AN INVESTIGATION INTO MONOLITHIC PACK MATERIALS

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October 1987

A Thesis Submitted to the

Faculty of Graduate Studies and Research

in Partial Fulfillment of the Requirements for the Degree of

Master of Engineering

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to Dr.F.P.Hassani for his continous supervision in completing this study. Thanks are also due to Dr.A.Afrouz, Dr.P.Cain and Mr.K.Shikatani for their valuable assistance.

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ABSTRACT

This work is part of an overall research investigation into the mechanical and physical properties of different types of monolithic packs used in coal mines as well as conducting an intensive testing programme to attempt to develop a pack material from the local resources of Nova Scotia to be employed in the Sydney Coalfield.

This study gives a brief review of different packing materials and systems available and currently employed in major coalfields in the world. A case study in England has been outlined to substantiate the effectiveness of such a support system from a strata control point of view.

The mechanical and physical properties of commercially available monolithic packs mainly Aquapak, Tekpak, and Astrapak is discussed with special reference to curing time, mixing water temperature as well as curing temperature.

A comprehensive study of Astrapak material currently employed in the Sydney Coalfield has for the first time investigated the exothermic temperature development within different sizes (volume) of samples with respect to curing time and temperature.

Because of the abundance of natural anhydrite and flyash in the Cape Breton region, the possibility exists of incoporating an anhydrite and/or flyash based packing system in the Sydney coalfields. The Cape Breton Development Corporation (C.B.D.C) has expressed an interest in using monolithic packing systems in

mine, using the Astrapack low solid, cement-based packing system. This system has shown the advantages of a monolithic packing system over traditional chock-type supports ; an improvement in ventilation efficiency (less cross-circuting of ventilation through the waste area), less time and manpower requirements for pack construction (a greater rate of face advance), and an improvement in roadway conditions (less deformation). However, the Astrapak system materials must be imported from Great Britain and packing costs are quite severe. The new packing system would provide similar advantageous monolithic properties and, because of its local availability, would be significantly cheaper.

RESUME

Ce travail fait partie d'une étude élaborée sur les propriétés mécaniques et physiques de différents types de remblais monolithiques (monolithic packs) utilisés dans les mines de charbon. Un programme intensif d'essais en laboratoire a aussi été mis en marche dans le but de développer un remblai utilisant les ressources locales de la Nouvelle-Ecosse qui puisse être employé dans la houillière de Sydney.

Cette étude donne un bref compte-rendu des différents types de remblais, des systèmes disponibles et couramment utilisés dans les plus importantes mines de charbon du monde. Une étude de cas faite en Angleterre y est décrite afin d'appuyer l'efficacité d'un tel système de support en ce qui a trait au contrôle des strates.

Les propriétés mécaniques et physiques de certains remblais monolithiques disponibles sur le marché, comme l'Aquapak, le Tekpak et l'Astrapak, y sont abordées en portant une attention spéciale au temps de cure, à la température de l'eau de minage ainsi qu'à la température de cure.

Une étude approfondie de l'Astrapak, présentement utilisé dans les mines de Sydney, a, pour la première fois, examiné la température exothermique de différentes grosseurs (volume) d'échantillons par rapport au temps et à la température de cure.

A cause de l'abondance d'anhydrite naturel de cendre dans la région du Cap Breton, il existe une possibilité d'incorporer un système de remblais à base d'anhydrite et/ou de cendre dans les mines de Sydney. Le Cape Breton Development Corporation (C.B.D.C.) a démontré son intérêt dans l'utilisation de remblais monolithiques dans ses mines et a déjà entrepris des essais, à la mine Lingan, en employant l'Astrapak (basse teneur en solides) à base de ciment.

Ce système a démontré des avantages certains par rapport aux supports traditionnels: amélioration de l'efficacité de la ventilation (moins de circuitage dans les zones de rejets), moins de temps et de main-d'oeuvre pour la construction des remblais (rythme d'avancement de la face supérieur) et une amélioration des conditions des voies de roulage (moins de déformations).

Cependant, le système de remblais Astrapak doit être importé de Grande-Bretagne et son coût est très élevé. Le nouveau système de remblais donne des résultats semblables et à cause de sa disponibilité locale, son coût de production serait réduit d'une façon significative.

CHAPTER 1

CHAPTER 1

INTRODUCTION

Monolithic packs are some form of hydraulically, quick setting materials. Their major ingredients are: high alumina content cement, bentonite, accelerator and/or retarder, which by introduction of water form a slurry. It is then pumped to the point, where the pack is to be set.

The advantages of monolithic packs over the conventional packs were seen as:

(a) A reduction in the time and effort spent on the transport of pack material. This was one of the principal factors in preventing the face supply system coping with advance rates over 6 m per day.

(b) Upon placement as a road side pack, they develop an early compressive strength, thereby reducing the convergence rate of the gate roads. This creates better strata bridging over the gate roads and less disturbance of roof beds.

(c) Improved face-end ventilation by preventing short circuiting of the airflow across the waste area.

(d) Greater protection against the likelihood of spontaneous combustion in the goaf area behind the face.

(e) A more uniform supporting action along gate-roads in comparison with the other pack types.(However monolithic packs create excessive heat that could interfere with the ventilation system.)

Subsequently, monolithic packs resulted in marked improvements in conditions of the gate roads and became well established in the mechanized underground coal mines.

1.1: Strata Movement Above A Longwall Extraction

If we first consider a face at its start point (Figure 1a). As the face advances from its start point the redistributed stresses cause crushing of the coal and possibly flow of the floor. This increases the effective span and so accelerates the time at which the first bed will fail and fall into the opening. This failure will usually be by shear in the Coal Measures but may be due to tension (e.g sandstone). Either immediately or after a few more strips, more beds will collapse into the opening.

A point will be reached when the next bed is either sufficiently resistant to collapse on its own or is so due to the assistance of the broken strata below. The stress difference, due to the redistributed stresses and the free surface along the underside of the bed, will cause shear failure along the line of effective stress that hades over the face, Phillips (1948). Movement along these shear planes will allow similar failure in the beds above.

The free surface along the failure planes of the beds that have collapsed will allow the formation of "induced cleavage", Faulkner and Phillips (1935).

Let us now consider the face when it is well away from its start line, Figure 1b. Failure in the immediate strata is attributed the presence of induced cleavage. Whittaker ,(1975) and Spruth (1951) have produced photographic evidence to show

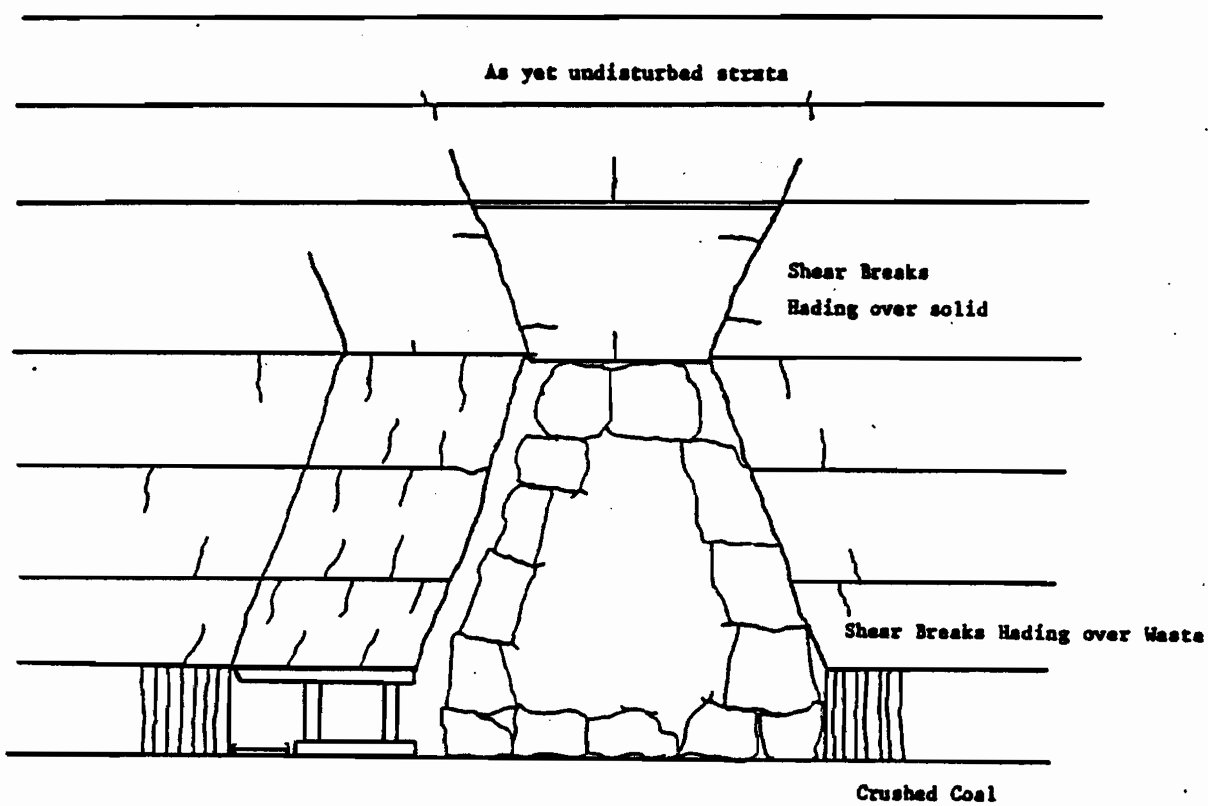


Fig. 1a Failure as Face Starts

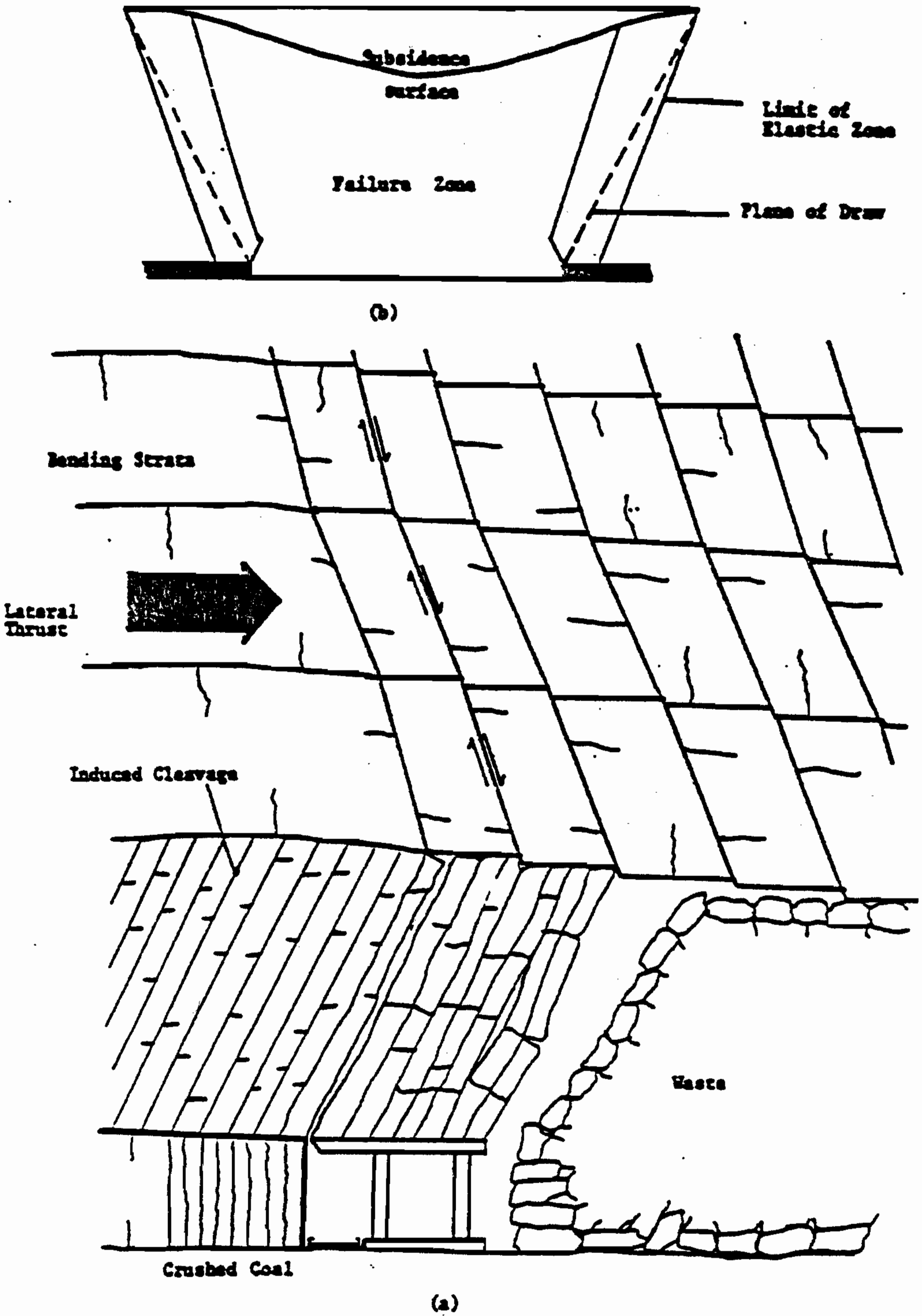


Fig. 1b Failure About a Longwall Face.

that as the high abutment pressure is relaxed and the lateral restraint removed, these planes of weakness open up and eventually fall into the waste.

The upper beds continue to fail in the same manner as their initial failure. As the face advances and movement along the shear planes increases fractures will ultimately reach the surface. Tension may become important near the surface if the overburden pressure can not produce shear failure. These beds do not fail completely for two reasons :

(A) Lateral Pressure : This existed before mining took place and must therefore still exist. It is transferred across the shear planes so increasing the friction along them.

(B) The waste will gradually become more and more compacted so offering greater resistance. The load in the waste will probably not reach cover load, much of the cover load being transferred across the shear planes by friction into the solid coal.

Outside the failed zone, the beds will bend within the elastic region. This bending will account for the small amounts of subsidence around the perimeter of the subsidence trough. There will therefore be a predominantly elastic region within the zone of influence of the face. In the failure region thin plastic beds or those that flow will not fail; the movement they undergo, however , will cause shear failures to continue in the beds above them.

The load on the face supports will be due almost entirely to that height of strata which has undergone induced cleavage. Existing planes of weakness will alter the nature of the fractures , possibly disrupting the equilibrium , as with faults on the face.

1.2: STRATA BEHAVIOUR AND CONTROL ABOUT A LONGWALL GATEROAD.

The general pattern of gateroad closure is well illustrated by Figures 2 and 3. The initial rapid closure is a result of the upper beds moving along the fracture planes under the action of the cover load. The ribside pillar becomes highly stressed as the weight of the strata above the excavated area is transferred across the fracture planes into solid strata. This stress will cause failure of the edges of the pillar and a progression of the lines of stress away from the gate.

This early movement must be regarded as being irresistable due to the magnitude of the loads that generate it. This fact has often been noted, Lewis and Stace (1981) . After the initial closure the strata pressures approch equilibrium as the waste is able to provide greater support and the coal pillar stabilizes.

In the case of re-used gates or finger panel extractions, the strata pressure is transferred to the strata above the former panel. This disturbs the equilibrium that has been established above the panel causing aggravated closure, both vertical and lateral. As the strata pressures approch equilibrium the load on the gate support system will be almost entirely due to the immediate roof. Resistance to this load is a realistic aim.

Unnecessary closure implies separation of the immediate roof beds from the upper beds and bed separation within the immediate roof. The importance of resisting this can not be over-emphasised. The immediate roof is a highly discontinous

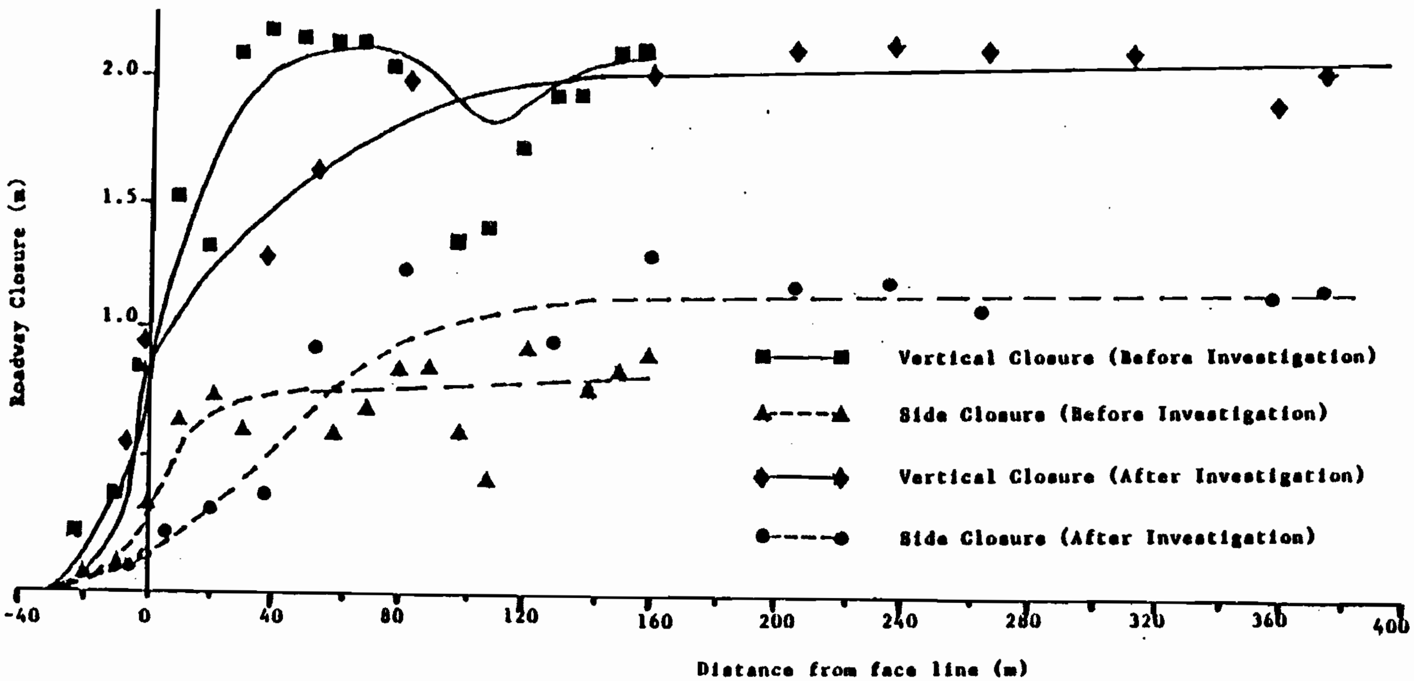


FIG. 2 - ROADWAY DEFORMATION SURVEYS RESULTS (MAINGATE), 61'S FACE ELLISTOWN COLLIERY

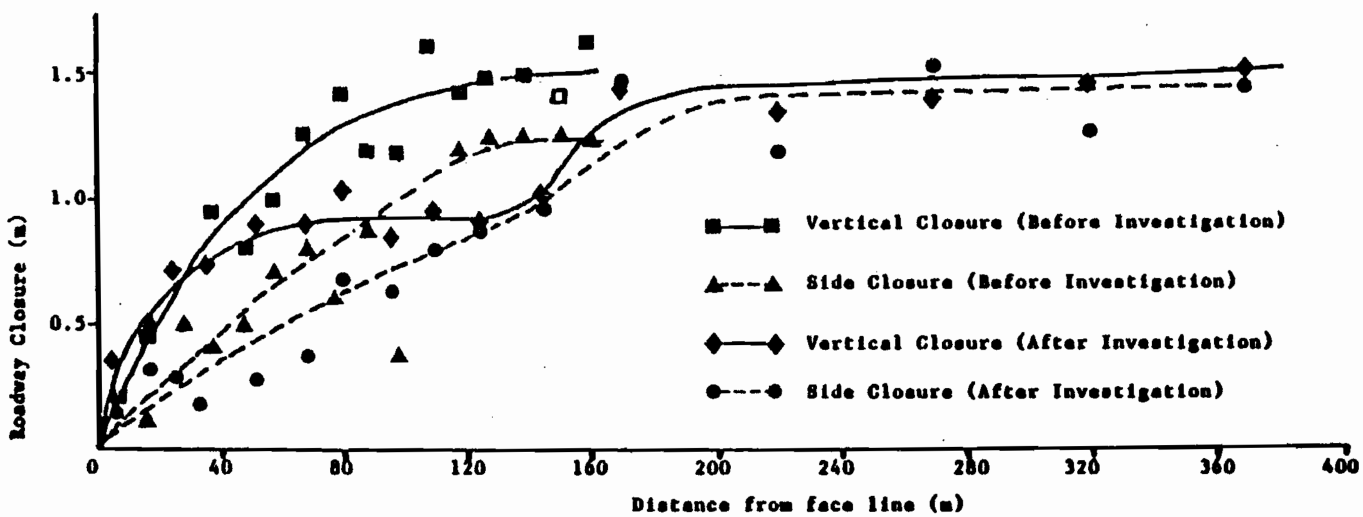


FIG 3 ROADWAY DEFORMATION SURVEYS RESULTS (TAILGATE), 61'S FACE ELLISTOWN COLLIERY

mass. The induced cleavage rotates its direction at the face-ends, tending to become parallel to the ribside, Faulker and Phillips (1935). Control over this mass requires its confinement, thus generating high frictional forces across the discountinuity boundaries. To allow bed separation will cause movement along shear planes, further rock failure and the migration of the caving line towards the gate.

Arches do not have the necessary characteristics to form the major supporting element. Rigid arches are unable to accommodate the inevitable closure without distortion. The resistance of any type of arch to roof lowering will result in local stress concentrations. Even if backfilling is employed, uneven stress distribution will occur along the axis of the gate. Arches are best regarded as providing a protective lining to the gate. Their relationship to packs should be similar to that of mesh to roofbolts. To meet this design criteria arches need to yield. Yieldable arches or stilts are available options. Ideally through ,the lowering of the roof strata about the gateroad should be uniform. The essential design requirements are summarized in Figure 4.

Wooden and concrete blocks would fall into the too rigid category. Most mechanically built packs fall into the too weak and not built to the roof categories. The local stresses about their pack walls will make them less than ideal but might prove initially weak, allowing bed separation. Monolithic packs provide the best potential for meeting the ideal requirements.

As noted previously, uniform lowering is the ideal method as this prevents differential loading and the creation of

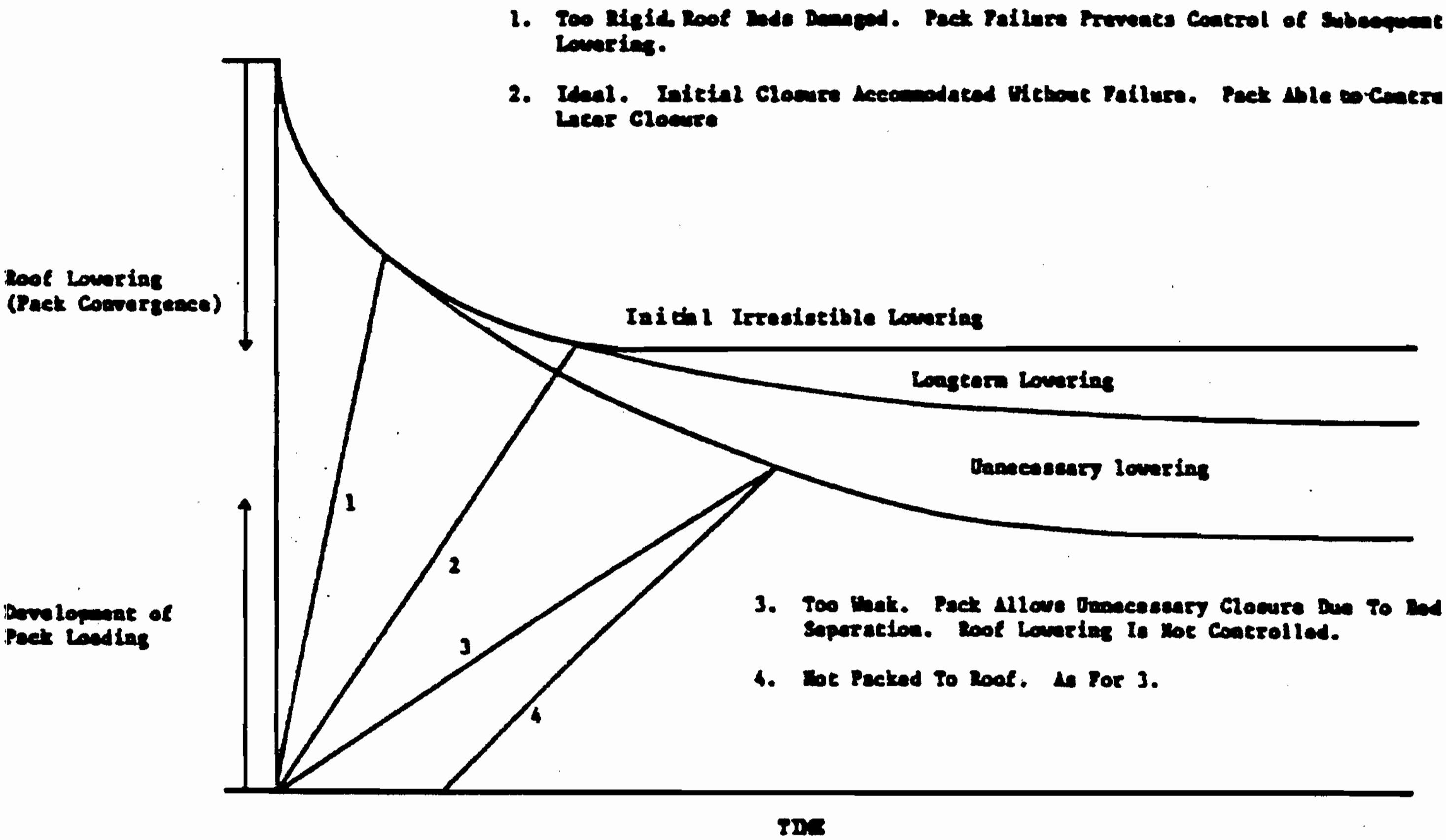


Fig. 4 Diagram to Illustrate the Essential Principles of Pack Design.

shear zones. The exception to this is in circumstances where the pack strength is unable to promote caving. Wooden chocks or props and bars must then be introduced.

The presence of shear zones and the existence of actual shear breaks above the ribside is a common problem. The remedy for this situation is to put on a ribside pack of the same characteristics as the faceside pack , thus equalizing the roof lowering about the gate. The shear break is then in an important area. Such a remedy, however, is often regarded as creating excessive work.

By having the outer pack stronger (i.e. longer), uniform lowering about the gate still takes place but the greatest load is taken by the outer packs. Relaxing the strata above the gate is likely to lead to greater failure so good roadway lining is important.

In circumstances where the roof is strong and the floor weak, it is better to form the gate by dinting to a good floor than by disturbing the roof. Such a system has been used successfully at Clipstone Colliery , Middleton 1980 . Taking the dint in any other position than behind the face would introduce a number of problems , particularly with the stability of the last powered support before the gate. The use of monorail haulage in this situation , or any situation where the floor gives rise to greater concern than the roof , would be an advantage. Some circumstances might warrant arranging to cut part of the floor and a part of the roof in order to ensure the gate is bound by good strata. This is in essence what is happening when dinting is used further down the gate on ripped gateroads. However, the full integration of the dinting into the system at the planning stage is perferable.

In the immediate vicinity of the face-end and gateroad, many years of experience and development have produced systems of working able to meet a variety of adverse conditions. Underlying many of these systems are a number of design principles that should be applied :

1: Regard the packs as being the major supporting element.

2: The gateroad arches ,etc., are largely a protective lining whose behaviour should fit that of the packs.

3: Uniform lowering of the strata is the optimum to be aimed for.

4: Where possible allow high stresses to be relieved , but not at the expense of gateroad cross-section.

5: Where zones of high stress are unavoidable ensure these are not close to the gate.

6: When forming the gates do so, by cutting the least stable strata whenever possible.

7: Anticipate a degree of closure and build this into the system.

1.3: TYPE OF THE MONOLITHIC PACKS

There are 5 main types utilized as the gate side packs. These are:

1.4: AQUAPAKS

A rapidly setting, specially developed cement (Aquacem) is mixed in a parallel mixer to form a slurry and pumped to the packhole. A parallel mixer and pump conveys a premixed water/bentonite and accelerator to the packhole where it is mixed with the grout before entering a brattice bag. The bentonite prevents the cement slurry from settling out and an acceptable pack can be prepared with a water: cement ratio of 2:1 by volume.

The advantages of this material are:

(a) Less cement is used.

(b) Economic mineral and/or coal is not lost to the pack.

(c) The equipment is simple.

The weight ratio of cement: Bentonite/accelerator: water for the Aquapak is 9:1:18.3.

1.5: AQUALIGHT

As a light weight foamed cementitious cavity filler which is non-toxic and non-combustible. It requires a weight ratio of solid:water at 1:1, which when mixed, yields about 15 times its original volume. Every 100 Kg. of the material yields one cubic metre of foamed fill. After one hour of curing time, its compressive strength reaches to 0.05 MPa. Reducing amount of water yields stronger pack, but increases the coast of material, proportionately.

1.6: ASTRAPAK AND TEKPAK

They are virtually the same type of low solids, water based packing materials. They are developed to reduce the material requirements and represent a 27% reduction in weight of material brought into the mine for each cubic metre of pack.

The method of placement into the packhole is identical to that of Aquapack.

The mix ratio is given below:

	Cement	Bentonite/Accelerator	Water
Astrapack	1	1	5.01
Tekpack	1	1	5.10

1.7: ANHIDRITE PACKS (ANPAK)

Anhydrite (Ca SO_4) will in the presence of water, form dihydrite (Ca SO_4, $2H_2O$), a strong solid material. The transformation is far too lengthy for the needs of pack construction unless an accelerator is introduced. In anhydrite packs the accelerator used is a mixture of one part potassium sulphate (K_2SO_4) and 1.8 parts hydrated iron (II) sulphate ($FeSO_4$, $7H_2O$). The relationship of accelerator to anhydrite is 1% by weight. UK laboratory work and experience suggest the optimum ratio of water to anhydrite is 0.1, Whittaker et al (1).

The above paper details underground trials of the system at Easington and Parkside Collieries. For a single gate road two men were required. One at the bunker station and one at the packhole. Both trials were very successful.

1.8: FLASHPAK

The beneficial effects of flyash addition in some concrete uses have been known for some time and cement/flyash mixture has been used for gateside packing in Japan and United Kingdom.

To make the pack, two grout mixing tanks and pumps with delivery tubes connected to an ejector nozzle at the packhole are needed. One mixer produces a 4:6 mix of cement:water, and the other a mixture of Flyash:accelerator:Bentonite:water of 10:1:1:4. The Flyash grout is stable for upto 4 days, and may be premixed and pumped from the surface. The cement grout has about 500 m pumping distance limit. The two grouts should be pumped at rates allowing a 3:1 Flyash grout:Cement grout mix at the mixing nozzle and sufficient velocity to allow the material to be sprayed to the back of the packhole. The mix gels almost immediately on mixing and can be built up like shotcrete in a packhole defined by steel sheeting. The pack becomes quite firm after 20 minutes. Packing rate can be 22 m^3/hour.

1.9: FACTORS AFFECTING PACK BEHAVIOUR

The major factors affecting gate road packs are:

(a) Physical and mechanical properties of the pack material.

(b) Dimensions of the pack.

(c) Method of constructing the pack.

(d) Rate of the face advanced.

(e) Rate of gate side closure and strata loading.

In order to have the best effect in reducing the convergence, the pack should be installed immediately behind the faceline, before any major deformation, bed separation and/or fracture in the vicinity of the face is developed.

Whenever extraction of over 2 metres are concerned, the pack width should not be less than 3 metres. Pack widths of 3 to 10 metres have shown uniform loading pattern under normal strata pressures. Very narrow packs will fail quickly unless made of strong materials, in which case floor and/or roof penetration will occur which results in gate road deterioration.

In any case the strength of the pack material should match the strata loading and the strength of roof and floor in the vicinity of the pack.

The strata loading is affected greatly by the rate of face advancement in two ways:

(i) If the method of packing can not maintain the pack near to the face during rapid face movement, excessive convergence will occur in this area.

(ii) If the pack exhibits creep to any great extent, excessive deterioration may occur during long periods of face standstill or slow rate of advance.

CHAPTER 2

THE DEVELOPMENT OF PUMP PACKING SYSTEM

2.1: PUMP PACK

A continous coal aggregate concrete packing system is known as "pump pack". In this chapter the parameters of strength, cost and mix constituents that are encountered in forming coal aggregate concretes are discussed. These results are then compared with other alternative methods of monolithic systems.

This system uses the run-of-mine coal , which is screened to extract the minus 19 mm material. This is stored at the bunker station to provide sufficient material for the formation of one pack. The bunker station consists of the bunker, extracted -19 mm coal, water and flow suspendent (bentonite) are mixed to make a pumpable slurry. The -19 mm coal material is fed into a paddle mixer and mixed with bentonite and water. The correct quantity of bentonite is controlled by a dispenser, the quantity depending upon the nature of the coal. The paddle mixer is hydraulically driven and feeds the material into the pack pump where it is mixed further. The pack pump which is used to pump the slurry mix is hydraulically operated and is powered by a 90 KW power pack.

The bentonite is stored at the pack pump and, as only small amounts are used, transportation is not a critical factor.

The slurry is pumped, with a 100 mm Victaulic pipeline to the face, where it is mixed with cement and accelerator slurry.

Cement and accelerator are fed into the grout mixer via a dispenser and is thoroughly mixed with water before feeding to the grout pump. The mixture is pumped from the grout pump to the face with a 25 mm diameter double braided hose, where it is introduced to the pack with the slurry. A manual relief valve is installed in the grout line to discharge the grout, in the event of blockage in either the line or the pack. Both the mixer and pump are hydraulically operated and a 220 KW electric motor drives the hydraulic pump.

First a central mixing and pumping station are established to feed the face, and then the grout pumping station is situated in the roadway at close proximity to the face. The maximum pumping distance is approximately 2 km.

The pack is formed by shutter, constructed as the face advances. At the shutter, the slurry and grout are injected through a turbulent flow mixer into the shuttering to form the pack.

Here, the main constituents of the pump pack and their respective contribution to the cost and strength of the packs are discussed.

2.1.1: Coal

The aggregate to be used for the pump pack mix should consist of run of mine coal (washplant rejects) sized to -19 mm, so that once it is mixed with water and bentonite, the slurry can be easily pumped through a 100 mm diameter pipe. Firstly the coal coming from the face should be screened, such that the -19 mm fraction is taken out and used as an aggregate. Secondly the -19 mm +6 mm fraction could be screened out. If this method is used then the -6 mm portion could be replaced by flyash or other suitable material. An aggregate consisting of evenly graded coarse and fine particles is a necessity for the mixing up of a high strength pack.

2.1.2: Cement

The percentage of cement to be used in the pack is of great importance to both the cost of the operation and to the effectiveness of the pump pack.

There are a number of physical characteristics of the pack that are directly related to the cement content. These are as follows :

1: STRENGTH :

The compressive and shear strength of the pack will increase with increasing proportions of cement,

2: SHRINKAGE :

The higher the cement, the less is the shrinkage,

3: SETTING TIME :

The pump pack mix must be made up such that the frame can be removed after 18 hours, without the pack slumping. So the cement content of the mix must be high enough to meet this requirement.

4: WATER CONTENT :

In mixing up the cement before the grouting pump, water must be added at a minimum of 35 % by weight of cement.

2.1.3: Water

The final water content of the pump pack will depend largely upon the amount of water that is needed to form a pumpable slurry when mixed with the aggregate and bentonite.

2.1.4: Bentonite

Bentonite is a ground clay that is added to the coal and water slurry to assist the flow of the slurry through the pipeline and reduce the tendency for the water to separate out of the mix and concentrate at the high points of the pipeline. Both the water content and compressive strength of the concrete mixes are affected by the presence of bentonite. Bentonite on contact with water swells up to eighteen times its original volume by the absorption of water. Therefore the addition is desirable for the hydration of cement, and that more water than usual must be added to make the mixture workable.

The major disadvantages of pump pack system are :

1 : Increased floor lift,

2 : Failure to totally eliminate spontaneous combustion,

3 : High capital cost,

4 : High methane concentrations at the tailgate face-end necessitating methane drainage of the waste through the pumped packs.

2.2: THE THYSSEN SYSTEM

This is one of the original and most widely used systems (Figure 5a). An outbye mixing station is established at which 19 mm run of mine coal is mixed with bentonite and water to form a thick slurry.

The production of coal and the needs of pack construction do not always coincide so it is necessary to provide some form of bunker to store the run of mine coal.

The slurry is pumped along 100 mm pipe ranges to the packhole areas, a valve allowing selection of either gate.

In the return gate, so as to reduce dust pollution on the unit , a cement grout mixer is sited. This mixes a quick setting cement (Packbind) with water and pumps it to either gate along 25 mm or 50 mm hose where it is introduced into the aggregate pipeline near the delivery nozzle.

Hand set shuttering was originally used but this was time consuming and often the packhole was not filled to the roof due to leakages and gradients. Purpose built shuttering was introduced which was advanced by the packhole and buttress chocks. Adequate containment of the pack mixture was still a problem and there was a tendancy for the packs to be dragged forward if not properly set. Ideally, 2 hours should elapse before the shuttering is removed. Self-advancing hydraulic shuttering also tended to suffer these disadvantages and, additionally, occupied too much space. The use of brattice cloth

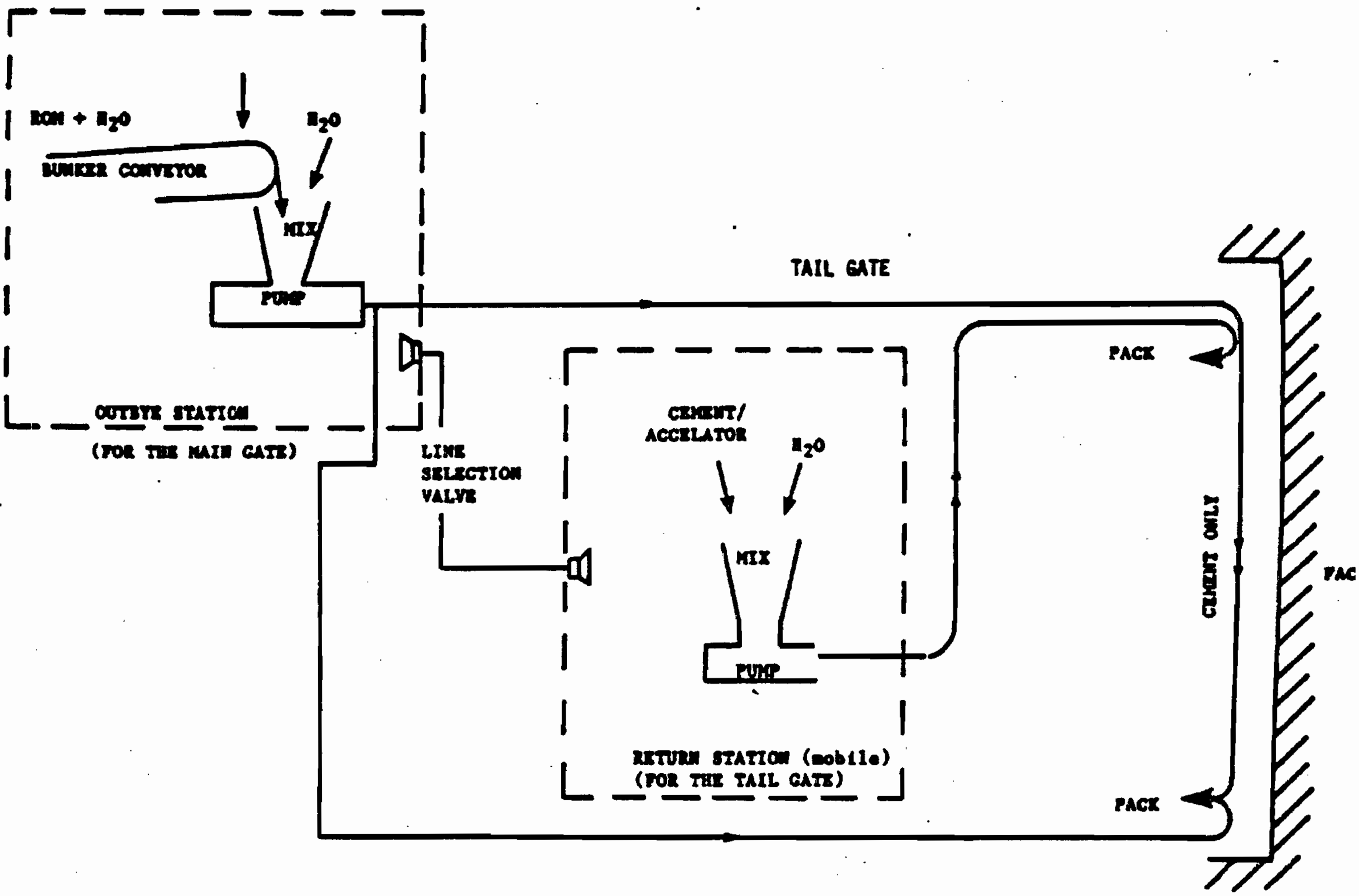


FIG 5A _ THYSSEN MONOLITHIC PACK SYSTEM

bags supported by weldmesh has solved these problems. Careful utilization can allow setting of packs to the roof even when there is a gradient within the packhole.

As with all such systems it is necessary to flush out the grout line after each pack operation. This should not be the case with the aggregate line but blockages did occur with the Thyssen System. These resulted from poor mixing, incorrect ratios of the various materials or the escape of water (bleeding) causing segregation of the water and solid constituents.

Complaints were received that the pack material was not always fully mixed which can lead to the collapse of the pack. This seems to arise from an excess of bentonite causing the aggregate slurry to be so viscous that a proper grout/slurry mix was unobtainable.

Facilitating pumping by increasing the water content of the slurry can lead to the cement grout flowing too readily giving grout free aggregate in parts of the pack.

An improved mixing nozzle has been designed and tested for future applications.

A further problem with the system is that Packbind is a skin irritant.

2.3: THE WARBRET SYSTEM

The system was developed within the NCB (the name is derived from Warwickshire and Bretby, the Mines Research and Development Establishment). The system is a modified Thyssen System.

More recently, Mindev (Figure 5b) and MRDE systems have undergone successful surface trials.

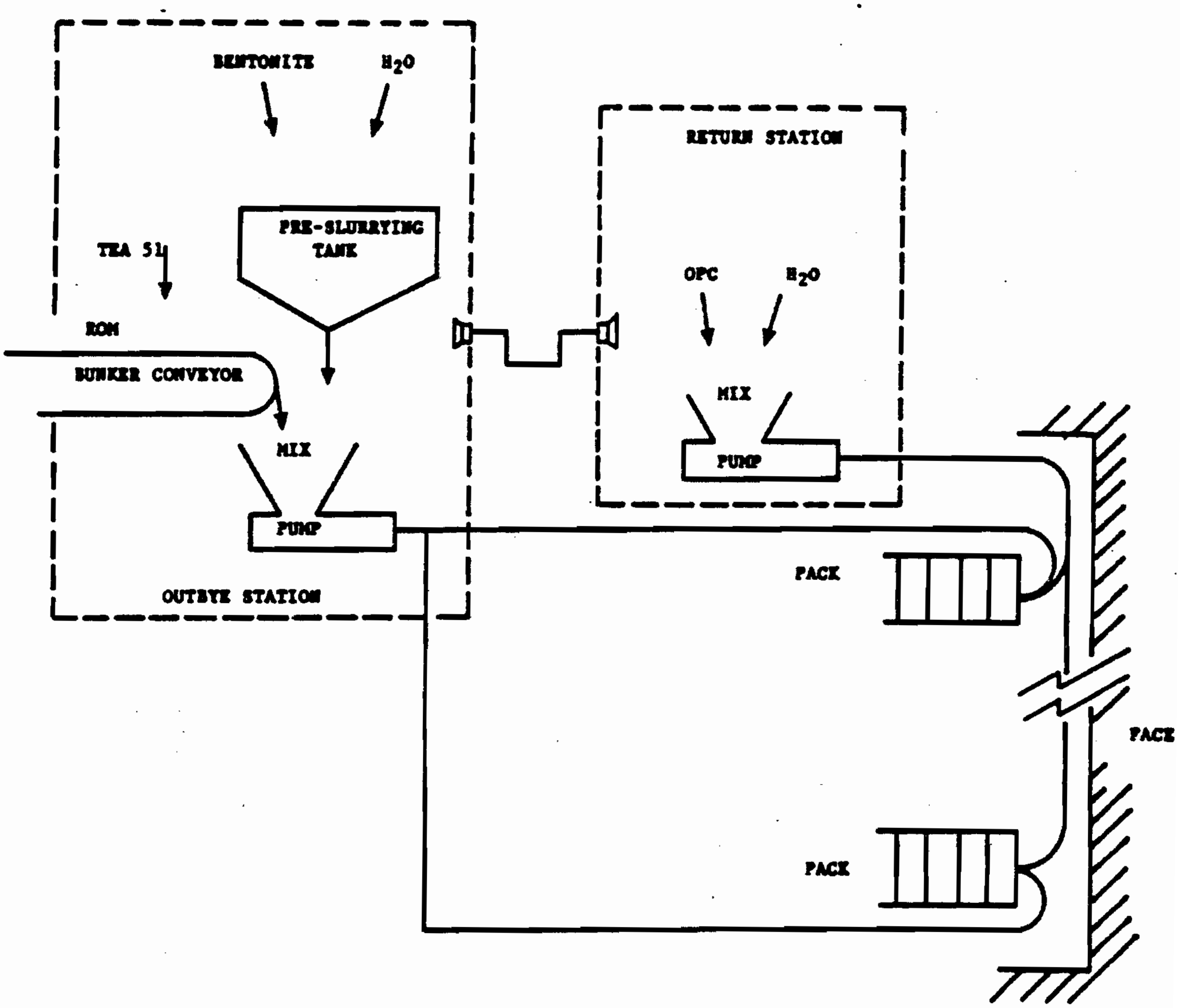


FIG. 5B WARBRET MONOLITHIC PACK SYSTEM

2.4: PUMP PACKING PERFORMANCE

In general, pump packing has been greeted enthusiastically by those who have applied it. When reviewing pump packing at Newdigate and Daw Mill Collieries, McCarthy and Robinson in U.K. (2) were more guarded in their optimism.

The new system designed to overcome the shortcomings of the old one is shown in Figure 6.

The likelihood of pipe blockages due to bleeding and segregation are diminished by pre-mixing the bentonite suspension so that gelling is complete before it is added to the aggregate. In the Thyssen system gelling of the suspension takes place in the pipeline where it is inhibited by the aggregate.

A special cement accelerator TEA51 developed at MRDE, Bretby is added to the ROM coal. The TEA51 neither inhibits nor is inhibited by the bentonite provided that the bentonite is pre-gelled. With commercial cement accelerators the pumpability of the bentonite or the accelerated setting times would be affected.

Ordinary Portland Cement (OPC) can be used instead of Packbind. Pre-gelling of the bentonite enables the correct amount of water to be used so excess cement consumption (sometimes 33% of consumption) is eliminated. This gives rise to a cost saving and a reduced load on the materials handling system.

2.5: SHORT RANGE SYSTEMS

These systems are not common. They involve the batch mixing of all the pack constituents in the gate close to the packhole.

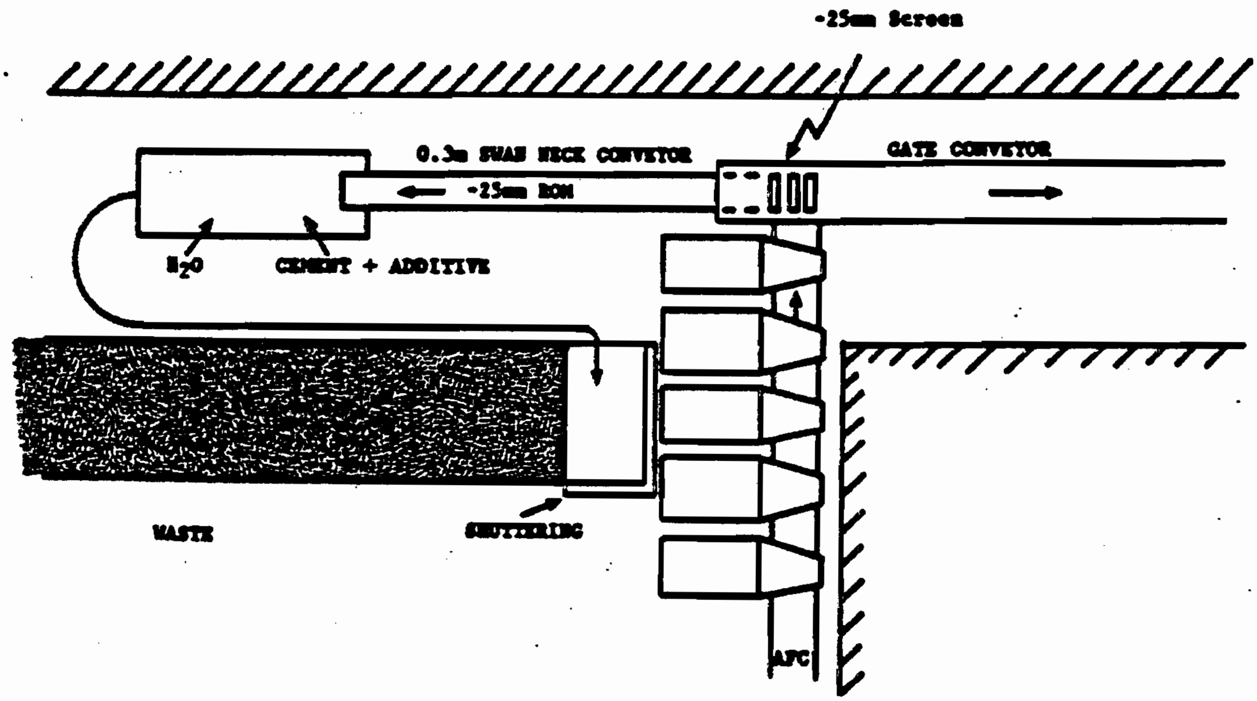


FIG 6 MINDEV MONOLITHIC SITE BATCH MIX SYSTEM

The elimination of long range pumping means that bentonite is unnecessary but the system uses space in an already congested area. The equipment advances with the face.

An early system installed at Kinneil/Valleyfield Colliery (U.K.) in 1973 was unsuccessful due to the pack being too brittle.

The greater load bearing capacity of the pump pack reduces arch distortion but transfers more load to the floor causing floor failure and subsequent heave. However, dinting is preferable to back-ripping and the floor could possibly be controlled by dowelling. Pack closure is down to 15-20%.

Although spontaneous combustion has not been totally eliminated there has been a vast reduction in the number of heatings on faces using pump packing.

The high capital cost is due in the main, to the coal pumping station and bunker and is unavoidable with present systems. The method of surface pumping of tailings would have a number of advantages. An entirely worthless aggregate would be used. The surface installation would be permanent and service far more faces. The packing operation would be less reliant on face production allowing more flexibility.

A logical additional step would be to pneumatically pump the cement from the surface. This would reduce the load on the supplies system, possibly eliminate the need for a grout pump and, coupled with the use of tailings, reduce manpower at multiface collieries.

Until surface pumping of the cement is practical improved handling could be provided by introducing a shredding device so that the cement bags could be loaded unopened. This would increase the rate of feed, reduce dust and dispose of the bags safely.

The necessity for methane drainage arises from the more efficient ventilation of the face-ends. This is a result of the impermeability of the packs preventing short-circuiting of the air across the waste.

CHAPTER 3

CHAPTER 3

THE NCB'S AQUAPAK

Hem Heath Colliery in U.K. had successfully applied pump packing to a number of faces before clay from a floor dint started causing difficulties. The swelling of the clay reduced the pumpability of the coal slurry to such a degree that the system was abandoned and cement grout packs were put on instead. This expensive and unsatisfactory solution highlighted the need for a non-aggregate filler and lead to the development by MRDE and Hem Heath of the Aquapak system. As its name implies the pack uses water as its filler. This is achieved by using a cement with a high affinity for water. The cement, developed at MRDE, and named Monopak comprises:

(i) Ordinary Portland Cement

(ii) High alumina cement

(iii) Anhydrous calcium sulphate and small quantities of:

(iv) Sodium carbonate

(v) Citric acid.

The sodium carbonate gives the cement its high reactivity so this ingredient is removed to give a greater pumping life. Monopak minus sodium carbonate is known as Aquacem. In order that the water does not separate from the cement a colloidal bentonite suspension is added to the cement grout at the packhole. The sodium carbonate is added to the Aquacem by including it in the bentonite (Aquabent).

As with the pump packing systems there are two parallel lines, each comprising of a pump and a mixer. The bentonite station is often situated outbye of the face and a pipe range is used to transfer the slurry up the gate.

The grout station is maintained at 45-60 m behind the face, the grout line being of 25 mm armoured flexible hosing.

Each line provides 50% of the required amount of water. A typical pack will comprise by volume 85% water, 14% Aquacem and 1% Aquabent. Aquabent comprises equal proportions by weight of bentonite and sodium carbonate.

