STUDY OF MECHANICAL BEHAVIOUR OF JUTE FIBRE REINFORCED PLASTICS

by

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CERTIFICATE OF RESEARCH

This is to certify that the work presented in this thesis is the outcome of the investigations carried out by the candidate under the supervision of Dr. Muhammad Fazli Ilahi in the Department of Mechanical Engineering at Bangladesh University of Engineering and Technology, Dhaka.

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CANDIDATE'S DECLARATION

It is hereby declared that neither this thesis nor any part thereof has been submitted or is being concurrently submitted anywhere for the award of any degree or diploma or for publication.

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ABSTRACT

Some strength characteristics of jute fibres, yarns, fibre bundles, yarn bundles, mats, and jute mat reinforced plastics, have been determined. The hardness, fatigue life, flexural modulus and percentage increase in weight due to immersion in water of jute mat reinforced plastics have also been investigated. The mean experimental value of strength of jute fibre bundle correlates well with that obtained theoretically on the basis of Daniels' theory. It was observed that the mean experimentalvalue of strength of jute fibre decreased with the increase of the gage length. There is a reduction of about 40% in strength when the gage length changes from 1 cm to 10 cm. The mean experimental values of strength of jute fibre for three different gage lengths (10 cm, 5 cm, 1 cm) correlated well with that obtained theoretically on the basis of Coleman's theory. The mean experimental value of strength of jute mat was found to be about 1½ times greater than the mean experimental value of strength of jute yarn bundle.

It was observed that the mean experimental values of strength and Young's modulus of jute mat reinforced plastics increased with the increase of volume fraction of jute in the composite. But the experimental Young's modulus values of jute reinforced plastics were found to be about 1½ times greater than the theoretically calculated values on the basis of Netting-type analysis.

It was also observed that the mean experimental values of flexural modulus, fatigue life, hardness, and percentage increase in weight due to immersion in water, of jute mat reinforced plastics increased almost linearly with the increase of volume fraction of jute in the composite.

PREFACE

Plastics are nonmetallic basic engineering materials that can be formed and shaped by many methods. Plastics may be man-made synthetic resins, or they may be compositions formed from natural resins. The reinforced plastics industry has grown enormously in size and gained importance. It has now become a major industry in almost every part of the world.

The work presented in this thesis deals with the mechanical behaviour of jute reinforced plastics. The experimental results have been correlated with the theoretical values.

The thesis is divided into seven chapters, which deal with the different aspects of the problem. A brief introduction of the problem is given in chapter I. A short discussion on plastics material is given in chapter II. In chapter III, some of the related studies and investigations of composites are summarily described in order to facilitate comparison with the present study. Mathematical models of fibre reinforced composites are described in chapter IV, in order to correlate theoretical results with experimental results. The preparation of specimens, and experimental procedure are discussed in chapter V . The results of the investigation are presented in chapter VI. Comparisons are made with other related works, where these are relevent and necessary. The conclusions,discussion and comments on possible extension of the work are presented in chapter VII.

Tables and Figures are placed at the end for easy reference. The numbers in the bracket ( ) in the text refer to the serial number in the reference list.

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DEDICATION

To my parents

Contents

LIST OF NOMENCLATURE

Symbol	Meaning
b	Specimen width, m m.
c m	Centimeter
d	Specimen thickness, m m
d_f	Diameter of jute fibre
D	Deflection of Specimen, m m.
E	Flexural modulus
E_c	Young's modulus of composite
E_f	Young's modulus of Fibre
E_m	Young's modulus of matrix
E_y	Young's modulus of yarn
L	Specimen span length
N	Number of fibre
α, β	Weibull distribution parameters
Γ	Gamma function
e	Strain
ψ	Standard deviation
σ_f	Average fibre strength
σ_B	Average bundle strength
σ_c	Average composite strength
Y	Shear strain
τ	Shear stress
θ	Angle
$\int$	Integration
z_1	Random variable
n	Positive variable

CHAPTER- I

INTRODUCTION

Composite materials have been in existence for centuries. Well known materials, such as glass, plywood, concrete and metal alloys are composites. These have been used in a wide variety of man-made structures. In the past, the designer was forced to choose among available materials to design a particular structure. Now he is in a position to prescribe material properties in the expectation that an appropriate composite will be fabricated. The main structural problems which these materials overcome are those involving strength, weight, and stiffness. Thus composites have been used in the construction of ships, submarines, and helicopter blades. Composite materials which can provide strength, and are at the same time corrosion resistant, dielectric and nonmagnetic are obviously desirable for many purposes.

Fibre-reinforced composites are usually anisotropic. It is a well-known fact that materials are stronger in fibre form than in bulk form. This property cannot be usefully exploited unless the fibres are held together by a matrix material. In fibre reinforced composite, the fibres carry the bulk of the applied load, and the matrix serves to bind the fibres together, to space them, to distribute the load to individual fibres, and to protect them from mechanical or chemical damage. In selecting a matrix material for a fibre-reinforced composite, it is necessary to ensure that the fibres are properly bonded and are in total contact with the matrix. Further more, the matrix must not react chemically with the fibres and should have adequate shear strength and ductility.

