PHYSICAL AND MECHANICAL PROPERTIES OF PAPER MULCHES IN ASSESSING DEGRADATION

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ABSTRACT

PHYSICAL AND MECHANICAL PROPERTIES OF PAPER MULCHES IN ASSESSING DEGRADATION

A series of tests was performed in winter 1996 to measure degradation of paper mulches with the help of physical and mechanical properties. Four types of paper used for mulching, kraft paper gauge 40, 60 and 80 and waxed paper were laid over soil in two growth chambers. They were kept under observation for 27 days under controlled temperature, humidity and light. Mulches were sprayed with water to simulate rain. Tensile and puncture tests were performed on each type of paper every day. Four mechanical properties; stress, strain, energy and tensile energy absorption were calculated from the force-deformation curve obtained by tensile test. Two mechanical properties; displacement and force to break were calculated from the force-deformation curve obtained by puncture test. A special die had to be designed to perform puncture tests. This design eliminated shear loading which otherwise would have been present in normal puncture tests.

Results showed that paper - 3 (kraft paper gauge - 80) was best suited for mulching as the mechanical properties were stable through 27 days with negligible fluctuations. Waxed paper required less force to break but was stable through 27 days of experimentation.

A three-way factorial model was developed to analyze the results statistically. A SAS program was written to model the results. The fitted model was in very good agreement with the actual values.

RÉSUMÉ

UTILISATION DES PROPRIÉTÉS MÉCANIQUES ET PHYSIQUES POUR LA DÉTERMINATION DU NIVEAU DE DÉGRADATION DU PAPIER UTILISÉ COMME PAILLIS

Une série de tests a été effectué pendant l'hiver 1996 afin de mesurer le niveau de dégradation de paillis de papier à l'aide de l'évaluation de leurs propriétés physiques et mécaniques. Quatre types de papier ont été utilisés pour la confection du paillis, du papier kraft de calibre 40, 60, et 80 de même que du papier glacé. Les paillis ont été placés à l'intérieur de deux chambres de croissance où ils ont été maintenus sous observation pour une période de 27 jours dans des conditions controlées de température, d'humidité et de lumière. Les paillis de papier ont été vaporisés à l'eau afin de simuler des précipitations de pluie. Des tests d'élasticité et de perforation ont été effectués sur chaque type de papier et ce quotidiennement. Quatre propriétés mécaniques: flexion, tension, énergie, et absorption élastique d'énergie, ont été calculées à partir de la courbe de force-déformation découlant des tests d'élasticité. Deux propriétés mécaniques soit le déplacement et la force de rupture, ont été calculées à partir de la courbe de force-déformation découlant des tests de perforation. Une étampe a dû être spécialement conçue pour effectuer les tests de perforation. Ce modèle d'étampe a éliminé l'effort de cisaillement qui aurait été pré

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CHAPTER 1
INTRODUCTION

1.1 Mulch

In agricultural usage, mulch may be defined as any artificial modification of the soil surface (Flint, 1928). The primary utility of mulch has been thought to be the conservation of the soil moisture. In cultivated soils, the water loss, exclusive of the drainage takes place through transpiration of plants and through evaporation from the soil surface. The almost universal practice of weeding aims to restrict transpiration to the productive plants. One way of weeding is to invert soil so that weeds are placed under the soil surface. Opposed to this contention is the one that such a disturbance of the soil exposes more moist soil to air and brings about a greater water loss. With the application of artificial mulches these losses could be controlled.

1.2 Different types of mulches

There are different types of mulches depending on the type of materials used, they are:

i) Soil Mulch
ii) Straw Mulch
iii) Paper Mulch
iv) Plastic Mulch

i) Soil Mulch - Soil mulches have a wide acceptance through the general practice of cultivation, although it is obvious that any acquired benefit from soil mulch obtained in this way does not need to be attributed to the conservation of soil moisture. In many cases, more over it would seem that the development of a soil mulch is of no significance and perhaps even harmful. Small-grain crops flourish without cultivation, and in some areas, cultivation is not practised with wider spaced crops except in incidental weed control; hence the functions of soil mulch, do not appear to be justified.

ii) Straw Mulch - The loss of soil moisture is reduced by the mulch partly through the diminution of weed growth and partly through the lessening of evaporation from the soil surface. The straw mulch, therefore, has appreciable advantages over the soil mulch as a conserver of soil moisture. Similar mulches composed of leaves, hay, dead weeds, and grass clippings are used in small gardens.

iii) Paper Mulch - The use of paper mulch came about through the problem of economical control of the rank weed growth on an irrigated sugar plantation in Hawaii (Flint, 1928). In field practice under such conditions, the crop refuse such as dead leaves, tops etc. was drawn into the middle spaces between the freshly cut rows and was allowed to remain there undisturbed while it decomposed under tropical, humid conditions and gradually became incorporated with the soil. This blanket of trash acted more or less as a weed suppression cover, but its lack of durability rendered its potency in this respect of a transitory nature. It occurred to C.F. Eckart, manager of the Olaa Sugar Co., at Olaa, Hawaii, that a more durable soil cover, such as a cheap grade of asphalt paper, might profitably be substituted for that afforded crop residue. The first use of mulching paper on Hawaiian crops was thereupon initiated by Eckart in 1914 (Flint, 1928). In 1916, Eckart extended the effectiveness of the paper mulch through the introduction of light weight paper, impervious to water, which was laid directly over the harvested stubble or seed cane. This mulch was readily pierced by the sharp young shoots, while the weed growth was kept down. The efficiency of the mulch was so great that its use became standard plantation practice and the paper itself was manufactured from the bagasse and wood pulp at Olaa.

iv) Plastic Mulch - After World War II, with flow of artificial polymers such as polyethylene and polyurethane into the market, plastics became a wide topic of interest for many agricultural applications. Hence, plastic mulches proved to be much cheaper and durable. Until recently, plastic mulches were considered the most economical and effective until more research on the effects of plastics on soil and plants proved that plastics in soil are not good for plants and environmentally not friendly. One of the problems with plastic mulch is removal of the plastic after its purpose is served. It cannot be left on the land as it can cause hindrance for other operations and it is quite labourious to remove plastic when the plants have already grown. There are advantages of using plastic for mulching such as durability, transparency or imperviousness to light, depending on the type of requirement, ease of application and their flexibility compared to other types of artificial mulching. But with more emphasis being given to environment, people are looking for substances which are degradable after the purpose is served.

CHAPTER 2

LITERATURE REVIEW

2.1 Mechanical properties of paper

The main factors which affect degradation of paper are Light, Temperature, Air pollution and time. Degradation can be measured two ways; by measuring the chemical changes or the change in physical properties. Figure 2.1 represents the factors which affect degradation and their parameters.

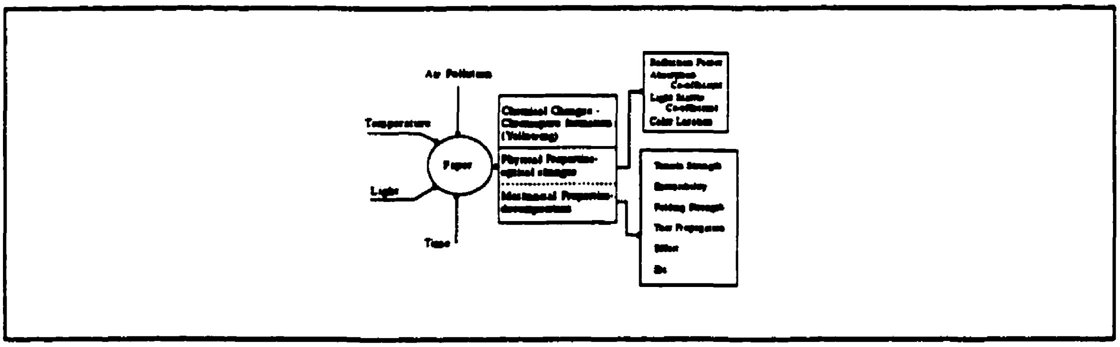

Figure 2.1, Representation of Degradation of Paper and its parameters.

One can view paper as a nonhomogeneous foil with a fibrous fine structure. The apparent flexibility and its range of thicknesses (30-300 μm) and mass distribution (10 - 300 g / m^2) merit the term foil-like for paper. However, close observation and quite simple experiments reveal an inhomogeneity of structure and a predilection for irreversible damage that defies attempts at classification with other foils. The nearest relative of paper or paperboard is probably wood veneer, but that is used in quite another way. Inhomogeneity arises firstly from the raw material, for fibres and fibre debris range over dimensions from millimetres to millimicrons. Finally, the drying process may involve local shrinkages of 20% (Dodson and Herdman, 1988). The upshot is that, though properties averaged over a square centimetre or so vary by only a few percent over a sheet of paper, these same properties may vary by a few tens of percent when averaged over a square millimetre. Since the resistance to small tensile deformations is proportional to areal density, it is important to note that the coefficient of variation of the latter (over areas of 1 mm^2) is 3-18%. For a given type of paper, greater inhomogeneity means reduced strength; if the above coefficient doubles then the 'modulus' can drop by 15%. For comparison, a similar drop is achieved by raising the temperature during testing by some 50°C. The anisotropy arising from the continuous nature of its manufacture leaves paper twice as resistant to small strains in the machine direction (direction of flow of paper while dried in the manufacturing process) as in the cross direction; one way of describing this is in terms of an equivalent pore as discussed by Silvy 1974. The same anisotropy causes unequal expansion upon saturation with water; 0.3% in machine direction, 3% in cross direction and 30% in thickness.

2.2 Molecular processes

It is fundamental that intra- and inter- fibre cohesion in paper arises from the same molecular phenomenon, the hydrogen bond(Kolseth and Ruvo 1987). Something of the order of 0.4% to 2% of all hydroxyl groups are additionally bonded in the manufacture of paper from cellulose fibres. The value of 4.5 kcal per mole OH (0.2 eV) as the average energy of hydrogen bonds in cellulose was determined by Nissan 1984. The average energy of hydrogen bonding was of the same order of magnitude as the mechanical energy consumed in the fracture zone during the tensile failure of paper strips. The idea of viewing cellulosic materials as essentially hydrogen-bonded solids was introduced by Nissan in 1984. Cellulose has rigid crystalline regions, and liquid like amorphous regions dominated by hydrogen bonds. Plainly these bonds, being non-linear entities, could be responsible for non-linearity in the mechanical behaviour of paper. They are also weak and hence might provide the mechanism for the internal fracture expected by Rance 1984.

2.3 Visco elastic properties of paper

The basic constituent in most paper is the pulp fibre. Bleached chemical wood pulp is almost pure cellulose, whereas unbleached pulp also contains hemicelluloses and lignin. Since all these three components are polymers, (i.e., consist of long molecular chains or large networks of covalently bonded atoms), it is natural to try to apply theory and test for polymeric materials on paper and paperboard. In order to discuss the viscoelastic properties of paper, it is therefore necessary to identify a few basic parameters and concepts from the field of polymer physics. A polymer material may possess both crystalline and disordered or amorphous regions or states. The crystalline phase is associated with a melting point, but for some polymers (such as cellulose) this temperature is so high that they decompose before they melt. The amorphous phase, however, does not have a melting point, but rather can be regarded as existing in a combination of two different states (Horoi et. al. 1951). At higher temperatures the polymer is rubbery or liquid like, whereas at temperatures below the glass transition point it is in many respects similar to ordinary inorganic glasses, showing, for instance, hardness, stiffness and brittleness. On passing through its glass transition, a 1000 fold reduction of elastic modulus is obtained in a completely amorphous polymer.

2.4 Wetting of paper

Wetting is a surface phenomenon; therefore, it is unsatisfactory to view paper as simply being composed of cellulose, hemicelluloses, and lignin, since the chemical composition of surface layers down to monomolecular thicknesses determines the wetting characteristics of paper (Lyne 1978). In particular, low surface energy resin and fatty acids present in all species of wood used for paper making tend to spread over the surface of paper, rendering it more hydrophobic.

Mechanically prepared wood pulp, such as that used in newsprint, also tends to have a very heterogeneous surface chemistry. In mechanical pulping, fibres are liberated from wood by physical degradation of middle lamella between the fibres. In order to increase opacity and promote interfibre bonding in paper, the surface area of the fibres is further "developed" by mechanically peeling the outer layers of the fibre wall. Lignin is more concentrated in the outer layers of the fibre. Thus paper made from mechanical pulp can vary in local lignin concentration due to variation in the degree to which the outer fibre layers have been stripped away and according to the location of the resulting debris, or fines. Since lignin is more hydrophobic than either cellulose or the hemicellulose, the surface chemistry varies locally with lignin concentration. The same can be said for the local concentration of resin-bearing ray cell fines in the paper sheet.

Surface morphology also plays a role in wetting. Drops of nonwetting liquids tend to exhibit higher contact angles on rough surfaces and tend to extend more readily along grooves or fibres than across them. Therefore, even paper made from chemically prepared wood pulps having relatively homogeneous fibre surface chemistries will exhibit local nonuniformities and anisotropy in wetting behaviour due to variation and orientation in fibre and network morphology.

The penetration of aqueous liquids into paper is further complicated by absorption into fibre walls and consequent increases in fibre wall thickness. It is thought that swelling occurs as aqueous liquids break and replace interchain hydrogen bonds in cellulose. Swelling appears to be proportional to the amount of liquid absorbed. and swelling of the fibre walls generally tends to close voids in the fibre surfaces while enlarging interfibre bonds in the fibre network. Thus the rate of capillary imbibition is generally altered by the absorption of aqueous liquids.

Properties such as wetting, absorption, and capillary imbibition can be altered by the addition of hydrophobic agents, during the manufacture of paper (typically rosin internally, starch, casein, polyvinyl alcohol, or wax emulsions externally). When added internally or added to the surface, they act chiefly to prevent absorption into the fibre walls and consequent swelling. Hard sizing can also be used to cause complete hydrophobicity or repellency.

Similar to the flow in inert liquids into and through paper, the flow of water has been investigated mostly in connection with practical problems and applications. Relatively few studies were directed towards the exploration of the phenomenon and Figure 2.2, shows what is possibly the only published record of a comparison between the flows of an organic liquid and of an aqueous solution through a sheet of pulp. An early study was stimulated by the observation that indicator papers used for testing the strength of acids or alkalis show a separation between the advancing water meniscus and that of the chemical which causes the colour change. A systematic investigation revealed that the separation increases with decreasing concentration of the solution. In capillary rise experiments, the ascents of acids and alkalis were compared after the water front had risen to a height of 100 mm, and it was found that as a rule, they were greater for weak (less dissociated) acids than for strong (more dissociated) acids of the same concentration. Alkalis showed the opposite behaviour; strong alkalis rose higher than weak alkalis.

The capillary rise of water in vertical strips of paper was studied by several authors Polcin, 1968, Kunaik, 1961 and Chatterjee, 1971. The materials used in these experiments were either filter papers or sheets of unbeaten pulp. The time scale of the experiments was in minutes or at most tens of minutes. It was also concluded that the swelling was not only slight but also fast, so that the water following the rising meniscus moved in a stable if possibly changed porous structure. Hence swelling of the fibres was therefore probably negligible.

