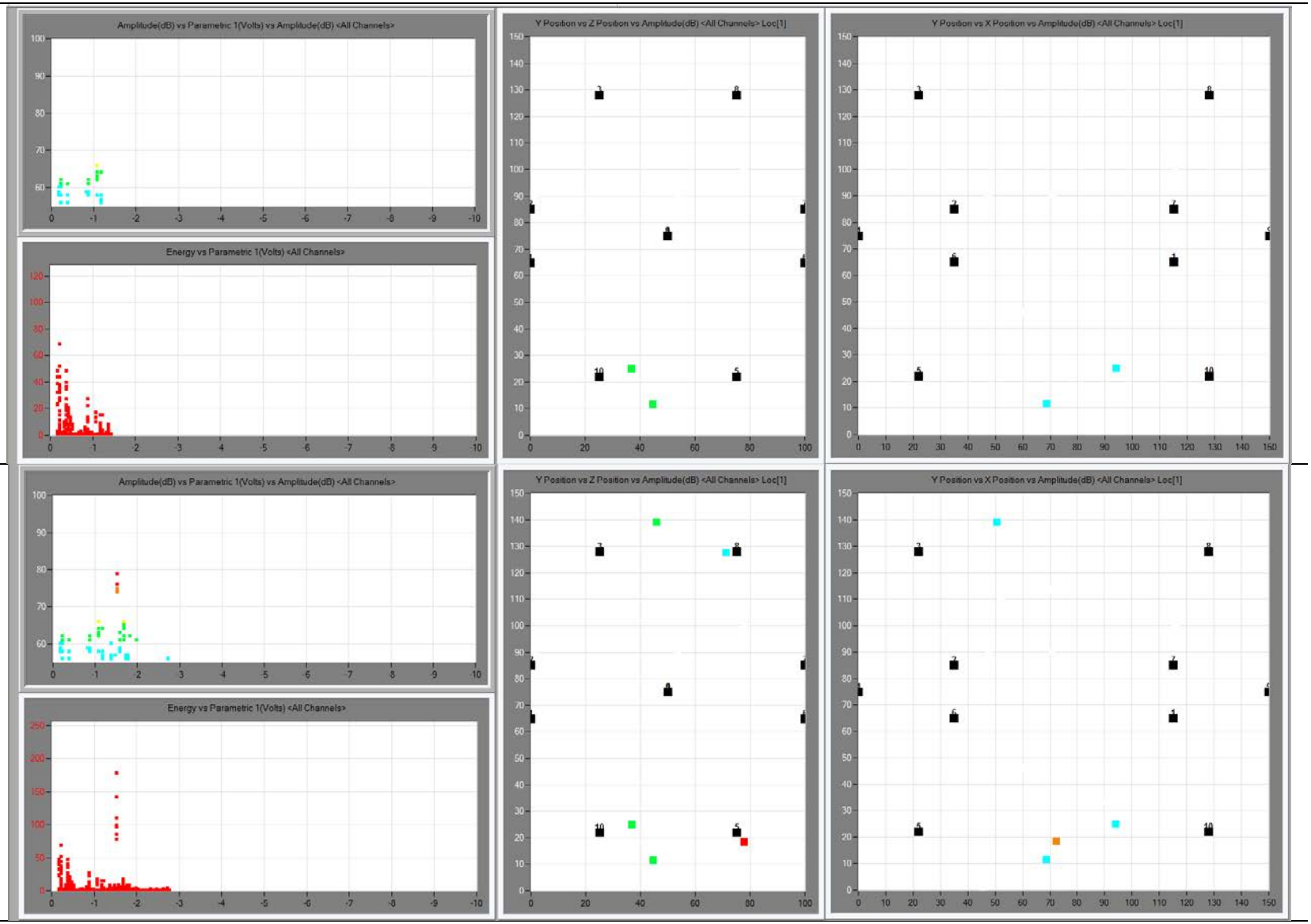
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2C1**
60%	
80%	

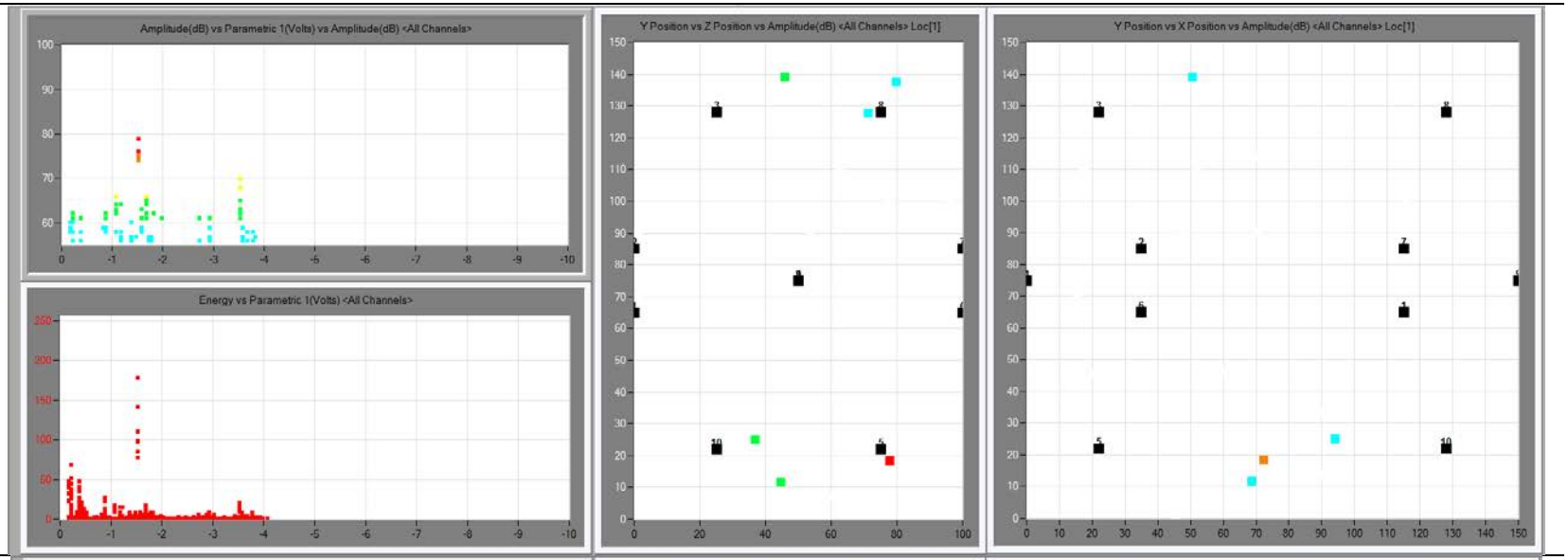
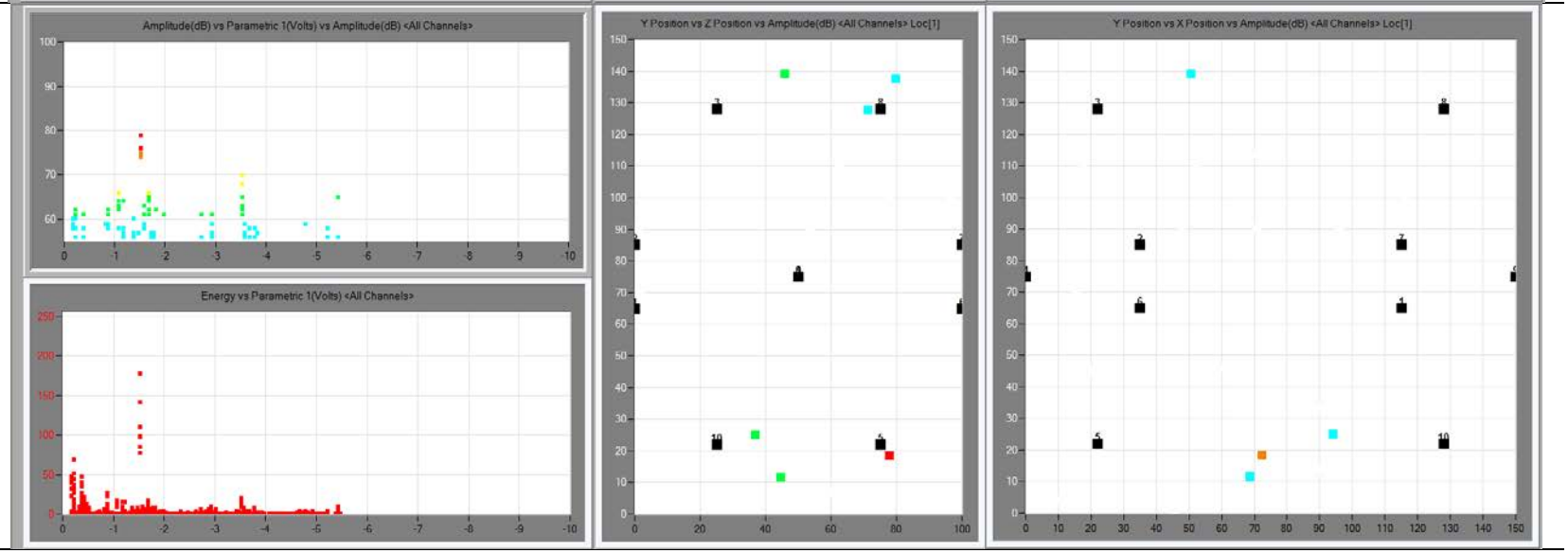
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2C1**
100%	

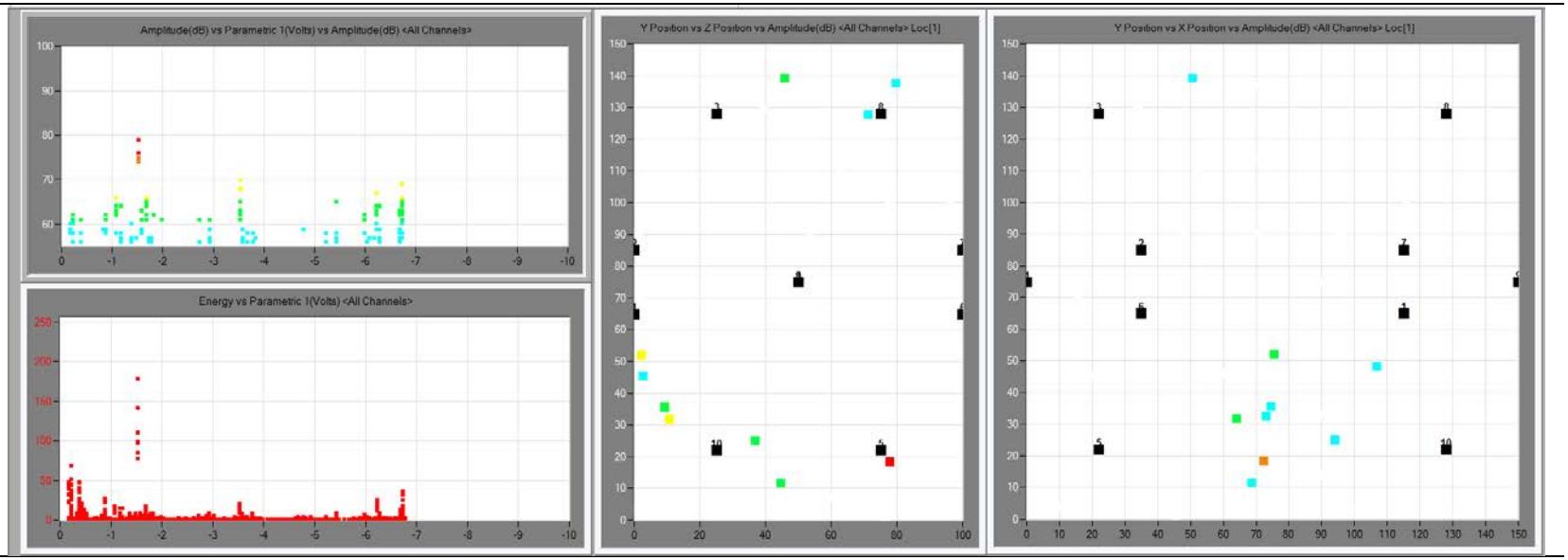
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2C2**
20%	
40%	

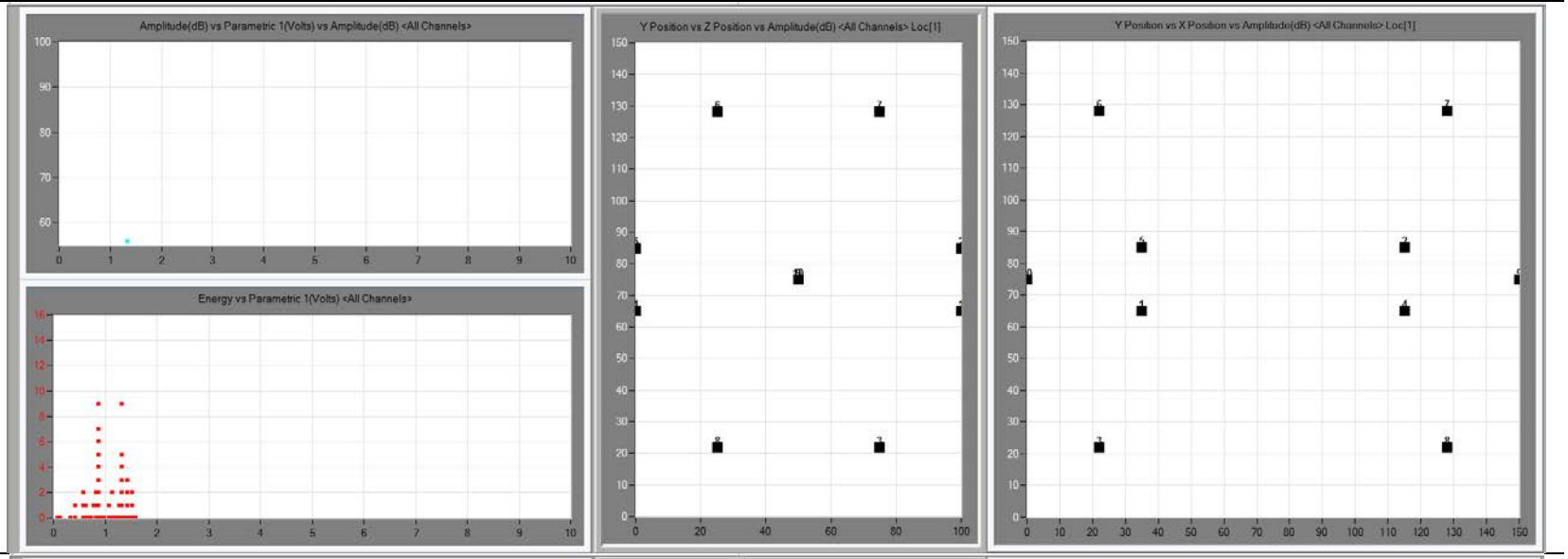
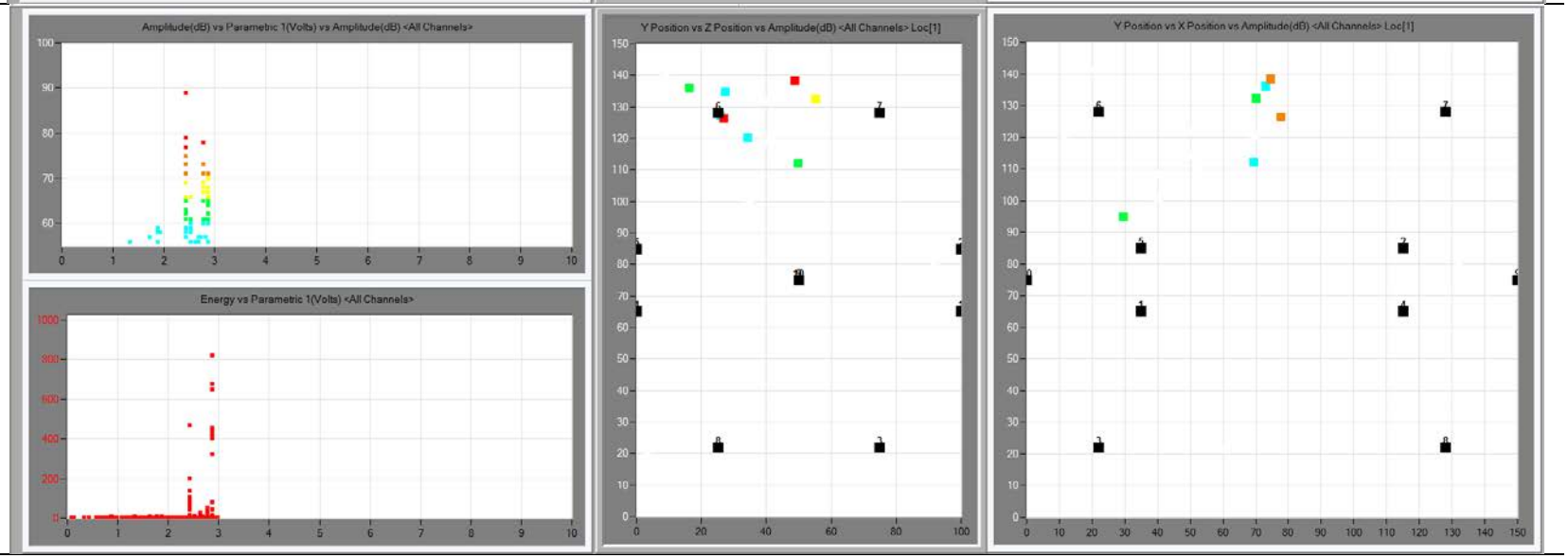
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2C2**
60%	
80%	

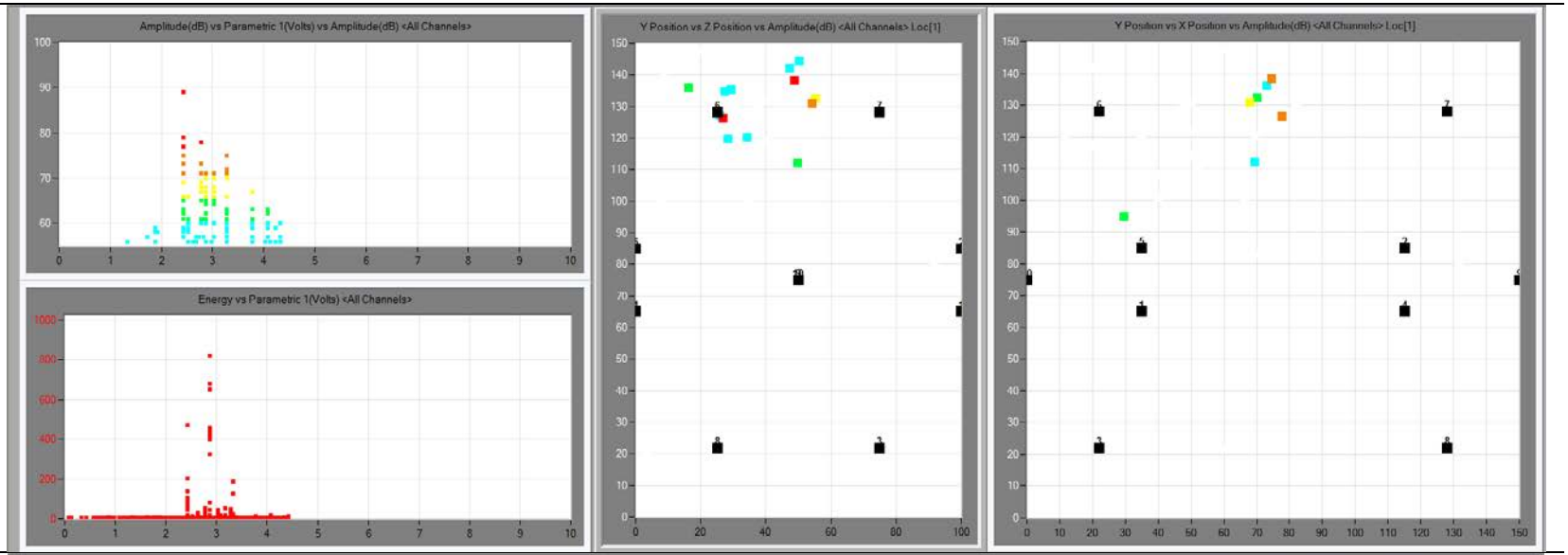
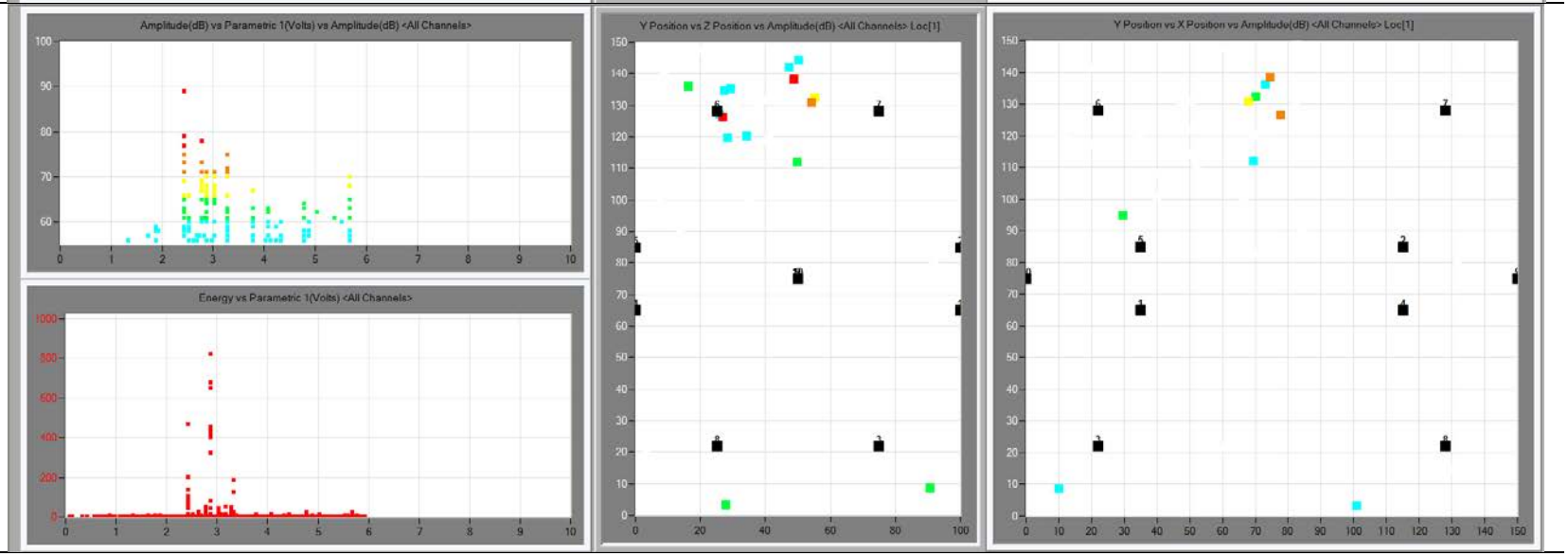
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2C2**
100%	

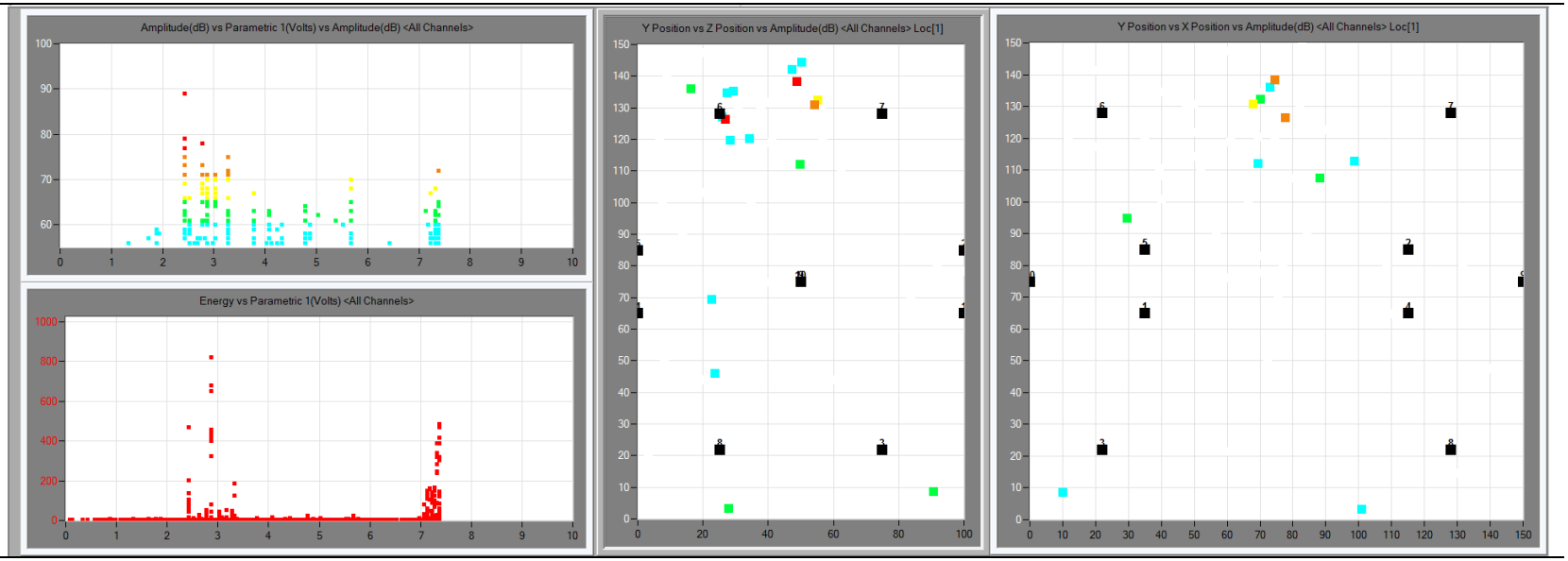
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2C3**
20%	
40%	

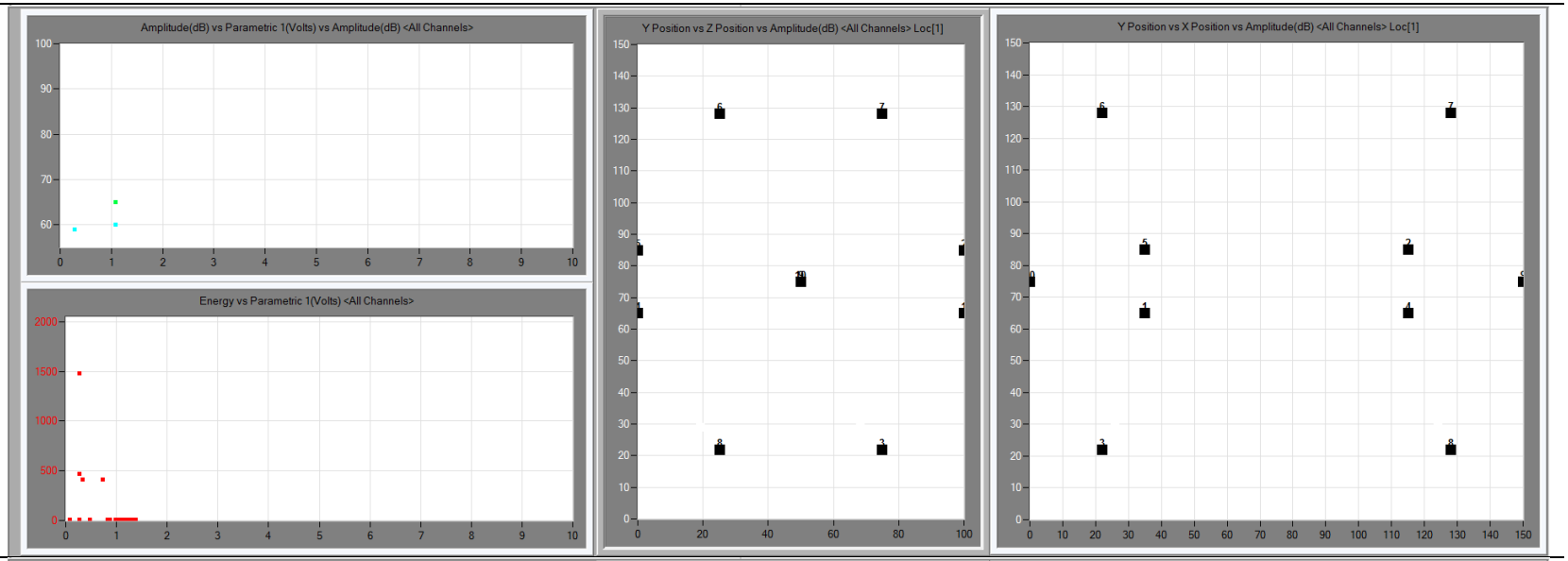
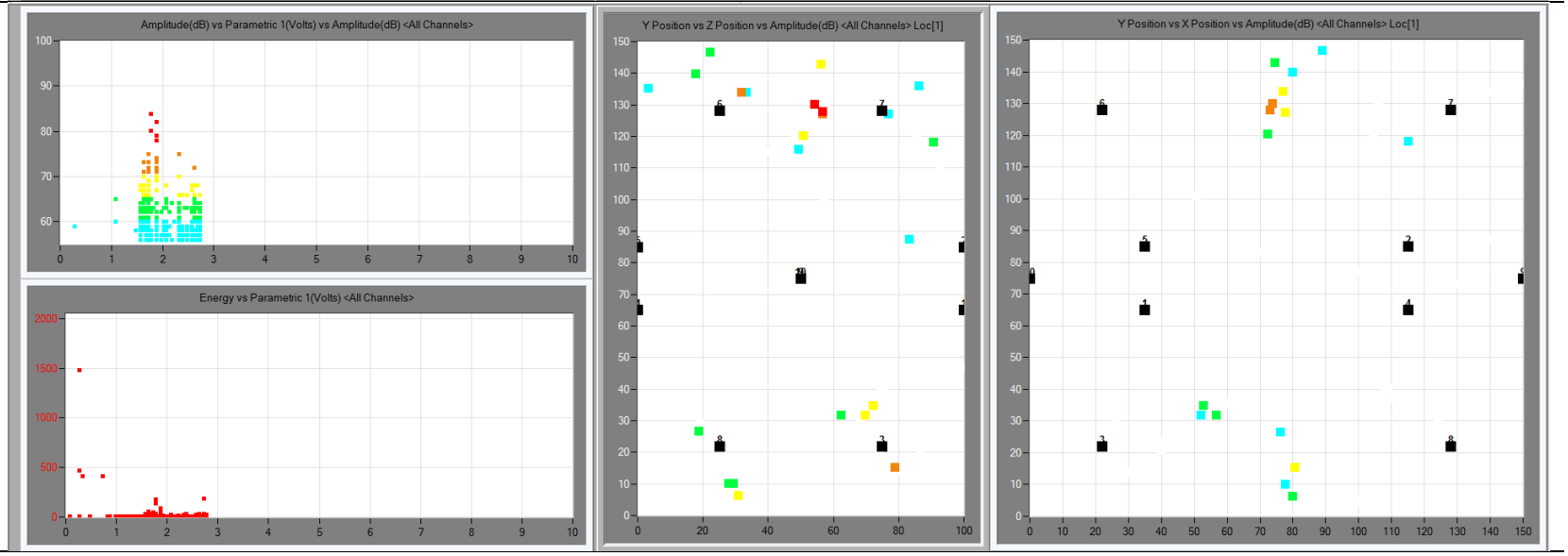
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2C3**
60%	
80%	

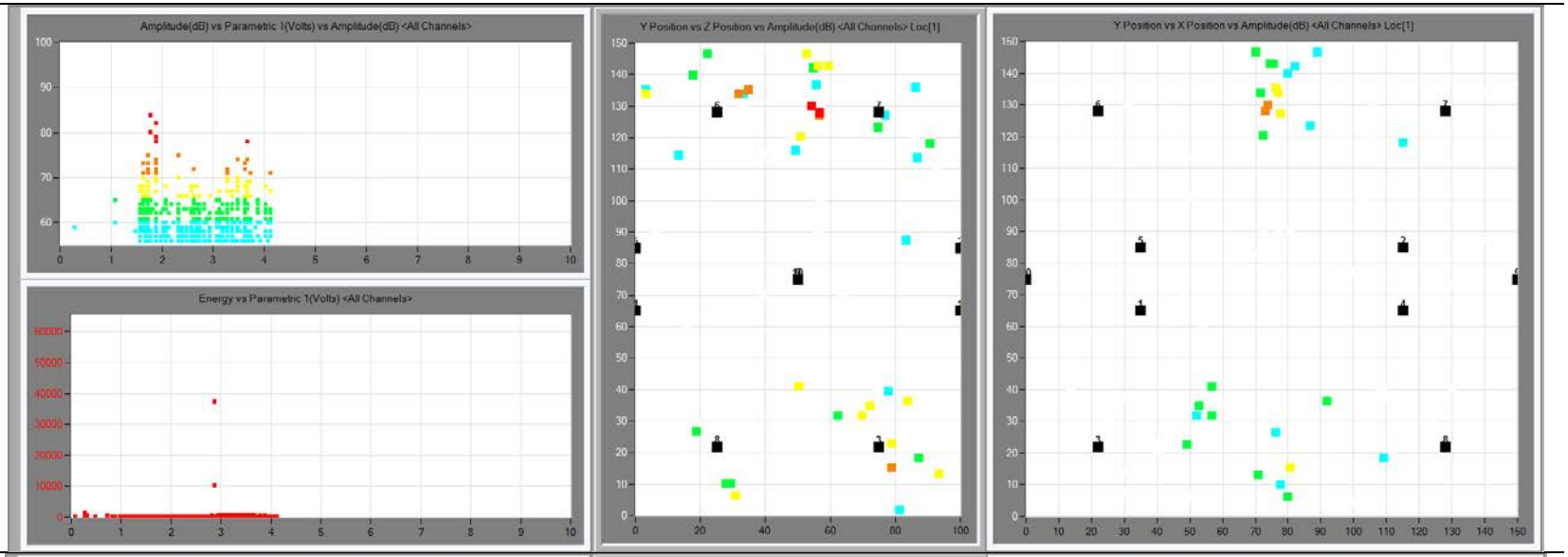
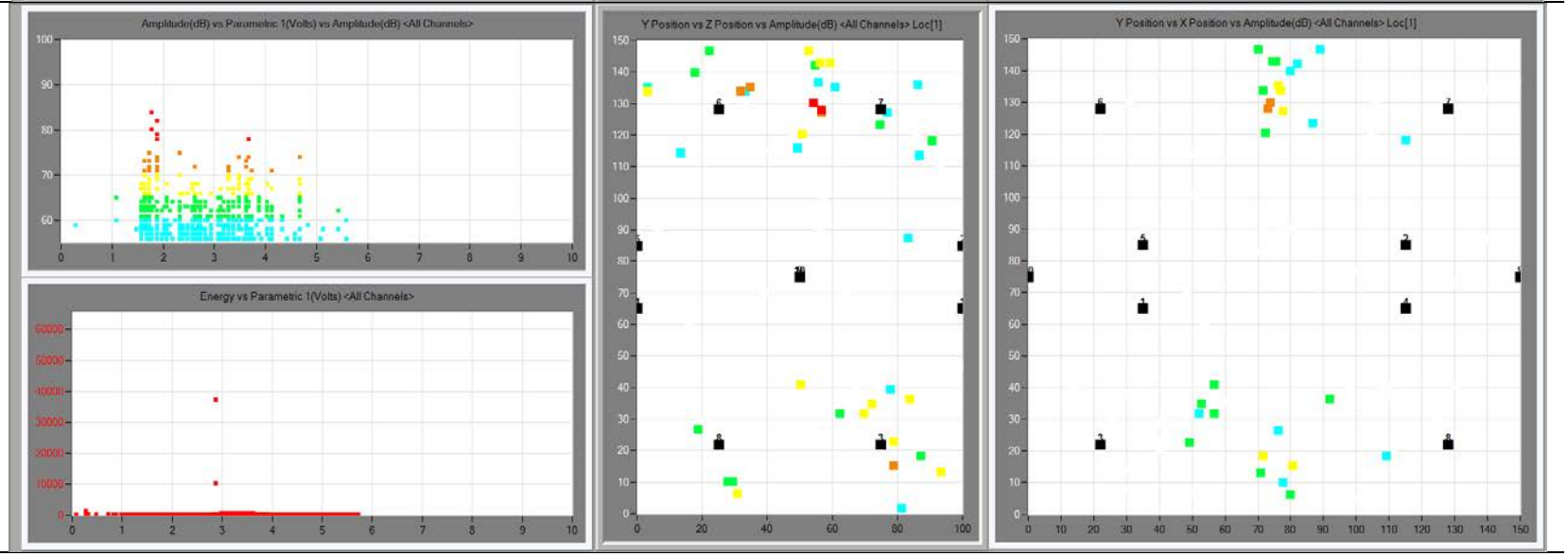
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2C3**
100%	