Aquapak provides the same benefits afforded by other monolithic packs in respect of strata control, spontaneous combustion and ventilation but also has additional advantages:

(i) simplicity of operation
(ii) low capital cost
(iii) unrelated to production
(iv) relatively small quantities of imported material
(v) capable of keeping up with the advance of high productivity faces
(vi) ability to place large volumes of pack material to suit strata control or ventilation needs

The early applications of the system have proved as encouraging as those of the other monolithic systems, Nixon and Mills (1981) Johnson et al (1982). A report is given below of an investigation into the merits of the system at Ellistown Colliery in the U.K.

3.1: AQUAPAK TRIALS ON ELLISTOWN 61'S FACE

61's face was 95 m long extracting 3.0 m of coal from the Five Feet/Splent seam (Figure 7). The seam dipped at an average gradient of 1 in 25 in the line of advance. The face worked at a depth of 160-170 m.

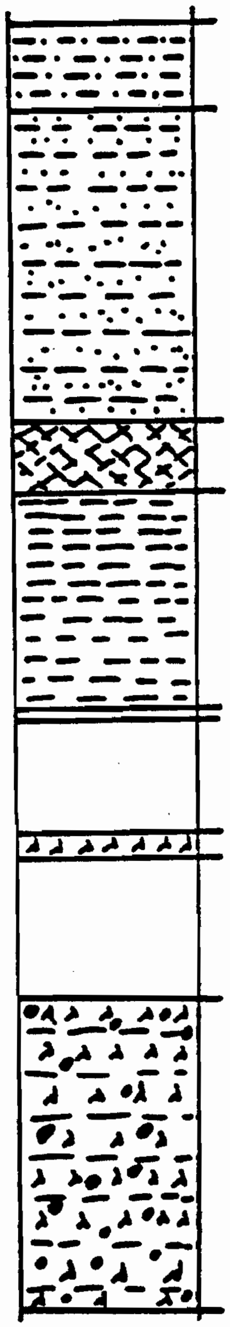
Table 1 gives the results of laboratory tests on samples taken from 61's face.

There exists a number of old workings in superjacent and subjacent seams in this area. Workings in the Minge seam were within 37 m and, to comply with The Mines (Precautions Against Inrushes) Regulations 1979, it was necessary for the manager to propose suitable measures as a precaution against an inrush. As a result the maingate was fashioned 25-30 m in advance of the face, by a DOSCO MK IIa, so that exploratory boreholes might be drilled ahead of the face. The gate was supported by 4.27 x 3.05 m arches on 0.6 m box stilts spaced at 0.7 m.

Table 1 - Strength and Density of Roof, Seam and Floor on 61's Face

Sample	Uniaxial Compressive Strength $MN.m^{-2}$	Density $tonne.m^{-3}$
Silty Mudstone (roof)	42.1	2.61
Five Feet/Splent Coal	23.61	2.52
Soft Mudstone (Floor)	36.69	2.52

The tailgate was ripped in-line by the face machine, an MS 400 hp DERDS. 0.25 m of the roof were shotfired in order to improve the turn round of the DERDS. The arches were the same as



Strata	Thickness
Siltstone (medium grey, sandy bands)	0.96m
Mudstone (medium grey, occasional silty laminae)	3.60m
Shale (dark grey)	0.81m
Mudstone (medium grey)	2.51m
Shale (black, carbonaceous)	0.10m
Five feet coal	1.45m
Seatearth (shale, sandy siltstone)	0.33m
Splent coal	1.58m
Seatearth (soft sheared mudstone, grey and black with small ironstone nodules)	2.26m
Mudstone (medium grey with occasional rootlets, and scattered iron bands)	2.16m

FIG 7 - GEOLOGICAL SECTION OF STRATA ABOUT FIVE FEET/SPLENT SEAM, 61's DISTRICT those in the maingate but they were not set on stilts and were spaced at 0.9 m centres.

3.2: AQUAPAK OPERATIONS AT ELLISTOWN

Both packs were originally constructed of three rows of wood chocks. After the onset of poor gate conditions a decision was taken to place Aquapaks in both gates. The system was initially tried in the tailgate (Figure 8) and later introduced into the maingate.

Both the Aquabent and Aquacem stations were sited in the gate and advanced with the face.

Each station was equipped with a 30 hp Mindev power pack.

The Aquacem station had a scroll mixer with input by a screw conveyor via a metered spray system. 50 litres of water per minute were mixed with 2 1/2 x 25 kg bags of Aquacem.

The Aquabent station had two 1000 litre Mindev impellor type mixers. The mixers had recirculating pumps with multi-jet outlets in order to hold the material in suspension. 2000 litres of water were mixed with 7 x 25 kg bags of Aquabent.

Both stations used 95 mm Hany pumps to feed the packholes through 32 mm armoured hose at a rate of 72 litres per minute.

A weldmesh cage was made in the packhole within which a prefabricated brattice cloth bag was hung. The bags (3 m x 3 m x 1 m) could be filled in 60-70 mins if no stoppages occurred.

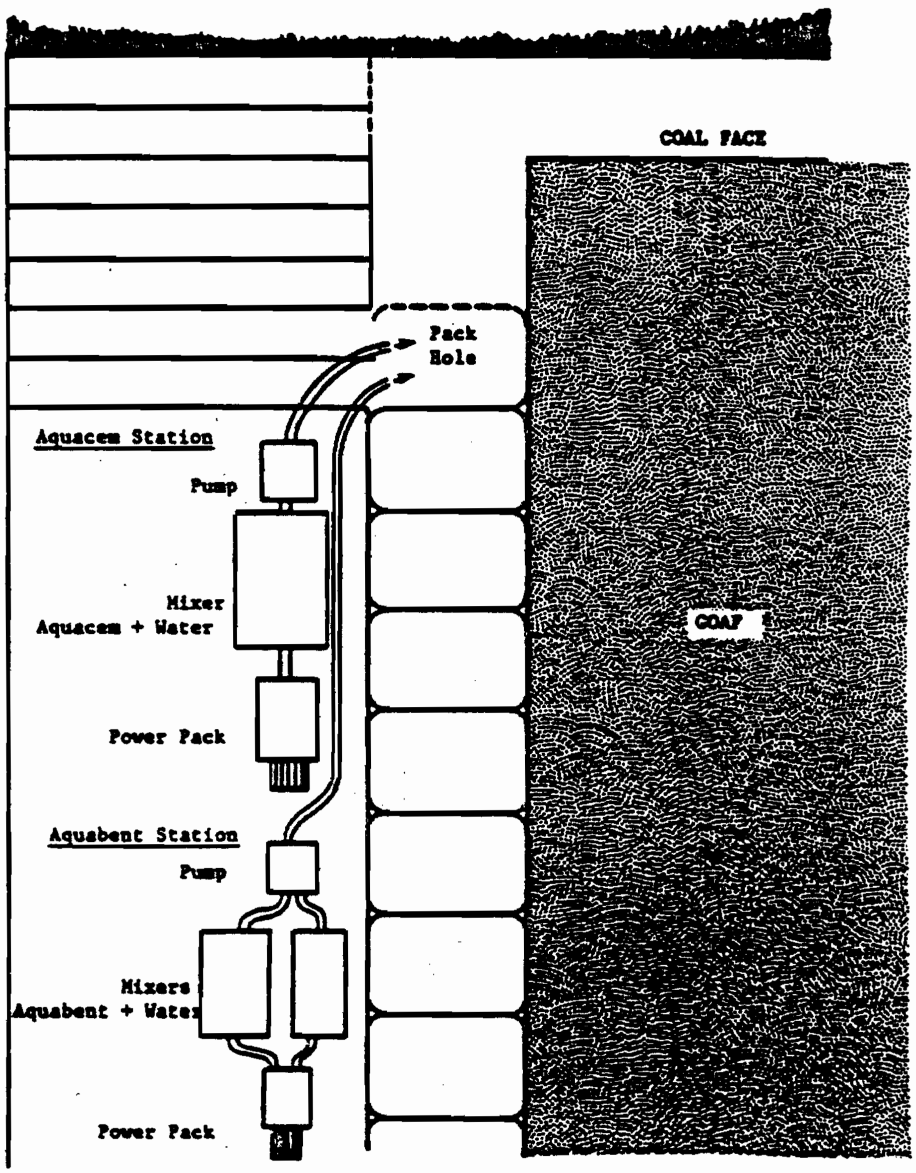


FIG. 8 - AQUAPAK LAYOUT, 61's TAILGATE

3.3 : SITE INVESTIGATIONS

Bandary (5) in U.K. was involved in an investigation regarding packs and summary of this work is presented here.

Pack and roadway closure measurements were taken, as the face advanced, at a point where the tailgate was being Aquapaked and the maingate was being packed with timber. The results are shown in Figures 9 and 10. In the maingate the initial roadway and pack heights were 2.34 m and 2.1 m, respectively. In the tailgate these values were 2.55 m and 2.22 m, respectively.

Closure in the maingate, measured from the point of pack construction, was 30% as opposed to 23.5% in the tailgate. Pack closure was 35% in the maingate and 15% in the tailgate.

Figures 2 and 3 show deformation surveys taken in both gates before and after the investigation. On the after investigation curves the points at which Aquapaking was introduced are shown.

In the tailgate there was a period of time in which the operators were familiarizing themselves with the technique and little improvement was evident. After this period the transformation was quite dramatic. The integrity of the arches was maintained and floor lift, previously severe on the ribside, was reduced.

Initial results in the maingate were not so encouraging. As a result a 1 m back-rip was established immediately behind the face line. Consequently, a much better roadway profile was established.

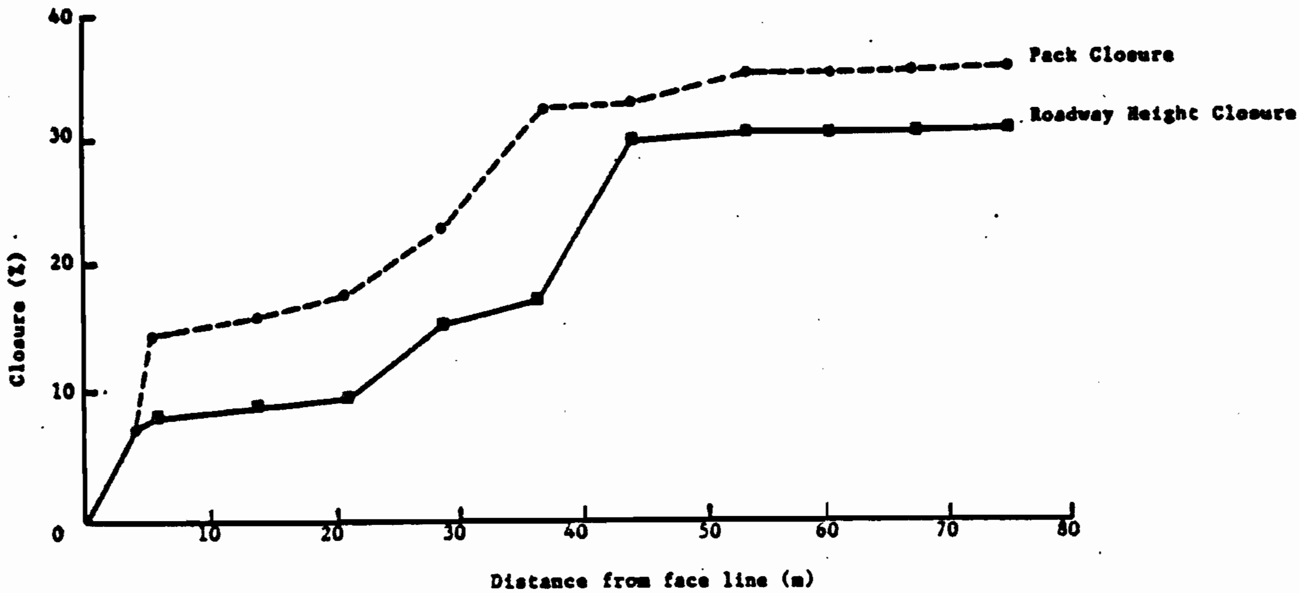


FIG 9 - PACK AND ROADWAY CLOSURE IN THE MAINGATE

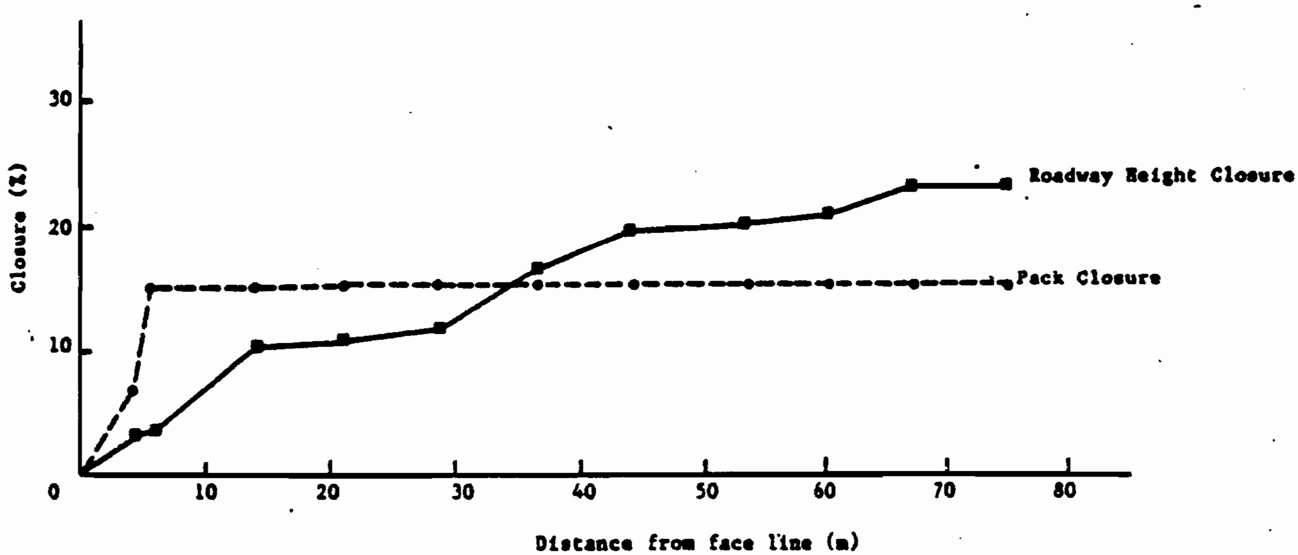


FIG 10 - PACK AND ROADWAY CLOSURE IN THE TAILGATE

3.4: TESTING TECHNIQUES

A compression testing machine with capacity of 20 tons and capability of applying constant rate of displacement was employed for all the testing programmes.

The uniaxial compressive strength tests were conducted on 50 mm diameter x 100 mm length cylinders at a displacement rate of 1 mm per minute. A minimum of five uniaxial or three triaxial tests were carried out for each parameter set.

The platens used for these tests were of the same diameter and height as the sample. This produces a better stress distribution than that associated with many platen configurations.

A latex rubber sheath was used during these tests to protect the sample for the air.

The test procedures accord with the standards of the I.S.R.M. (7).

3.5: AQUAPAK TESTS

Preparation of Samples

Aquapak was the first cementitious pack material made available for testing. A period of familiarization was therefore necessary in order to ensure that the prepared samples could be confidently regarded as representing the material. Samples were prepared and failed on the compression testing machine. When the results repeatedly agreed to within 10% of those of MRDE Bretby,Chambers (8) over the range 1 day to 1 month, the sample preparation was considered to be of a suitably competent and consistent nature.

The standard or correct mix is suggested to be: 1 volume of Aquacem grout comprising 0.8 parts water and 1 part Aquacem by weight. 1 volume of Aquabent slurry comprising a 10% concentration of Aquabent.

The grout and slurry stood for 5 minutes prior to being mixed together. Vigorous hand mixing was employed. This caused no separation of solids from water. The Aquapak was then poured into plastic (50 mm diameter) moulds. After 1-2 hours it was possible to remove the samples from their moulds.

The mixing water temperature was 25^{o}C and the samples were cured in plastic bags at 25^{o}C.

When a sample is said to have an "excess" of a constituent this excess is by weight.

3.6: AQUAPAK DENSITY

Aquapak prepared with the correct proportions has a density of 1.375 tonnes m^{-3} upon initial set. With a 50% excess of Aquacem this figure rises to 1.475 tonnes m^{-3}. A 50% excess of Aquabent produces a mix with a density of 1.373 tonnes m^{-3} upon initial set. A similar excess of water will cause this value to fall to 1.260 tonnes m^{-3}.

After a month the value for the correct mix falls to 1.368 tonnes m^{-3} when cured in a plastic bag at 25^{o}C. The density values of various Aquapak mixed at different temperature after 30 days of curing are given in Table 2.

Table 2 - Aquapak Density After 30 Days Of Curing

Mixing/Curing Conditions	Density, $tonnes.m^{-3}$
50% excess Aquacem	1.475
50% excess Aquabent	1.369
50% excess water	1.243
Air cured	0.692
Cured 1 month bag/1 month air	0.609
50% Air cured	0.790
Fraction air cured	1.299
Cured at 9^{o}C	1.387
Cured at 60^{o}C	0.570
Mixing water temp. 5^{o}C	1.291
Mixing water temp. 40^{o}C	1.278

Clearly, exposure to the air or high temperatures causes excessive water loss.

3.7: UNCONFINED COMPRESSIVE TESTS

3.7.1: Correct and Excess Mixes

Figure 11 shows a log plot of strength against curing time for the correct mix and for 50% excesses of each constituent. Typical stress/strain curves are given in Figure 12-15.

The correct mix exhibits good early strength followed by rapid strength development from 2 to 5 hours. The strength does not rise significantly again until 3 days when, up to 7 days, there is a further rapid rise.

The form of the curve is a function of the very complicated cement chemistry of this mixture.

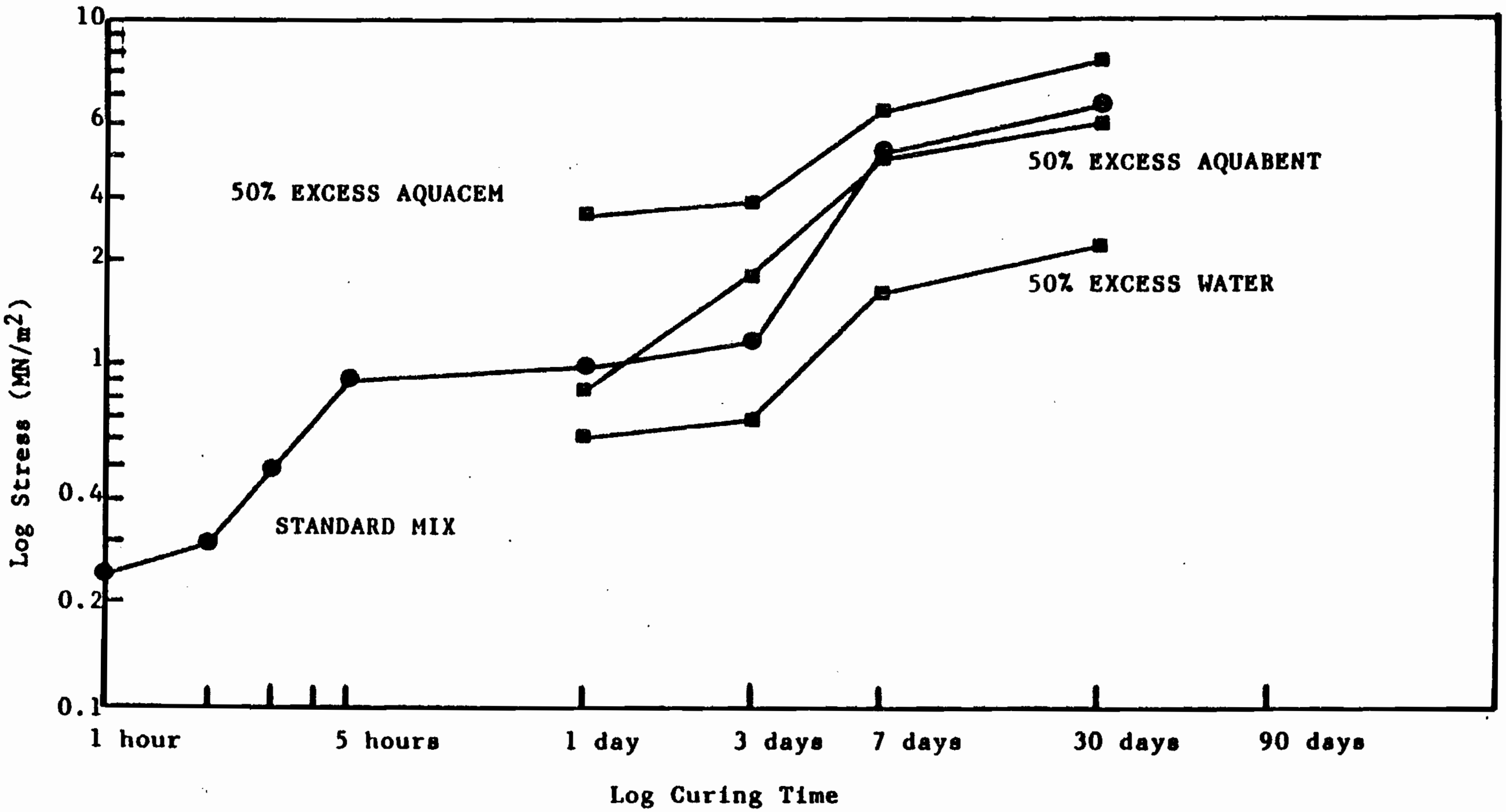


FIG. 11. - STRENGTH DEVELOPMENT OF CORRECT AND EXCESS AQUAPAK MIXES

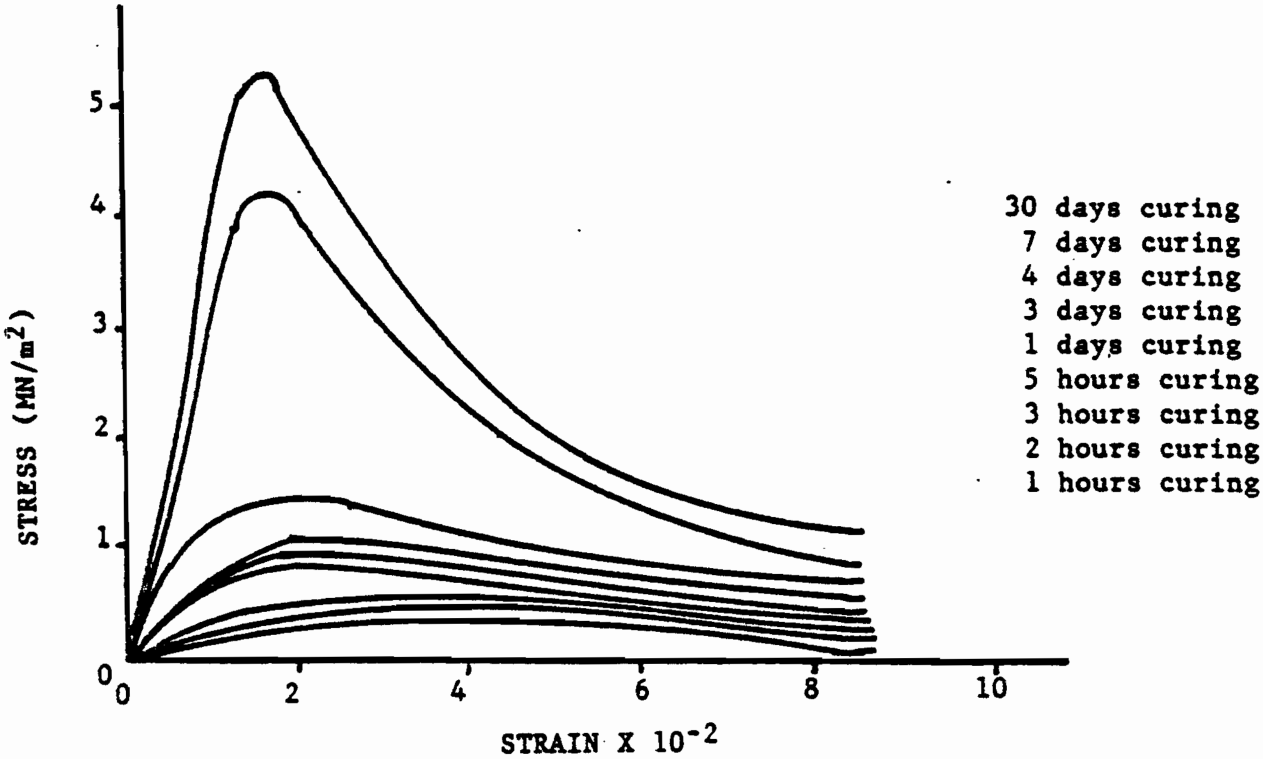


FIG. 12. - STRESS/STRAIN CURVES FOR CORRECT MIX

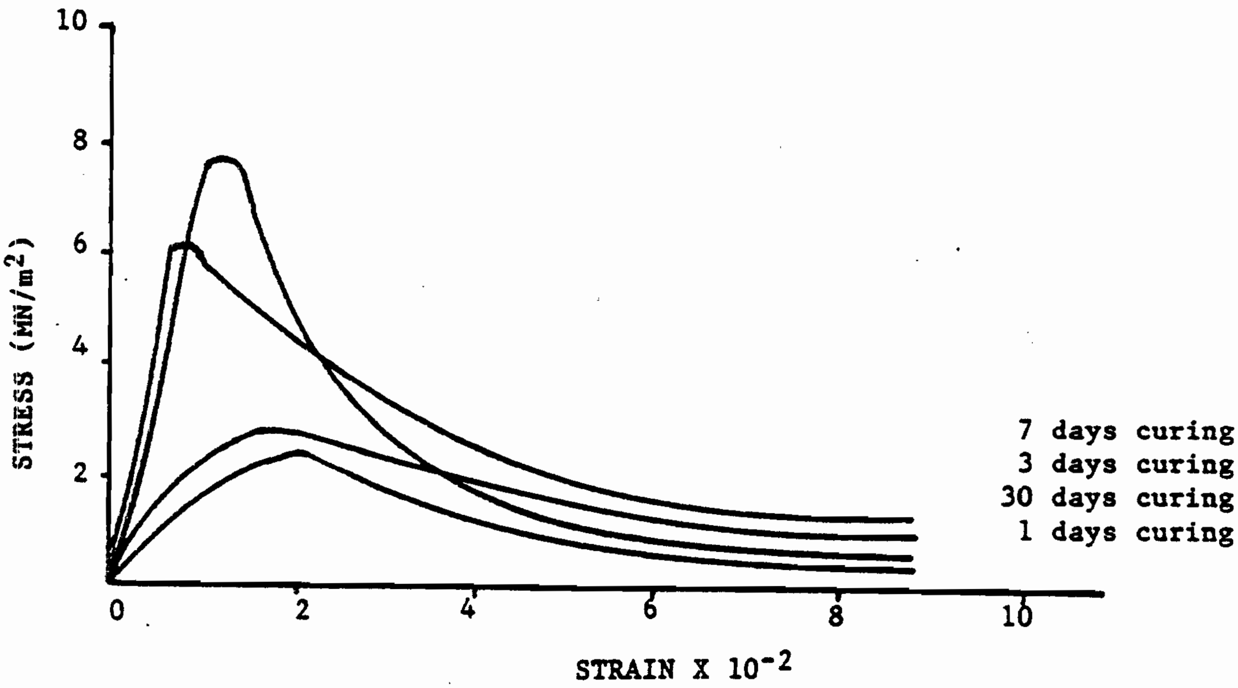


FIG. 13. - STRESS/STRAIN CURVES FOR EXCESS AQUACEM

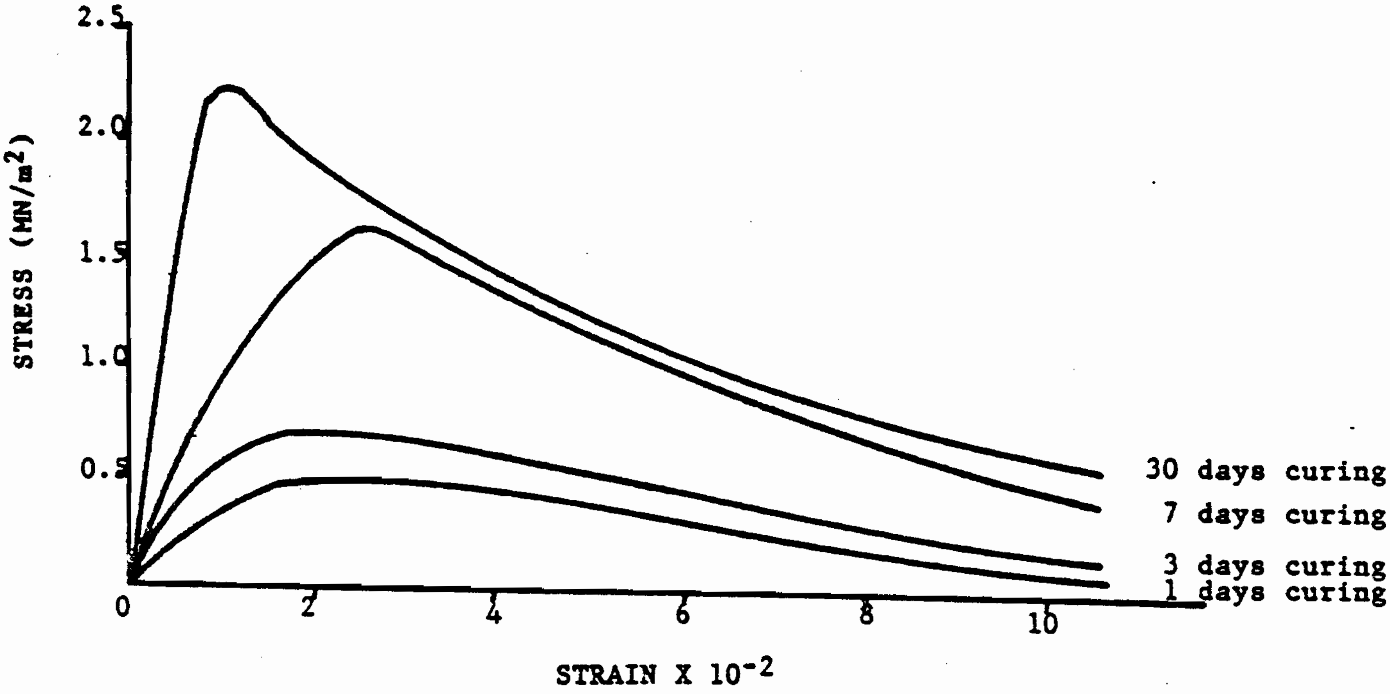


FIG. 14. - STRESS/STRAIN CURVES FOR EXCESS WATER

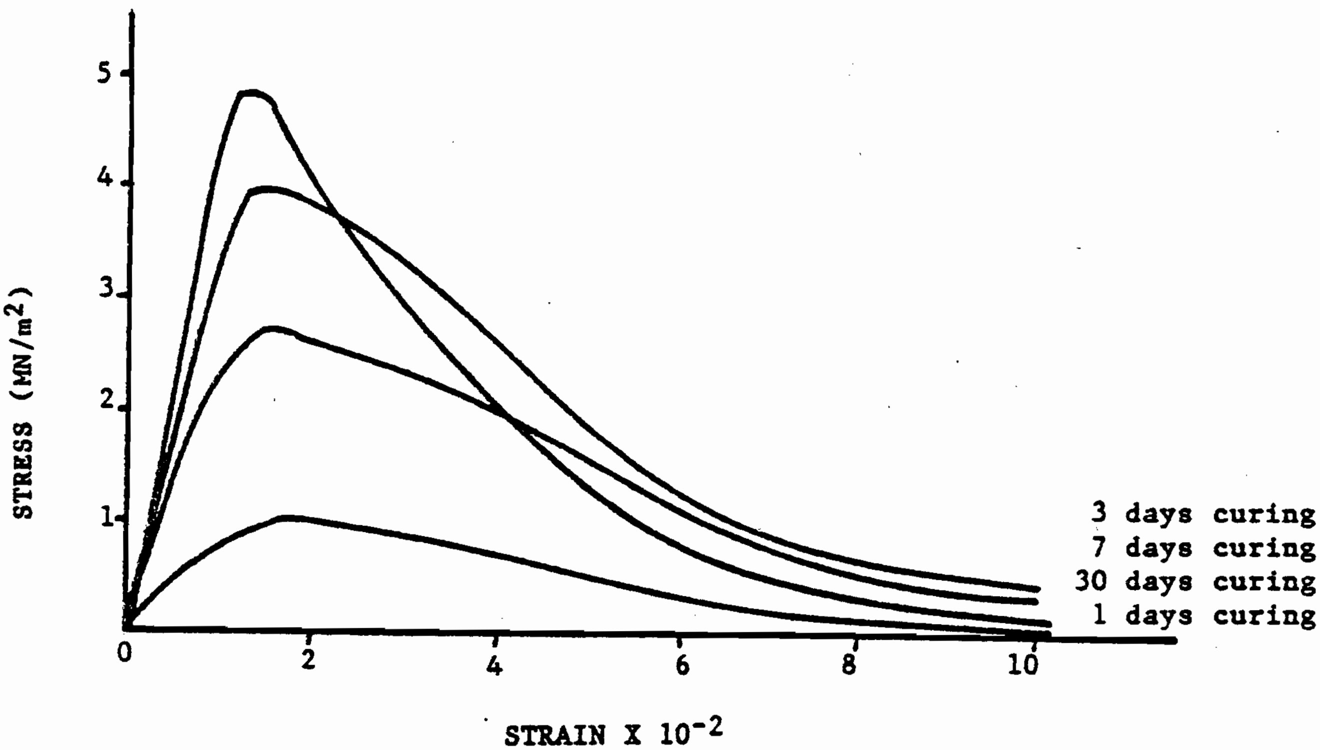


FIG. 15.- STRESS/STRAIN CURVES FOR EXCESS AQUABENT

Up to three days the stress/strain curves (Figure 12) display a plastic form; steady yield under stress to a low peak strength followed by only a small loss of strength. At four days and after the rate of increase is more rapid and leads to a more significant peak strength. Once the peak strength is reached there is a rapid fall off in strength as the material breaks up. Such behaviour is characteristic of a brittle material. This transformation from plastic to brittle behaviour is associated with a lightening of the material's grey colour.

The curves for excess Aquacem and excess water (Figure 11), have a similar trend to the correct mix. It must be borne in mind that, whilst proving a marked success in mining, Aquapak is a very weak cement. This is a direct result of the large proportion of water. Therefore, increasing the amount of water will further weaken the cement, conversely increasing the cementitious content will strengthen the cement. Up to 1 week the excess water samples shed water under compression.

An unnecessarily strong cement adds needlessly to material costs. A too weak cement could prove very much more expensive, as a result, roof control is lost. In the crudest Aquapak systems, in which bags are manually opened and loaded into gate hoppers, the latter is very much more likely. Underground storage silos or, preferably, pneumatic transport would allow far greater control over the quantities of each constituent used. It is clear from Figure 11 that the packing systems have an in-built flexibility that might be useful where conditions are heavier than usual.

The excess Aquabent curve (Figure 11) displays a more uniform increase in strength between 1 day and 7 days. The

strengths of Aquapak with a 50% excess of Aquabent are, however, largely the same as those for the respective correct mix. This indicates that the correct mix itself has an excess of Aquabent. The further excess cannot accelerate the hydration of the cement and is not large enough to inhibit the strength development.

3.7.2: Change of Mixing and Curing Parameters

A number of parameters were altered in order to investigate the effect of such an action on a correct mix.

Using cold water (10^{o}C) to prepare the samples does not significantly effect the long term strength. The thirty day strength being 4.37 MPa. Time to initial set was 15 mins instead of the usual 5-7 mins, this, the lower density (Table 2) and the reduced strength indicate that low water temperatures do inhibit hydration of the cement.

Warm water does have a markedly detrimental effect. The average strength was only 2.47 MPa. Of great importance is that the use of warm water produced a number of samples that conformed to the definition of a "bad mix". These samples behaved plastically with a peak strength of 0.91 MPa.

One batch of samples was left to stand without mixing. This batch produced samples of varying strength (2.90-4.49 MPa) and varying density (1.323-1.418 tonnes m^{-3}). Generally, samples with the greater density exhibited the higher strength. Clearly separation of the constituents takes place producing samples with an excess of one or other constituent. An excess of the higher density cement producing samples of higher strength.

Curing at low temperatures (10°C) has as little affect as mixing at low temperatures. Samples so cured had a thirty day strength of 4.39 MPa. Curing at 60°C temperature, however, dehydrates the samples resulting in low strengths, 0.81 MPa.

The effects of air on a correct mix were investigated. A number of samples were left to cure completely exposed to the atmosphere. A further set were left to cure with 50% of their surface area exposed and a further set had just a tiny fraction of their surface area exposed. This was carried out with the aid of saran wrap. Another set of samples was cured in a plastic bag for 1 month and then cured for an additional month exposed to air. The curing temperature was maintained at 25°C.

As mentioned earlier, exposure to air causes a change of colour and a reduction of the density. It also greatly reduces the strength to 2.47 MPa.

Allowing only 50% exposure to air remarkably reduces the strength yet further to 1.60 MPa. The unexposed half remained unaffected by the test. The uneven dehydration of the sample produced a large unconformity that resulted in the seemingly anomolous low strength.

The effect of only fractional exposure is insignificant. The strength of 5.04 MPa being only marginally below the 5.17 MPa of a standard mix.

The density of the samples cured in a plastic bag for one month was lower than that for the fully exposed thirty days samples and the strength was also lower at 2.14 MPa.

samples and the strength was also lower at 2.14 MPa.

To appreciate the reason for this it must be understood that set cement contains two types of water, Lea (9). Evaporable water and non-evaporable water. The former is held in pores within the structure or gel of the cement whereas the latter is water of hydration of set cement compounds. In reality the division is not quite so clear but such a simplified picture is adequate for present purposes.

The samples initially set in a plastic bag will develop full strength with a full compliment of water. When dried out the structural pores, formed about the water, and the gel pores will have lost their water, so weakening the cement.

The samples that were exposed to the atmosphere from mixing will have lost water by evaporation immediately. This will have reduced the water available for hydration so inhibiting strength development. However, by way of compensation the water/cement ratio of subsequent hydration will have been reduced, and the number and size of structural pores will also have been reduced.

The results illustrate that the drying out process is a slow one and that small tears are unlikely to affect the strength of an Aquapak. Drying out on a large scale would be detrimental. The differential drying associated with larger exposed volumes of material produces differential contraction of the cement, which can induce failure, Lea (9). The probability of such an event underground does not seem very likely. That the bag does more than just retain the Aquapak when liquid is, however, well illustrated.

CHAPTER 4

CHAPTER 4

ASTRAPAK AND TEKPAK TESTS

4.1: TEKPAK TESTS

There is much similarity between the application of Aquapak and Tekpak. The cement and bentonite products are marketed as Tekcem and Tekbent, respectively. They are mixed in the ratio of 1 to 1 by weight. The proportion of water in the pack is 91% by volume, Newson(11).

The initial density is 1.281 tonnes m^{-3}, falling to 1.221 tonnes m^{-3} after 1 week.

4.1.1: Sample Preparation

The two solid constituents were prepared separately with a water/solids ratio of 2.5 to 1 by weight. After standing for ten minutes the grout and slurry were mixed together in a 1 to 1 volume ratio. Tekpak relies on its own generated heat to ensure correct curing. The samples were kept close together and insulated by a number of cloths so that curing was not adversely affected.

4.1.2: Unconfined Compressive Tests

Figure 16 gives a log plot of strength against curing time for correct and excess mixes. Typical stress/strain curves are given in Figures 17-21.

The correct mix exhibits very good early strength development up to 5 hours. The strength then develops steadily

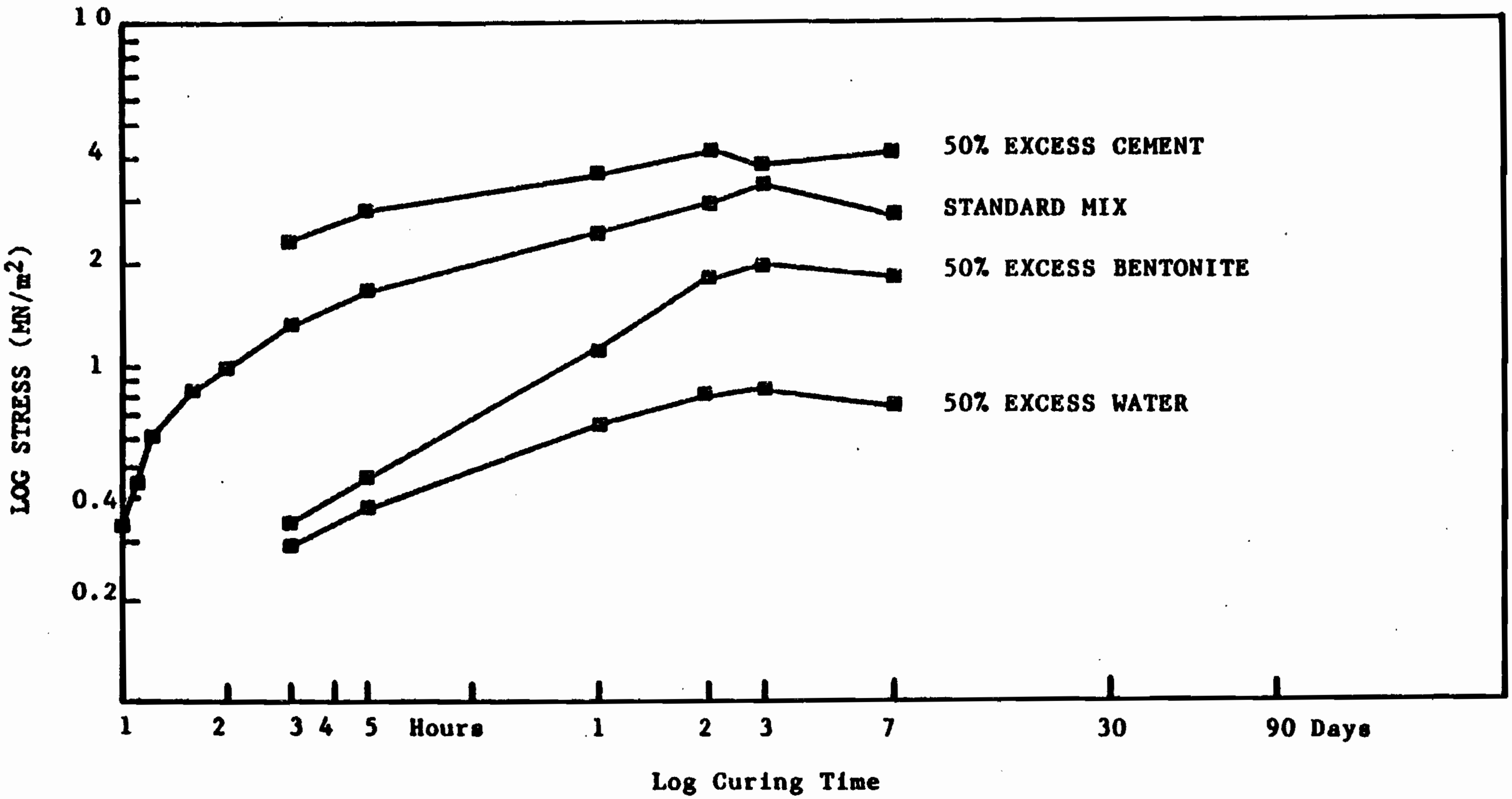


FIG. 16 STRENGTH DEVELOPMENT OF CORRECT AND EXCESS TEKPAK MIXES

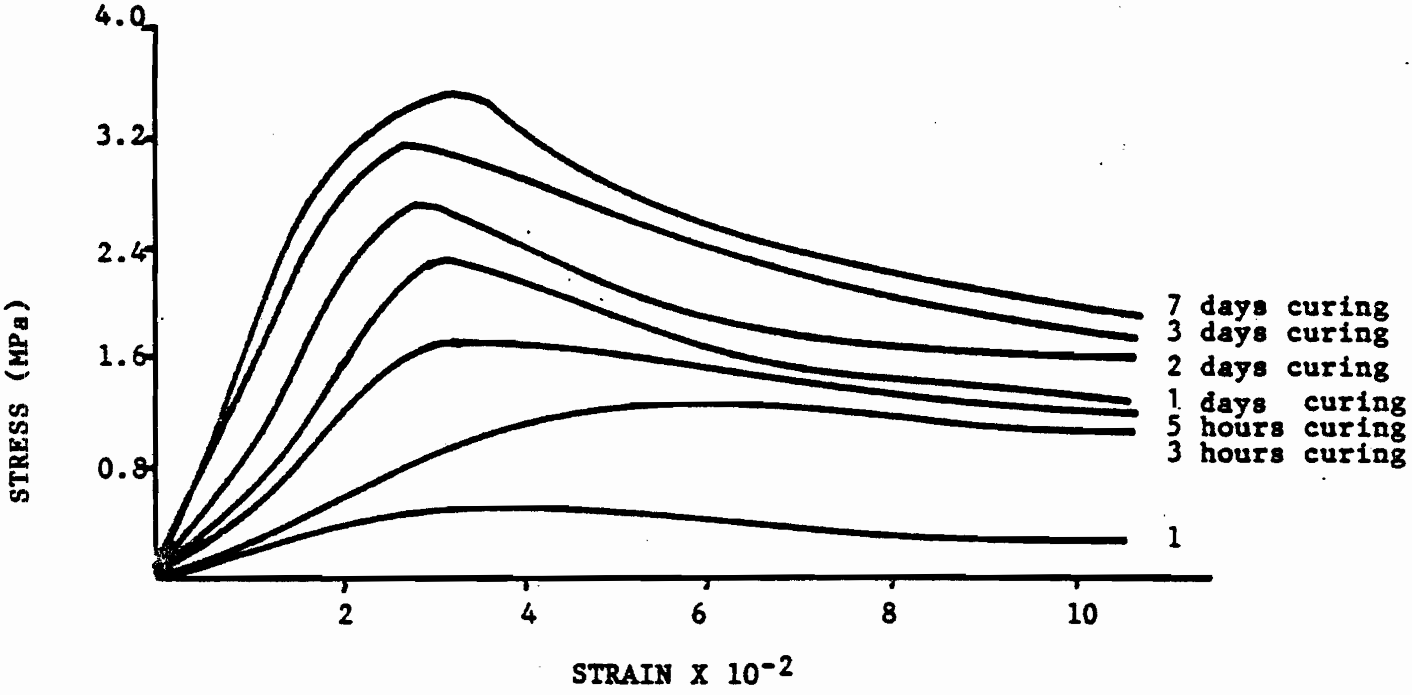


FIG. 17.- STRESS/STRAIN CURVES FOR STANDARD MIX

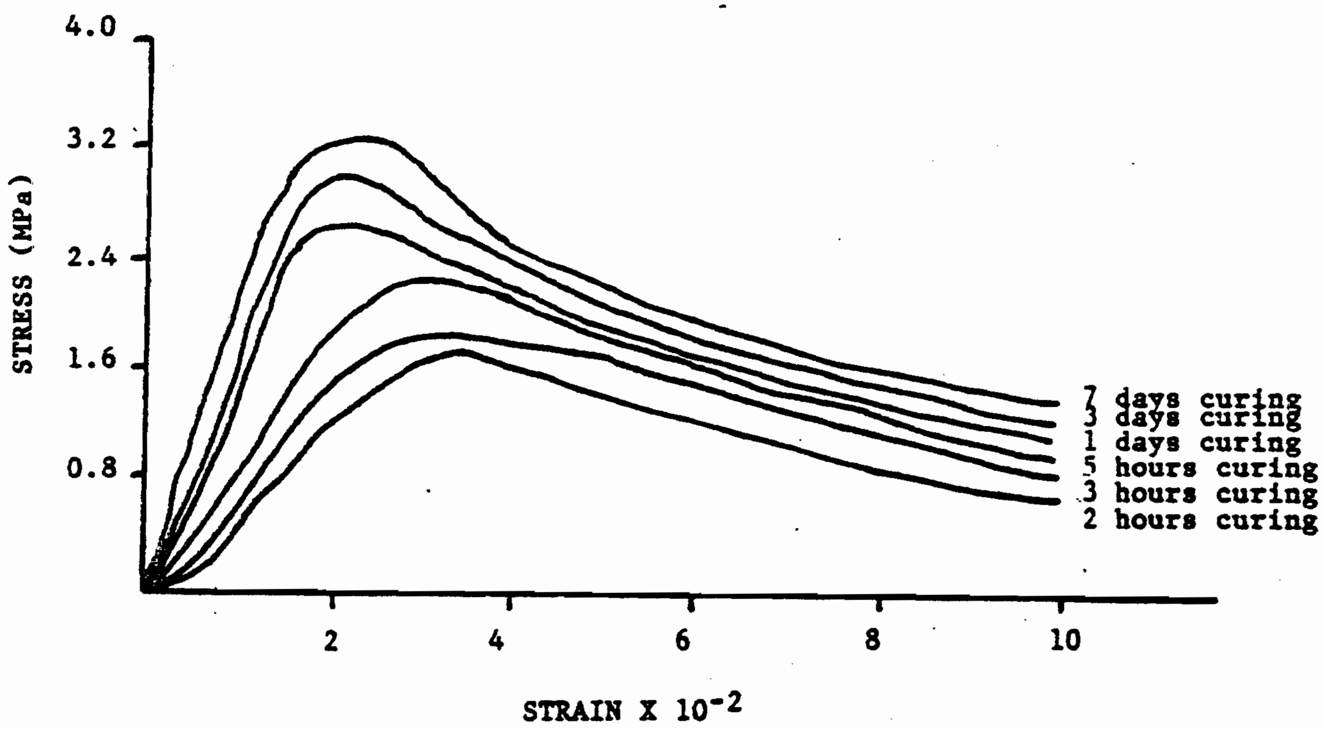


FIG. 18 - STRESS/STRAIN CURVES FOR EXCESS TEKCEM

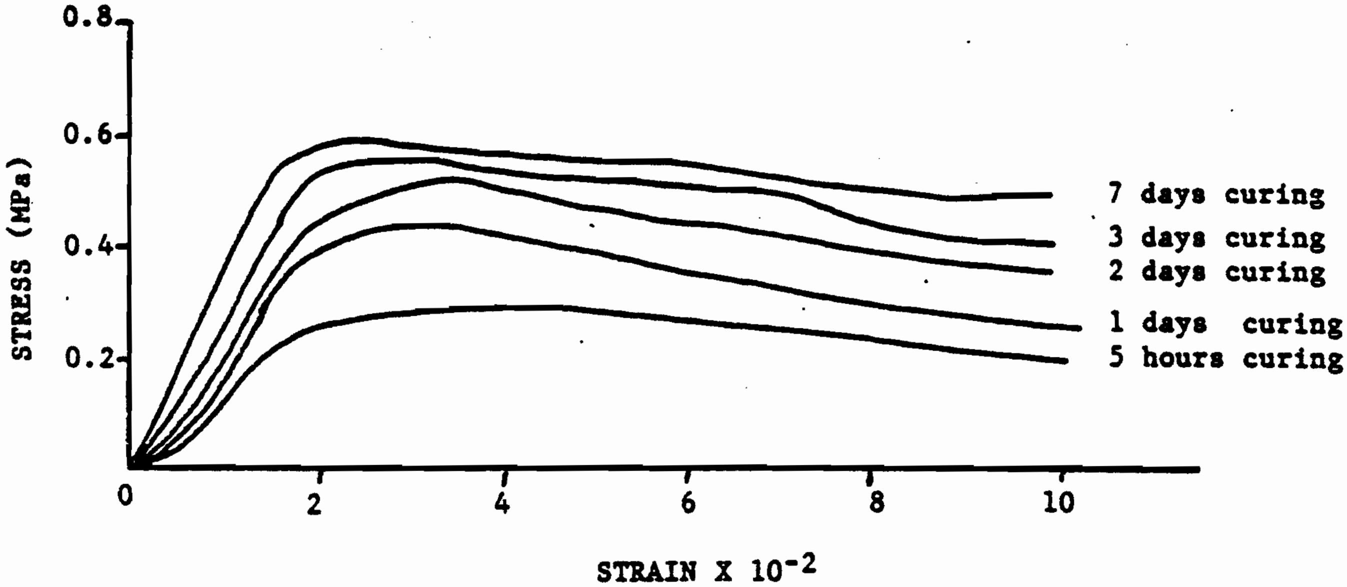


FIG. 19 - STRESS/STRAIN CURVES FOR EXCESS WATER

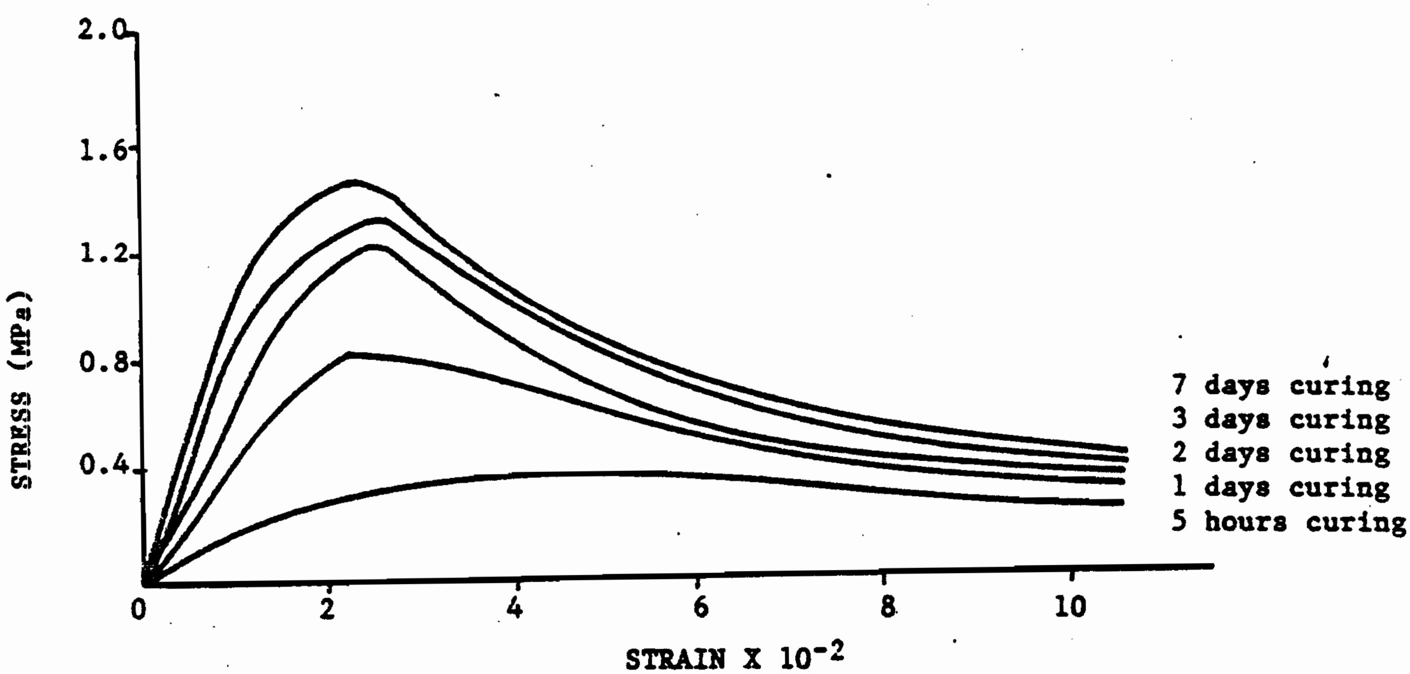


FIG. 20 - STRESS/STRAIN CURVES FOR EXCESS WATER

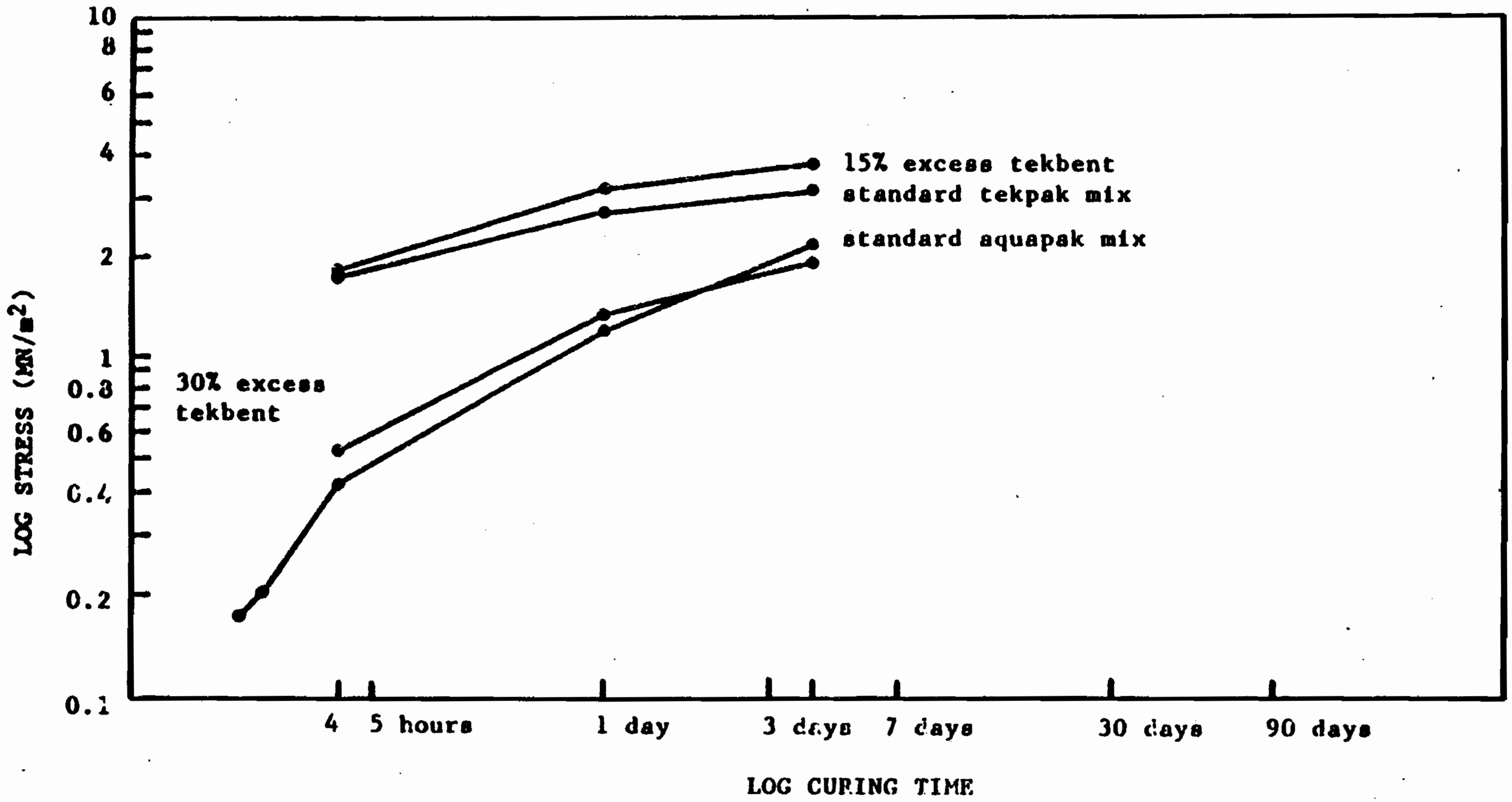


FIG. 21. STRENGTH DEVELOPMENT OF AQUAPAK AND TEKPAK MIXES.

to a peak strength of 3.37 MPa at 3 days. After this the strength tails off to 2.73 MPa after 7 days. The curve is characteristic of some high alumina cements. The transition from plastic to brittle behaviour appears to occur between 5 hours and 1 day (Figure 17).