Arledter, 1979, using mineral oils and aqueous resin solutions, reported results from which it appears that the time for complete penetration decreased with increasing temperature and to a different degree for different papers, including one where the viscosity of a silicone oil had no effect at all on the penetration time. The increase of the

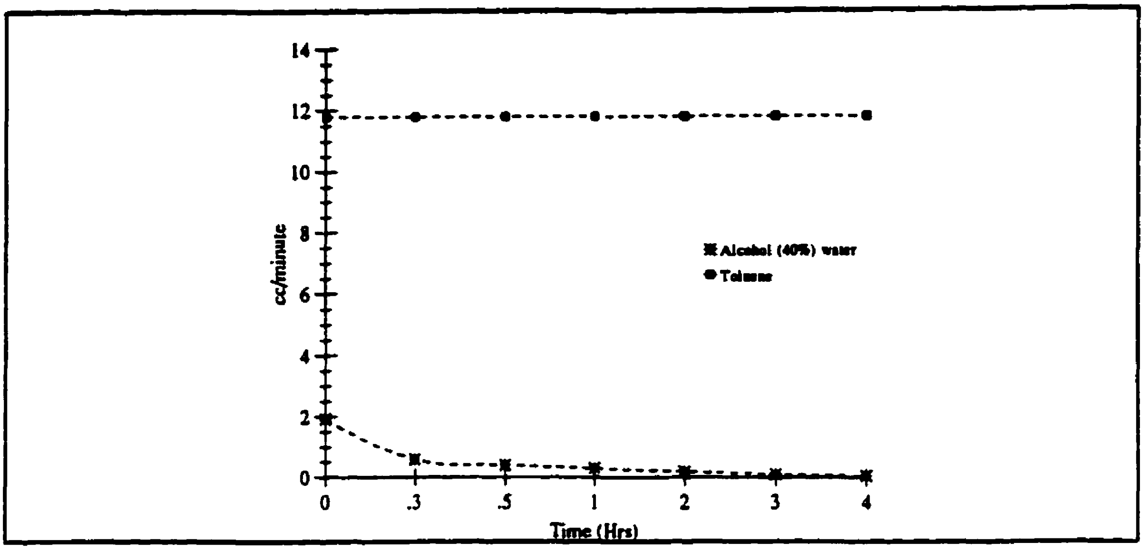

Figure 2.2, Flow of toluene and a mixture of alcohol through a pulp sheet.

viscosity of aqueous solutions reduces the rate of inter-fibre penetration but does not affect the rate of intra-fibre penetration. Claxton, 1956, found no effect of the viscosity of aqueous solution of adhesives on their rate of penetration. The total penetration times of sized papers by water and by a solution of CMC in water are essentially the same although the CMC solution was three times as viscous as water. Bristow found a linear relationship between the uptake of water and $t^{1/2}$ but with an intercept at about 5 g m^{-2} uptake at zero time. This fast initial uptake could be the filling of surface pores since 5 g m^{-2} is about half the basis weight of a single fibre. A rapid initial period of water uptake or penetration, followed by a slower one, was observed by several authors like Windle et al., Hoyland et al. and Clark et al. Together with the finite intercept at zero time, it is usually interpreted as the initial wetting (or strike-in or receptivity) phase, determined by the contact angle and its change. It sounds plausible enough but does not agree with the observation by Windle et al. that the addition of a wetting agent to the water causes a virtual disappearance of the fast initial period and makes the penetration-time curve much straighter. In addition, the opposite curvature (slower initial uptake, followed by a steeper branch linear in $t^{1/2}$) was found for water penetrating into hardboard and for alkaline solutions penetrating into rosin-sized liner board.

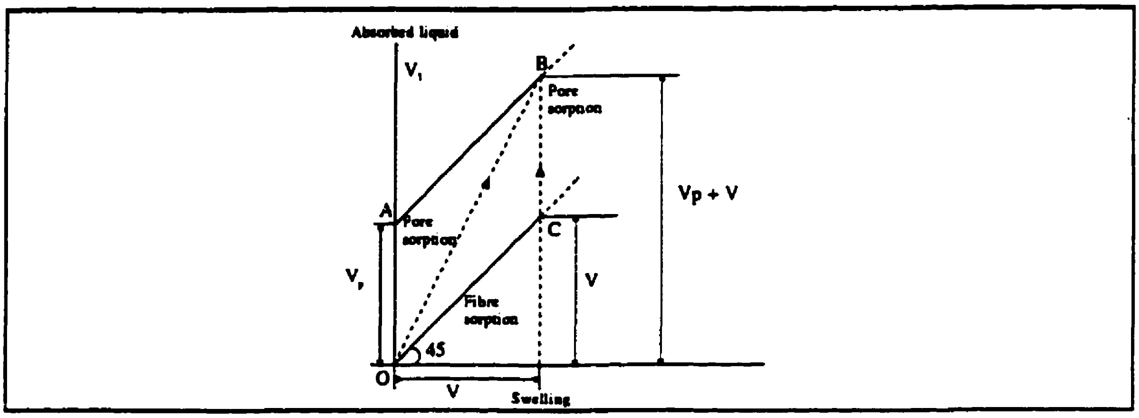

Figure 2.3, Bristow's Sorption Curves.

Bristow 1967, plotted the absorbed volume of water against the volume increase of the sample, expressed as the increase of its thickness and claimed that this presentation of data permits a separation between what he termed "pore sorption" and "fibre sorption". The distinction between the transport of water (or liquids in general) between and inside fibres had been made by several authors before, for example, Goring, 1963, and Bristows, 1967, procedures were designed to make the transport of water measurable. The model on which it is based is very simple and shown in Figure 2.3. It is certainly useful as a rough guide to grade papers whose absorption swelling curves occupy different regions of the parallelogram OCBA. To take it too literally, however, can lead to rather bizarre conclusions; for example, that in papers whose absorption-swelling curves lie below the line OC, the volume of the absorbed water is less than the volume increase owing to the fact that the pore volume has increased without the liquid being able to fill the space created. Uptake of water was always proportional to the square root of the time, whether the sorption-swelling curve was below or well above the line OC. Hoyland 1978 found that the depth of penetration as a function of the time and the degree of swelling can be described by the equation

$$h=(\alpha r\cos\Theta/2\eta)^{1/2}(t-t_w)^{1/2}-K(\delta Z) \qquad \text{------------(Eqn 1)}$$

In an attempt to give the above equation , a physical foundation, swelling was treated as a diffusion process.

2.5 Effect of Temperature , Moisture Content and Solar Radiation

2.5.1 Temperature

A survey of the literature shows that the influence of temperature on the physical properties of paper is well documented for properties such as moisture content and tensile strength, but that the effect of temperature on other properties has not been investigated as thoroughly as it might have been. The Testing Committee of The Technical Section, British Paper and Board Makers Association suggested that the effect of temperature within the range 13° to 22° C should be considered.

Among the most interesting observations is that tensile strength, which is already well-known to be strongly affected by humidity is also quite sensitive to temperature, there being a marked decrease as the temperature increases. A fifteen degree Celsius rise in temperature reduces tensile strength, on the average, by about 5 percent. Stretch-to-break generally increases as temperature rises but there is a lot of error associated with the measurement of this property. It is difficult to generalise about tear; on the whole there is no appreciable difference.

2.5.2 Moisture Content

It is now the usual practice to relate changes in moisture content to relative humidity and temperature but it was at one time considered that the moisture content of paper varied directly with the moisture content of the atmosphere, that is, was a function of the absolute humidity. Later opinion was that although it could not positively be shown that moisture content varied directly with either the absolute humidity or the relative humidity there appeared to be a closer relationship with relative humidity.(Brect. 1960)

The direction and magnitude of the effect of temperature changes on moisture content has also been a matter of controversy. Early papers (Kress and McNaughton, 1918 and McKee and Shotwell, 1933) reported that moisture content at constant relative humidity was a minimum at about 22°C, but it was later pointed out by Brecht. 1960, that this phenomenon was due to the high humidity (95% RH) at which the data were obtained. The same authors (Kress and McNaughton, 1918 and McKee and Shotwell, 1933) also disagreed on the relation of the moisture content to temperature at constant absolute humidity, the former finding no change in moisture content and the latter producing evidence of an appreciable decrease with increased temperature. Another report (Hoyland, 1978) that moisture content tended to increase with increasing temperature also stated that the differences observed were scarcely beyond the experimental error of the work. Further opinion was that temperature would become important only when extreme humidity changes take place. However, most investigators have shown that for moderate and constant relative humidities there is a linear drop of moisture content with rise in temperature and the changes, though small, are not negligible.

The time taken for the moisture content of paper to reach equilibrium in a given atmosphere depends upon a number of factors, Therefore it is impossible, without knowing the precise effect of these factors for a particular sample, to quote more than an approximate figure for its rate of conditioning. However, a few generalisations follow. The shape of moisture content - time of exposure curve is similar for all papers and is of exponential form

(Rhodius, 1978) that is, the rate of change of moisture content is proportional to the difference between the initial moisture content and the final equilibrium value. The time to reach equilibrium may vary considerably (from 1 hour to several days) but it is accepted that the greatest change takes place in the first few minutes of exposure. Increased basis weight slows down the rate of conditioning so while a thin paper may be conditioned within the hour a heavy board may take more than 24 hours to reach the same equilibrium. Good air circulation is necessary for fast conditioning and this implies that a sheet of paper fully exposed rather than left folded will condition more rapidly. The type of paper and its finish or sizing also affect the rate of change of moisture content.

One very important factor is the direction of approach to equilibrium, whether by adsorption or by desorption of moisture; in desorption it takes about three times as long is required as by adsorption. An increase of temperature is reported to have negligible effect on the rate of adsorption in vacuum but it has also been found that paper in a conditioning machine conditions more quickly when the temperature is increased.

A paper in equilibrium with an atmosphere of given relative humidity was found to have a higher moisture content if conditioning had been carried out by desorption from the wetter state, than by adsorption from the drier state (Huston, P. I et.al 1968). The difference between these two equilibrium moisture contents is at least 1% at 65% RH.

Changes of humidity influence paper and board properties to different degrees. Of the properties studied, folding endurance was the most affected, then follow in roughly descending order, moisture content, stretch, tear resistance, stiffness, dynamic tensile strength, static tensile strength, bursting strength, air resistance and thickness.

The most general conclusion must be that this study demonstrates the necessity of testing materials under standardized atmospheric conditions and that the previous conditioning history must also be known if precision is to be obtained.

2.5.3 Solar Radiation

The degradation caused by light radiation is more significant in the mechanical pulp containing paper. (Raysbro Oye. et. al 1991). The degree of brightness degradation is high in acid wood free paper at the lower wavelengths of light. However, in medium low quality papers, a sudden deterioration of the brightness was commonly observed. This is due to the absorption of carbonyl group and double bonds coexisting with benzene nuclei in lignin. (Rayabro Oye. et. al 1991).

2.6 Tests done by Technical Association of the Pulp and Paper Industry (TAPPI)

Any paper which comes out of the industry needs grading regarding its specifications. The grading can be done by testing samples to verify whether they satisfy the required standards. Physical properties play an important role in testing paper as they represent some physical parameters which show the quality of paper such as the strength of paper, texture, endurance which can be measured.

The Technical Association of the Pulp and Paper Industry, has standardized some of the tests which are done for quality assurance, but not all the tests are suitable to measure the degradation as applicable to our problem of quantifying deterioration of paper.

Following are some of the tests done by TAPPI

i) Tensile Test (TAPPI D.34)

ii) Zero Span Tensile (TAPPI D.27U)

iii) Endurance Test (TAPPI D.17P)

iv) Shear Test (Scotts Test)

v) Burst Test (TAPPI D.8)

vi) Tear Test (TAPPI 414 OM-88)

vii) Roughness Test (TAPPI D.29)

All the tests are done under controlled atmosphere, particularly temperature and humidity.

i) Tensile Test

A specified test sample is subjected to a tensile load and the maximum load which the sample can withstand is recorded by the load cell thus yielding the practical tensile load which the paper can withstand. In this test the composite tensile strength of the sample is gauged.

ii) Zero Span Tensile Test

In the previous test one could gauge the overall tensile strength of the paper sample but actually when a sample of certain length "L" (L>0) is subjected to a tensile load there are forces acting in many different directions and the load is not taken evenly by all fibres of the sample; therefore to compensate for this effect the length of the sample is reduced to zero (L=0) and load is applied to the surface shackles (Figure 2.4). The maximum tensile strength is recorded as gauge length is taken as zero; it is assumed that the load is applied on a single fibre.

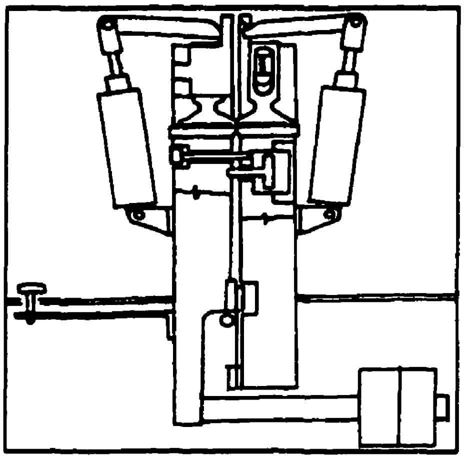

Figure 2.4 Zero Span tensile test
(schematic diagram)

iii) Endurance Test

The sample is subjected to a standard tensile load of 1 kg force and repeated bending is applied at a pivot point. The number of cycles at which the sample gives way at the pivot point is determined (Figure 2.5).

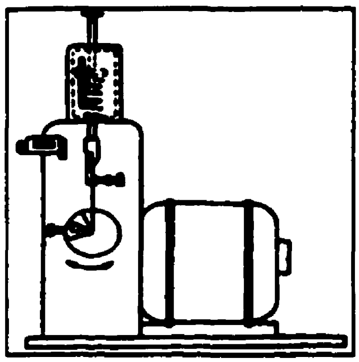

Figure 2.5, Endurance Test

iv) Scotts Test (Shear Test)

A paper sample is clamped (sandwiched) between two shackles and one of the shackles is subjected to transverse impact load. The shear resistance is calculated by recording the angular displacement of the load after the impact. Since energy lost due to impact is directly proportional to the angular displacement after impact, angular displacement is calibrated to the energy lost and thus the shear energy is determined.

v) Burst Test

This test is done to record the maximum pressure the paper sample can withstand.

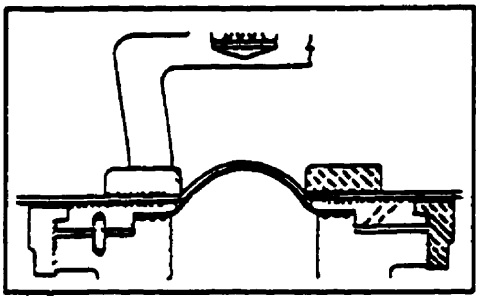
Figure 2.6, Burst Test

A paper sample is clamped between two shackles and a rubber inflatable membrane is positioned in such a way that when inflated it embraces the whole sample's one side area. (Figure 2.6) The membrane is inflated until the paper ruptures and the corresponding pressure is recorded at the point of rupture of the sample.

vi) Tear Test

Determination of the tearing resistance of paper consists of measuring the work done when a sample is torn through a specified distance. The work is done partly in rupturing the paper along the line of the tear and partly in bending the paper sample as it is being torn. The total work done, the length of the tear and the number of sheets torn together in the test are used to calculate a single force which, for the purpose of this method, is considered as the force required to continue the tearing of a single sheet of paper. (Figure 2.7)

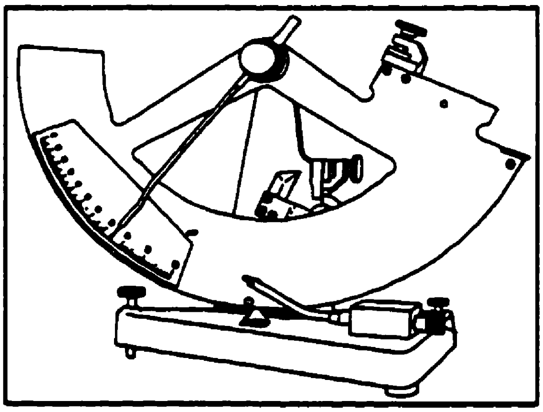
Figure 2.7, Tear test

vii) Roughness

Surface roughness is evaluated by determining the flow of air between the sample surface and the circular concentric lands (Figure 2.8). This is an air-leak type of roughness measurement, similar in principle to the Bekk and Bendtson testers. The flow is measured in Sheffield units. (millilitres/minute).

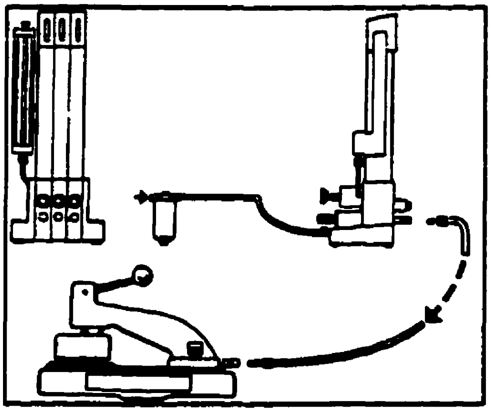

Figure 2.8, Roughness test

CHAPTER 3
OBJECTIVES

Temperature plays a major role in the degradation of paper, Tensile strength decreases where as extensibility increases with increase in temperature which is well documented in literature. Moisture content and solar radiation also play an important role in degradation. The effect of wetting on degradation of paper is not sufficiently documented, though one can find some literature on the effect of wetting on paper but not on its degradative properties. The simultaneous action of absorption and desorption is thought to be the main cause for degradation.