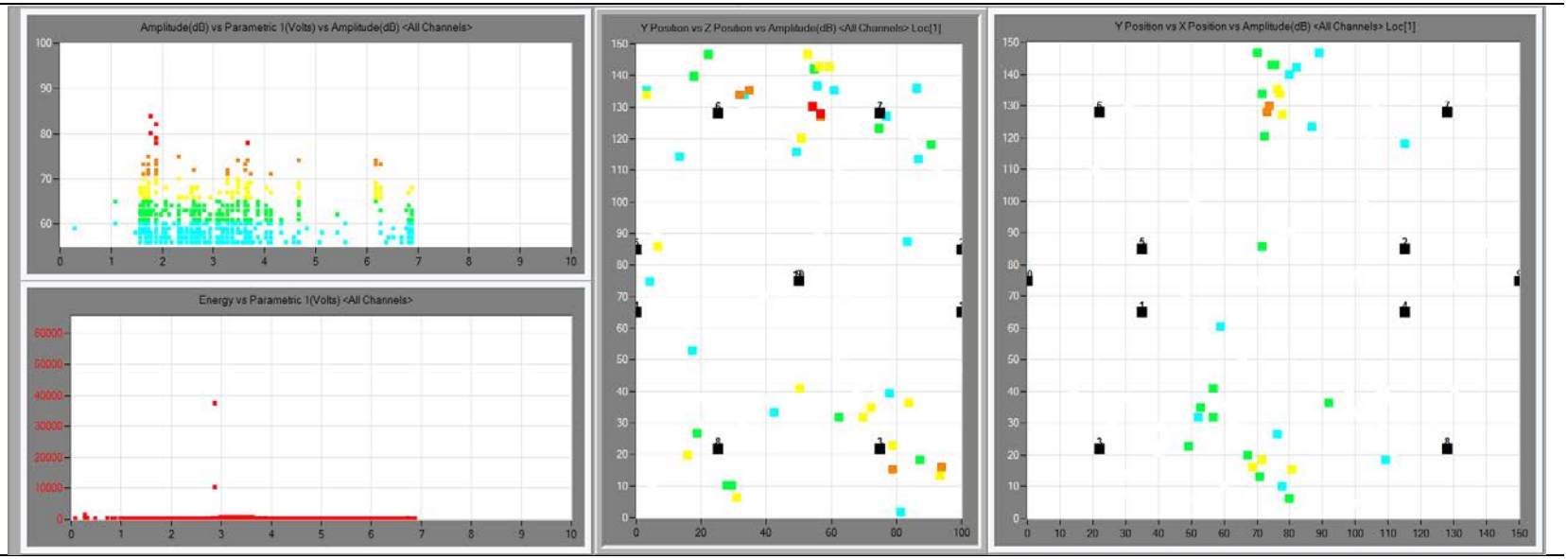
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5C1**
20%	
40%	

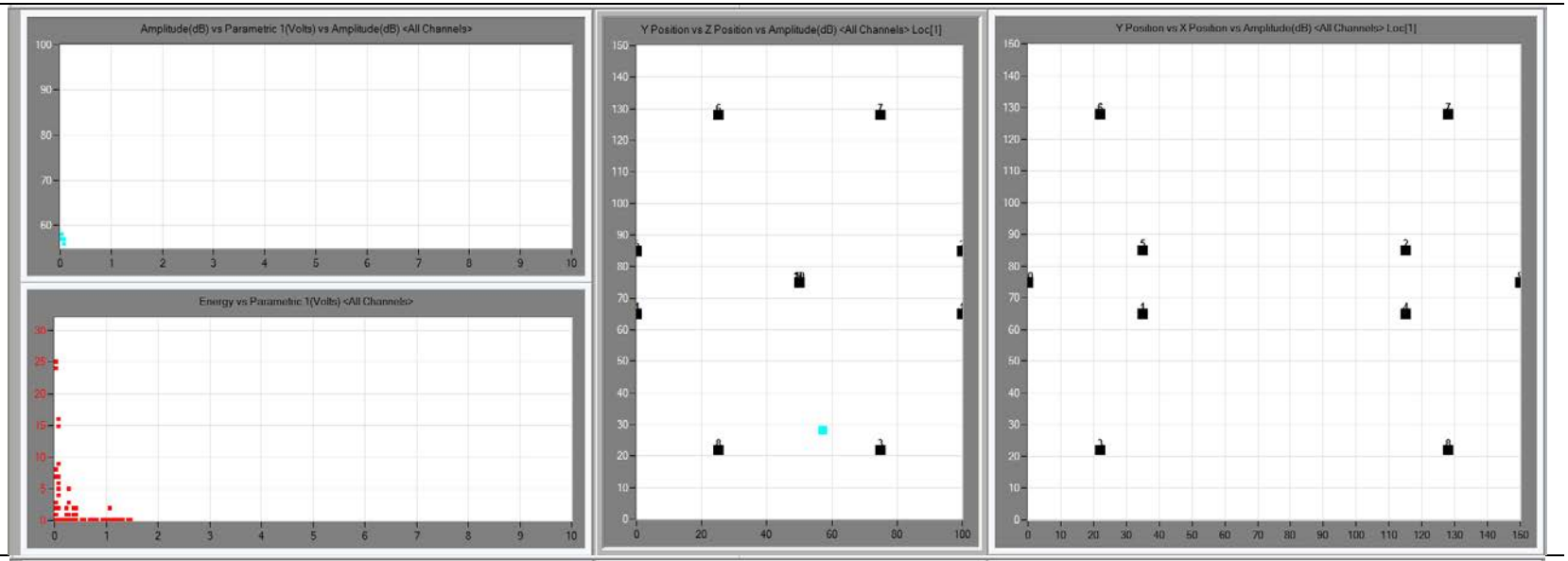
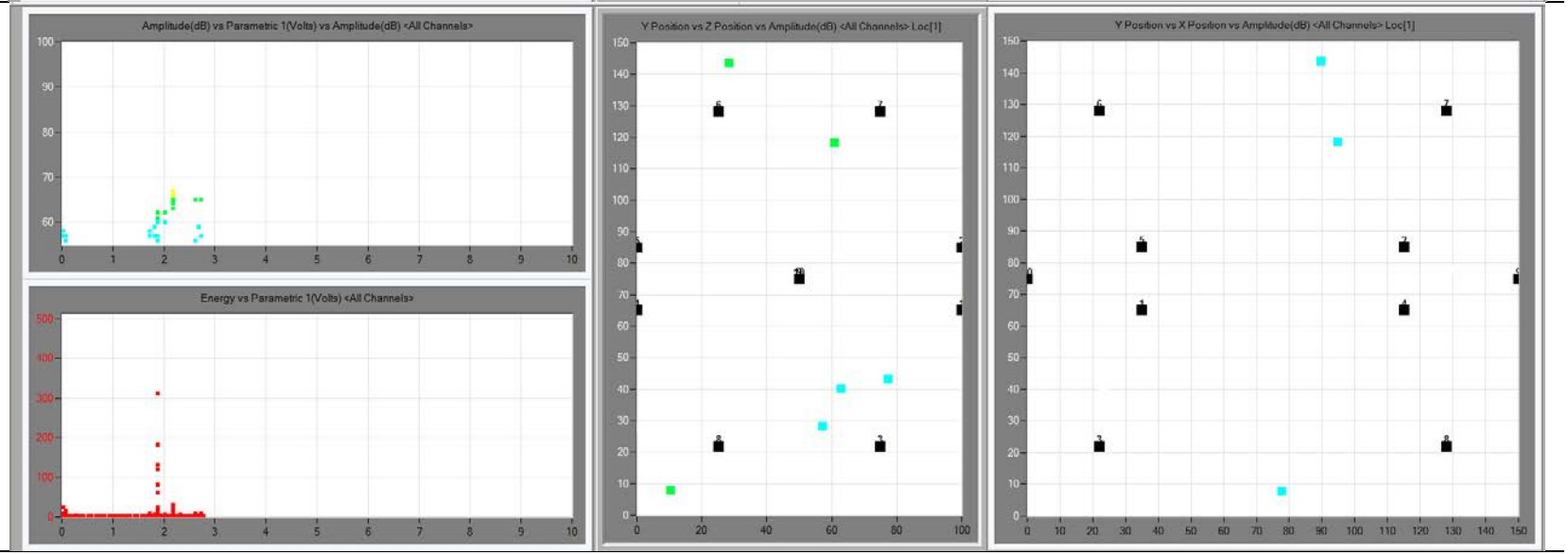
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5C1**
60%	
80%	

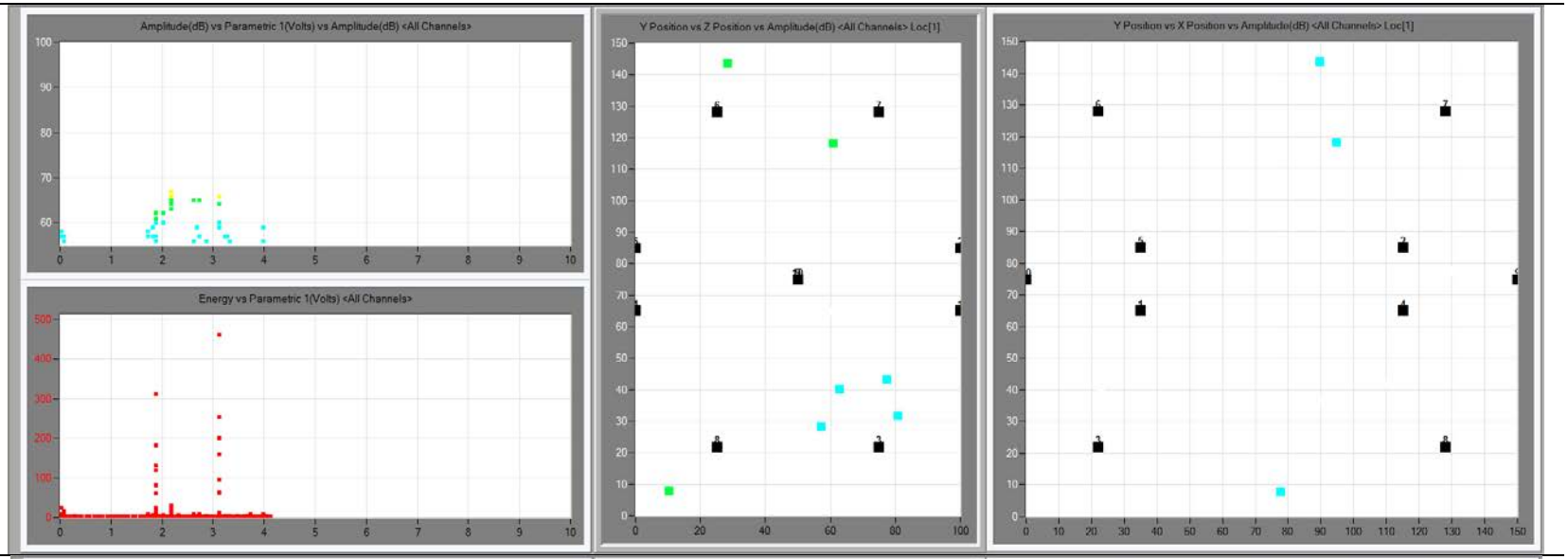
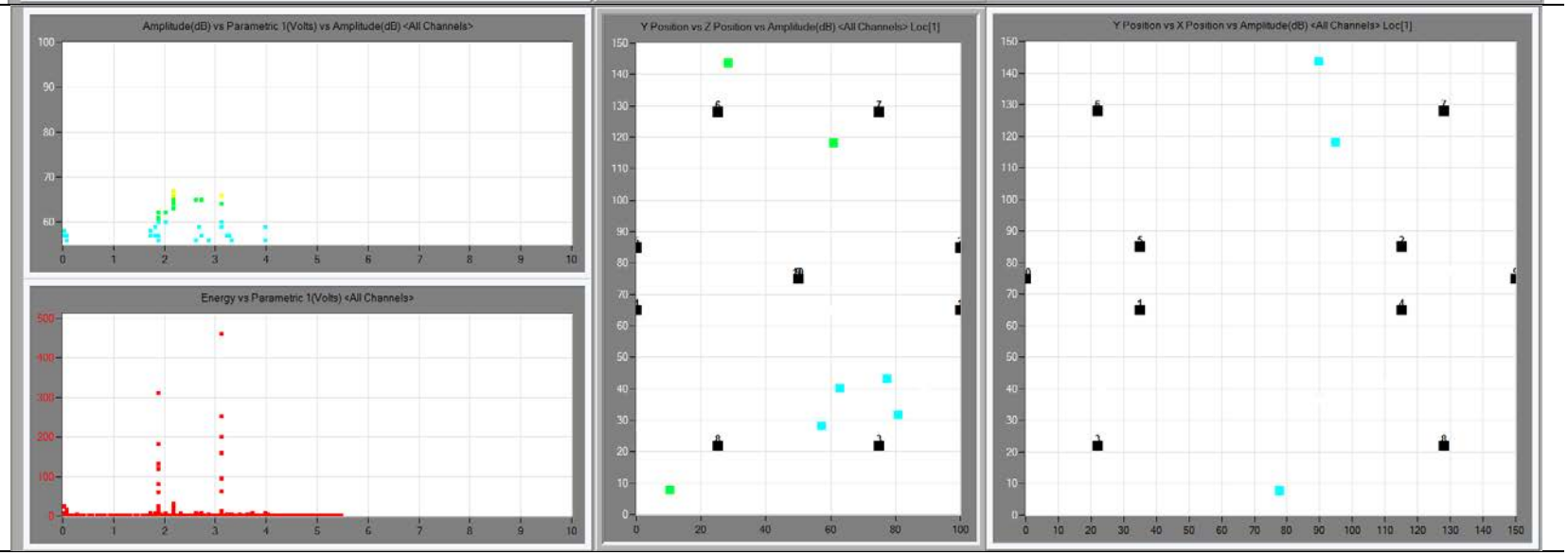
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5C1**
100%	

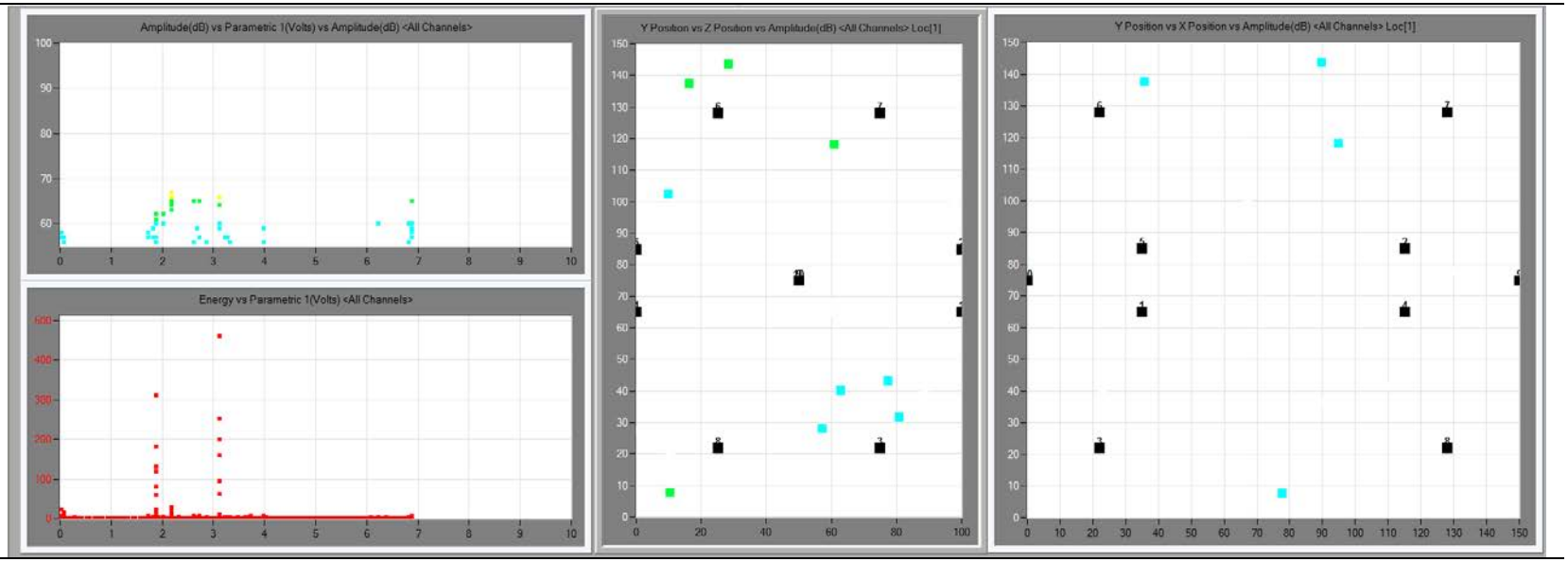
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5C2**
20%	
40%	

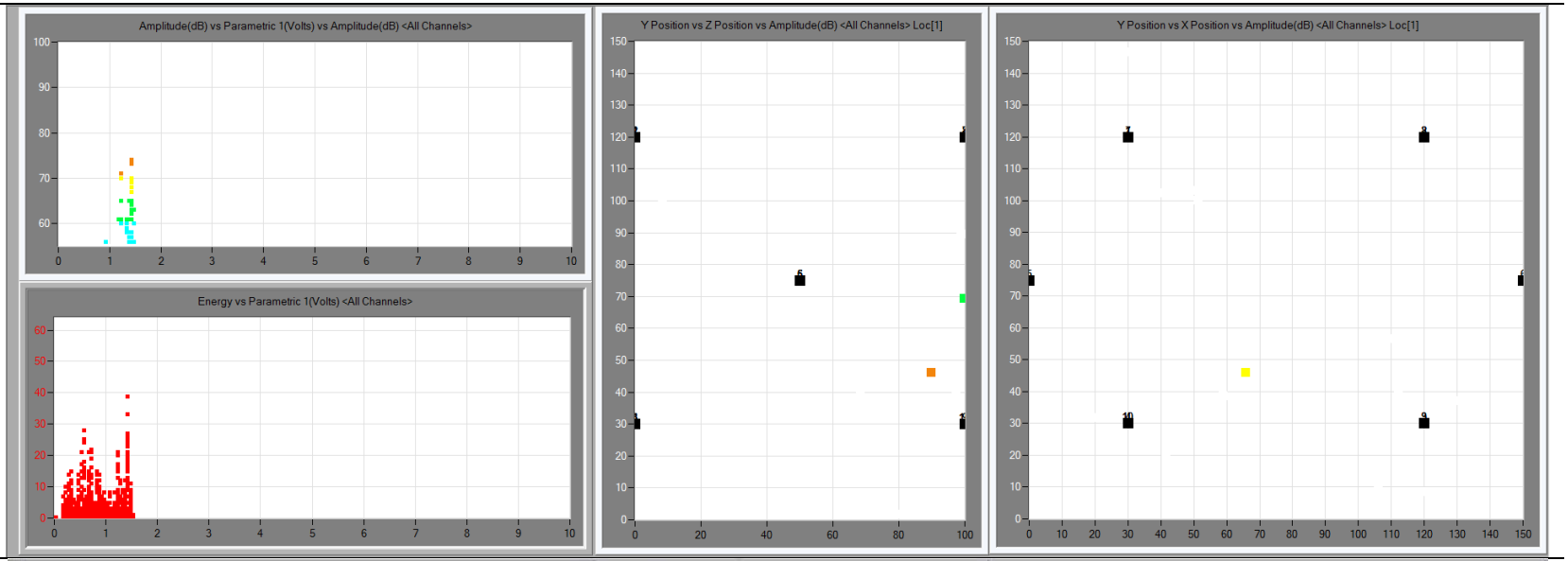
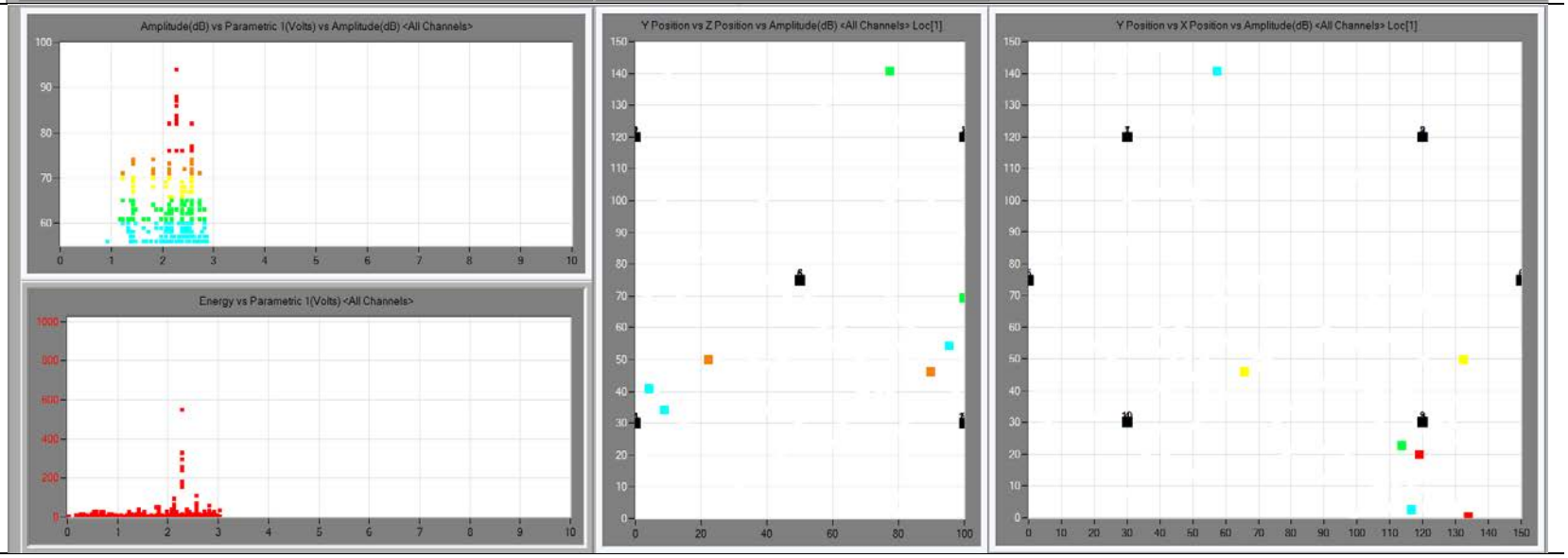
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5C2**
60%	
80%	

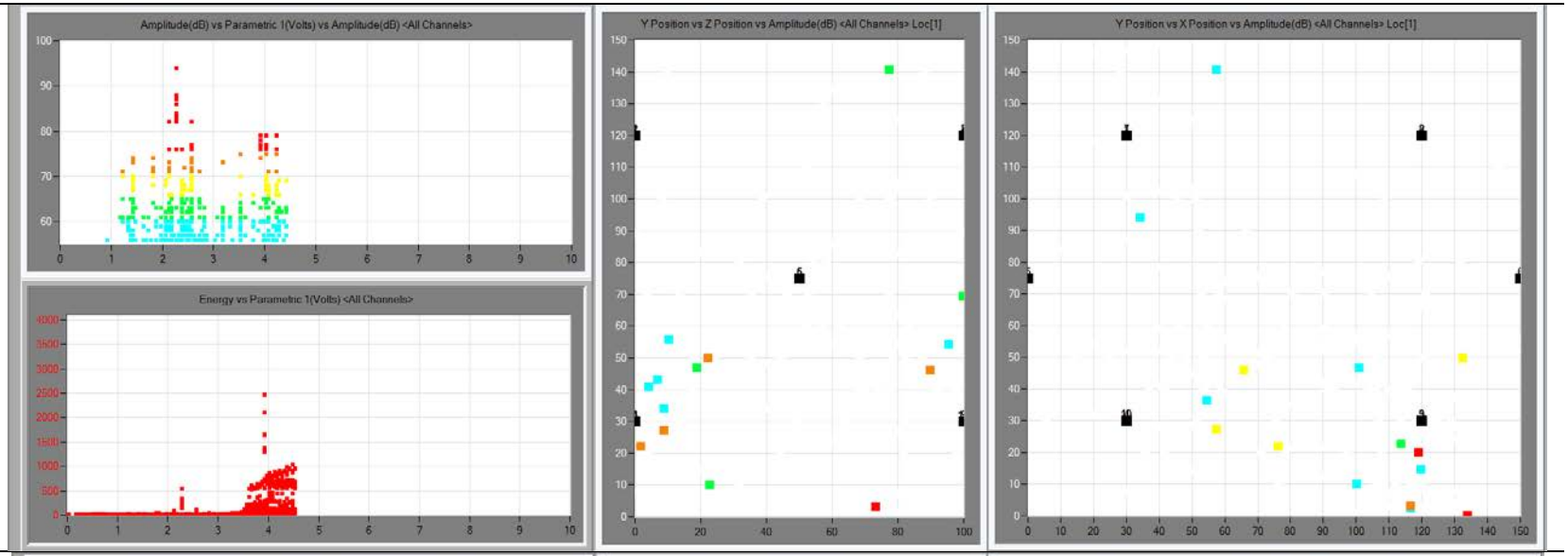
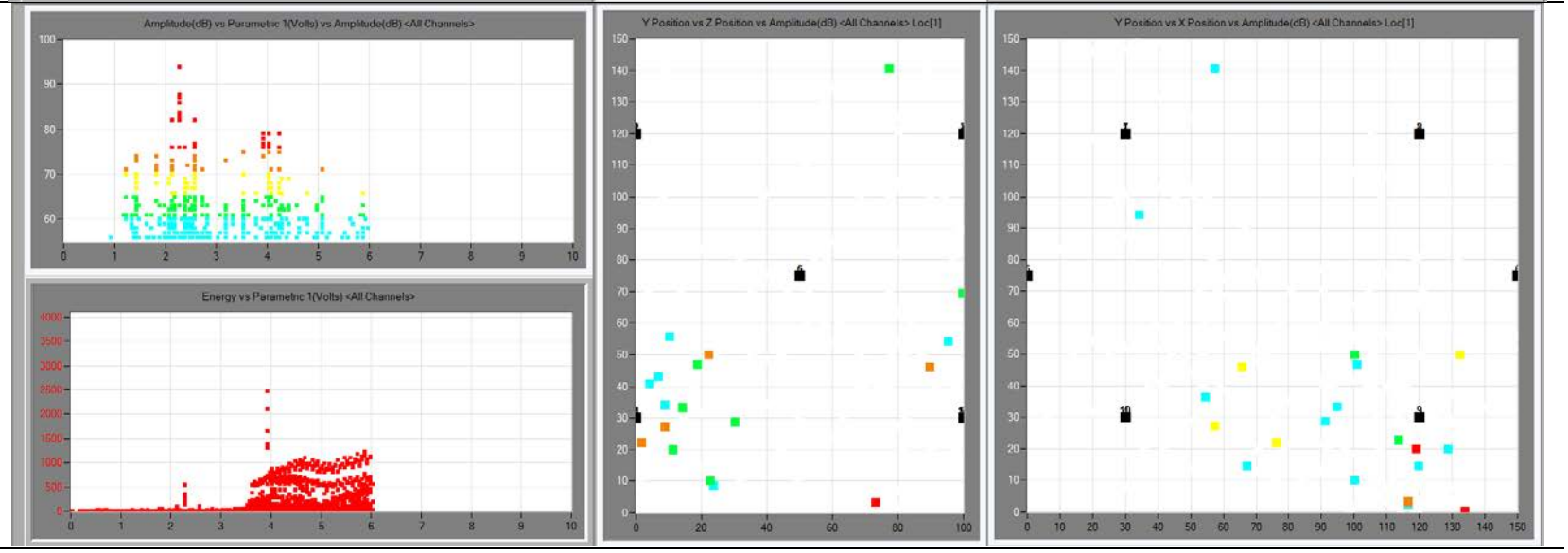
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5C2**
100%	

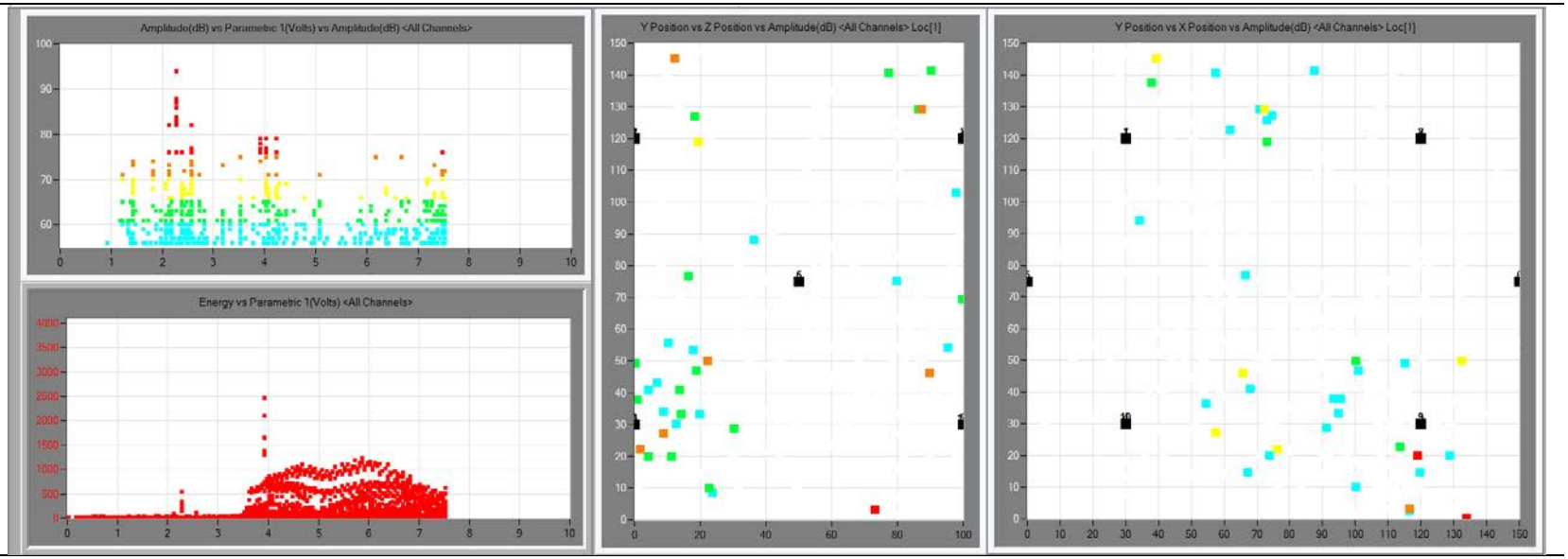
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5C3**
20%	
40%	

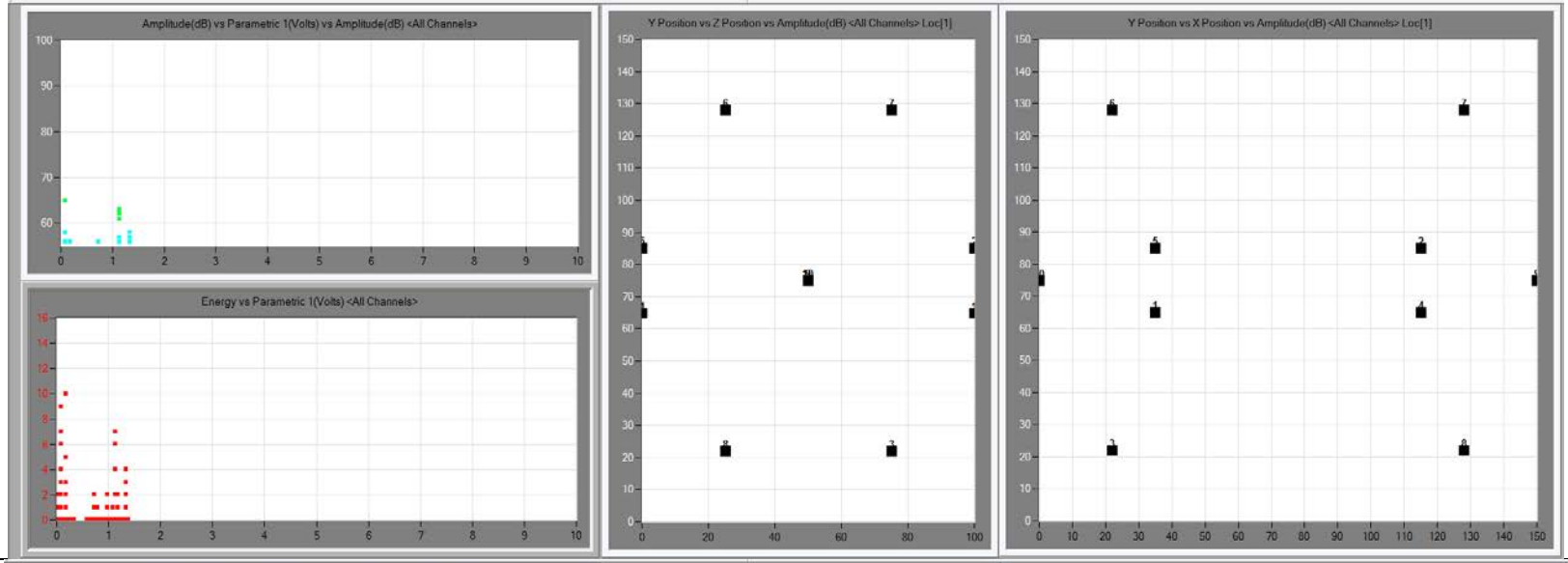
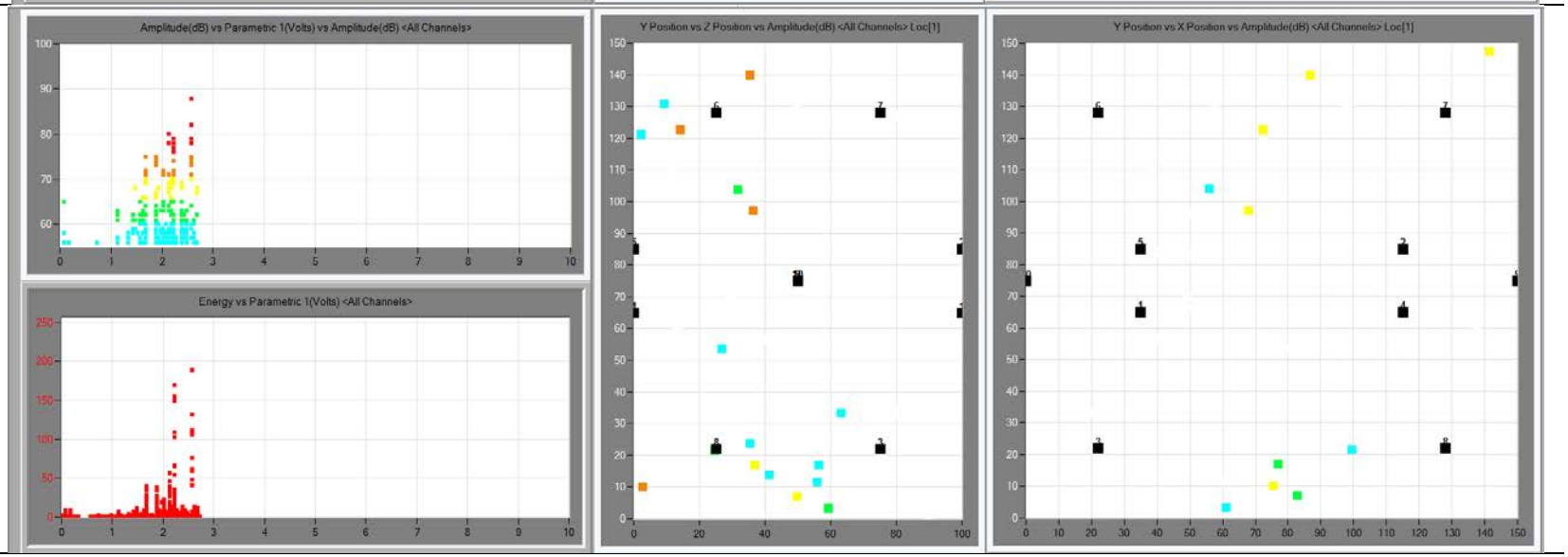
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5C3**
60%	
80%	