In the last 30 years, a number of analytical and experimental studies have been made on the determination of mechanical properties of fibre-reinforced composites, In continuing search for light weight materials of high strength and stiffness, considerable effort has been made in the past years in the technological development of fibre-reinforced materials. Such materials consist of a relatively soft binder in which much stiffer fibres are embedded. Fibre-reinforced plastics consist of one or more types of fibres within a common matrix. The types of fibres being used most often are glass, carbon, boron, and aramids such as kevler 49. Most fabricated composites consist of several layers glued together at various orientations to each other. Mutilayer laminates are cross-ply or angle-ply composites.

Several mathematical models are formulated in order to obtain estimates of the properties of composite material. All of these models have one common feature, i.e., assumption of a specific idealized geometry and packing arrangement. In many composite materials, this regularity in geometry does not exist, and the material cannot be identified as having a hexagonal, rhombic, or a square packing arrangement. Thus the models do not truly represent a real composite. One way to avoid this idealization problem is through the use of the variational techniques.

Most of the composites are made by using thermosetting plastics as a binder material. The common thermosets, which are used as binder material, are polyester resins and epoxy resins. Polyester resins can claim to be among the first of the many synthetic resins which are now the basis of the plastic industry.

Jute is a naturally occuring fibre, The length and diameter of jute fibre changes with grades. Jute fibres have different mechanical properties according to their grades, soil conditions, fertilization techniques, and the climate. Constant mechanical properties, diameter and length are impossible in jute fibres. Jute is the cheapest among all fibres used as a reinforcing material. The present study has been undertaken since no organised record of mechanical properties of jute reinforced plastics exists. The work is concerned with the experimental study of the mechanical behaviour of jute-reinforced plastics and its correlation with the theoretical results.

CHAPTER - II

PLASTIC MATERIALS

2.1 INTRODUCTION

The general term polymer includes all natural and synthetic plastics, fibres, elastomers, paints, and adhesives. The American Society for Testing Materials has defined plastics as "materials that contain as an essential ingredient organic solid in the finished state but are shaped by flow at some stage of their manufacture or during processing into finished articles".

There are many different kinds of plastics. Within each kind, there are hundreads of classification. Many plastics are compounded to gain special properties by the addition of plasticizers, stabilizers or fillers, or by alloying two or more synthetic resins. There are two basic types of plastics, thermoplastic and thermosetting.

The plastic industry uses the word additive to describe the materials which are combined with the basic resins and polymers to modify their properties, or to facilitate their processing, or to achieve special colour and finish.

Fillers play a very important part in the manufacture of plastics compound. They reduce cost, accelerate the cure or hardening, minimize shrinkage, improve thermal endurance, add strength, and provide special electrical and chemical properties.

2.2 LAMINATED PLASTICS

A laminated structure is formed from layers of materials bonded together into a unit body. Plastics industry manufactures large quantities of laminated sheets, tubes, rods, and products using various materials such as paper, cloth, asbestos, wood, glass fabric, etc., bonded by the synthetic resins. Resins for this purpose are generally used in a varnish form. High molding pressures are required for the manufacture of laminated plastics.

2.3 REINFORCED PLASTICS

The reinforced plastics are similar to the laminates in many applications, differing primarily by their use of resins that do not require molding pressures. Pressure is often used to acquire higher density, desirable surface textures, and for quicker rate of curing. Resin used for the reinforced plastics include polyester, epoxy, phenolic, melamine, vinylester, silicone, and diallylphthalate.

2.4 FIBRE GLASS

Many types of reinforcement are available to meet the multiple product requirement. Glass is one of the most commonly used reinforcement materials. Glass fibre-reinforcement gives high tensile strength, high modulus of elasticity, and excellent dimensional stability. It is used with all principal resins for such products as aircraft parts, ducts, electrical components, motor body parts, and building panels. There are two basic forms of glass fibre-continuous and staple fibres.

A continous filament is an individual fibre of any desirable length. But a staple filament is an individual fibre of 8 to 15 inches long. Both continuous and staple fibres can be fabricated into yarns and cords through conventional twisting. Reinforcing mats are made of either chopped strands or continuous swirl strands laid in nonwoven random pattern.

2.5 Hand lay-up molding technique of reinforced plastics :

Hand lay-up, or wet lay-up is an open mold process. Since no pressure is applied, other than rolling with a squeeze to remove entrapped air, very light weight and simple molds can be employed for the process. In this process, fabric or mat is saturated with liquid resin, and the thickness of the product is built up by applying successive layers of wet fabric. Usually a special gel coat is sprayed, against the mold before the layers of fabric are applied. This gel coat provides a high surface quality. Curing usually occurs at room temperature.

The procedure begins by placing mat or fabric over the mold. The mats are trimmed to suit the mold dimensions. Catalyzed resin is applied to the reinforcement and rolled thoroughly to wet out the fibres. All air bubbles must be removed.