Following were the objectives for the experiments.

1) To determine whether paper degradation could be quantified effectively by measuring changes in mechanical properties during the degradation process.
2) To determine whether two types of tests (Tensile and Puncture) were sufficient to measure the variation of mechanical properties of paper.
3) To compare the quality of four types of paper for the purpose of mulching.
4) To determine the effect of wetting on the degradative properties of paper.

CHAPTER 4
MATERIALS AND METHODS

4.1 Types of paper used :-

Four types of commercially available paper which were commercially available were selected. They were three types of Kraft paper and a waxed paper.

Kraft paper - Kraft is usually second grade recycled paper, which has many applications other than mulching such as binding and packaging in industries. It is a non-coated paper which is commercially available in different gauges depending on the thickness, density and length of the paper rolls. The three gauges (thickness) of Kraft paper used were:

i) Gauge 40 (40 µm in thickness)

ii) Gauge 60 (60 µm in thickness)

iii) Gauge 80 (80 µm in thickness)

Waxed paper - Waxed paper is made of Kraft paper which is coated with paraffin wax on both the sides. Basically this type of paper is waterproof and found applied in packing industry.

4.2 Soil

Commercially available organic potting soil was used as the substrate for application of soil mulch. The soil was a blend of Sphagnum peat moss, perlite, vermiculite, organic black soil and other ingredients. It had good moisture retention and provided proper drainage and aeration and was free from fungi, weeds and insects.

4.3 Growth Chambers

The mulches were laid in two growth chambers of dimensions 1.82 m x 2.43 m. temperature and humidity were controlled and sun light was simulated by artificial lights which were on for 12 hours and off for 12 hours to simulate day and night (Figure B-1, Appendix-B). Ordinary tap water was sprinkled every 48 hours to simulate rain. Care was taken to achieve uniform wetting with no runoff. The growth chambers were maintained at a temperature of 22°C, humidity of 60% and radiation of 12 sunlight hours.

The process of wetting was complicated to quantify but as described in the section 2.4, absorption takes place within seconds and desorption takes more time. It was not the processes which was our objective but the effect of these processes on the physical properties of the paper used for mulches.

Wetting was quantified by amount of water sprinkled on each mulch on every alternate days. About 1.5 litres of water was sprinkled every alternate day using an atomiser over an area of 147 cms x 127 cms in each growth chamber.

4.4 Mechanical Testing Equipment

The mechanical tests were performed using an Instron universal testing machine. As the name indicates, it is a machine used to test various physical properties of materials (Figure B-2, Appendix-B). The basic concept is to apply a force on a given material of specific dimension. The force can be tensile, compressive, shear, etc and observations are made on how the material responds by monitoring some physical parameters such as displacement, force to break, yield point etc.

Two types of tests were performed. They were

1. Tensile test
2. Puncture test

4.5 Mechanical Tests :-

4.5.1 Tensile Test

The paper specimen was cut to dimensions of 30 mm by 100 mm. Thickness was measured using a Micrometer. Each specimen was mounted on a pair of shackles which operate pneumatically and then subjected to a tensile load (Figure - 4.1). The whole setup was mounted on the Universal Testing Machine (INSTRON) Series 4502. The testing machine was connected through a GIPB interface to an IBM 386 computer. An automated material testing software Series IX (V - 5.2) was used for machine controls. For each

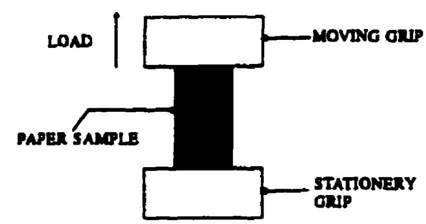

Figure 4.1, Schematic Diagram of the Tensile Test

experimental setup a test method was created for the Series IX software to be able to control the machine. The required initial data for the tests were based on some of the preliminary tests and literature on mechanical properties of paper. Once the procedure was established and saved, the main experiments started. Force and deformation were measured by the machine and transmitted to the computer as raw data. The raw data were used to compute Energy to break. (Figure B-3, Appendix-B)

First of all the Instron machine had to be calibrated i.e. when a 50 kN load is used it had to be initialized. After calibration, the specimen is mounted between the grips. The grips were pneumatically operated with compressed air. A maximum of 200 kPa pressure was used to operate the grips. One noticeable problem with the grips was the slippage of the specimen on application of the load. This was compensated by attaching a pair of rubber surfaces to the grips to give more friction. Care was taken to hold the specimen on a plane perpendicular to the grip as any misalignment would give room for shear loading.

After the specimen was placed the Instron machine had to be balanced, then displacement and load had to be initialized; the rest of the procedure is automatically executed by the computer. The computer calculates the stress, strain, Young's modulus, energy absorption and energy to break. This procedure would take about 10 minutes for one test.

4.5.2 Puncture Test

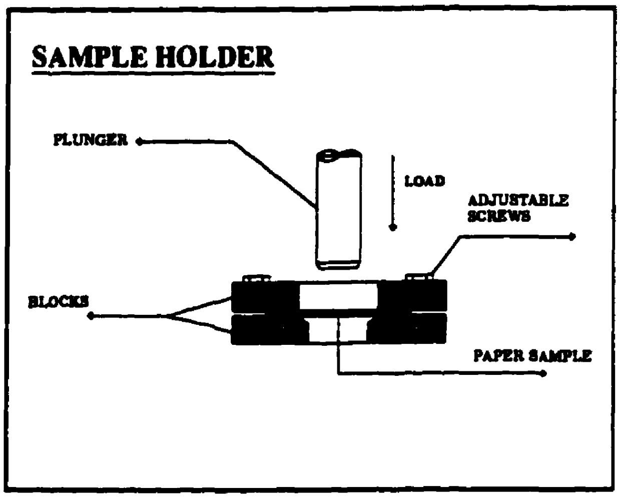

Figure 4.2, Schematic Diagram of Puncture Test Setup

For this test, a specimen was cut to dimensions of 50 mm by 50 mm. A special die was designed to hold the specimen. The die was made of mild steel and consisted of two blocks between which the specimen is held by 4 adjustable screws (Figure 4.2). The inner surface of the dies had to be broached to have a smooth surface to avoid any frictional load while testing. Load was applied through a plunger (dia 12.75 mm) which pierces perpendicular to the plane of paper through a circular opening (dia 35 mm) in the centre of the block. Edges of the opening were rounded to prevent unnecessary shear loading from otherwise sharp edges. The whole apparatus was mounted in the Universal Testing Machine. A different method was created for this test and the same procedure was followed as in tensile test. Raw data were used as input for the Series IX software which produced the specified outputs.

The test specimen was placed between the blocks, bolts were just tightened to hold the specimen firmly. The dead weight of the upper block itself was sufficient to hold the specimen, but to be on safer side, the four bolts were tightened to about a quarter turn past finger tight. The die was mounted on the machine and force was applied by moving the crosshead. A low speed of 10 mm per minute was used to evaluate the web strength of the paper. (Figures B-4 and B-5, Appendix - B).

4.6 Variables

Tensile load at Break - It is the max. force required to break the specimen in a tensile test. Force is measured in Newtons (N).

Displacement - It is the extension from the initial position until the specimen broke. It is measured in millimetres

Stress - It is the ratio of the Tensile load at break to the area over which the load is acting.

$$S=\frac{F}{A} \qquad \text{------------(Eqn 2)}$$

S = Stress, (Mpa)

F = load at break (kN)

A = Area in (m^2)

Strain at Break - It is the ratio of the displacement to the initial length of the specimen.

$$Z=\frac{\delta l}{L} \qquad \text{-----------(Eqn 3)}$$

Z = strain

δl = change in length (mm)

L = original length (mm)

Young's Modulus - is the slope of stress/strain curve.

$$Y=\frac{S}{Z} \qquad \text{-----------(Eqn 4)}$$

Energy to Break - Is the gross energy required to break the specimen which is measured in Joules.

Tensile energy absorption (T E A) - It is the energy absorbed by the specimen per unit length until it broke which is measured in kN / m

Dependent variables :-

Tensile Test:---- Displacement (mm), Load (N), Energy (J), T E A (kN/mm)

Puncture Test:--- Displacement (mm), Load (N).

4.7 Experimental design

A statistical model was constructed, where the four types of paper were considered as four treatments. Two growth chambers were considered as two blocks. Time was another factor.

A three way factorial design was chosen to address the objective of comparing the quality of four types of paper and degradation of the paper mulch as a function of time. A factorial design was appropriate because the interactions between four types of papers and the two growth chambers could be evaluated and their interaction with the time was also studied. Theoretically a repeated measures model would be a better way to evaluate any time based experiment, but the tests which were performed were destructive, which opposes the definition of repeated measures which states that the tests should be done on the same specimen.

The equation describing the experimental model is as follows;

$$X_{ijk}=\mu +a_i+B_j+T_k+(aB)_{ij}+(BT)_{jk}+(Ta)_{ki}+(aBT)_{ijk}+\epsilon_{ijk} \qquad \text{(Eqn 5)}$$

where

X ---- Variable, (displacement, force to break for both Tensile and Puncture tests, Energy, T E A for the tensile test.)

μ ---- Mean,

a ---- Treatment main effects (four types of paper)

B ---- Block main effects (two growth chambers)

T ---- Time main effects (degradation)

(aB) ---- Treatment by Block Interaction

(BT) ---- Block by Time Interaction

(Ta) ---- Time by Treatment Interaction

(aBT) ---- Interactions among all three factors.

ϵ ---- Error Term

i ---- Number of treatments (4)

j ---- Number of Blocks (2)

k ---- Number of time factors. (28)

The experimental layout is shown on Figure 4.3. Each growth chamber was considered as a block. Two replicates of each type of paper(treatment) were used because when one chamber is considered as a block, edge effects had to be taken into consideration, with two edges there was a probability of two edge effects for each block. As seen in the Figure 4.3, the edges AD and BC are perpendicular to the mulch layers. Hence any error due to these edges are compensated because whatever is the error, it is going to be the same for all the treatments. Hence edge effects in both the chambers (blocks) due to the edges AD and BC are compensated.

The randomization was done in such a way as to compensate the edges effect due

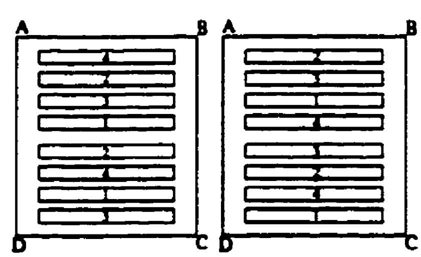

Figure 4.3, Experimental Layout.

to edges AB and CD in both the blocks. By exposing each type of paper once to the edge, AB and CD in any of the blocks edge effects were compensated. Hence with four edges and four replicates, the edge effects were compensated.

The data from the mechanical testing equipment were tabulated in Lotus - 123 and formatted in a print file. Results are shown in Appendix A.

A SAS programme was built for a three way factorial design and data were fed to the programme,

1. Displacement (tensile) - TENDISP
2. Load (Tensile) - TENLOAD
3. Energy to break (Tensile) - TENEGY
4. Tensile energy absorption (Tensile) - TENEGYAB
5. Displacement (Puncture) - PUNDISP
6. Load (Puncture) - PUNLOAD

4.8 SAS MODEL

```
DATA GROOVY;
INFILE 'C:\ROOT\NYM01.PRN' LRECL=150;
INPUT TIME TRT BLK TENDISP TENLOAD TENEGY TENEGYAB PUNDISP
PUNLOAD;
CARDS;
PROC SORT;
BY TIME TRT BLK;
PROC GLM;
CLASSES TIME TRT BLK;
MODEL TENDISP TENLOAD TENEGY TENEGYAB PUNDISP PUNLOAD=TIME
TRT BLK TIME*TRT TIME*BLK BLK*TRT TIME*TRT*BLK;
TEST H=TRT E=TRT*BLK;
TEST H=TIME E= TIME*BLK;
TEST H=TRT*TIME E=TRT*TIME*BLK;
LSMEANS TRT/E=TRT*BLK;
MEANS TIME TRT BLK/DUNCAN;
RUN;
```

CHAPTER 5

RESULTS AND DISCUSSION

Since the area of each specimen was a constant (i.e 30 mm x 100 mm for tensile test and 50 mm x 50 mm for the puncture test) and stress is a function of both load and area, it was logical to consider just load as a variable. Strain was a function of length and change in length due to applied force. Since original length of the specimen was a constant (i.e 100mm for tensile test) it was logical to consider strain as a function of displacement.

The puncture test was a modified compression test as discussed in section 4.6. One cannot consider Stress and Strain as variables because the actual area on which the load acts was not known and one cannot define strain, as force applied is perpendicular to the plane of paper. (Figure 4.2).

Since our objectives were concerned with the treatment (paper) main effects and their interaction with the time and blocks, time and block main effects and their interactions were neglected.

Duncan's Test was thought suitable, because pairwise comparisons had to be made to know if any of the treatment main effects were similar. This test was helpful in addressing some of our objectives.

5.1 Results of Tensile Test

5.1.1 Displacement at Break (Tensile)

ANOVA of the Statistical Model for the variable displacement at break is presented in Table 5.1. This table shows values of the Mean Squares and F values. In Table 5.2, analysis for the treatment main effects and their interactions are presented. This table shows degrees of freedom, type of sum of squares used, mean square values and F values. Duncan's test for pairwise comparison is presented in Table 5.3.

The F values are significant for the model as the F values are highly significant at 0.1 % level. (Table 5.1)

Treatment and time main effects are significant as the F values are highly significant at 0.1 % level. Block main effects and the interactions among time, treatment and block are not significant. (Table 5.2.)

Table 5.3 shows that the means are significantly different since none of the groupings have the same letter.

When displacement was plotted against time Figure 5.1, there was no similarity or no two curves followed the same trend. This indicates that each type of paper behaves independently with time. This was justified by the Duncan's test Table 5.3.

Overall evaluation of this particular plot is that, displacement was relatively uniform for waxed paper because of its inactivity to wetting. Hence there was no substantial change. For other papers, displacement increased with time and then attained a constant value through out the experiment.

Table - 5.1, ANOVA of the Statistical Model for the variable *Displacement at Break*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	223	281.27157177	1.26130750	8.82	0.0001 *
Error	224	32.03904241	0.14303144		
Corrected Total	447	313.31061418			

R-Square	C.V.	Root MSE	TENDISP Mean
0.897740	15.41131	0.37819498	2.45400982

* highly significant at 0.01 % level

Table - 5.2, Treatment main effects and their interactions for the variable *Displacement at Break*

Source	DF	Type I SS	Mean Square	F Value	Pr > F	
TIME	27	29.12489636	1.07869987	7.54	0.0001	*
TRT	3	222.39413671	74.13137890	518.29	0.0001	*
BLK	1	0.09152002	0.09152002	0.64	0.4246	
TIME*TRT	81	15.88717574	0.19613797	1.37	0.0369	
TIME*BLK	27	3.87121155	0.14337821	1.00	0.4666	
TRT*BLK	3	0.17447257	0.05815752	0.41	0.7484	
TIME*TRT*BLK	81	9.72815881	0.12010073	0.84	0.8184	

* highly significant at 0.01% level

Table - 5.3, Results of the Duncan's Test for the variable *Displacement* Means* and Paper Types

Tensile Test

Grouping	Mean	Paper Type
A	3.30256	Paper G-80
B	2.65759	Paper G-60
C	2.50703	Paper G-40
D	1.34886	Waxed Paper

$\alpha = 0.05$, MSE = 0.143031

* Means with the same letter are not significantly different.