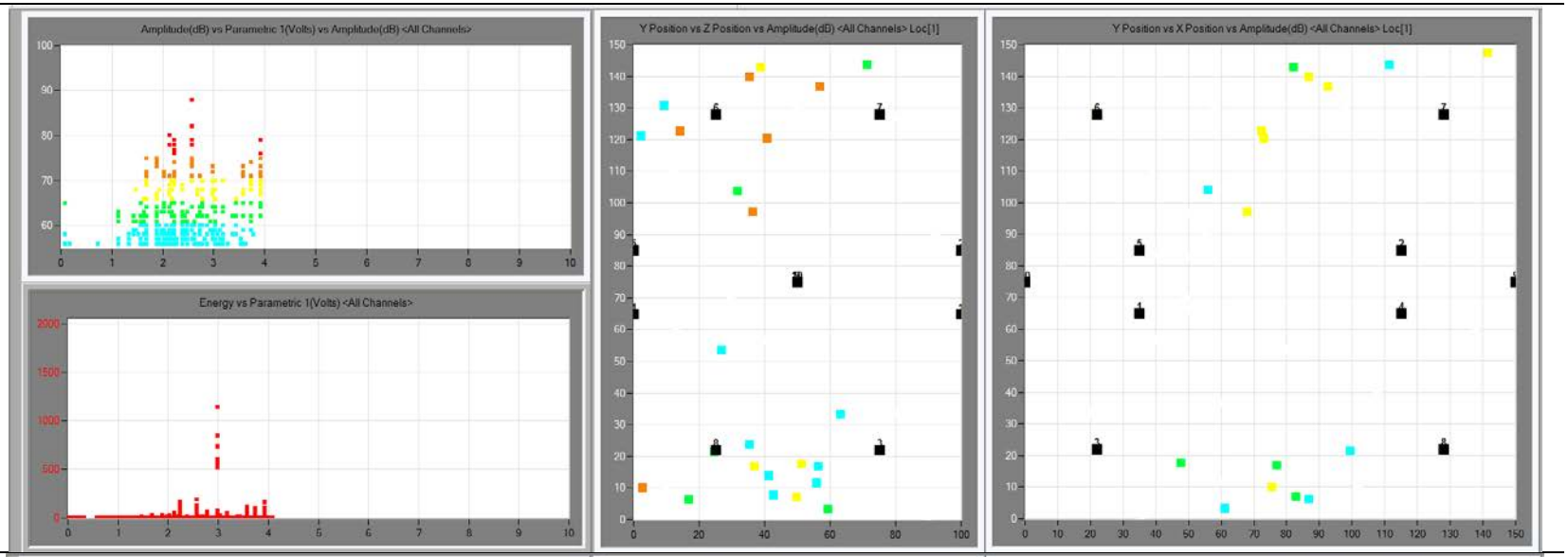
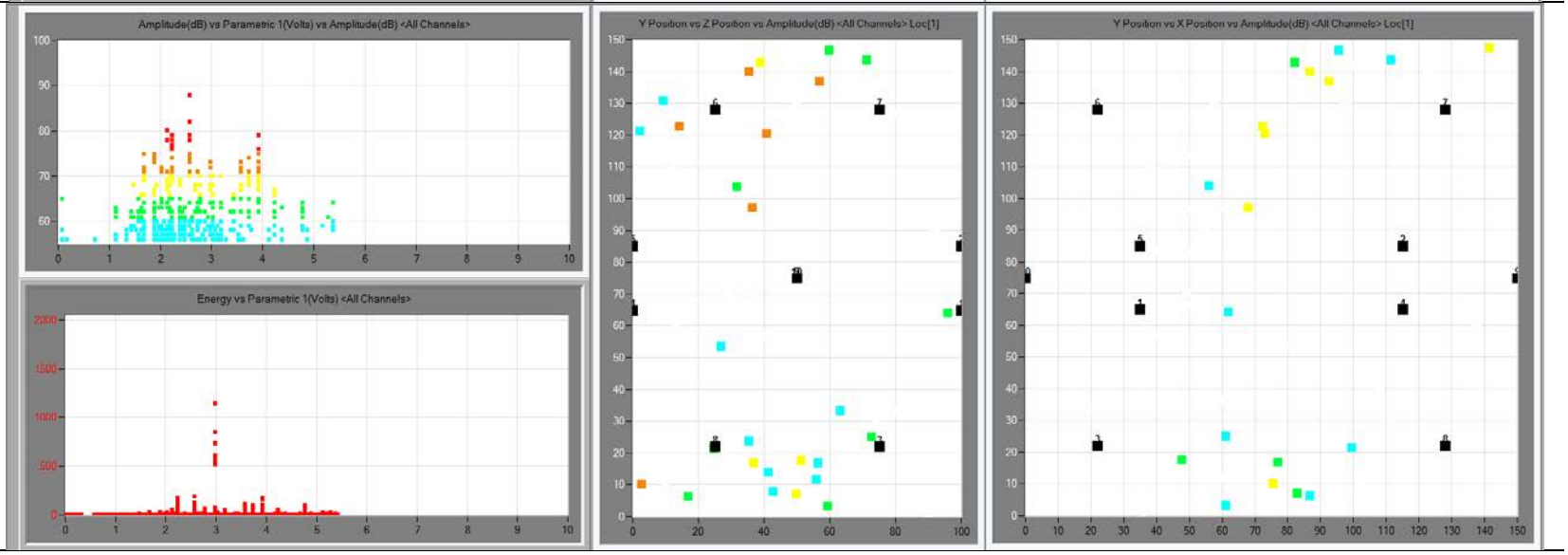
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5C3**
100%	

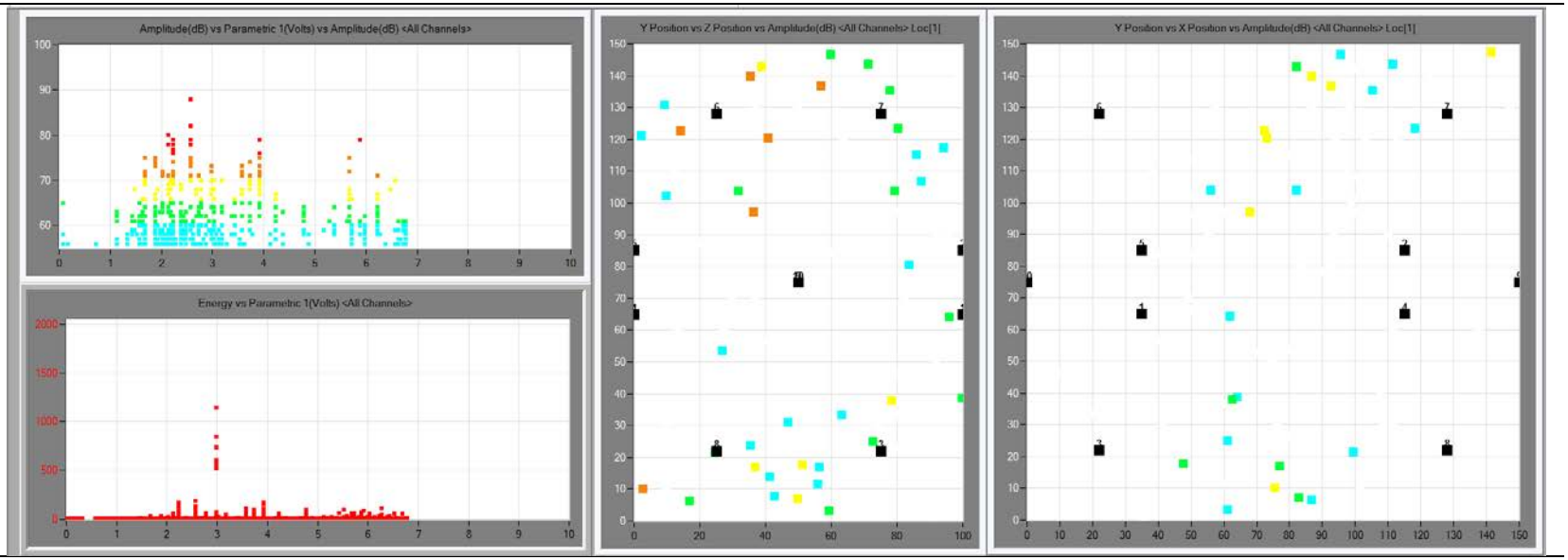
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0W1**
20%	
40%	

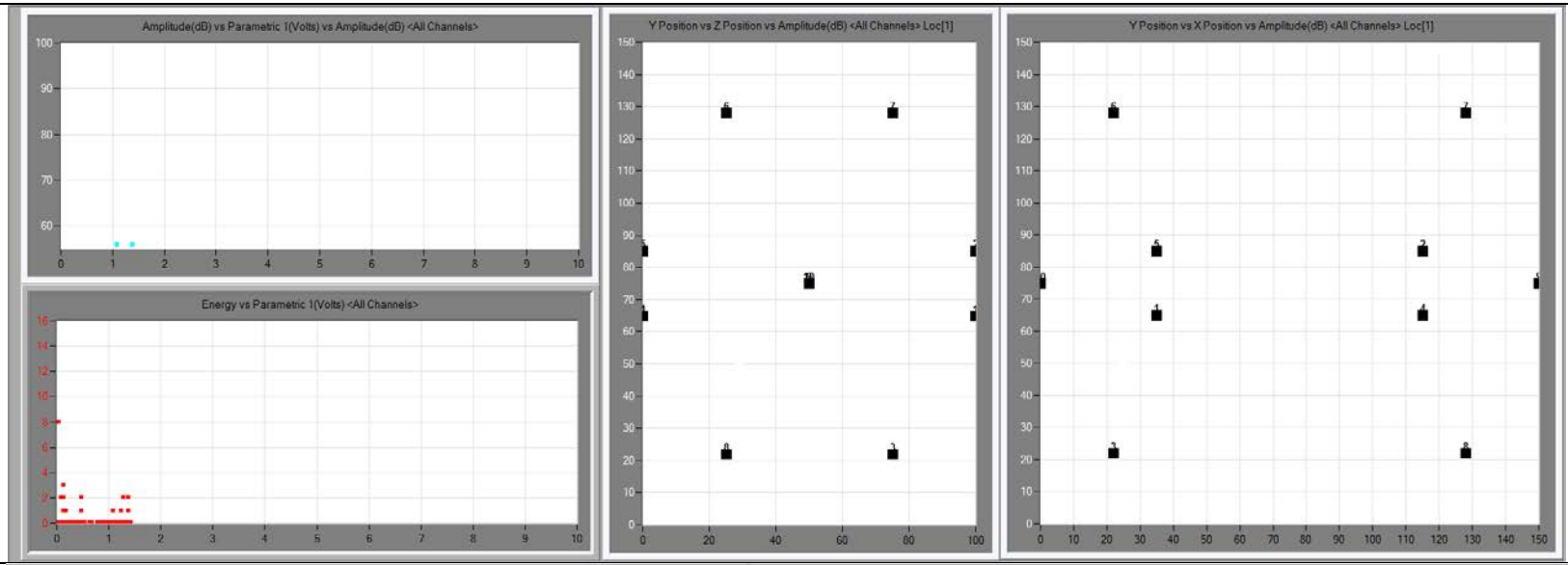
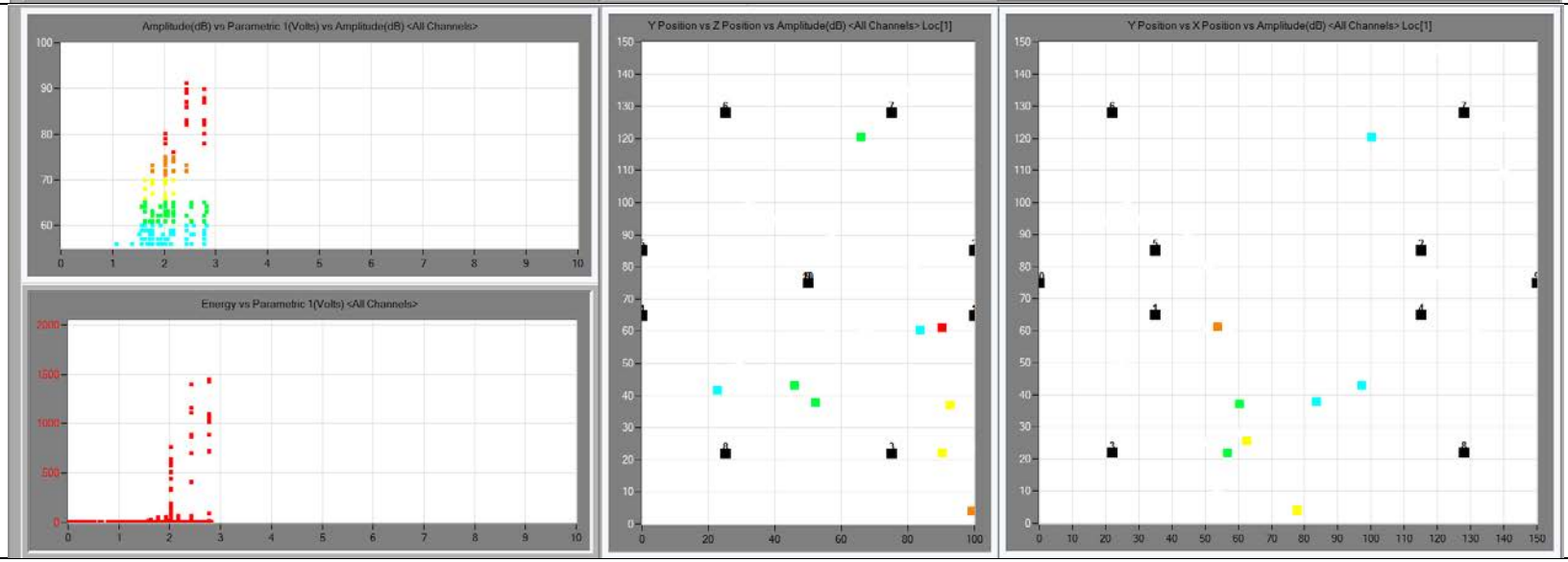
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0W1**
60%	
80%	

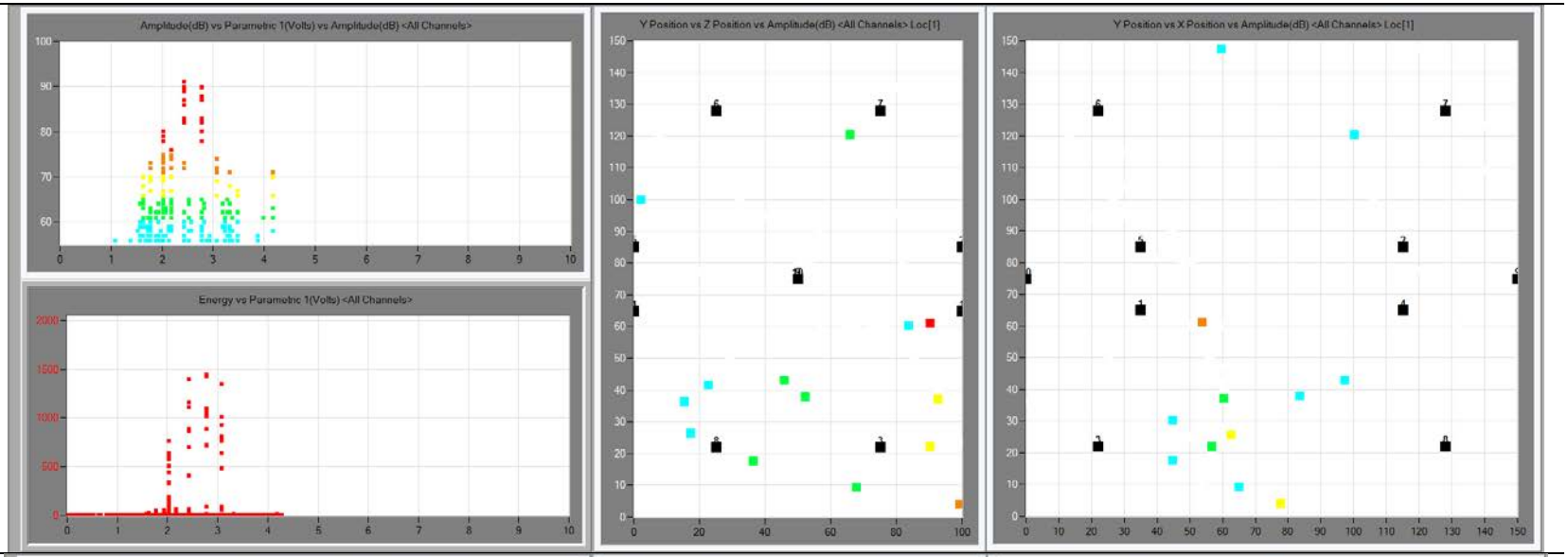
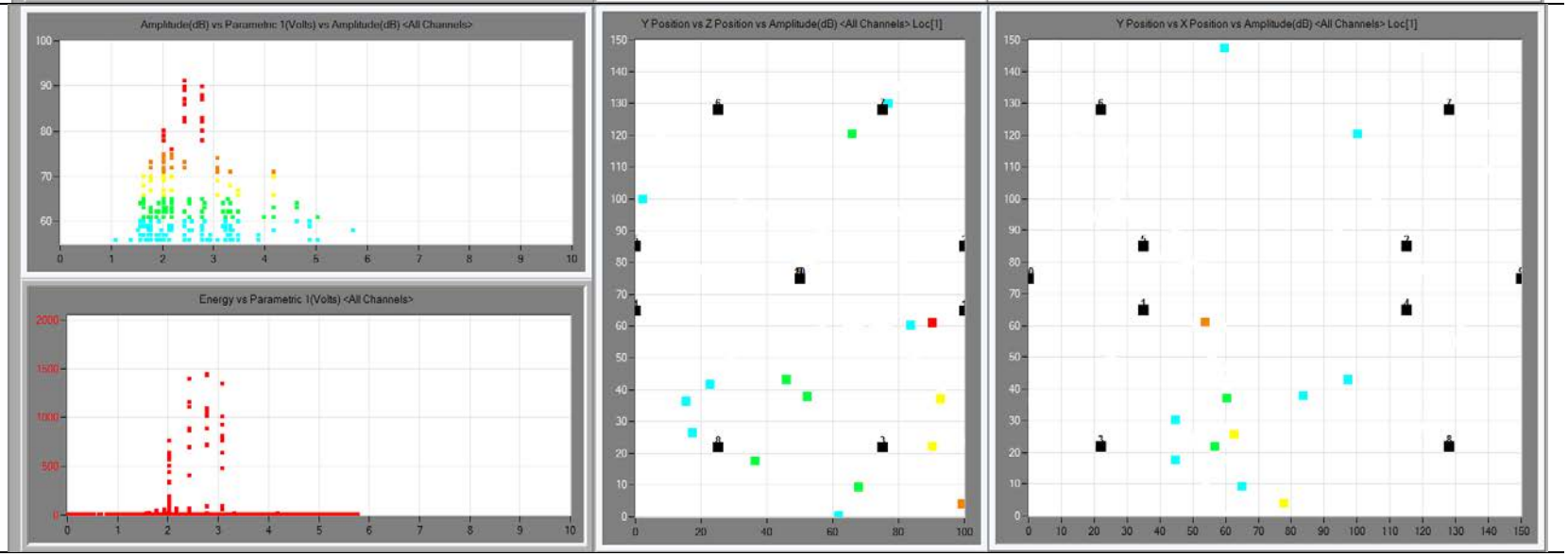
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0W1**
100%	

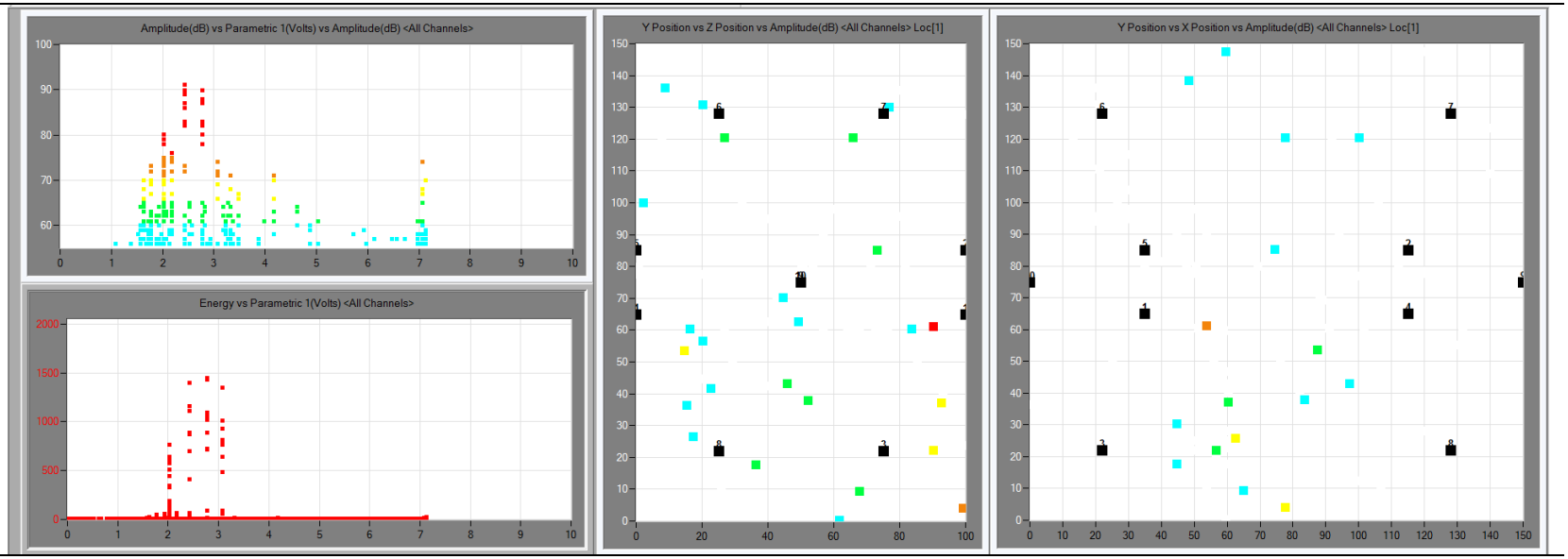
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0W3**
20%	
40%	

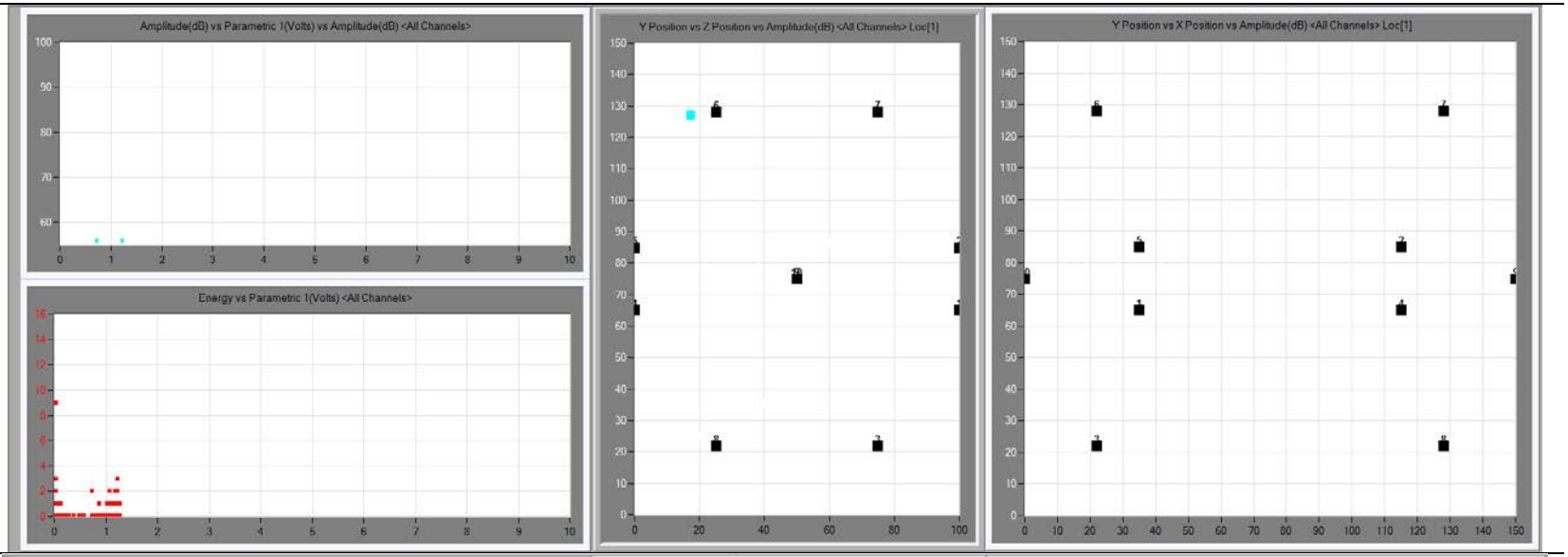
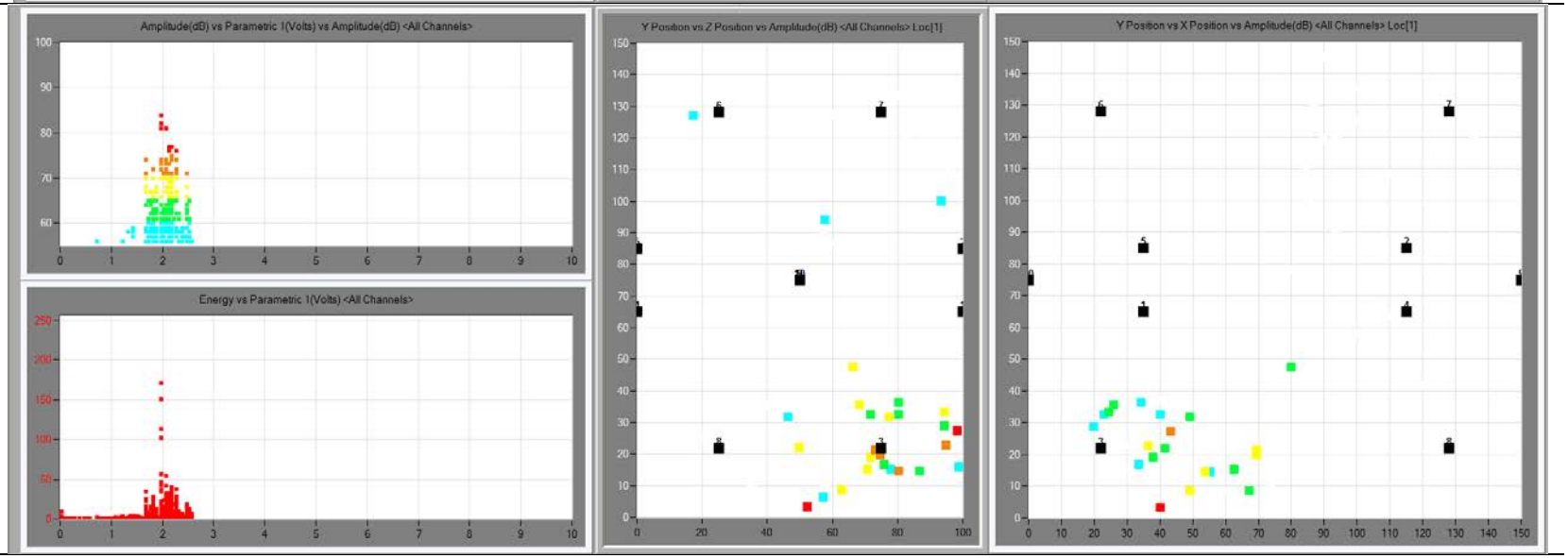
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0W3**
60%	
80%	

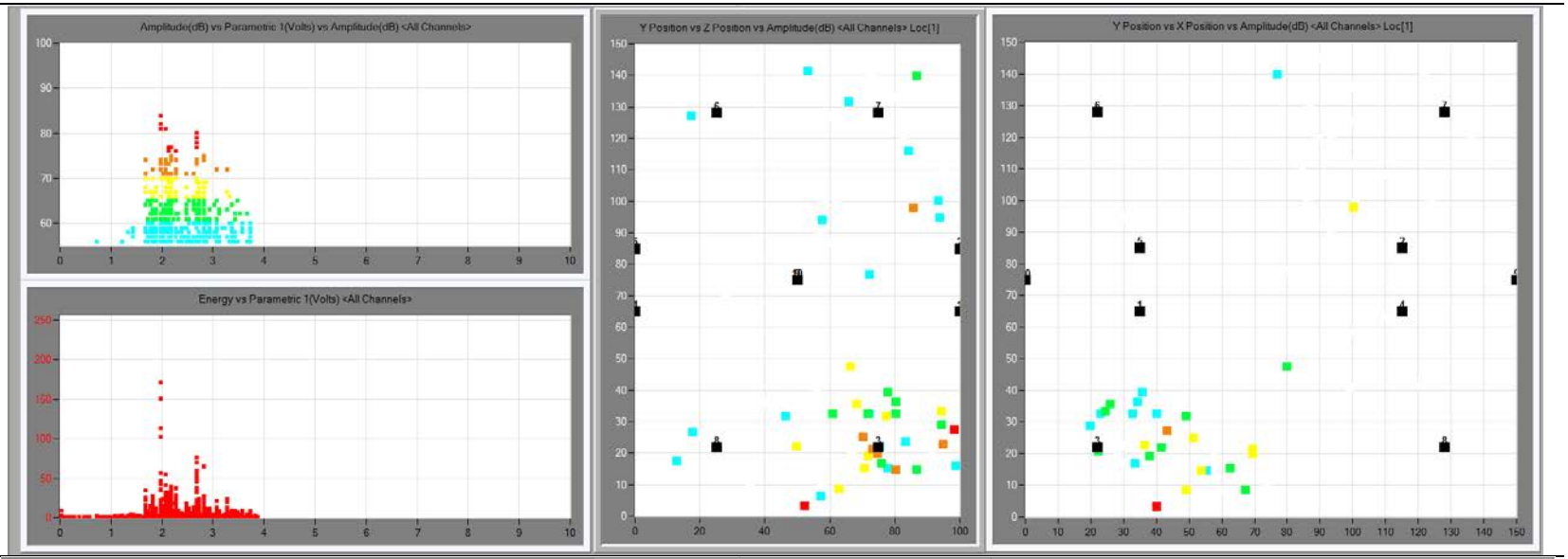
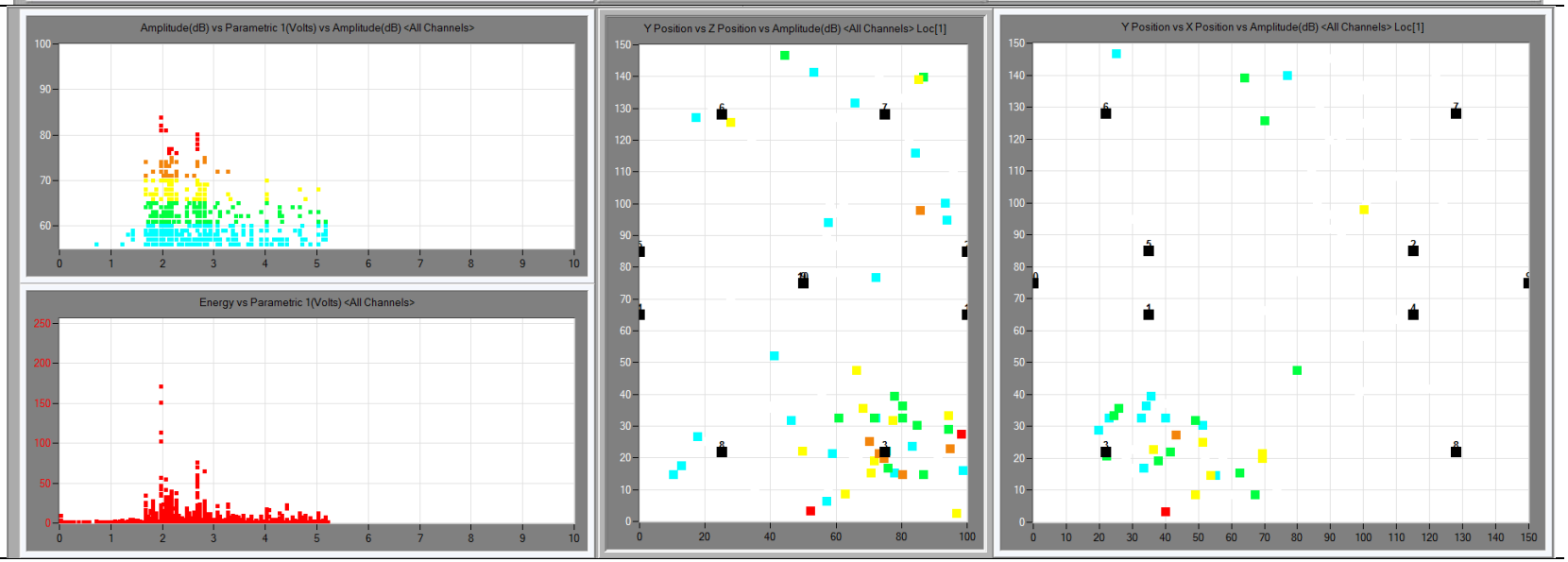
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0W3**
100%	

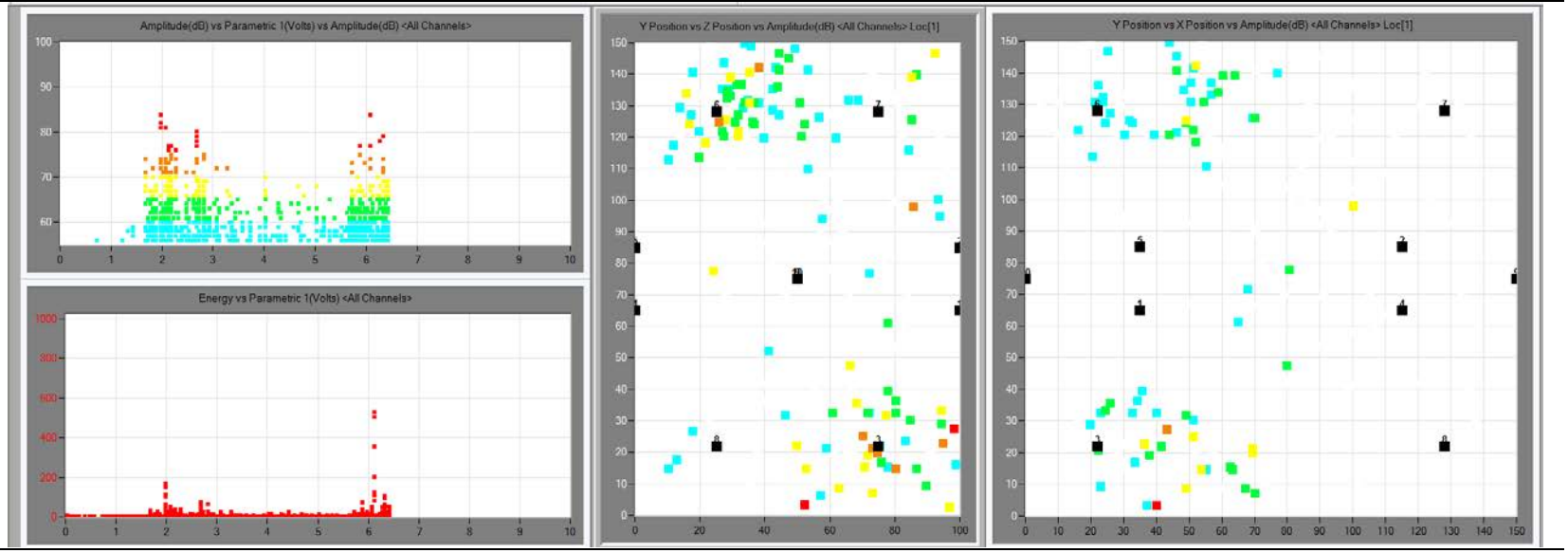
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0W4**
20%	
40%	