The other three curves on Figure 21 are similar to that of the correct mix. The Aquapak curve rises more steeply to 2 days. The Aquacem curve peaks after 2 days but the tail off is less apparent.

The 50% excess Tekbent has a marked affect on the strength of the cement. It must be noted that 50% Tekbent represents a much larger proportion of the solids than does 50% Aquabent. The former means that the final cement will contain 50% more Tekbent than Tekcem by weight. By contrast 50% more Aquabent means that the Aquacem/Aquabent weight ratio is reduced from 9 to 1 to 6 to 1, still a substantial ratio in favour of Aquacem.

The result of this excess bulk of Aquabent is to reduce the strength but to greatly increase the plastic behaviour. The 5 hour samples closed 10 mm (10%) without any cracks evident. The samples "barrelling" in a classic plastic failure fashion. The samples were then removed from the press and allowed to cure for a further 19 hours before being retested. The samples then had a mean strength of 1.15 MPa compared to 1.10 MPa for the 1 day tests.

The 50% excess water is detrimental to the all round performance of the cement. The 50% excess Tekcem produces impressive early strengths but the later strengths are low in the light of those achieved by a 50% excess of Aquacem.

4.2: ASTRAPACK TEST

An extensive laboratory testing programme was conducted on the physical and mechanical properties of the Astrapak material in order to investigate:

a. Effect of curing time on the density

b. Effect of curing time on the P-wave velocity through the specimen

c. Effect of curing time on the modulus of elasticity

d. Effect of curing time on the unconfined compressive strength

e. Effect of water and curing temperature on the above noted parameter

f. Effect of sample size on the internal increase of sample temperature due to chemical reaction during the curing period

g. Effect of excess water and cement on the mechanical properties of Astrapak

h. The mechanical behaviour of the Astrapak under very slow strain rate (long term compressive strength test).

4.3: SAMPLE PREPARATION

4.3.1: Sample Preparation for Standard Mix

The correct standard mix for Astrapak recommended by the manufacturer is:

Astrabent:Astracem:Water = 1:1:5.01

This mixture was prepared by mixing 2.5 parts of water with one part of Astrabent in a mixer for 2 minutes to form a creamy coloured slurry. Similarly 2.51 parts of water was mixed with one part of Astracem for 2 minutes to form a dark gray slurry.

The Astrabent slurry was mixed manually for a few seconds prior to the Astracem slurry being poured onto it (Plate 1). The final mixture was stirred manually for 1 minute prior to being poured into cylinderical specimen moulds with internal diameter of 50 mm and height of 130 mm (Plate 2). The samples were left in the moulds for 45 minutes before it was taken out and the ends were cut and ground. The final length of the specimens were 100 mm. Each individual samples were wrapped in saran wrap (Plate 3). The standard mix specimens were prepared with water which was at the temperature of 12^{o}C and 25^{o}C.

4.3.2: Preparation of Specimens with 50% Excess Water

These samples were prepared in similar manner for the standard mix discussed earlier. However 50% more water was introduced to each slurry. The water and curing temperatures for these samples were kept at 25^{o}C.

4.3.3: Preparation of Specimens with 50% Excess Astracem

Similar technique as that employed for preparation of the standard mix specimen were adopted for these batch of sample. However 50% more Astracem was added to the slurry.

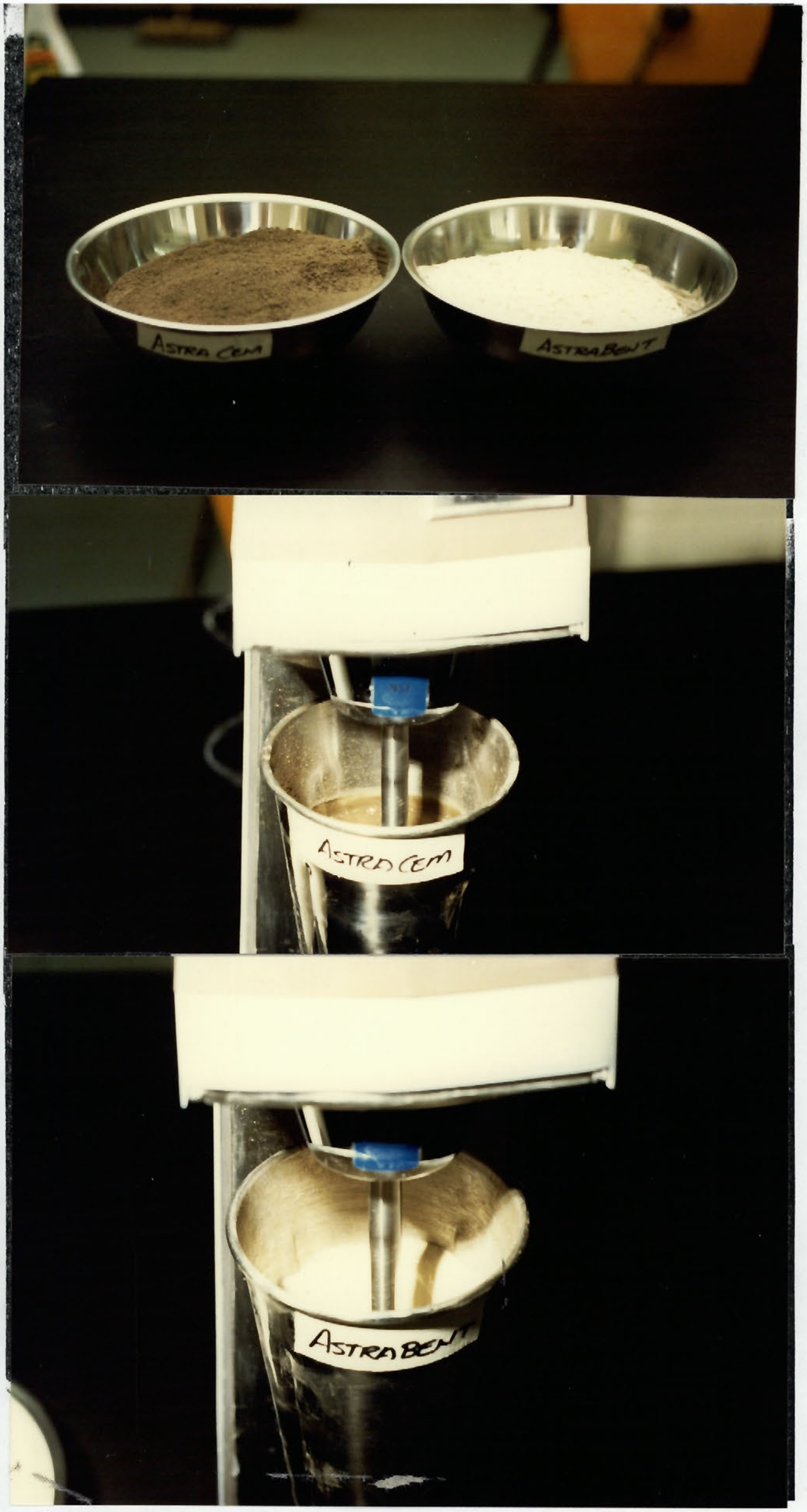


PLATE 1: MIXING ASTRABENT AND ASTRACEM

PLATE 2: CYLINDRICAL SPECIMEN MOLDS WITH INTERNAL DIAMETER OF 50 mm AND LENGTH OF 130 mm.

PLATE 3: PLACING THE SPECIMEN IN SARAN WRAP (PLASTIC BAGS).

4.3.4: Preparation of Specimen for Long Term Tests

Standard mix was used for these specimen. The water and curing temperature was kept at 25^{o}C.

4.3.5: Preparation of Specimen for Temperature Measurement During Curing

Standard mix slurry described earlier was employed for these tests. The slurry, however, was poured into cubic moulds of 5, 10, 15 and 25 cm. This gave specimen surface areas of 150, 600, 1350 and 3750 cm^2 and volume of 125, 1000, 3375 and 15626 cm^3 respectively.

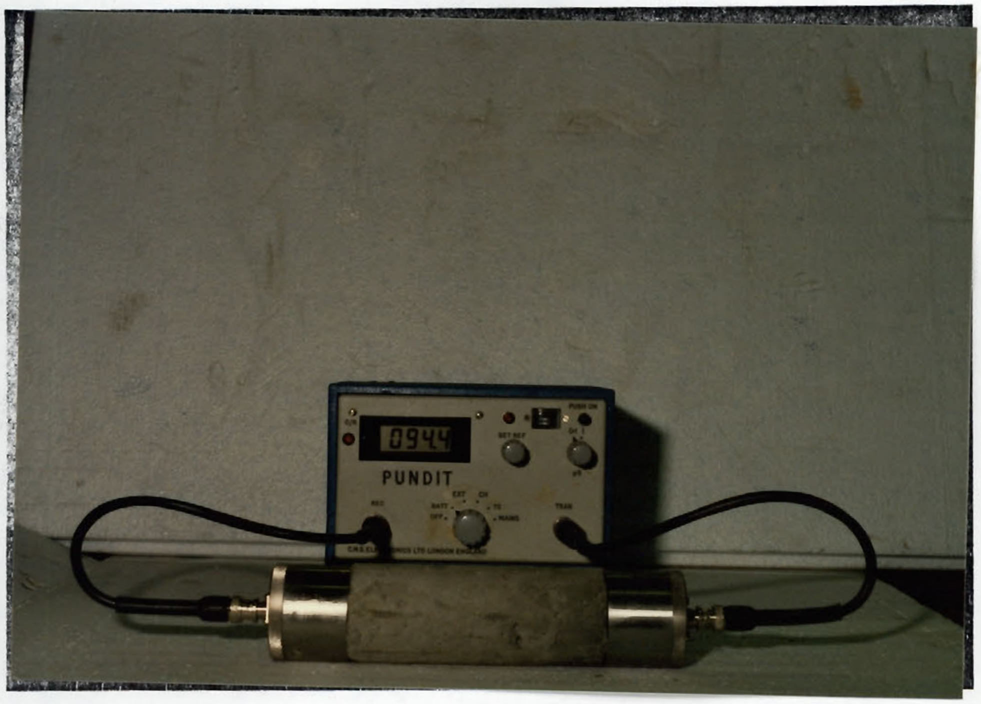
4.4: TESTING PROCEDURE

4.4.1: Density Measurements

In order to determine the density of each sample the weight and volume of each particular sample was measured after 1, 1.5, 2, 2.5, 3, 6, 24, 48, 72, 168 and 720 hours of curing time. The results for each batch of samples regarding any particular curing time is averaged and presented in Table 3 and Figure 22.

4.4.2: P-Wave Velocity Measurement

This test was conducted by a portable ultrasonic non-destructive digital indicating tester (PUNDT) as shown in Plate 4. For assessing the quality of the specimen from ultrasonic pulse velocity measurement, it is necessary for this measurement



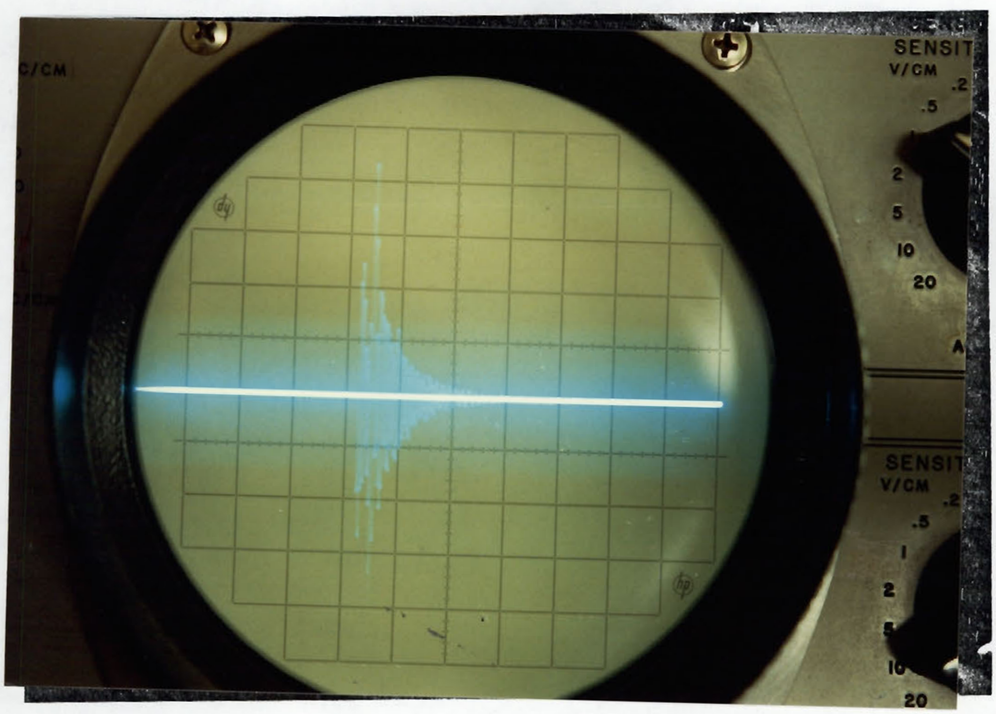


PLATE 4: ULTRASONIC PULSE VELOCITY MEASUREMENT OF ASTRAPAK SAMPLES BY PUNDIT.

Table 3 - Change in the Density of Astrapak during Curing (Average of 5 Tests)

Type of Sample			Density (γ), in gr/cm³										Remarks
			Curing Time (hours)										
Type of Mixture in Sample	Water Temperature (°C)	Curing Temperature (°C)	1	1.5	2	2.5	3	6	24	48	72	168	
Standard	12	10	1.48	1.47	1.47	1.46	1.46	1.44	1.44	1.44	1.44	1.44	
Standard	12	25	1.57	1.56	1.54	1.53	1.52	1.50	1.36	1.22	1.15	1.07	
Standard	25	10	1.58	1.56	1.56	1.53	1.51	1.46	1.46	1.46	1.46	1.46	
Standard	25	25	1.48	1.47	1.46	1.45	1.45	1.42	1.31	1.24	1.21	1.19	
50% excess water	25	25	1.52	1.50	1.49	1.48	1.48	1.44	1.32	1.16	1.13	1.01	
50% excess Astracem	25	25	1.61	1.59	1.57	1.56	1.55	1.52	1.40	1.26	1.20	1.15	

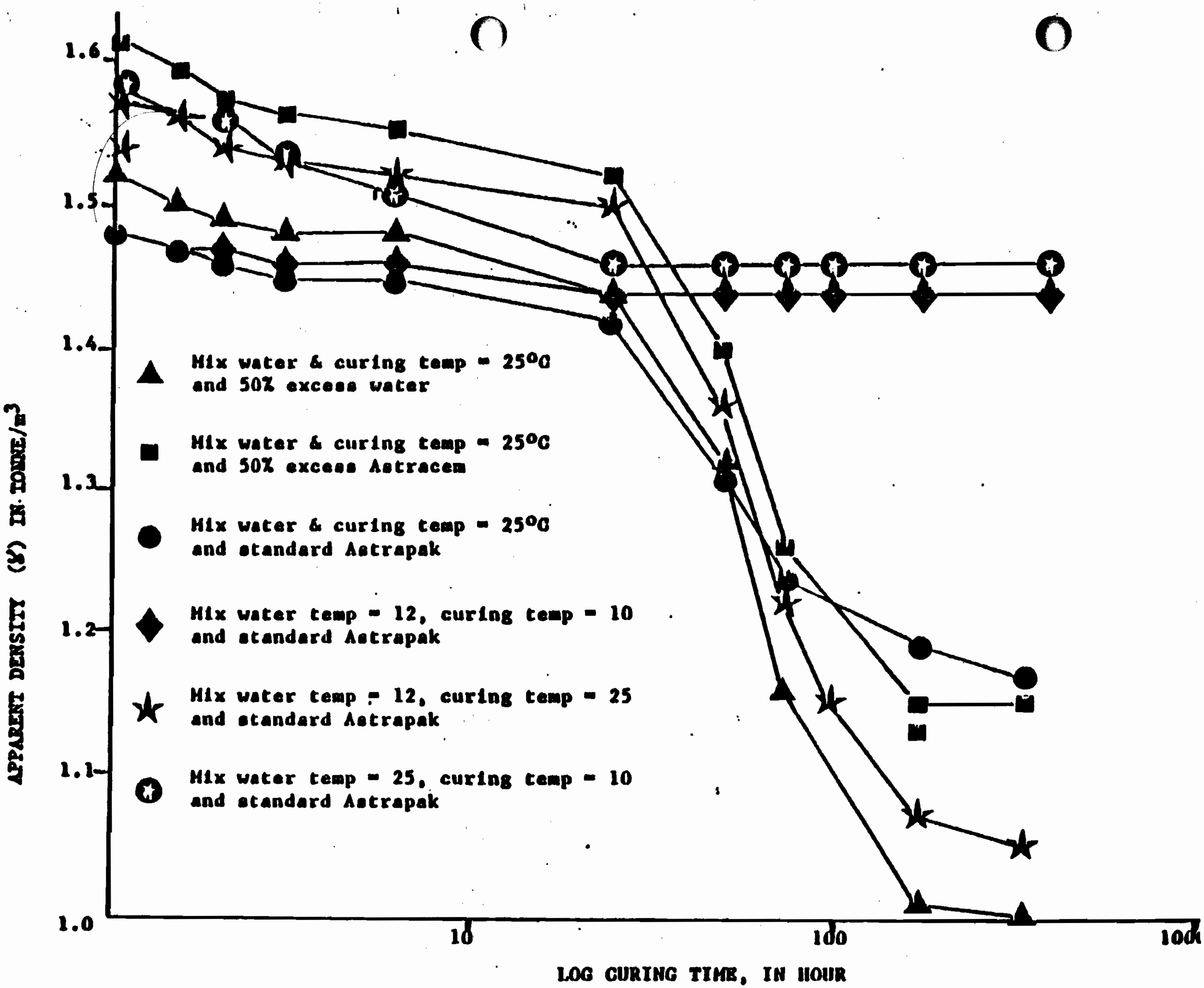


FIG. 22 - CHANGE IN THE APPARENT DENSITY OF ASTRAPAK DURING CURING

to be of a high order of accuracy. This is done using an apparatus which generates suitable pulses and accurately measures the time of their transmission (i.e. transit time) through the specimen tested. The distance which the pulses travel in the material (i.e. the path length) must also be measured to enable the velocity to be determined from:

$$\text{Pulse Velocity} = \frac{\text{Path Length}}{\text{Transit Time}}$$

Path lengths and transit time should each be measured to an accuracy of about $\pm$ 1%.

The instrument indicates the time taken for the earliest part of the pulse to reach the receiving transducer measured from the time it leaves the transmitting transducers when these transducers are placed at suitable points on the surface of the specimen (the end surfaces). This method of testing was originally developed for use on concrete and the published accounts of its application are concerned predominaately with this material. The author believes that this could have significant use in the in situ quality determination of the pack material discussed in this report.

The pulse-velocity measurements were taken several times for each specimen cured at different time period (1 to 168 hours). The average results are presented in Table 4 and Figure 23.

Table 4 - Change in the Ultrasonic Velocity (V_p) of Astrapak during Curing Time (Average of 5 Tests)

Type of Sample			Ultrasonic Velocity (V_p), in mm/μsec.										Remarks
			Curing Time (hours)										
Type of Mixture in Sample	Water Temperature (°C)	Curing Temperature (°C)	1	1.5	2	2.5	3	6	24	48	72	168	
Standard	12	12	1.79	1.82	1.85	2.27	2.93	2.94	1.87	2.99	3.11	2.65	
Standard	12	25	1.19	1.78	1.91	2.32	2.67	2.87	2.75	2.90	3.06	2.09	
Standard	25	10	1.77	1.77	2.39	2.47	2.58	2.68	2.77	2.84	2.92	1.90	
Standard	25	25	1.88	1.90	2.99	2.97	2.97	3.01	3.21	3.46	2.40	2.37	
50% excess water	25	25	1.61	1.63	2.56	2.50	2.49	2.46	2.56	2.78	2.52	2.01	
50% excess Astracem	25	25	1.66	2.77	2.77	2.76	2.79	2.81	2.86	3.03	2.84	2.07	

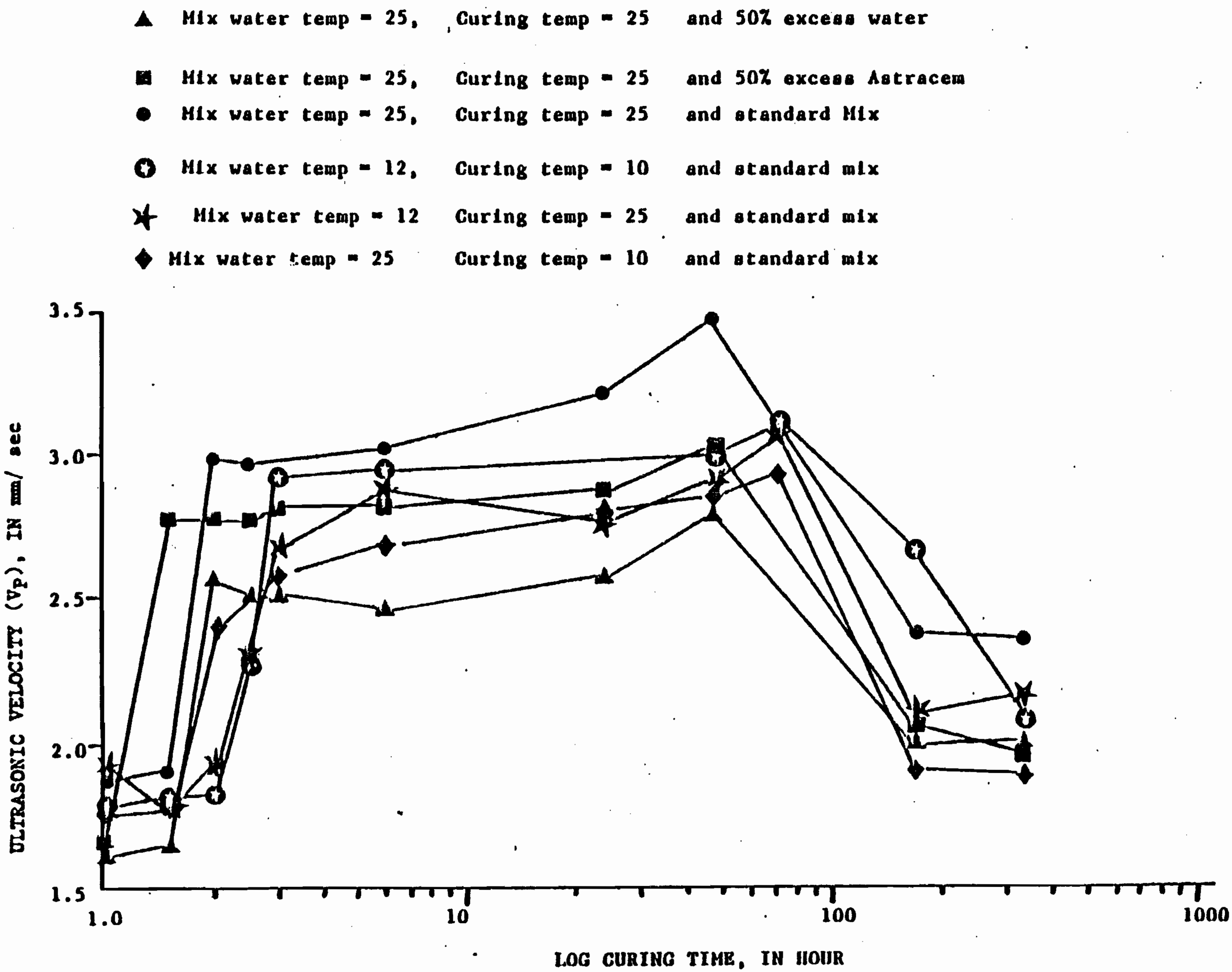


FIG. 23 - CHANGE IN THE ULTRASONIC VELOCITY IN ASTRAPAK DURING CURING

4.4.3: Determination of Unconfined Compressive Strenth and Modulus of Elasticity

The unconfined compressive strength tests were conducted at a slow rate of deformation of 0.017 mm/sec. The deformation was measured by an L.V.D.T. placed between the platens (Plate 5). The load and deformation measurements were directly recorded by a computer control data acquisition system (Plate 6). The stress and strain were then calculated and plotted and the modulus of elasticity were evaluated at 50% of the failure load. The summary of the averaged results are presented in Tables 5 and 6 and shown in Figures 24-37.

4.4.4: Temperature Measurements of Astrapak Specimens During Curing

This test was conducted on a special request from Dr. P. Cain of CANMET, Sydney Coal Laboratory. The object of this series of tests was to determine the effect of volume or size of samples on the temperature change generated from the chemical reaction within the sample during the curing period of 1 to 168 hours.

The temperature was measured by inserting a pair of prob thermometer in the sample immediately after it is poured in the mold (Plate 7). The prob is fixed in the sample without any movement until it is set hard.

The temperature measurements required for the testing programme were conducted with the aid of National Semiconductor's LM335AH temperature sensors and custom amplifier circuits.

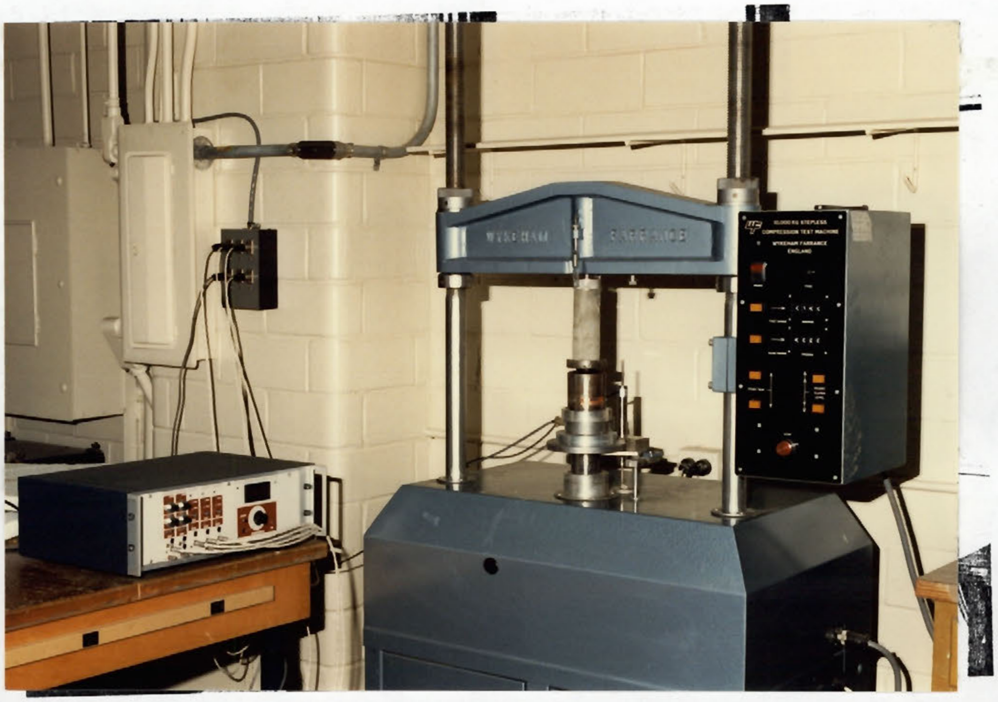


PLATE 5: COMPRESSIVE TESTING MACHINE.

PLATE 6: DATA ACQUISITION SYSTEM.

Table 5 - Change in the Static Modulus of Elasticity of Astrapak during Curing Time (Average of 5 Tests)

Type of Sample			Static Modulus of Elasticity (E), in MPa												Remarks
			Curing Time (hours)												
Type of Mixture in Sample	Water Temperature (°C)	Curing Temperature (°C)	1	1.5	2	2.5	3	6	24	48	72	96	168	720	
Standard	12	10	9.1	18.9	24.5	33.8	40.1	64.3	141.3	147.5	148.4	149.8	145.0	150.5	
Standard	12	25	13.0	35.3	39.5	48.9	55.2	86.5	138.5	155.2	183.8	179.6	174.9	239.7	
Standard	25	10	11.2	11.8	13.6	15.1	20.3	22.3	29.0	34.9	38.2	54.3	92.1	70.5	
Standard	25	25	23.2	35.0	58.6	62.5	72.0	90.4	136.1	148.5	154.3	155.7	166.1	227.0	
50% excess water	25	25	17.1	13.6	26.7	30.2	32.5	35.7	51.9	55.1	61.5	66.1	46.7	64.4	
50% excess Astracem	25	25	38.3	44.4	75.8	97.5	100.1	105.6	116.8	117.5	118.9	120.0	168.9	193.7	

Table 6 - Change in the Unconfined Compressive Strength of Astrapak during Curing Time (Average of 5 Tests)

Type of Sample			Unconfined Compressive Strength (σ_c), in MPa											Remarks
			Curing Time (hours)											
Type of Mixture in sample	Water Temperature (°C)	Curing Temperature (°C)	1	1.5	2	2.5	3	6	24	72	96	168	720	
Standard	12	10	0.01	0.20	0.35	0.42	0.52	0.91	1.49	2.04	2.51	3.19	2.73	
Standard	12	25	0.23	0.60	0.71	0.75	0.80	1.53	3.03	3.95	4.02	4.11	3.24	
Standard	25	10	0.24	0.25	0.26	0.28	0.28	0.30	0.46	0.53	0.71	1.24	1.47	
Standard	25	25	0.35	0.57	0.81	0.92	1.08	1.35	2.07	2.69	2.76	2.83	3.40	
50% excess water	25	25	0.12	0.15	0.16	0.17	0.19	0.28	0.52	0.65	0.73	0.70	0.51	
50% excess Astracem	25	25	0.60	0.80	1.19	1.56	1.57	1.61	2.21	1.65	1.74	2.15	2.46	

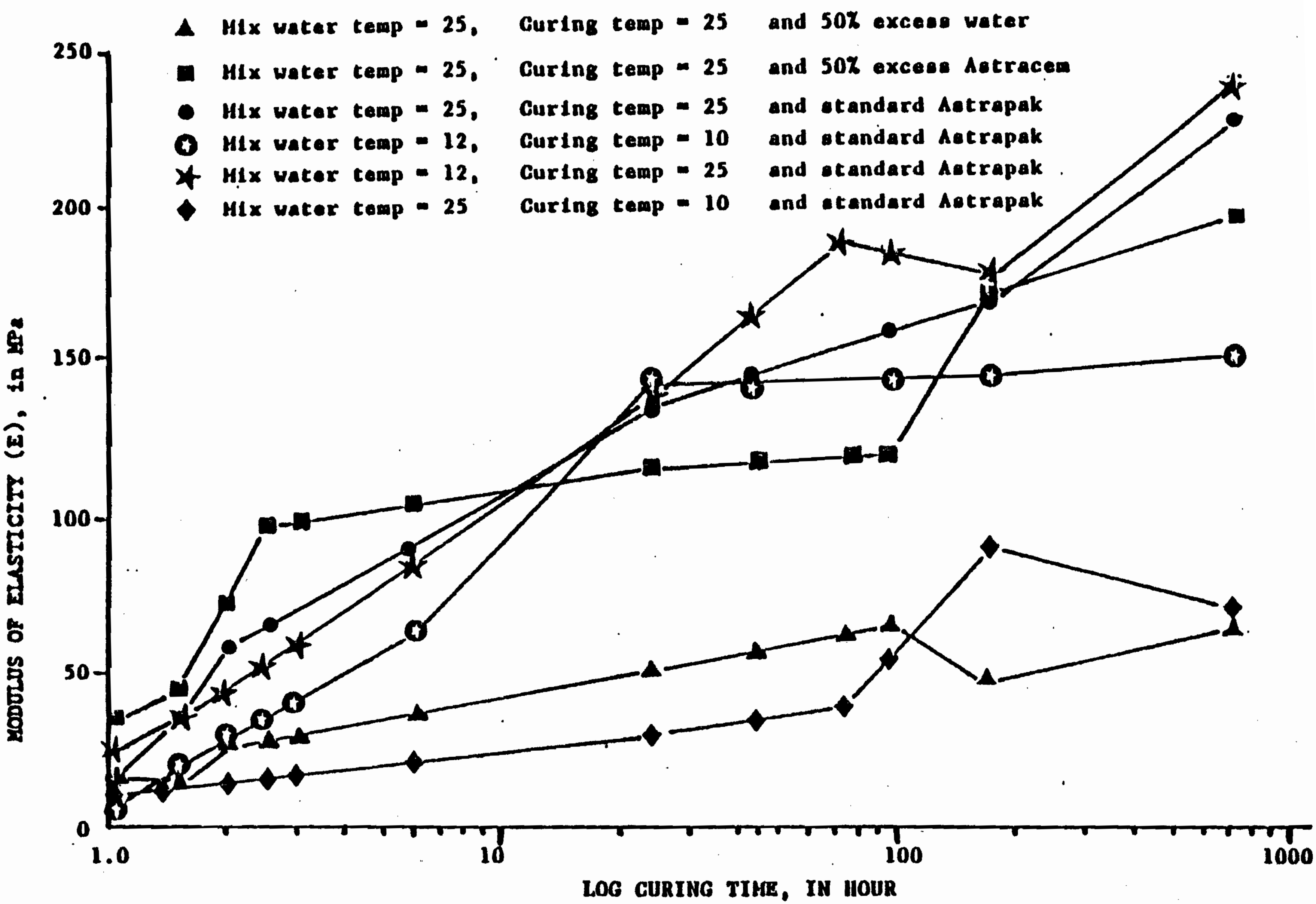


FIG. 24 - CHANGE IN THE STATIC MODULUS OF ELASTICITY OF ASTRAPAK DURING CURING

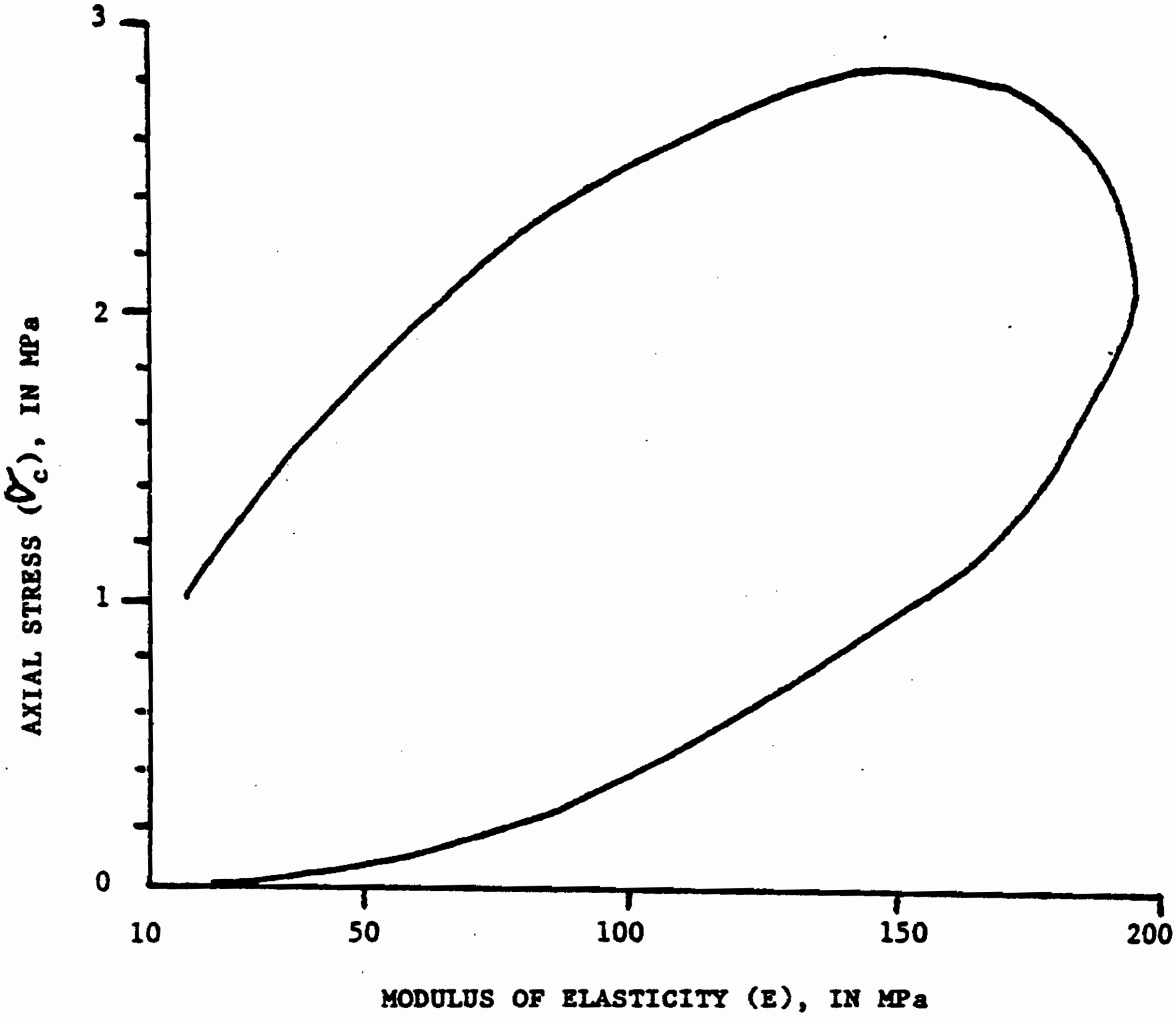


FIG. 25 - UNCONFINED COMPRESSIVE STRESS VS. STATIC MODULUS OF ELASTICITY FOR ASTRAPAK MADE OF STANDARD MIX AT WATER TEMPERATURE OF 12 NAD CURING TEMPERATURE OF 25°C AFTER 30 DAYS CURING

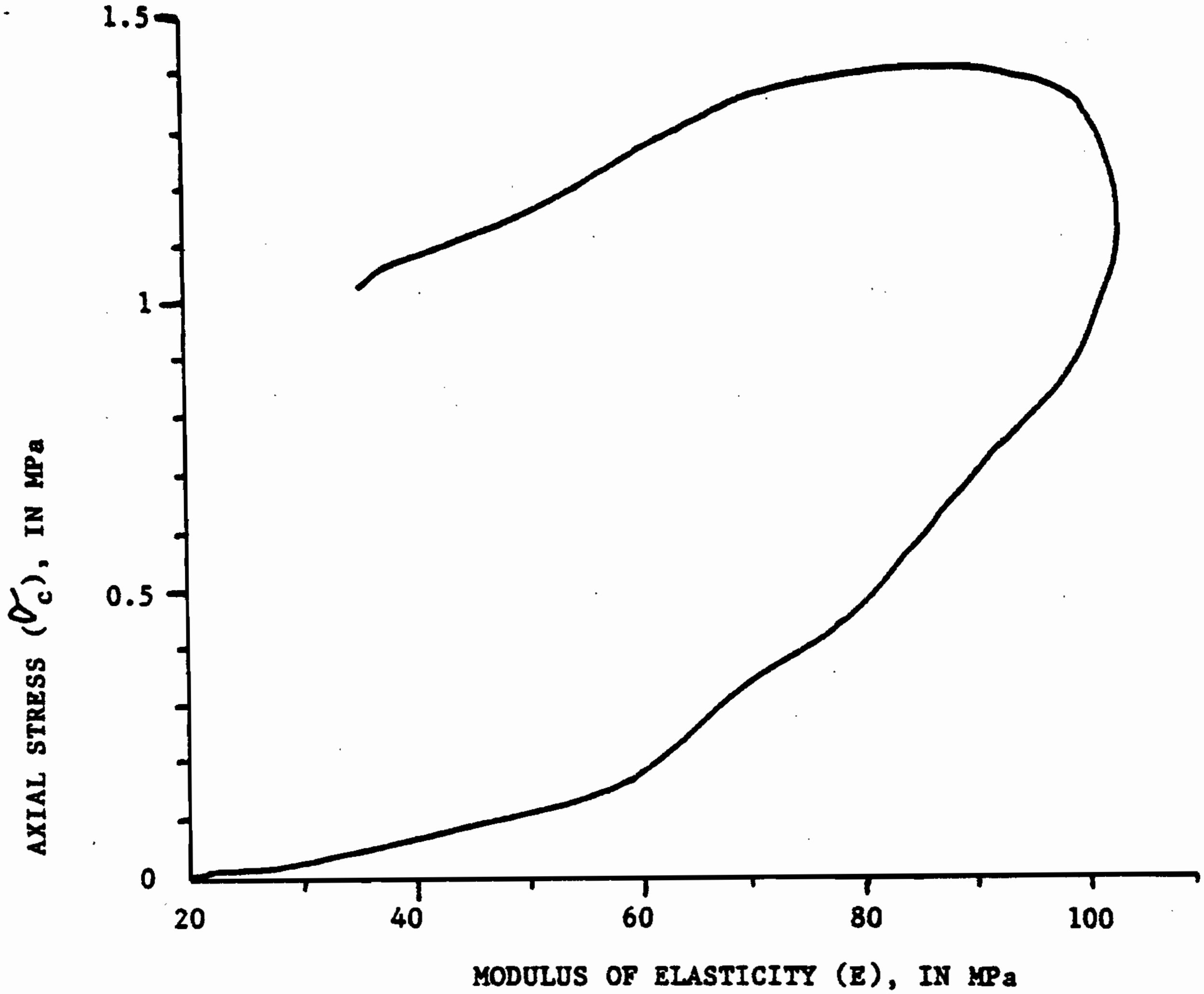


FIG. 26 - UNCONFINED COMPRESSIVE STRESS VS. STATIC MODULUS OF ELASTICITY FOR ASTRAPAK MADE OF STANDARD MIX AT WATER TEMPERATURE OF 25 AND CURING TEMPERATURE OF 10°C AFTER 30 DAYS CURING

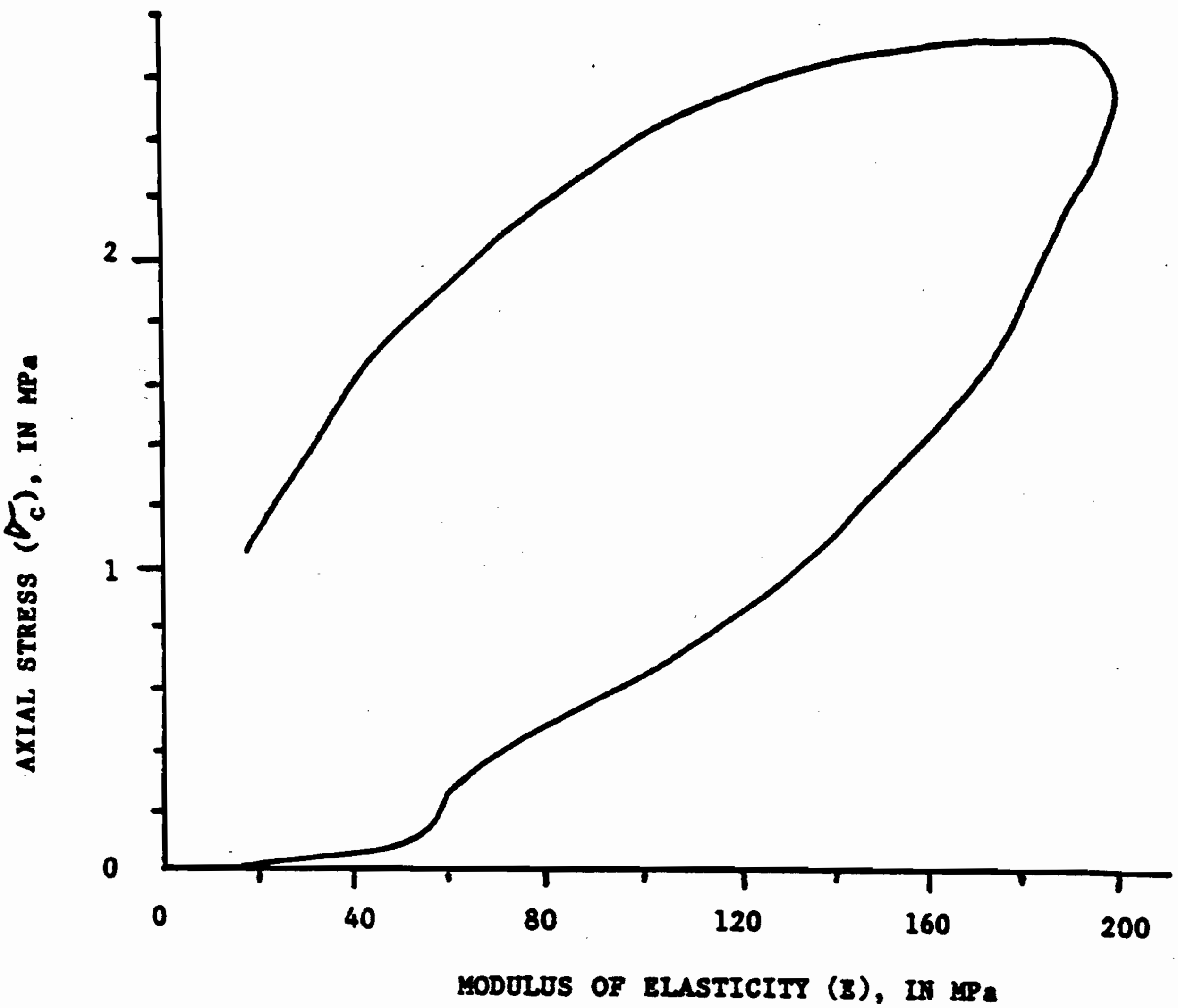


FIG. 27 - UNCONFINED COMPRESSIVE STRESS VS. STATIC MODULUS OF ELASTICITY FOR ASTRAPAK MADE OF STANDARD MIX AT WATER AND CURING TEMPERATURES OF 25°C AFTER 80 DAYS CURING.