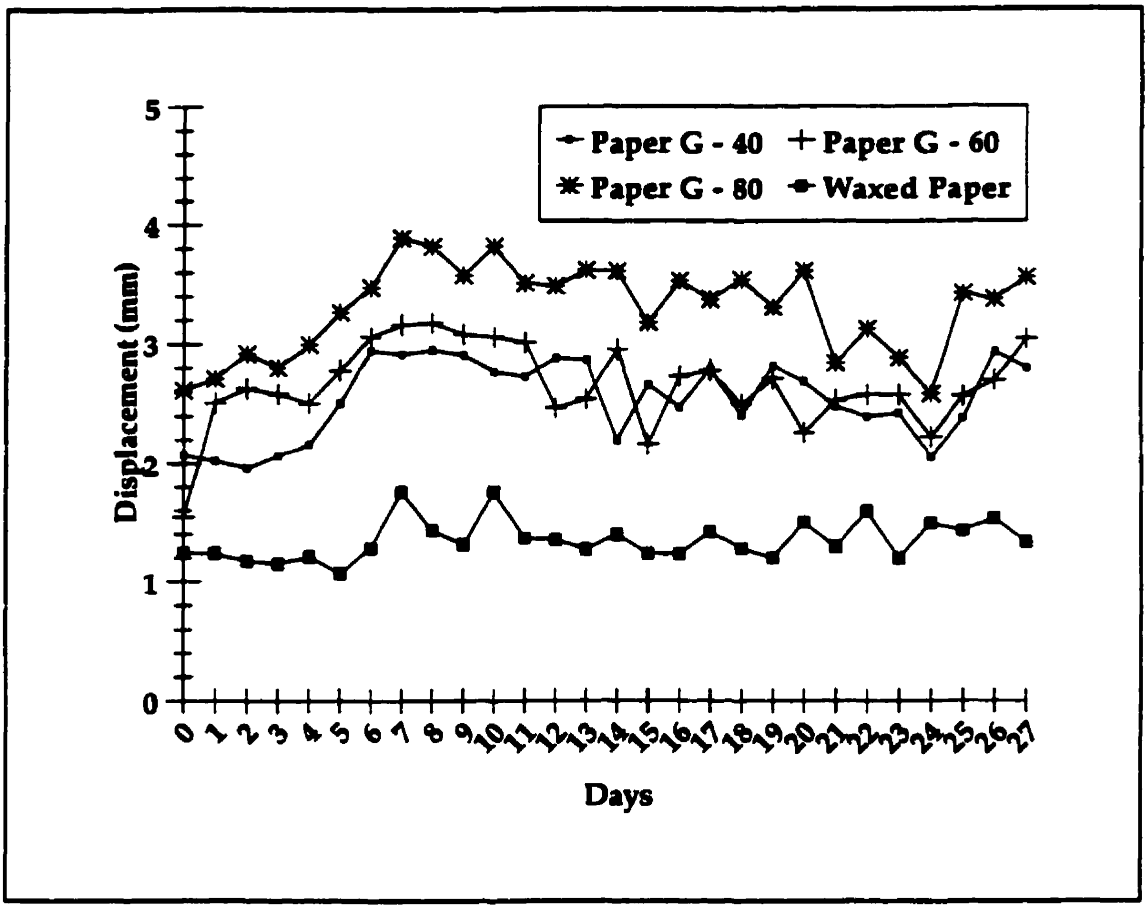

Figure 5.1, Variations in Displacement Vs Time (Tensile Test)

5.1.2 Load at Break (Tensile)

ANOVA of the statistical model for the variable load at break is presented in Table 5.4. This table shows values of the Mean Squares and F values. In Table 5.5, analysis for the treatment main effects and their interactions are presented. This Table shows degrees of freedom, type of sum of squares used, mean square values and F values. Duncan's test for pairwise comparison is presented in Table 5.6.

The F values are significant for the model as the F values are highly significant at 0.1 % level. (Table 5.4)

Treatment and time main effects are significant as the F values are highly significant at 0.1 % level. Block main effects and the interactions between time, treatment and block are not significant. (Table 5.5)

In Table 5.6, means of paper type 3 and 2 (i.e paper g-80 and paper g-60) are not significantly different since they both have same letters in the groupings.

When mean values of load to break are plotted against time, one can see that paper type 2 and 3 follow the same trend, whereas other two were independent as shown by the Duncan's test. (Table 5.6)

One can arrive at a conclusion that the stress vs strain curves for paper g-80 and paper g-60 were similar, as the force required to break the specimen was almost same. One more observation is that waxed paper required a lower force to break compared to other types of paper.

Table - 5.4, ANOVA of the Statistical Model for the variable *Load at Break*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	223	1.27521190	0.00571844	3.10	0.0001 *
Error	224	0.41295006	0.00184353		
Corrected Total	447	1.68816196			

R-Square	C.V.	Root MSE	TENLOAD Mean
0.755385	32.77503	0.04293631	0.13100313

* highly significant at 0.01% level

Table 5.5, Treatment main effects and their interactions for the variable *Load at Break*

Source	DF	Type I SS	Mean Square	F Value	Pr > F	
TIME	27	0.15169183	0.00561822	3.05	0.0001 *	
TRT	3	0.82278748	0.27426249	148.77	0.0001	*
BLK	1	0.00014743	0.00014743	0.08	0.7776	
TIME*TRT	81	0.13054011	0.00161161	0.87	0.7566	
TIME*BLK	27	0.03334877	0.00123514	0.67	0.8924	
TRT*BLK	3	0.00725622	0.00241874	1.31	0.2713	
TIME*TRT*BLK	81	0.12944005	0.00159803	0.87	0.7705	

* highly significant at 0.01% level

Table - 5.6, Results of Duncan's T for *Load at Break* Means* and Paper Types

Tensile Test

Grouping	Mean	Paper Type
A	0.175319	Paper G-80
A	0.170450	Paper G-60
B	0.101737	Paper G-40
C	.076506	Waxed Paper

$\alpha = 0.05$, MSE = 0.001844

* Means with the same letter are not significantly different.

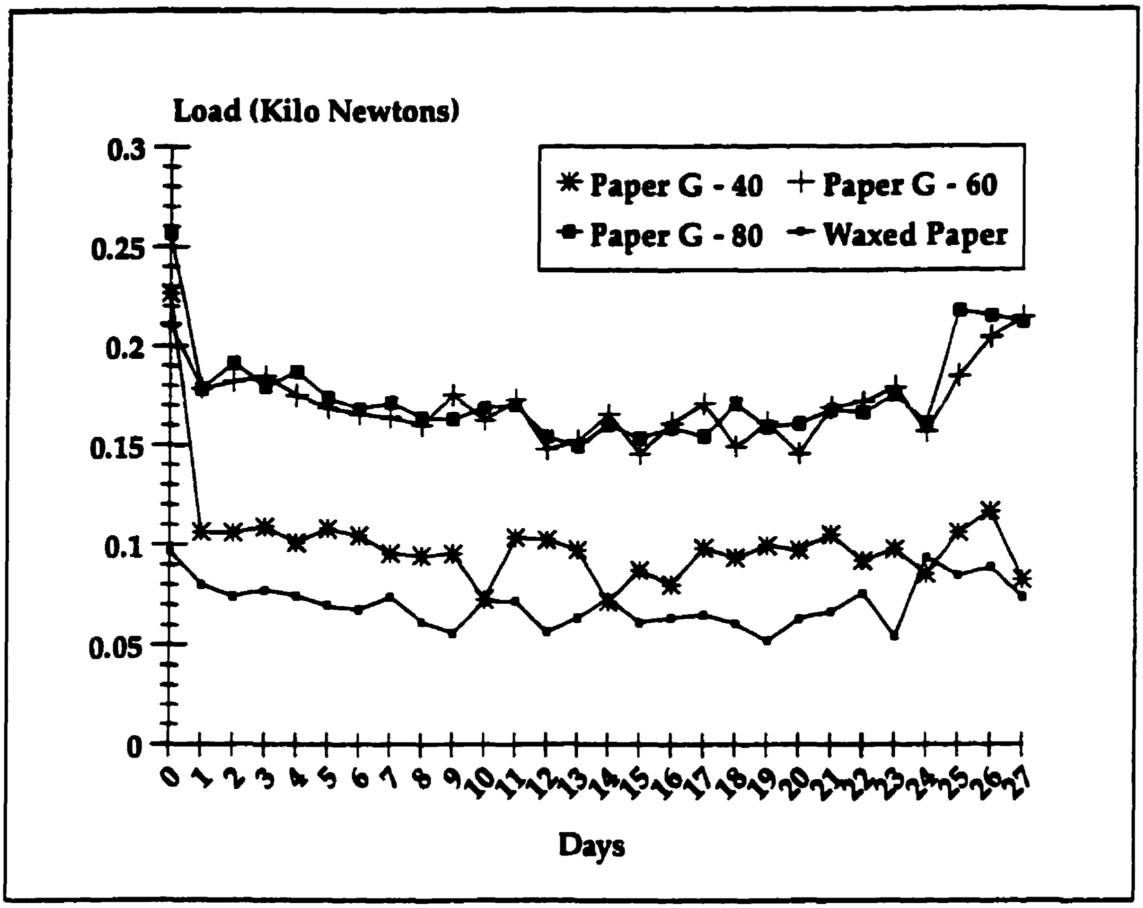

Figure 5.2, Load at Break Vs Time (Tensile Test)

5.1.3 Energy at Break (Tensile)

ANOVA of the statistical model for the variable energy at break is presented in Table 5.7. This table shows values of the Mean Squares and F values. In Table 5.8, analysis for the treatment main effects and their interactions are presented. This table shows degrees of freedom, type of sum of squares used, mean square values and F values. Duncan's test for pairwise comparison is presented in Table 5.9.

The F values are significant for the model as the F values are highly significant at 0.1 % level. (Table 5.7)

Treatment and time main effects are significant as the F values are highly significant at 0.1 % level. Block main effects and the interactions between time, treatment and block are not significant. (Table 5.8)

In Table 5.9, means are significantly different since none of the groupings have the same letter.

When energy at break was plotted against time Figure 5.3, there was no similarity or no two curves followed the same trend. This indicates that each type of paper behaves independently with time. This was verified by the Duncan's test. (Table 5.9)

The behaviour of all types of paper was independent of time (Figure 5.3), no two curves were similar which was confirmed by the Duncan's test.(Table 5.9) One noticeable feature was that there were many fluctuations in the behaviour of the waxed paper which indicates that energy required to break was independent of time.

Table - 5.7, ANOVA of the Statistical Model for the variable *Energy at Break*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	223	7.07654050	0.03173337	7.88	0.0001 *
Error	224	0.90242154	0.00402867		
Corrected Total	447	7.97896204			

R-Square	C.V.	Root MSE	TENEGY Mean
0.886900	28.37823	0.06347179	0.22366362

* highly significant at 0.01 level

Table - 5.8, Treatment main effects and their interactions for the variable *Energy to Break*

Source	DF	Type I SS	Mean Square	F Value	Pr > F	
TIME	27	0.34815382	0.01289459	3.20	0.0001	*
TRT	3	5.96230307	1.98743436	493.32	0.0001	*
BLK	1	0.00559845	0.00559845	1.39	0.2397	
TIME*TRT	81	0.38776291	0.00478720	1.19	0.1635	
TIME*BLK	27	0.06102683	0.00226025	0.56	0.9624	
TRT*BLK	3	0.01042611	0.00347537	0.86	0.4612	
TIME*TRT*BLK	81	0.30126930	0.00371937	0.92	0.6567	

* highly significant at 0.01% level

Table - 5.9, Results of Duncan's Test for variable *Energy at Break* Means* and Paper Types

Tensile Test

Grouping	Mean	Paper Type
A	.376331	Paper G-80
B	.278731	Paper G-60
C	.171362	Paper G-40
D	.068230	Waxed Paper

$\alpha = 0.05$, MSE = 0.004029

* Means with the same letter are not significantly different.

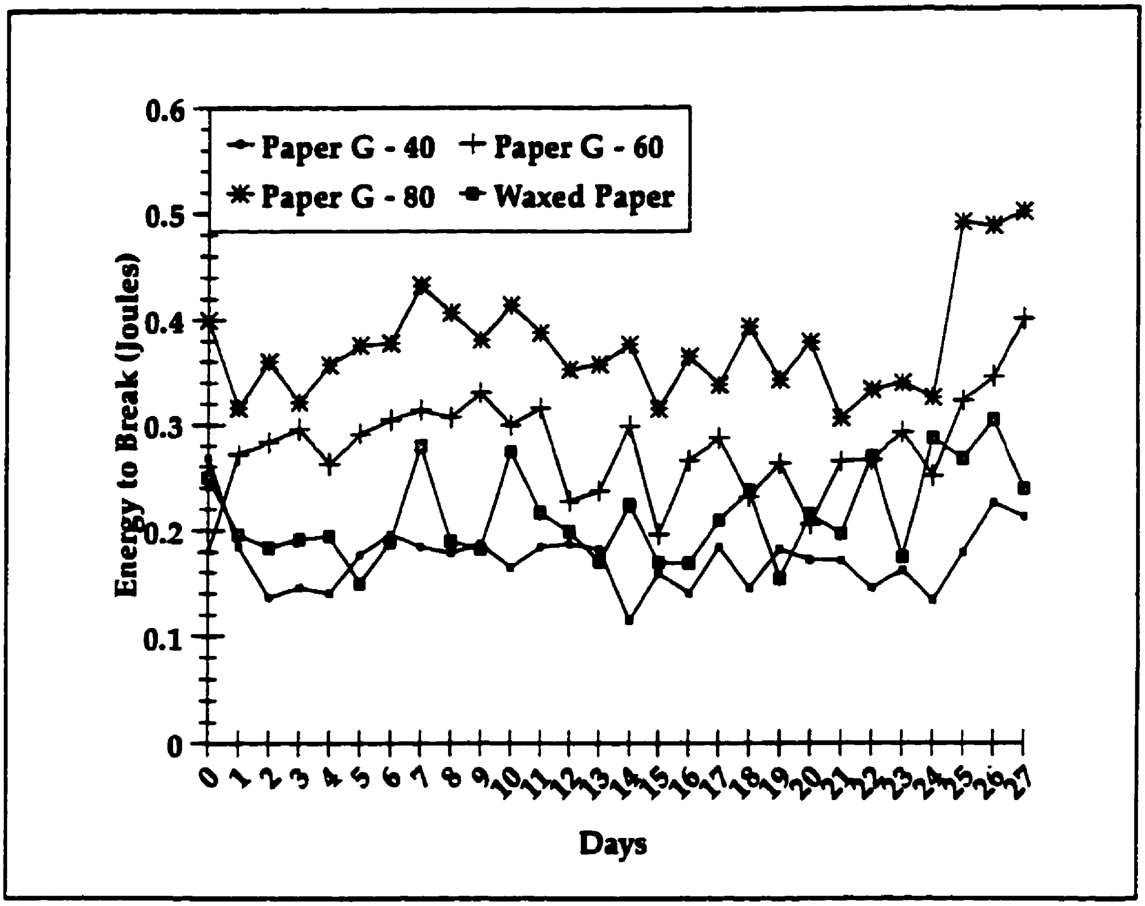

Figure 5.3, Energy at Break Vs Time (Tensile Test)

5.1.4 Tensile Energy Absorption

ANOVA of the Statistical Model for the variable Tensile Energy Absorption is presented in Table 5.10. This table shows values of the Mean Squares and F values. In Table 5.11, analysis for the treatment main effects and their interactions are presented. This table shows degrees of freedom, type of sum of squares used, mean square values and F values. Duncan's test for pairwise comparison is presented in Table 5.12.

The F values are significant for the model as the F values are highly significant at 0.1 % level. (Table 5.10) Treatment and time main effects are significant as the F values are highly significant at 0.1 % level. Block main effects and the interactions between time, treatment and block are not significant.(Table 5.11) In Table 5.12, means are significantly different since none of the groupings have the same letter.

When Tensile energy absorption was plotted against time (Figure 5.4), there was no similarity or no two curves followed the same trend. This indicates that each type of paper behaves independently with time. This was verified by the Duncan's test. (Table 5.12)

All four types of paper behave differently when this variable is considered, Figure 5.4 which is again confirmed from the Duncan's test Table (5.12). As anticipated paper- 3 (paper g-80) absorbs more energy than any other type because as discussed earlier tensile energy absorption increases with thickness and paper 4 (waxed paper) the least. Tensile energy absorbed by paper- 4(waxed paper) was uniform throughout the experiment.