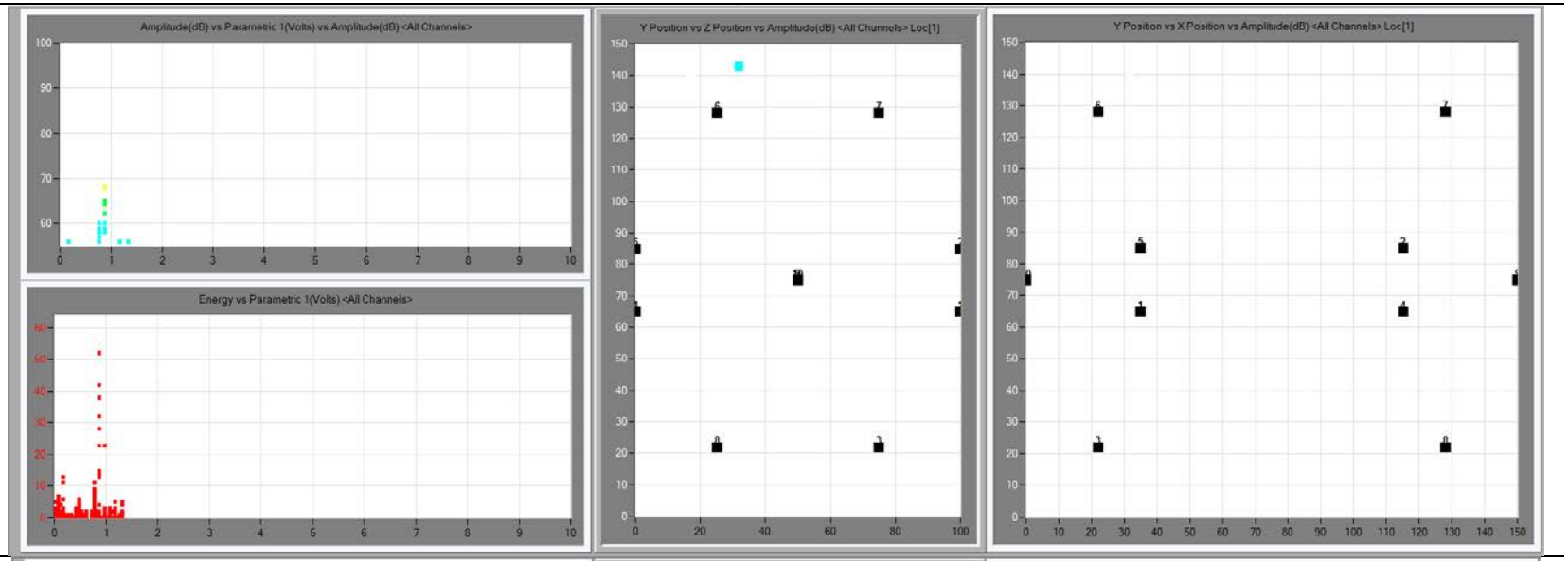
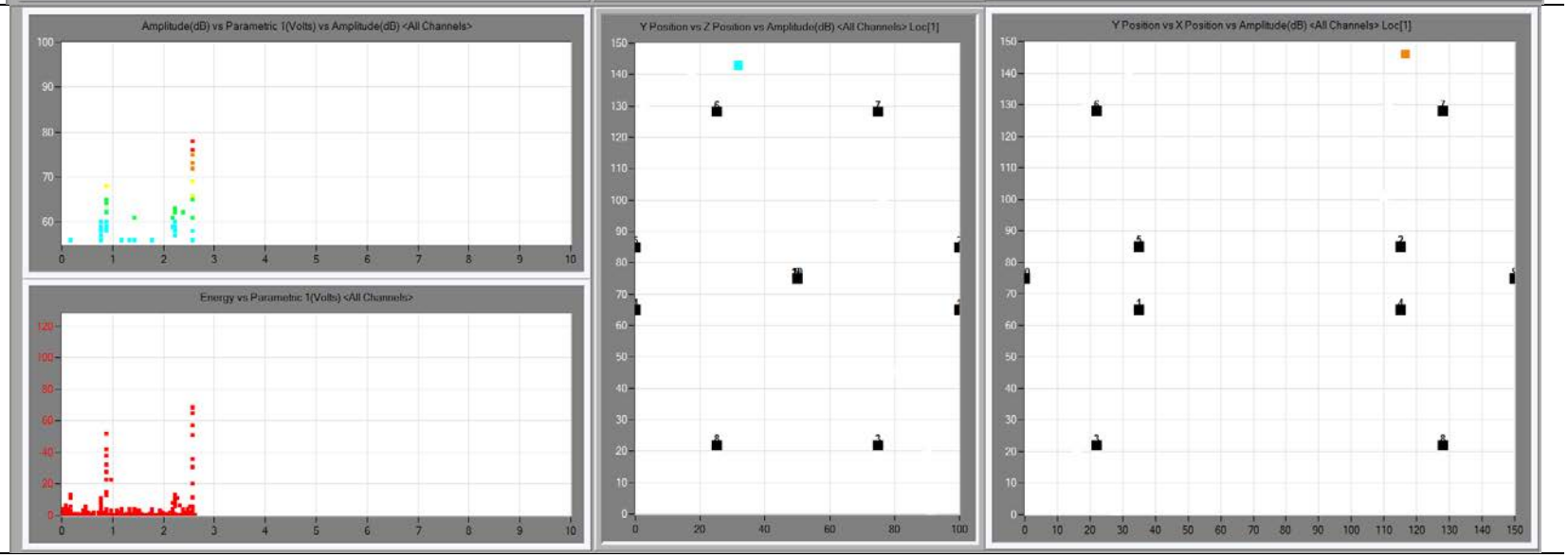
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0W4**
60%	
80%	

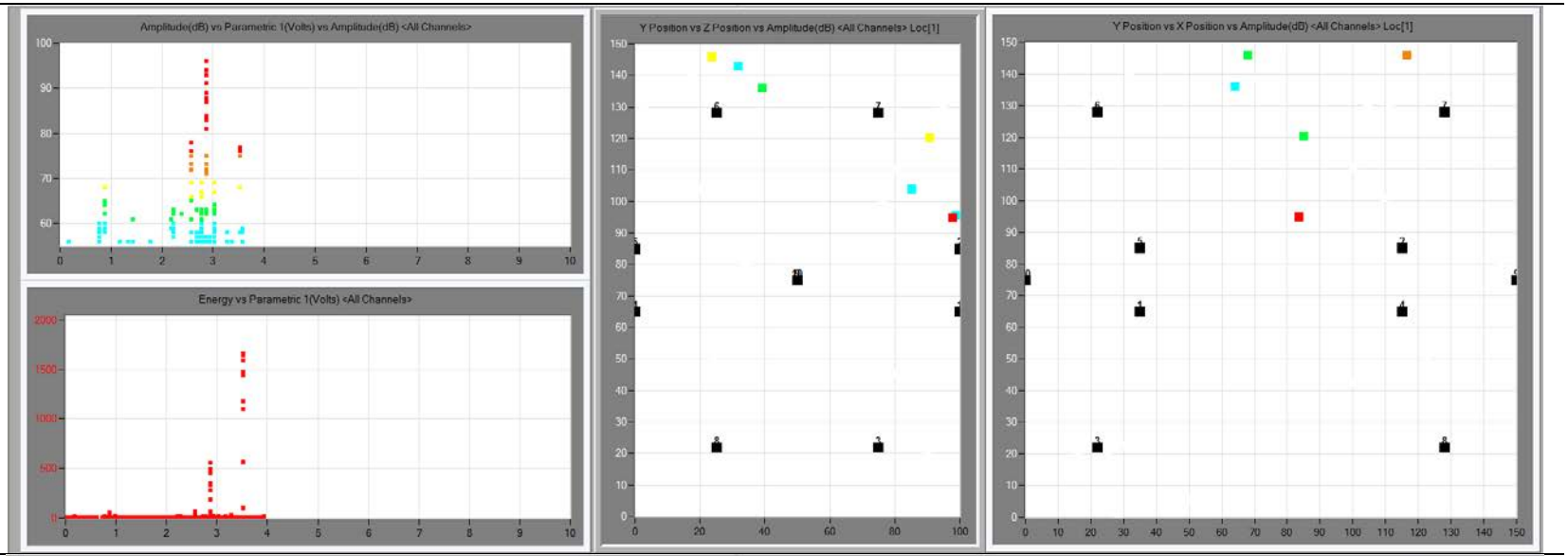
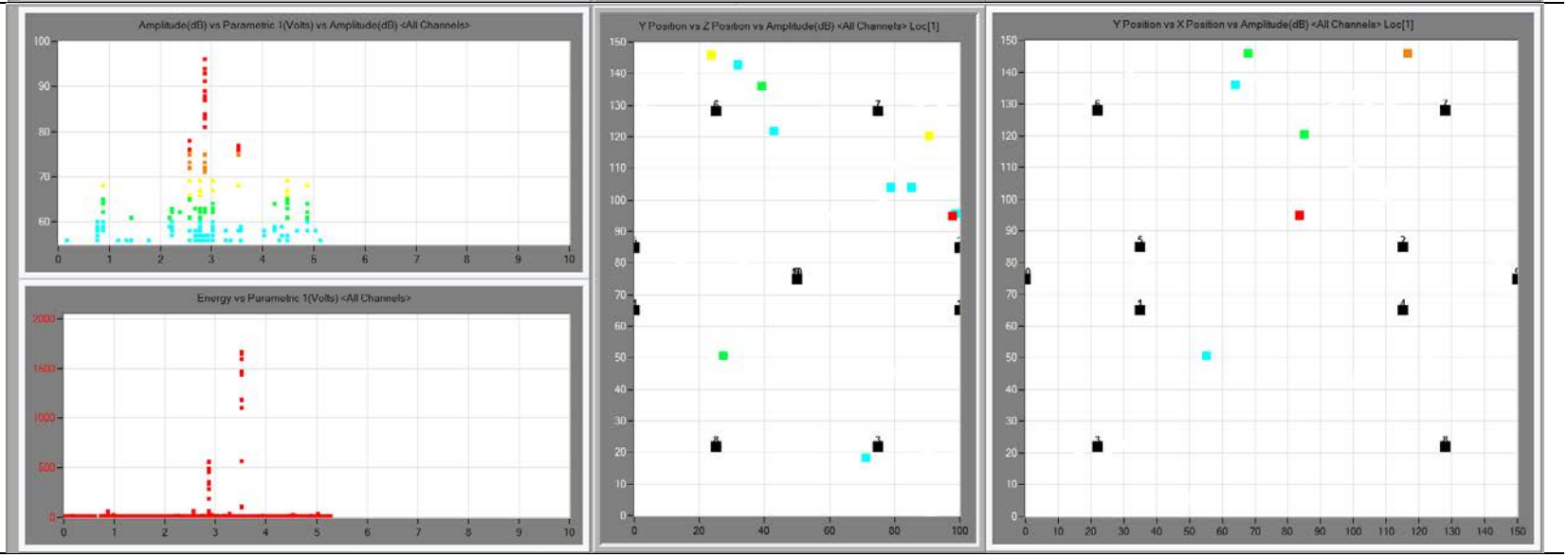
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0W4**
100%	

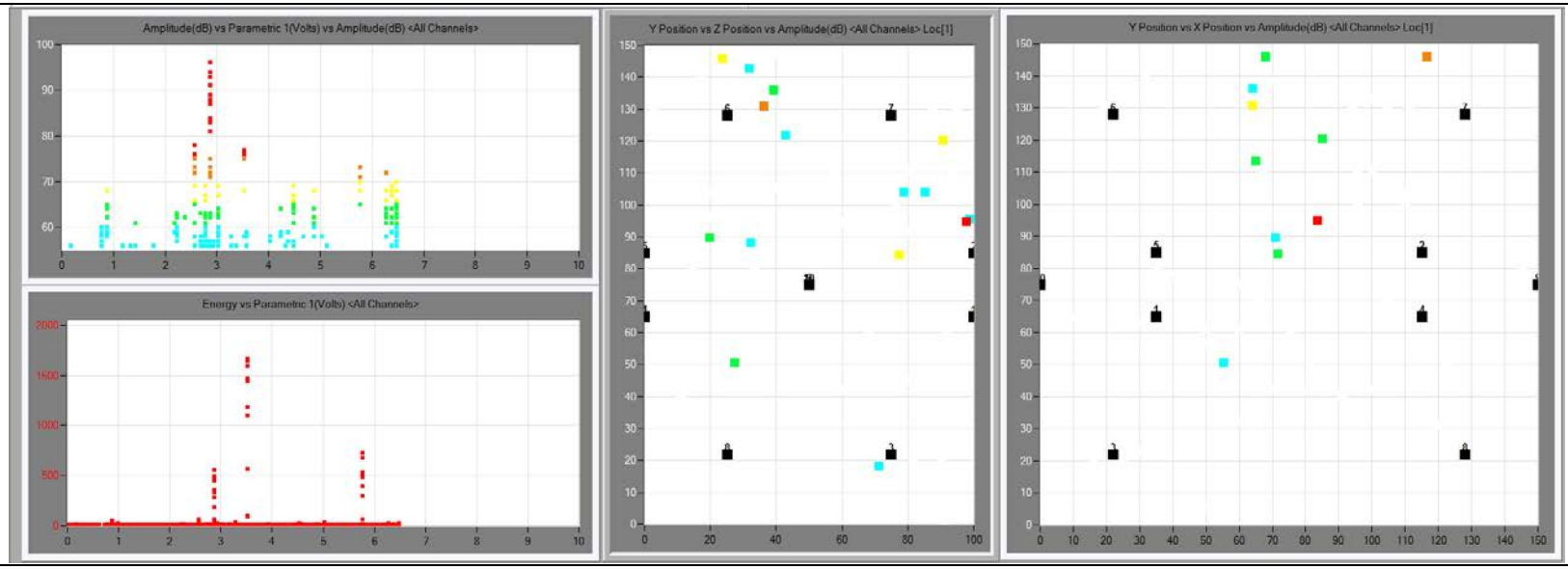
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2W1**
20%	
40%	

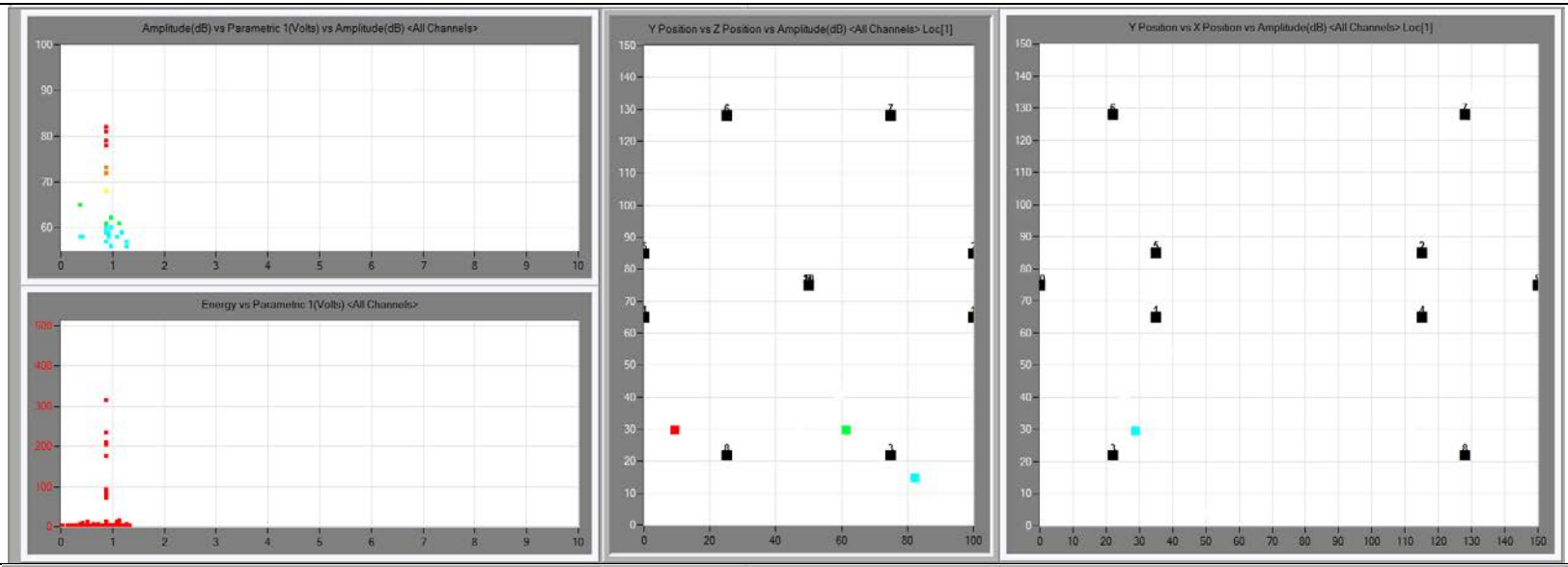
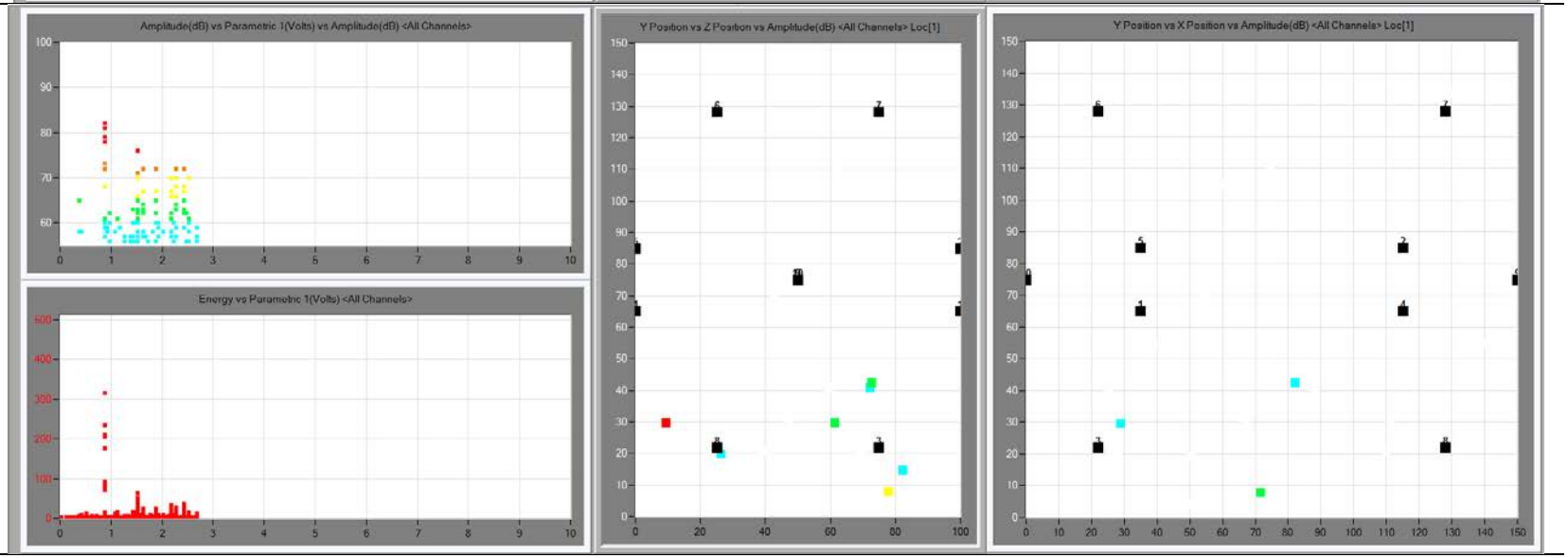
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2W1**
60%	
80%	

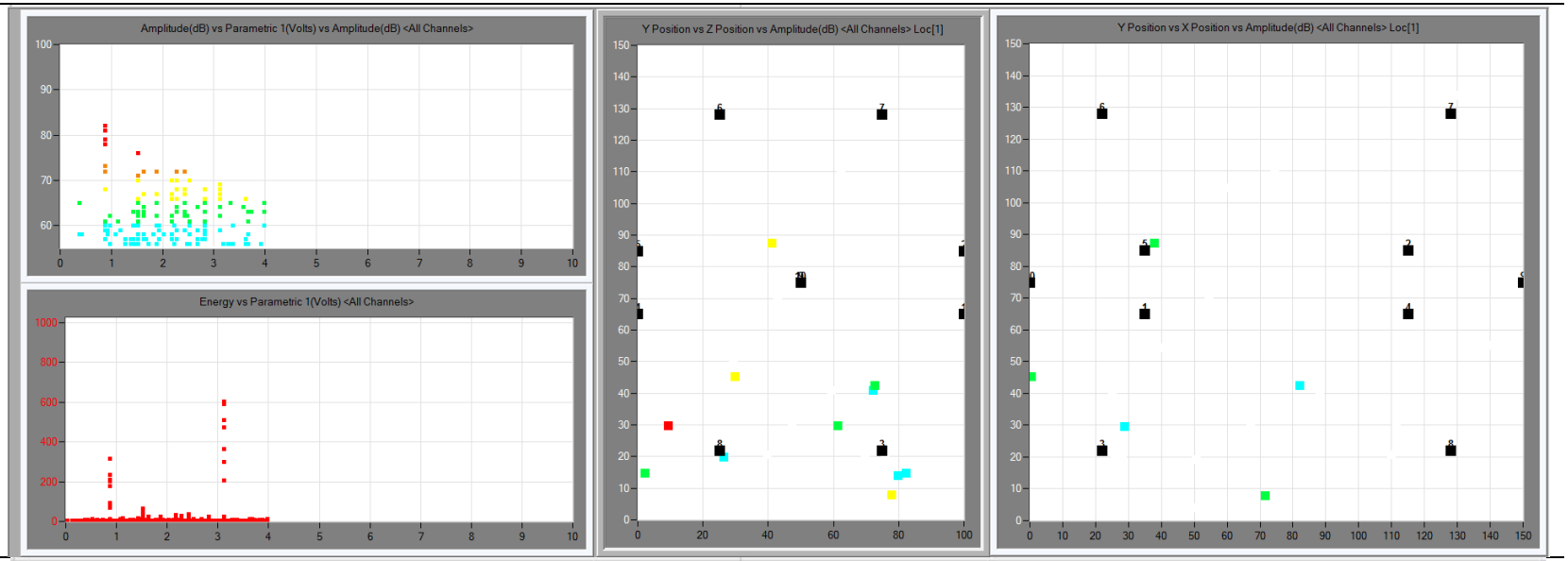
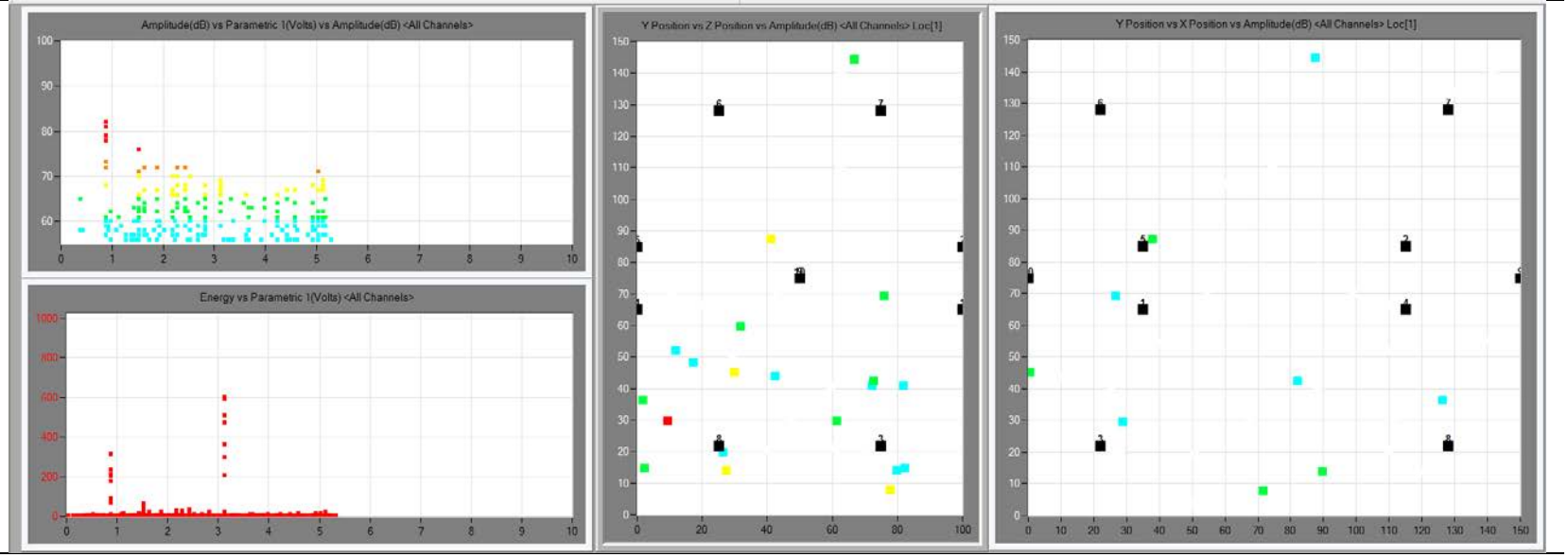
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2W1**
100 %	

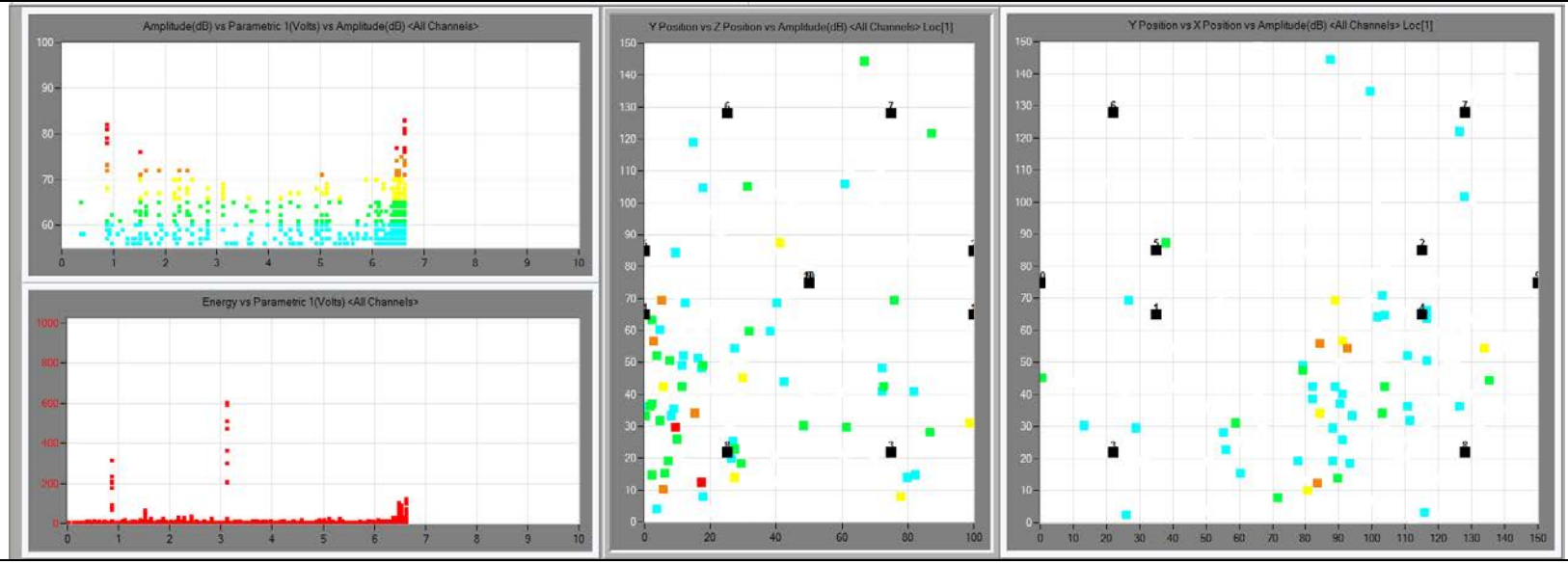
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2W3**
20%	
40%	

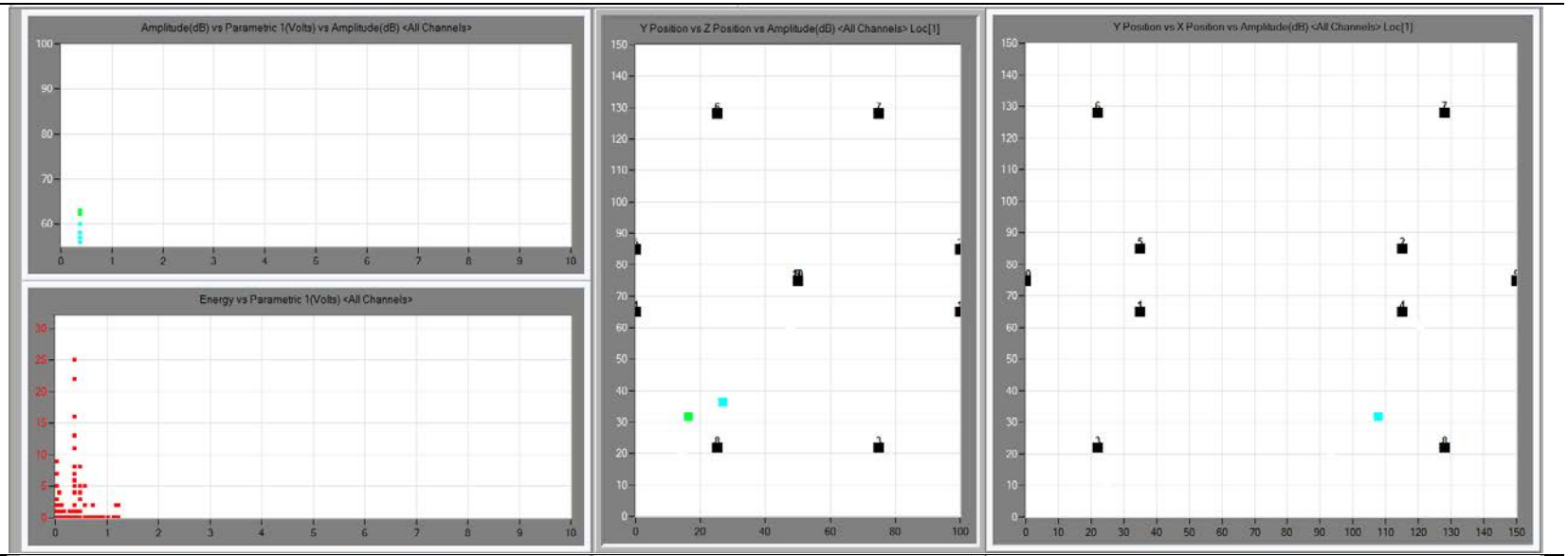
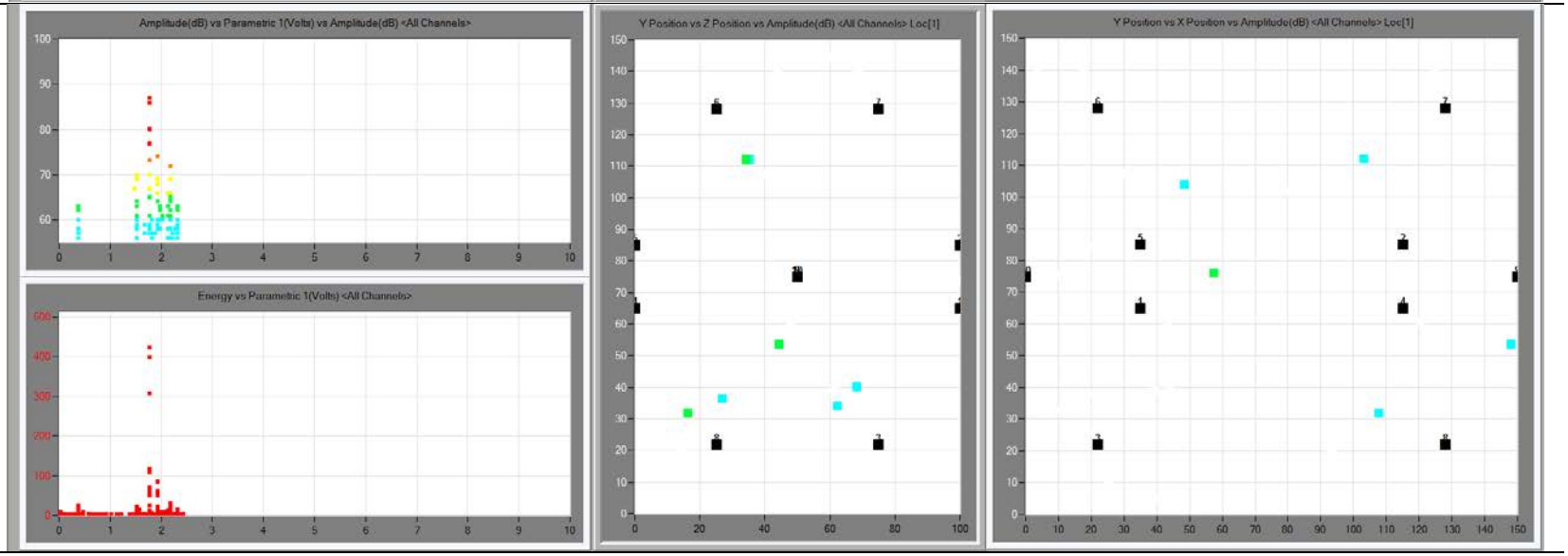
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2W3**
60%	
80%	