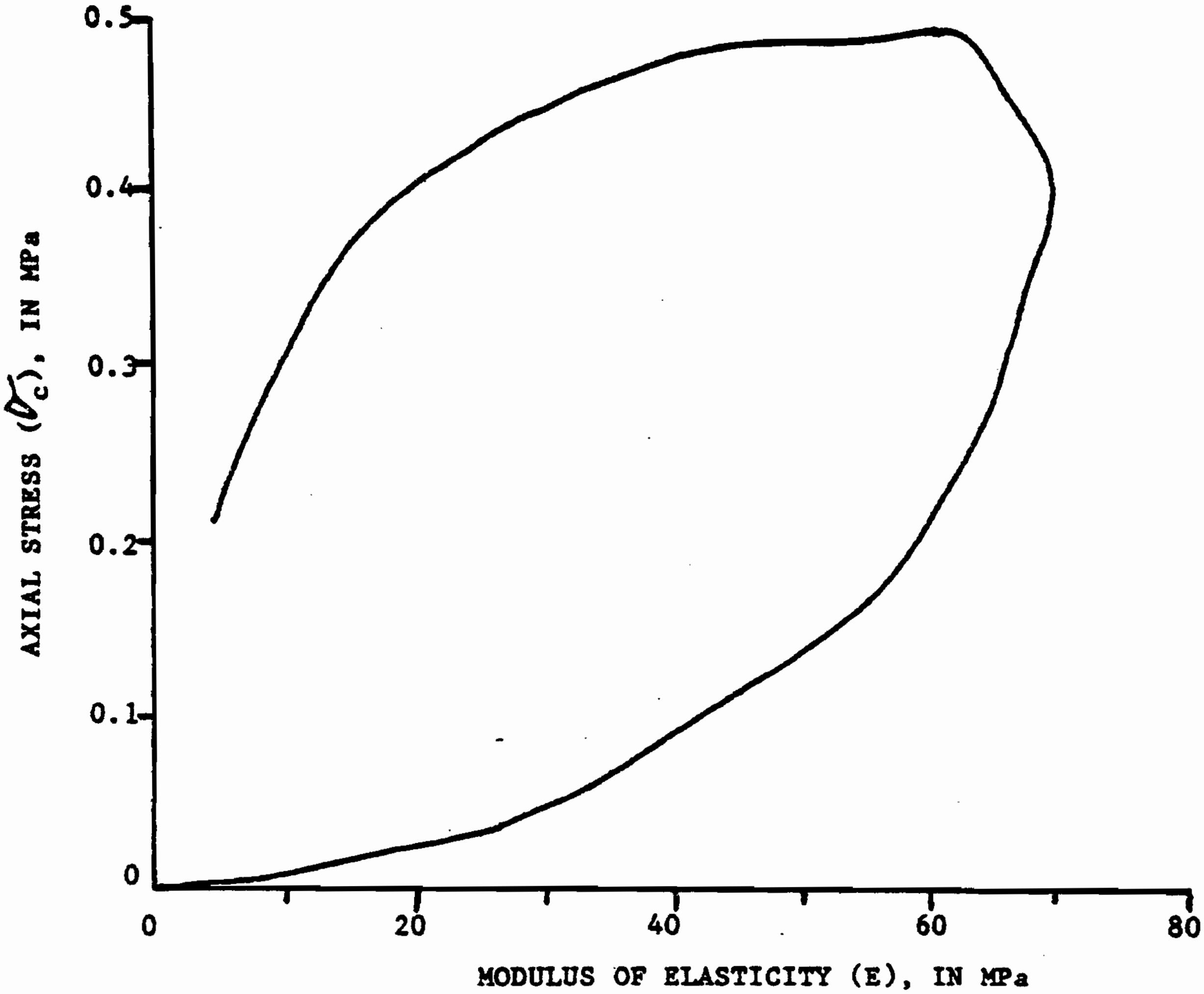


FIG. 28 - UNCONFINED COMPRESSIVE STRESS VS. STATIC MODULUS OF ELASTICITY FOR ASTRAPAK MADE OF 50% EXCESS WATER FROM THE STANDARD AT WATER AND CURING TEMPERATURES OF 25°C AFTER 30 DAYS CURING

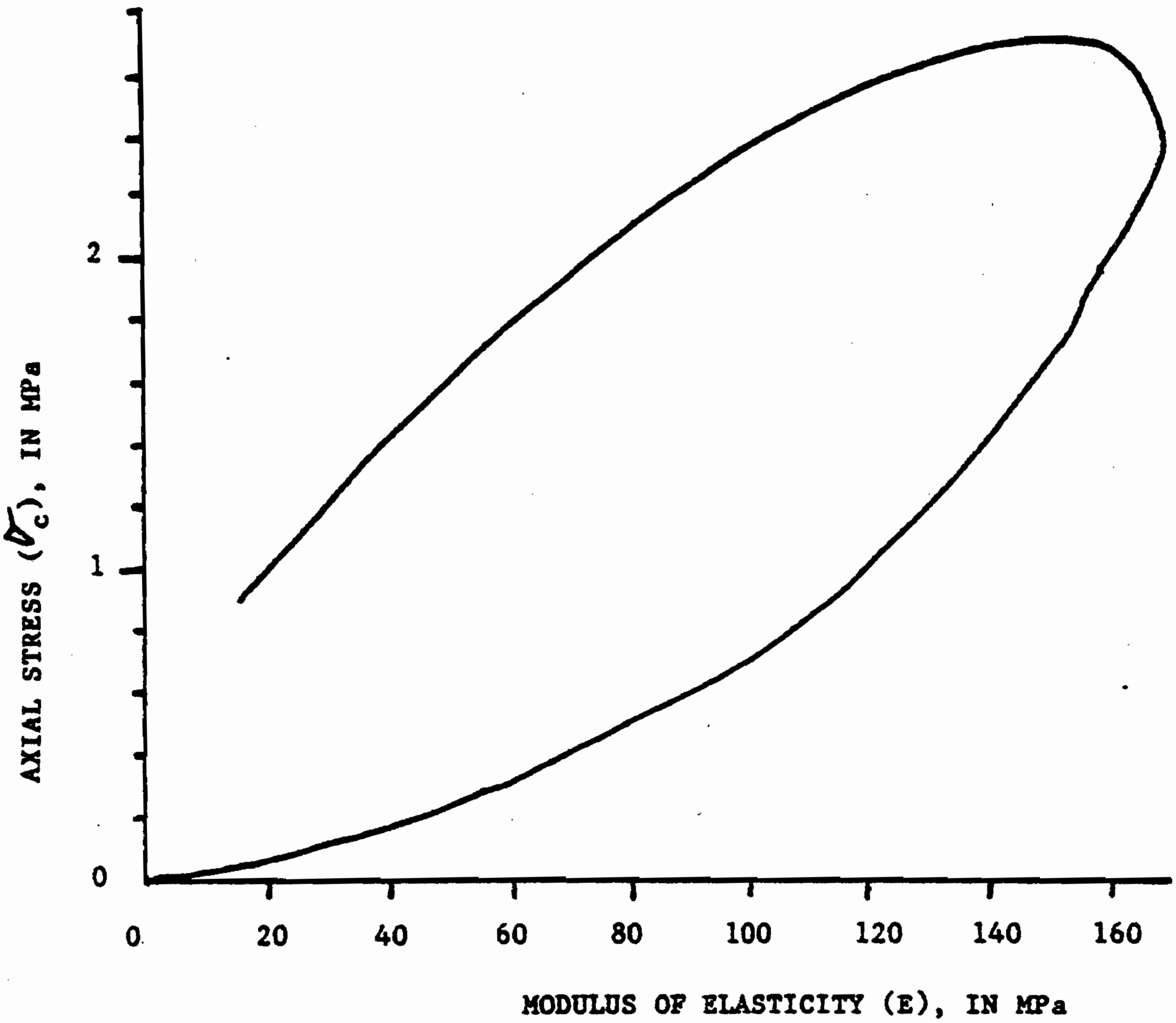


FIG. 29 - UNCONFINED COMPRESSION STRESS VS. STATIC MODULUS OF ELASTICITY FOR ASTRAPAK MADE OF 50% EXCESS ASTRACEM FROM THE STANDARD AT WATER AND CURING TEMPERATURES OF 25°C AFTER 30 DAYS CURING.

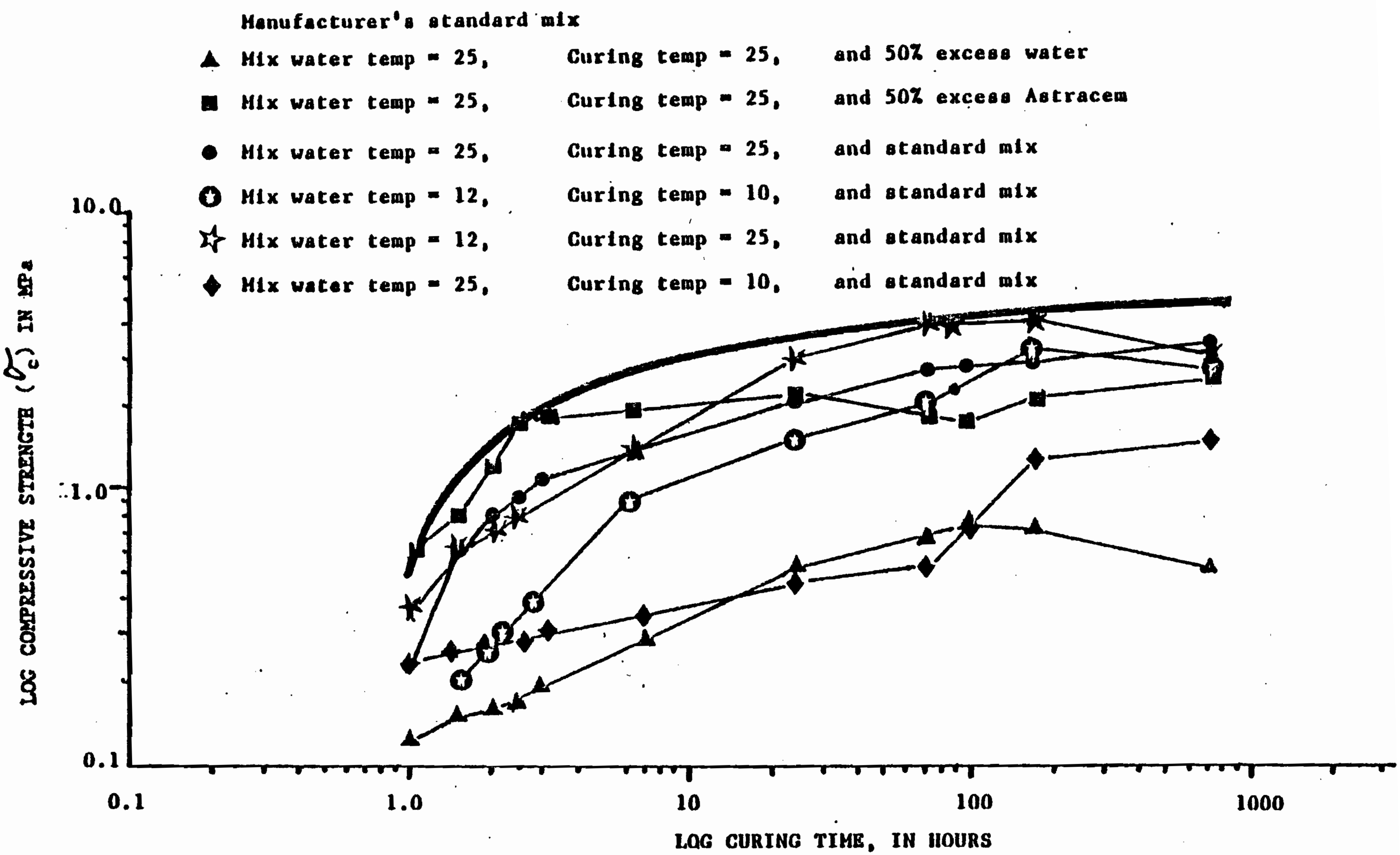
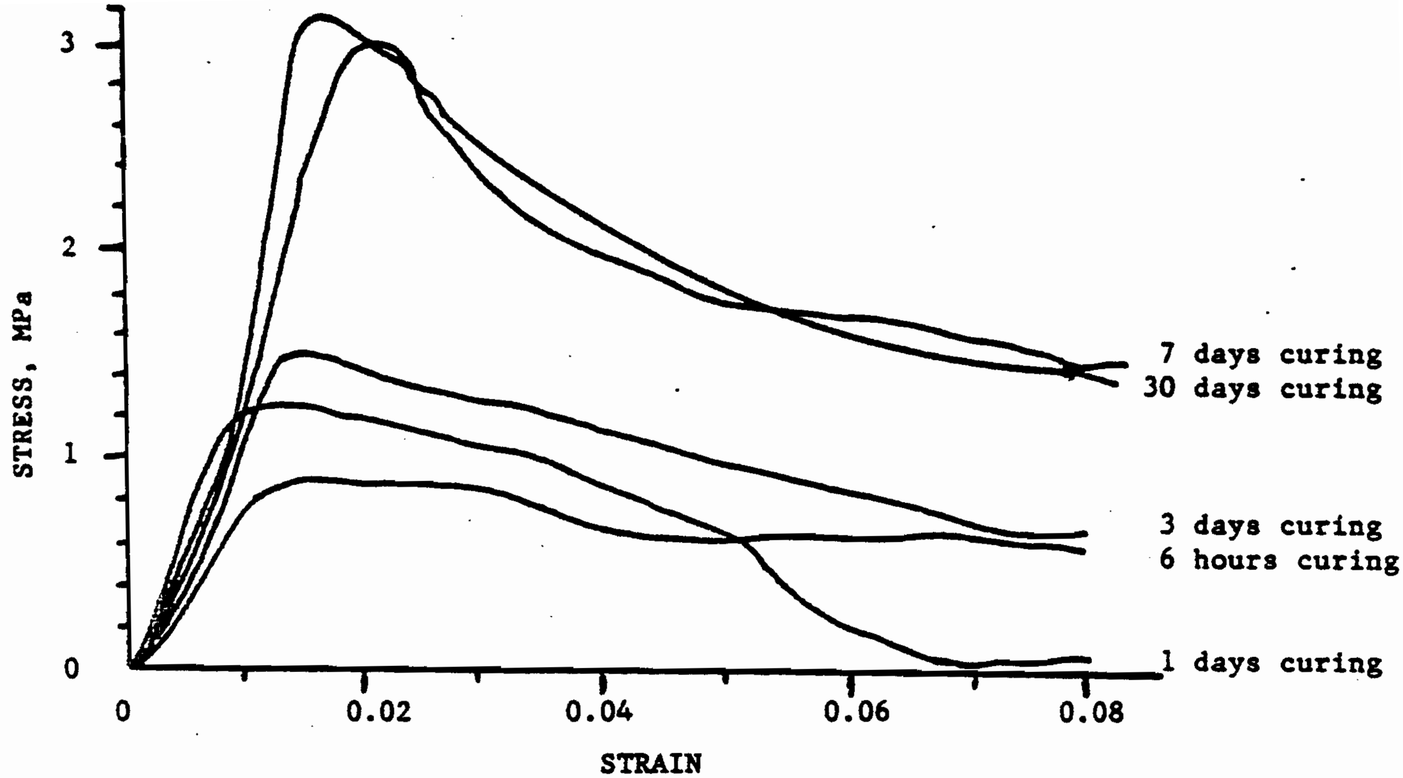
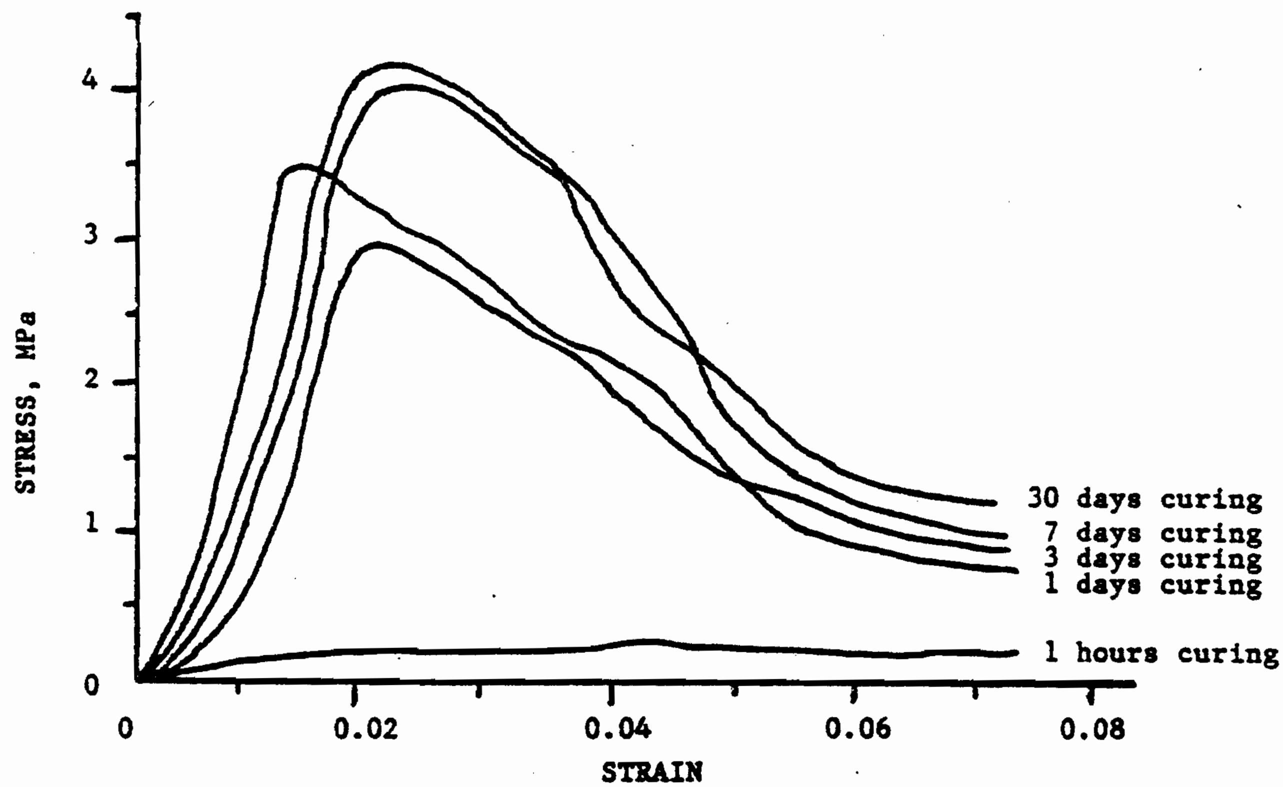


FIG. 30 - DEVELOPMENT OF COMPRESSIVE STRENGTH WITH CURING TIME FOR VARIOUS MIXTURES OF ASTRAPAKS



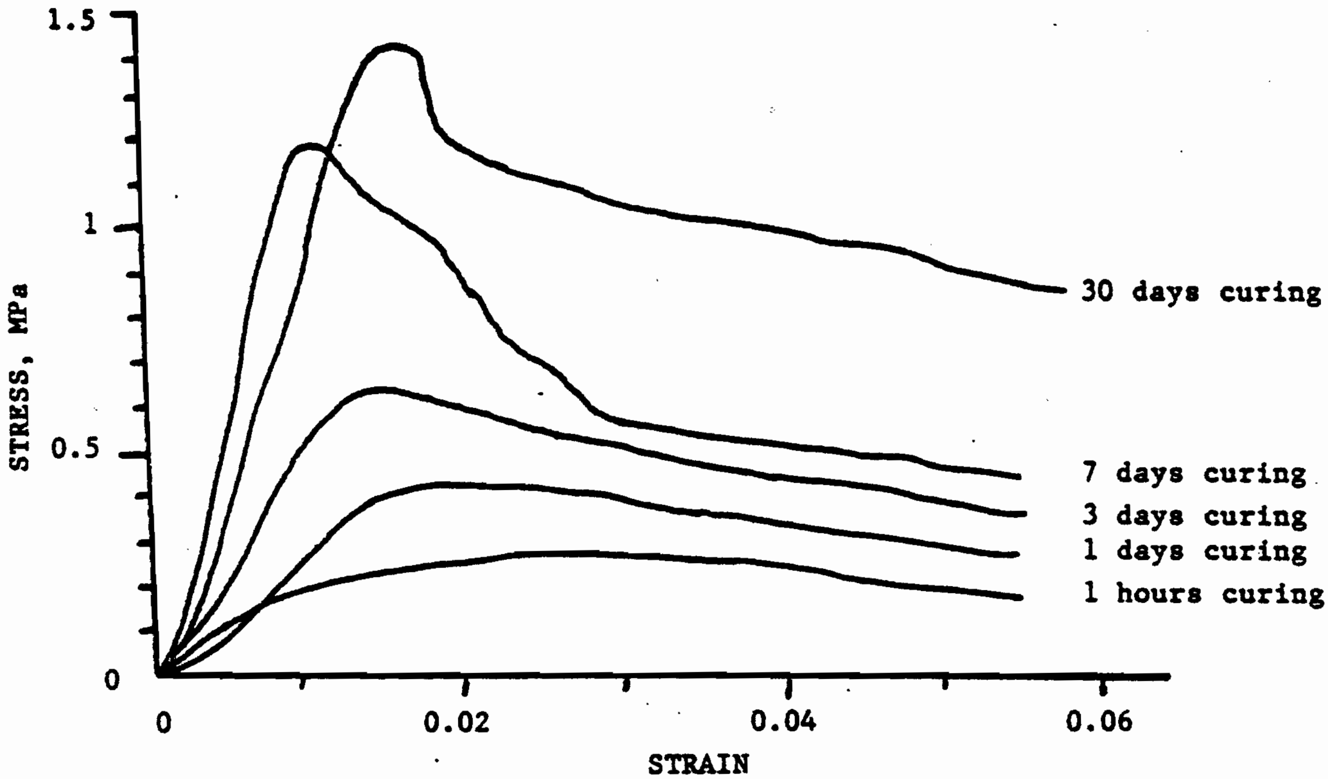
Mix water temp = 12°C, Curing temp = 10°C

FIG. 31 - STRESS/STRAIN CURVES FOR THE STANDARD MIX OF ASTRAPAK



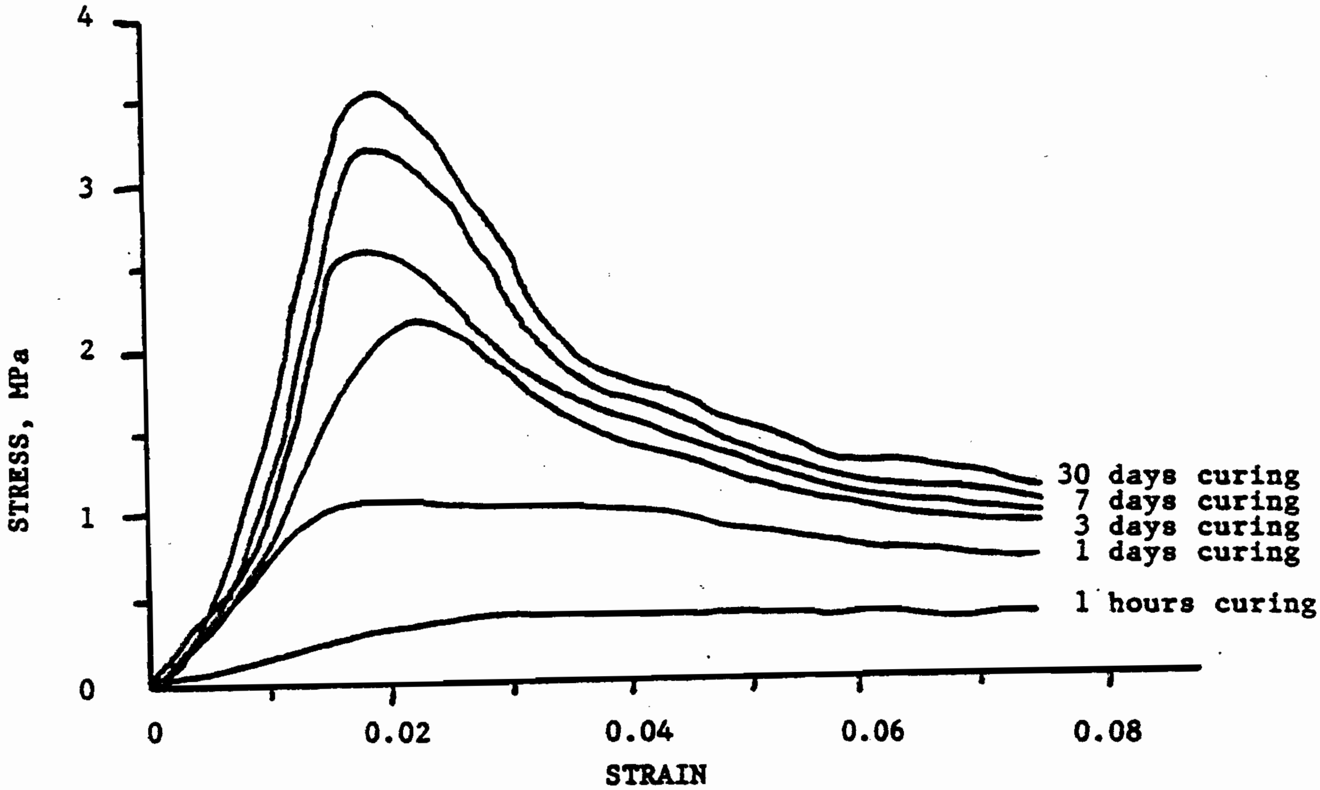
Mix water temp = 12°C Curing temp = 25°C

FIG. 32 _ STRESS/STRAIN CURVES FOR THE STANDARD MIX OF ASTRAPAK



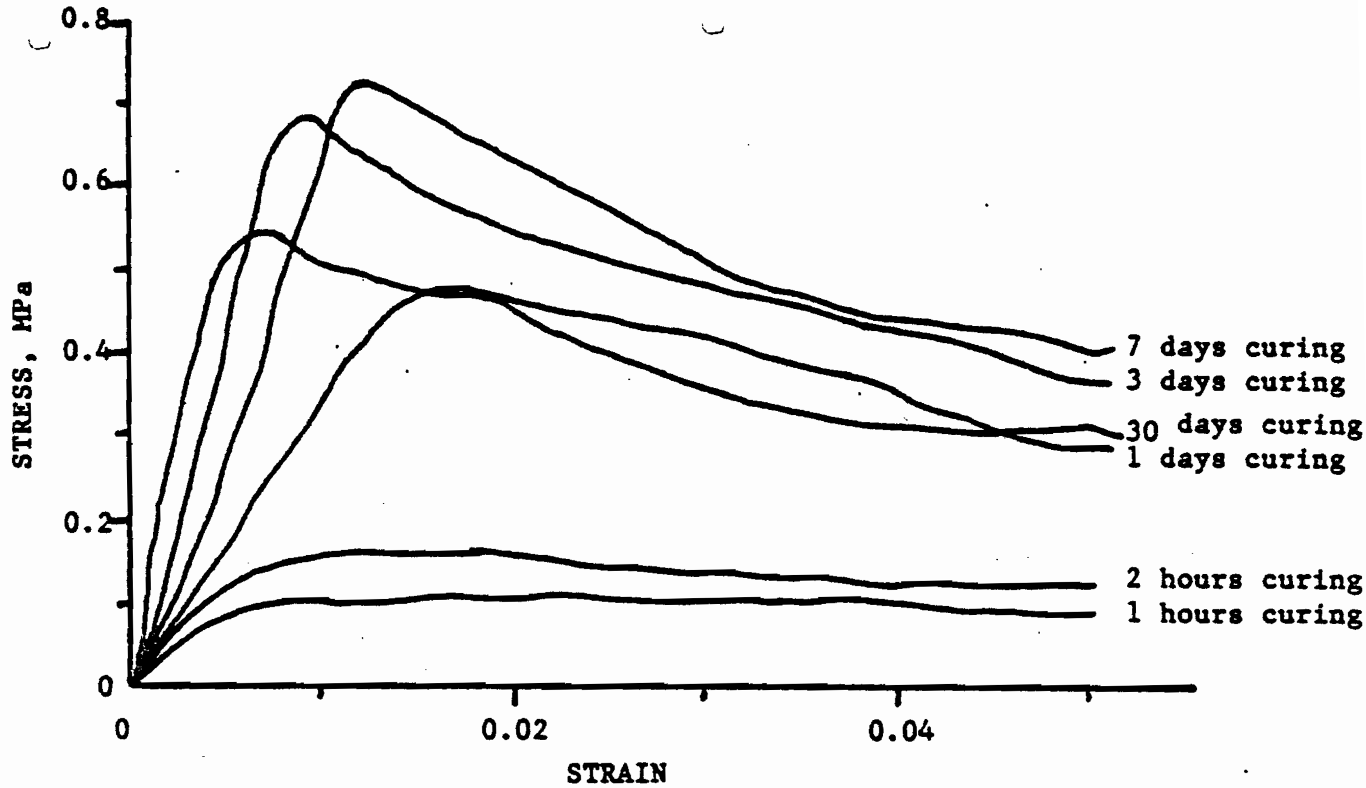
Mix water temp = 25°C,   Curing temp = 10°C

FIG. 33 - STRESS/STRAIN CURVES FOR THE STANDARD MIX OF ASTRAPAK



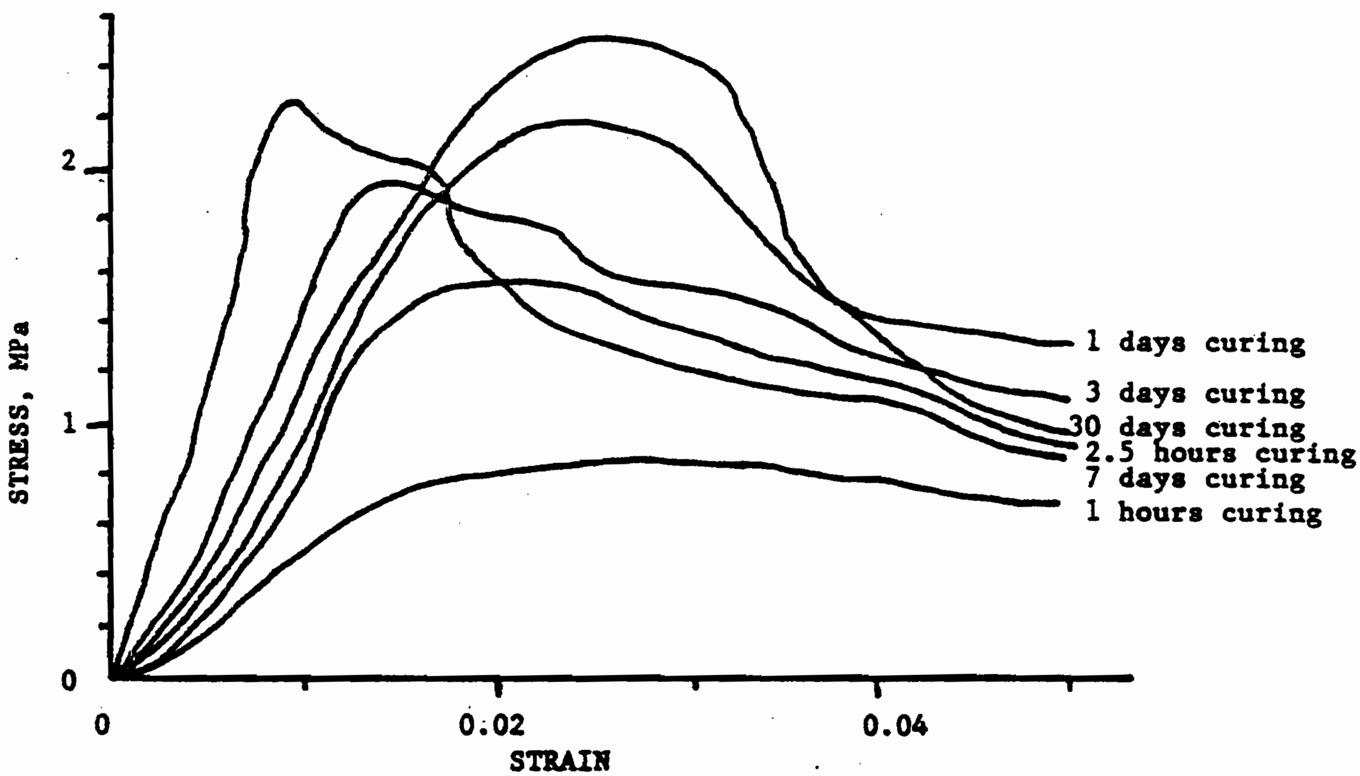
Mix water temp = 25°C,   Curing temp = 25°C

FIG. 34 - STRESS/STRAIN CURVES FOR THE STANDARD MIX ASTRAPAK



Mix water temp = 25°C,   Curing temp = 25°C

FIG. 35 - STRESS/STRAIN CURVES FOR THE ASTRAPAK WITH 50% EXCESS WATER



Mix water temp = 25°C,   Curing temp = 25°C

FIG. 36 _ STRESS/STRAIN CURVES FOR THE ASTRAPAK WITH 50% EXCESS ASTRACEM

PLATE 7: THE SPECIMEN MOLDS OF VARIOUS SIZES FOR TEMPERATURE

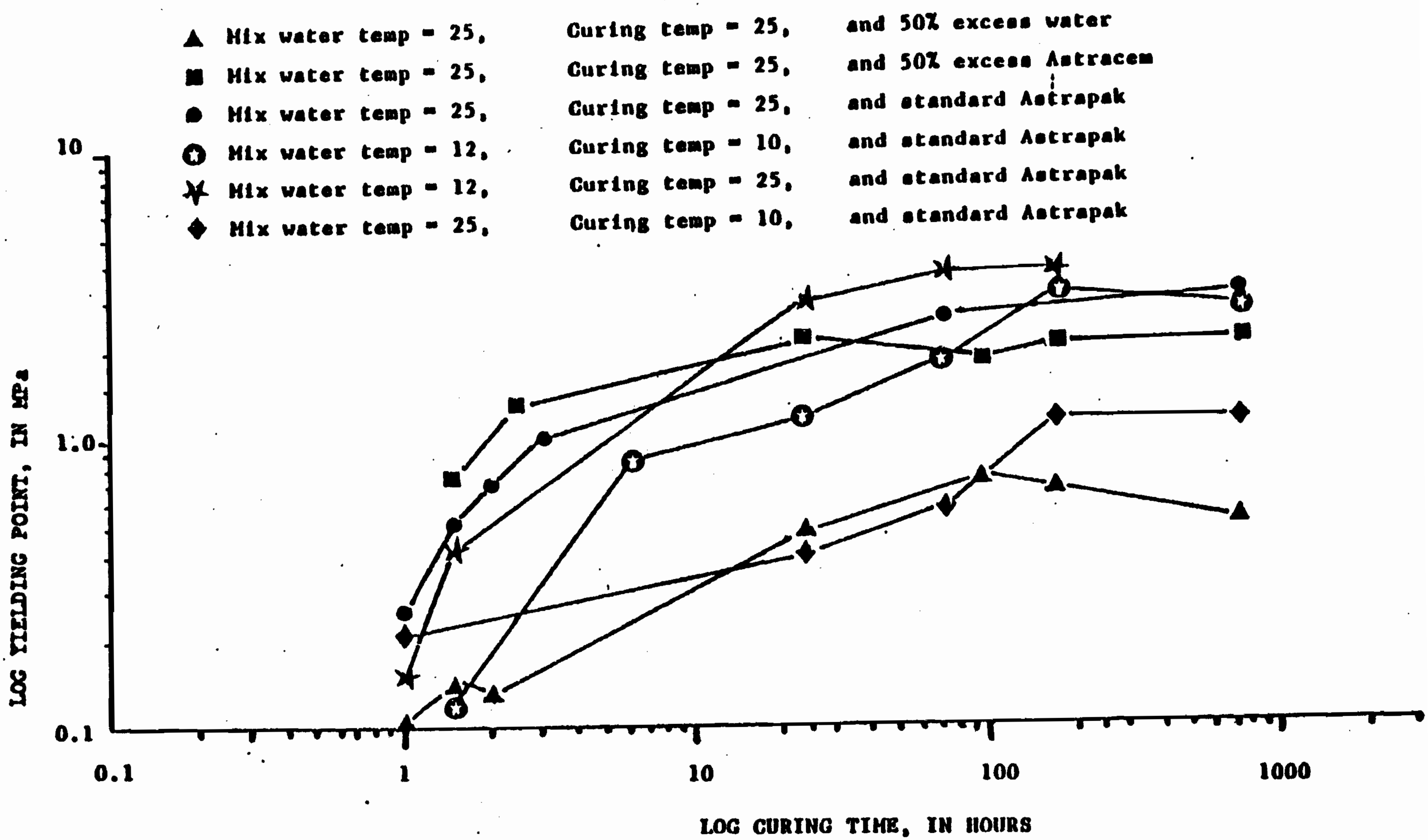


FIG. 37 _ COMPARISON OF YIELDING POINTS WITH CURING TIME FOR VARIOUS MIXTURES OF ASTRAPAK

The LM335AH is a percision, integrated circuit temperature sensor. The LM335AH, operating as a 2-terminal zener, has a breakdown voltage which is directly proportional to absolute temperature at +10 mV/degree Kelvin. This sensor was chosen over others because of its linear output. The operating range of this sensor (which is of Military Grade) is -10 to +100 degrees celcius. When calibrated at 25 degrees celcius, the LM335AH has typically less than 1 degree celcius error over a 100 degree range.

The actual circuit which was utilized was adapted from the National semiconductor's Linear Applications Handbook. The chosen circuit uses the LM335AH as the sensor, a LM308 percision operational amplifier, a LM336 percision 2.5 volt reference diode, a multi-turn 2.0k potentiometer for zeroing purposes and several other support components.

The entire circuit was layed out onto a copper-clad, epoxyglass board and etched to achieve the final printed circuit layout. Epoxy-glass boards were chosen rather than other cheaper material boards because of their higher durability and temperature stability.

After the printed circuit boards were completed, the part were placed on the board and were hand soldered. The completed boards were electrical noise rejection.

The temperature sensors were then mated to specific amplifier circuits and calibrated in degrees celcius. The outputs from the sensors/amplifiers were then patched into the data acquisition system for the final processing of voltage to an actual temperature figures.

Although the entire circuit was relatively simple in design and application, the resolution of the temperature sensors is greater than 0.1 degrees celcius. The circuit board and the temperature sensors are shown in Plate 8.

The temperature readings is taken automatically by a transducer temperature measuring device and recorded by data acquisition system. The acquired data was then specified to be processed by the Lotus 1-2-3 for tabulation, (Table 7), mathematical process and graph presentation (Figures 38-52).

4.4.4: Long Term Tests

The samples for this purpose were wrapped in plastic bags and placed the same way as noted in the section 9.2.3. However, the rate of deformation was kept at 0.00001 mm/sec (i.e. 0.00058 mm/min) over 3 days period. The axial and lateral strain development in the sample and the axial stress was noted. Average curve for the results is shown in Figure 53.

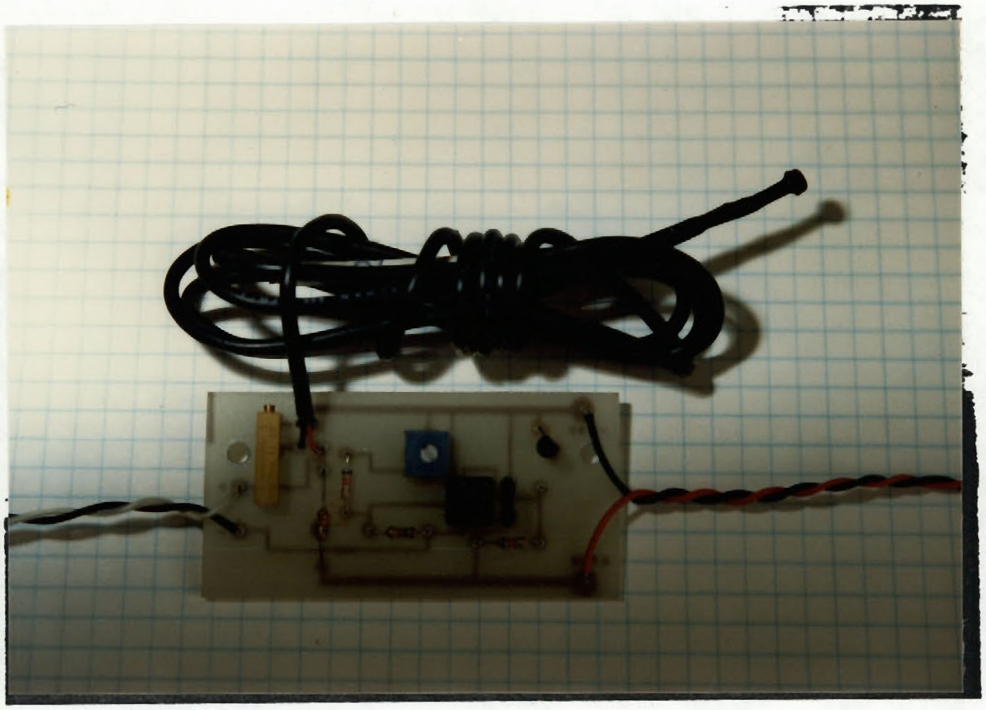
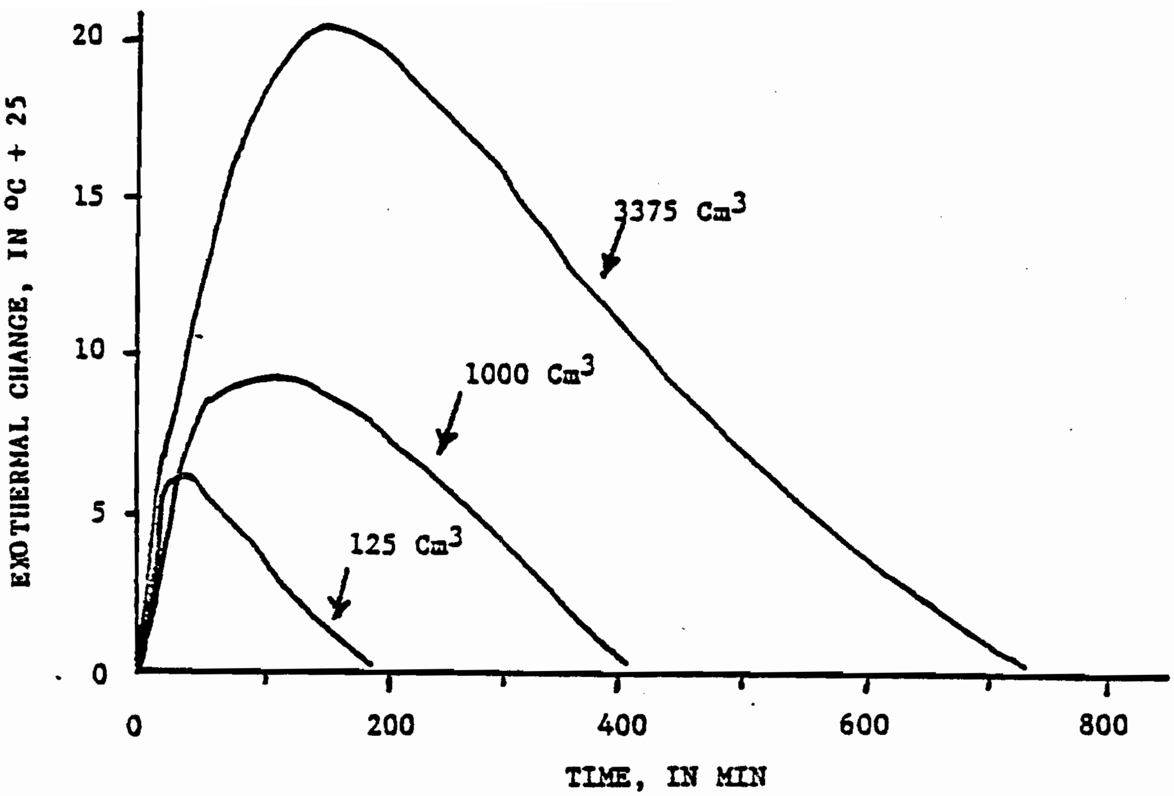


PLATE 8: TEMPERATURE MEASUREMENT ARRANGEMENT FOR THE ASTRAPAK DURING CURING.

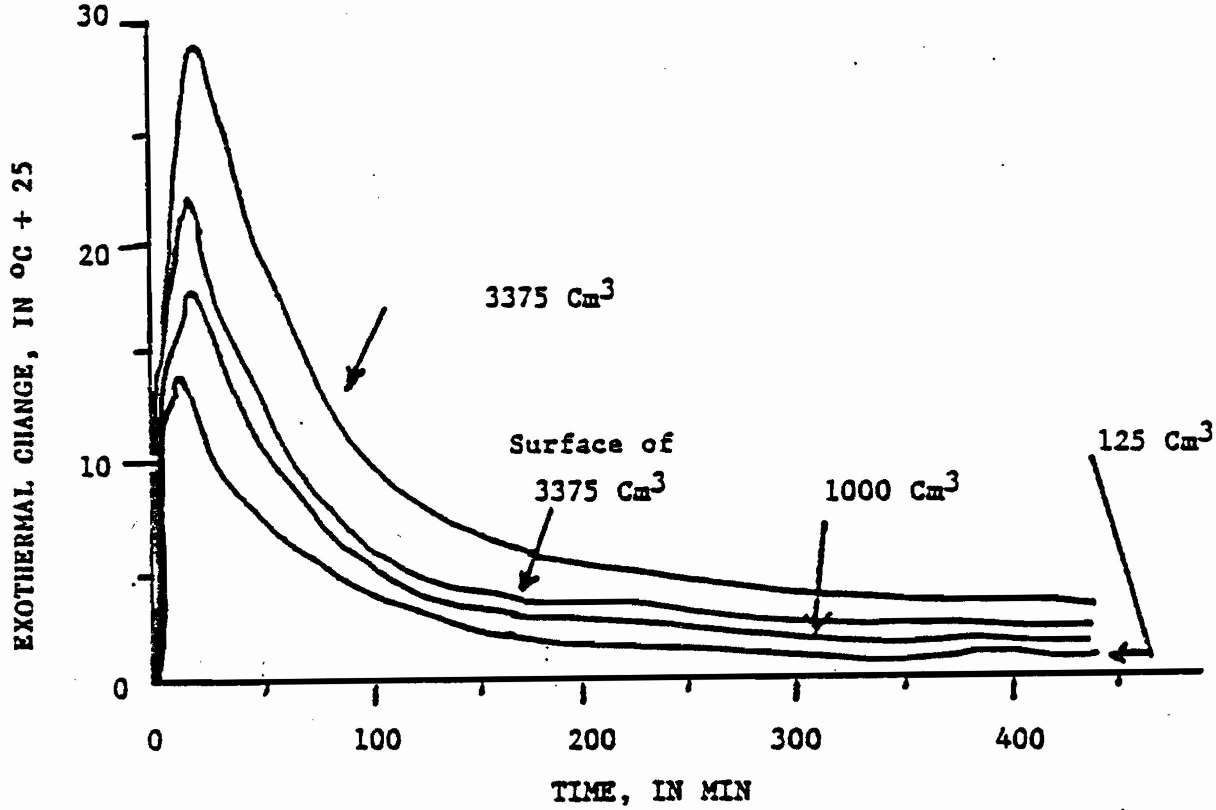
Table 7 - Effect of type and volume of Astrapak on its exothermic activity and evaluation of the relevant constants (Average of 5 Samples)

Item No.	Pack material mixture	Water temp. (°C)	Curing temp (°C)	Pack volume (v), in Cm^3	Curing time (t) (Hour)	Max. Exotherm (°C)	Total temperature change (T) in °C	m	n
				0	0	0	0	23.72	0.06
1	Standard Mix	12	10	125	1.4	6.2	31.2	(Standard error = 3.0%)	
2				1000	1.9	12.4	37.4		
3				3375	2.7	15.3	40.3		
				6,431,250			63.0		
4	Standard Mix	12	25	125	0.2	9.5	34.5	28.00	0.06
5				1000	0.3	17.1	42.1	(Standard error = 5.9%)	
6				3375	0.4	21.0	46.0		
				6,431,250			65.0		
7	Standard Mix	25	10	125	0.8	4.5	24.5	17.25	2.4%
8				1000	1.1	9.8	29.8	(Standard error = 4.2%)	
9				3375	1.7	14.5	34.5		
				6,431,250			59.0		
10	Standard Mix	25	25	125	0.9	10.0	35.0	29.48	0.06
11				1000	2.4	21.6	46.6	(Standard error = 9.2%)	
12				3375	2.8	24.6	49.5		
13				15625	4.4	30.8	55.8		
				6,431,250			69.0		
14	Astrapak + 50%	25	25	125	0.4	3.7	28.7	20.86	0.07
15	Excess Water			1000	1.8	9.6	34.6	(Standard error = 2.7%)	
16				3375	2.6	15.0	35.7		
				6,431,250			61.0		
17	Astrapak +50%	25	25	125	1.3	9.2	44.2	38.98	0.04
18	Excess Astracem			1000	1.6	25.8	50.8	(Standard error = 4.9%)	
19				3375	2.1	30.6	54.5		
				6,431,250			71.0		



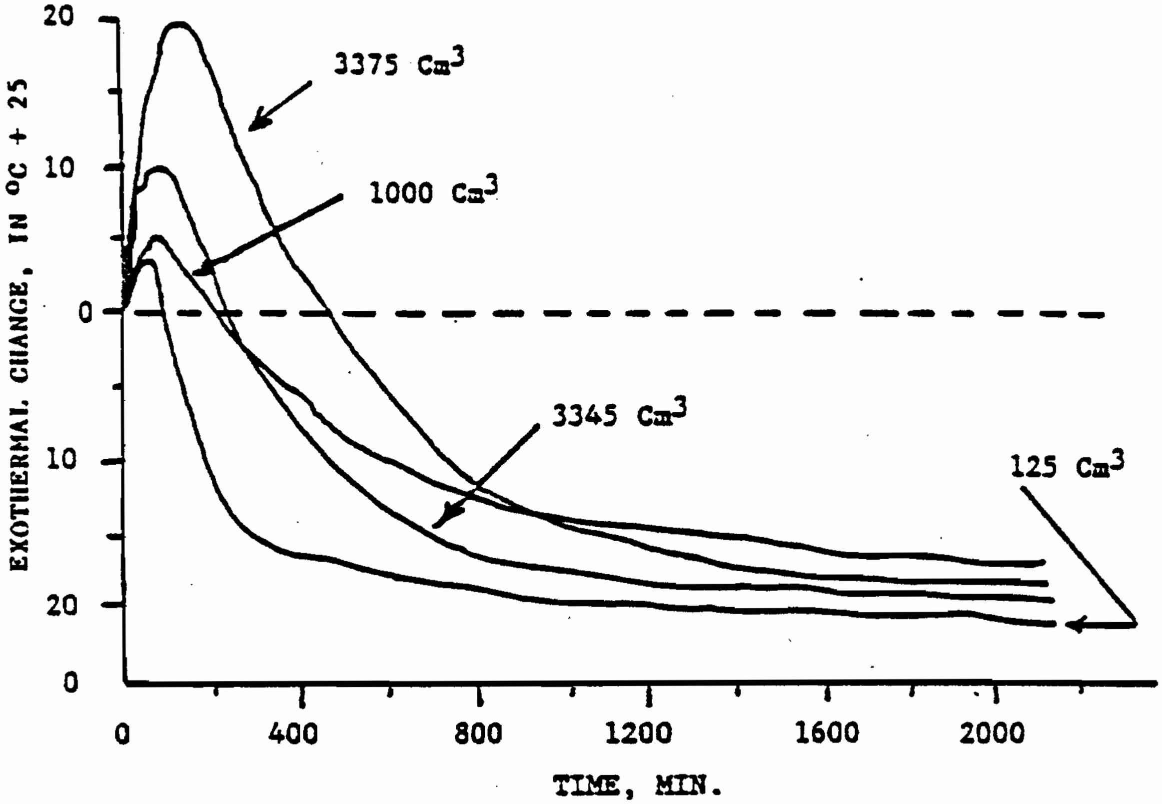
Mix water temp = 12°C, Curing temp = 10°C

FIG. 38 _ EFFECT OF PACK SIZE ON THE EXOTHERMIC ACTIVITY OF THE STANDARD ASTRAPAK



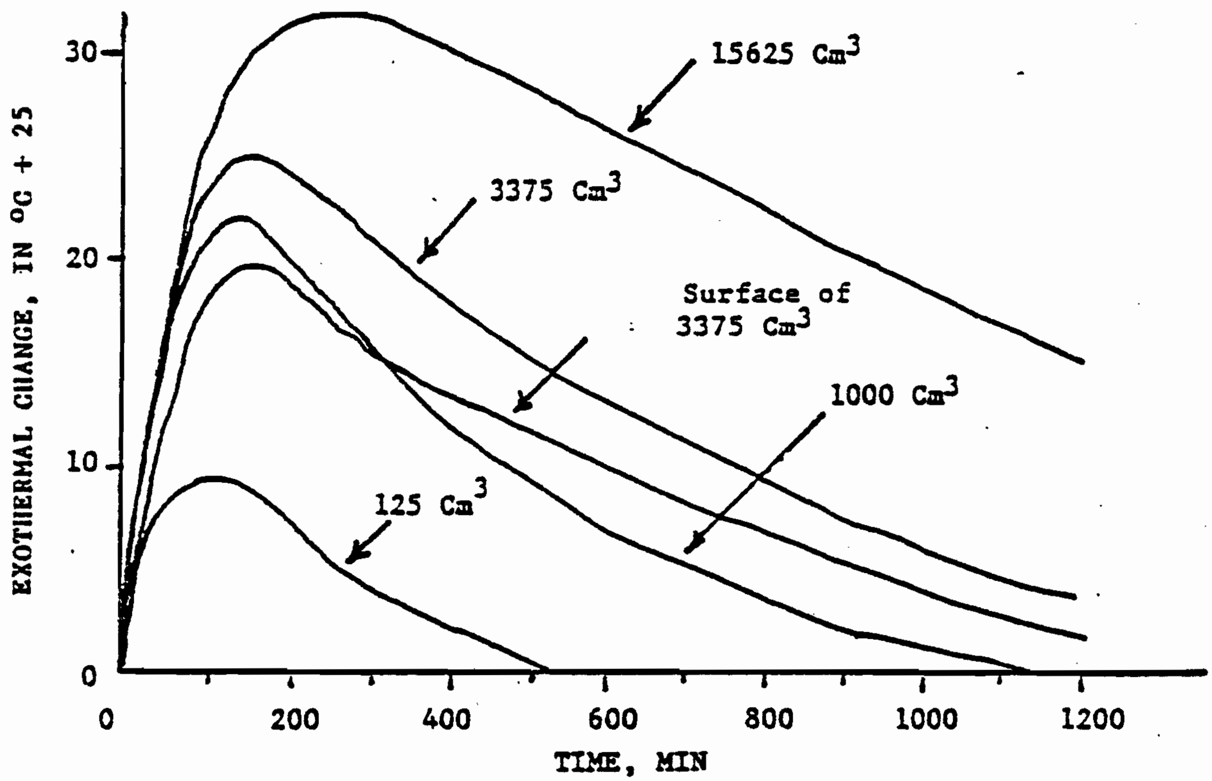
Mix water temp = 12°C, Curing temp = 25°C