Table - 5.10 , ANOVA of the Statistical Model for the variable *Tensile Energy Absorbtion*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	223	77.79597680	0.34886088	7.55	0.0001 *
Error	224	10.35290601	0.04621833		
Corrected Total	447	88.14888281			

R-Square	C.V.	Root MSE	TENEGYAB Mean
0.882552	29.35963	0.21498449	0.73224531

* highly significant at 0.01% level

Table - 5.11, Treatment main effects and their interactions the variable *Tensile Energy Absorption*

Source	DF	Type I SS	Mean Square	F Value	Pr > F	
TIME	27	3.91658251	0.14505861	3.14	0.0001	*
TRT	3	64.98511557	21.66170519	468.68	0.0001	*
BLK	1	0.10919695	0.10919695	2.36	0.1257	
TIME*TRT	81	4.35032618	0.05370773	1.16	0.1961	
TIME*BLK	27	1.07395132	0.03977597	0.86	0.6677	
TRT*BLK	3	0.05709085	0.01903028	0.41	0.7447	
TIME*TRT*BLK	81	3.30371341	0.04078659	0.88	0.7406	

* highly significant at 0.01% level

Table - 5.12, Results of Duncan's Test for Variable *Tensile Energy Absorption* Means*

and Paper Types

Tensile Test

Grouping	Mean	Paper Type
A	1.23266	Paper G-80
B	0.91351	Paper G-60
C	0.57113	Paper G-40
D	0.21168	Waxed Paper

$\alpha = 0.05$, MSE = 0.046218

* Means with the same letter are not significantly different.

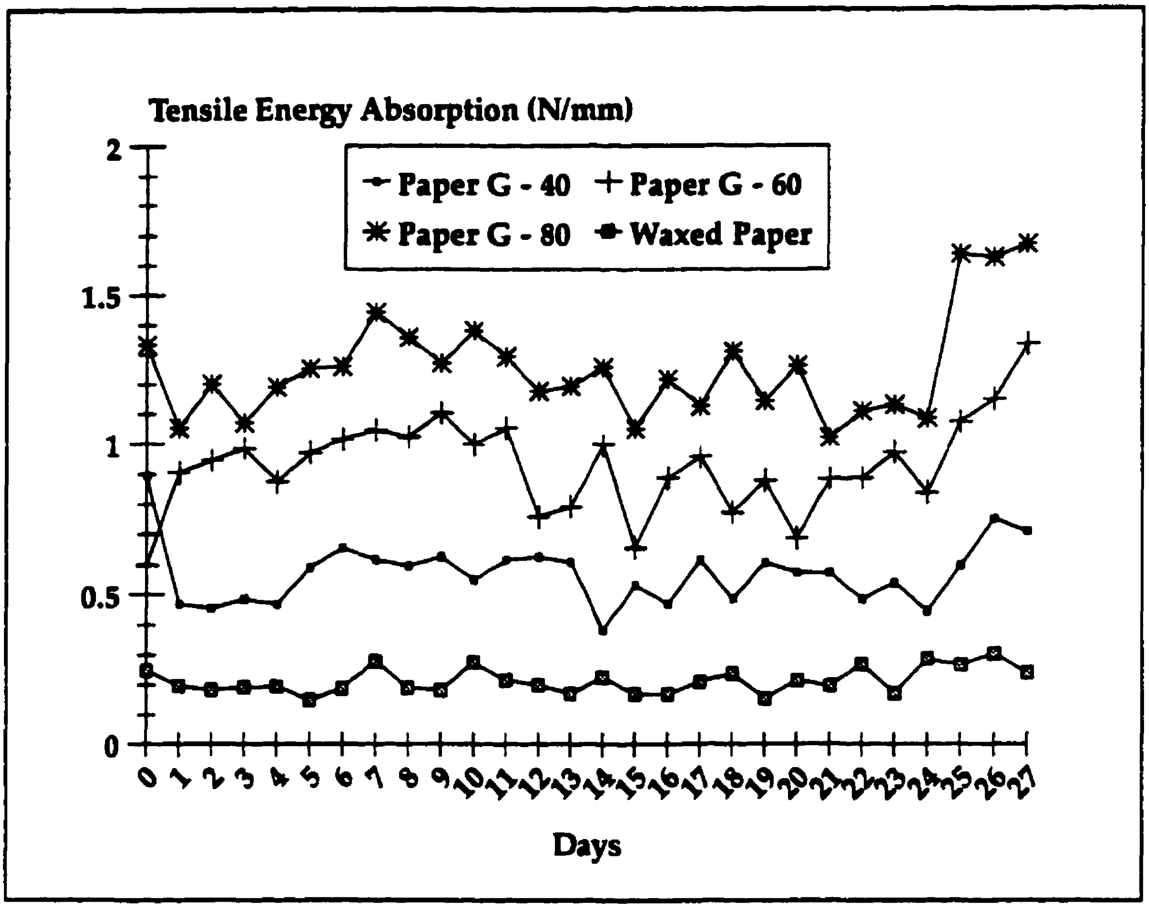

Figure 5.4, Tensile Energy Absorption Vs Time (Tensile Test)

5.2 Results of the Puncture Test

5.2.1 Displacement at Break

ANOVA of the Statistical Model for the variable Displacement at Break is presented in Table 5.13. This table shows values of the Mean Squares and F values. In Table 5.14, analysis for the treatment main effects and their interactions are presented. This table shows degrees of freedom, type of sum of squares used, mean square values and F values. Duncan's Test for pairwise comparison is presented in Table 5.15.
The F values are significant for the model as the F values are highly significant at 0.1 % level. (Table 5.13). Treatment and time main effects are significant as the F values are highly significant at 0.1 % level. Block main effects and the interactions between time, treatment and block are not significant.(Table 5.14) In Table 5.15, means are shown to be

significantly different since none of the groupings have the same letter. When displacement was plotted against time (Figure 5.5), there was no similarity or no two curves followed the same trend. This indicates that each type of paper behaves independently with time. This was verified by the Duncan's test Table 5.12.

As seen in Figure 5.5, no two curves follow the same trend which was confirmed by the Duncans test Table 5.15. As seen in this parameter, extensibility of the type - 4 paper is almost same as that of other paper. This means that, as far as web-strength is concerned, waxed paper opposes external force in the same magnitude as other three types of paper.

Table - 5.13, ANOVA of Statistical Model for the variable *Displacement at Break*(Puncture)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	223	130.97537064	0.58733350	8.46	0.0001 *
Error	224	15.54786750	0.06941012		
Corrected Total	447	146.52323814			

R-Square	C.V.	Root MSE	PUNDISP Mean
0.893888	7.899457	0.26345801	3.33514062

* highly significant at 0.01% level

Table - 5.14, Treatment main effects and their interactions for the variable *Displacement at Break*

Source	DF	Type I SS	Mean Square	F Value	Pr > F	
TIME	27	85.23317058	3.15678410	45.48	0.0001	*
TRT	3	12.83041940	4.27680647	61.62	0.0001	*
BLK	1	0.00073800	0.00073800	0.01	0.9180	
TIME*TRT	81	25.44407641	0.31412440	4.53	0.1723	*
TIME*BLK	27	1.07541644	0.03983024	0.57	0.9566	
TRT*BLK	3	0.34983040	0.11661013	1.68	0.1721	
TIME*TRT*BLK	81	6.04171941	0.07458913	1.07	0.3363	

* highly significant at 0.01% level

Table - 5.15, Results of Duncan's Test for Variable *Displacement at Break* Means* and Paper Types

Puncture Test

Grouping	Mean	Paper Type
A	3.58441	Paper G-40
B	3.38265	Paper G-80
C	3.24209	Waxed Paper
D	3.13141	Paper G-60

$\alpha = 0.05$, MSE = 0.06941

* Means with the same letter are not significantly different.

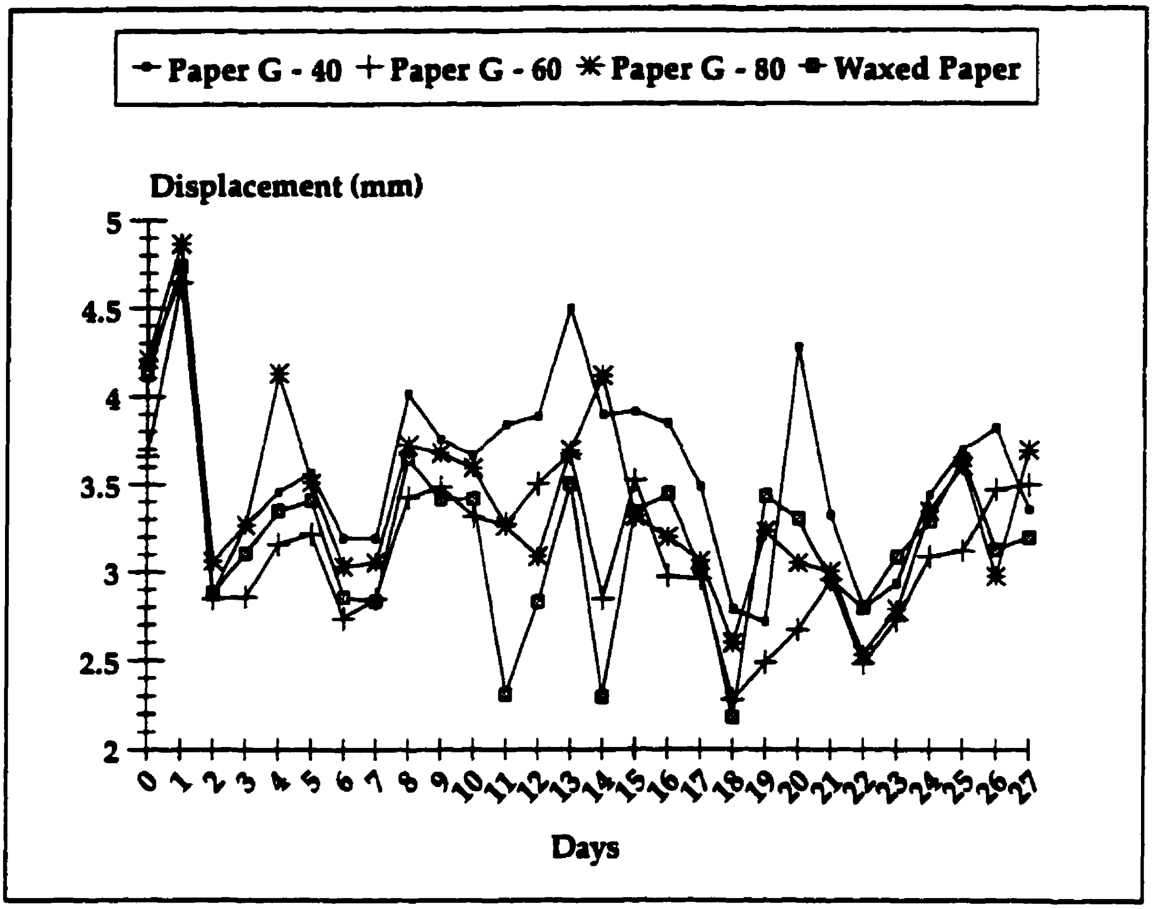

Figure 5.5, Variation of the Displacement at Break Vs Time (Puncture Test)

5.2.2 Load at Break (Puncture Test)

ANOVA of the statistical model for the variable Load at Break is presented in Table 5.16. This table shows values of the Mean Squares and F values. In Table 5.17, analysis for the treatment main effects and their interactions is presented. This table shows degrees of freedom, type of sum of squares used, mean square values and F values. Duncan's Test for pairwise comparison is presented in Table 5.18.

The F values are significant for the model as the F values are highly significant at 0.1 % level. (Table 5.16)

Treatment main effects are significant as the F values are highly significant at 0.1 % level. Time, block main effects and the interactions between time, treatment and block are not significant. (Table 5.17)

In Table 5.18, means of paper 1 and paper 2 (i.e paper g-40 and paper g-60) are not significantly different since they both have same letters in the grouping.

When load was plotted against time (Figure 5.6), one can see that paper 1 and 2 (i.e paper g-40 and paper g-60) are similar and behave same way which was confirmed by the Duncan's Test, Table 5.18. Here again force required to rupture the type 4 was least and was uniform through out the Experiment, where as for type - 3 (paper g-80) it was high and there were a lot of fluctuations through time.

Table - 5.16, ANOVA of statistical Model for the variable *Load at Break* (Puncture)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	223	0.66318570	0.00297393	4.56	0.0001 *
Error	224	0.14605157	0.00065202		
Corrected Total	447	0.80923727			

R-Square	C.V.	Root MSE	PUNLOAD Mean
0.819519	28.49035	0.02553460	0.08962545

* highly significant at 0.01% level

Table - 5.17, Treatment main effects and their interactions for the variable *Load at Break*

Source	DF	Type I SS	Mean Square	F Value	Pr > F	
TIME	27	0.01807262	0.00066936	1.03	0.4338	
TRT	3	0.50929697	0.16976566	260.37	0.0001	*
BLK	1	0.00054384	0.00054384	0.83	0.3621	
TIME*TRT	81	0.06065284	0.00074880	1.15	0.2147	
TIME*BLK	27	0.01831159	0.00067821	1.04	0.4159	
TRT*BLK	3	0.00116102	0.00038701	0.59	0.6198	
TIME*TRT*BLK	81	0.05514682	0.00068082	1.04	0.3956	

* highly significant at 0.01% level

Table - 5.18, Results of Duncan's Test for the variable Force at Break *Load at Break*

Means* and Paper Types

Puncture Test

Grouping	Mean	Paper Type
A	3.58441	3
B	0.081338	1
B	0.0773469	2
C	0.054542	4

$\alpha = 0.05$, MSE = 0.000652

* Means with the same letter are not significantly different.

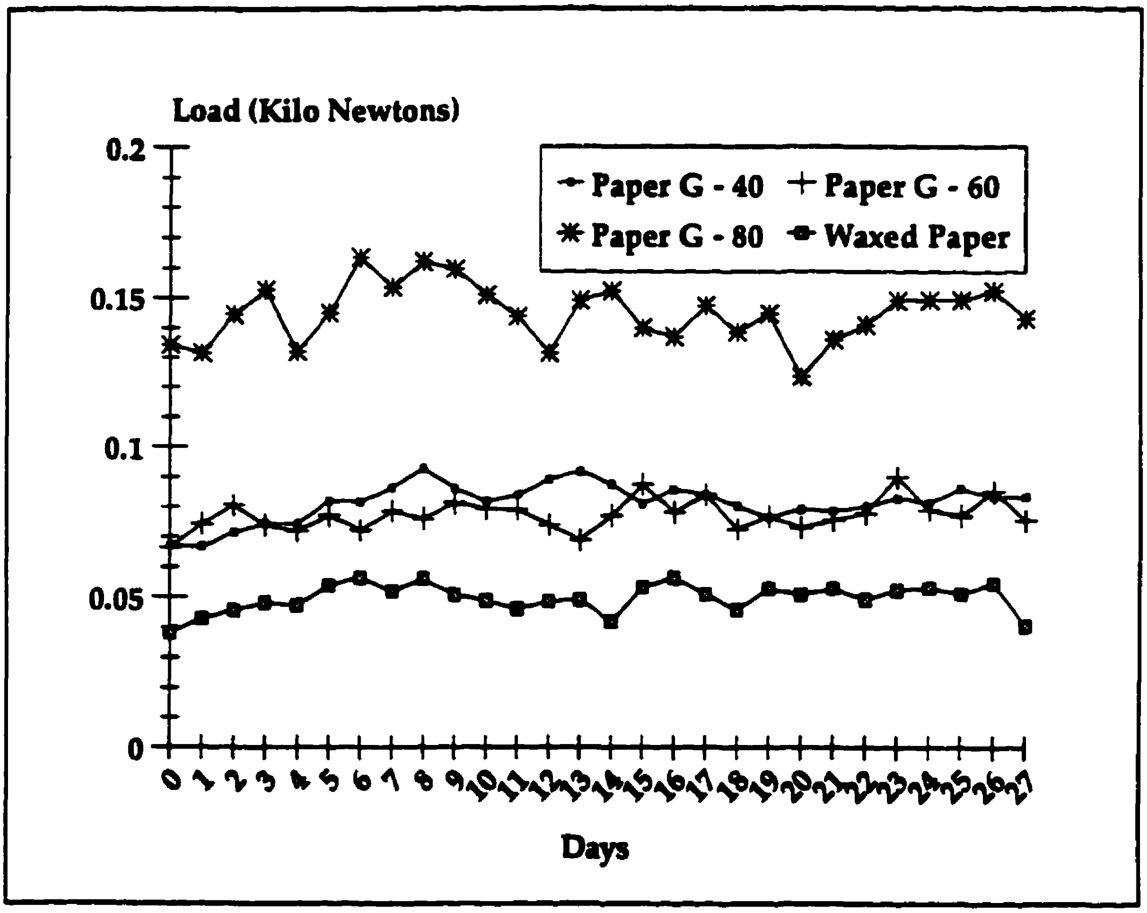

Figure 5.6, Load at Break Vs Time (Puncture Test)

CHAPTER 6
CONCLUSIONS

Conclusions drawn from this study can be stated as

1) Degradation can be quantified for different types of paper used for mulching, by making use of the physical and mechanical properties.