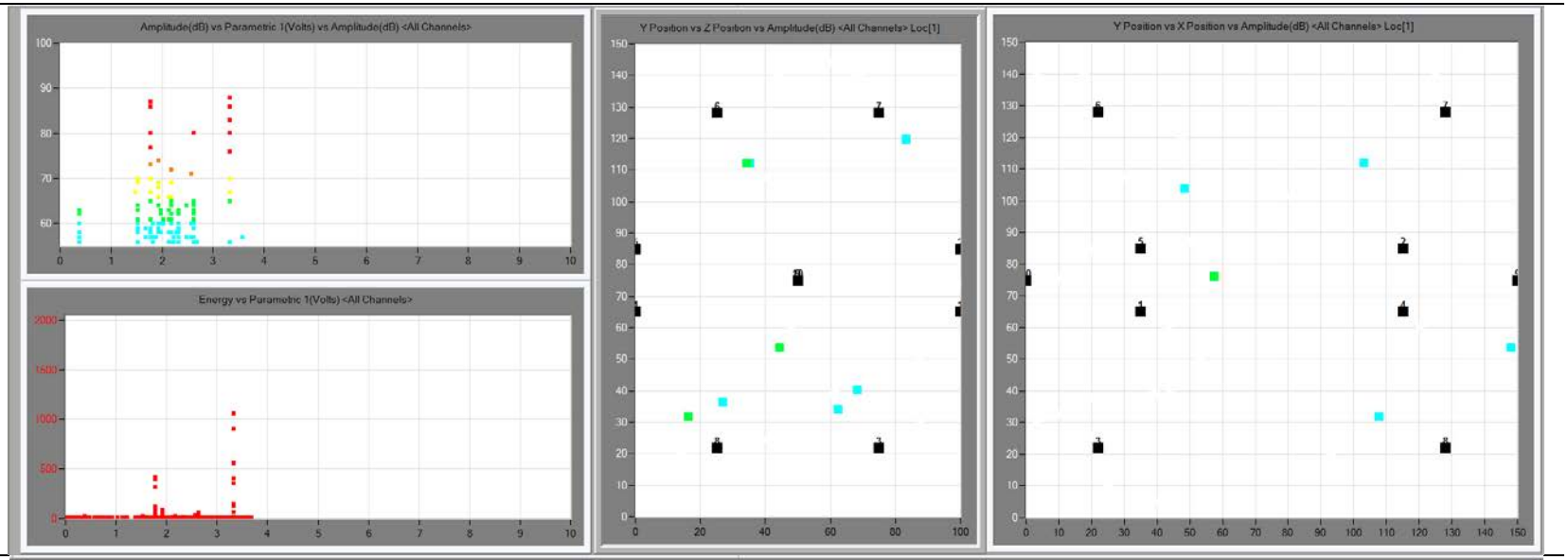
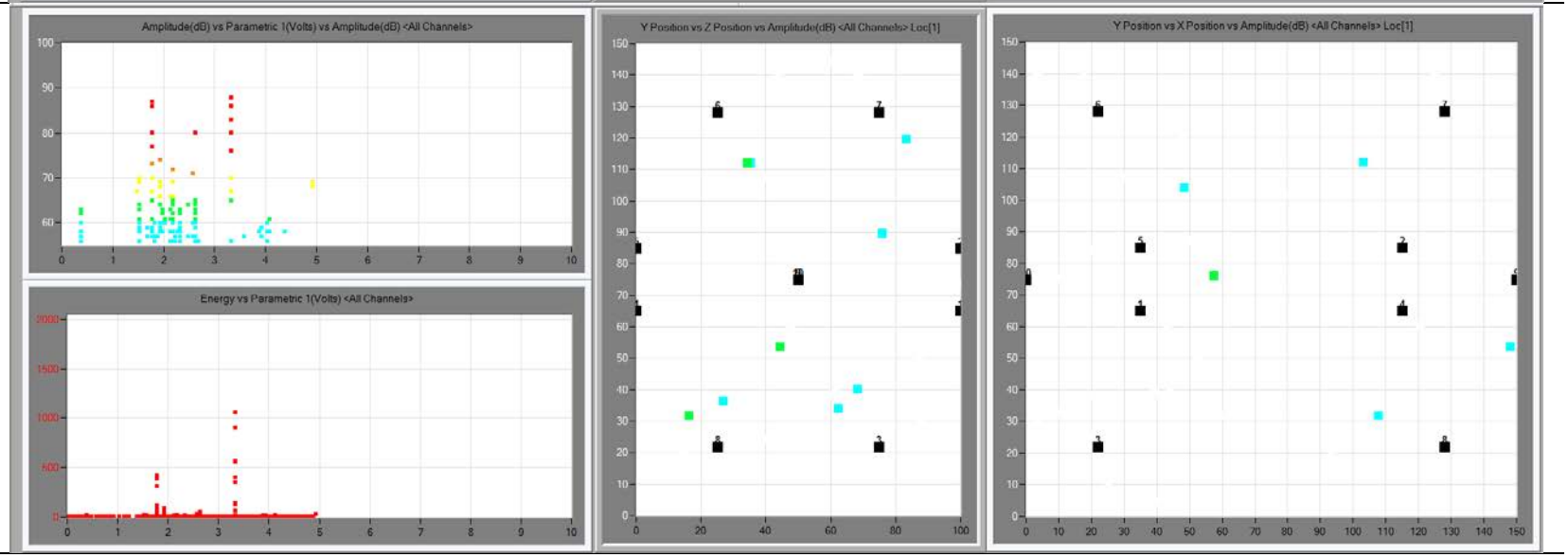
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2W3**
100%	

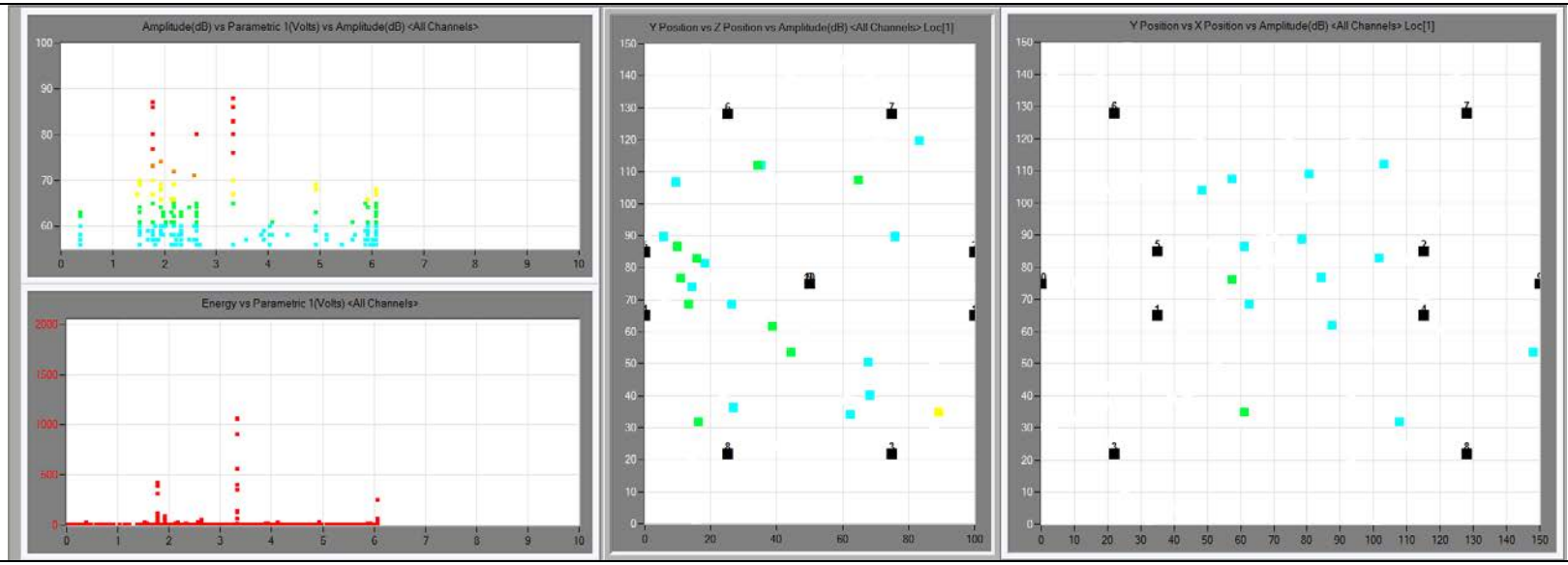
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5W1**
20%	
40%	

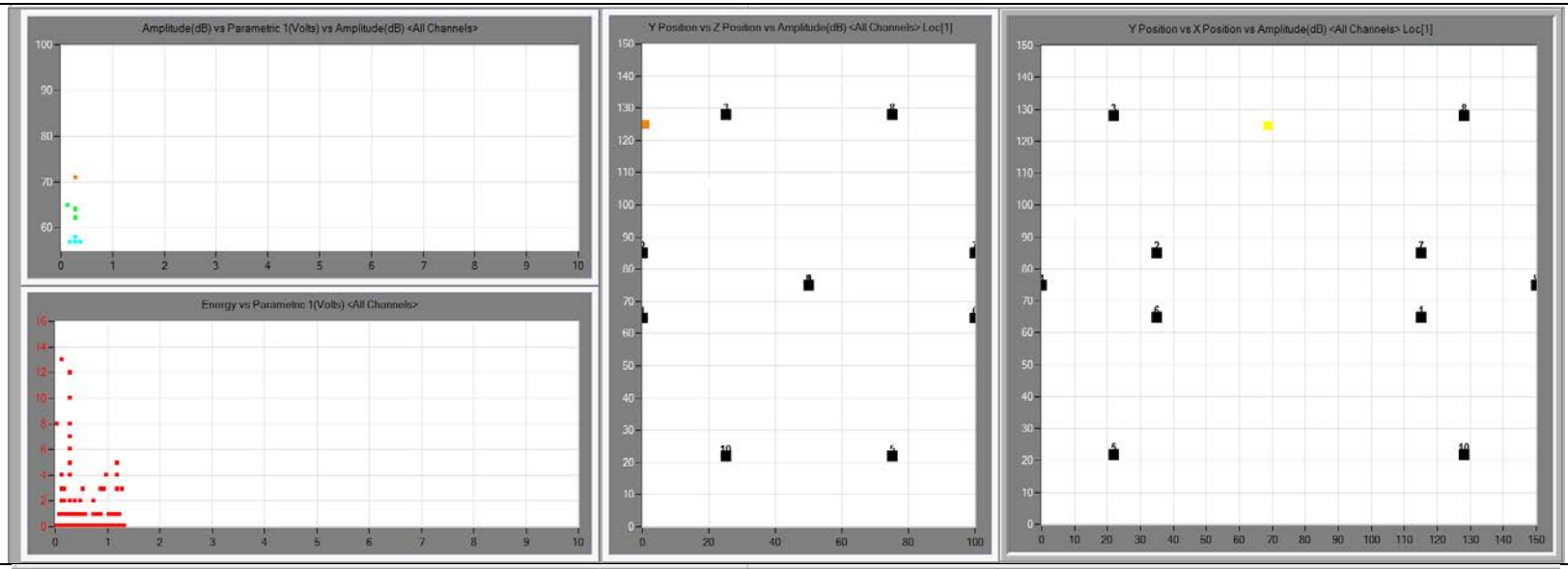
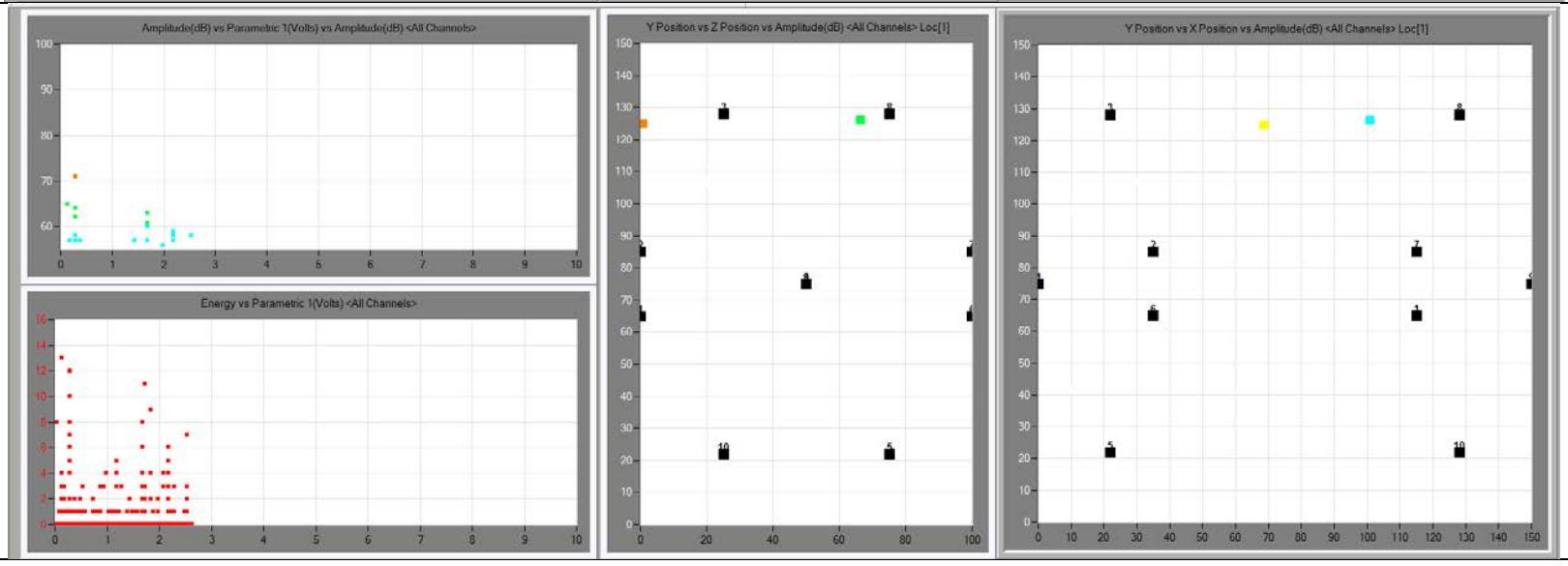
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5W1**
60%	
80%	

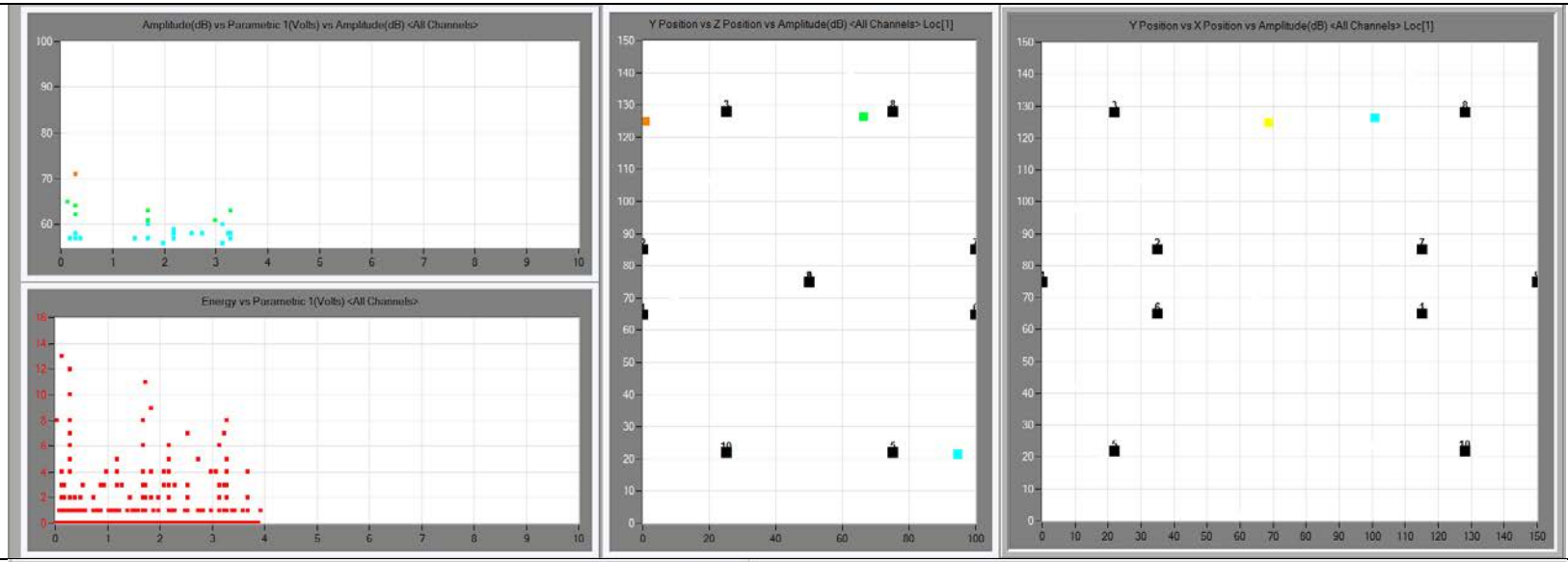
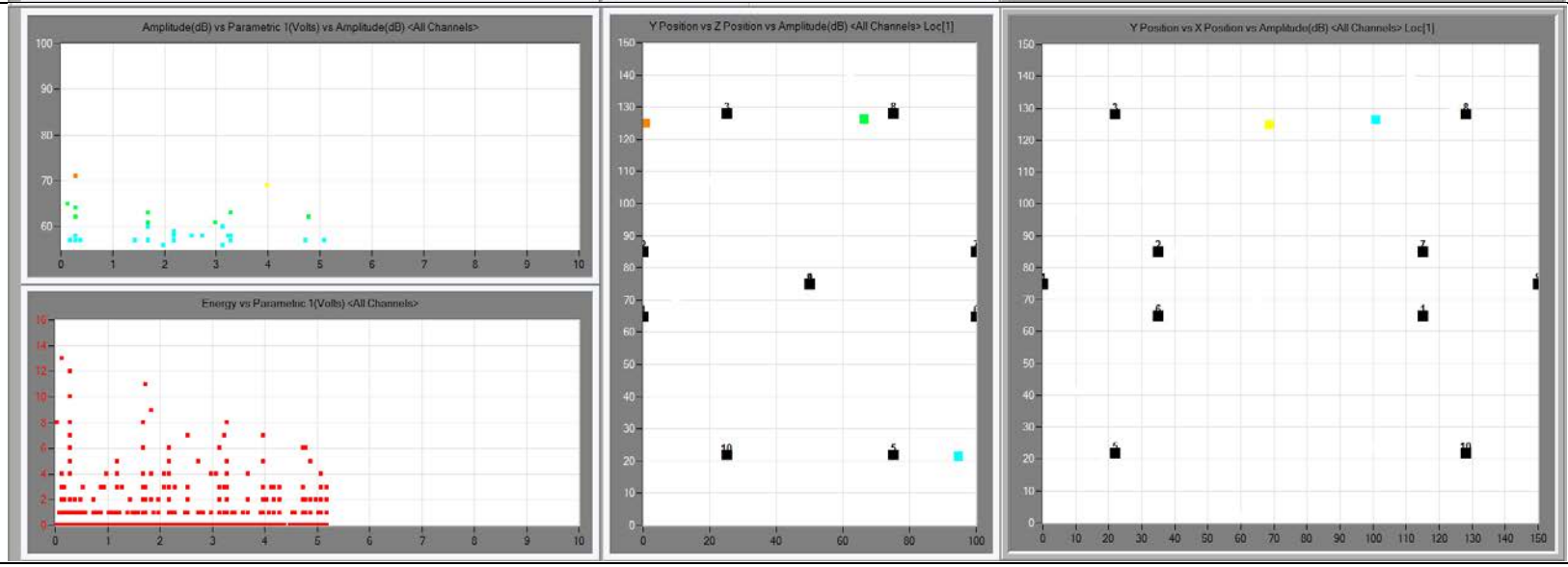
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5W1**
100%	

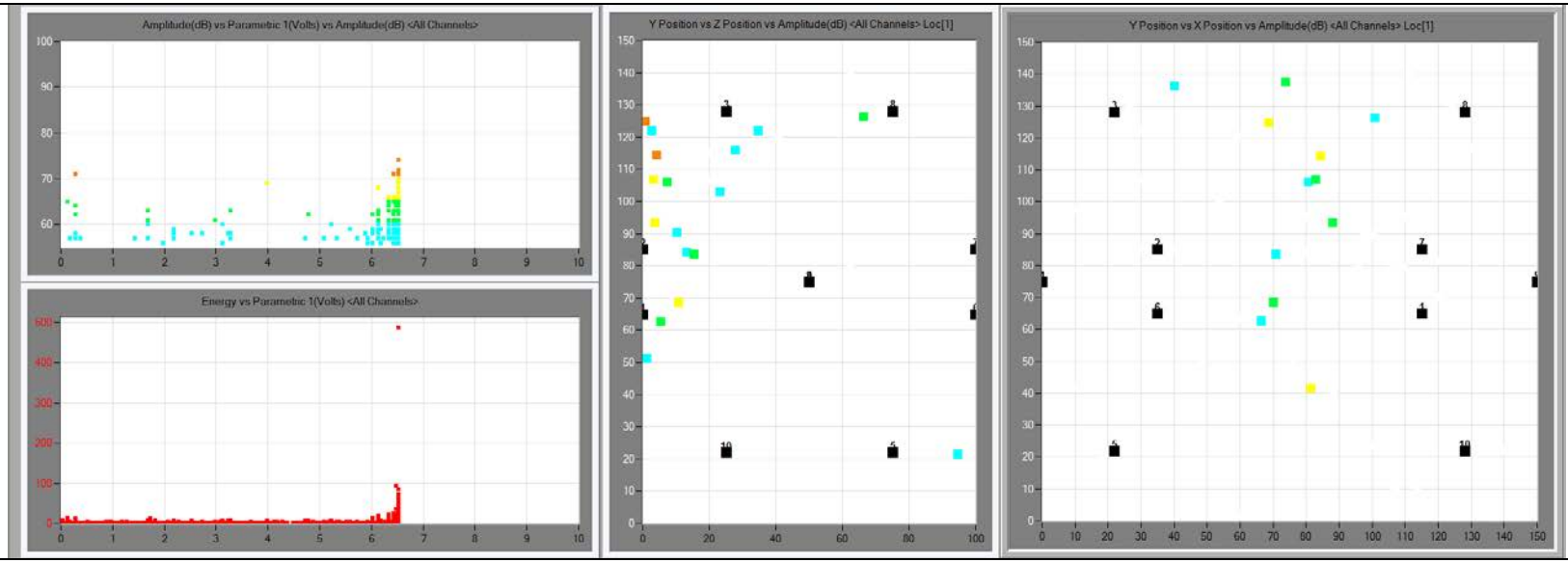
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5W2**
20%	
40%	

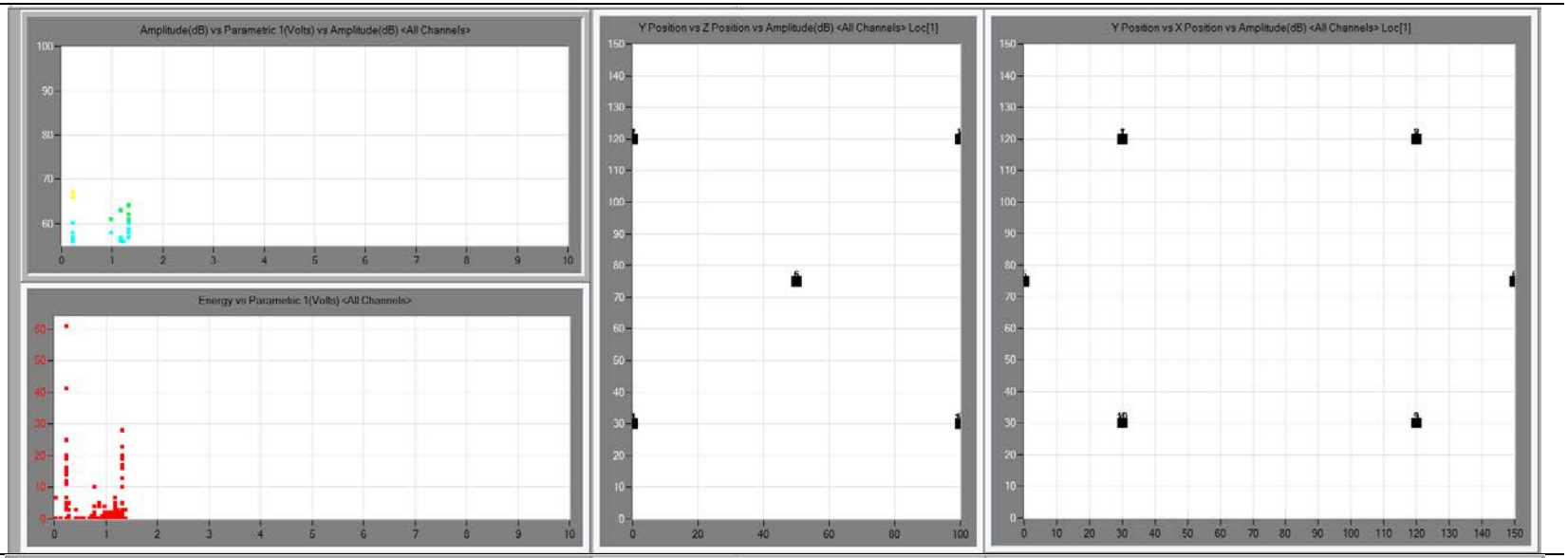
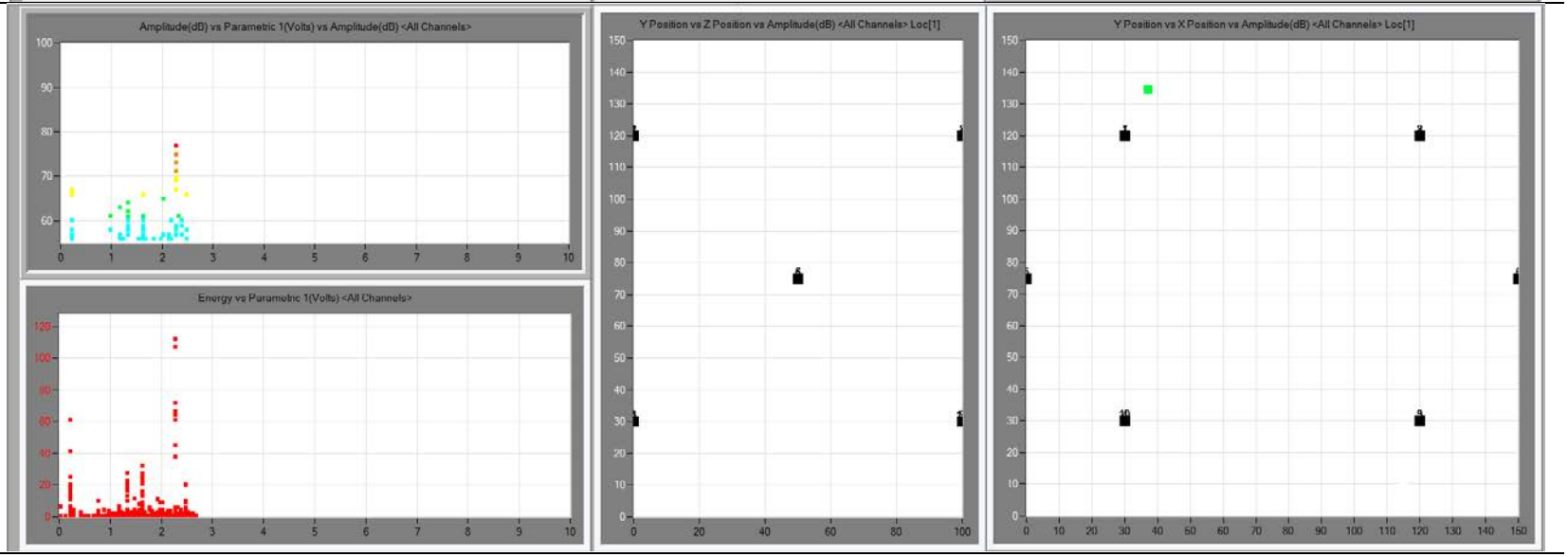
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5W2**
60%	
80%	

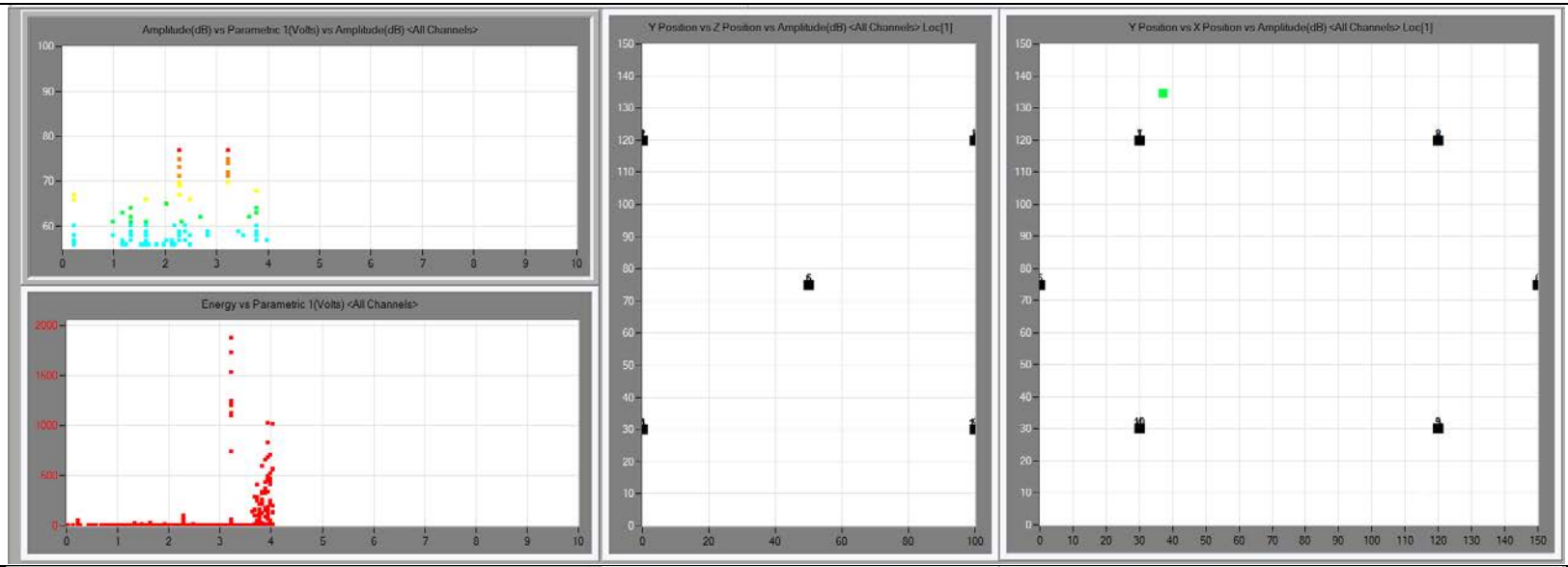
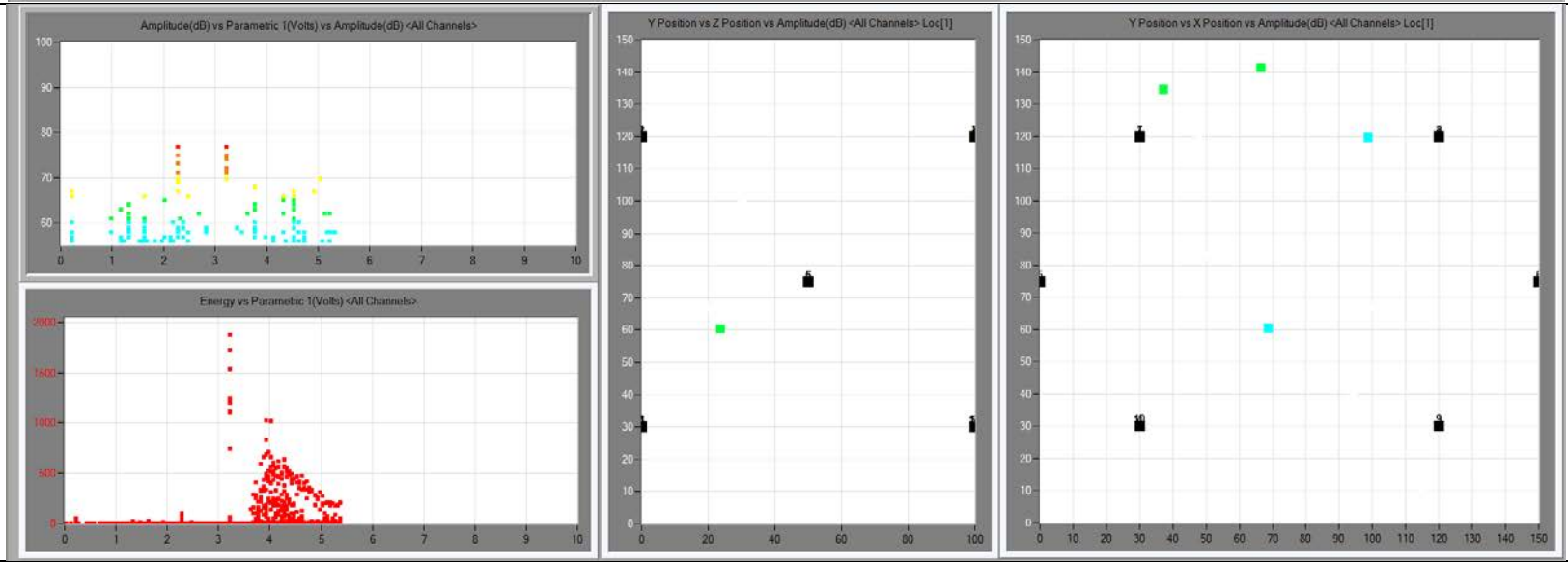
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5W2**
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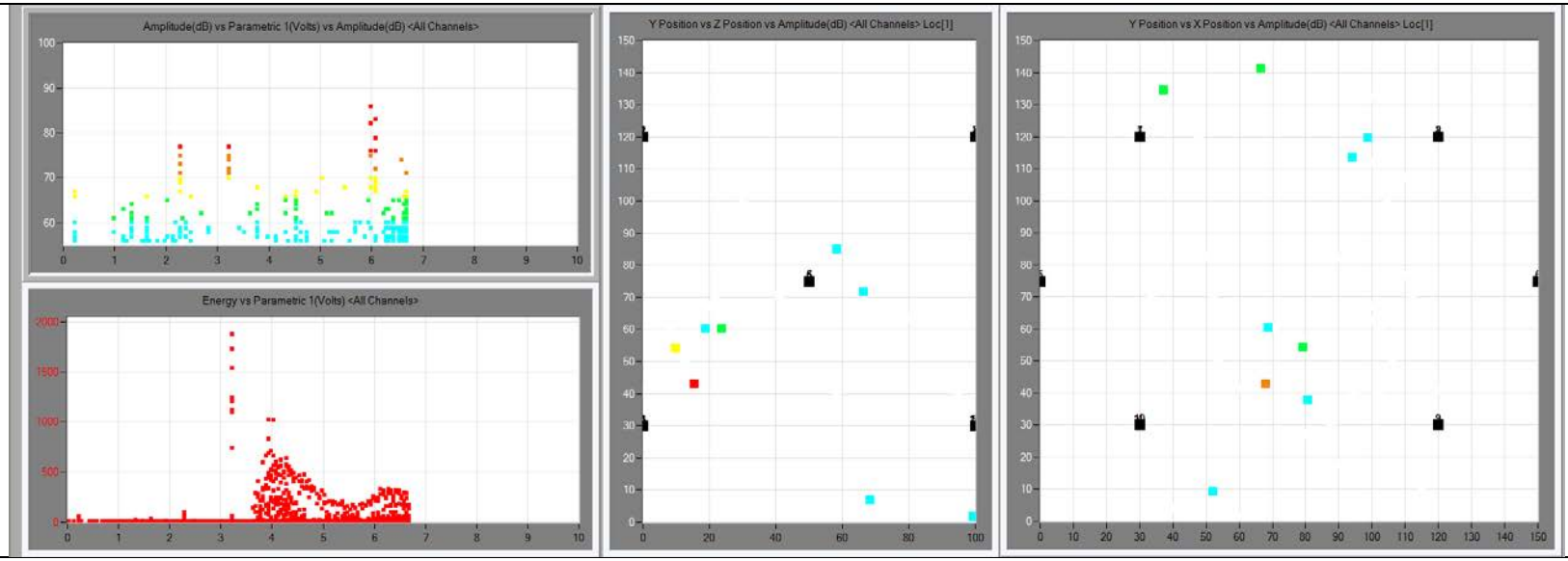
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5W3**
20%	
40%	