FIG. 39 - EFFECT OF PACK SIZE ON THE EXOTHERMIC ACTIVITY OF STANDARD ASTRAPAK



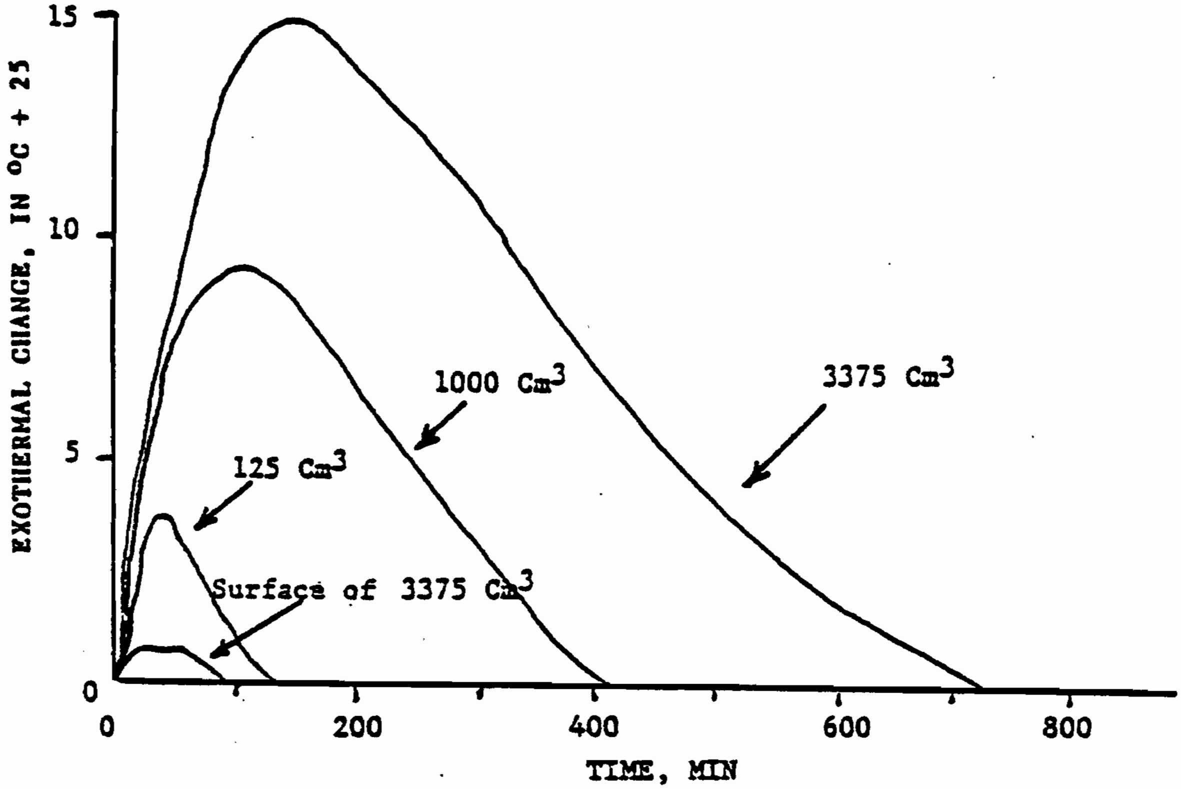
Mix water temp = 25°C, Curing temp = 10°C

FIG. 40 - EFFECT OF PACK SIZE ON THE EXOTHERMIC ACTIVITY OF THE STANDARD ASTRAPAK



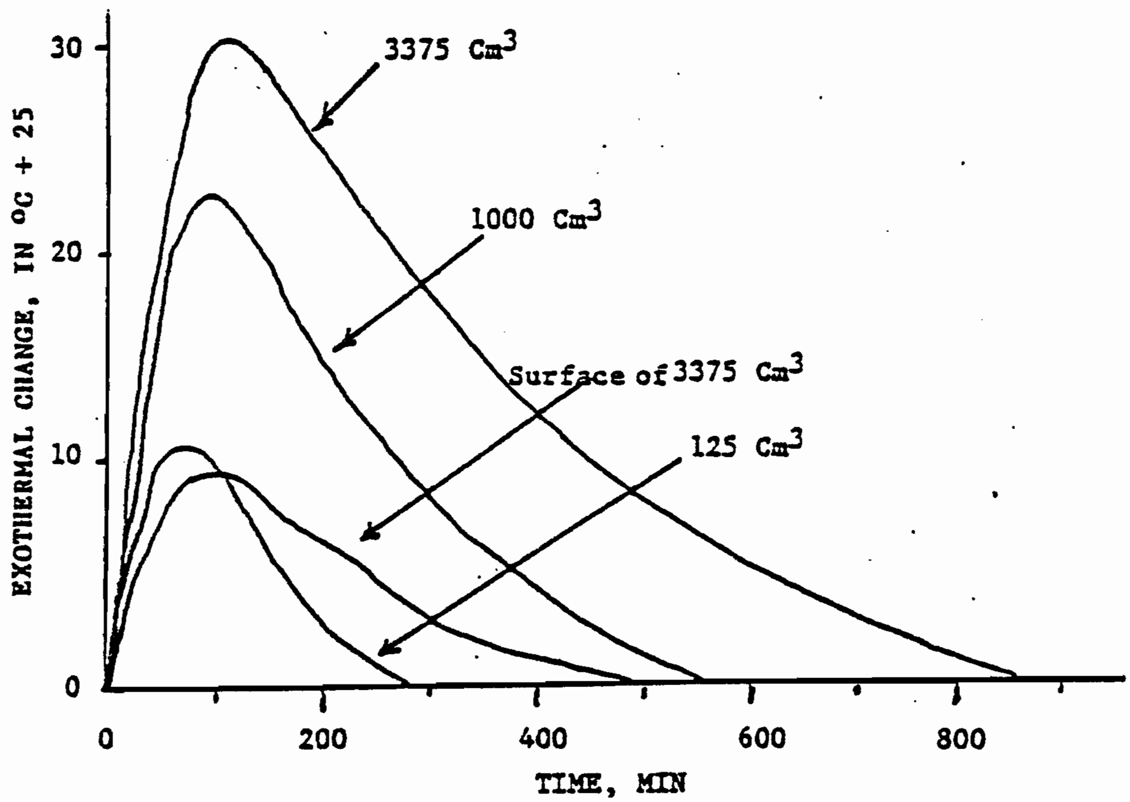
Mix water temp = 25°C, Curing temp = 25°C

FIG. 41 - EFFECT OF PACK SIZE ON THE EXOTHERMIC ACTIVITY OF THE STANDARD ASTRAPAK



Mix water temp = 25°C, Curing temp = 25°C

FIG. 42 - EFFECT OF PACK SIZE ON THE EXOTHERMIC ACTIVITY OF THE ASTRAPAK WITH 50% EXCESS WATER



Mix water temp = 25°C, Curing temp = 25°C

FIG. 43 - EFFECT OF SIZE ON THE EXOTHERMIC ACTIVITY OF THE ASTRAPAK WITH 50% EXCESS ASTRACEM

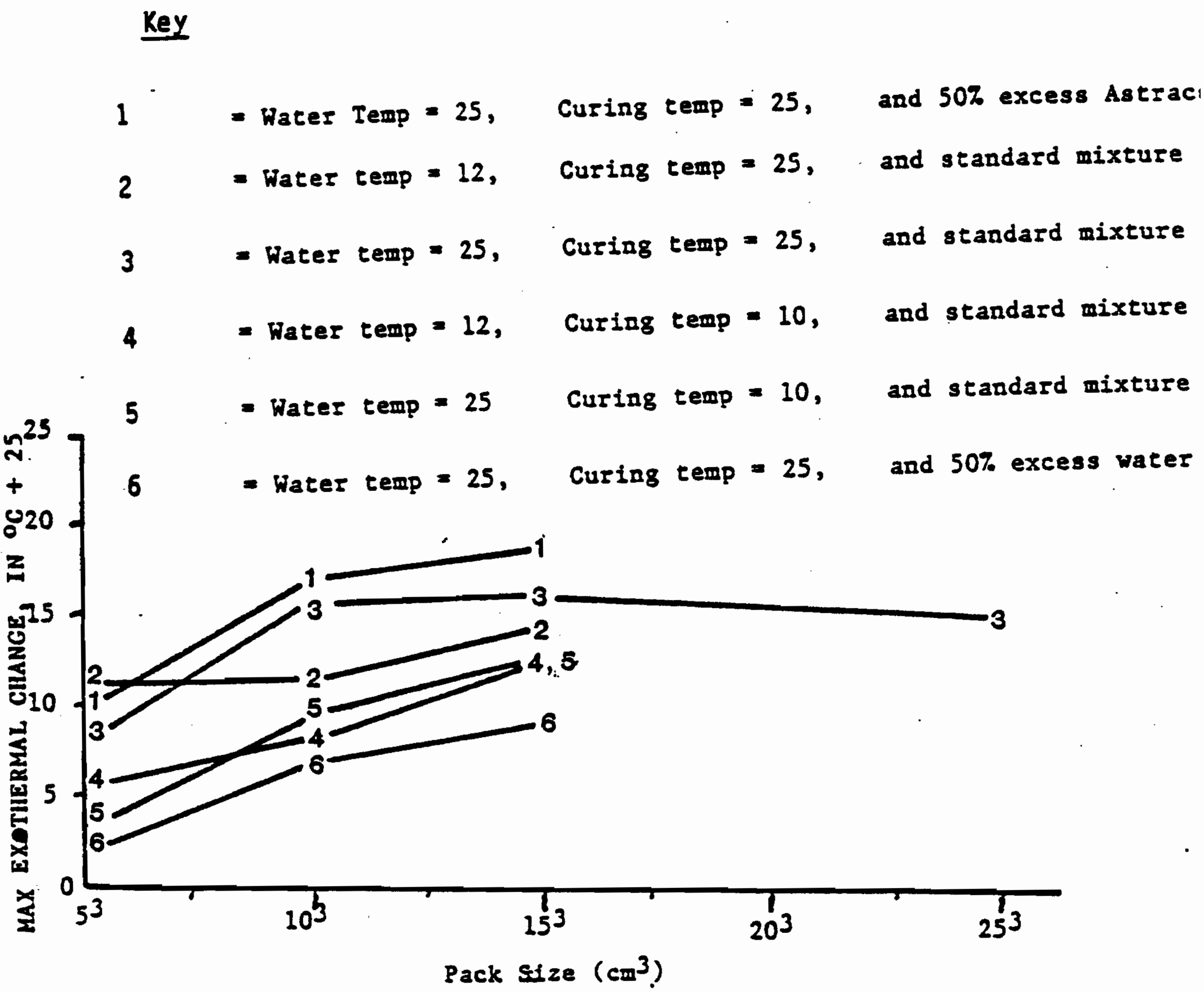


FIG. 44 - COMPARISON OF PACK.SIZE EFFECT ON THE MAX. EXOTHERMIC ACTIVITY OF THE VARIOUS MIXTURES OF THE ASTRAPAK AFTER ONE HOUR OF CURING

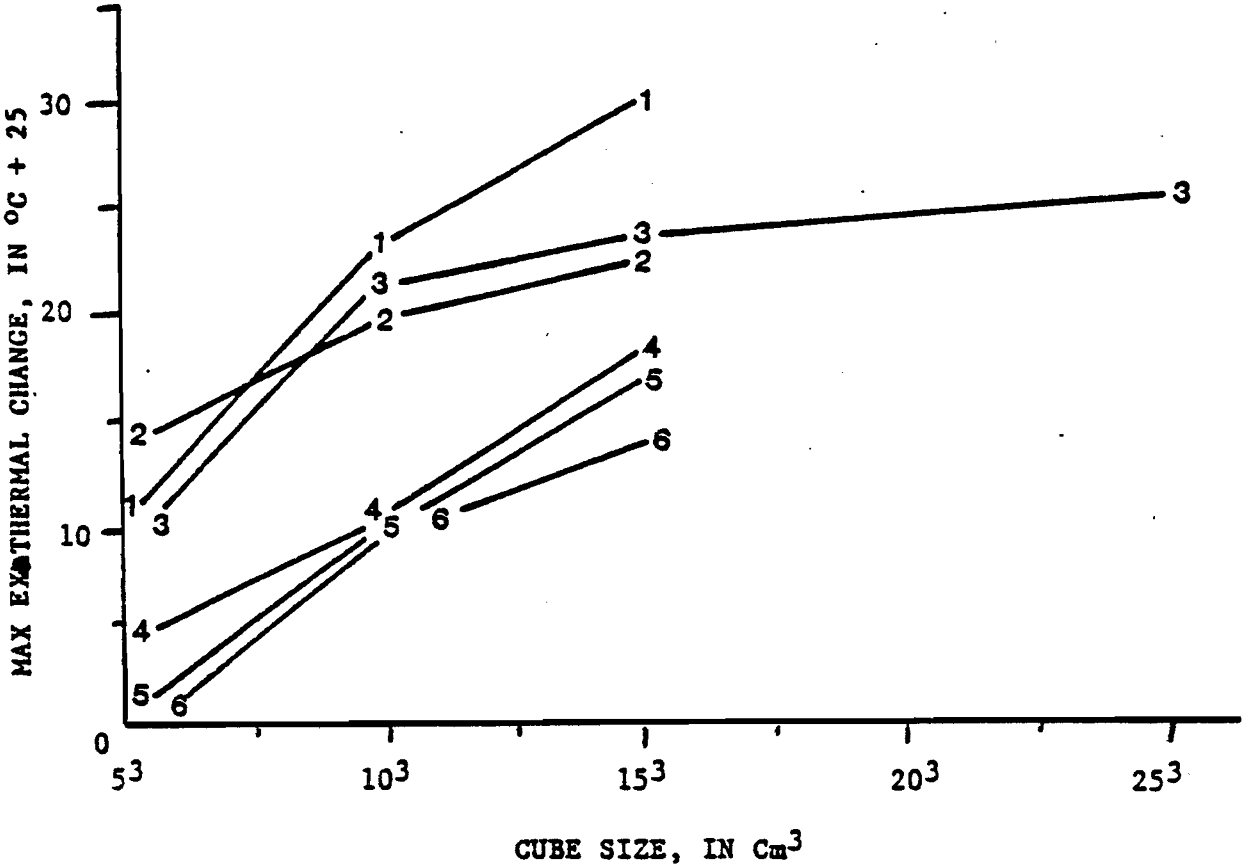


FIG. 45 - COMPARISON OF PACK SIZE EFFECT ON THE MAX. EXOTHERMIC ACTIVITY OF VARIOUS MIXTURES OF THE ASTRAPAK AFTER 1 1/2 HOUR OF CURING

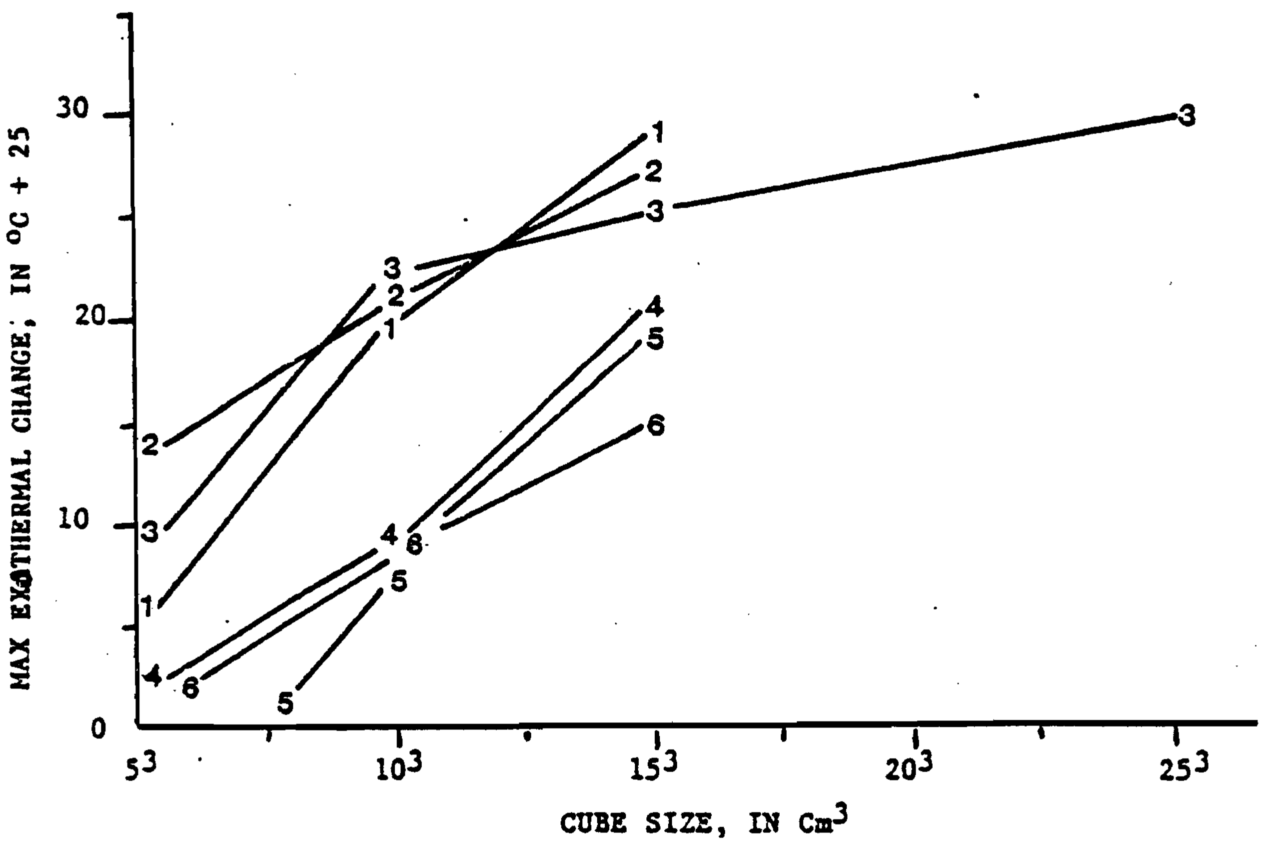


FIG. 46 - COMPARISON OF PACK SIZE EFFECT ON THE MAX. EXOTHERMIC ACTIVITY OF VARIOUS MIXTURES OS ASTRAPAK AFTER 2 1/2 HOURS OF CURING

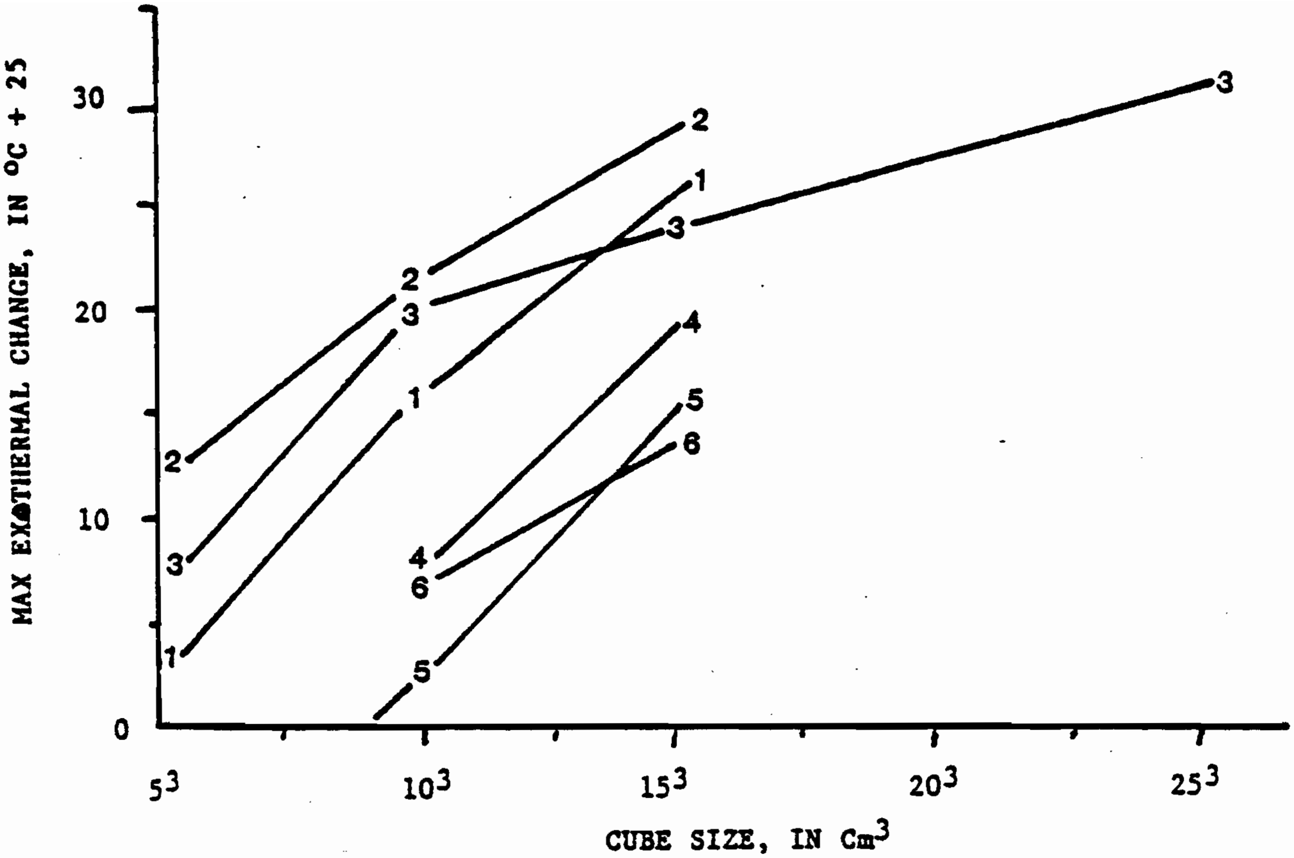


FIG. 47 - COMPARISON OF PACK SIZE EFFECT ON THE MAX. EXOTHERMIC ACTIVITY OF VARIOUS MIXTURES OF ASTRAPAK AFTER 4 HOURS OF CURING

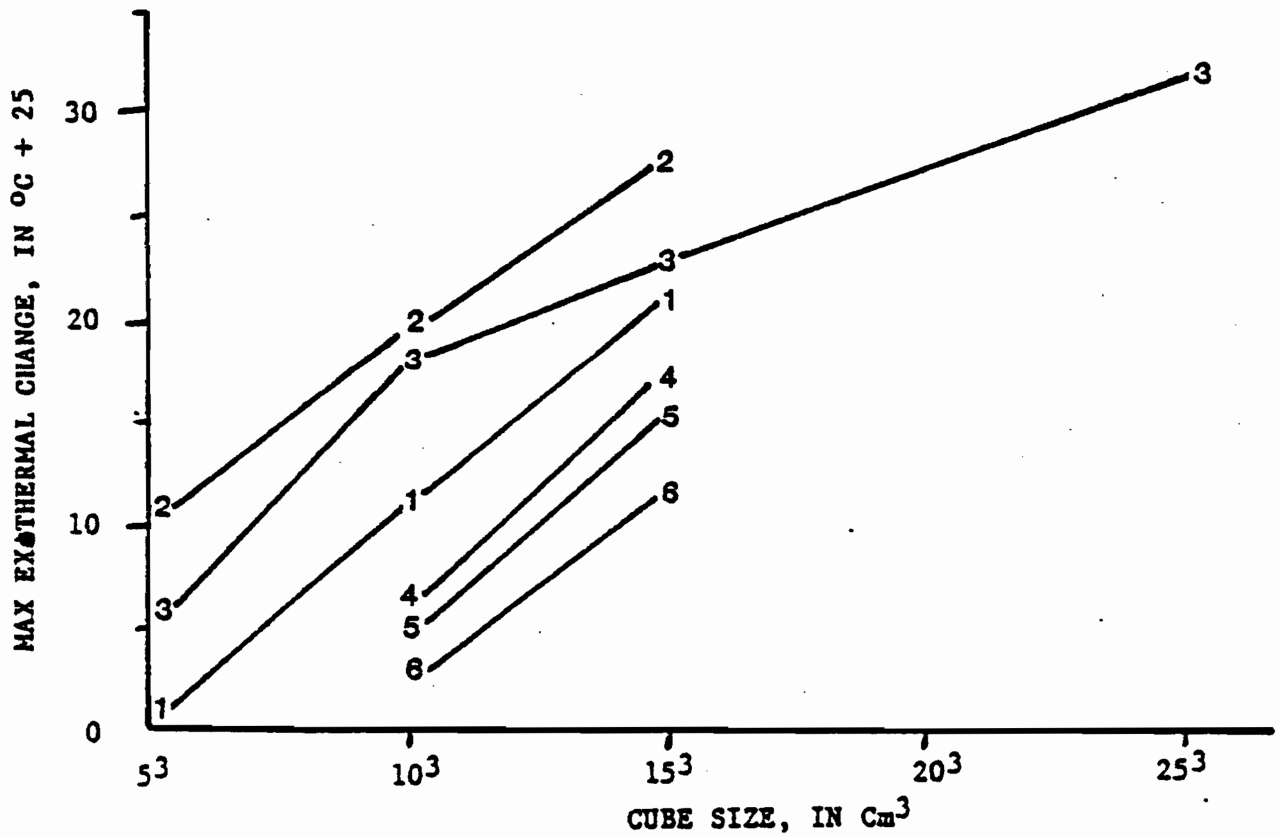


FIG.48 - COMPARISON OF PACK SIZE EFFECT ON THE MAX. EXOTHERMIC OF VARIOUS MIXTURES OF ASTRAPAK AFTER 3 HOURS OF CURING

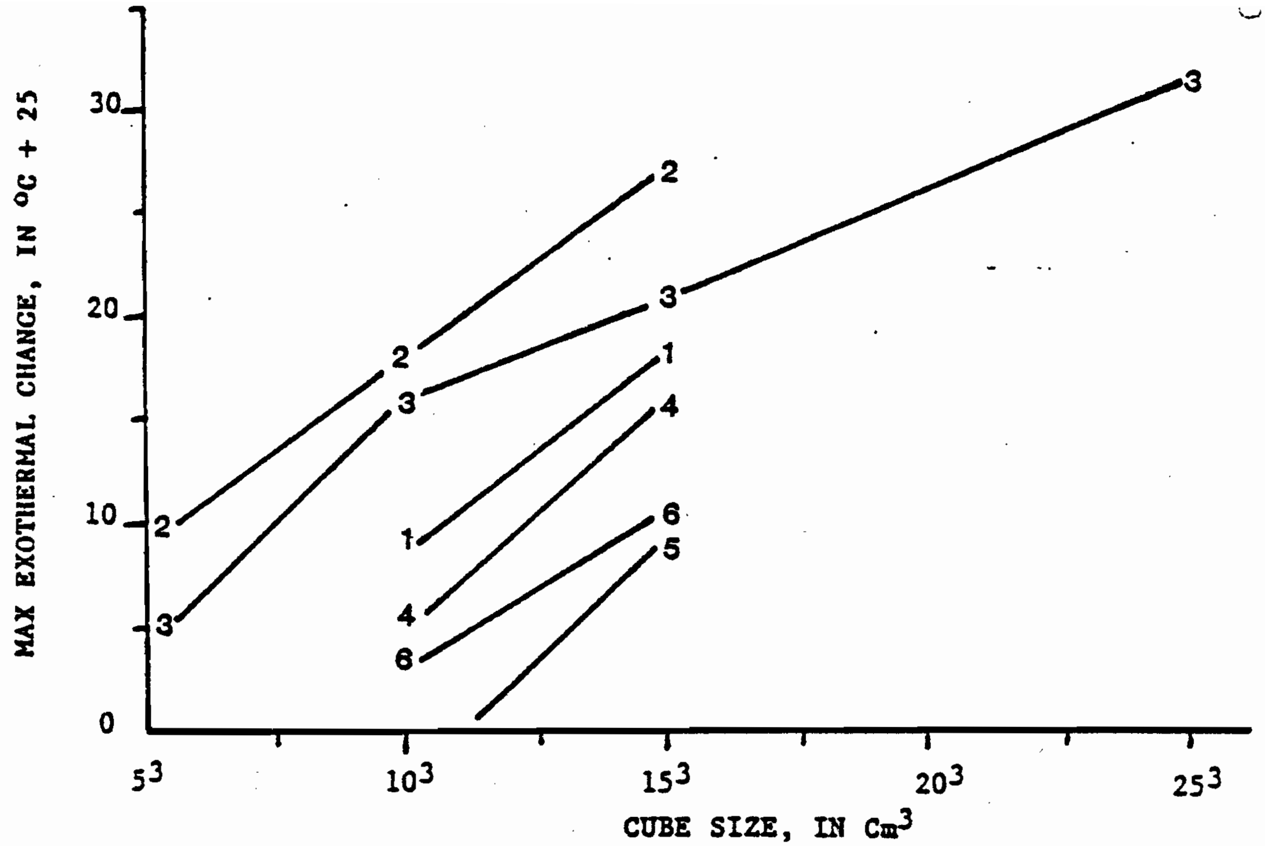


FIG. 49 - COMPARISON OF PACK SIZE EFFECT ON THE MAX. EXOTHERMIC ACTIVITY OF VARIOUS MIXTURES OF ASTRAPAK AFTER 6 1/2 HOURS OF CURING

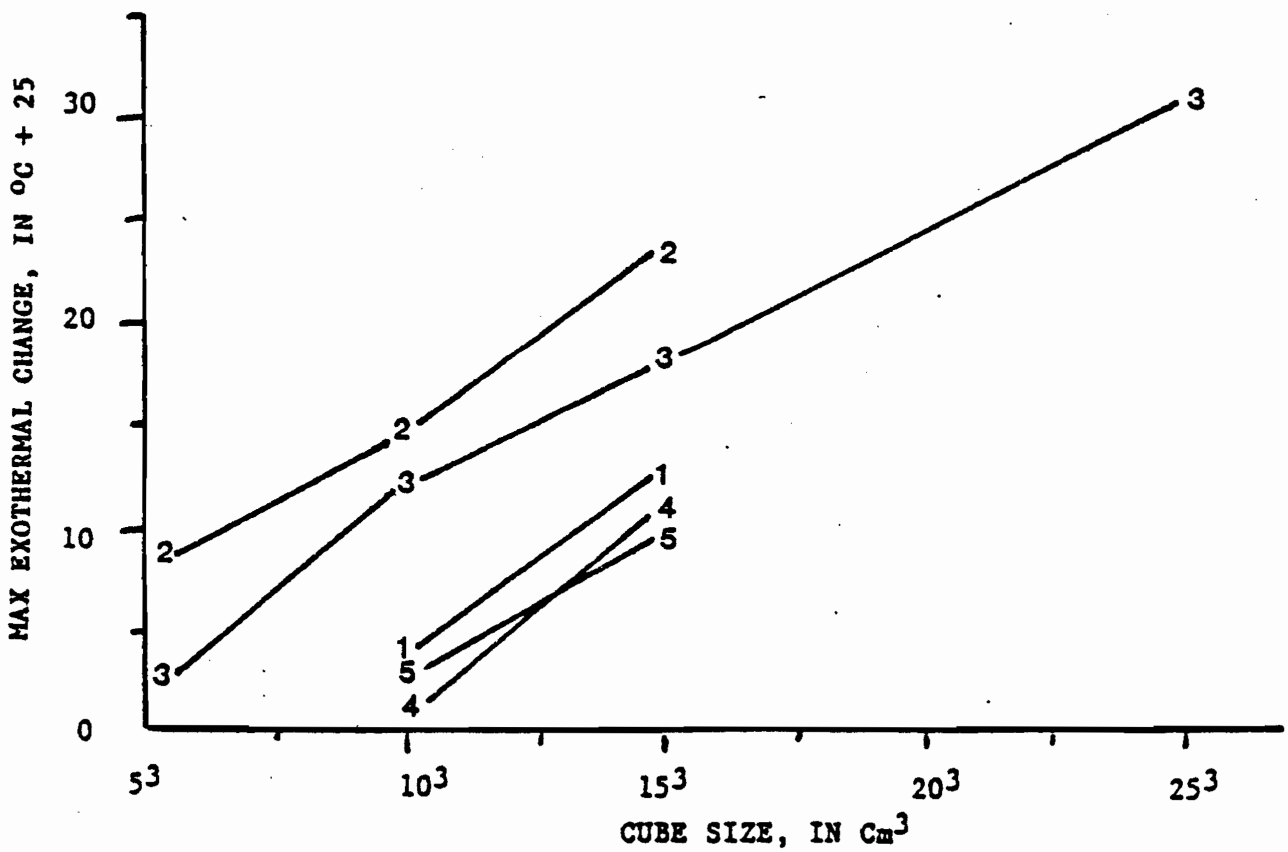


FIG. 50 - COMPARISON OF PACK SIZE EFFECT ON THE MAX. EXOTHERMIC ACTIVITY OF VARIOUS MIXTURES OF ASTRAPAK AFTER 5 HOURS OF CURING

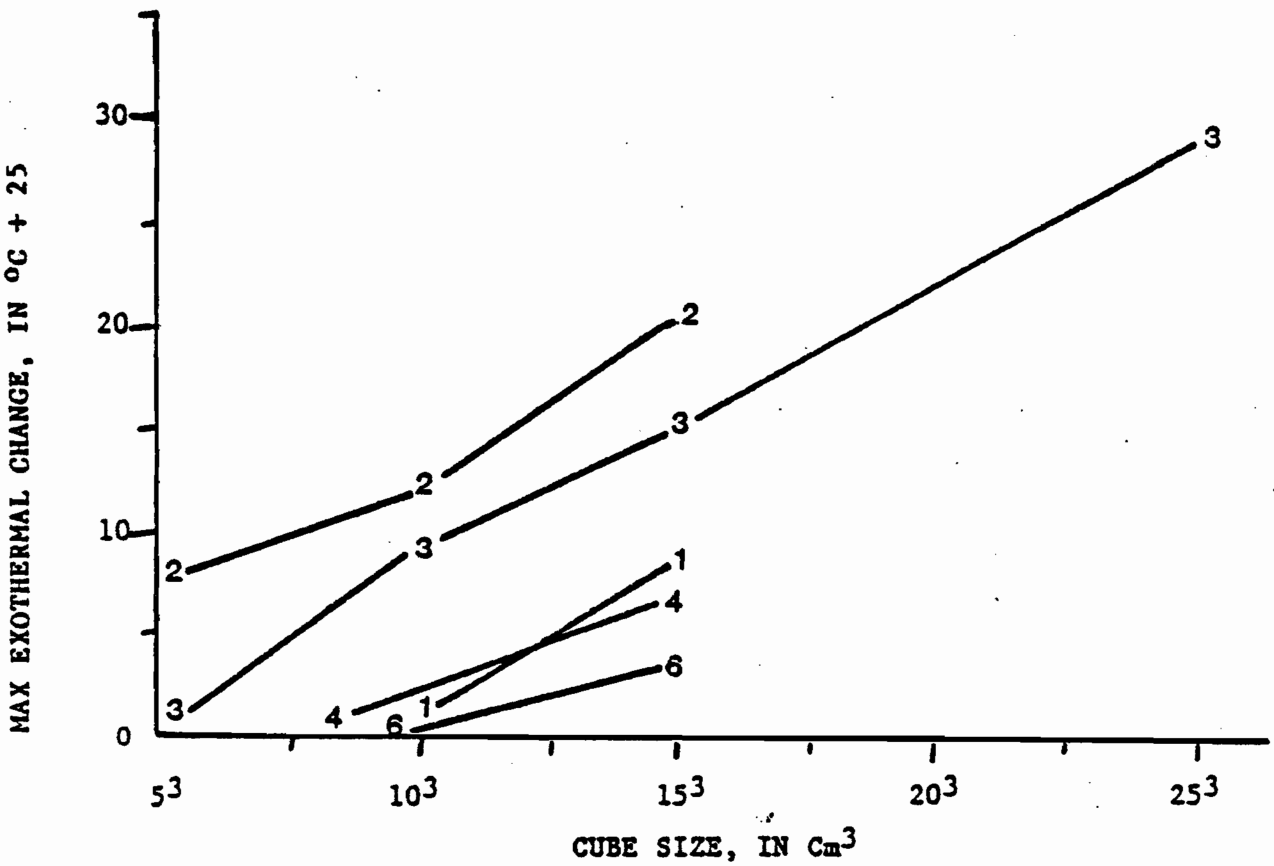


FIG. 51 - COMPARISON OF PACK SIZE EFFECT ON THE MAX. EXOTHERMIC ACTIVITY OF VARIOUS MIXTURES OF ASTRAPAK AFTER 8 1/4 HOURS OF CURING

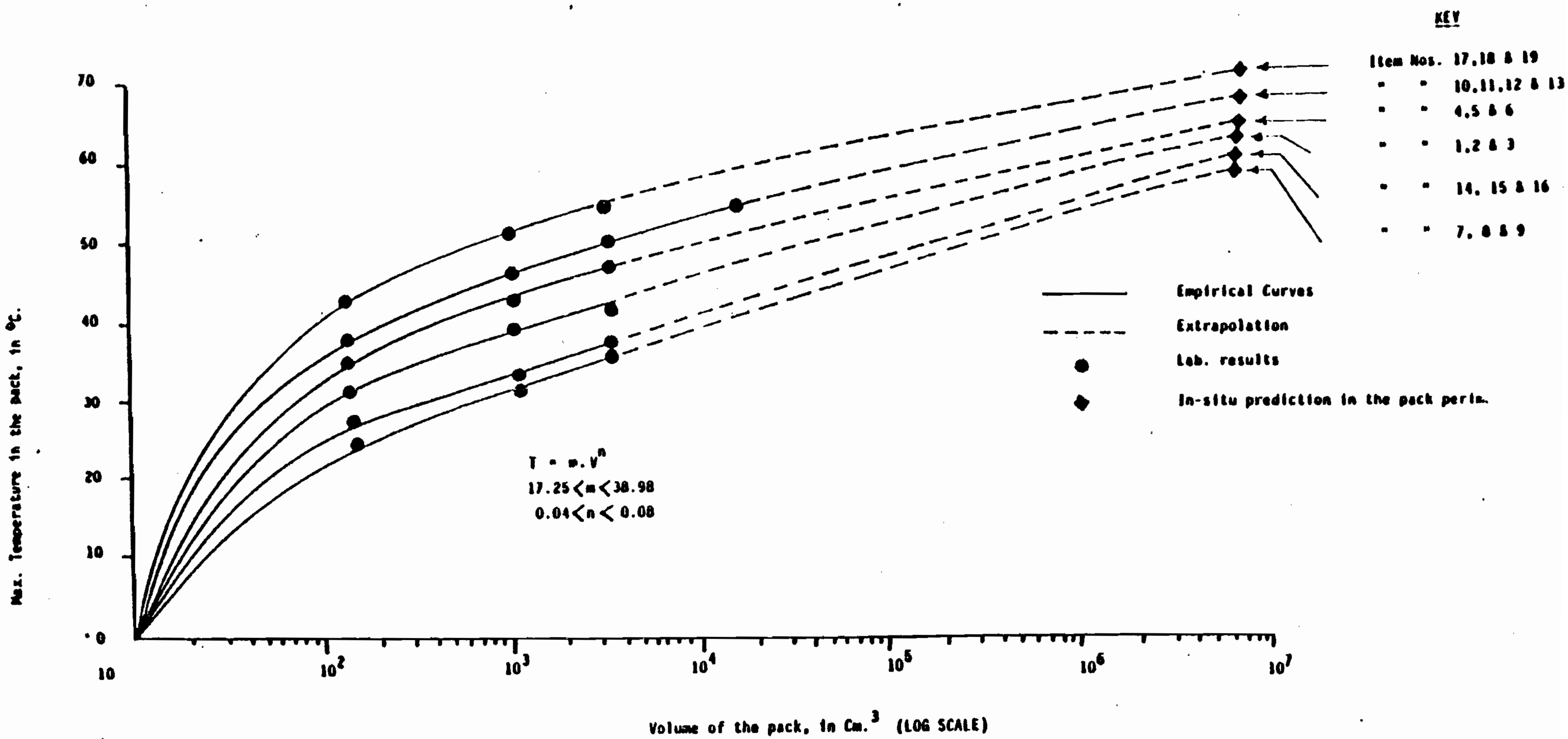


FIG. 52. EFFECT OF VOLUME ON THE THERMAL EVOLUTION DURING CURING FOR VARIOUS TYPES OF ASTRAPAK MIXTURE.

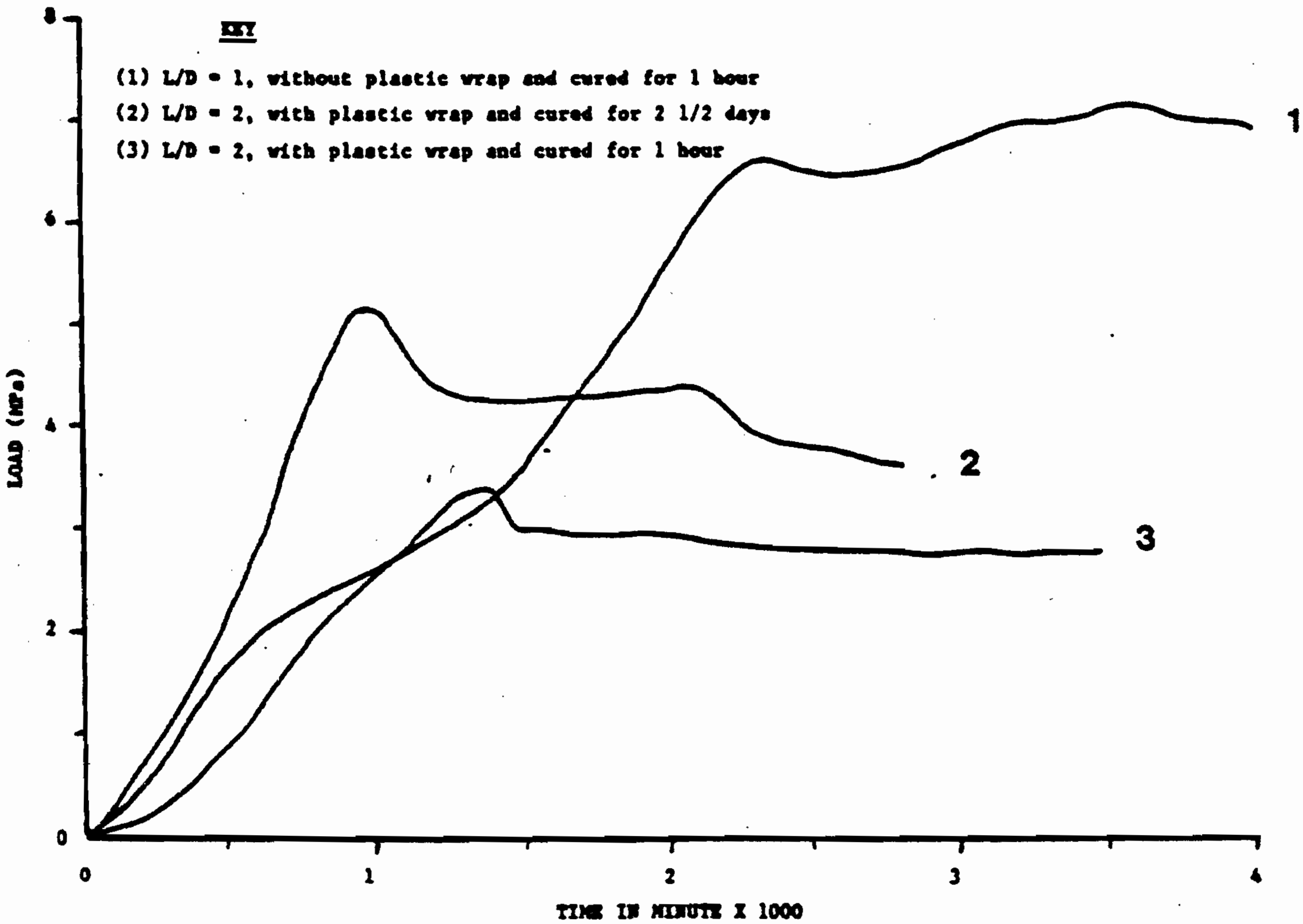


FIG. 53. LONG TERM BEHAVIOUR OF VARIOUS ASTRAPAK SAMPLES OF CONSTANT RATE OF DISPLACEMENT (0.0006 mm 1 min).

CHAPTER 5

CHAPTER 5

ANALYSIS OF THE ASTRAPAK TEST RESULTS

5.1 : CHANGE OF DENSITY (δ) WITH CURING TIME (t)

In this test change of density in the Astropack samples was considered to be due to reduction of water in the sample. This was due to 2 phenomena:

(a) Creation of heat due to chemical action in the mixture during curing which tend to vaperize the water and moisture in the sample. The vapor is then directed towards the surface of the sample.

(b) Exchange of water and vapour between the sample and its surroundings. In this context, if the environment surrounding the sample is saturated with moisture and/or the percent moisture of the sample is less than that of the surrounding, then the rate of transfer of moisture from sample to the surrounding environment is reduced proportionally. This general trend was seen in various types of Astrapack cured in the room temperature of 25^{o}C (Figure 27). However, in the 10^{o}C temperature environment, the samples have shown constant density after 24 hours of curing time, which was due to the part (b) described above. As can be seen from Figure 22, the rate of density change was markedly different after 24 hours of curing time for all the sample types. Hence the first 24 hours is a crutial curing time to make a good Astrapak with least flows . Lower water temperature in the mix and/or excess water had an adverse effect on the density and rate of curing. In general, the mix with 50%

extra Astracem had the highest density and the standard mix cured at 25^{o}C had the lowest density throughout the test. The rate of density change was gradually declined with increase in the curing time.

5.2: CHANGE IN THE ULTRASONIC PULSE VELOCITY (V_p) IN THE SAMPLES WITH CURING TIME (t)

There was a marked increase in the V_p with time upto 2 to 3 hours of curing period. After that the rate of increase in the V_p was gradually slower (Figure 23). The results show that the samples made of standard mix and cured at 25^{o}C exhibited higher value of V_p. Since the value of V_p is proportional to the dynamic modulus of elasticity of the pack material, it can be expected that the packs made of standard mix and left at a higher temperature environment would be stronger and resistive to the dynamic loading than the pack made of higher percentage of water and/or low water temperature and curing environment. However, after 45 to 72 hours of curing time, the measured V_p of the samples started to decrease. It is believed that this reverse phenomena to be due to the end or marked decrease in the chemical activity of the Astrapak sample material during the curing. This causes stopage or at least a drastic decrease in the production of heat undergoing curing which, in turn, results the samples, especially the central core of the samples, to become as cold as the environment surrounding it. Hence, the molecules and grains constitutes of the samples become contracted forming micro-cracks and voids inside the material. Formation of such micro-discontinuities can be the principal cause of low V_P propagation throughout the pack material. Such phenomena for the samples prepared and cured at water and room temperature of 25°C occurred in 45 to 48 hours of curing time. Whereas for the samples prepared at temperature ranges of 10 to 12°C occurred at a later curing time of 70 to 72 hrs (Figure 24).

5.3: FACTORS INFLUENCING THE STATIC MODULUS OF ELASTICITY (E) OF THE ASTRAPACK

A general increase in the E-value of all the sample types under stress was noted with increase in the curing time (Figure 25). However, the rate was decreased by 60% on average when 50% excess water was introduced to the mixture, and there was a 70% decrease in the E-development rate when the curing temperature was decreased by 17%. Typical curves of the modulus of elasticity vs. compressive strength of astrapak having different mixture, water temperature and curing temperature is shown in Figures 26-30. It can be seen that the pack exhibit elasto-plastic behaviour, except when 50% excess Astracem is added to the standard mixture at water and curing temperature of 25°C, when the behaviour tends towards elastic, in short duration test.

5.4: CHANGE IN UNCONFINED COMPRESSIVE STRENGTH OF THE ASTRAPAK (σ'_c) WITH CURING TIME

The strength in all types of samples tested increased relatively rapid by the curing time during the first day. After this period the rate of strengthening was in decreasing order (Figure 31). In two cases where 50% excess water and also where water at 50% lower temperature was used, the strength tended to decreased after 4 days by reaching a peak of 0.7 and 4 MPa, respectively.

In all cases the strength development vs. curing time for the Astrapak was below the manufacturer's suggestion.

The samples with 50% excess Astracem reached σ_C = 0.6 MPa within an hour. Whereas the samples with 50% excess water content reached σ_C = 0.12 MPa in one hour of curing time. Lower water and curing temperatures had an adverse effect on the σ_C of the Astrapak, as is shown in Figures 32-37. Yielding points of the samples under unconfined compressive stress has shown a similar characteristics to that method for the σ_C as is shown in Figure 42.

5.5: EFFECT OF THE SAMPLE SIZE ON THE TEMPERATURE CHANGES DURING CURING

For all the samples, the larger the dimensions of the pack material, the higher was the temperature evolved during their curing. This effect was observed underground to such extent that it would interfere with the ventilation and working environment of the section where the pack was employed. The extent of the effect was thought to accelerate the spontaneous combustion of the coal in the vicinity. Figures 39 to 48 show the trend of exothermic activity of Astrapk samples and its relation with sample size. The maximum temperature in the molded samples are reached within one to three hours of their placement. After which the total temperature gradually drops towards the ambient. The temperature measurements in the above noted graphs was measured from the ambient value of 25°C upwards. Therefore, all the values on the curves should be added to 25°C for total temperature evaluation. The general rate of max. temperature increase with size is noted in Table 7 and shown in Figure 51 and expressed mathematically as follows:

$$T = m.V^n$$

where:

T = Max. internal temperature of curing Astrapak, in °C.

m= Constant related to the mix. water and curing, or ambient, temperatures

Between 12.4 to 30.0. For the standard Astrapak at low temperatures it averages to about 12.4 to 20.9.

n = Constant related to the free sides of the pack for heat transfer between the pack and the mine air and the pack dimensions.

Between 0.08 to 0.12. For the standard Astrapak at low temepratures it averages to about 0.10 to 0.13.

Introduction of 50% excess water and 50% excess Astracem caused lowest and highest temperature at any incremental curing time, respectively. This behaviour is evident from Figures 45 to 52, at various increments of time.

Low water temperature and curing temperature also caused lower rate of temperature increase with size which in turn increased the curing time, Figures 40 to 52. However, at 11 of the above noted conditions and mixture preparations the size effect was directly but non-linearly proportional to the max. temperature creation during the curing.

5.6 : LONG TERM EFFECT OF THE ASTRAPAK ON ITS UNCONFINED COMPRESSIVE STRENGTH (σ_c)

The aim was to improve understanding of the Astrapak behaviour under constant rate of displacement, underground. For this reason a displacement rate of 0.0006 mm/min was chosen. This provided an average rate of stress equivalent to 0.0012 MPa/min upto failure under unconfined condition.

Three different categories of standard mix made at water and curing temperatures of 25^{o}C was tested. The test results are shown in Figure 53. It appears that packs with lower L/D ratio exhibit higher long term σ_C. Also longer initial curing before application of the load on the pack will result to a higher failure strength. This has a practical application for in situ mixing, pouring and setting time before the strata load is acted on the packs.

It should be noted that after the failure, the pack still does have load resistance to collapse much the same way as a pillar would have underground. This mechanism can be clearly seen from Figure 53.

5.7: EFFECT OF WATER ON THE COMPRESSIVE STRENGTH (U.C.S.) OF ASTRAPAK

As noted previously, ratio of the Astrapak constituents for the standard mix was:

Astrabent : Astracem: Water = 1 : 1 : 5.01

Increase in the water content causes decrease in the U.C.S. of the pack, proportionately. Therefore, a decrease in the water content would increase the U.C.S. of the pack.

It was found that the following ratio to provide the optimum compressive strength of the order of 2 to 4 times higher than the standard mix, depending on the curing time. These strengths are much higher than needed in the pack for coal measures.

Astrabent: Astracem: Water = 1 : 1 : 2.9

Test results for the latter mix is noted in Table 8 and shown in Figures 54 to 56.

Advantages of the later mix ratio are as follows:

(a) Various mixes are pumpable by long piping to the pack site as the standard mix is.

(b) The mix does not gel so quickly. Therefore placing of the final mix is practical.

(C) The reduction in volume of the Astrapak between the standard mix and the latter mix can be overcome by addition of mine tailing and/or waste rocks of -6 mm in size in the form of slurry to the Astrabent mix. This will give extra volume to the pack while decrease the U.C.S. of the Astrapak to a lower pre-selected

Table 8 - Physical and mechanical properties for the Astrapaks with 58% of the standard water.