2) Of the two tests considered, the Tensile test was more effective than the puncture test in showing the variation of physical properties in paper.

3) Of the four types of paper considered for mulching Type -3 i.e, kraft paper gauge - 80 proved to be durable for mulching as the tensile force required to break even after 28 days was higher than the average tensile force of all the papers throughout the study.

4) Waxed paper showed one advantage; that is, most of the parameters considered were constant throughout the experiment. The degradation of waxed paper is not a function of time and the physical properties of this type of paper differ to an extent, when compared to kraft paper.

5) From the study, one can conclude that wetting plays an important role on the degradation properties. Wetting did not affect waxed paper as this type of paper is resistant to wetting. The method adopted was rather large scale observation, hence one could not get the effect of wetting at the micro structure of paper.

CHAPTER 7

SUGGESTIONS FOR FURTHER RESEARCH

Based upon the results of this study the following suggestions could be made for further research

1) Other than kraft or waxed paper, use of coated papers like lignin coated paper, L A S (Ligno Ammonium Sulphate) coated paper, plastic coated paper should be considered.

2) A study could be initiated for the measurement of physical and mechanical properties of paper with varying temperature, humidity, moisture content and radiation.

3) Use of other physical properties like tear, shear, burst, folding endurance, opacity, permeability etc.. to quantify degradation.

4) Wetting plays an important role in degradation, as discussed the effect of wetting immediately after wetting is important, hence a close observation of physical and mechanical properties after wetting is suggested.

5) The Statistical design could be considered as a repeated measures or a composite design instead of a factorial design.

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APPENDIX A

RESULTS OF TENSILE TESTS

AND

PUNCTURE TESTS

Results of Tensile and Puncture Tests

TE ------- Time (hours)

TRT ------ Treatments

B -------- Blocks

TENDIS --- Displacement at break (mm) (Tensile test)

TENLD ---- Load at break (N) (Tensile test)

EGY ------ Energy at break (J) (Tensile test)

TEA ------ Tensile Energy Absorption (kN/m) (Tensile test)

PUNDIS --- Displacement at Break (mm) (Puncture test)

PUNLD ---- Load at Break (N) (Puncture test)

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
0	1	1	1.481	0.2064	0.1615	0.5384	5.095	0.0695
0	1	2	2.805	0.1929	0.3382	1.127	3.763	0.0627
0	1	1	1.953	0.2538	0.2771	0.9237	4.099	0.0726
0	1	2	2.046	0.2531	0.2945	0.9816	3.814	0.0645
0	2	1	1.655	0.2339	0.2116	0.7052	3.48	0.0564
0	2	2	1.272	0.1614	0.1107	0.369	3.811	0.0753
0	2	1	1.636	0.2267	0.1958	0.6527	3.646	0.0638
0	2	2	1.623	0.2227	0.1994	0.6647	3.646	0.0638
0	3	1	2.382	0.2025	0.2884	0.9615	4.125	0.1344
0	3	2	2.711	0.4482	0.675	2.25	4.363	0.1288
0	3	1	2.925	0.2029	0.3823	1.274	4.342	0.1274
0	3	2	2.445	0.1717	0.2526	0.8421	4.009	0.1462
0	4	1	1.114	0.063	0.588	0.196	3.743	0.0347
0	4	2	1.432	0.1434	0.1141	0.3804	4.977	0.0216
0	4	1	1.377	0.0931	0.0747	0.2491	4.011	0.0502
0	4	2	1.041	0.0881	0.0513	0.1711	3.771	0.0462
24	1	1	1.782	0.0987	0.1102	0.3672	4.827	0.0748
24	1	2	2.376	0.1195	0.1771	0.5902	4.862	0.0742
24	1	1	1.48	0.0959	0.0908	0.3026	4.597	0.0632
24	1	2	2.463	0.1107	0.1844	0.6145	4.414	0.0544
24	2	1	2.37	0.1666	0.2348	0.7828	5.035	0.0844
24	2	2	2.624	0.1803	0.2898	0.9661	4 .134	0.0486
24	2	1	2.506	0.1796	0.2801	0.9338	4.869	0.0887
24	2	2	2.544	0.1862	0.281	0.9366	4.549	0.0761

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
24	3	1	2.234	0.1546	0.215	0.7168	5.446	0.1283
24	3	2	3.202	0.2134	0.4388	1.463	4.855	0.1432
24	3	1	2.603	0.1721	0.2926	0.9753	4.423	0.1199
24	3	2	2.807	0.1731	0.3177	1.059	4.746	0.1347
24	4	1	1.157	0.0824	0.0536	0.1785	4.056	0.0291
24	4	2	1.179	0.0698	0.0486	0.1619	4.895	0.05
24	4	1	1.339	0.0794	0.0674	0.2246	4.569	0.043
24	4	2	1.282	0.0886	0.0657	0.2189	5.437	0.0495
48	1	1	1.901	0.1012	0.1273	0.4244	5.699	0.0801
48	1	2	1.951	0.108	0.138	0.46	2.831	0.0724
48	1	1	1.959	0.1072	0.1431	0.477	2.964	0.0617
48	1	2	2.018	0.1072	0.1363	0.4544	3.003	0.0717
48	2	1	2.177	0.1537	0.1969	0.6562	2.773	0.0676
48	2	2	2.672	0.1916	0.2962	0.9873	2.793	0.0912
48	2	1	2.906	0.2012	0.3518	1.173	2.85	0.0819
48	2	2	2.751	0.1821	0.2892	0.9639	2.975	0.0819
48	3	1	2.981	0.2062	0.3827	1.276	2.925	0.1279
48	3	2	2.591	0.1856	0.3034	1.011	3.297	0.1643
48	3	1	2.704	0.176	0.3104	1.035	2.984	0.1405
48	3	2	3.381	0.1982	0.4437	1.479	3.035	0.1454
48	4	1	1.263	0.0715	0.0551	0.1838	2.756	0.0476
48	4	2	1.148	0.0771	0.0572	0.1908	3.079	0.049
48	4	1	1.232	0.0811	0.0614	0.2046	2.966	0.0516
48	4	2	1.035	0.0666	0.0464	0.1547	2.725	0.0345
72	1	1	1.971	0.1087	0.1392	0.464	3.119	0.0733
72	1	2	2.131	0.1188	0.1575	0.5251	3.319	0.065
72	1	1	2.312	0.1078	0.1647	0.5489	3.394	0.0859
72	1	2	1.863	0.0997	0.1215	0.405	3.239	0.0737
72	2	1	2.777	0.1943	0.3318	1.106	2.891	0.0688
72	2	2	2.537	0.1843	0.292	0.9732	2.779	0.0737
72	2	1	2.302	0.1808	0.2573	0.8576	3.019	0.0851
72	2	2	2.724	0.1787	0.3028	1.009	2.749	0.0681
72	3	1	2.397	0.1649	0.2415	0.8051	3.05	0.157
72	3	2	2.762	0.1969	0.3531	1.177	3.367	0.1647
72	3	1	2.98	0.1852	0.3498	1.166	3.213	0.1352
72	3	2	3.066	0.171	0.3424	1.141	3.447	0.1544
72	4	1	1.33	0.0742	0.0648	0.216	3.192	0.0531
72	4	2	1.083	0.0697	0.052	0.1733	3.081	0.0539
72	4	1	1.084	0.0802	0.0534	0.178	2.821	0.0407
72	4	2	1.103	0.0849	0.0595	0.1985	3.335	0.0446
96	1	1	2.352	0.1096	0.177	0.59	3.359	0.0745
96	1	2	2.046	0.1066	0.1363	0.4542	3.812	0.0843

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
96	1	1	2.115	0.0944	0.1275	0.4251	3.262	0.0712
96	1	2	2.123	0.0929	0.12	0.4	3.4	0.0671
96	2	1	2.509	0.1691	0.2436	0.812	3.243	0.0723
96	2	2	2.261	0.171	0.2189	0.7298	2.911	0.0643
96	2	1	2.56	0.186	0.2944	0.9812	3.381	0.0865
96	2	2	2.697	0.1753	0.2916	0.9719	3.096	0.0653
96	3	1	3.032	0.1806	0.3494	1.165	4.65	0.1524
96	3	2	3.059	0.1908	0.3739	1.246	3.375	0.1385
96	3	1	2.529	0.175	0.2712	0.904	3.565	0.129
96	3	2	3.361	0.2013	0.4344	0.1448	4.94	0.1082
96	4	1	1.259	0.0759	0.0591	0.1969	3.111	0.0494
96	4	2	1.093	0.0676	0.0469	0.1564	3.067	0.0454
96	4	1	1.184	0.0771	0.0607	0.2022	4.369	0.0556
96	4	2	1.295	0.0763	0.0666	0.222	2.849	0.0388
120	1	1	2.452	0.1039	0.1677	0.5591	3.462	0.0848
120	1	2	2.08	0.0993	0.1311	0.437	3.545	0.0818
120	1	1	2.72	0.1196	0.2104	0.7013	3.307	0.0705
120	1	2	2.766	0.1093	0.1968	0.656	3.956	0.0904
120	2	1	2.678	0.1584	0.2594	0.8647	3.107	0.0737
120	2	2	2.765	0.1667	0.2873	0.9576	3.296	0.0793
120	2	1	3.049	0.1834	0.3466	1.155	3.3	0.0807
120	2	2	2.625	0.167	0.272	0.9067	3.161	0.0741
120	3	1	3.074	0.1693	0.3406	1.135	3.639	0.1477
120	3	2	3.172	0.1771	0.3732	1.244	3.603	0.1466
120	3	1	3.036	0.1679	0.3366	1.122	3.436	0.1398
120	3	2	3.774	0.1815	0.4525	1.508	3.368	0.1456
120	4	1	0.825	0.0645	0.0316	0.1053	3.616	0.0599
120	4	2	1.414	0.076	0.0635	0.2115	3.498	0.0582
120	4	1	1.041	0.0708	0.0466	0.1554	3.342	0.0542
120	4	2	0.9828	0.0668	0.0382	0.1274	3.173	0.0431
144	1	1	3.377	0.1178	0.2515	0.8382	3.286	0.0903
144	1	2	2.868	0.1051	0.1862	0.6207	3.138	0.0694
144	1	1	2.369	0.0938	0.1422	0.4742	3.033	0.0869
144	1	2	2.369	0.1009	0.2047	0.6825	3.316	0.0794
144	2	1	3.167	0.1645	0.3112	1.037	2.78	0.0769
144	2	2	3.173	0.176	0.3365	1.122	2.895	0.0908
144	2	1	3.236	0.1783	0.3424	1.141	2.455	0.0615
144	2	2	2.663	0.144	0.2284	0.7614	2.819	0.0794
144	3	1	3.687	0.1686	0.3913	1.304	3.375	0.1931
144	3	2	3.839	0.1776	0.4518	1.506	2.972	0.1534
144	3	1	2.765	0.1455	0.2513	0.8377	2.81	0.1477
144	3	2	3.606	0.1818	0.4167	1.389	2.963	0.1595

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
144	4	1	1.144	0.0663	0.05	0.1667	2.428	0.0474
144	4	2	1.307	0.0602	0.0581	0.1938	3.204	0.0618
144	4	1	1.402	0.0724	0.0588	0.1959	2.98	0.0619
144	4	2	1.283	0.0712	0.06	0.2	2.805	0.0546
168	1	1	3.009	0.1048	0.2074	0.6914	3.106	0.0875
168	1	2	3.47	0.115	0.2531	0.8437	3.243	0.0937
168	1	1	2.353	0.0785	0.1184	0.3948	3.055	0.0773
168	1	2	2.825	0.0842	0.1599	0.5329	3.367	0.0868
168	2	1	2.989	0.1561	0.279	0.9301	2.827	0.075
168	2	2	3.079	0.1619	0.2977	0.9924	2.877	0.0807
168	2	1	3.174	0.1604	0.3177	1.059	2.926	0.0851
168	2	2	3.408	0.1787	0.3627	1.209	2.759	0.0738
168	3	1	4.26	0.1919	0.5241	1.747	3.099	0.1613
168	3	2	4.163	0.1757	0.4742	1.581	2.882	0.1392
168	3	1	3.336	0.1542	0.337	1.123	2.922	0.146
168	3	2	3.796	0.1644	0.395	1.317	3.316	0.1677
168	4	1	1.746	0.0722	0.0807	0.269	2.807	0.0487
168	4	2	1.926	0.0794	0.0955	0.3184	3.065	0.0588
168	4	1	1.41	0.0692	0.0579	0.1929	2.44	0.0422
168	4	2	1.958	0.0753	0.1017	0.3391	3.019	0.0574
192	1	1	2.724	0.094	0.1642	0.5474	3.964	0.0883
192	1	2	2.63	0.0926	0.1563	0.5209	3.714	0.0859
192	1	1	2.871	0.0926	0.1705	0.5682	4.29	0.1044
192	1	2	3.578	0.0986	0.2229	0.7431	4.091	0.0926
192	2	1	4.031	0.1968	0.4569	1.523	3.741	0.0899
192	2	2	3.253	0.1655	0.3106	1.035	3.382	0.0713
192	2	1	2.576	0.1263	0.2103	0.7009	2.957	0.0569
192	2	2	2.848	0.1531	0.251	0.8367	3.619	0.0858
192	3	1	3.42	0.1489	0.3294	1.098	3.881	0.163
192	3	2	3.78	0.1696	0.4122	1.374	3.643	0.1523
192	3	1	3.873	0.1657	0.4163	1.388	3.628	0.1579
192	3	2	4.208	0.1713	0.4701	1.567	3.748	0.1751
192	4	1	1.249	0.0612	0.0497	0.1655	3.724	0.0596
192	4	2	1.597	0.0657	0.0687	0.2289	3.708	0.0568
192	4	1	1.373	0.056	0.0475	0.1585	3.385	0.0513
192	4	2	1.501	0.0637	0.0615	0.2051	3.782	0.0567
216	1	1	3.088	0.0808	0.2111	0.7037	3.781	0.0799
216	1	2	2.663	0.1019	0.1718	0.5727	3.967	0.0983
216	1	1	2.746	0.096	0.1706	0.5686	3.591	0.0848
216	1	2	3.127	0.1024	0.1954	0.6513	3.601	0.0814
216	2	1	3.547	0.2006	0.4141	1.38	3.367	0.0662
216	2	2	2.98	0.1707	0.3146	0.1049	3.477	0.0861