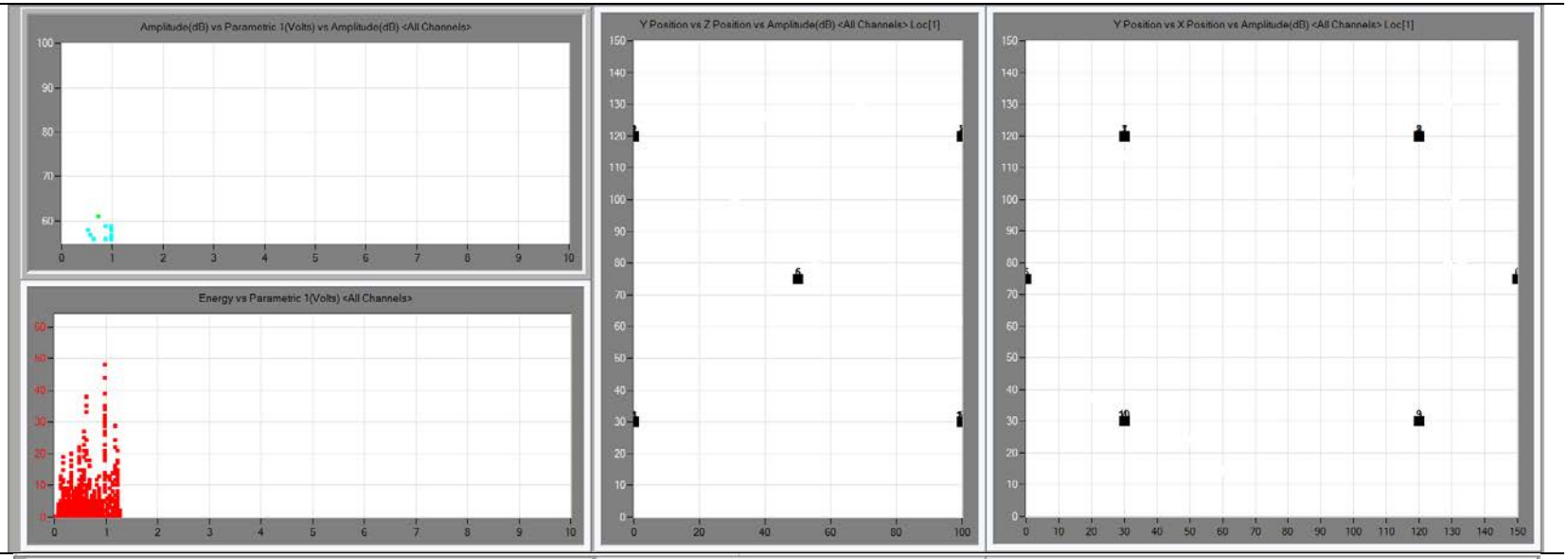
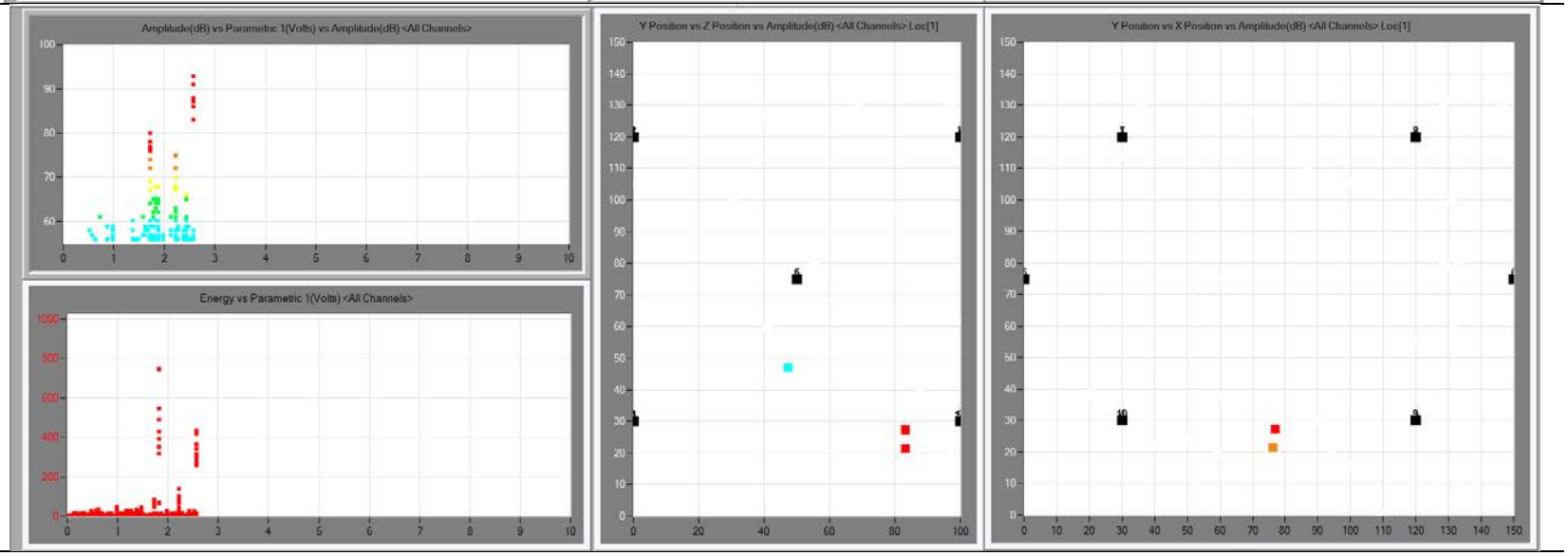
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5W3**
60%	
80%	

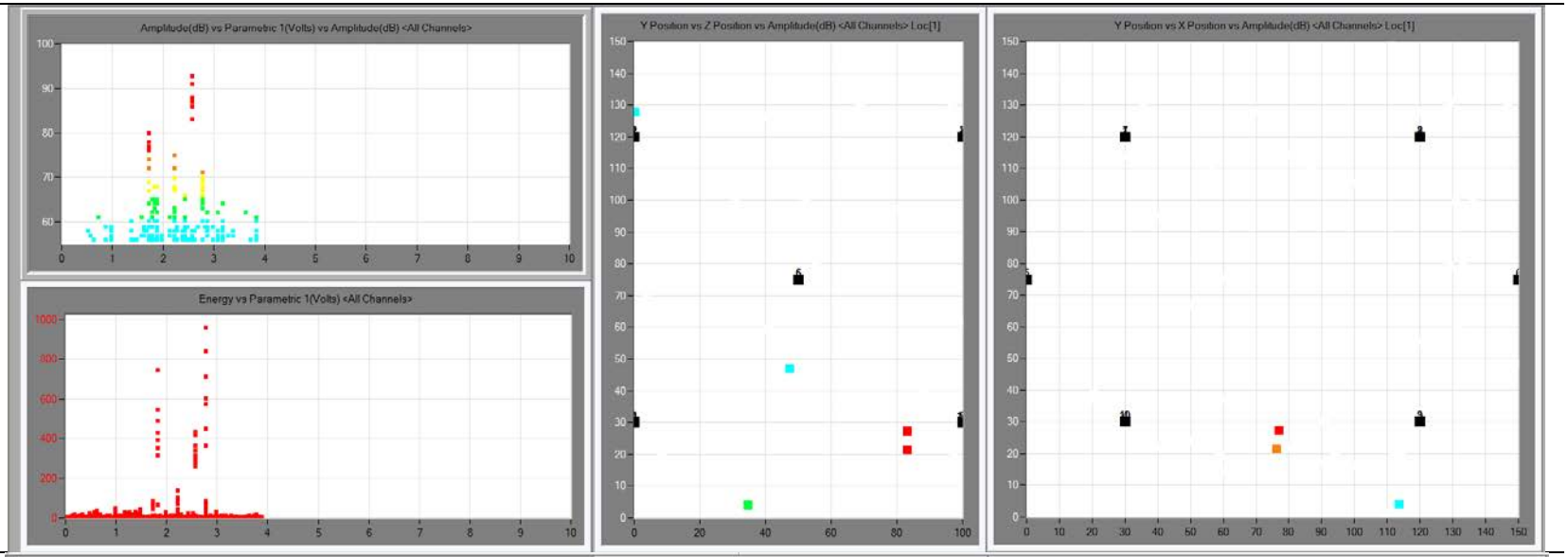
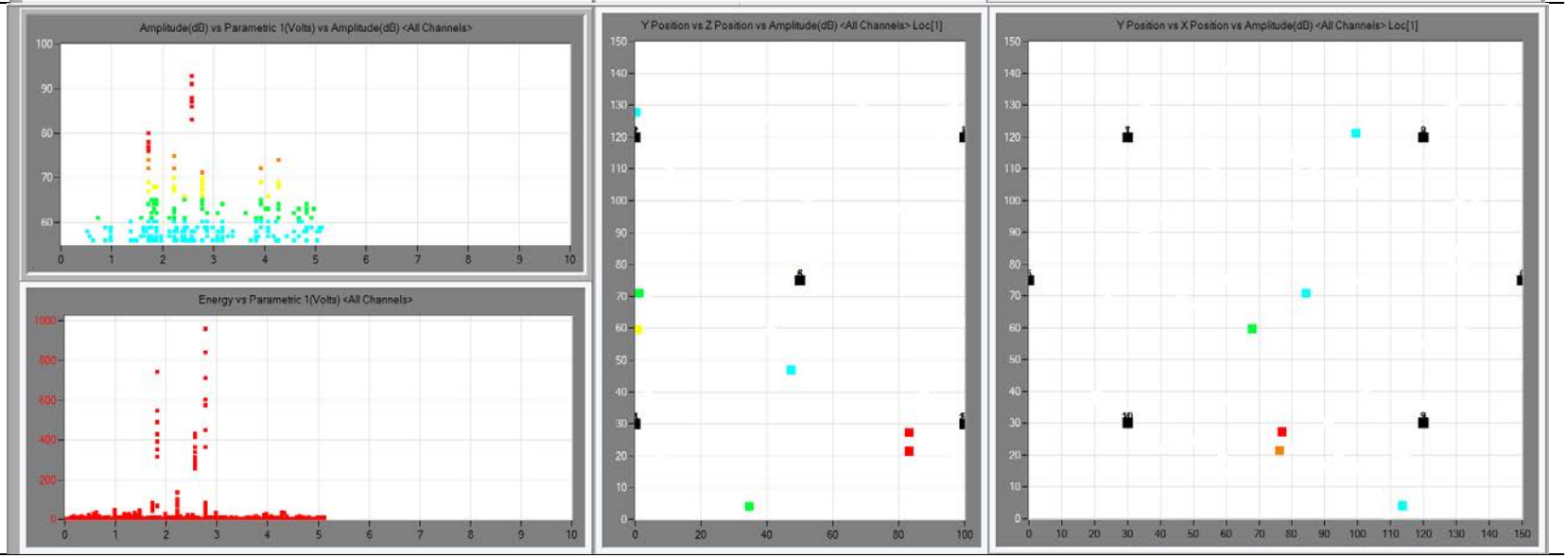
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5W3**
100%	

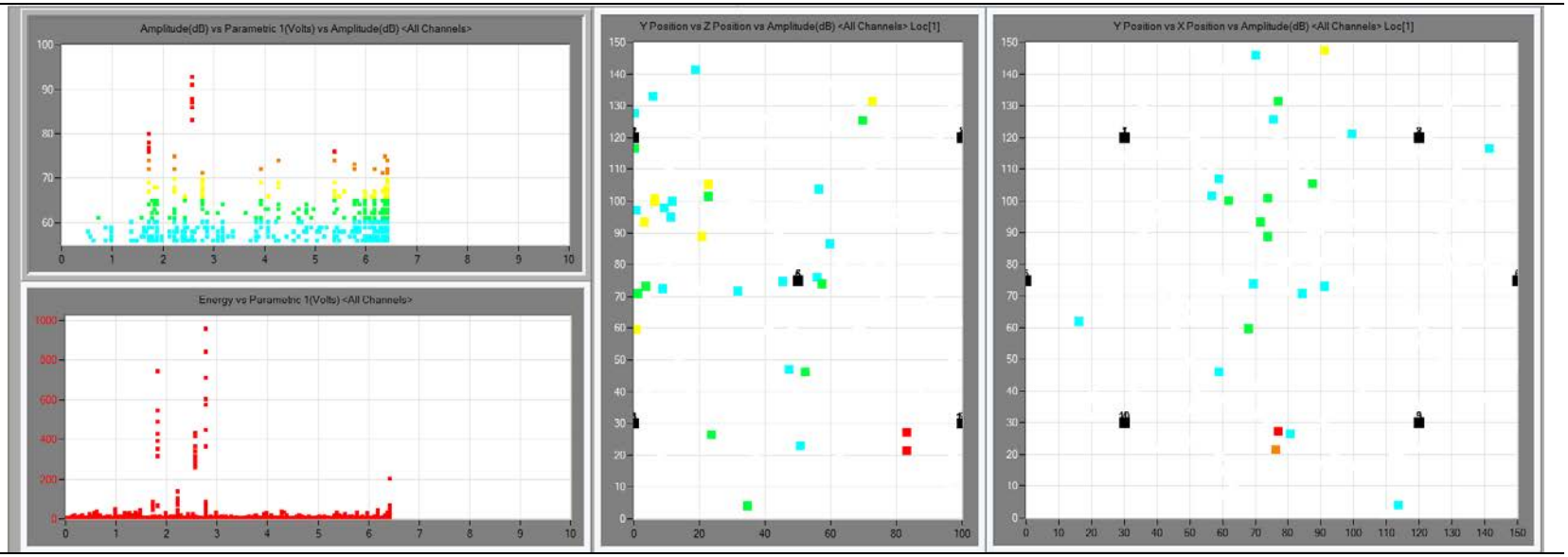
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0F1**
20%	
40%	

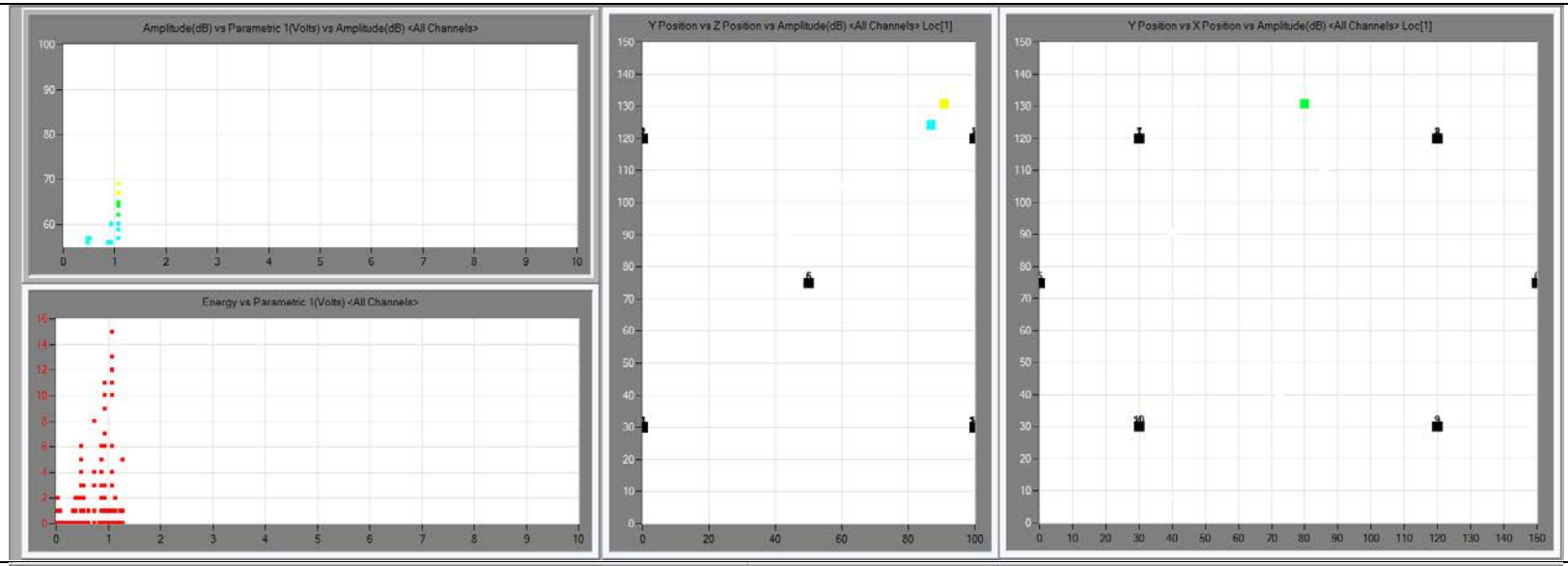
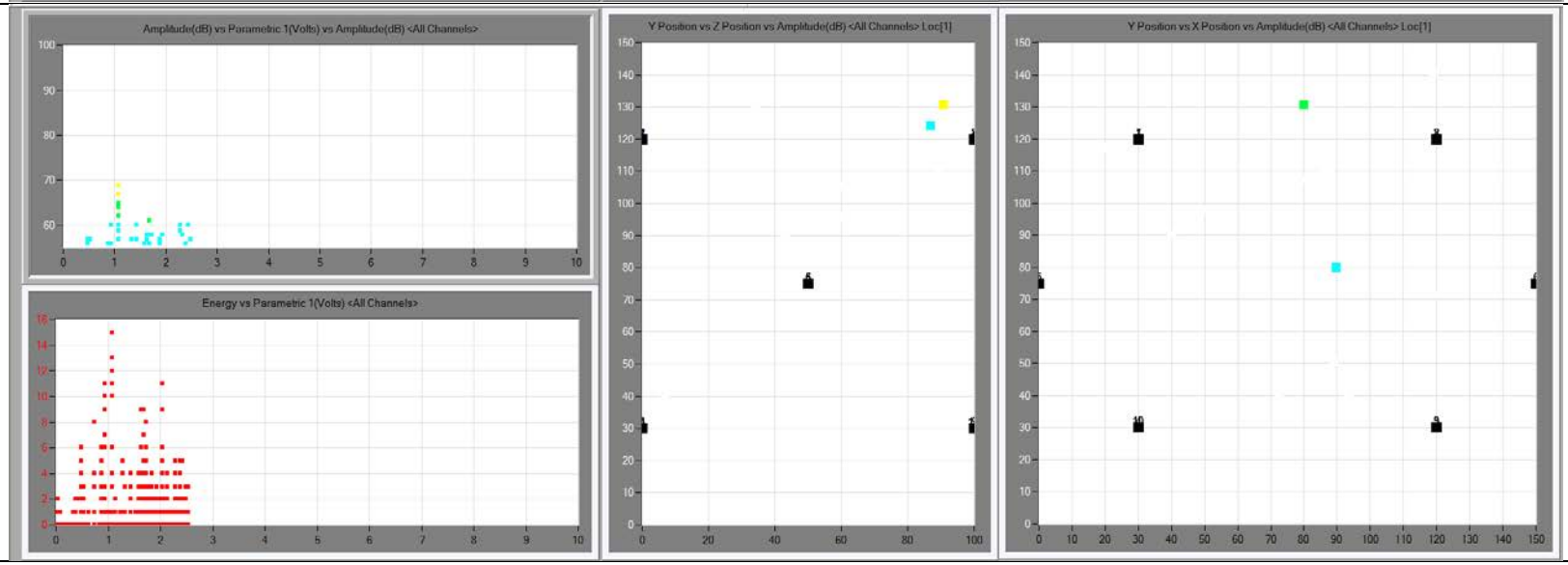
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0F1**
60%	
80%	

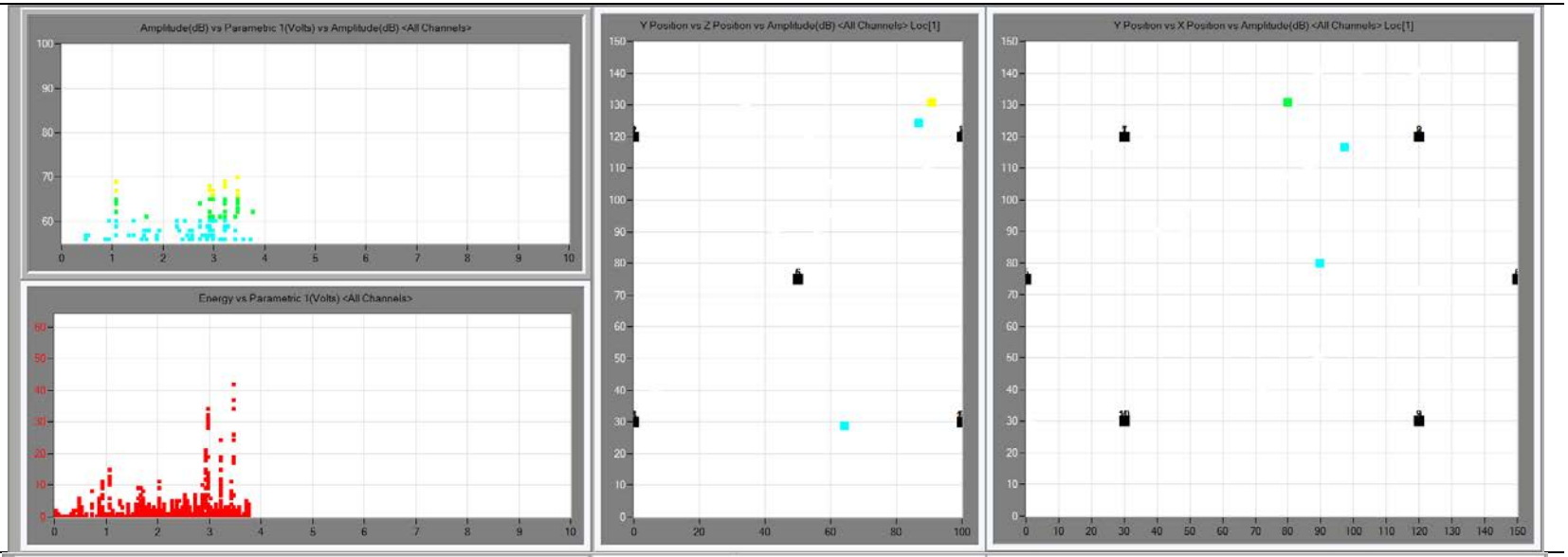
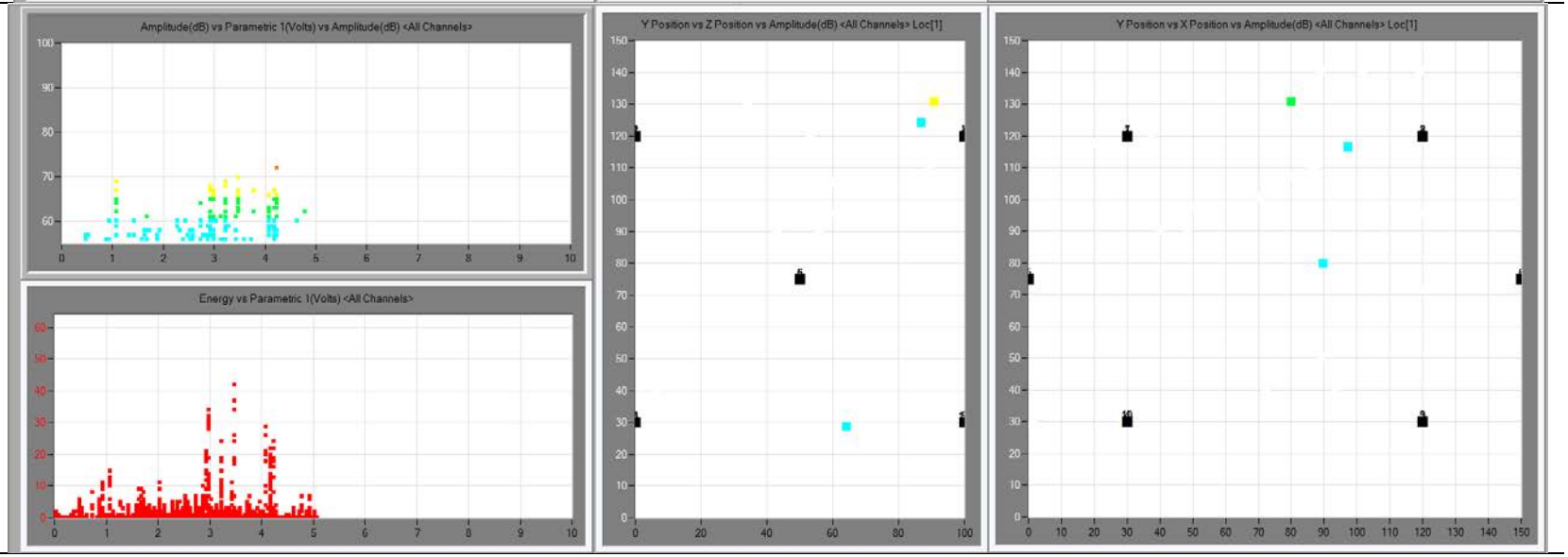
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0F1**
100%	

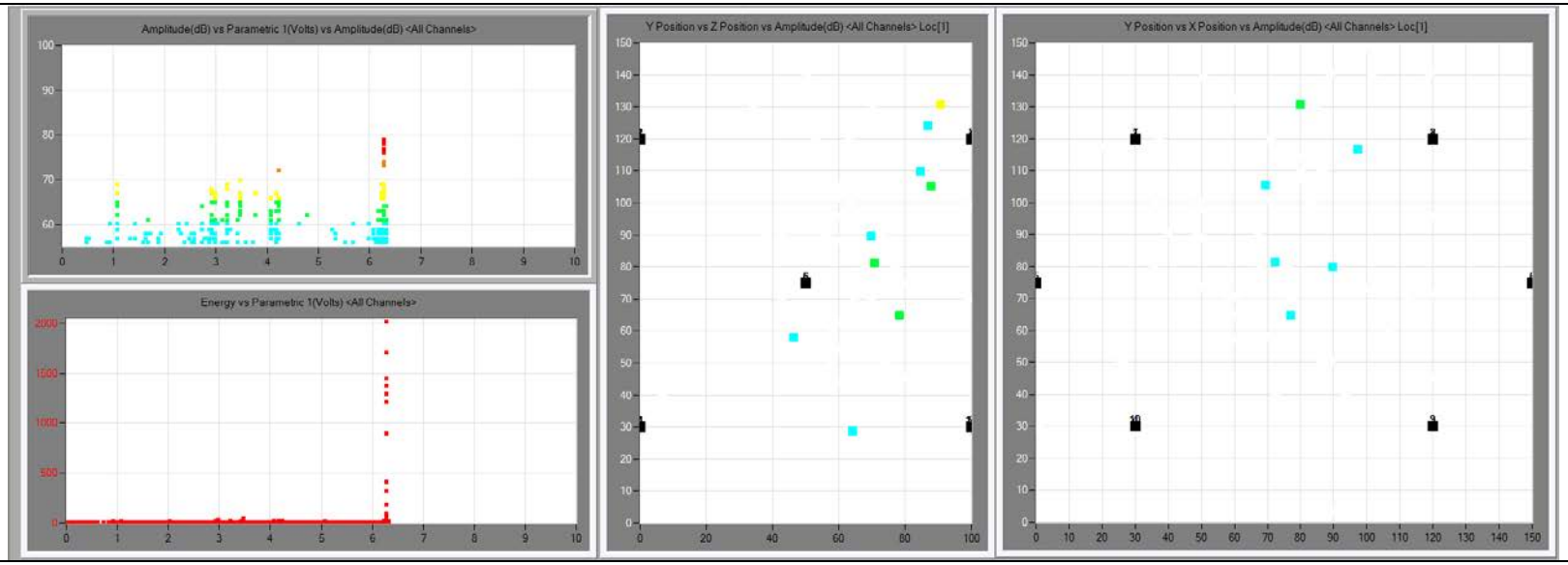
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0F2**
20%	
40%	

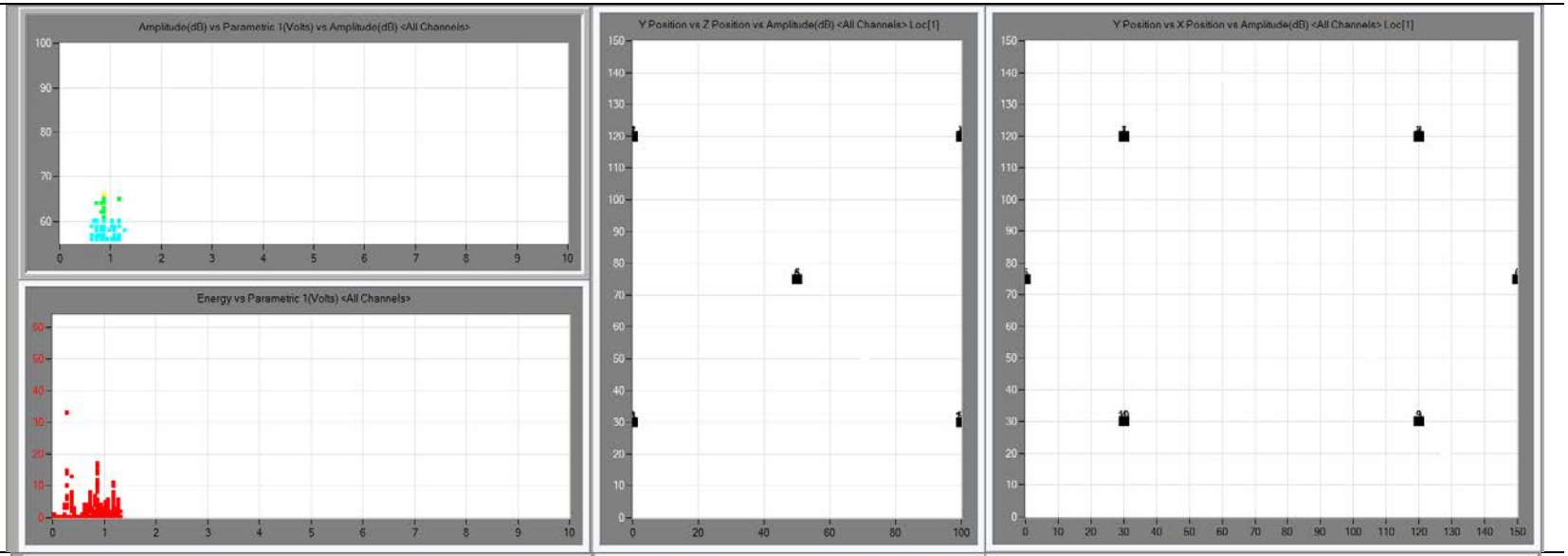
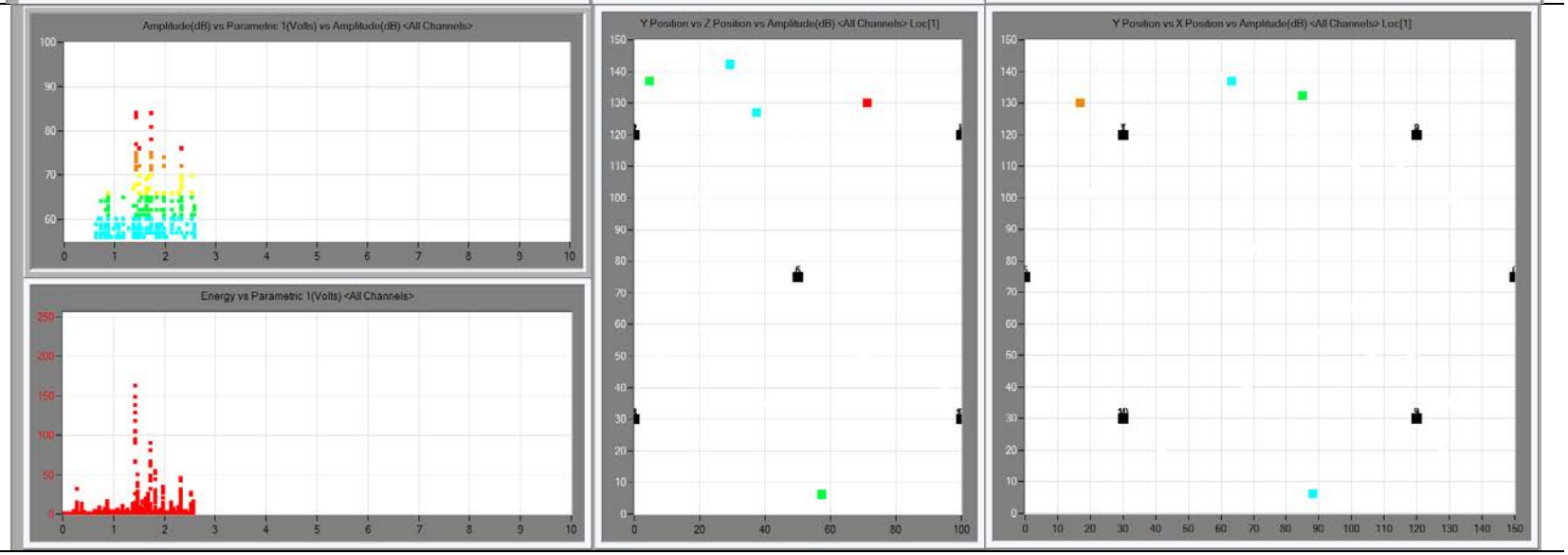
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0F2**
60%	
80%	

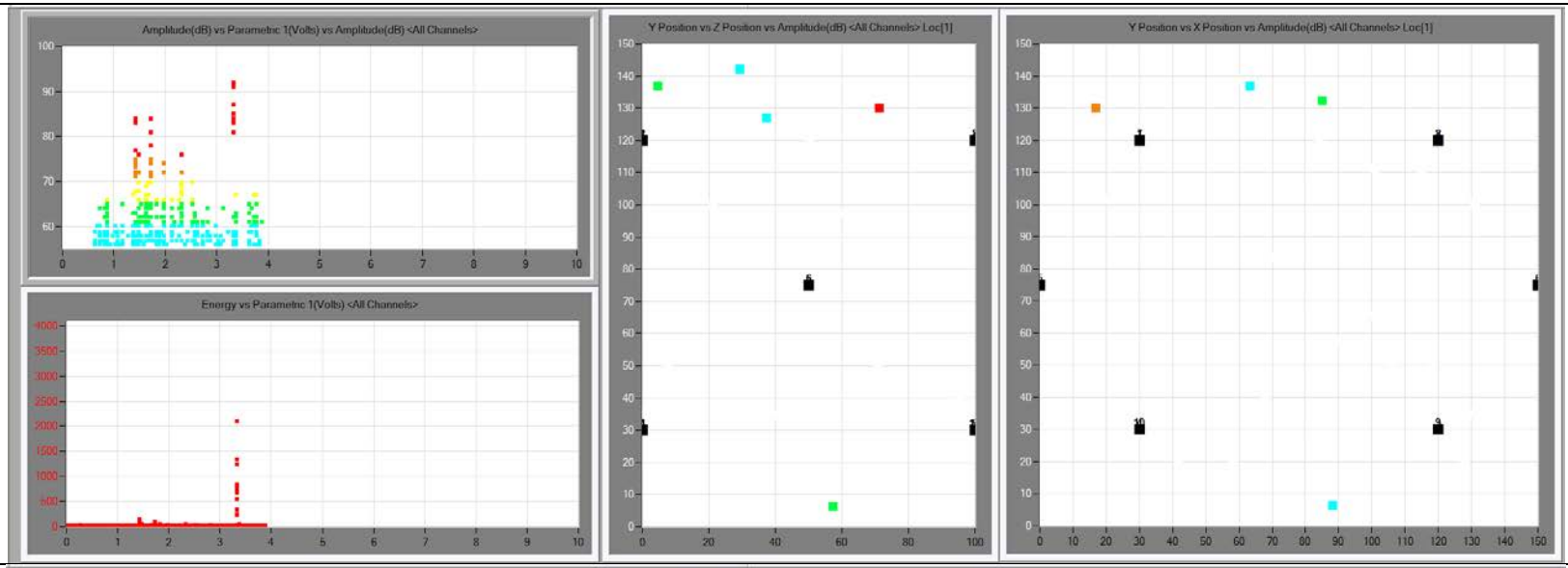
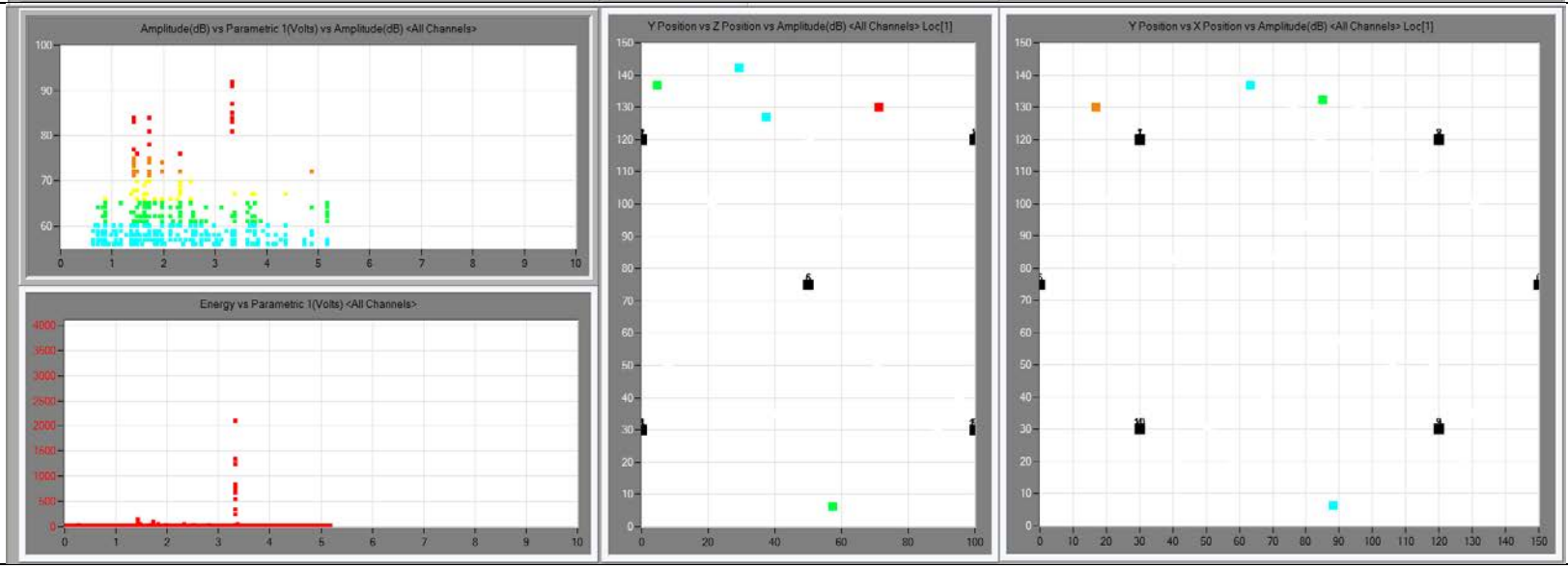
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0F2**
100%	