Properties	Temperature (°C)	Curing Time before Test				
		1 Hr.	5 Hrs.	1 Day	1 Week	3 Weeks
Density (gr/cm^3)	WT = 24 CT = 24	1.40	1.42	1.39	1.40	1.44
	WT = 12 CT = 24	1.41	1.41	-	1.41	-
	WT = 12 CT = 12	1.41	1.40	1.40	1.42	1.41
Ultrasonic Velocity (mm/μsec)	WT = 24 CT = 24	1.73	1.71	1.78	1.90	1.91
	WT = 12 CT = 24	1.64	1.80	-	1.99	-
	WT = 12 CT = 12	1.67	1.77	1.80	1.90	2.02
Unconfined Compressive Strength (MPa)	WT = 24 CT = 24	2.23	3.06	5.19	7.77	8.35
	WT = 12 CT = 24	1.21	3.33	-	9.75	-
	WT = 12 CT = 12	1.29	3.58	3.84	6.79	10.11
Modulus of Elasticity (MPa)	WT = 24 CT = 24	426.9	199.1	370.7	431.7	597.7
	WT = 12 CT = 24	232.7	320.2	-	870.5	-
	WT = 12 CT = 12	215.0	596.7	640.0	772.3	902.7

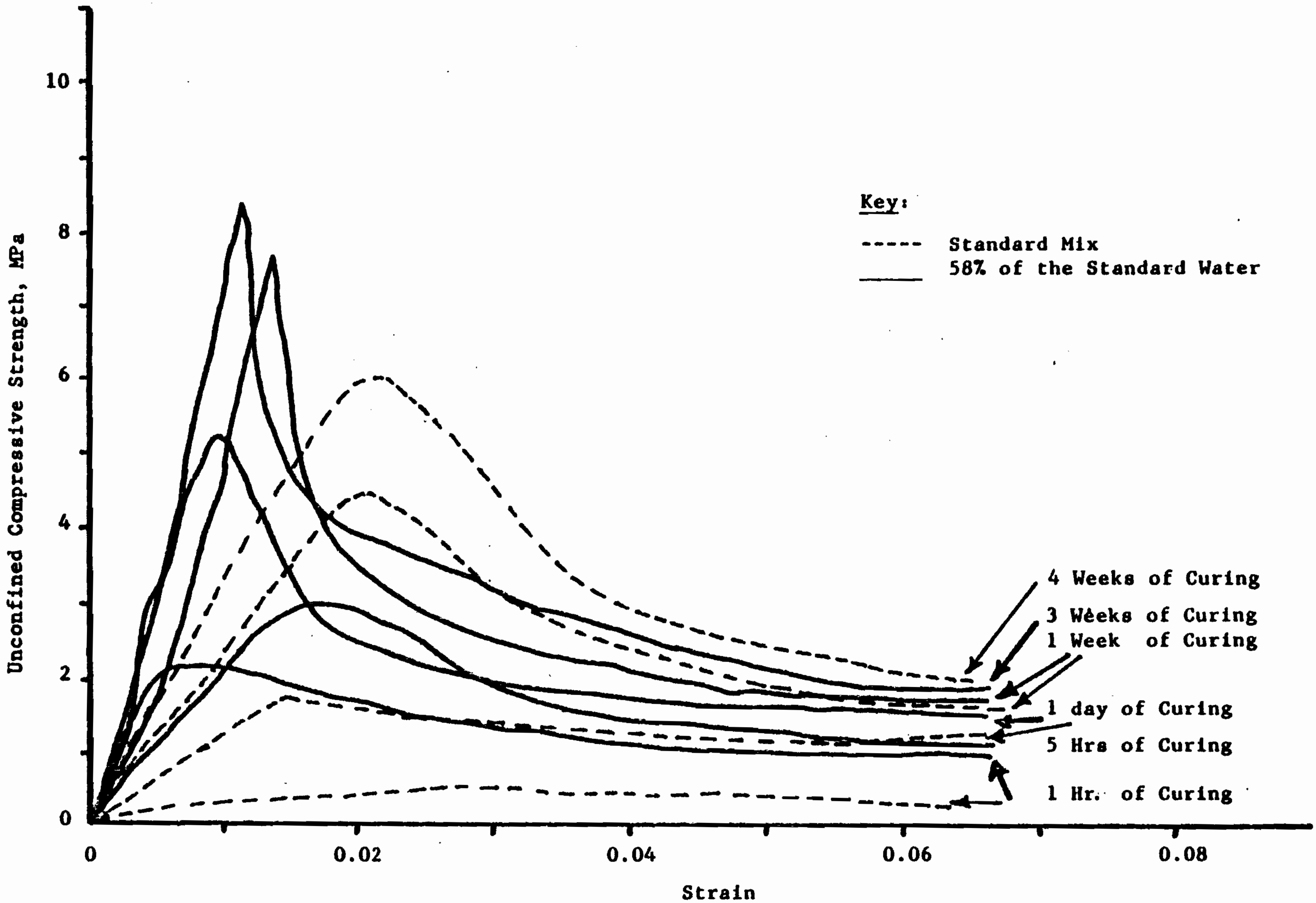


FIG. 54 COMPARISON OF STRESS/STRAIN CURVES FOR THE ASTRAPAKS WITH 58% OF THE STANDARD WATER MADE AT W.T. = C.T. = 24°C

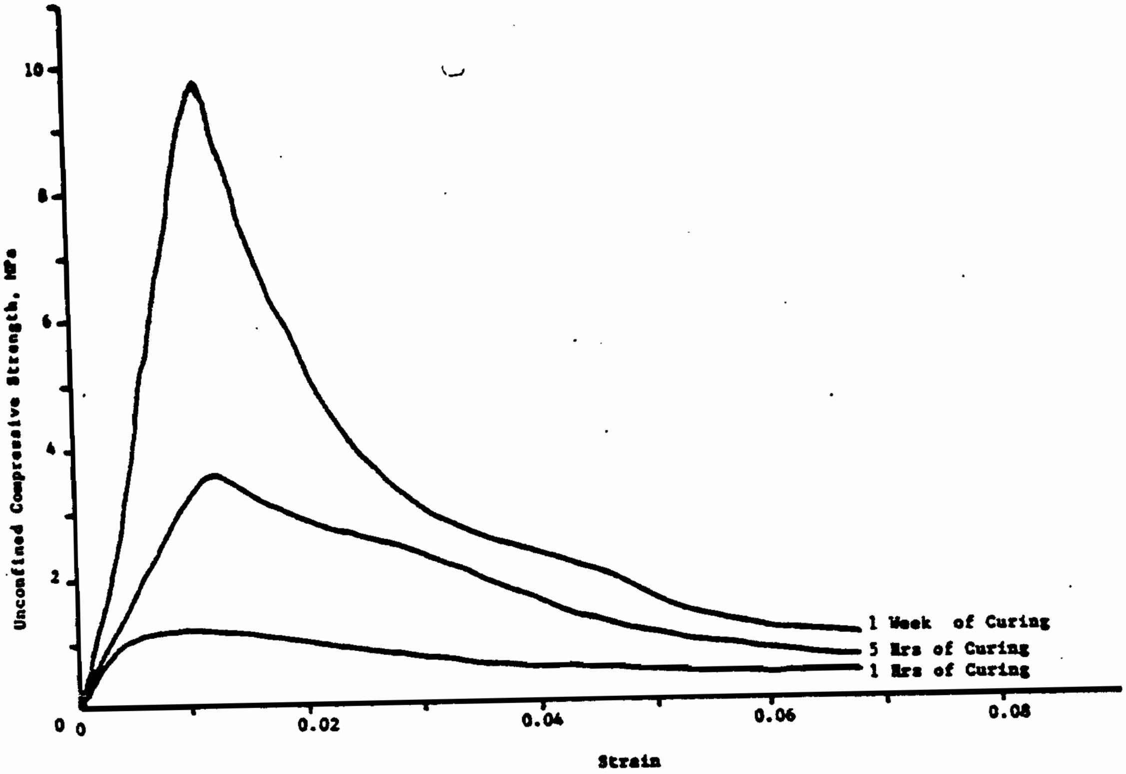


FIG. 55. COMPARISON OF STRESS/STRAIN CURVES FOR THE ASTRAPAKS WITH 58% OF THE STANDARD WATER MADE AT W.T.= 12^{0}C AND C.T.= 24^{0}C.

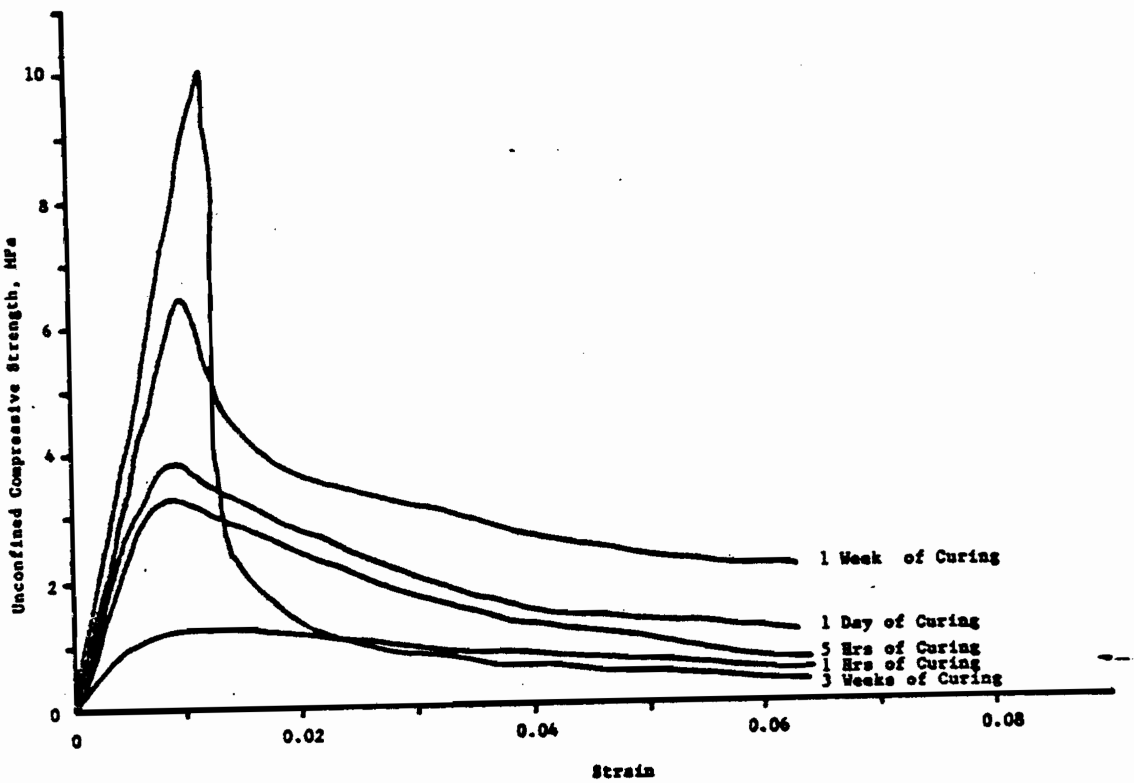


FIG. 56. COMPARISON OF STRESS/STRAIN CURVES FOR THE ASTRAPAKS WITH 58% OF THE STANDARD WATER MADE AT W.T.= C.T.= 12^{0}C.

value by proportioning the ratio of the mixes. Work is on hand to formulate appropriate and economically feasible ratios for the latter mix. In this way some of the waste rocks can be utilized and the transportation cost to move them out of the mine to the waste dump reduced.

The disadvantage of utilizing the waste rock and or the mine tailings as the pack filling material is that an additional cost may be incurred for a small cycle of crusher classifier - 6 mm, larger mixer and pump for the waste rock plus Astrabent slurry as shown schematically in Figure 57.

5.8: COMPARISONS BETWEEN AQUAPAK, TEKPAK AND ASTRAPAK

The material cost of Tekpak and Astrapak is 17% less than that of the Aquapak.

Tekpak and Astrapak need higher % of water than the Aquapak.

Aquapak performs better in cool environment, whereas Tekpak and Astrapak require warmth for correct curing.

Aquapak has a more yielding ability under load than the other two pack types. However, its strength development per curing time is relatively lower than the Tekpak and Astrapak (Figure 58).

Later on, as the pack's strength rather than yielding properties become more important Aquapak has the greater strength. Once again, underground experience leads to the conclusion that the Aquapak strength is adequate for the task. It is likely that the strength displayed by Tekpak at 7 days,

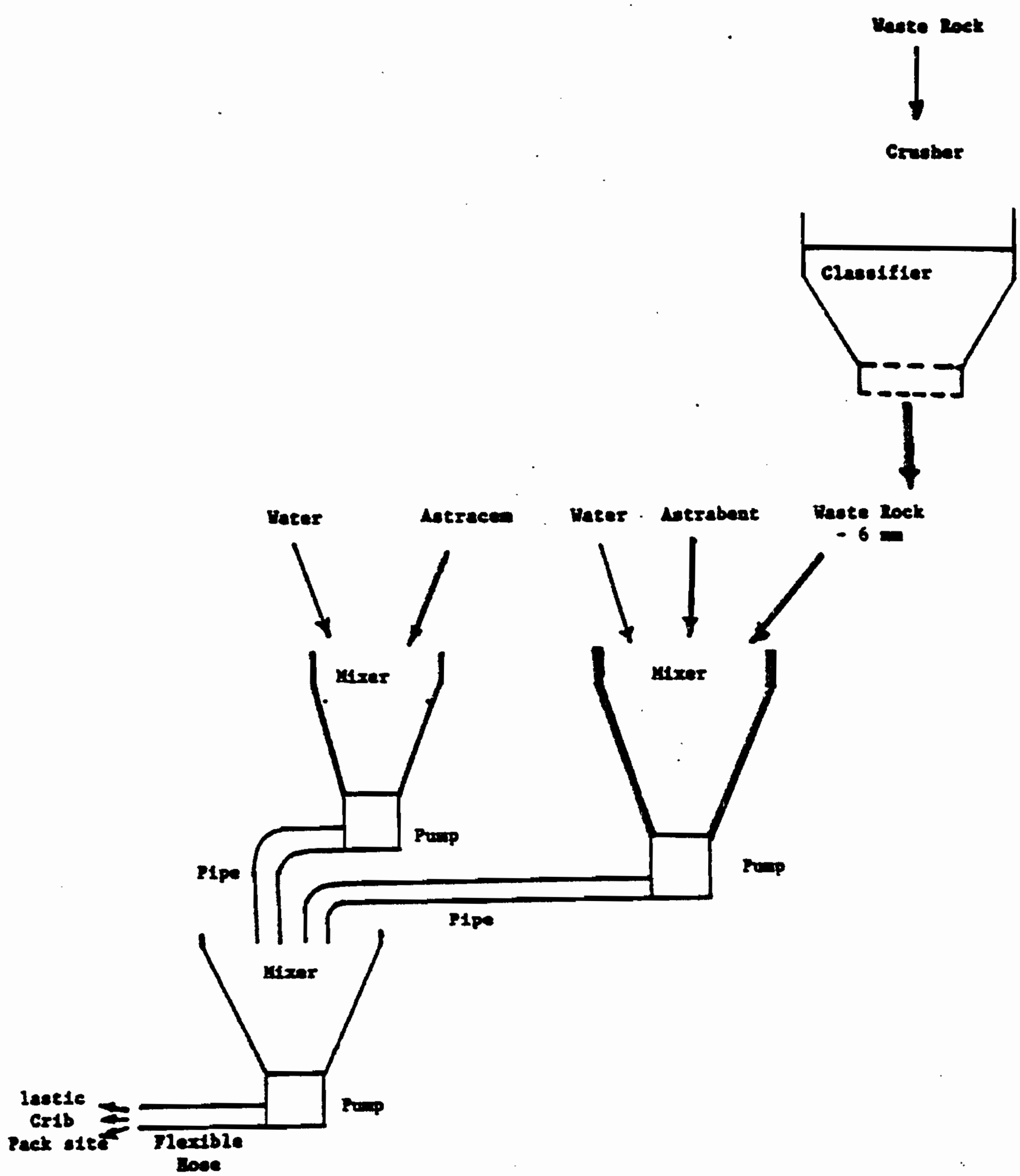


FIG. 57. SCHEMATIC OF THE ASTRAPAK/WASTE ROCK ARRANGEMENT.

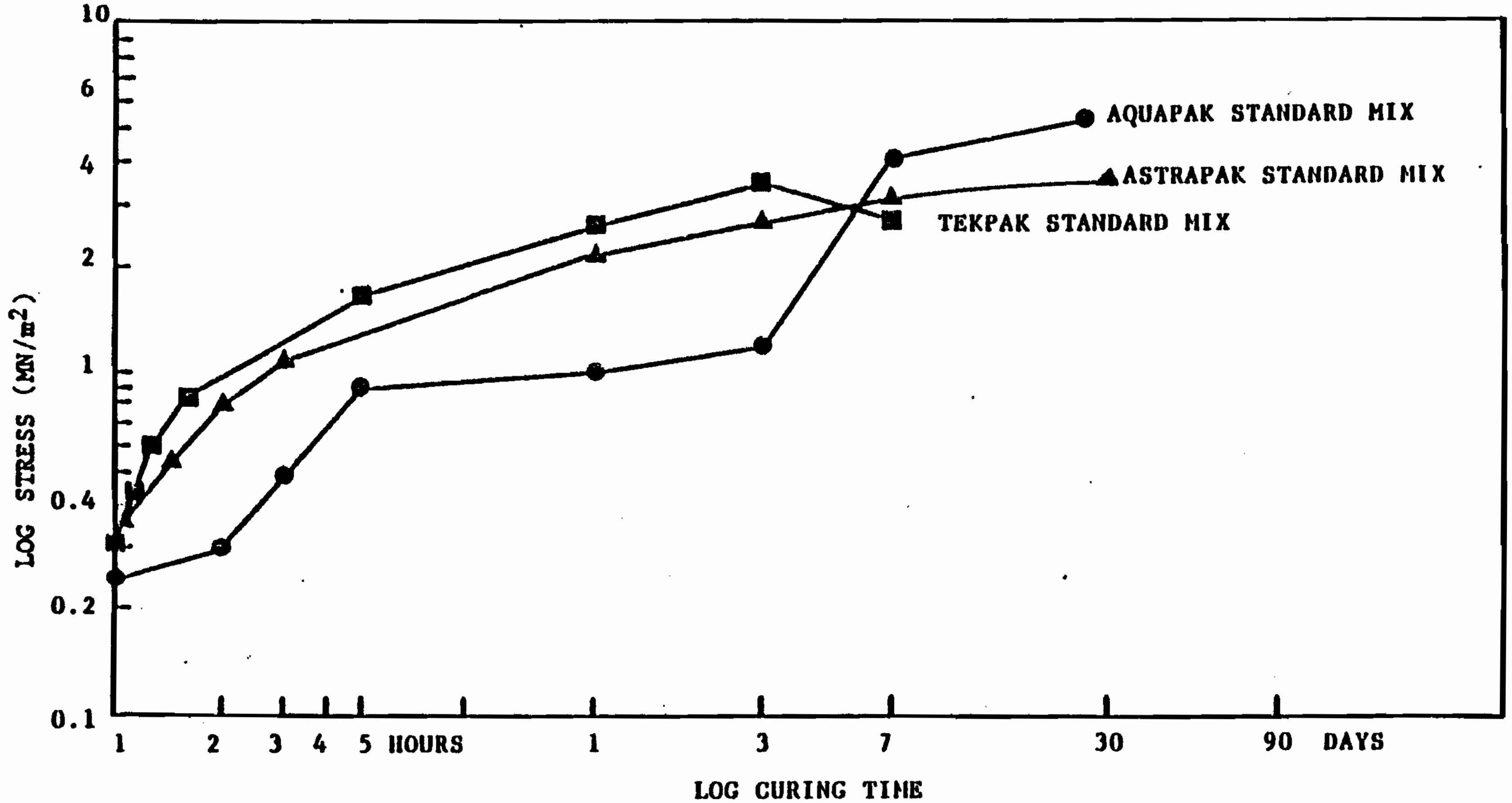


FIG. 58 - COMPARISON OF STRENGTH DEVELOPMENT FOR AQUAPAK, TEKPAK AND ASTRAPAK

given sufficient pack dimensions, would also prove adequate, Whittaker et al (1). Further deterioration in the strength of the material might cause failure of the pack. At this stage of the pack's life restitution of its strength by further curing is an extremely remote possibility.

The form of the long term graphs for Aquapak is more ideal than that for the Tekpak, the rate and amount of stress change being lower. Further tests along these lines are necessary to clarify the situation.

All three materials displayed the ability to develop full strength despite a degree of failure during their early life. This is a very valuable property.

Tekpak and Astrapak are very similar in their mechanical behaviour.

Tekpak improves its strength properties with a 15% increase in Tekbent. 30% and 50% increases of Tekbent dramatically improve the plasticity of the material but markedly reduce its strength. Further investigations may reveal that Tekpak behaviour can be improved upon by varying the proportion of the constituents.

Astrapak would have a higher strength when 50% Astracem is added to its standard mix. However, its cost would increase proportionally.

Cost breakdown and unconfined compressive strength comparison for various monolithic pack materials is noted in Table 9.

Table 9 - Cost breakdown and U.C.S. comparison for various monolithic pack materials
(As of 1985 prices)

Pack type	Material costs (CAN$/m³ of pack)				Uniaxial Compressive Strength (MPa)				
	Materials		Costs excluding transport and crib bag						
	Name	Weight (kg)	Individual	Total	2 Hours	1 Day	7 Days	28 Days	
Aquapak	Aquabent Aquacem	50 450	12.50 95.86	108.36	0.52	1.30	4.00	5.00	
Thyssen	Coal Flowmat Packbind	588 16 298	33.57 2.16 64.44	100.17	0.45	0.48	0.95	1.34	
Warbret	Coal Flowmat O.P.C. (Bulk) TEA 51	588 16 298 30	33.57 2.16 23.53 24.03	83.29	0.07	2.40	3.10	4.90	
Tekpak	Tekbent Tekcem	182 182	40.85 57.95	98.80	0.67	2.50	4.0	4.2	
Astrapak	Astrabent Astracem	183 183	37.75 52.96	90.71	0.5	1.4	4.4	4.5	

Table 9 - Cost breakdown and U.C.S. comparison for various monolithic pack materials (Cont'd)

Pack type	Material costs (CAN$/$m^3$ of pack)				Uniaxial Compressive Strength (MPa)				
	Materials		Costs excluding transport and crib bag						
	Name	Weight(kg)	Individual	Total	2 Hours	1 Day	7 Days	28 Days	
Flashpak	Fly Ash	921	27.63		0.02	0.9	4.1	9.3	
	OPC (Bulk)	255	41.31						
	Fe So_4	100	22.50						
	Fulbent	18	5.94	97.38					
	Fly Ash	930	30.63		0.40	1.6	4.4	8.2	
	OPC (Bulk)	255	41.31						
	$Al_2(SO_4)_3$	65	24.62						
	Fulbent	95	31.67	128.23					
	Fly Ash	930	30.63		0.34	4.50	7.65	17.00	
	OPC (Bulk)	255	41.31						
	$Al_2(SO_4)_3$	43	16.29	88.23					
Preblend	Limestone+ Rapid Setting Cement (Bulk)	2000	73.59	73.59	0.78	1.53	8.80	9.80	

Table 9 - Cost breakdown and U.C.S. comparison for various monolithic pack materials (cont'd)

Pack type	Material costs (CAN$/m^3 of pack)				Uniaxial Compressive Strength (MPa)				
	Materials		Costs excluding transport and crib bag						
	Name	Weight(kg)	Individual	Total	2 Hours	1 Day	7 Days	28 Days	
Ampak	Synthetic Anhydrite (Bulk)	2000	39.79		0.26	6.1	21.0	28.0	
	Accelerator	20	8.65	48.44					
	Natural Anhydrite (Bulk)	2000	19.90		0.05	0.8	14.5	20.3	
	Accelerator	56	24.22	44.12					

In comparison between the three pack materials, followings are definite conclusions :

Incorrect mixture proportions, and excess water content will slow the pack curing time, slowing the pack cycle and therefore cause insufficient long term pack strength development. Excess solids (in particular cement) will substantially increase the density and initial setting and packing costs. The rate of hardening per curing time was thereafter slower, comparatively.

Density change in the pack materials can be expected to be rapid during the first 2 to 3 hours of curing time. After which the rate of change would gradually decrease with time until relative stability is reached in about 7 days.

Packs prepared water of 25^{o}C and cured at ambient temperature of 25^{o}C exhibit rapid to instantaneous gelling properties. Similar pack materials prepared at lower water temperatures of 10 to 12^{o}C exhibit no gelling properties and no strength development after approximately one hour.

Water and curing temperatures are more influential factors than the excess cement for the strength of a pack, over long periods. However excess cement cause more rapid initial hardening within the first 2-hours of curing time.

Since the dynamic E of a pack material is directly proportional to the propagation of ultrasonic velocity in the material (V_p), the factors having adverse effect on the density would also have an adverse effect on the V_p and the dynamic E of the pack.

50% increase in the water temperature of the pack would increase its V_P by 5%, on average.

50% decrease in the curing temperature of the pack would decrease its average V_P by 10%.

50% increase in the water content of the mix would decrease its V_P by 18.3% on average.

After 45 to 72 hours of curing time, the Astrapak material undergoes cooling, contraction and finally formation of micro-crack and void within the material. The result is marked decrease in the V_P throughout the material.

The rate of increase in modulus of elasticity of Astrapak is adversely affected by 70%, when a decrease of 17% occurred in the curing temperature and/or 50% excess water was introduced to the mixture.

The general behaviour of Aquapak can be classed as semi-plastic, and that of the Tekpak and Astrapak as elasto-plastic.

The rate of increase in the unconfined compressive strength of Astrapak is relatively fast in the first day of curing, after which it gradually becomes asymptotic to the curing time axis.

The samples with 50% excess Astracem content reach to σ_C = 0.6 MPa within an hour whereas the samples with 50% excess water content reach the lowest σ_C value of 0.12 MPa in one hour. Lower water and curing temperatures had an adverse effect on the σ_C of the Astrapak.

The effect of pack size on the temperature creation during curing fits the following expression:

$$T = m.V^n$$

where

T= Max. internal temperature of the curing pack material, in ^{o}C.

V = Volume of the pack, in Cm^3.

m = Constant related to the mix. water and curing, or ambient, temperatures.

Between 12.4 to 30.0. For the standard Astrapak at low temperatures it averages to about 12.4 to 20.9.

n = Constant related to the number of free sides of the pack for heat transfer between the pack and the mine air and the pack dimensions.

Between 0.08 to 0.12. For the standard Astrapak at low temperatures it averages to about 0.10 to 0.13.

The lower the L/D ratio or the ratio of pack height to the pack base dimensions, the higher would be its unconfined compressive strength.

Longer initial curing before application of the strata load on the pack would result to a higher long term pack strength.

CHAPTER 6

CHAPTER 6

ANHYDRITE PACKING (ANPAK)

Anhydrite packing was developed for use in German coal mines in 1964 with the first major trial taking place at the Holland Colliery. Anhydrite was introduced as a substitute material for pack formation and has since grown in popularity, especially in German longwall mining operations. Current Ruhr coalfield anhydrite consumption exceeds 300,000 tons. Anhydrite packing systems were developed to :

1: Minimize the quantities of expensive wooden chocks required for packing.

2: Reduce costly pack material transportation and installation time and manpower.

3: Overcome the face supply problems associated with wood chock packing.

4: Improve face-end ventilation efficiency by reducing air leakage through the waste area.

5: reduce the risk of spontaneous heating in the goaf.

The anhydrite packing system relies on the pumping of an anhydrite, water, accelerator mixture into the packhole where the anhydrite slurry sets by hydrating to gypsum. Both crushed natural anhydrite and screened synthetic anhydrite are used in this system of gateroad support. Pack strength development is based on the following reaction ;

ANHYDRITE	+	WATER	----	DIHYDRITE (GYPSUM)
$CaSO_4$	+	$2H_2O$	----	$CaSO_4.2H_2O$

Since the rate of formation of dihydrite crystals is very slow it is necessary to add an accelerator to the hydration reaction. A good pack requires early strength. The presence of an accerlator dramatically increases the rate of gypsum crystal formation and provides excellent early strength qualities.

6.1: NATURAL ANHYDRITE

Natural anhydrite packing system uses material that is crushed to a size distribution of 0-7 mm (National Coal Board,U.K, Recommendation) mixed with an accelerator of 1 parts by weight potassium sulphate (K_2SO_4) and 1.8 parts by weight ferrous sulphate ($FeSO_4.7H_2O$). The accelerator is added to the anhydrite in a quantity of 1% by weight and the anhydrite : water ratio is kept to 9 to 10% by weight. The anhydrite is pneumatically blown to the pack site where the water-accelerator mix is added before ejection. The anhydrite slurry will then hydrate to gypsum with accelerators providing the required reaction speed for rapid pack strength development.

Natural anhydrite can be effectively pneumatically transported up to distances of 1500 meters. Pneumatic transport, however, relies on a very fine material size disturbution with inter-mix of large granules. A large portion of the anhydrite must consist of very fine material in order that the anhydrite : water reaction occur rapidly and uniformly. This permits the formation of a finely granulated mixture which acts as a reconstituted mass in a similar way to aggregate in concrete and also provides the required size gradient for successful pneumatic required size gradient for successful pneumatic transportation of solids.

6.2 : SYNTHETIC ANHYDRITE

Synthetic anhydrite is a by-product formed during hydrofluric acid production, phosphate fertilizer production or the gas desulpherization at the coal fired power plants. Because it is usually formed as an amorphous powder it cannot easily be adopted to penumatic transportation . A typical synthetic anhydrite size distribution consists of the majority of the total weight in dust with the largest granule not exceedding 2-3 mm. Such a fine size distribution requires synthetic anhydrite to be slurried and then pumped into the packs.

The by weight ratio of the Anpck mix is :

	ANYHDRITE	:	ACCERLERATOR	:	WATER
NATURAL :	100	:	2.8	:	10
SYNTHETIC:	100	:	1	:	10

6.3: TYPICAL INSTALLATIONS

6.3.1: Alsteden System

This system of packing was first developed by Karl Briedtn and Co. of Germany and has remained the most extensively used packing system in Continental European Collieries. Natural anhydrite crushed to the required 0-7 mm size distribution is delivered to the colliery and stored in 50 ton silos on surface.

from the silos the packing material can be easily fed into mine cars or monorail containers for transport underground. The anhydrite, once transported to the appropriate longwall panel, is then deposited into storage bunkers. An adjustable length, scraper-feed, chain conveyor feeds the anhydrite into the intake hopper of Brieden stower delivers the anhydrite, at a predetermined feed rate, into a compressed air stream of approximately 40 p.s.i. The intake hopper of the Brieden stower should be kept full at all times and must be specially coated with a hardened material to minimize corrosion. Special hardened basalt-lined pipes and fittings transport the pneumatically blown air-anhydrite mix to the pack area.

The accelerator and water and/or flyash are pre-mixed in a mixing tank located near the Brieden stowing machine and then pumped through 25 mm lines (line pressure=12.5 atm.)to within 5 m of the pack site. The accelerator salts dissolve in the water through the mixing tank. When the fluid level drops to 2/3 of the tank height, the tank is topped up with water and 1 bag (40 kg) of accelerator. At a location approximately 5 m from the pack hole the fluid accelerator stream and air-anhydrite stream are mixed using a special flanged annulus. This annulus incorporates a number of wetting nozzles that evenly mix the anhydrite, water and accelerator throughout the circumference of the annula. This special annulus is coupled to a 100 mm flexible discharge hose. The flexible hose allows the operator to direct the mix, the mixture being of a similar consistency to thick porridge, to any location within the pack site. This ensures a consistent, dense, monolithic pack. Because of compressed air requirements this system is limited to a range of around 1000 m of stowing pipe.

The anhydrite packs are lined with brattice cloth along the goaf and faces sides. Timbers are fitted between the arches to contain the slurry as the anhydrite pack builds up. Packing tends to be done after two face end cuts (4 ft.) and packs are usually 5-6 feet in width. Within 1 hour the pack is dry to touch and within two hours it can be considered solid.

This system can also be further simplified by adding the accelerator, in a dry state, to the anhydrite at the Breiden pneumatic mixing station. As long as a properly calibrated dosimeter is used to regulate the flow of the accelerator proper mixture ratios can be maintained. This simplification elliminates the need for an accelerator-water mixing tank and its associated manpower requirements. Besides the elimination of the water-accelerator mixing tank and the addition of a dosimeter and accelerator addition hopper on the Breiden stower the original layout and proceedure remains the same. Man power requirements for the Alstadem system include 1 to 2 men to operate the Breiden machine and associated anhydrite hopper, 1 man to operate the water-accelerator mixing tank (if used), and one man to control the discharge of the anhydrite slurry into the pack hole. A portion of a face end shift may be required in preparing the anhydite pack screen or brattice curtain.

Pipe blockages associated with this system are minimal but abrasion is a serious problem. Pipes, hoppers and mine cars must be specially lined with a hardened protective liner. Replaceable basalt lines are used inthe pipes and pipe fittings. This system can output 8-20 dry tons/hour of natural anhydrite using compressed air quantities of 75 m 3/hour to 400 m 3/hour, depending on the distance the material is pneumatically blown.

6.4 : ADVANTAGES OF ANPAK

1: Simplicity of operation,

2: The cheapest of all pack types,

3: Displays high strength characteristics after a long curing time.

6.5 : DISADVANTAGES OF ANPAK

1: Low strength development within the first 2 hours of curing,

2: Corrosive in contact with metals underground,

3: Very brittle.

CHAPTER 7

CHAPTER 7

FLYASH (FLASHPAK)

7.1: PREPARATION

"Flashpak" is an MPP system based on flyash and Ordinary portland cement.The flashpak is made from mixtures noted below:

Mixture I : flyash + accelerator + bentonite + water

The accelerator can be either Ferrous sulphate ($FeSO_4$) OR Aluminum sulphate ($Al_2(SO_4)_3$). The latter is more effective, but more costly. Usage of Ferrous sulphate decreases the early pack strength, but not enough to be a problem.

Mixture II : cement + water

This slurry has about 500 m pumping distance limit since it hardens in the pipe quickly.

The by weight ratio of the flashpak is :

	FLYASH	CEMENT	ACCELERATOR	BENTONITE	WATER
(%)	50.2	13.9	4.5	1	20.4

Both grouts are pumped to the face end where they are mixed in a mixing gun and sprayed into the prepared packhole. The volume of flyash slurry is approximately twice that of the cement slurry. The resulting mortar gels instantaneously, so the need for a waterproof containing bag is eliminated. With the cement pump adjusted to pump at half the rate of the flyash pump, the two slurries are then pumped simultaneously through one and quarter inch hoses into an ejector mixer device and allowed to spray into a container.

7.2 : COST EFFECTIVENESS

Both flyash and cement are locally avilable in Nova Scotia. Ferrous sulphate is only obtainable from Quebec, where it is a by-product of the manufacture of nails. Due to high cost of Ferrous sulphate delivered from Quebec ($225/tonne), it is more economical to import the Ferrous sulphate from the U.K, resulting in a savings of $30/tonne. Bentonite, from Wyoming, is avilable from the oil service industries in Halifax, Nova Scotia. Again, importing bentonite from the U.K would result in a savings of $66.5/tonne. The cost per tonne of each material is summarized below :

MATERIAL	LINGAN	IMPORTED
FLYASH	($30)	$8.2
CEMENT	($162)	$120
FERROUS SULPHATE	($225)	£80 ($195)
BENTONITE	($330)	£148.5 ($264)

NOTE: The values in ( ), are the delivered costs. The transportation cost from the U.K is $115/tonne.

This difference in costs per cubic metre between mixes based on local and imported materials would result in a saving of $ 46,000 on a 2500 m long face using a 2.1 m wide by 2.1 m high pack. (P. Cain)

A typical face at Lingan Colliery advances at a rate of 18-20 m a week. Required strength / time characteristics of flashpak for a face advance of 18 m a week is shown below :

TIME	2 HR	1D	7D	14D	28D
STRENGTH (Mpa)	0.4	2.4	5.2	6.7	8-11

7.3: ADVANTAGES OF FLASHPAK

1: Quick gelling properties. It needs no brattice cloth and weldmesh during the curing.

2: It reaches to a relatively high final strength after 15 days of curing.

3: Its cost is in the medium range of the monolithic packs.

4: The packing rate can be high and upto 22 m3/hour.

7.4: DISADVANTAGES OF FLASHPAK

1: Its initial strength development is low and can not act as a support during the first day of curing.

2: Since it gels quickly, each of the mixtures I and II (noted in section 7.1) must be flushed separately into the packhole, where they will be mixed together. Hence, a uniform mixture and quality control is difficult to achieve.

CHAPTER 8

CHAPTER 8

ANHYDRITE AND FLYASH MIXTURE, ANFL

8.1 :SAMPLE SPECIFICATION AND PREPARATION

The flyash used was F ash, produced from bituminous coals and had a low lime content possessing little cementitious value by itself. This flyash has a minimum of 97% passing a 150 micro sieve and a minimum of 87% passing a 45 micro sieve. The anhydrite was a naturally occuring material (Fundy 2) which had been finely crushed. The grading and different sizes are given in Figure 59 . There are four different sizes of anhydrite which were selected to be tested in laboratory . The major particle size distribution used in testing was size no.1 . Afterreceiving the anhydrite from Little Gypsum Company (sized 1-2 in.), the laboratory cone crusher was used to crush the anhydrite and obtain size no.1 .The coarse particles of size 1 were screened out to obtain size 2 . In order to get size 3 distribution , a ball mill was used to reduce the size of the material . Size 4 was the coarsest size distribution of anhydrite in mixes selected for testing . To facilitate the curing process of anhydrite , a small amount of accelerator was employed comprising 1.8 parts of Ferrous sulphate to one part Potassium sulphate

8.2: UNCONFINED COMPRESSIVE TESTS

Three series of tests were carried out . In the first series, the standard Anpak was tested using locally available anhydrite from the Sydney area (Table 11) . In the second series, varying proportions of anhydrite were mixed with flyash

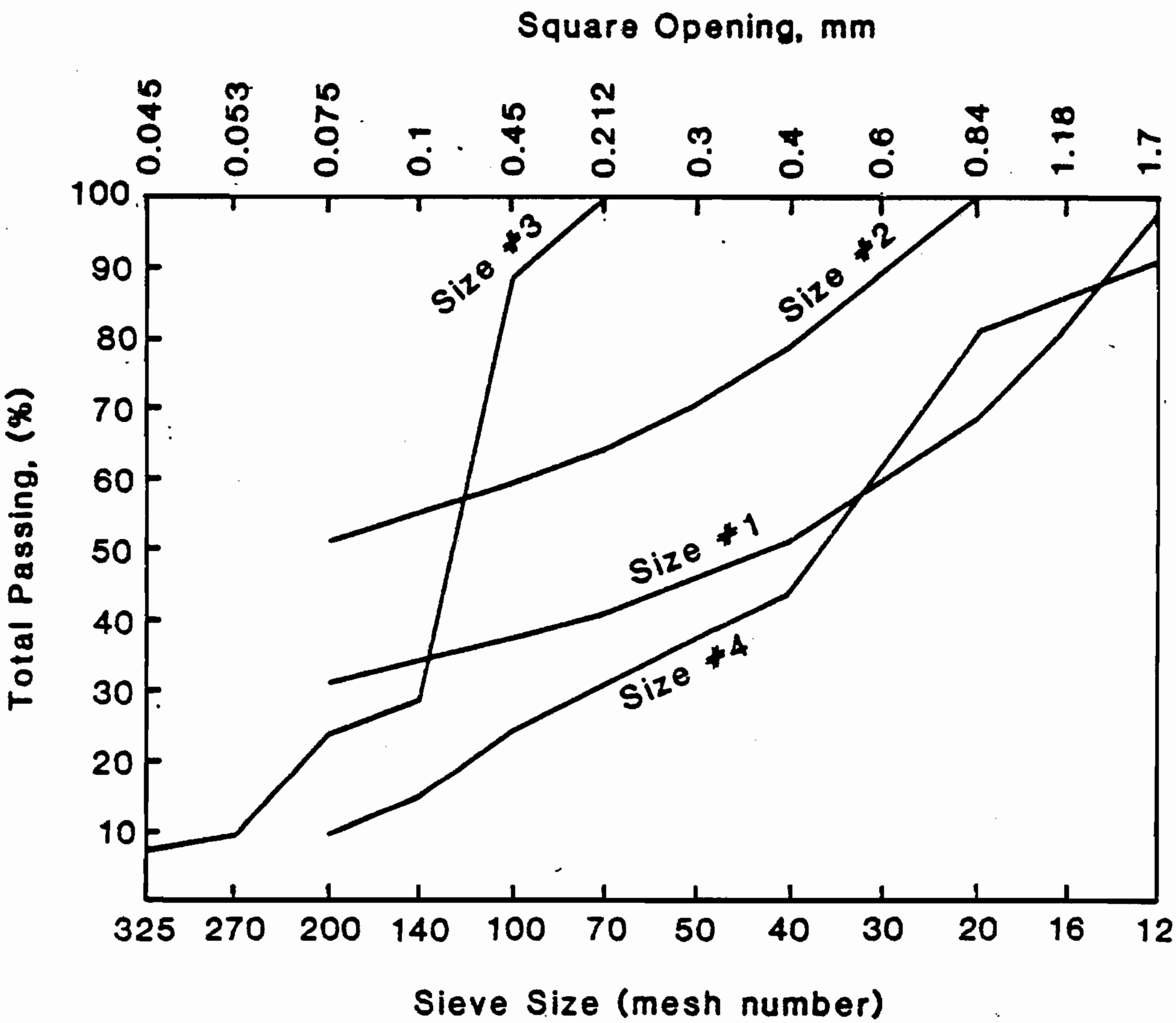


FIG 59 : SIZE DISTRIBUTIONS OF NATURAL ANHYDRITE USED IN TESTING.

(Tables 12-19). The third series , was the evaluation of the washplant tailings as fill material (Tables 20,21).

The uniaxial compressive strength tests were conducted , as described previously , on 50 mm diameter x 100 mm length cylinders at a constant displacement rate of 1mm per minute . A minimum of three uniaxial tests were carried out for each parameter set and the test procedures accord with the standard of the I.S.R.M. (7) .

The materials were dry-mixed until a uniform appearance was achieved . Meanwhile the accelerator , with a weight equal to 1% of the total weight of anhydrite and/or flyash , was dissolved in a measured quantity of water . This solution was then mixed with the dry constituents.

8:3: TEST RESULTS

Table 10 shows the constituents, density , modulus of elasticity , cost and compressive strength of each combination that was tested. This table also shows the potential savings that could be achieved using the local resources . The average cost per m^3 for the locally available pack (ANFL) is around $35 plus grinding costs and for commercially available packs , such as Astrapak , the cost is around $110 .

In all the different mixes of anhydrite and flyash ,the amount ,by weights, of water and accelerator were kept constant . Figures 64 and 65 show that the finer anhydrite (size 2) has increased the compressive strength by 140% after 28 days of curing. The figure also states that the early strength, 1 day, is increased by almost 300% . The more anhydrite used in the sample, the more pronounced the effect of size distribution on compressive strength (Figures 66-70) . The compressive strengths and curing times for all the flyash/anhydrite mixes are shown in Figure 71. It can be seen that the addition of up to 40% anhydrite by weight to flyash has little effect upon the compressive strength. The data for flyash/anhydrite mixes show that between 60% and 80% of the 28-day strength is gained after 7 days.

Type F flyash, locally available in the Sydney area, has a low lime content and addition of lime to the mixes was investigated (Figure 72). This Figure shows that the addition of lime does not result in any increase in compressive strength for 28-day curing.This is perhaps due to small amount of flyash, 16.5% , used in the specific mix under study.

The effect of size distribution of anhydrite on compressive strength of 20:80 flyash to anhydrite ratio mix was studied and presented in Figure 68. Reducing the size of anhydrite increases the compressive strength of the mix and the rate of increase varies for different curing times. In selecting one of the available four sizes for use underground, an economical evaluation of the capital costs involved, especially in grinding and transportation costs, should be carried out. If pneumatic transportation is chosen the size distribution no.3 is the most suitable one. In case of hydraulic transportation all four sizes

SET A

THIS SET IS CALLED AN-PACK . HERE, SIZE 1 ANHYDRITE HAS BEEN USED.

1. ANHYDRITE = 100 PARTS

2. ACCELERATOR = 2.8 PARTS (1.8 P OF $FeSO_4$ & 1 P OF K_2SO_4)

3. WATER = 10 PARTS

TYPE A (DAYS)	COMP.STRNGTH Mpa	DENSITY kg/m3	MOD.ELAST Mpa
1	9.4	2424	1064
3	11	2368	1075
7	11.2	2307	1097
30	11.2	2292	1102

Table 11: Strength characterstics of standard ANPACK

SET M

THIS IS A MIXTURE OF BOTH FLYASH AND ANHYDRITE . IN ALL THE FOLLOWING MIXTURES THE WATER CONTENT AND AMOUNT OF ACCELERATOR ARE KEPT CONSTANT .

1. FLYASH = 80 PARTS (66 %)
2. ANHYDRITE = 20 PARTS (16.5 %)
3. Feso4 = 0.77 PARTS (0.64 %)
4. K2so4 = 0.43 PARTS (0.33 %)
5. WATER = 20 PARTS (16.5 %)

TYPE M (DAYS)	COMP.STRNGTH Mpa	DENSITY kg/m3	MOD.ELAST Mpa
1	0.4	2159	42
3	.61	2139	88
7	.54	2134	46
30	.72	2114	84

Table 12 : Strength characterstics of ANFL-M SIZE#1.

SET N

THIS IS THE SECOND MIXTURE OF FLYASH AND ANHYDRITE . THE ANHYDRITE USED HERE IS SIZE 1 .

1. FLYASH =60 PARTS (49.5 %)
2. ANHYDRITE = 40 PARTS (33 %)
3. Feso4 = 0.77 PARTS (0.64 %)
4. K2so4 = 0.43 PARTS (0.35 %)
5. WATER = 20 PARTS (16.5 %)

TYPE N DAYS	COMP.STRNGTH Mpa	DENSITY kg/m3	MOD.ELAST Mpa
1	.51	2216	87
3	1.1	2205	137
7	1.43	2190	182
30	1.77	2180	241

Table 13 : Strength characterstics of ANFL-N SIZE#1.

SET O

THIS IS THE THIRD COMBINATION OF FLYASH AND ANHYDRITE . SIZE 1 ANHYDRITE HAS BEEN USED .

1. FLYASH = 40 PARTS (33 %)
2. ANHYDRITE = 60 PARTS (49.5 %)
3. Feso4 = 0.77 PARTS (0.64 %)
4. K2so4 = 0.43 PARTS (0.35 %)
5. WATER = 20 PARTS (16.5 %)

TYPE O (DAYS)	COMP.STRNGTH Mpa	DENSITY kg/m3	MOD.ELAST Mpa
1	.64	2342	78
3	2.0	2317	311
7	2.6	2256	356
30	2.65	2246	403

Table 14 : Strength characterstics of ANFL-O SIZE#1.

SET T

IN THIS PART SET O ,IS REPEATED WITH FINER SIZE OF ANHYDRITE, TO SEE THE EFFECT OF ANHYDRITE SIZE ON COMPRESSIVE STRENGTH.

1. FLYASH = 40 PARTS (33 %)
2. ANHYDRITE = 60 PARTS (49.5 %)
3. Feso4 = 0.77 PARTS (0.64 %)
4. k2so4 = 0.43 PARTS (0.35 %)
5. WATER = 20 PARTS (16.5 %)

TYPE T (DAYS)	COMP.STRNGTH Mpa	DENSITY kg/m3	MOD.ELAST Mpa
1	2.54	2292	377
7	3.0	2277	779
30	6.45	2252	899

Table 15 : Strength characterstics of ANFL-O SIZE#2.

SET P

THIS IS THE FOURTH COMBINATION OF FLYASH AND ANHYDRITE . AGAIN , Anhydrite SIZE 1 HAS BEEN USED HERE.

1. FLYASH = 20 PARTS (16.5 %)
2. ANHYDRITE = 80 PARTS (66 %)
3. Feso4 = 0.77 PARTS (0.64 %)
4. K2so4 = 0.43 PARTS (0.35 %)
5. WATER = 20 PARTS (16.5 %)

TYPE P (DAYS)	COMP.STRNGTH Mpa	DENSITY kg/m3	MOD.ELAST Mpa
1	1.62	2358	293
3	3.3	2348	579
7	5.13	2326	416
30	5.63	2312	569

Table 16 : Strength characterstics of ANFL-P SIZE#1.

SET S

HERE, SET P HAS BEEN REPEATED WITH FINER SIZE ANHYDRITE . EVERY OTHER PARAMETER HAS BEEN KEPT THE SAME AS SET P .

1. FLYASH = 20 PARTS (16.5 %)
2. ANHYDRITE = 80 PARTS (66 %)
3. Fes04 = 0.77 PARTS (0.64 %)
4. k2so4 = 0.43 PARTS (0.35 %)
5. WATER = 20 PARTS (16.5 %)

TYPE S (DAYS)	COMP.STRNGTH Mpa	DENSITY kg/m3	MOD.ELAST Mpa
1	3.47	2309	599
7	7.2	2292	816
30	11.1	2277	1193

Table 17 : Strength characterstics of ANFL-P SIZE#2.

SET R

SET R IS THE SAME AS SET S WITH ADDITION OF 5 PARTS OF LIME.

1. FLYASH = 20 PARTS (15.7 %)
2. ANHYDRITE = 80 PARTS (63 %)
3. LIME = 5 PARTS (3.9 %)
4. Feso4 = 0.77 PARTS (0.61 %)
5. K2so4 = 0.43 PARTS (0.34 %)

TYPE R (DAYS)	COMP.STRNGTH Mpa	DENSITY kg/m3	MOD.ELAST Mpa
1	2.85	2316	345
7	10.2	2293	849
30	11.1	2269	983

Table 18 : Strength characterstics of ANFL-P(size#2+5p lime).

SET Q

SET Q IS THE SAME AS SET S WITH ADDITION OF 10 PARTS OF LIME.

1. FLYASH = 20 PARTS (15 %)
2. ANHYDRITE = 80 PARTS (60 %)
3. LIME = 10 PARTS (7.5 %)
4. Feso4 = 0.77 PARTS (0.58 %)
5. K2so4 = 0.43 parts (0.32 %)

TYPE Q (DAYS)	COMP.STRNGTH Mpa	DENSITY kg/m3	MOD.ELAST Mpa
1	1.87	2241	419
7	5.5	2204	623
30	11.1	2198	1122

Table 19 : Strength characterstics of ANFL-P(size#2+10p lime).

SET SR

THIS SET IS STANDARD WARBRET SYSTEM . FILLER IS -2 CM R.O.M TAILING .

1. CEMENT =19 %

2. ACCELERATOR (Feso4) =2 %

3. BENTONITE = 1 %

4. TAILING FROM WASHPLANT = 48 %

5. WATER = 30 %

TYPE SR (DAYS)	COMP.STRNGTH Mpa	DENSITY kg/m3	MOD.ELAST Mpa
3	0.65	1678	139
7	2.01	1543	218
30	3.05	1495	295

Table 20 : Strength characterstics of PUMP PACK#1 system.

SET 2S

THIS SET IS STANDARD WARBERT SYSTEM PLUS 50% EXCESS CEMENT AND 50% EXCESS ACCELERATOR .

1. CEMENT= 28.5%

2. ACCELERATOR (Feso4) =3%

3. BENTONITE = 1%

4. TAILING FROM WASHPLANT =48%

5. WATER = 30%

TYPE 2S (DAYS)	COMP.STRNGTH Mpa	DENSITY kg/m3	MOD.ELAST Mpa
3	.27	1914	32
7	4.6	1674	693
30	3.8	1625	517

Table 21 : Strength characterstics of PUMP PACK #2 system.

System	Materials (%)	Quantity of Materials (kg)	Individual and Total costs	Curing Time (days)	c Mpa	Density kg/m3	Modulus of Elasticity
Anpack (size 1)	Anhydrite = 89	2157	32.0	1	9.4	2424	1064
	$FeSO_4$ = 1.6	39	7.6	3	11	2368	1075
	K_2SO_4 = 0.9	22	4.6	7	11.2	2307	1097
	Water = 8.9			28	11.2	2292	1102
			$44.2				
ANFL-M (size 1)	Flyash = 66	1425	18.5	1	0.4	2159	42
	Anhydrite = 16.5	356	5.3	3	.61	2139	88
	$FeSO_4$ = 0.64	13.8	2.7	7	.54	2134	46
	K_2SO_4 = 0.35	7.6	1.6	28	.72	2114	84
	Water = 16.5						
			$28.1				
ANFL-N (size 1)	Flyash = 49.5	1097	14.3	1	.51	2216	87
	Anhydrite = 33	731	11	3	1.1	2205	137
	$FeSO_4$ = 0.64	14.2	2.8	7	1.43	2190	182
	K_2SO_4 = 0.35	7.8	1.6	28	1.77	2180	241
	Water = 16.5						
			$29.7				
ANFL-O (size 1)	Flyash = 33	773	10.0	1	0.64	2342	78
	Anhydrite = 49.5	1160	17.4	3	2.0	2317	311
	$FeSO_4$ = 0.64	15	2.9	7	2.6	2256	356
	K_2SO_4 = 0.35	8.2	1.7	28	2.65	2246	403
	Water = 16.5						
			$32.0				
ANFL-P (size 1)	Flyash = 16.5	389	5.1	1	1.62	2358	293
	Anhydrite = 66	1556	23.3	3	3.3	2348	579
	$FeSO_4$ = 0.64	15.1	2.9	7	5.13	2326	716
	K_2SO_4 = 0.35	8.2	1.7	28	5.63	2312	792
	Water = 16.5						
			$33.0				

Table 10 : STRENGTH AND COST COMPARISON BETWEEN ALL DIFFERENT COMBINATIONS .