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
216	2	1	2.772	0.1543	0.2725	0.9082	3.319	0.0774
216	2	2	3.027	0.1766	0.3232	1.077	3.779	0.0951
216	3	1	3.499	0.1543	0.3482	1.161	3.737	0.1661
216	3	2	3.671	0.1659	0.4006	1.335	3.765	0.1619
216	3	1	3.432	0.1588	0.353	1.177	3.829	0.1718
216	3	2	3.706	0.1739	0.4238	1.413	3.386	0.1381
216	4	1	1.062	0.0482	0.0393	0.1311	3.382	0.0528
216	4	2	1.684	0.0409	0.0732	0.2441	3.667	0.0554
216	4	1	1.394	0.077	0.07	0.2332	3.477	0.0481
216	4	2	1.095	0.0565	0.0362	0.1205	3.146	0.0461
240	1	1	2.615	0.0804	0.1661	0.5538	3.983	0.0907
240	1	2	2.66	0.1017	0.1657	0.5522	3.514	0.0748
240	1	1	2.593	0.0922	0.155	0.5165	3.388	0.0784
240	1	2	3.213	0.0154	0.1707	0.569	3.778	0.0825
240	2	1	3.154	0.1682	0.3145	1.048	3.264	0.0757
240	2	2	2.979	0.1554	0.2856	0.9521	3.616	0.0961
240	2	1	2.561	0.1489	0.2215	0.738	3.408	0.0877
240	2	2	3.542	0.1787	0.3375	1.258	2.984	0.0576
240	3	1	3.612	0.1661	0.3791	1.264	3.449	0.1501
240	3	2	3.989	0.1674	0.4241	1.414	3.819	0.1731
240	3	1	3.402	0.1586	0.3511	1.17	3.687	0.1459
240	3	2	4.279	0.1848	0.5015	1.672	3.426	0.1347
240	4	1	1.546	0.0737	0.0711	0.2369	3.131	0.05
240	4	2	1.951	0.0688	0.0899	0.2996	3.631	0.0558
240	4	1	1.664	0.069	0.0765	0.2551	3.221	0.0394
240	4	2	1.87	0.0752	0.0927	0.3089	3.697	0.0499
264	1	1	2.702	0.1038	0.1859	0.6197	3.843	0.089
264	1	2	2.816	0.1046	0.196	0.6532	3.738	0.0848
264	1	1	2.907	0.1046	0.1921	0.6403	3.877	0.0863
264	1	2	2.483	0.1002	0.1634	0.5445	3.899	0.075
264	2	1	2.911	0.1753	0.3101	0.1034	3.227	0.0745
264	2	2	3.637	0.2015	0.441	1.47	3.56	0.0867
264	2	1	2.768	0.1609	0.2649	0.8829	3.174	0.065
264	2	2	2.731	0.1539	0.249	0.8299	3.131	0.0891
264	3	1	3.358	0.1562	0.3432	1.144	3.287	0.1353
264	3	2	3.737	0.177	0.4214	1.405	3.23	0.1522
264	3	1	3.513	0.1602	0.3652	1.217	3.423	0.1539
264	3	2	3.429	0.1883	0.4221	1.407	3.107	0.1333
264	4	1	1.454	0.0771	0.0774	0.2579	2.317	0.0452
264	4	2	1.373	0.0694	0.0598	0.1992	2.261	0.0406
264	4	1	1.191	0.0646	0.0515	0.1715	2.257	0.0485
264	4	2	1.441	0.0751	0.0715	0.2383	2.406	0.0494

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
288	1	1	2.841	0.1095	0.2005	0.6685	3.759	0.0825
288	1	2	2.957	0.0978	0.1882	0.6274	3.554	0.0762
288	1	1	3.066	0.0974	0.1903	0.6343	4.257	0.0991
288	1	2	2.655	0.1038	0.1701	0.5671	3.972	0.0977
288	2	1	2.065	0.1201	0.1693	0.5642	3.586	0.0782
288	2	2	2.796	0.1692	0.2862	0.954	3.461	0.0724
288	2	1	2.716	0.1616	0.2604	0.868	3.442	0.0752
288	2	2	2.28	0.1412	0.1943	0.6477	3.524	0.0693
288	3	1	3.78	0.1721	0.426	1.42	3.591	0.1294
288	3	2	3.179	0.1346	0.2763	0.9209	2.895	0.1402
288	3	1	3.744	0.1548	0.3796	1.265	2.762	0.1065
288	3	2	3.241	0.1551	0.33	1.1	3.1	0.1496
288	4	1	1.56	0.0655	0.077	0.2568	2.735	0.0464
288	4	2	1.627	0.068	0.0755	0.2517	3.207	0.0504
288	4	1	1.246	0.0667	0.0557	0.1856	2.762	0.0437
288	4	2	0.9802	0.0255	0.0301	0.1005	2.611	0.0532
312	1	1	2.857	0.0985	0.184	0.6134	5.423	0.1136
312	1	2	2.925	0.0984	0.1974	0.658	4.412	0.0908
312	1	1	2.925	0.0995	0.182	0.6066	4.224	0.0847
312	1	2	2.746	0.0916	0.1638	0.5462	3.931	0.0776
312	2	1	1.805	0.1161	0.1272	0.424	3.772	0.0743
312	2	2	2.754	0.1625	0.2681	0.8937	3.71	0.0676
312	2	1	2.813	0.1663	0.2797	0.9322	3.552	0.0646
312	2	2	2.786	0.1627	0.2733	0.9109	3.648	0.0688
312	3	1	4.139	0.1554	0.4237	1.412	3.966	0.1423
312	3	2	3.413	0.1339	0.3013	1.004	3.457	0.1379
312	3	1	3.647	0.1503	0.3587	1.196	3.812	0.1592
312	3	2	3.311	0.1584	0.3474	1.158	3.543	0.1566
312	4	1	1.233	0.0739	0.0561	0.1869	3.189	0.044
312	4	2	1.393	0.0665	0.0643	0.2144	3.502	0.048
312	4	1	1.336	0.061	0.0479	0.1597	3.493	0.0458
312	4	2	1.117	0.0513	0.0363	0.1211	3.825	0.0583
336	1	1	3.111	0.0894	0.1867	0.6224	3.865	0.0815
336	1	2	2.597	0.0818	0.1389	0.4631	4.092	0.0875
336	1	1	1.295	0.0409	0.0463	0.1544	3.852	0.0915
336	1	2	1.789	0.0728	0.0872	0.2908	3.763	0.0892
336	2	1	3.217	0.1765	0.3436	1.145	2.771	0.0795
336	2	2	2.939	0.1711	0.3085	1.028	2.824	0.0795
336	2	1	2.722	0.1546	0.2579	0.8595	2.682	0.0843
336	2	2	2.94	0.1593	0.2864	0.9547	3.114	0.0644
336	3	1	3.883	0.1734	0.4354	1.451	4.16	0.1683
336	3	2	3.947	0.1664	0.4289	1.43	4.022	0.142

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
336	3	1	3.572	0.1477	0.3408	1.136	4.046	0.1504
336	3	2	3.049	0.1533	0.302	1.007	4.238	0.148
336	4	1	1.349	0.0737	0.0657	0.2189	2.874	0.0543
336	4	2	1.614	0.0742	0.0762	0.2538	2.623	0.0474
336	4	1	1.459	0.0799	0.0801	0.2671	2.857	0.0517
336	4	2	1.162	0.0637	0.0467	0.1558	2.904	0.0551
360	1	1	2.741	0.089	0.1526	0.5087	3.894	0.0873
360	1	2	0.015	0.0988	0.2009	0.6698	4.132	0.0791
360	1	1	2.685	0.0726	0.1636	0.5455	3.961	0.0739
360	1	2	2.202	0.0872	0.1199	0.3997	3.661	0.0828
360	2	1	2.402	0.1511	0.2226	0.7421	3.302	0.0873
360	2	2	2.418	0.1706	0.2523	0.8408	3.921	0.1005
360	2	1	1.805	0.1157	0.1278	0.4261	3.467	0.0862
360	2	2	2.026	0.1447	0.1826	0.6085	3.204	0.0751
360	3	1	3.557	0.166	0.3929	1.31	2.707	0.1365
360	3	2	2.887	0.1287	0.2382	0.794	3.19	0.1633
360	3	1	3.127	0.1548	0.3084	1.028	3.626	0.1183
360	3	2	3.144	0.1638	0.3221	1.074	3.745	0.141
360	4	1	1.243	0.0656	0.055	0.1833	3.405	0.041
360	4	2	1.115	0.053	0.0408	0.1361	3.73	0.0639
360	4	1	1.417	0.062	0.056	0.1865	2.874	0.0441
360	4	2	1.178	0.0638	0.0512	0.1708	3.367	0.0507
384	1	1	3.171	0.0915	0.1907	0.6356	3.823	0.0871
384	1	2	2.591	0.1005	0.1658	0.5528	4.168	0.0972
384	1	1	1.716	0.0449	0.0769	0.2562	3.72	0.0786
384	1	2	2.0405	0.0823	0.128	0.4268	3.665	0.0801
384	2	1	3.113	0.1738	0.3209	1.07	3.116	0.0918
384	2	2	2.468	0.1537	0.2335	0.7785	3.008	0.0726
384	2	1	2.624	0.1571	0.247	0.8233	2.963	0.0771
384	2	2	2.706	0.159	0.2617	0.8725	2.811	0.0705
384	3	1	3.796	0.1564	0.3862	1.287	3.349	0.1293
384	3	2	3.48	0.1657	0.3793	1.264	3.435	0.1557
384	3	1	3.394	0.1542	0.3313	1.104	3.276	0.1336
384	3	2	3.455	0.158	0.3636	1.212	2.741	0.1292
384	4	1	0.9322	0.0602	0.0356	0.1187	3.54	0.0568
384	4	2	1.081	0.0484	0.0388	0.1295	3.182	0.0461
384	4	1	1.383	0.0729	0.058	0.1934	3.449	0.0576
384	4	2	1.532	0.0716	0.0699	0.2332	3.619	0.0647
408	1	1	2.943	0.0907	0.1788	0.5959	3.629	0.0863
408	1	2	3.346	0.1906	0.2701	0.9004	3.419	0.0811
408	1	1	2.715	0.0909	0.1615	0.5383	3.701	0.0849
408	1	2	2.17	0.09	0.127	0.4232	3.212	0.0835

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
408	2	1	2.591	0.1572	0.2526	0.842	3.053	0.0839
408	2	2	2.734	0.1727	0.2838	0.9461	2.922	0.0778
408	2	1	2.891	0.1772	0.3134	1.045	3.557	0.0982
408	2	2	2.895	0.1763	0.3001	1	2.314	0.0762
408	3	1	3.77	0.1802	0.442	1.473	3.218	0.1297
408	3	2	3.735	0.1472	0.3525	1.175	3.226	0.1649
408	3	1	3.175	0.1452	0.3051	1.017	2.837	0.1348
408	3	2	2.816	0.1447	0.2531	0.8436	2.973	0.1597
408	4	1	1.3	0.061	0.0537	0.179	3.05	0.0495
408	4	2	1.193	0.0674	0.0521	0.1737	3.336	0.0579
408	4	1	1.652	0.0654	0.0826	0.2754	2.737	0.045
408	4	2	1.541	0.066	0.0632	0.2106	2.941	0.0513
432	1	1	2.847	0.1056	0.1892	0.6305	2.549	0.0741
432	1	2	2.52	0.0976	0.1553	0.5178	2.747	0.0839
432	1	1	2.69	0.0972	0.1673	0.5576	3.03	0.0795
432	1	2	1.562	0.073	0.0686	0.2287	2.829	0.083
432	2	1	2.922	0.1705	0.3091	1.03	2.438	0.0812
432	2	2	2.712	0.1478	0.2482	0.8275	2.238	0.0687
432	2	1	2.286	0.1451	0.2049	0.6829	2.194	0.0671
432	2	2	2.06	0.1339	0.1637	0.5457	2.251	0.073
432	3	1	3.789	0.1771	0.4342	1.447	2.459	0.1394
432	3	2	3.282	0.1476	0.3154	1.051	2.589	0.1345
432	3	1	3.613	0.1682	0.394	1.313	2.63	0.1514
432	3	2	3.478	0.1905	0.4298	1.433	2.718	0.1288
432	4	1	1.114	0.0663	0.0463	0.1544	2.086	0.0433
432	4	2	1.414	0.0707	0.0633	0.211	1.979	0.0435
432	4	1	1.014	0.0624	0.0379	0.1264	1.886	0.041
432	4	2	1.569	0.0428	0.0712	0.2372	2.782	0.055
456	1	1	2.594	0.0962	0.1599	0.5331	2.64	0.0798
456	1	2	3.143	0.1106	0.2242	0.7474	2.905	0.0848
456	1	1	2.888	0.0979	0.1866	0.622	2.596	0.0687
456	1	2	2.646	0.093	0.1577	0.5257	2.728	0.0715
456	2	1	2.562	0.1571	0.251	0.8366	2.627	0.0819
456	2	2	2.745	0.1668	0.2735	0.9118	2.363	0.0723
456	2	1	2.736	0.1577	0.2624	0.8748	2.513	0.0795
456	2	2	2.797	0.1633	0.2663	0.8876	2.454	0.073
456	3	1	3.559	0.1621	0.3788	0.1263	3.104	0.1476
456	3	2	3.808	0.1797	0.434	1.447	3.108	0.1357
456	3	1	3.163	0.156	0.3161	1.054	3.276	0.1396
456	3	2	2.705	0.1392	0.2436	0.812	3.458	0.1558
456	4	1	0.8834	0.0537	0.0312	0.104	3.55	0.0627
456	4	2	1.027	0.0311	0.0342	0.1139	3.314	0.0448

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
456	4	1	1.237	0.0603	0.0532	0.1774	3.373	0.0482
456	4	2	1.66	0.0625	0.0665	0.2218	3.515	0.0553
480	1	1	2.595	0.0968	0.1669	0.5562	3.928	0.0723
480	1	2	2.59	0.1031	0.1659	0.5529	4.529	0.0889
480	1	1	2.794	0.0906	0.1707	0.5689	4.392	0.0838
480	1	2	2.777	0.0983	0.1832	0.6112	4.25	0.0718
480	2	1	1.45	0.1028	0.095	0.3168	2.59	0.0918
480	2	2	2.102	0.1375	0.1747	0.5824	2.283	0.0594
480	2	1	2.891	0.1712	0.2947	0.9824	2.847	0.0711
480	2	2	2.599	0.1713	0.2585	0.8616	2.964	0.0697
480	3	1	3.856	0.1656	0.4093	1.364	3.402	0.1427
480	3	2	3.619	0.1575	0.3791	1.264	2.808	0.0989
480	3	1	3.943	0.1674	0.436	1.453	2.7	0.0977
480	3	2	3.051	0.1533	0.2911	0.9702	3.298	0.1539
480	4	1	1.431	0.0621	0.0563	0.1877	3.223	0.548
480	4	2	1.745	0.0625	0.0781	0.2604	3.47	0.0508
480	4	1	1.279	0.0615	0.0536	0.1787	3.366	0.0511
480	4	2	1.562	0.066	0.07	0.2332	3.156	0.0458
504	1	1	2.187	0.0945	0.135	0.4501	3.278	0.0794
504	1	2	2.816	0.1123	0.2093	0.6976	3.544	0.0803
504	1	1	2.445	0.1155	0.1835	0.6116	3.444	0.0871
504	1	2	2.466	0.0946	0.1575	0.525	3.051	0.0673
504	2	1	1.766	0.1378	0.1436	0.4785	2.883	0.0736
504	2	2	3.094	0.1915	0.371	1.237	2.76	0.066
504	2	1	2.745	0.1727	0.2886	0.9621	3.277	0.0887
504	2	2	2.51	0.1733	0.2576	0.8587	2.909	0.0731
504	3	1	2.661	0.17	0.2913	0.9712	3.003	0.1461
504	3	2	2.938	0.1729	0.326	1.087	2.988	0.1276
504	3	1	3.083	0.1745	0.3516	1.172	3.209	0.1351
504	3	2	2.679	0.1531	0.2561	0.8536	2.818	0.1346
504	4	1	1.372	0.0706	0.0694	0.2313	2.577	0.0428
504	4	2	1.206	0.0693	0.0537	0.1791	3.021	0.0553
504	4	1	1.399	0.0673	0.0626	0.2086	3.01	0.0543
504	4	2	1.2	0.0597	0.05	0.166	3.192	0.0582
528	1	1	2.465	0.0933	0.1505	0.5016	2.779	0.0799
528	1	2	1.986	0.0782	0.1001	0.3335	2.73	0.0831
528	1	1	3.003	0.1121	0.2143	0.7144	2.844	0.0752
528	1	2	2.119	0.084	0.116	0.3865	2.826	0.0819
528	2	1	2.293	0.1542	0.212	0.7066	2.612	0.0826
528	2	2	2.991	0.1917	0.343	1.143	2.418	0.0776
528	2	1	2.634	0.1776	0.2716	0.9054	2.348	0.0662
528	2	2	2.396	0.1628	0.2381	0.7936	2.547	0.0876