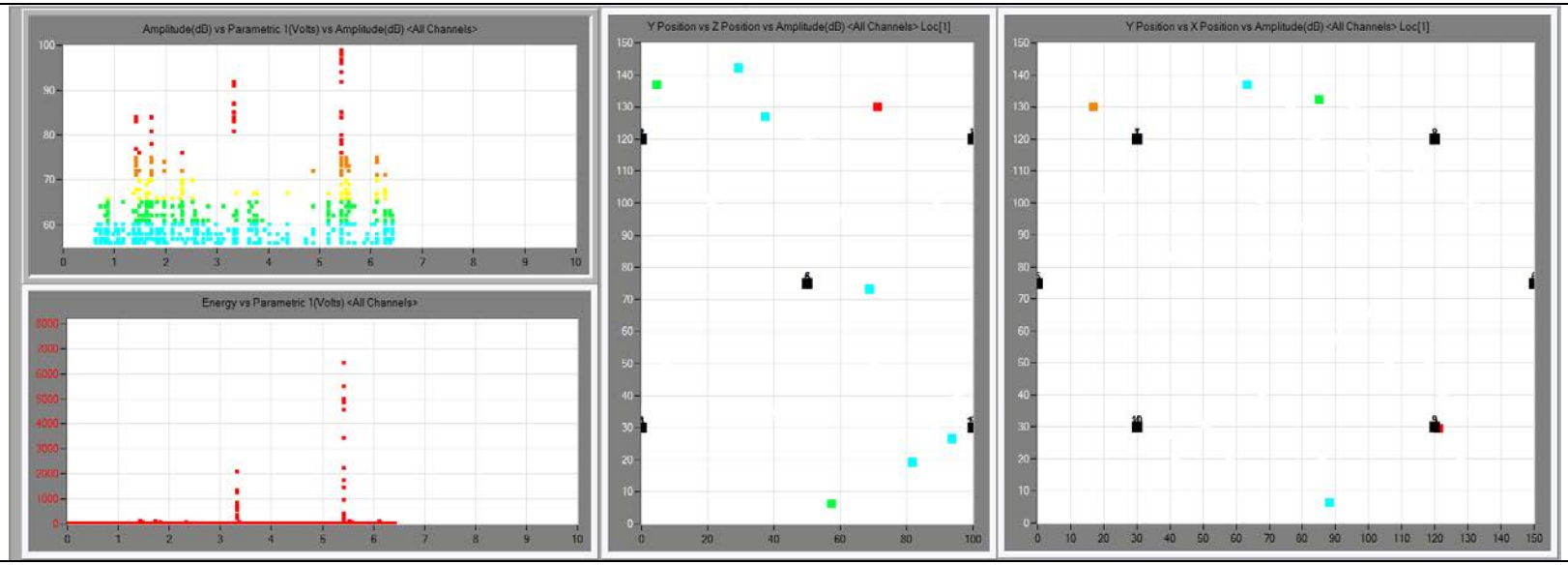
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0F3**
20%	
40%	

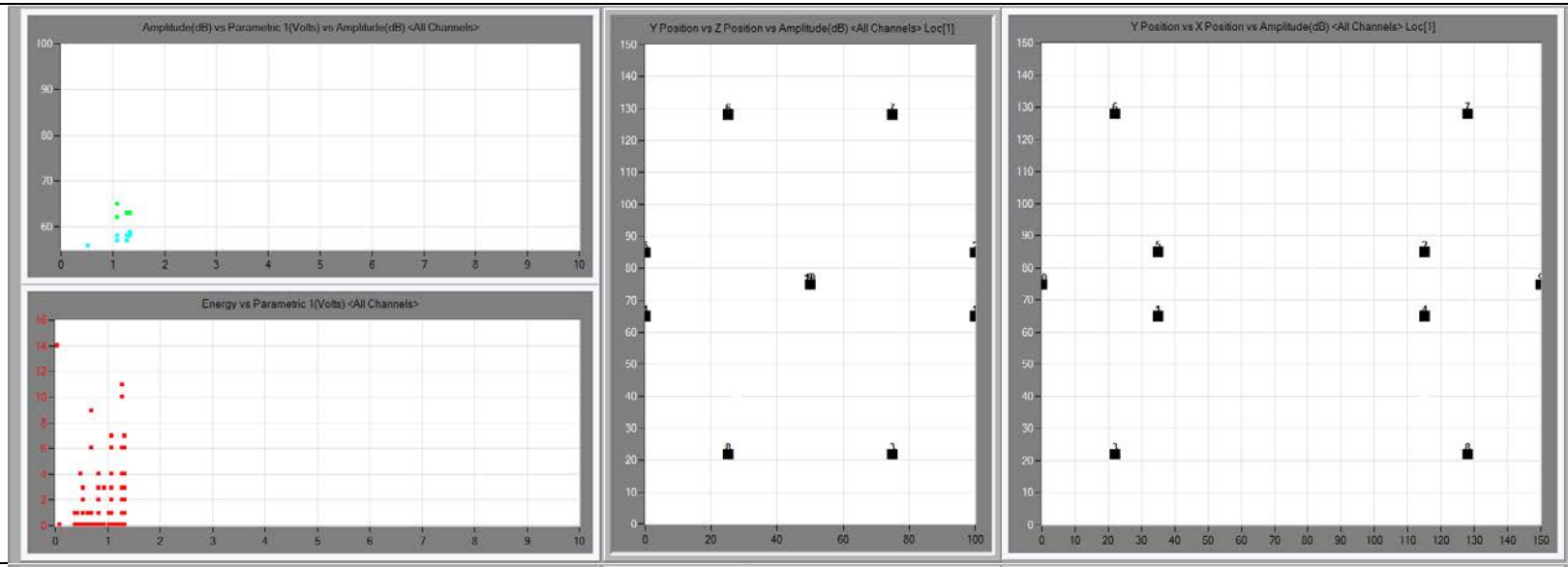
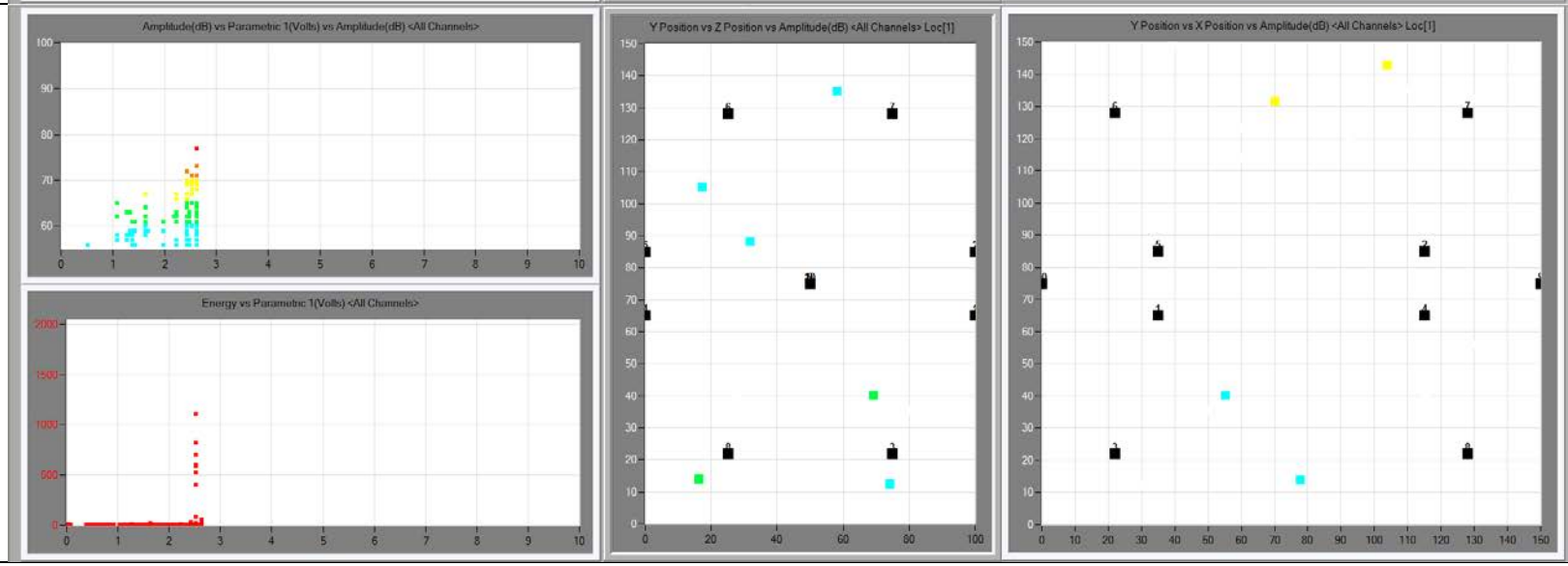
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0F3**
60%	
80%	

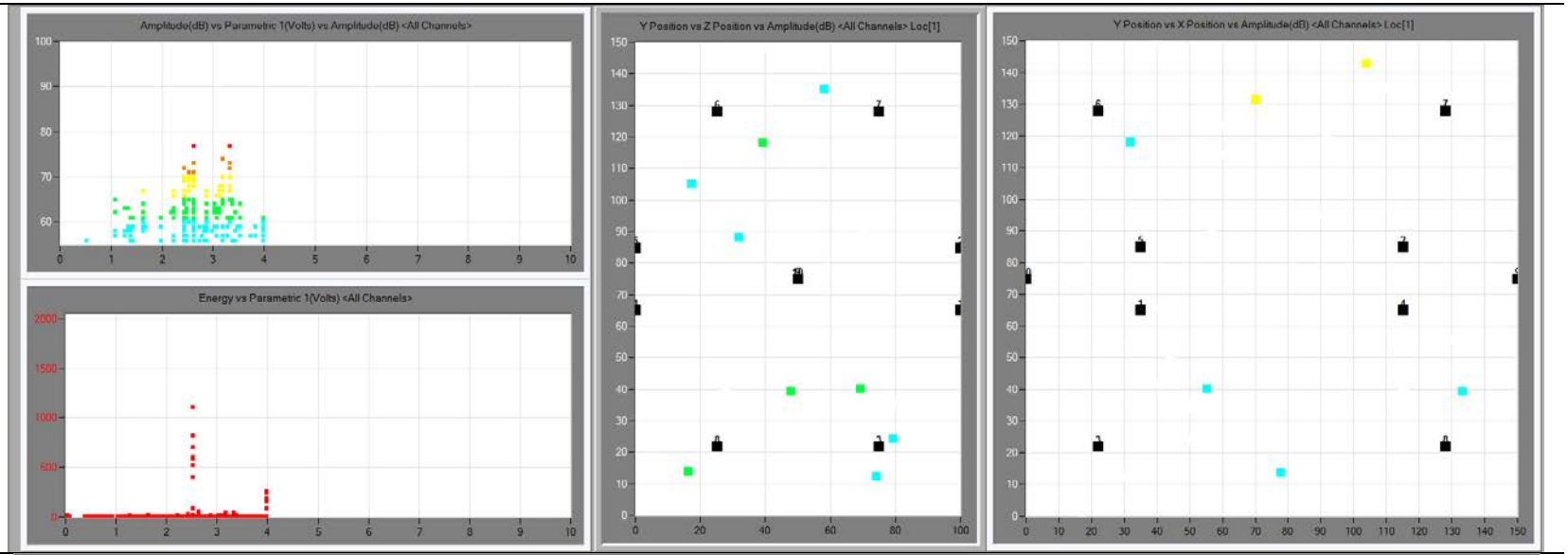
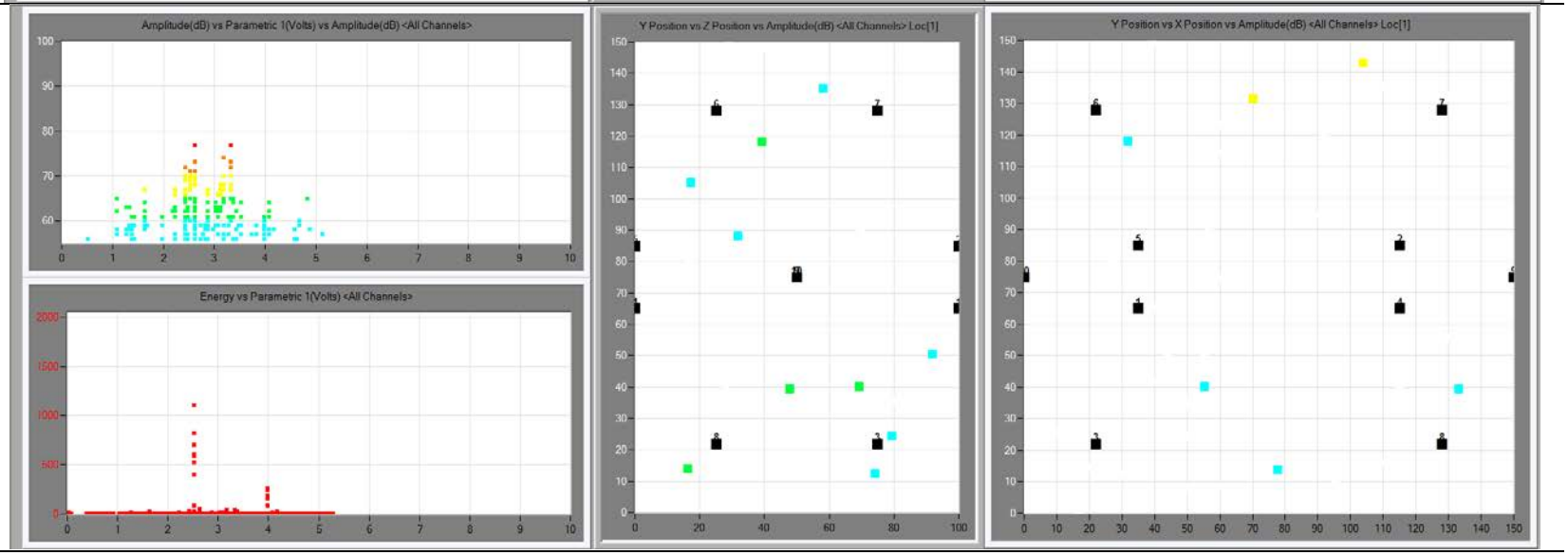
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24LW0F3**
100%	

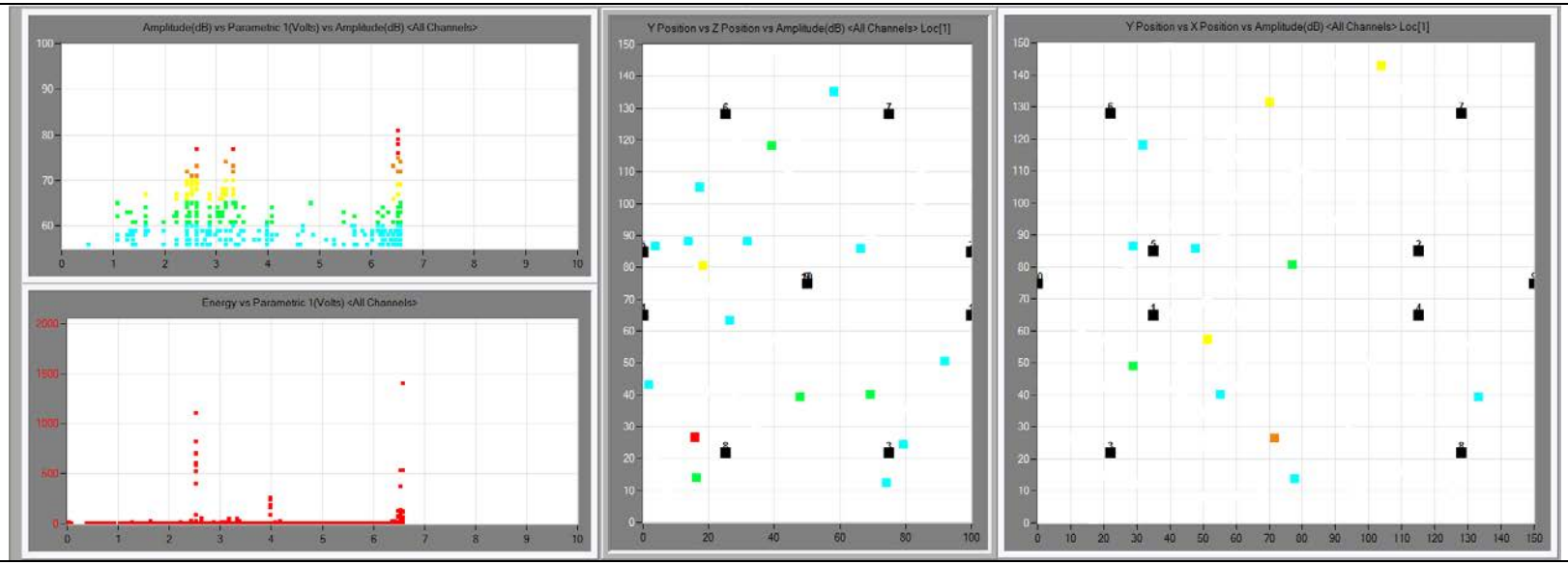
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2F1**
20%	
40%	

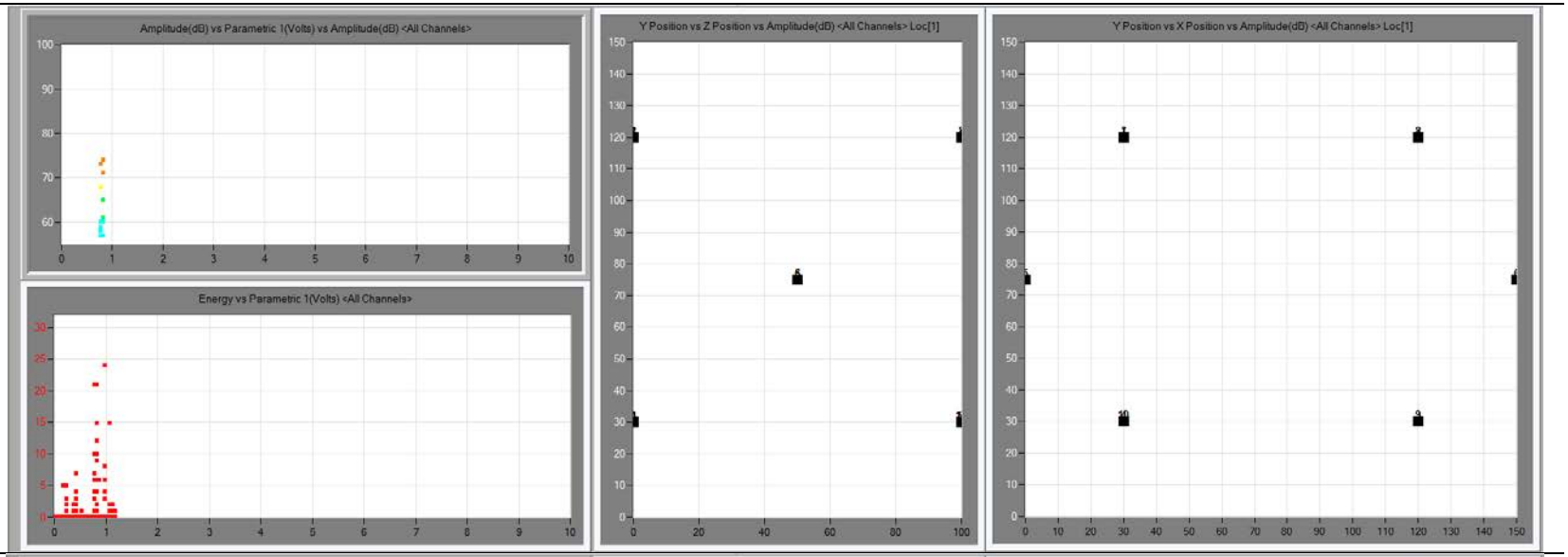
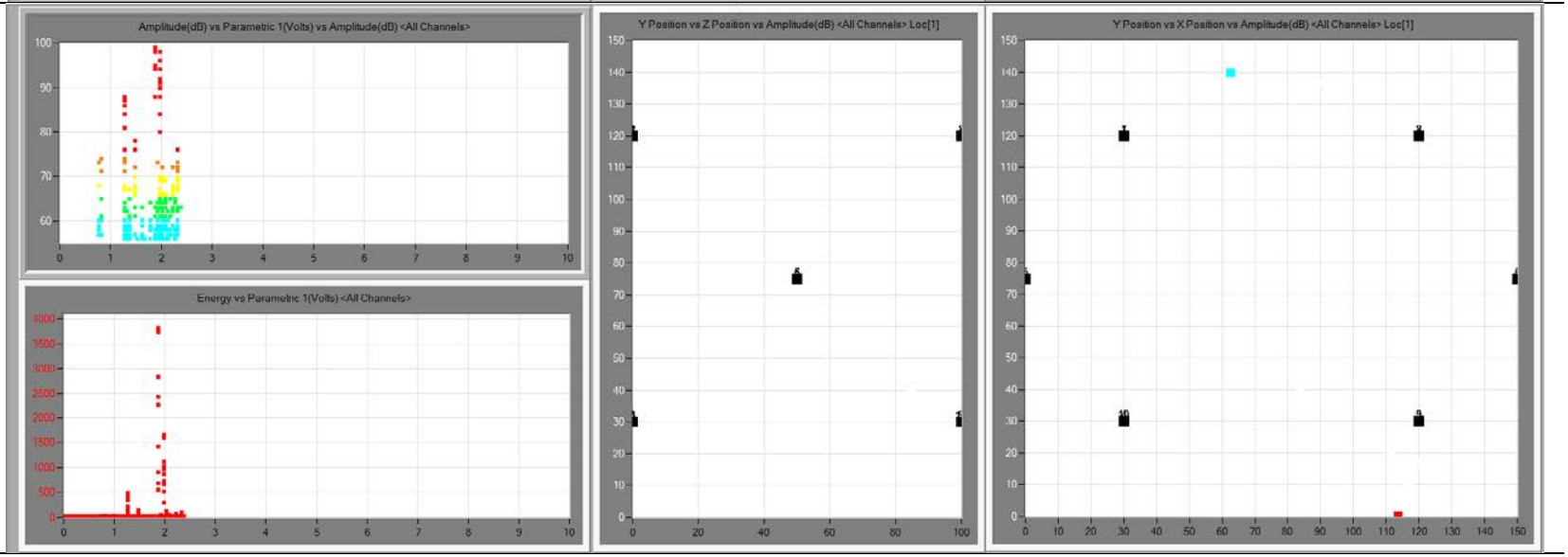
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2F1**
60%	
80%	

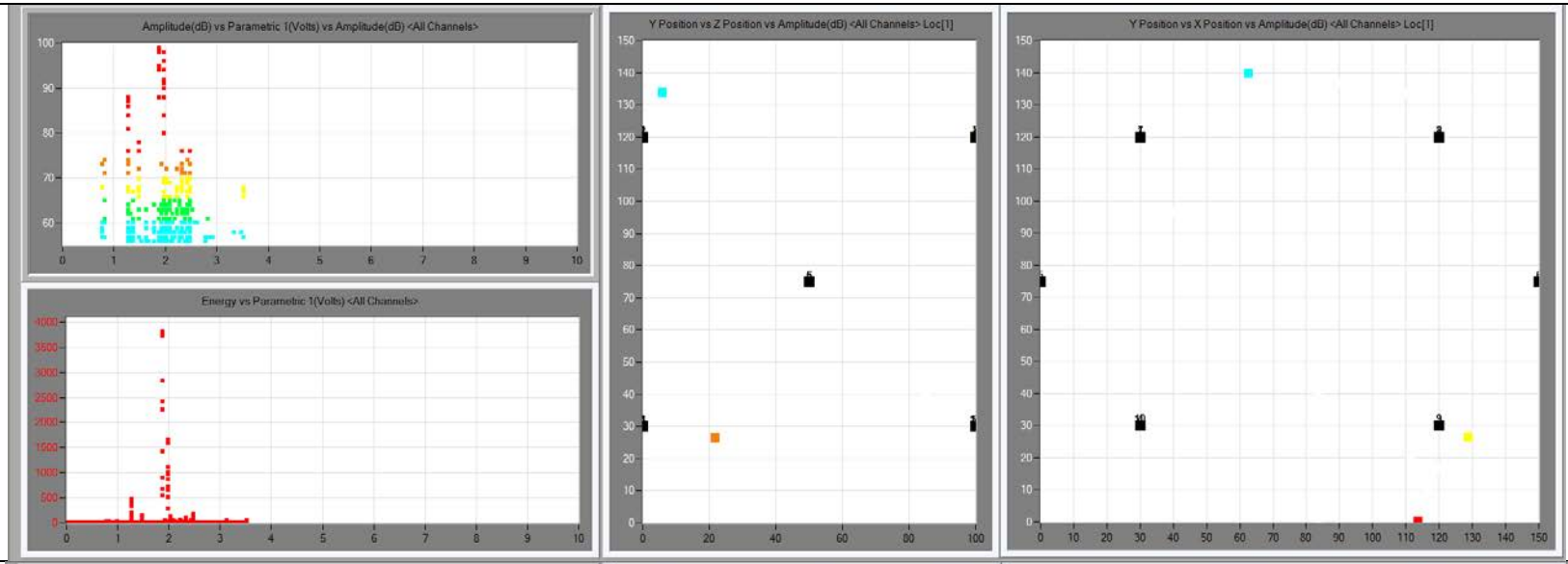
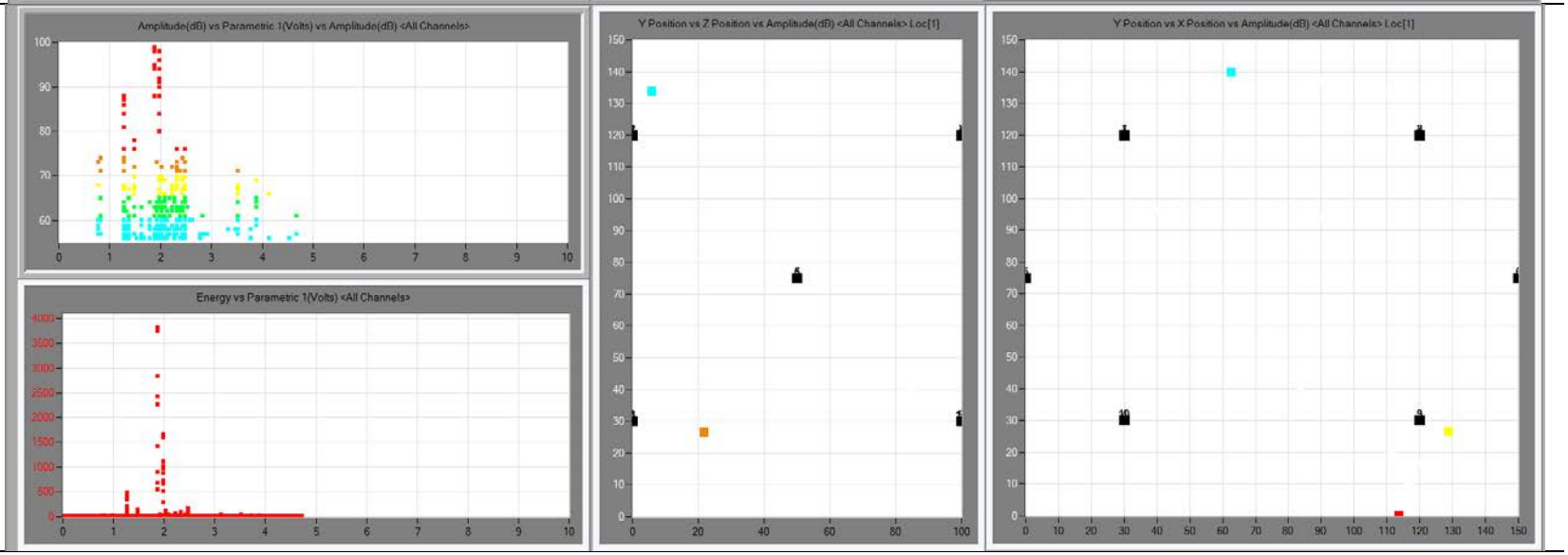
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2F1**
100%	

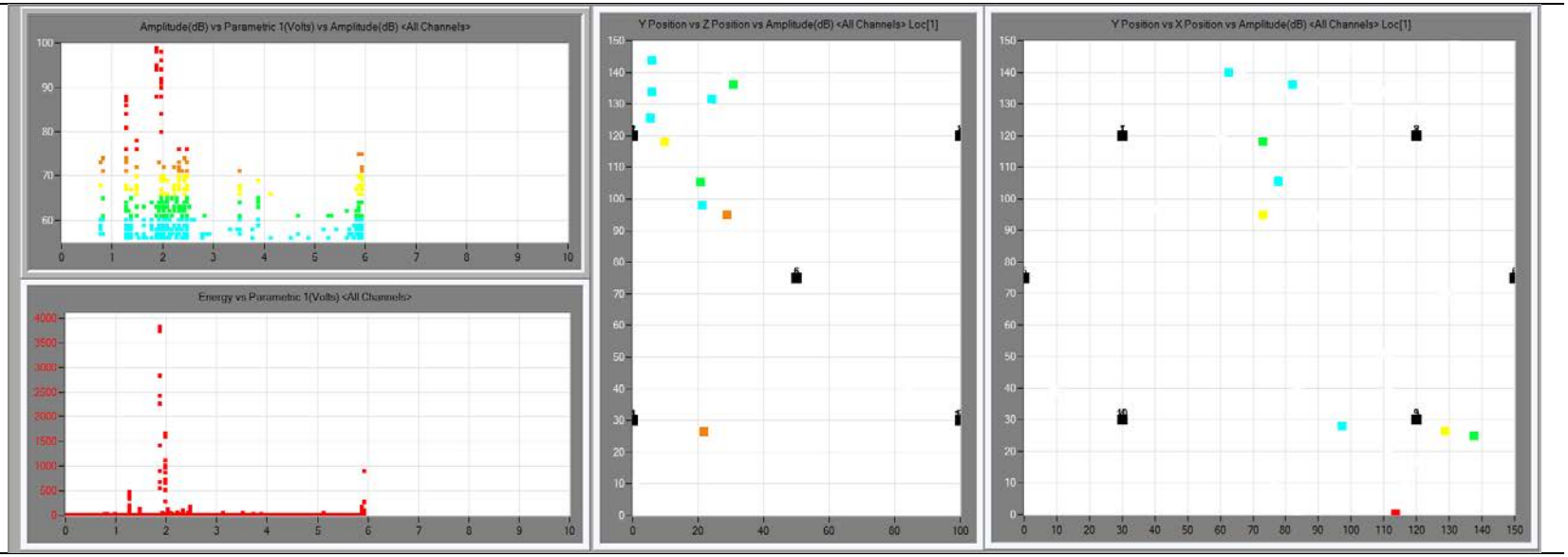
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2F2**
20%	
40%	