System	Materials (%)	Quantity of Materials (kg)	Individual and Total costs	Curing Time (days)	c Mpa	Density kg/m3	Modulus of Elasticity
ANFL-O (size 2)	Flyash = 33	756	9.8				
	Anhydrite = 49.5	1134	17.0	1	2.54	2292	377
	$FeSO_4$ = 0.64	14.7	2.9	7	3.0	2277	779
	K_2SO_4 = 0.35	8.0	1.7	28	6.45	2252	899
	Water = 16.5						
			$31.4				
ANFL-P (size 2)	Flyash = 16.5	381	4.95				
	Anhydrite = 66	1524	22.9	1	3.47	2309	599
	$FeSO_4$ = 0.64	14.8	2.9	7	7.2	2292	816
	K_2SO_4 = 0.35	8.1	1.7	28	11.1	2272	1193
	Water = 16.5						
			$32.4				
1 ANFL-P (size 2) + 5 parts Lime	Flyash = 15.7	364	4.7				
	Anhydrite = 63	1460	22	1	2.85	2316	345
	Lime = 3.9	90.3	3.9	7	10.2	2293	849
	$FeSO_4$ = 0.61	14.1	3.0	28	11.1	2269	983
	K_2SO_4 = 0.35	8.1	1.6				
	Water = 16.5						
			$35.2				
ANFL-P (size 2) + 10 parts Lime	Flyash = 15	336	4.4				
	Anhydrite = 60	1345	20.2	1	1.87	2241	419
	Lime = 7.5	168	7.2	7	5.5	2204	623
	$FeSO_4$ = 0.58	13	2.5	28	11.1	2198	1122
	K_2SO_4 = 0.32	7.2	1.4				
	Water = 16.5						
			$35.7				
ANFL-P (size 3)	Flyash = 16.5	386	5.0				
	Anhydrite = 66	1544	23.16	3	3.9	2340	812
	$FeSO_4$ = 0.64	15	2.9	7	7.5	2301	1422
	K_2SO_4 = 0.35	8.2	1.7	28	15.3	2289	1687
	Water = 16.5						
			$32.8				

Table 10 : STRENGTH AND COST COMPARISON BETWEEN ALL DIFFERENT COMBINATIONS. (CONT'D)

System	Materials (%)	Quantity of Materials (kg)	Individual and Total costs	Curing Time (days)	c Mpa	Density kg/m3	Modulus of Elasticity
ANFL-P (Size 4)	Flyash = 16.5	389	5.0				
	Anhydrite = 66	1554	23.3	3	0.57	2355	121
	$FeSO_4$ = 0.64	15.1	2.9	7	1.66	2187	180
	K_2SO_4 = 0.35	8.2	1.7	28	3.3	2177	502
	Water = 16.5						
			$32.9				
Pump Pack 1	O.P.C. = 19	319	40.5				
	$FeSO_4$ = 2	34	6.63	3	0.65	1678	139
	Bentonite = 1	17	4.5	7	2.01	1543	218
	Tailing = 48	805	5.6	28	3.05	1495	295
	Water = 30	503					
			$57.3				
Pump Pack 2	O.P.C. = 28.5	545	69.2				
	$FeSO_4$ = 3	57	11.1	3	.27	1914	32
	Bentonite = 1	19.1	5.0	7	4.6	1674	693
	Tailing = 48	918.7	6.4	28	3.8	1625	517
	Water = 30						
			$91.7				

Table 10: STRENGTH AND COST COMPARISON BETWEEN ALL DIFFERENT COMBINATIONS. (CONT'D)

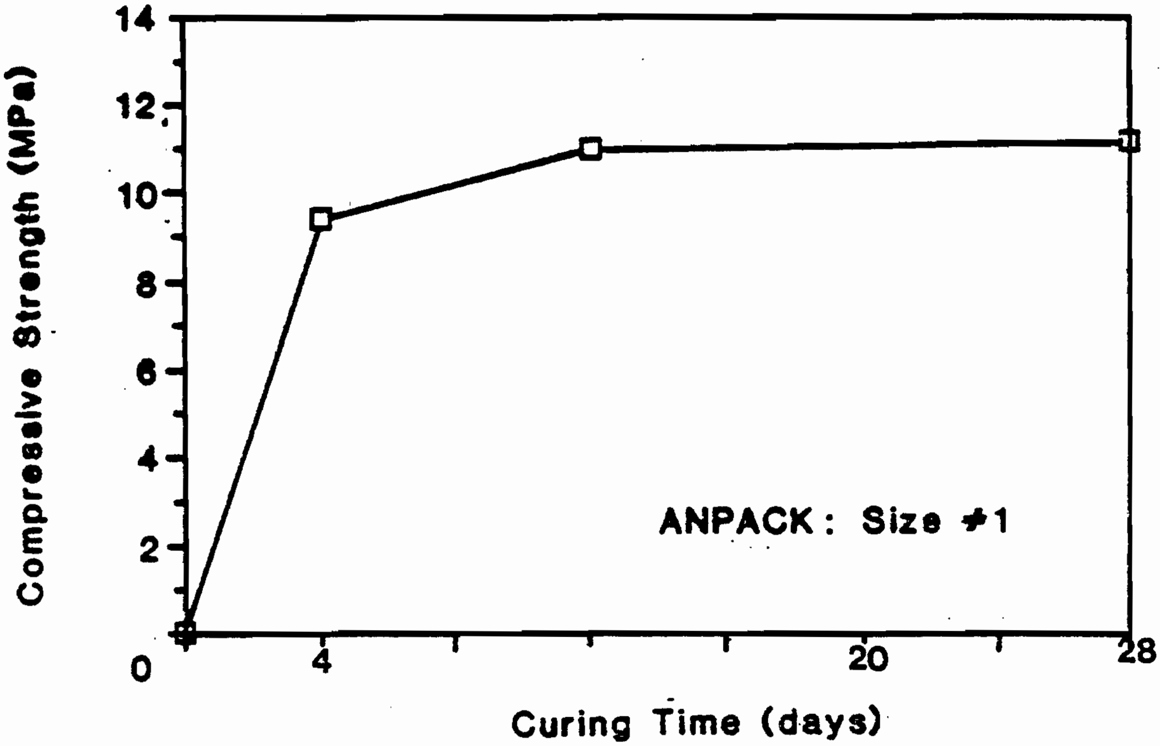


Fig 60 : Strength development of standard ANPAK.

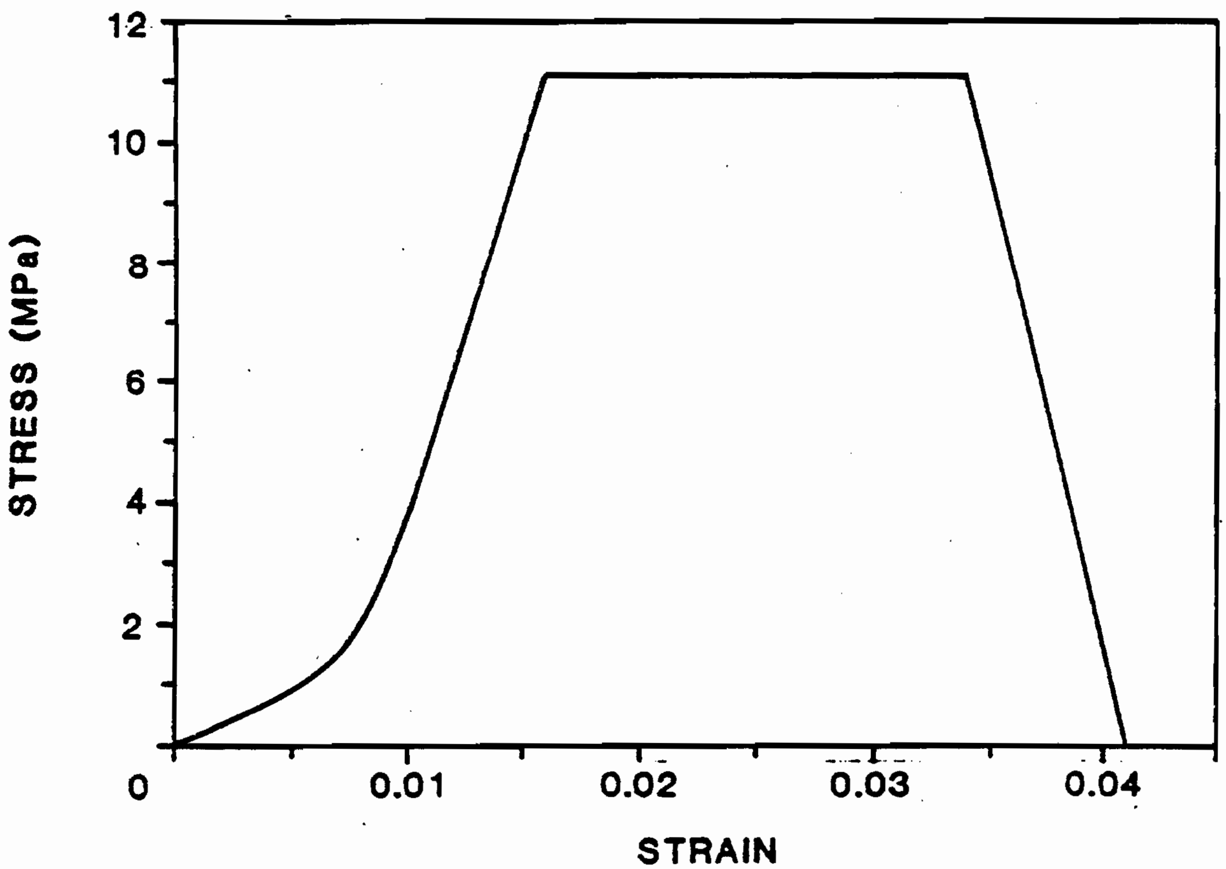


Fig 61: Typical stress/strain curve for standard ANPAK.

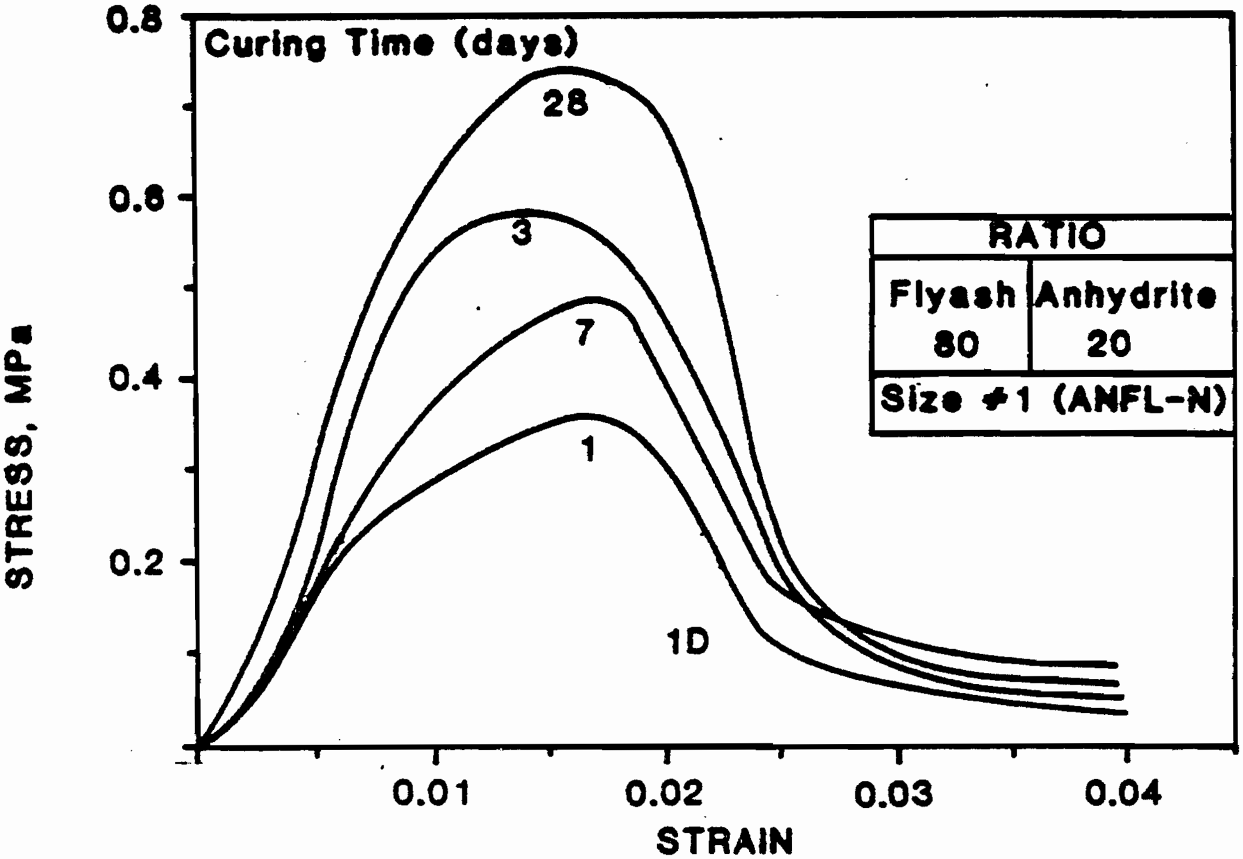


FIG 62: Stress/strain curves for ANFL-N (size#1).

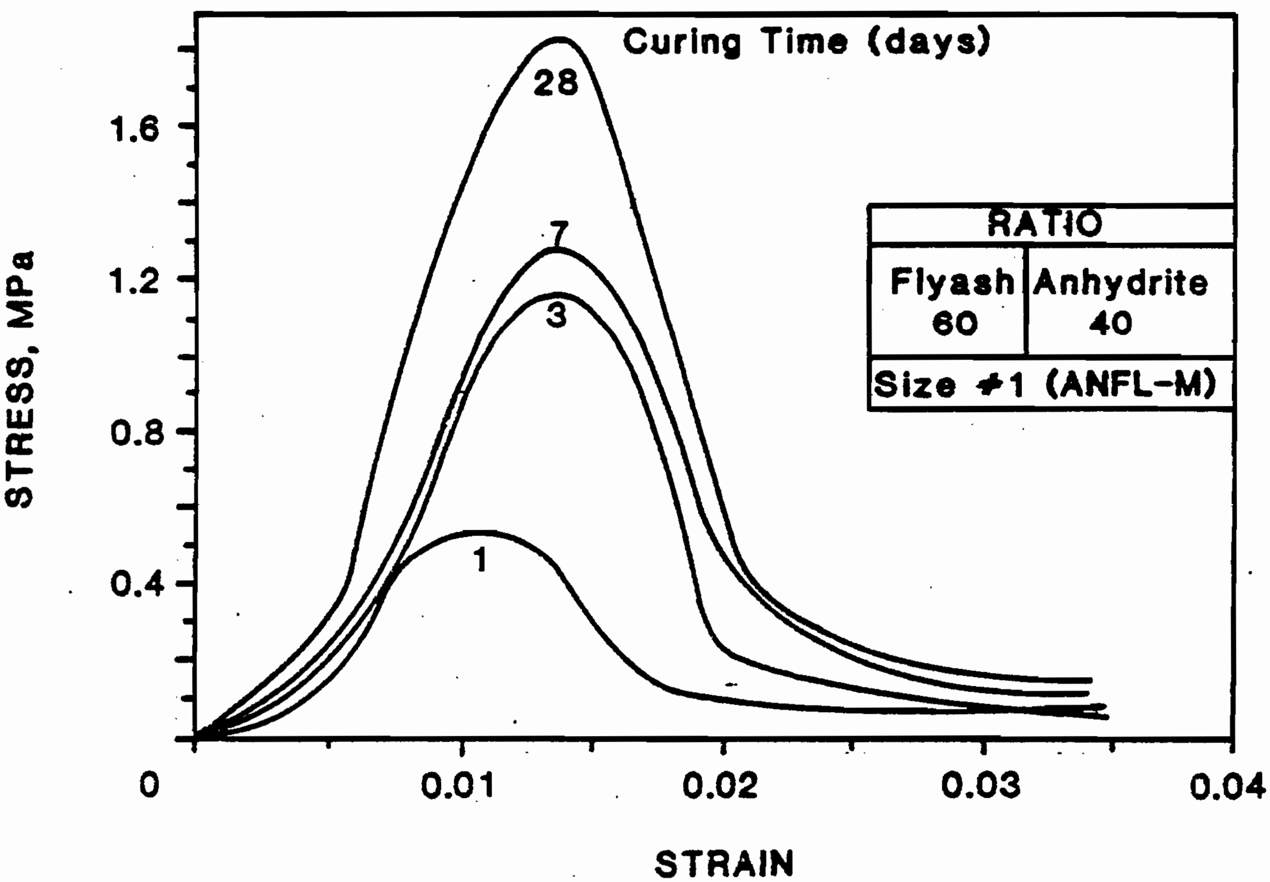


FIG 63: Stress/strain curves for ANFL-M (size#1).

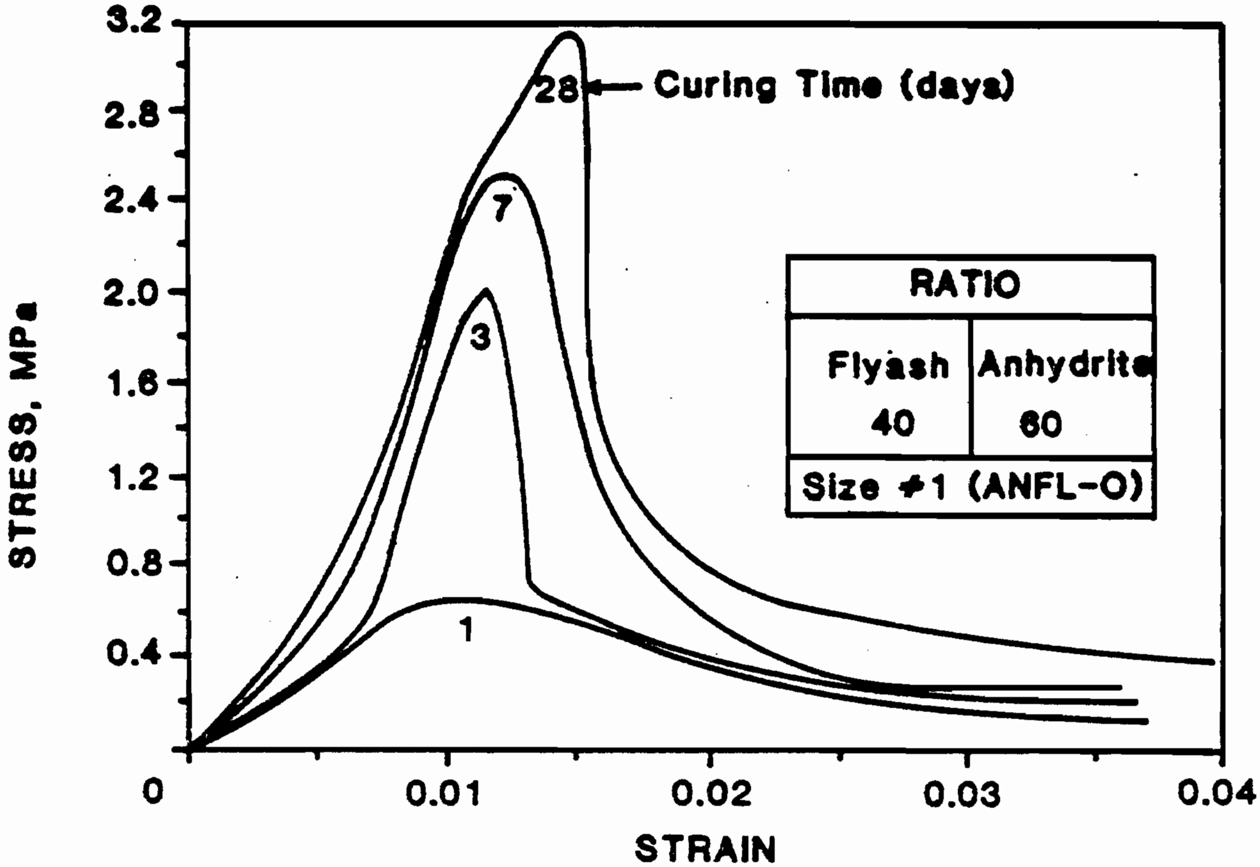


Fig 64 : Stress/strain curves for ANFL-O SIZE#1.

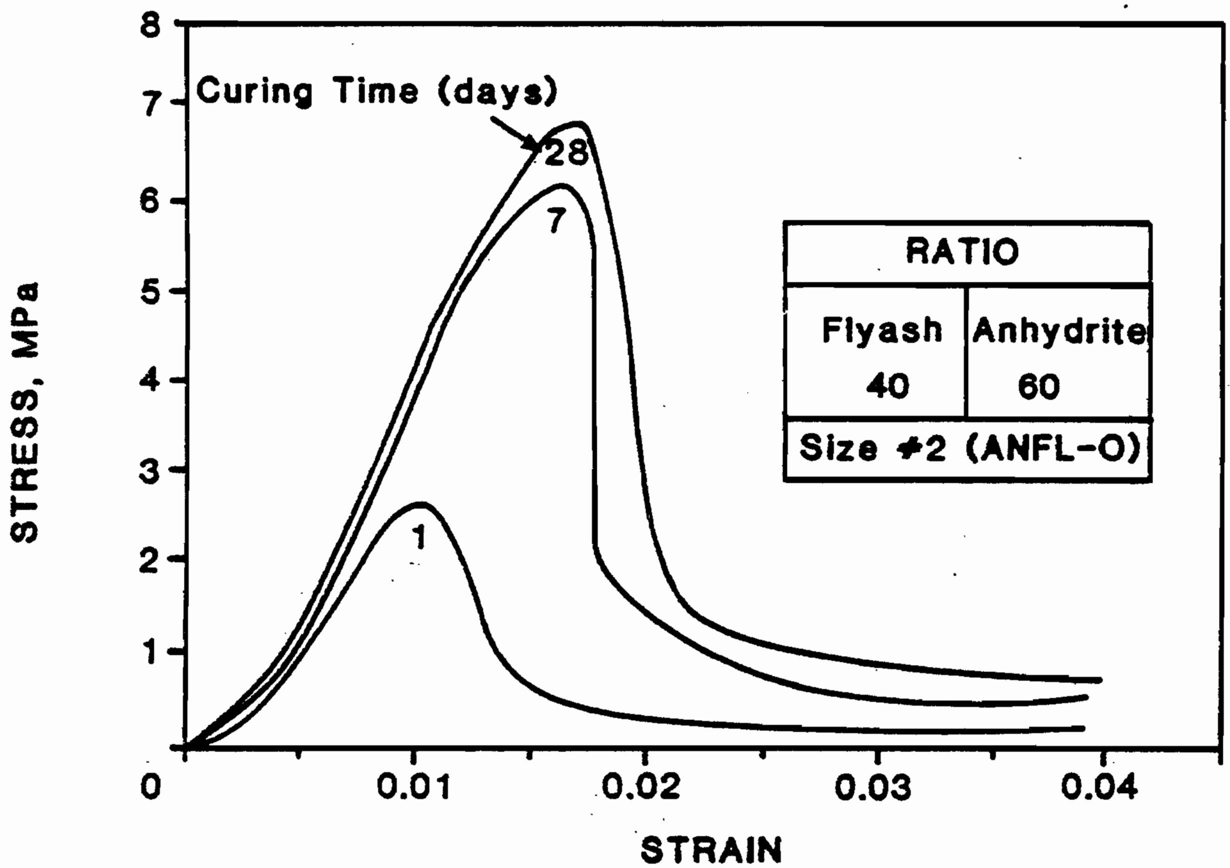


Fig 65 : Stress/strain curves for ANFL-O SIZE#2.

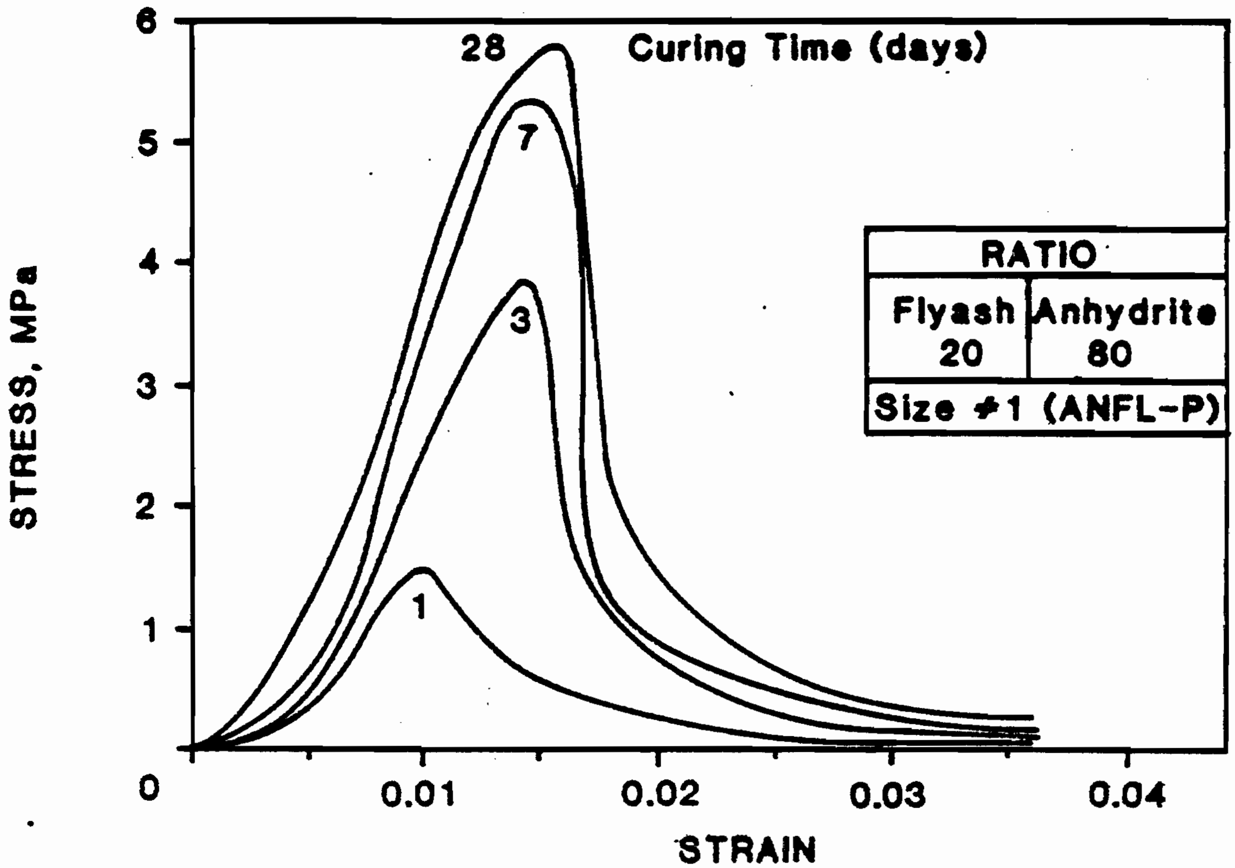


Fig 66 : Stress/strain curves for ANFL-P SIZE#1.

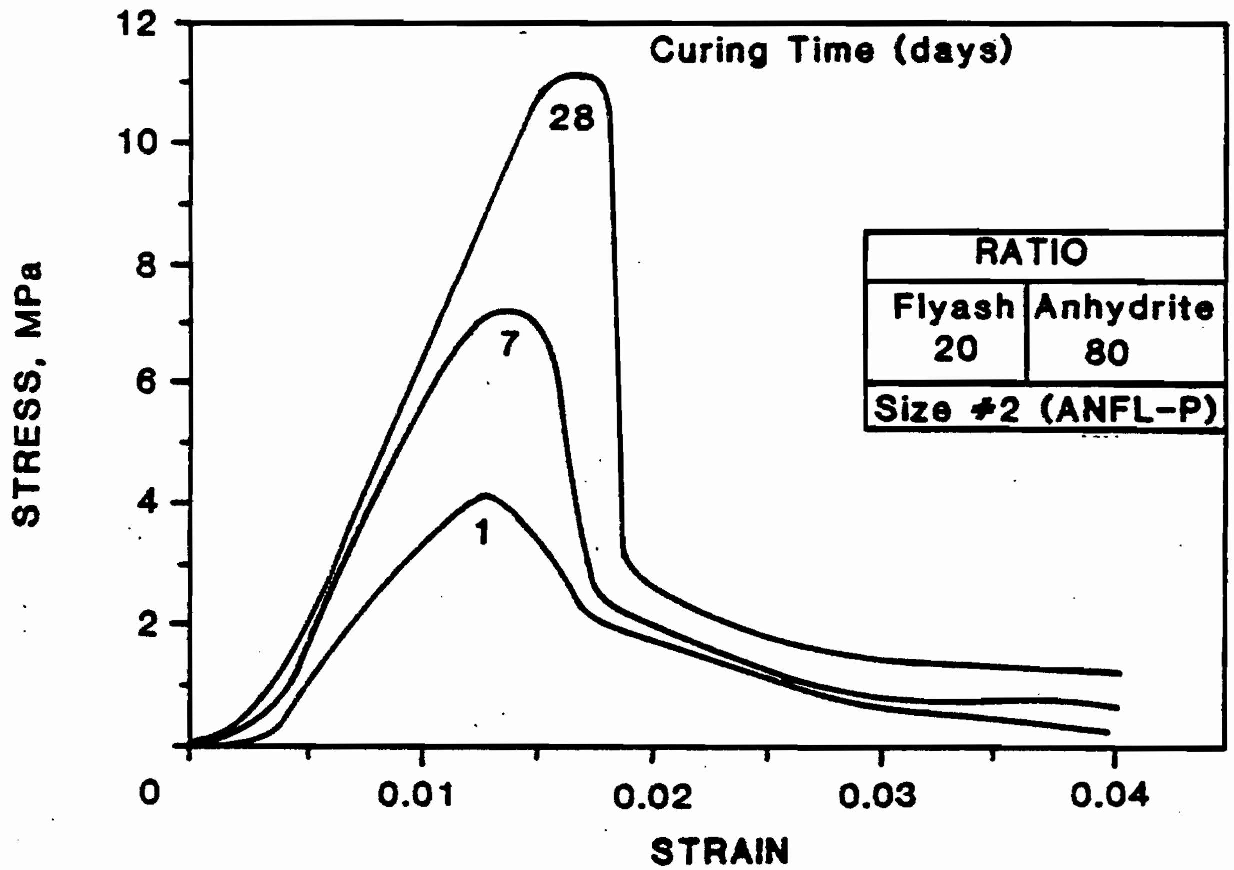


Fig 67 : Stress/strain curves for ANFL-P SIZE#2.

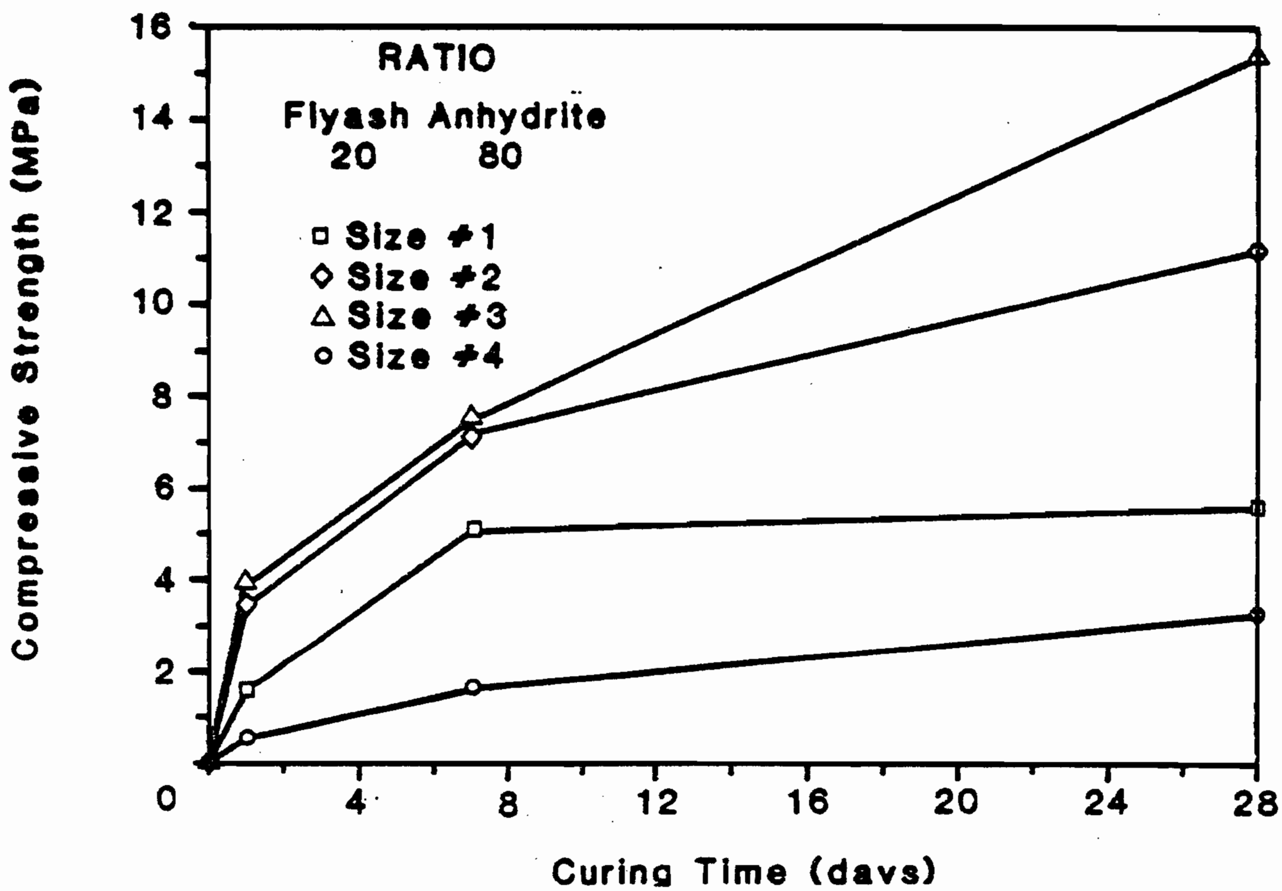


Fig 68 : Strength development of ANFL-P (all four sizes).

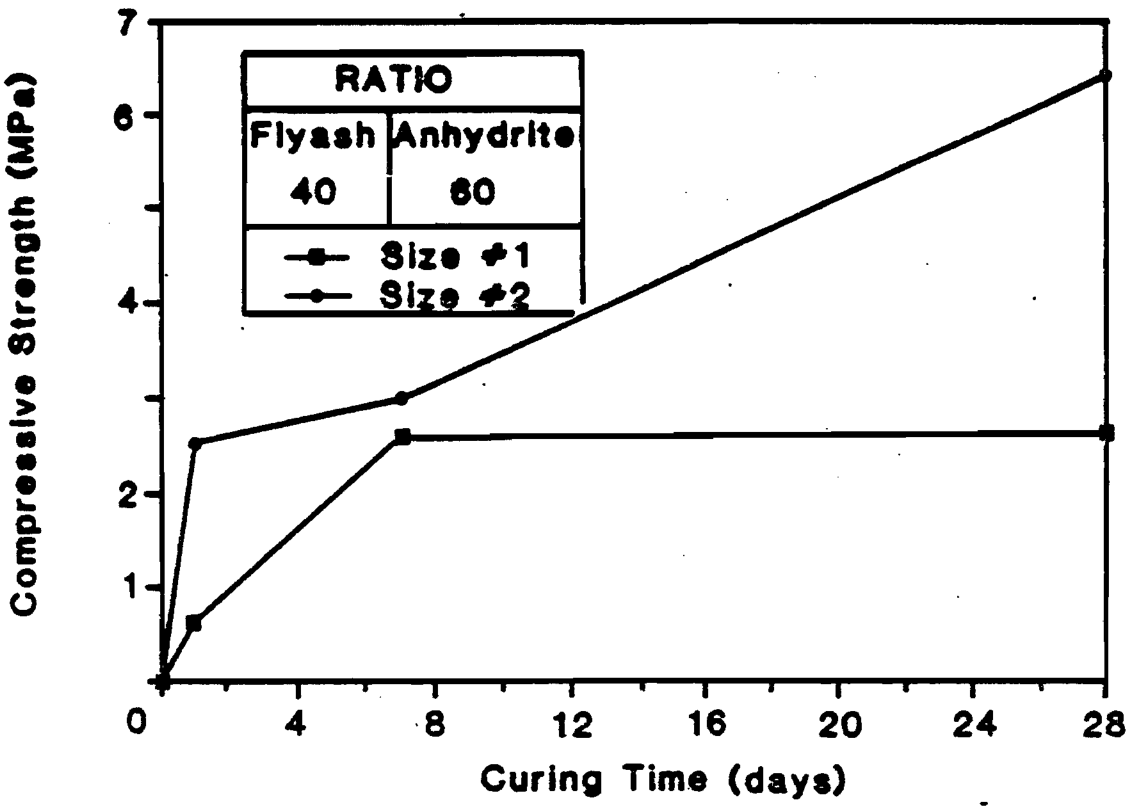


Fig 69: Strength developments of ANFL-0 (sizes #1 and #2).

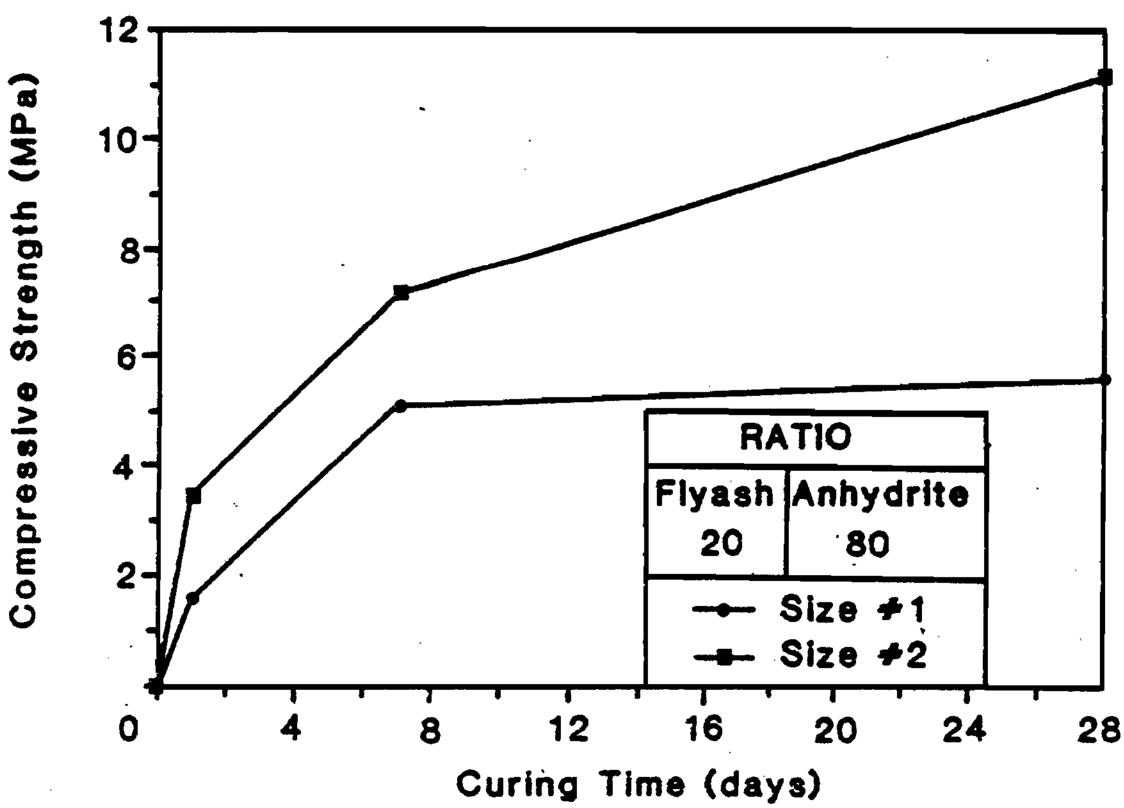


Fig 70 : Strength development of ANFL-P (sizes #1 and #2).

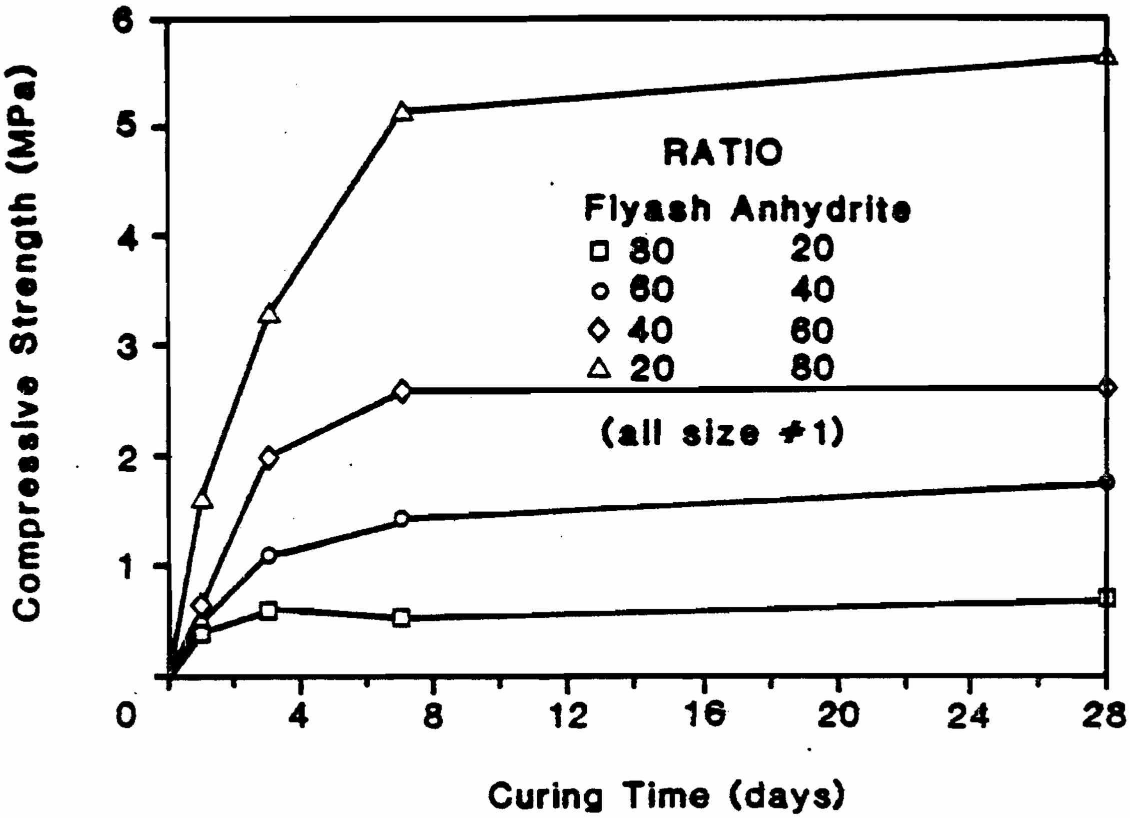


Fig 71 : Strength developments of all ANFL combinations.

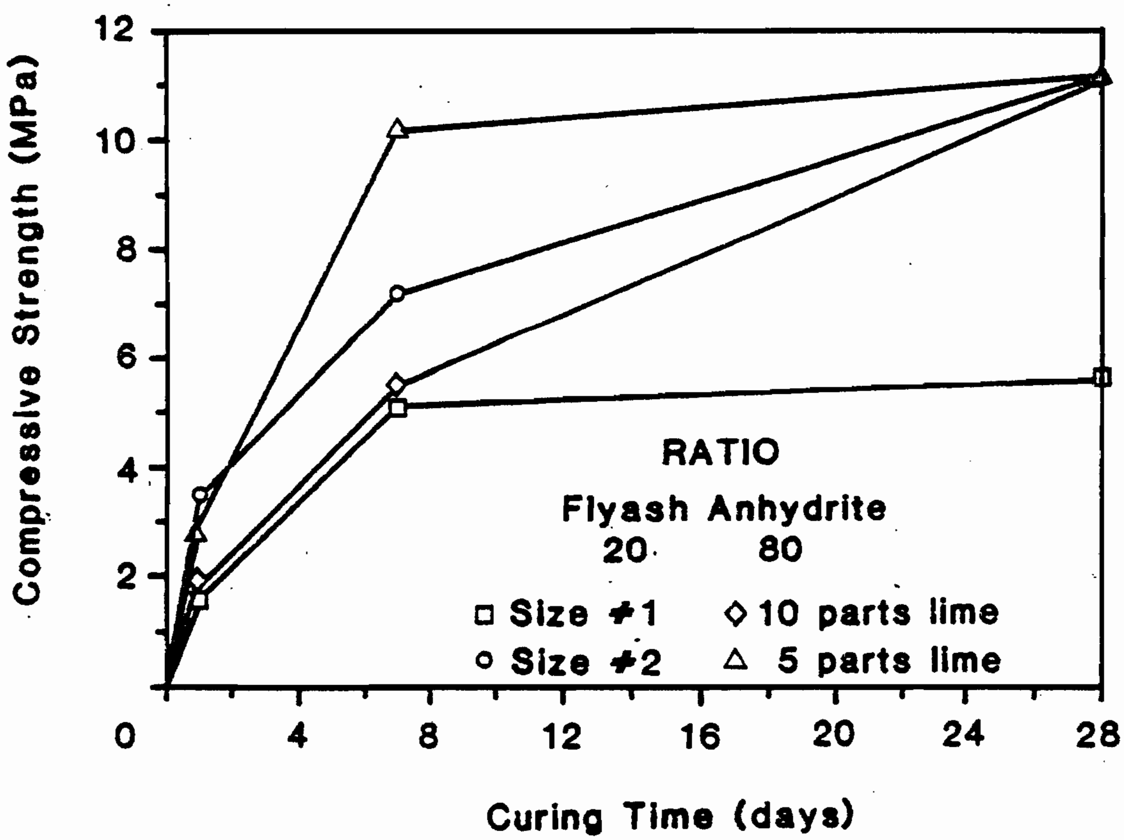


Fig 72 : Strength developments of ANFL-P + LIME.

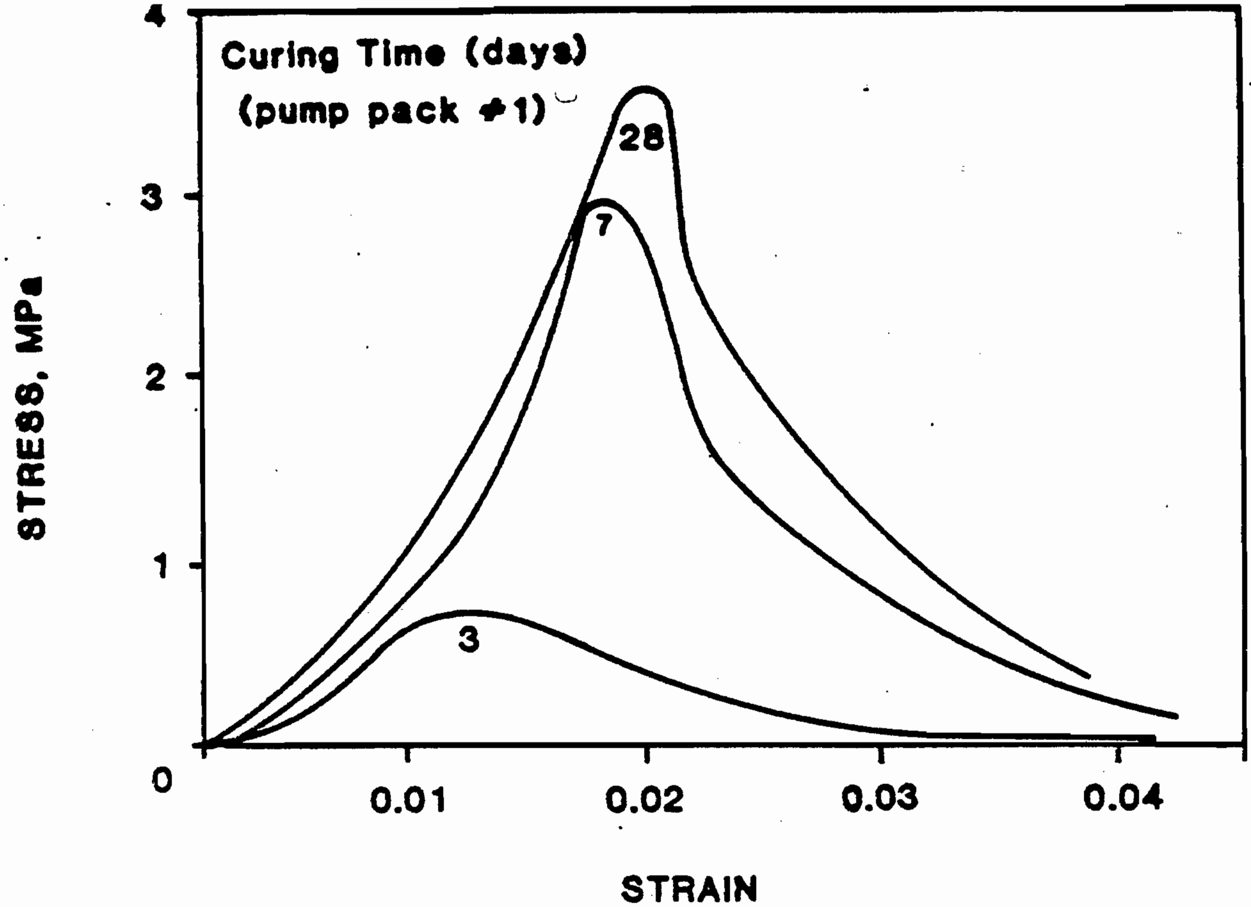


FIG 73 : Stress/strain curves for pump pack#1.

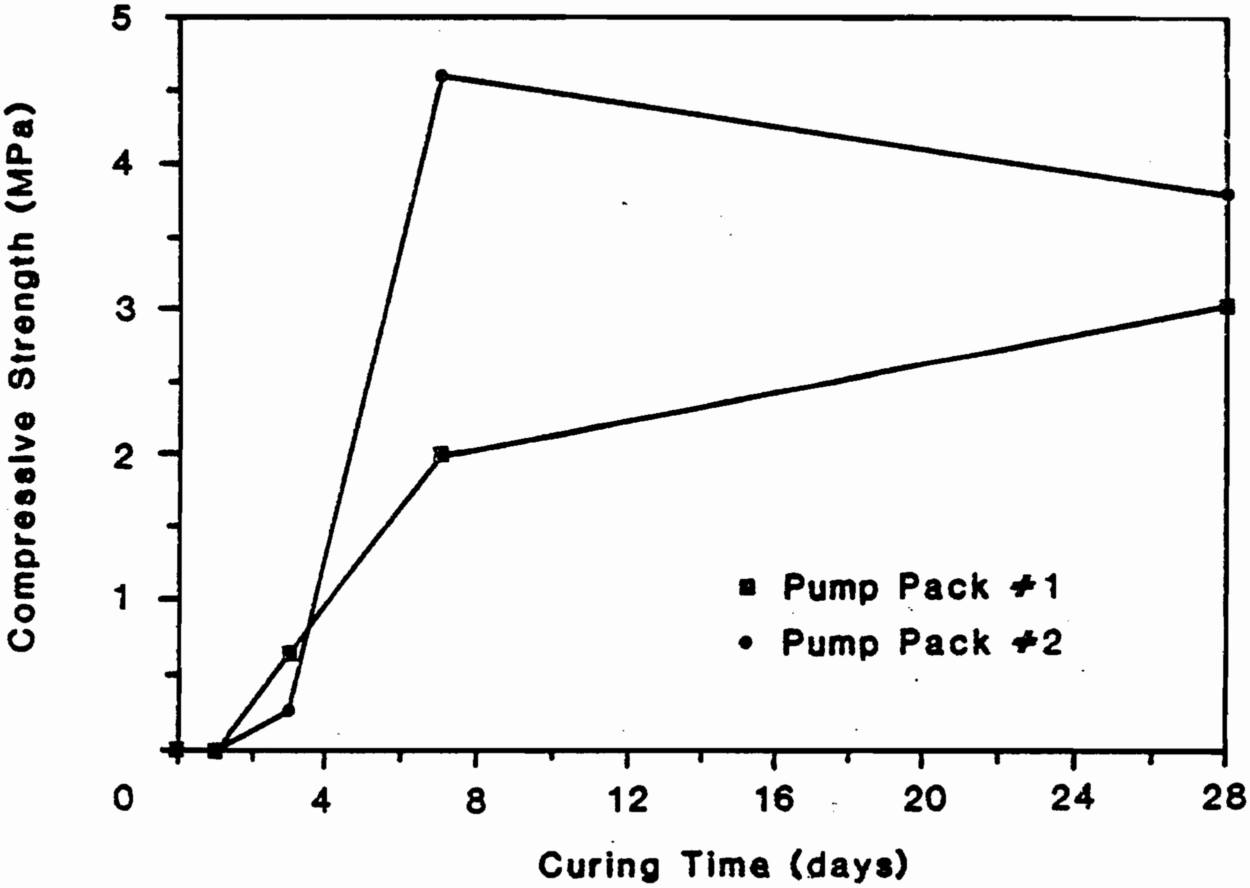


FIG 74 : Strength developments of #1 and #2 pump packs are possible alternatives.