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
528	3	1	3.419	0.1686	0.3752	1.251	2.506	0.1382
528	3	2	2.804	0.1571	0.2815	0.9382	2.584	0.1419
528	3	1	3.285	0.1779	0.3696	1.232	2.638	0.1525
528	3	2	3.004	0.1625	0.3059	1.02	2.408	0.1347
528	4	1	1.424	0.0636	0.0577	0.1922	2.716	0.0432
528	4	2	1.8	0.0797	0.0951	0.3171	2.74	0.0528
528	4	1	1.365	0.0795	0.0716	0.2388	2.971	0.0492
528	4	2	1.806	0.0798	0.0995	0.3316	2.764	0.0508
552	1	1	2.442	0.0965	0.1617	0.5389	3.081	0.087
552	1	2	2.481	0.1013	0.172	0.5734	3.015	0.0838
552	1	1	1.807	0.0837	0.0933	0.3109	2.799	0.0773
552	1	2	2.965	0.1093	0.2206	0.7355	2.847	0.0831
552	2	1	3.026	0.1979	0.366	1.22	2.833	0.0938
552	2	2	2.652	0.1771	0.3072	1.024	2.832	0.0977
552	2	1	2.125	0.1586	0.2175	0.725	2.427	0.0734
552	2	2	2.5	0.1824	0.2803	0.9343	2.818	0.0944
552	3	1	2.007	0.1471	0.1991	0.6637	2.784	0.1421
552	3	2	2.982	0.1743	0.3463	1.154	2.836	0.1569
552	3	1	3.552	0.1968	0.4691	1.564	2.779	0.1526
552	3	2	2.993	0.1817	0.3442	1.147	2.74	0.1443
552	4	1	1.412	0.0223	0.0499	0.1665	3.605	0.0604
552	4	2	0.9633	0.0672	0.0454	0.1513	2.944	0.0495
552	4	1	1.242	0.772	0.0604	0.2013	3.009	0.0493
552	4	2	1.176	0.0506	0.0537	0.1791	2.795	0.0491
576	1	1	2.749	0.1191	0.2154	0.718	3.535	0.0784
576	1	2	2.478	0.1043	0.1727	0.5757	3.588	0.0842
576	1	1	1.56	0.0812	0.0798	0.266	3.257	0.0751
576	1	2	1.413	0.0363	0.0662	0.2206	3.397	0.0876
576	2	1	2.226	0.1698	0.2417	0.8057	3.086	0.0749
576	2	2	2.479	0.1955	0.3118	1.039	3.143	0.0784
576	2	1	2.734	0.2012	0.3373	1.124	3.1	0.0819
576	2	2	1.443	0.0609	0.1143	0.3809	3.022	0.0805
576	3	1	2.841	0.1844	0.3472	1.157	3.67	0.1616
576	3	2	2.734	0.2192	0.4	1.333	3.255	0.1442
576	3	1	1.701	0.0391	0.1448	0.4827	3.379	0.1551
576	3	2	3.057	0.2018	0.4119	1.373	3.086	0.136
576	4	1	1.738	0.0914	0.1029	0.343	2.873	0.0434
576	4	2	1.567	0.096	0.0892	0.2973	3.424	0.0536
576	4	1	1.349	0.0899	0.0734	0.2446	3.567	0.0627
576	4	2	1.334	0.0972	0.079	0.2634	3.303	0.0523
600	1	1	2.707	0.1258	0.2261	0.7537	3.889	0.0949
600	1	2	2.769	0.1096	0.2088	0.6961	3.72	0.0839

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
600	1	1	1.836	0.0872	0.1332	0.4438	3.553	0.0817
600	1	2	2.203	0.1013	0.1473	0.4909	3.629	0.0838
600	2	1	2.632	0.1612	0.307	1.023	2.916	0.0665
600	2	2	3.128	0.2336	0.4636	1.545	3.03	0.0719
600	2	1	1.511	0.0969	0.1239	0.4129	3.183	0.0813
600	2	2	3.001	0.2169	0.3966	1.322	3.357	0.0909
600	3	1	3.397	0.2208	0.4803	1.601	3.704	0.1517
600	3	2	3.721	0.2264	0.5501	1.834	3.607	0.1435
600	3	1	3.403	0.2231	0.5167	1.722	3.598	0.1525
600	3	2	3.193	0.1997	0.4178	1.393	3.512	0.1495
600	4	1	1.632	0.0831	0.094	0.3132	3.813	0.0537
600	4	2	1.46	0.0868	0.0844	0.2812	3.361	0.0458
600	4	1	1.459	0.0867	0.0807	0.269	3.745	0.0491
600	4	2	1.185	0.0808	0.0613	0.2044	3.649	0.0553
624	1	1	3.302	0.1098	0.2389	0.7962	4.055	0.0884
624	1	2	2.479	0.1123	0.1845	0.6151	3.608	0.0739
624	1	1	2.757	0.1169	0.206	0.6866	3.934	0.0877
624	1	2	3.216	0.128	0.2733	0.9019	3.693	0.0833
624	2	1	3.097	0.2116	0.4024	1.341	3.581	0.0826
624	2	2	2.328	0.1834	0.2715	0.9051	3.624	0.0921
624	2	1	2.425	0.183	0.2777	0.9257	3.395	0.0859
624	2	2	2.937	0.2389	0.4294	1.431	3.291	0.0797
624	3	1	2.723	0.1611	0.2885	0.9617	2.878	0.1469
624	3	2	3.735	0.2316	0.5744	1.915	3.027	0.1587
624	3	1	3.671	0.233	0.5658	1.886	2.914	0.1545
624	3	2	3.389	0.2343	0.5219	1.74	3.089	0.1493
624	4	1	1.576	0.0807	0.0785	0.2618	3.196	0.0548
624	4	2	1.287	0.0889	0.0713	0.2377	3.028	0.0535
624	4	1	1.642	0.0804	0.099	0.3299	3.092	0.054
624	4	2	1.648	0.1053	0.117	0.39	3.191	0.0552
648	1	1	3.005	0.038	0.2067	0.6889	3.49	0.0922
648	1	2	2.245	0.0362	0.1344	0.448	3.399	0.0863
648	1	1	2.935	0.1336	0.2678	0.8927	3.382	0.0822
648	1	2	3.004	0.1223	0.2416	0.8055	3.17	0.0723
648	2	1	3.357	0.2221	0.4578	1.526	3.179	0.053
648	2	2	2.83	0.2021	0.3547	1.182	3.669	0.0822
648	2	1	3.251	0.2326	0.4503	1.501	3.525	0.0868
648	2	2	2.745	0.2002	0.3383	1.128	3.63	0.0795
648	3	1	3.25	0.1986	0.4338	1.446	3.581	0.1393
648	3	2	3.404	0.1956	0.4404	1.468	3.647	0.1346
648	3	1	3.98	0.2336	0.6001	2	3.683	0.193
648	3	2	3.606	0.2197	0.5294	1.765	3.882	0.1488

TE	TRT	B	TENDIS	TENLD	EGY	TEA	PUNDIS	PUNLD
648	4	1	1.021	0.0593	0.0445	0.1483	3.83	0.0531
648	4	2	1.158	0.0732	0.0549	0.1829	4.061	0.0525
648	4	1	1.493	0.0675	0.0799	0.2663	4.258	0.0573
648	4	2	1.665	0.0944	0.1069	0.3563	3.488	0.0388

APPENDIX B
PICTURES OF THE EXPERIMENTATION

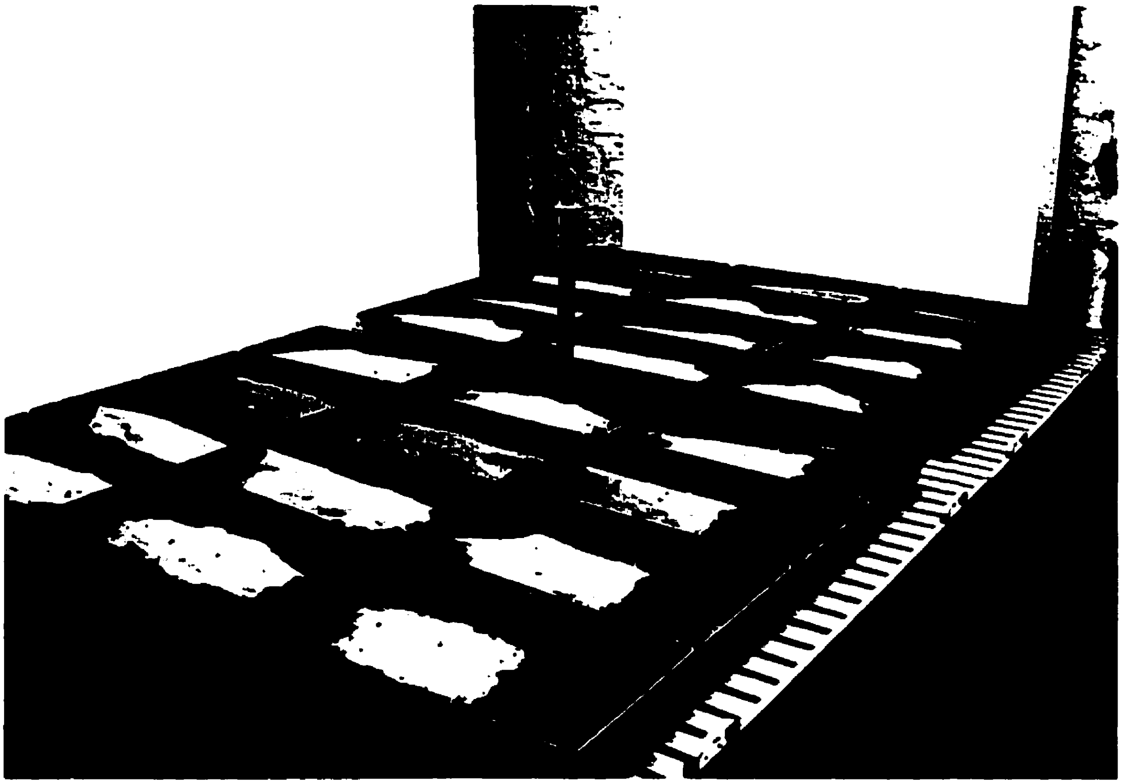

Figure B-1, Experimental Layout (Growth Chamber)

Figure B-2, Mechanical Testing Equipment (INSTRON)

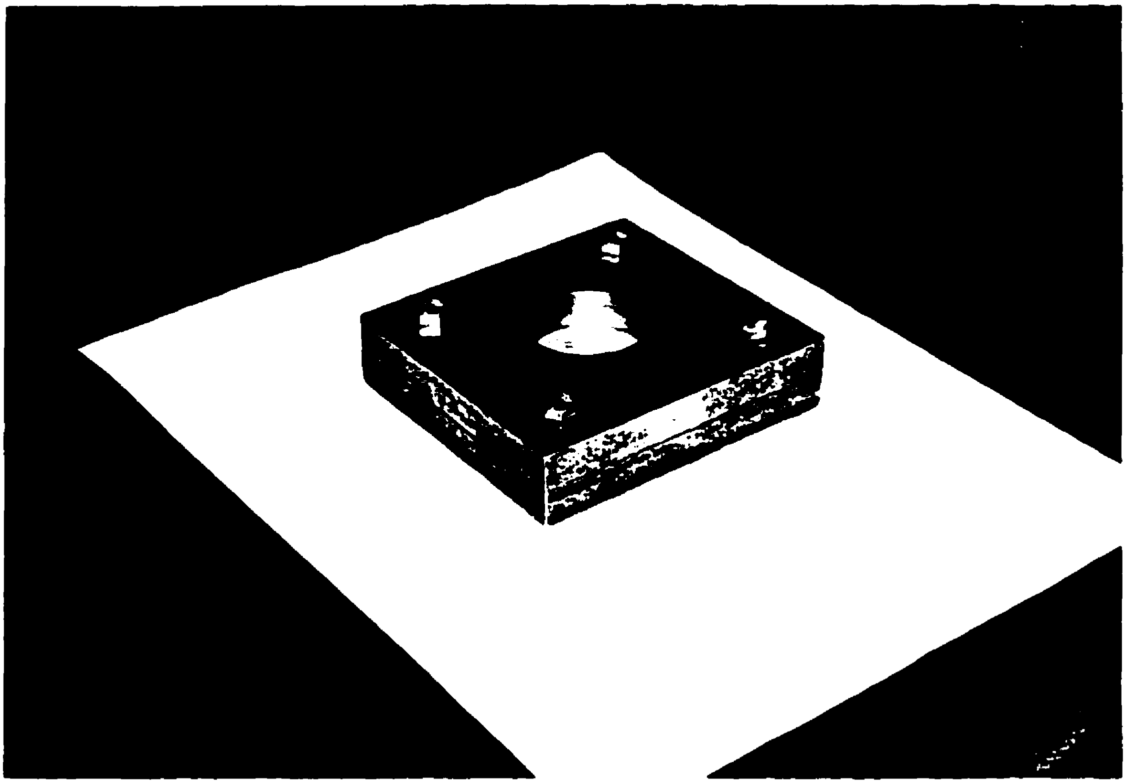

Figure B-4, Special Dies for Puncture Test

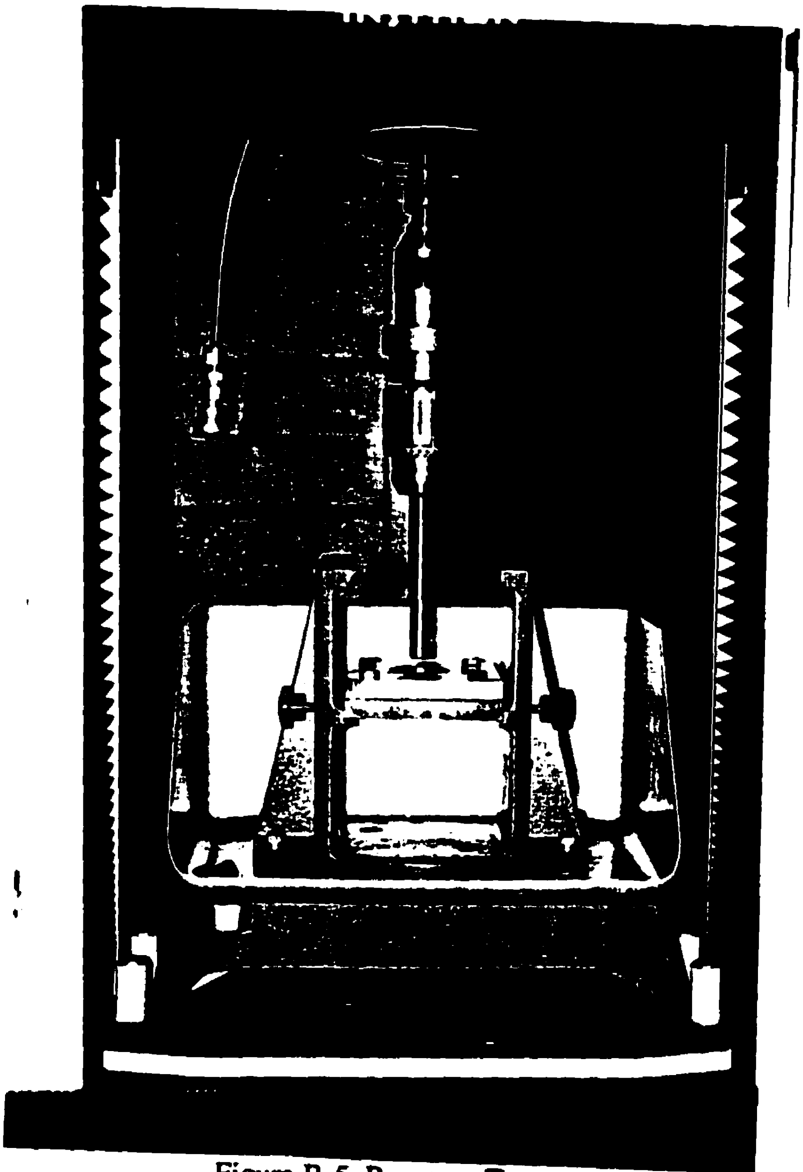

Figure B-5, Puncture Test