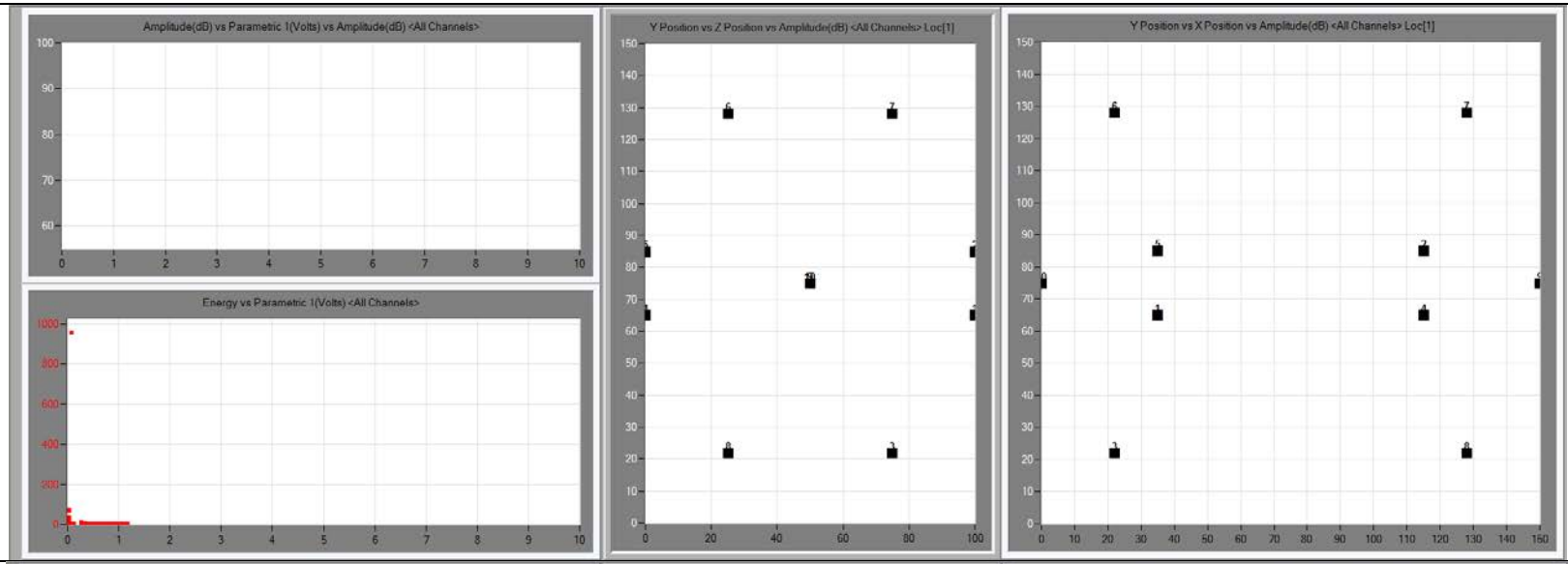
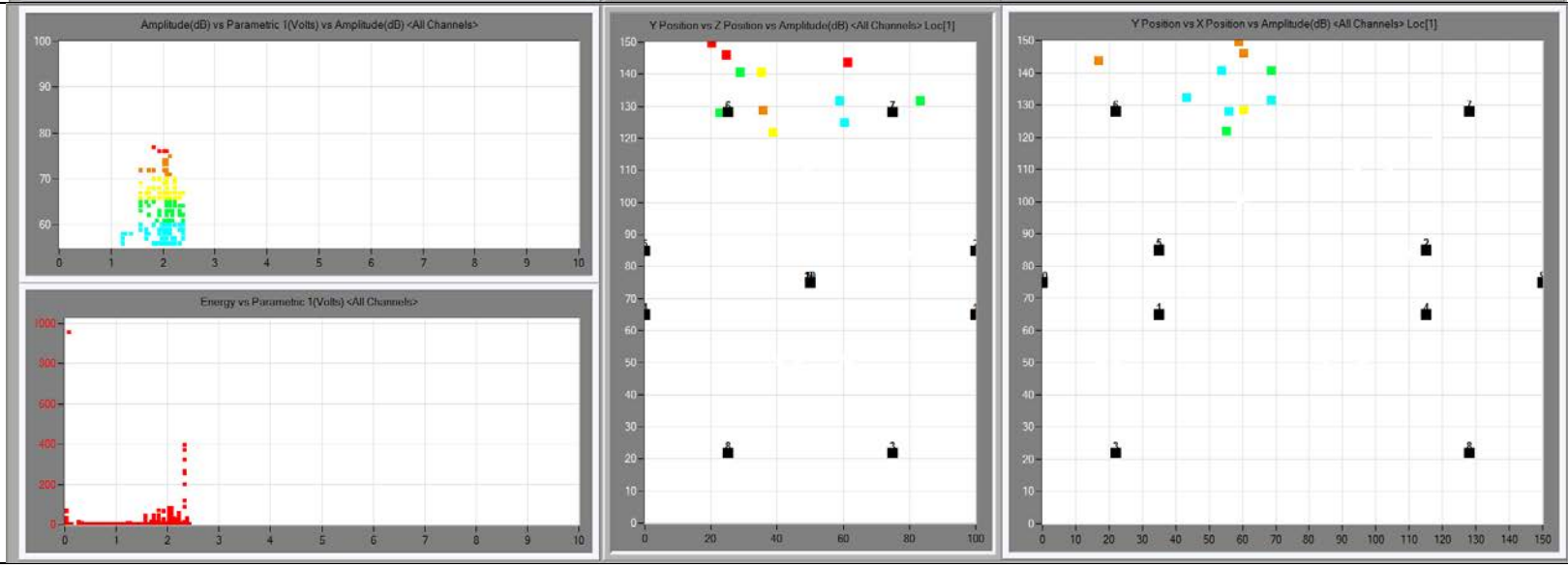
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2F2**
60%	
80%	

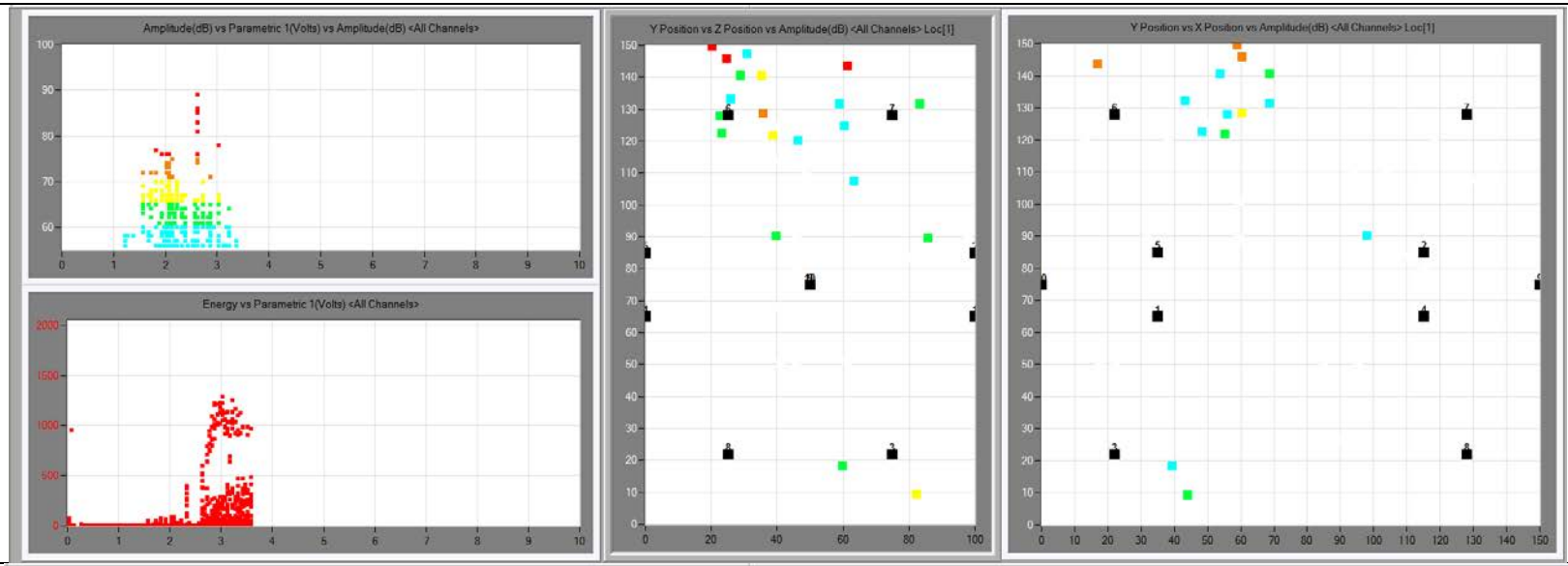
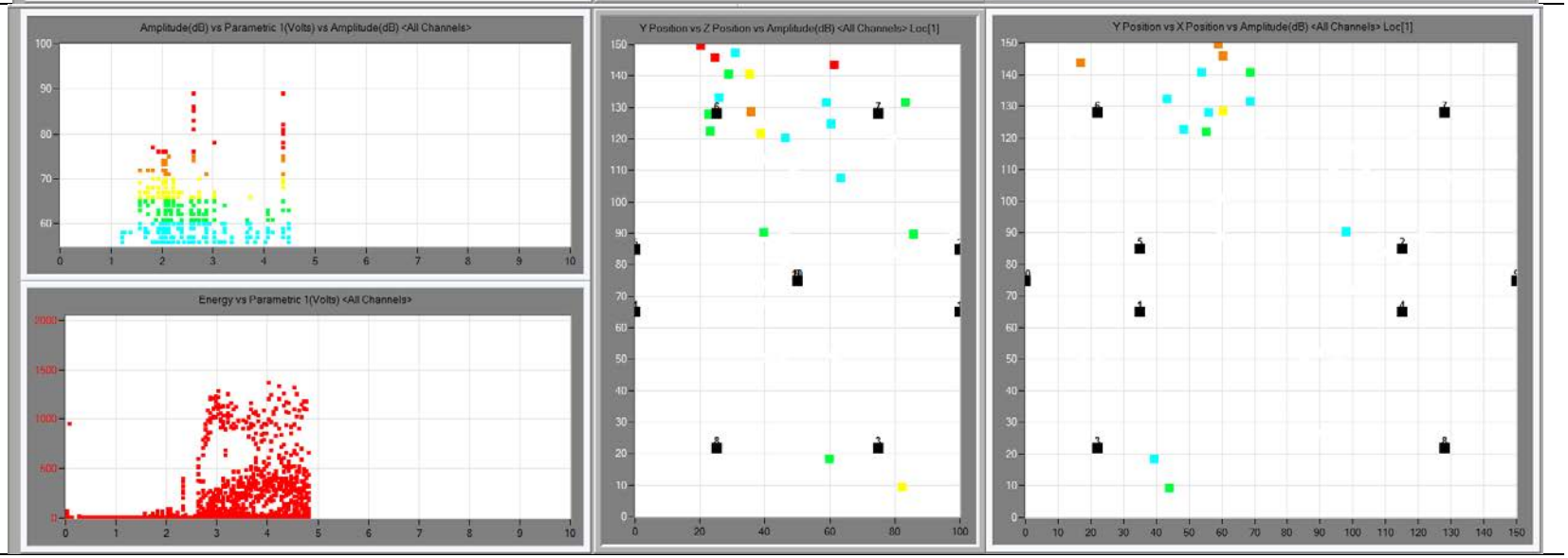
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2F2**
100%	

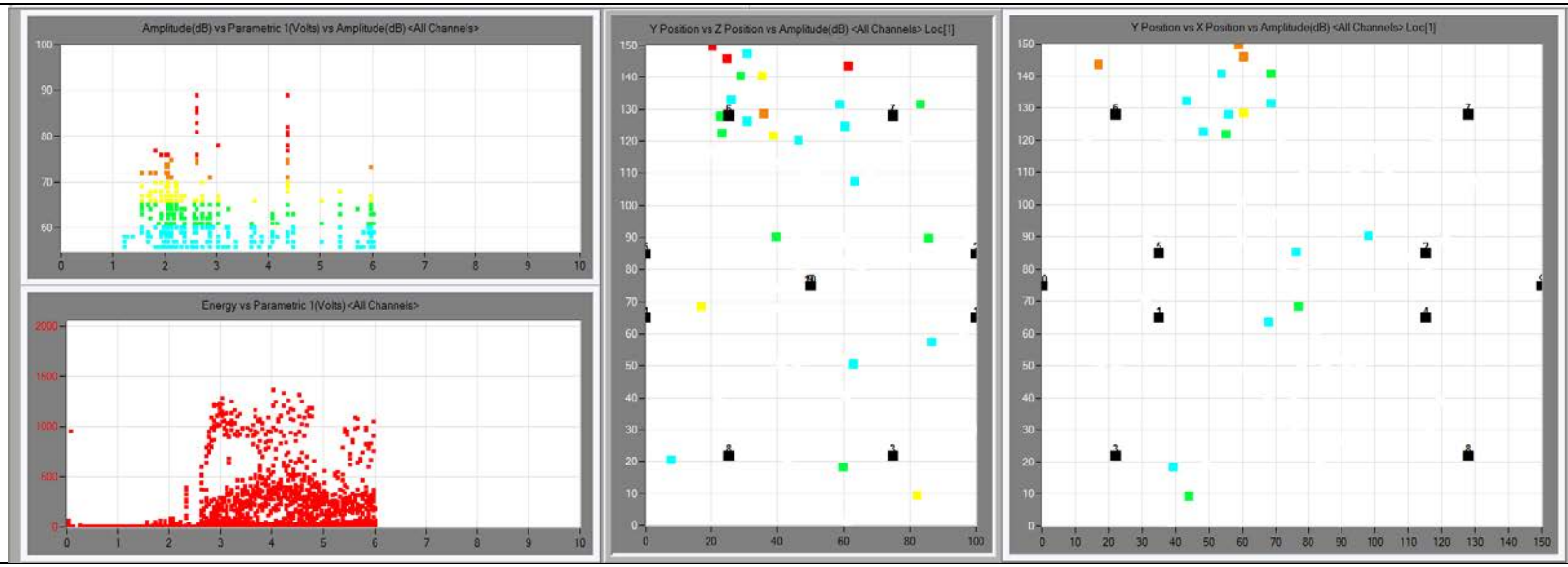
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2F3**
20%	
40%	

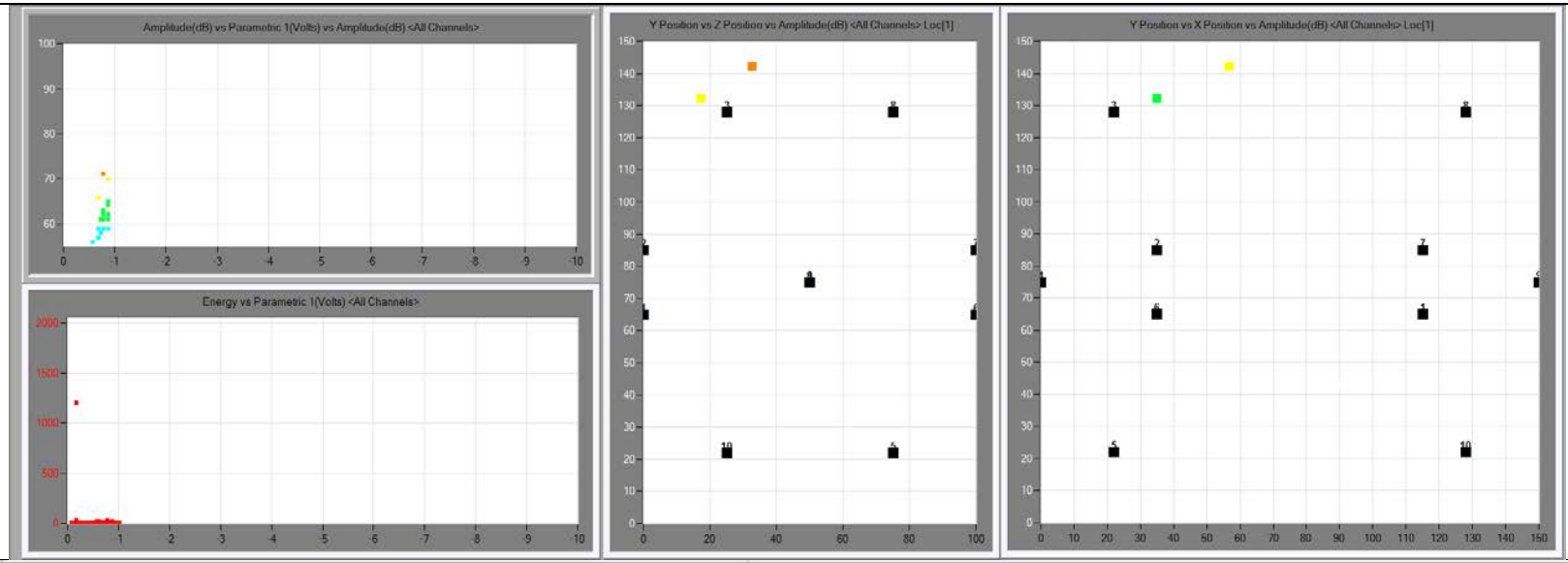
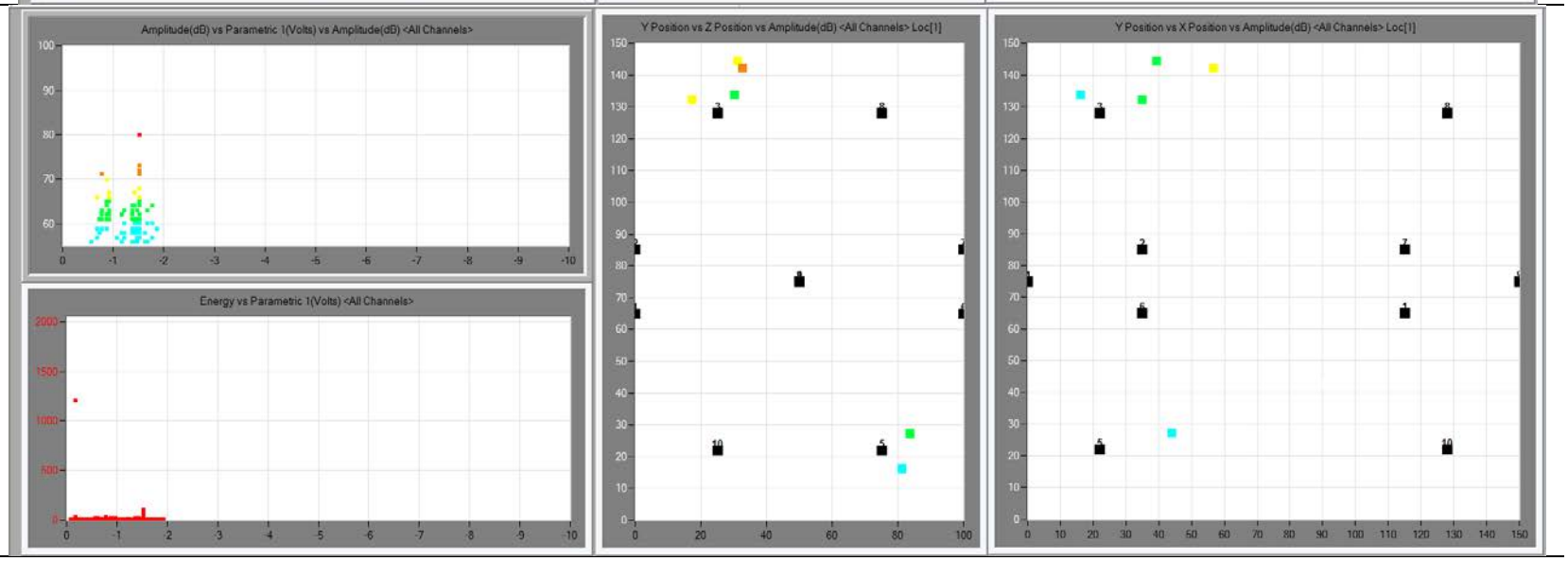
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2F3**
60%	
80%	
% of	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and

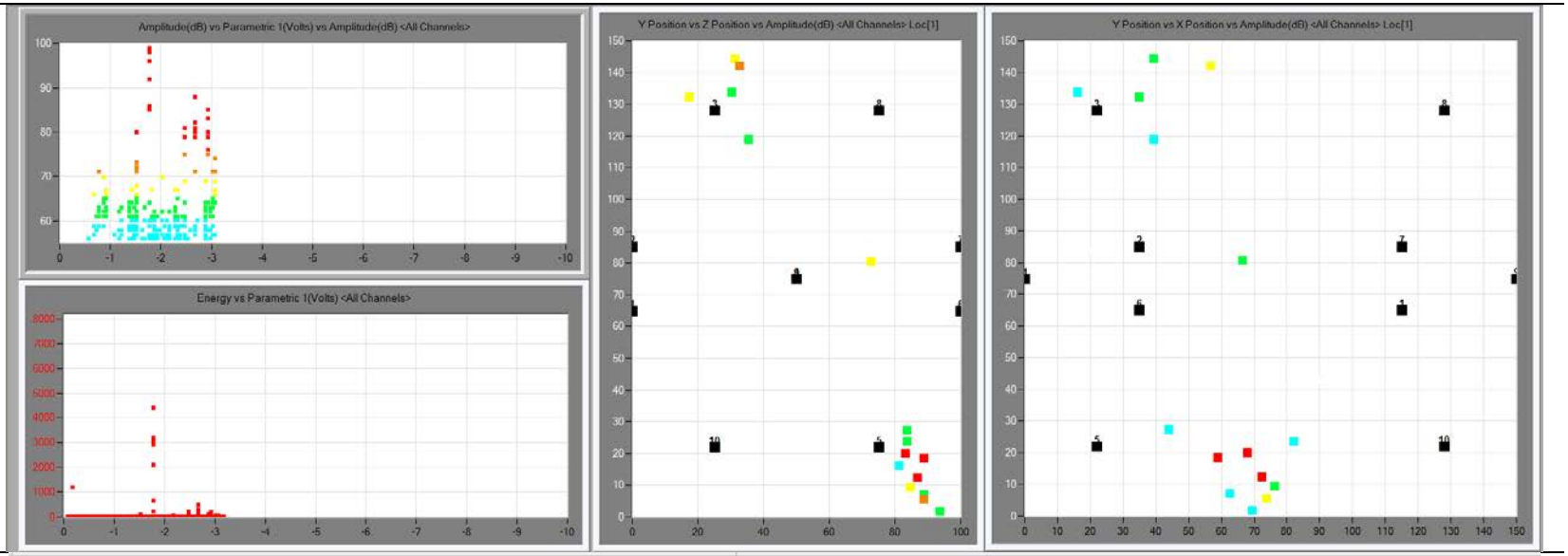
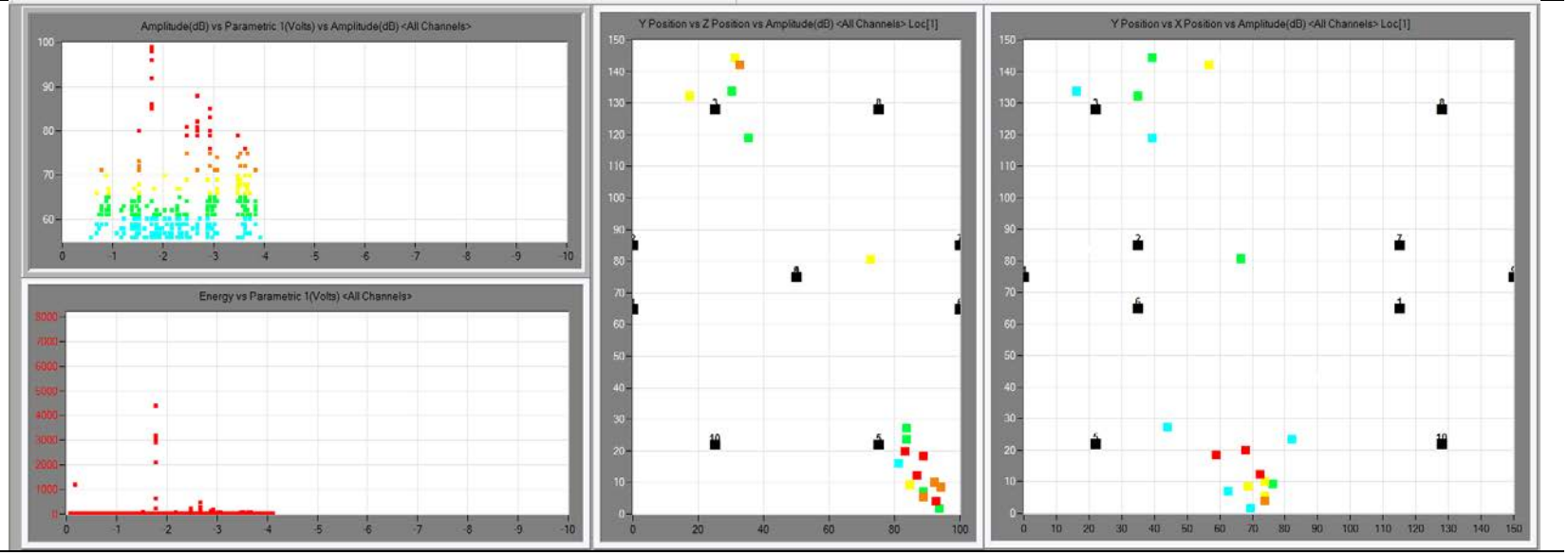
P_{ult}	Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS2F3**
100%	

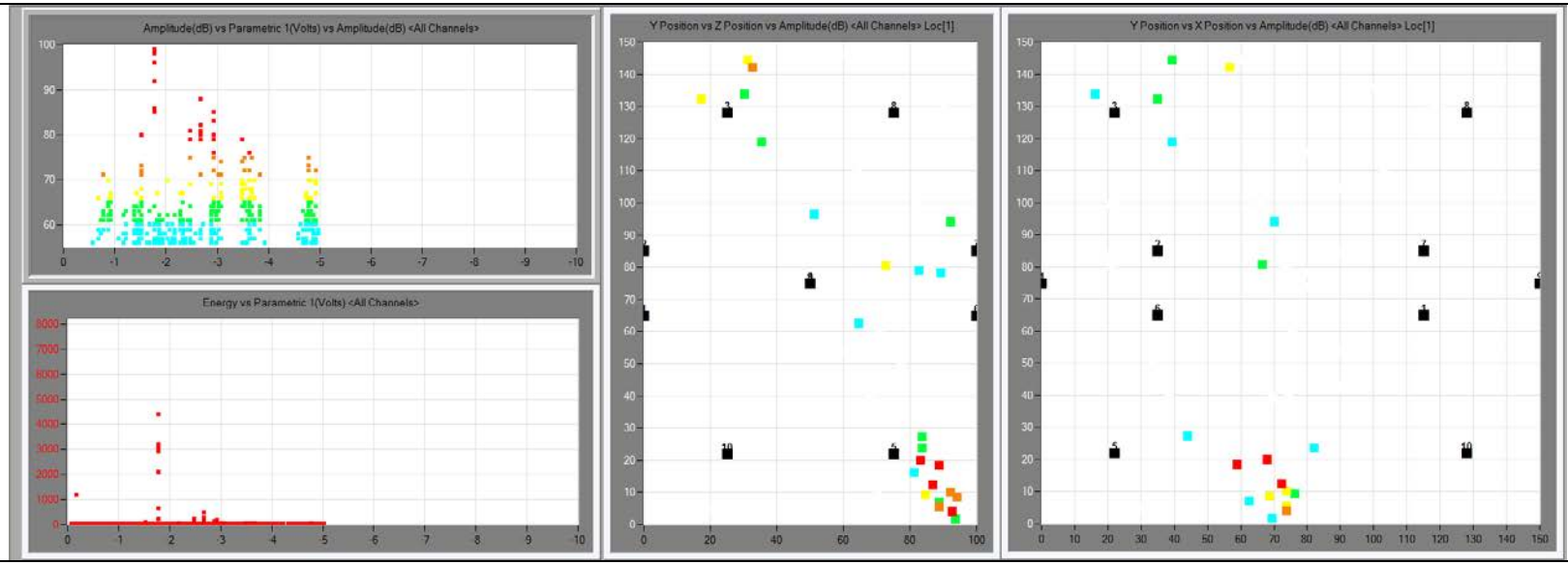
% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5F2**
20%	
40%	

% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5F2**
60%	
80%	

% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5F2**
100%	

% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5F3**
20%	
40%	

% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5F3**
60%	
80%	

% of P_{ult}	Amplitude (Top-Left) and Energy (Bottom-Left) of Acoustic Emission Hits versus Applied Load and Localization of Events Viewed Along Longitudinal Axis (Middle) and Diametral Axis (Right) **Sample 24SS5F3**
100%	

Appendix D

Results for Prisms Specimens

Prisms - Flexural Strenght Test					
Sample	Section Dimensions (mm)			Load (kN)	Flex. Str. (MPa)
	1	2	Average		
6 Months Solution Exposures					
P06LW0A1	77.92	75.50	76.71	13.16	6.5597
P06LW0A2	77.17	76.78	76.98	12.62	6.2258
P06LW0A3	77.48	75.56	76.52	13.22	6.6388
P06LW0C1	76.38	77.29	76.84	12.07	5.9870
P06LW0C2	77.36	77.35	77.36	14.15	6.8782
P06LW0C3	78.12	76.83	77.48	12.55	6.0721
P06SS2A1	76.99	75.05	76.02	13.84	7.0882
P06SS2A2	77.27	78.96	78.12	15.95	7.5290
P06SS2A3	77.43	77.74	77.59	14.87	7.1641
P06SS2C1	78.98	76.96	77.97	16.09	7.6376
P06SS2C2	77.48	76.85	77.17	16.36	8.0113
P06SS2C3	77.15	77.71	77.43	15.39	7.4592
P06SS5A1	77.30	78.31	77.81	16.05	7.6672
P06SS5A2	76.46	76.62	76.54	13.73	6.8913
P06SS5A3	76.50	77.43	76.97	13.64	6.7316
P06SS5C1	77.00	78.06	77.53	14.57	7.0345
P06SS5C2	77.14	77.83	77.49	16.61	8.0334
P06SS5C3	77.13	76.16	76.65	16.50	8.2455
12 Months Solution Exposures					
P12LW0A1	75.74	77.06	76.40	12.53	6.3220
P12LW0A2	77.49	76.65	77.07	11.64	5.7211
P12LW0A3	77.21	75.59	76.40	11.58	5.8427
P12LW0C1	76.40	76.95	76.68	12.49	6.2342
P12LW0C2	75.86	76.68	76.27	12.37	6.2732
P12LW0C3	75.00	76.75	75.88	11.20	5.7691
P12SS2A1	75.48	77.59	76.54	13.06	6.5546
P12SS2A2	76.44	76.90	76.67	13.09	6.5350
P12SS2A3	76.34	77.11	76.73	12.53	6.2420
P12SS2C1	77.22	76.75	76.99	15.72	7.7521
P12SS2C2	76.72	74.68	75.70	14.46	7.5000
P12SS2C3	77.13	75.14	76.14	12.44	6.3423
P12SS5A1	77.19	74.35	75.77	12.08	6.2482
P12SS5A2	77.82	75.96	76.89	13.32	6.5929
P12SS5A3	76.03	78.54	77.29	14.49	7.0618
P12SS5C1	76.67	77.48	77.08	16.18	7.9503
P12SS5C2	77.12	75.02	76.07	14.99	7.6620
P12SS5C3	75.27	76.64	75.96	13.25	6.8035

Prisms - Flexural Strenght Test					
Sample	Section Dimensions (mm)			Load	Flex. Str.
	1	2	Average	(kN)	(MPa)
18 Months Solution Exposures					
P18LW0A1	77.39	77.76	77.58	10.65	5.1329
P18LW0A2	77.03	75.85	76.44	10.10	5.0879
P18LW0A3	77.65	77.92	77.79	10.52	5.0293
P18LW0C1	76.76	78.18	77.47	12.30	5.9523
P18LW0C2	77.07	77.24	77.16	11.76	5.7610
P18LW0C3	77.15	78.48	77.82	12.54	5.9881
P18SS2A1	75.84	78.48	77.16	9.83	4.8146
P18SS2A2	77.20	76.06	76.63	11.70	5.8502
P18SS2A3	76.92	77.06	76.99	14.62	7.2082
P18SS2C1	77.31	76.62	76.97	13.96	6.8895
P18SS2C2	76.93	78.44	77.69	12.68	6.0854
P18SS2C3	77.34	75.32	76.33	13.04	6.5974
P18SS5A1	75.76	77.53	76.65	16.24	8.1155
P18SS5A2	77.54	76.87	77.21	14.21	6.9000
P18SS5A3	77.13	79.76	78.45	12.30	5.7331
P18SS5C1	76.83	74.68	75.76	16.16	8.3635
P18SS5C2	77.31	77.46	77.39	15.55	7.5499
P18SS5C3	76.48	76.87	76.68	14.48	7.2275
24 Months Solution Exposures					
P24LW0A1	77.63	77.56	77.60	11.67	5.6178
P24LW0A2	78.79	77.26	78.03	13.90	6.5841
P24LW0A3	76.65	76.70	76.68	11.78	5.8799
P24LW0C1	78.26	77.39	77.83	11.26	5.3748
P24LW0C2	77.77	76.78	77.28	9.54	4.6509
P24LW0C3	76.79	77.44	77.12	10.30	5.0536
P24SS2A1	77.23	77.17	77.20	13.93	6.8121
P24SS2A2	78.85	76.91	77.88	15.06	7.1735
P24SS2A3	77.07	77.49	77.28	16.13	7.8635
P24SS2C1	77.54	77.30	77.42	15.24	7.3894
P24SS2C2	77.94	77.69	77.82	15.09	7.2058
P24SS2C3	78.05	77.61	77.83	13.56	6.4714
P24SS5A1	78.51	76.94	77.73	17.86	8.5582
P24SS5A2	78.03	77.18	77.61	18.02	8.6750
P24SS5A3	77.17	77.64	77.41	14.98	7.2675
P24SS5C1	77.11	78.28	77.70	14.50	6.9562
P24SS5C2	78.26	76.46	77.36	14.87	7.2268
P24SS5C3	77.12	77.26	77.19	15.92	7.7876

Flexural Strenght Test - Sample Statistics

Sample	Average (MPa)	Standard Deviation	Coeff. of Variation	Sample	Average (MPa)	Standard Deviation	Coeff. of Variation
6 Months Solution Exposures				**12 Months Solution Exposures**			
P06LW0A	6.47	0.22	3.39	P12LW0A	5.96	0.32	5.33
P06LW0C	6.31	0.49	7.79	P12LW0C	6.09	0.28	4.60
P06SS2A	7.26	0.24	3.25	P12SS2A	6.44	0.18	2.72
P06SS2C	7.70	0.28	3.66	P12SS2C	7.20	0.75	10.44
P06SS5A	7.10	0.50	7.05	P12SS5A	6.63	0.41	6.16
P06SS5C	7.77	0.65	8.32	P12SS5C	7.47	0.60	7.98

Statistical Evaluation for Differences Between Samples

F-Test

6 Months Exposures	Samples	P06LW0A	P06LW0C	P06SS2A	P06SS2C	P06SS5A	P06SS5C	t-Test
	P06LW0A	1.000	0.629	0.013	0.004	0.120	0.030	
	P06LW0C	0.332	1.000	0.040	0.013	0.125	0.036	
	P06SS2A	0.928	0.374	1.000	0.105	0.635	0.268	
	P06SS2C	0.754	0.494	0.823	1.000	0.142	0.875	
	P06SS5A	0.322	0.982	0.363	0.481	1.000	0.226	
	P06SS5C	0.206	0.733	0.235	0.319	0.749	1.000	

F-Test

12 Months Exposures	Samples	P12LW0A	P12LW0C	P12SS2A	P12SS2C	P12SS5A	P12SS5C	t-Test
	P12LW0A	1.000	0.623	0.083	0.059	0.088	0.018	
	P12LW0C	0.876	1.000	0.139	0.075	0.131	0.022	
	P12SS2A	0.466	0.561	1.000	0.166	0.499	0.046	
	P12SS2C	0.303	0.244	0.103	1.000	0.317	0.647	
	P12SS5A	0.754	0.641	0.311	0.456	1.000	0.115	
	P12SS5C	0.442	0.362	0.159	0.773	0.638	1.000	

Flexural Strenght Test - Sample Statistics							
Sample	Average (MPa)	Standard Deviation	Coeff. of Variation	Sample	Average (MPa)	Standard Deviation	Coeff. of Variation
18 Months Solution Exposures				**24 Months Solution Exposures**			
P18LW0A	5.08	0.05	1.02	P24LW0A	6.03	0.50	8.29
P18LW0C	5.90	0.12	2.07	P24LW0C	5.03	0.36	7.22
P18SS2A	5.96	1.20	20.15	P24SS2A	7.28	0.53	7.33
P18SS2C	6.52	0.41	6.24	P24SS2C	7.02	0.49	6.92
P18SS5A	6.92	1.19	17.22	P24SS5A	8.17	0.78	9.56
P18SS5C	7.71	0.59	7.59	P24SS5C	7.32	0.42	5.79

Statistical Evaluation for Differences Between Samples

F-Test

18 Months Exposures	Samples	P18LW0A	P18LW0C	P18SS2A	P18SS2C	P18SS5A	P18SS5C	t-Test
	P18LW0A	1.000	0.000	0.334	0.024	0.116	0.016	
	P18LW0C	0.307	1.000	0.942	0.064	0.277	0.029	
	P18SS2A	0.004	0.020	1.000	0.482	0.382	0.085	
	P18SS2C	0.032	0.165	0.206	1.000	0.618	0.045	
	P18SS5A	0.004	0.021	0.992	0.209	1.000	0.357	
	P18SS5C	0.016	0.083	0.384	0.652	0.389	1.000	

F-Test

24 Months Exposures	Samples	P24LW0A	P24LW0C	P24SS2A	P24SS2C	P24SS5A	P24SS5C	t-Test
	P24LW0A	1.000	0.048	0.041	0.069	0.016	0.027	
	P24LW0C	0.690	1.000	0.004	0.005	0.003	0.002	
	P24SS2A	0.933	0.631	1.000	0.565	0.181	0.923	
	P24SS2C	0.972	0.716	0.905	1.000	0.097	0.464	
	P24SS5A	0.581	0.355	0.637	0.558	1.000	0.176	
	P24SS5C	0.837	0.845	0.773	0.865	0.455	1.000	