In the third series of tests, washplant tailings, were used as fill material in a standard Warbert system. The quantities of materials used in this system are reported in Table 10. Figure 73 shows that using tailing-based pack gives an acceptable longterm strength, but has a very low early strength. In order to improve the early strength of the pack, 50% excess cement and accelerator were added to the standard mix. The 7-day compressive strength of the new mix increased by 130% compared to the one of the standard Warbert system (Figure 74). However, the new mix started to deteriorate around 7 days of curing and this is perhaps due to high amount of accelerator in the mix. The 28-day compressive strength of the mix decreased by 20% compared to the 7-day strength. Typical stress/strain curves for most of the combinations tested are presented in Apendix A.

8.4: DISCUSSION OF THE RESULTS

a: The water percentage by weight in all the ANFL combinations was kept constant at 16.5% . For anhydrite size distributions 1, 2 and 4, this was the minimum water content needed for hydraulic transportation . More water should be added when anhydrite size 3 (the finest size) is used and this is due to increased surface area of contact. If pneumatic transportation is chosen , water content could drop up to 9% by weight. At ratios less than 9% incomplete hydration occurs which reduces the strength of the mixture. At ratios greater than 9% , the presence of water leads to an excessive reduction in compressive strength, probably due to an increased void space in the mixture.

b: The maximum value of 3 day compressive strength occurs at progressively higher water/anfl ratios as the grain size is reduced. This is probably due to the increased surface area of the finer grains providing more surface area and better reactivity of the material with water.

c: Table 10 shows the following:

a: All ANFL-P combinations are feasable as a packing system in the Sydney Coalfield.

b: ANFL-P SIZE 3 is suitable for pneumatic transportation. Sizes 1 and 2 are the most suitable combinations for hydraulic transportation.

c: ANFL-M,N and ANFL-O (size 1) have a very low compressive strength and are not applicable for use underground.

d: Addition of lime to ANFL-P combination did not effect the longterm strength.

e: Pump pack 1 did not offer adequate early strength and more investigation into the different types and amounts of accelerator should be carried out.

f: Addition of 50% excess cement and accerelator to the standard mix (pump pack 1) did not result in increased strength.

g: Figure 69 states that the 1-day compressive strength of the ANFL-0 combination has increased by almost 300% when size 1

anhydrite is replaced with size 2. There is also a sharp increase in compressive strength after 7-days of curing.

h: Standard ANPACK system is very brittle and could create floor heave problems in weak strata.

i: All ANFL combinations,except ANFL-P size 4, are easily flowable and should have excellent bearing contact with the roof and floor. This is a desirable characteristic since the pack will accept load equally over the entire cross-section.

j: ANFL-P sizes 2 and 3 are the most suitable systems for use in the Sydney Coalfield. They provide the required strength with the minimum cost. These combinations provide very high early pack resistance and low convergence rates enabling better strata bridging over the roadway and immediate load acceptance (resistance to downward roof movement and upward floor movement is offered at a very early stage).

8.4: CONCLUSION

The ANFL packing system is suggested to be the best packing method. Although high initial capital investment is required for pumping system, pipework, pneumatic or hydraulic bulk handling system and compressed air provisions, crushing, grinding and other facilities, numerous long term benefits include a reduction in roadway repair costs, a reduction in supply or underground transportation costs, and a much more reliable operating packing system that will result in improved ground control and face production rates. The system is the simplest of the monolithic packing methods and is the least expensive of all monolithic packs with good strength development. ANFL pack strength can be adjusted to suite any particular ground condition along the gate roads. This type of packing method does not generate excessive heat to interfere with the ventilation system . Most importantly, because of the local availability of anhydrite/flyash in Cape Breton, packing material costs will be significantly reduced compared to the other methods.

REFERENCES

REFERENCES

1. Baudary, Personal Communication.

2. Chambers, W.R., Monolithic Packing, Coventry Colliery, 14th April, (1980).

3. Clark, C.A, Newson, S.R, A Review of Monolithic Pumped Packing Systems, Mine Engr., March 1985.

4. Cox, D.J., Colliery General Manager, Ellistown Colliery, (1982).

5. "Design of Supports in Mines." John Wiley and Sons, 1983

6. Faulkner, R., Phillips, D.W., "Cleavage, Induced by Mining", Trans. Inst. Min. Eng., Vol. 89, pp. 264-288, 1939.

7. Hyde, A.F.L, Some Preliminary Test Data on Cement-pfa-Anhydrite Mixes, Magazine of Concrete Research , Sept.1984

8. Industrial Minerals, Dept. of Mines and Energy, Handbook, 1985.

9. I.S.R.M., Suggested Methods for Determining the Uniaxial Compressive Strength of Rock Materials and the Point Load Strength Index, Committee on Laboratory Tests, Document No. 1, pp. 12, (1972).

10. Johnson, G., Kellet, W.H., and Mills, P.S., Aquapak: A Cementitious Pack Material with High Water Content, 7th Int. Strata Control Conf., Liege, (1982).

11. Kellet, W H and Mills P S . Advances in Monolithic Packing Materials Developed by MRDE .Vol 228 , June 1980.

12. Lea, F.M., The Chemistry of Cement and Concrete, 3rd Ed., Edward Arnold, (1970).

13. Lewis, S. Systems of Roadway Supports. Proc.Symp. on Strata Control in Roadways 1970. London, IMinE ,33-45.

14. Lewis, S., Stace, L.R., A Rationale of Rosdoide Packing, Min. Wng. Vol. 140, No. 235, pp. 717-722, 1981.

15. McCarthy, K. and Robinson, A., Pump Packing Experiences at Newdigate and Daw Mill Collieries, Min. Engr., Vol. 140, No. 236, pp. 831-838, (1981).

16. Middleton, F. Total Face-End Systems IV: Improving Face-End Technique, Inst. Min. Eng., FETEX 80 symp. ,Harrogate, 1980.

17. Newson, S.R., Strata Control - Present Problems, Future Plans, Mine Engr., Vol. 143, No. 266, pp. 229-235, (1983).

18. Nixon, D.N. and Mills, P.S., Pump Packing Developments at Hem Heath Colliery, Min. Engr., Vol. 140, No. 234, pp. 645-652, (1981).

19. "Pack Design Criteria at Betws Colliery", Min. Eng., V.142, p. 15-21, 1982

20. Smith, I., Experience With Anhydrite Packing at Easington Colliery , Mine Engr, Oct.1976

21. Spruth, F., Distribution of Pressure on and near the Coal Face, Proc. International Conf. Rock Pressure, Liege, 1951.

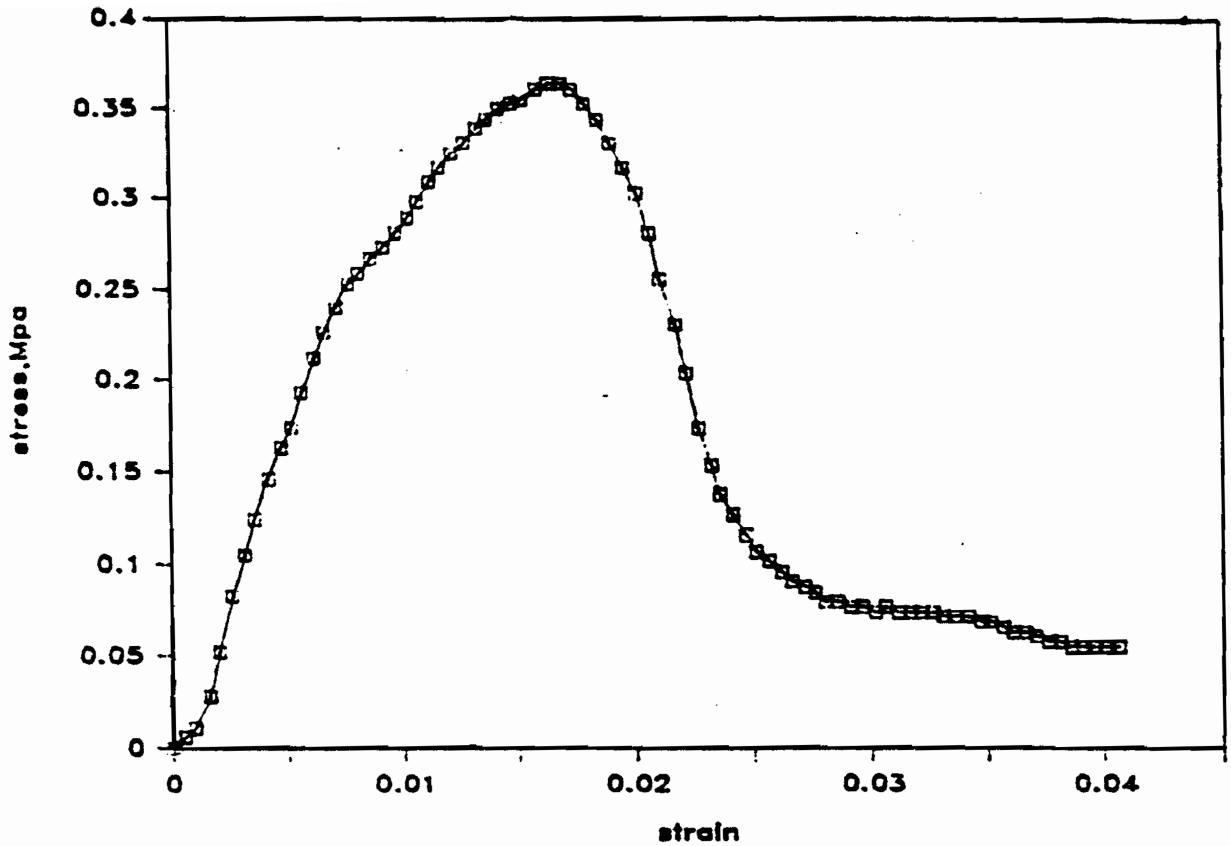
22. Whittaker, B.N., Discussion on paper by Wilson, A.H. "Support Load Requirements on Longwall Faces", Min. Engr., Vol. 134, pp. 479-491, (1975).

23. Whittaker, B.N., Singh, R.N. and Whittaker, P.E., Anhydrite Packing in European Coalfields, University of Nottingham, U.K., (1980).

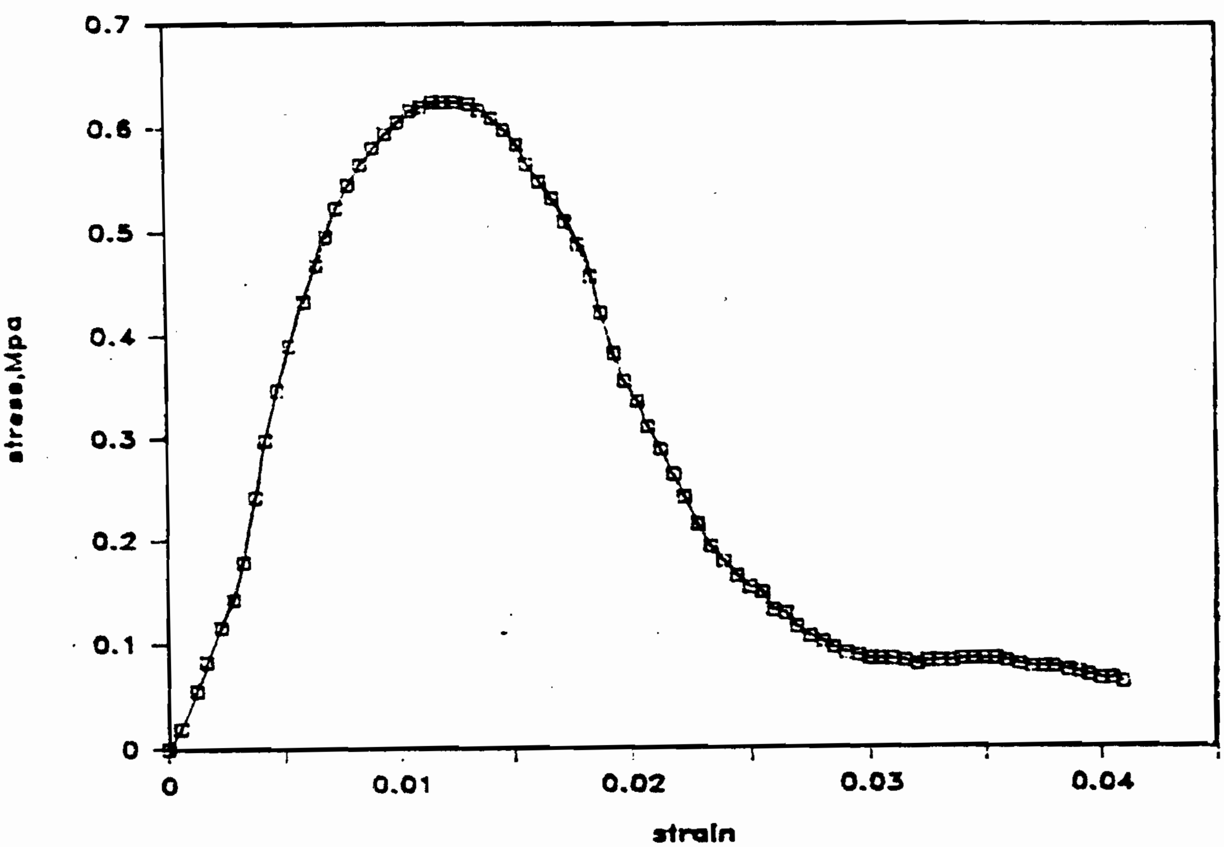
24. White, M.J., The Influence of Post Failure Characteristics of Coal Measure Rocks on the Stability of Mine Tunnels, Ph.D. Thesis, Univ. of Nottingham, U.K. (1983).

APPENDICES

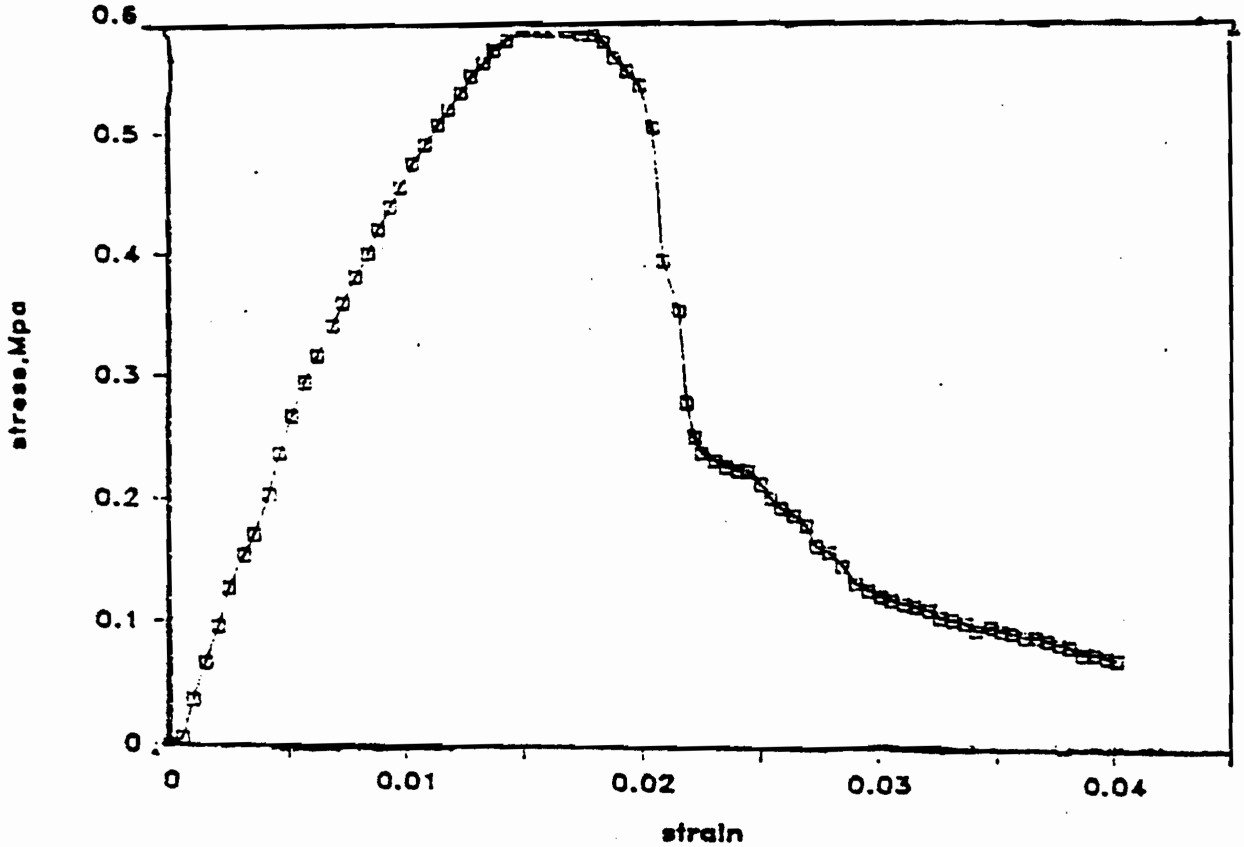
APPENDIX A



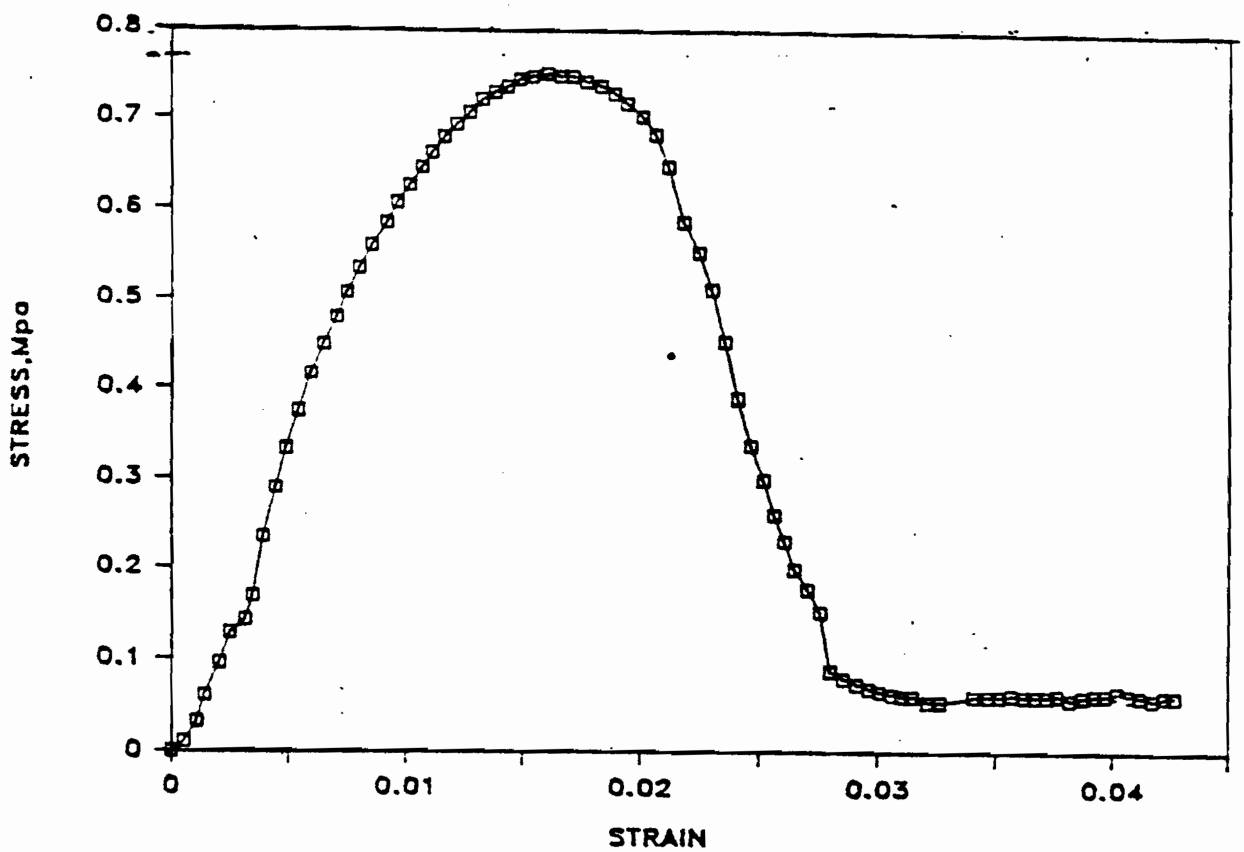
Typical stress/strain curve for ANFL-M size#1, 1 day old



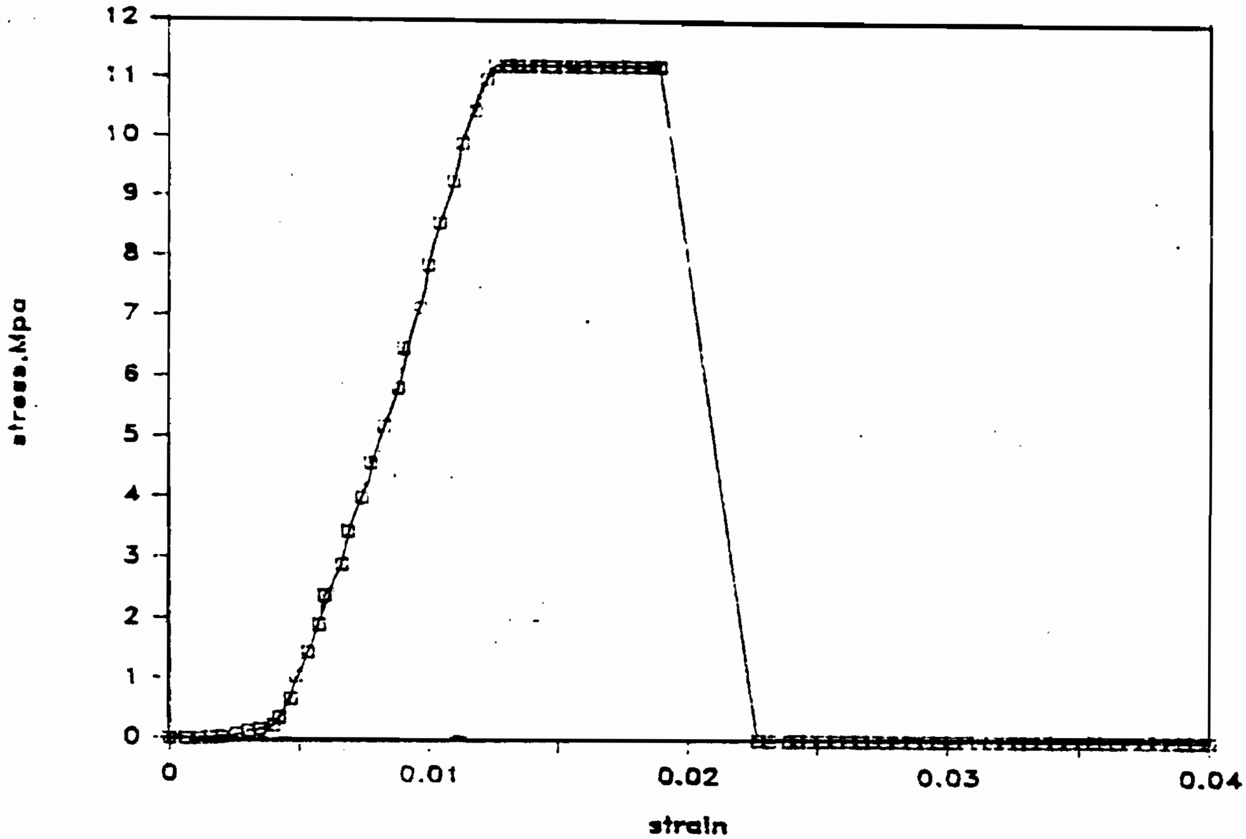
Typical stress/strain curve for ANFL-M size#1, 3 days old



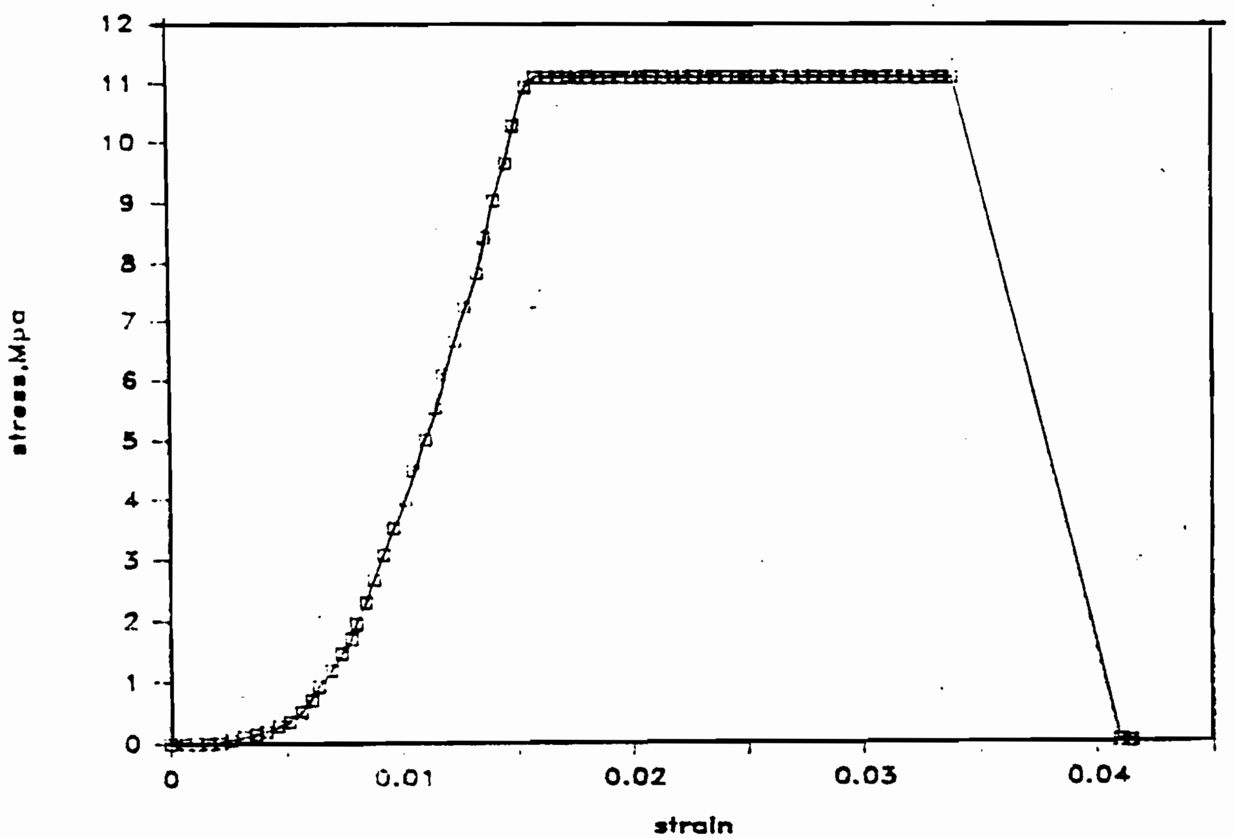
Typical stress/strain curve for ANFL-M size#1, 7 days old



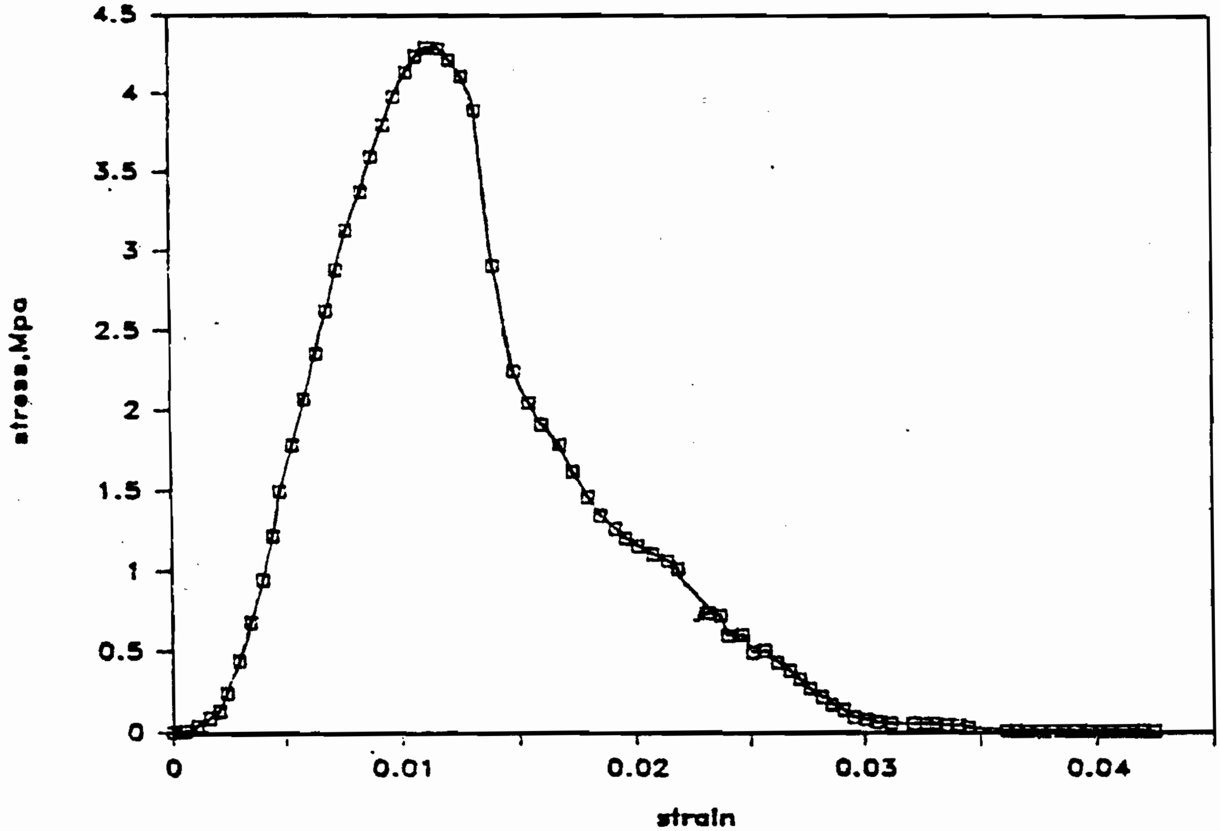
Typical stress/strain curve for ANFL-M size#1, 28 days old



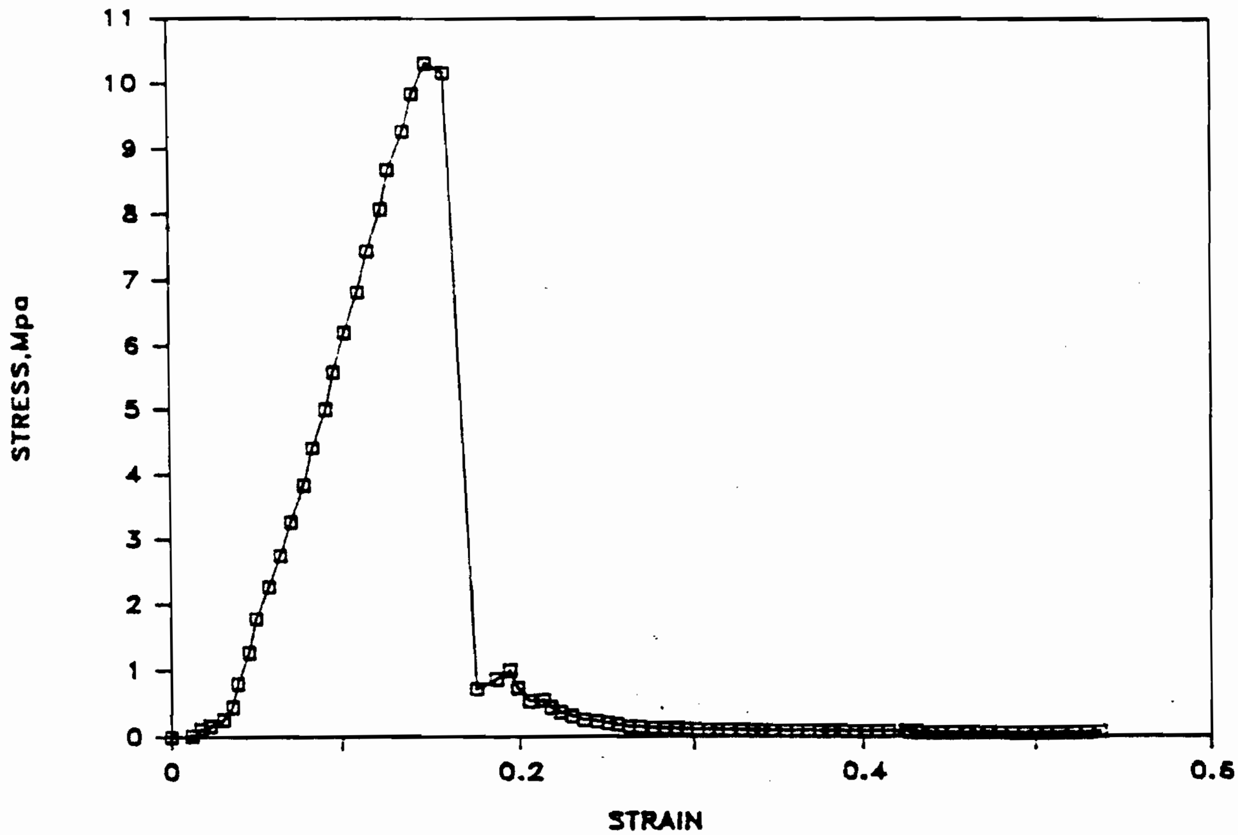
Typical stress/strain curve for ANPACK , 3 days old



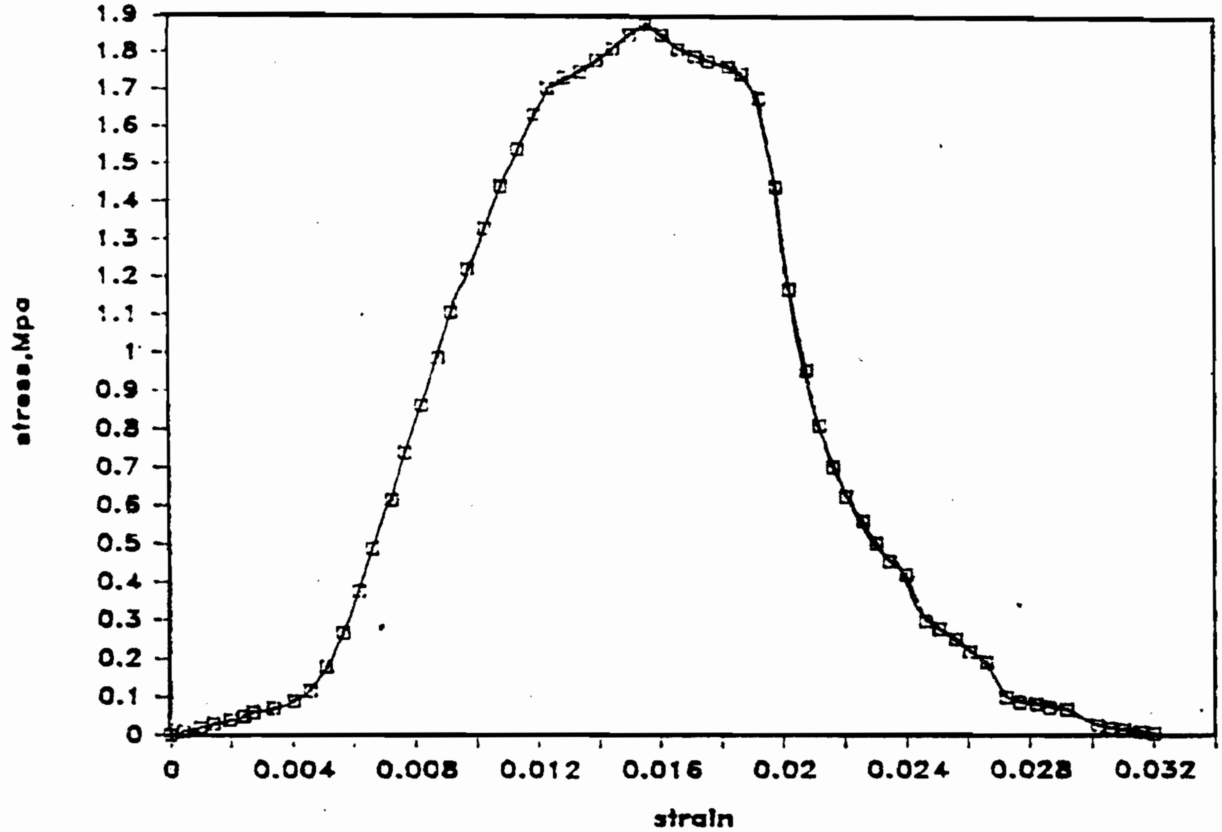
Typical stress/strain curve for ANPACK, 28 days old



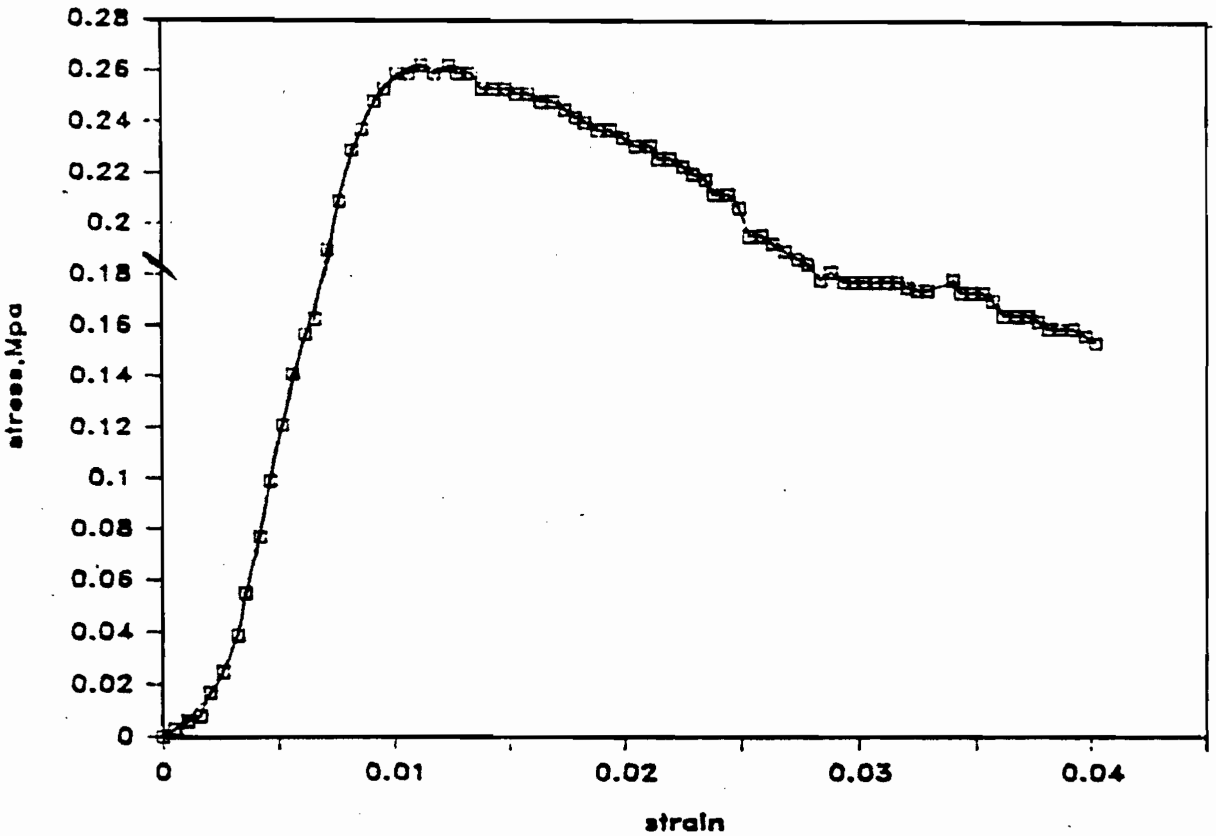
Typical stress/strain curve for PUMP PACK#2 ,7 days old



Typical stress/strain curve for ANPACK, 1 day old



Typical stress/strain curve for PUMP PACK#1, 7 days old



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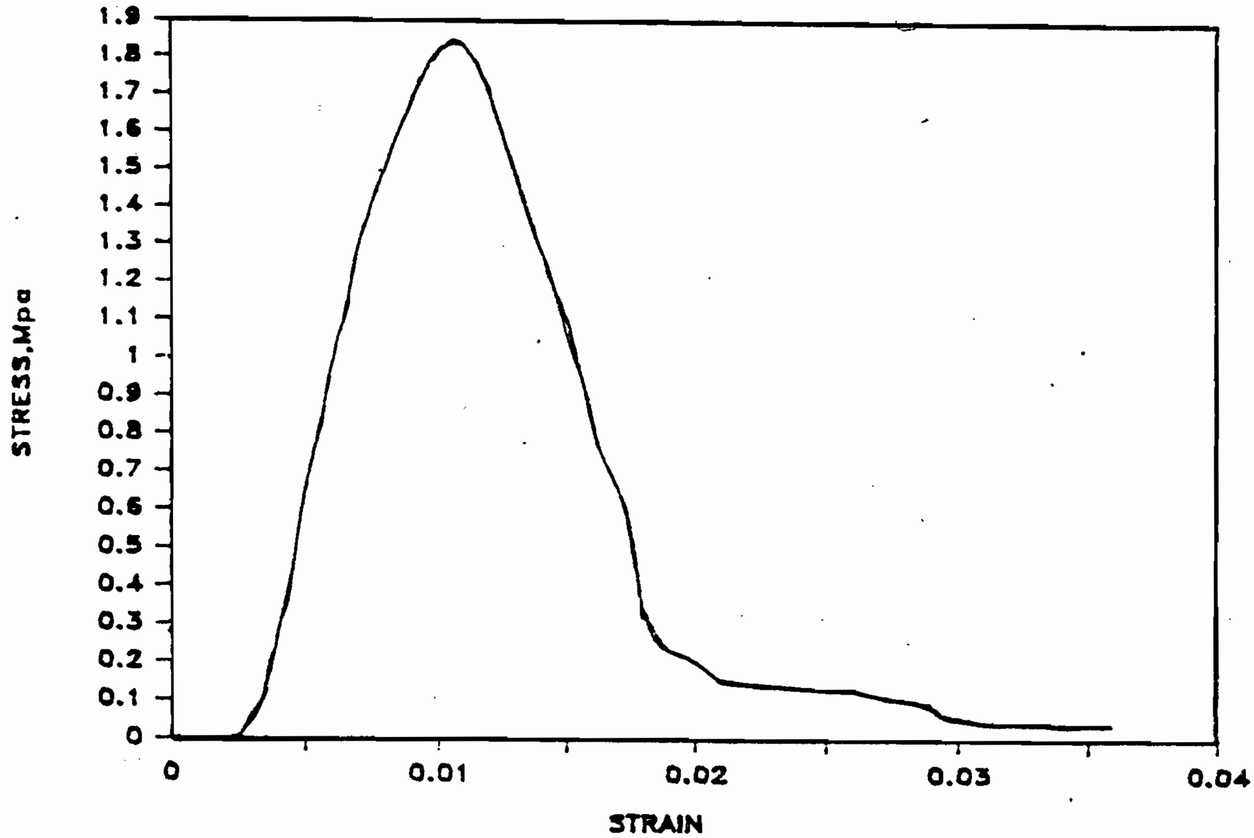
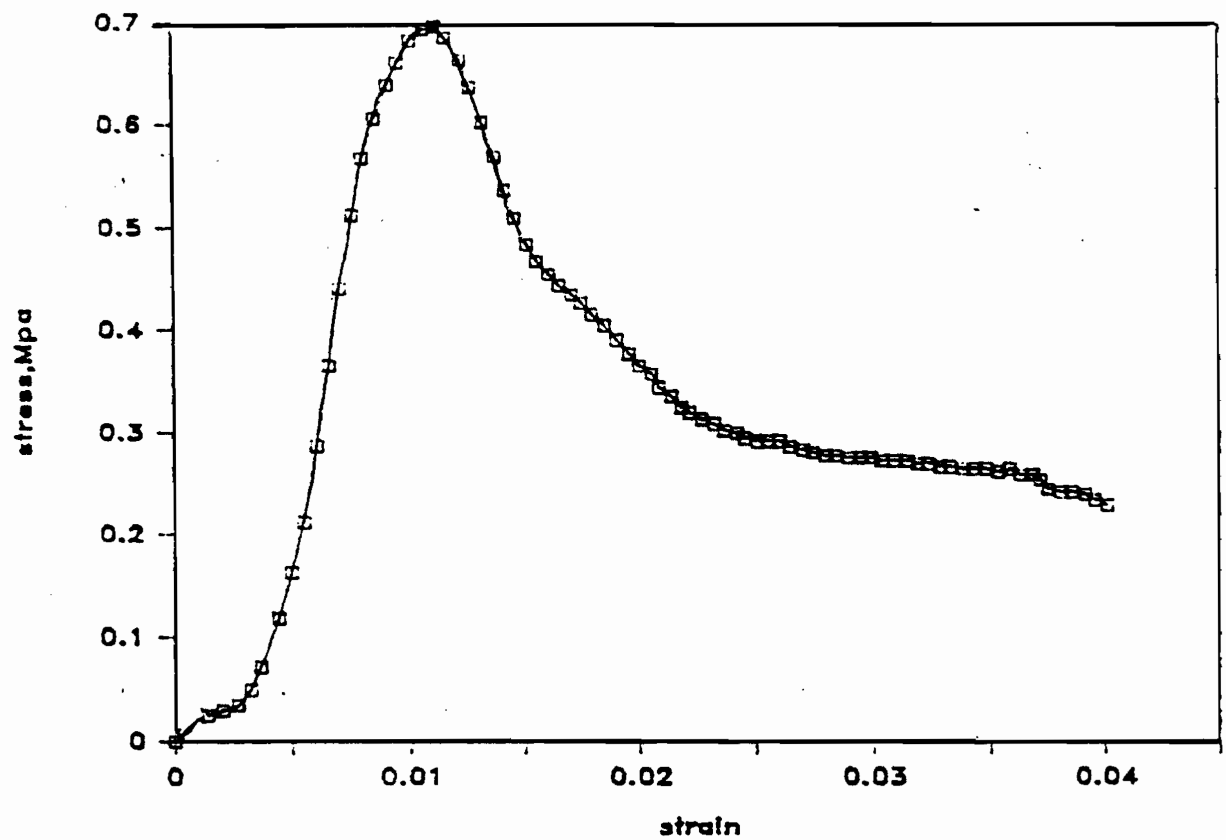
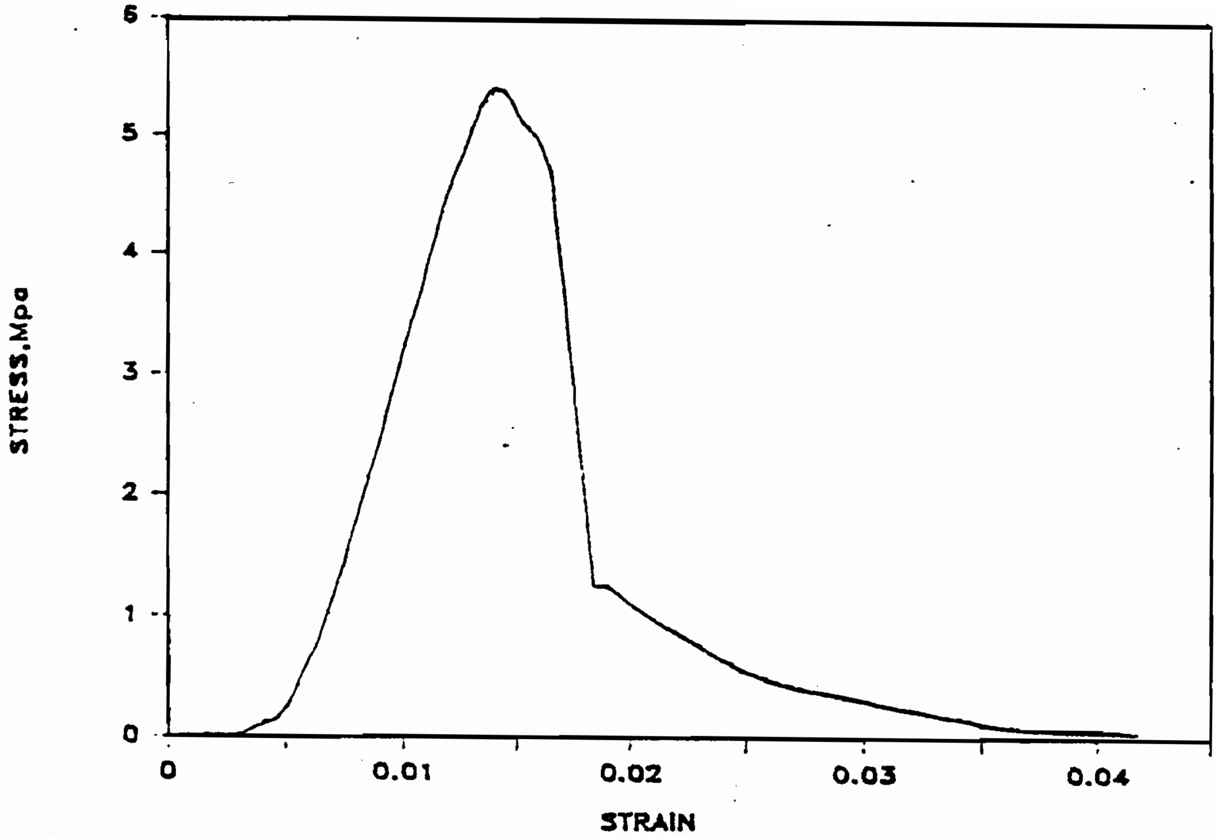


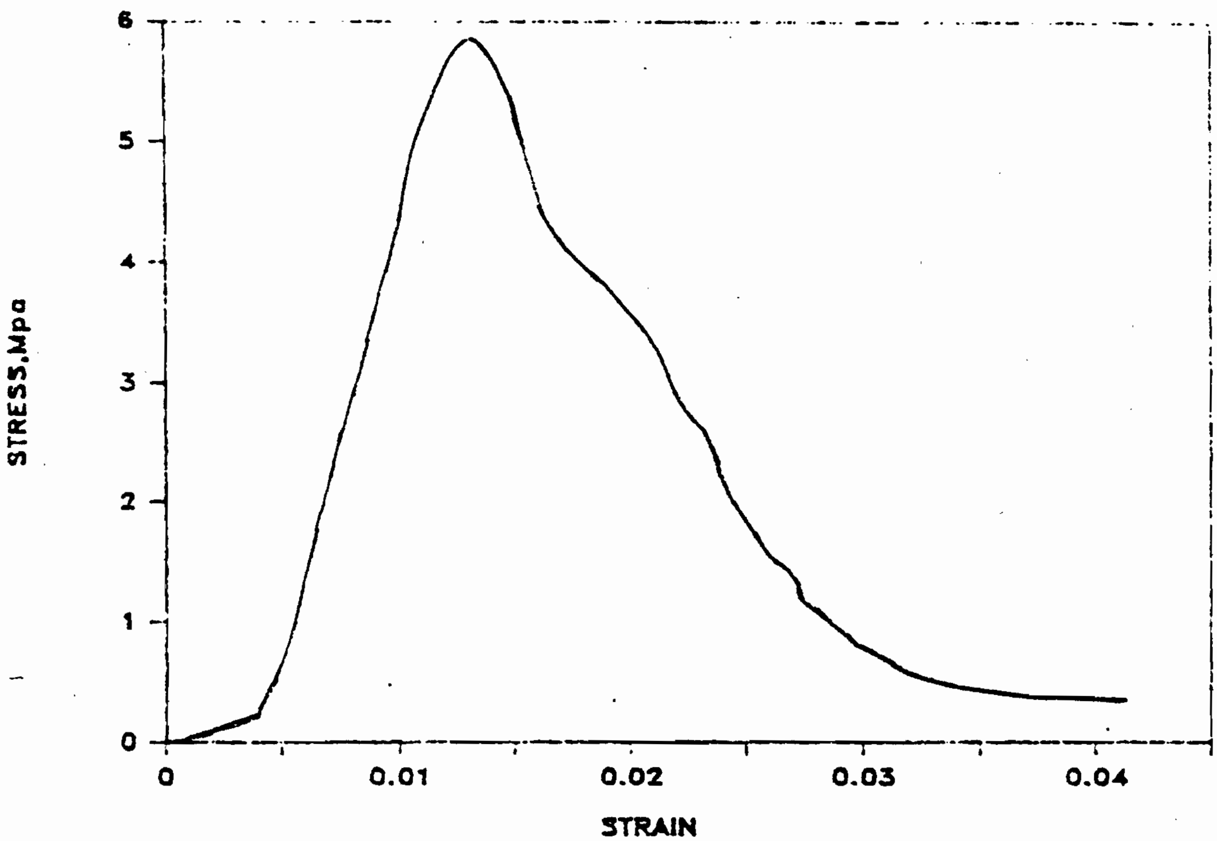
Typical stress/strain curve for ANFL-N size#1, 28 days old



Typical stress/strain curve for PUMP PACK #1, 3 days old



Typical stress/strain curve for ANFL-P size#1, 7 days old



Typical stress/strain curve for ANFL-P size#1, 28 days old