2.6 Polyesters :

Unlike almost all other thermosets, the polyesters polymerize rapidly at room temperature without pressure. A large number of acids and alcohols may be selected for the copolymerization of polyesters. A polyester is the result of the reaction between a dihydric alcohol and dibasic acid. Polyesters are a large family of condensation polymers made from saturated and unsaturated organic acids and alcohols and cross-linked by styrene, acrylics, or other monomers by means of a suitable catalyst. The polyesters are cured rapidly by the intervention of a small quantity of catalyst, usually a peroxide such as methyl ethyl ketone peroxide. Curing process is exothermic.

CHAPTER -III

LITERATURE REVIEW

A number of experimental investigations have been directed toward establishing the mode of failure of unifibre and multifibre, unilayer and multilayer specimens subjected to uniaxial tension in the direction of fibres only (1- 8). In 1962, Boue (9) established the effect of the fibre to matrix volume ratio on the failure mode of fibre-reinforced composites. He found that, for specimens with low fibre volume fraction, the failure commences by transverse resin cracking followed by fibre fracture and fibre pullout from both sides of the resin crack. For the high fibre volume fraction specimens, random fibre failures occured below 50 percent of the ultimate load. The failure of the composite occured by an accumulation of random fractures.

In 1964, Tsai (10) presented some experimental data to verify the analytical results for both cross-ply and angle-ply laminations. The test specimen layers were made up of unidirectional glass fibres preimpregnated with an epoxy resin. The laminated specimens consisted of two or three layers. The test results were obtained by measuring the surface strains of the loaded specimens. The measured components of the (A'), (B'), and (D') matrices agreed resonably well with the theoretically predicted values for both cross-ply and angle ply laminations. In 1964, Schuster and Scala(11) utilized, Sapphire whiskers embedded in an epoxy matrix and approximately evaluated the three dimensional stress distribution from the average values of birefringence measured in a conventional polariscope. Measured values of shear stresses showed fair agreement with theoretical computations.

In 1965, Rosen (12) conducted tests on E-Glass unilayer specimens with approximately 50 percent fibre volume fraction. The specimen were observed photoelastically during the test. The observed mode of failure was similar to that of Boue (9). In 1965, Tyson and Davies (13) utilized a two dimensional model to study the shear-stress distribution near a fibre end. They filed a slot in a sheet of photoelastic material, fitted an alumium stiffener to the slot and glued it in space. They found peak shear stresses greater than those predicted theoretically.

In 1967, Friedman, Flom and Mazzio (14) had also run tests on continuous glass fibre reinforced specimens. The mode of failure was of the same type as that observed in Rosen's experiments(12). In 1967, Edelman and Dahlke (15) utilized three dimensional models and the stress freezing technique. The ratio of the elastic modulus of the stiffener to that of the matrix was selected to match the anticipated ratio in the prototype material. In 1968, Pih (16) analyzed photoelastically the effect of the fibre end-geometry,fibre orientation, fibre to matrix percent volume ratio. Most of the works done are on two-dimensional models, although some three-dimensional cases were also considered. In 1968, MacLaughlin (17) has performed a comprehensive study of the effect of fibre discontinuties in composite materials using two dimensional models. As may be antici-pated,from the two-dimensional structure of the models, very high stress-concentration factors were observed.

In 1968, Grinius (18) conducted an experimental investigation on fibre-reinforced composites subjected to tension, shear, bending and repeated loading in order to establish the effect of the matrix and the fibre orientation. Only two specimens were tested for each case. The observed mode of failure for tension was similar to that found by Boue (9) for low fibre-volume fraction specimens.

In 1968, Tsai (19) compared the uniaxial strength predicted by maximum stress, maximum strain, and maximum work theories, with the test data obtained from uniaxial tensile and compressive tests on a unidirectional E-glass -epoxy composite. He found that the maximum work theory offered better agreement with experimental data than did the other theories.

In 1972, Armenakas, Garg, Sciammarella, and Svalbon (20) investigated the strength characteristics of S-glass fibre bundles and composites subjected to quasi-static loading. The specimens were observed photographically during deformation. Their experimental bundle strength compared well with that obtained on the basis of Daniels' theory (21). The mean experimental composite strength compared well with that obtained on the basis of rule of mixtures and Gucer-Gurland models (22,23,24).

In 1984, Fariborg, Yang and Harlow (25) investigated the tensile behaviour of "Intraply Hybrid composites". They modified the basic chain of bundles probability model. They used the monte carlo simulation technique for their method of analysis. They considered the effect of the volume ratio of the constituents and the degree of dispersion of the types of fibres. The existence of the "Hybrid Effect" for strain is shown along with its sensivity of volume ratio and dispersion. The Weibull distribution function was shown to be a good representation for the hybrid breaking strain.

From the previous works, it can be concluded that based upon certain assumption a mathematical modelling is possible for the determination of mechanical properties of composite.

CHAPTER - IV

ANALYSIS OF COMPOSITE MATERIALS

In order to analyze the mechanical behaviour of composite materials, it is better to have a mathematical model to predict strength values theoretically. Some of the important models are discussed below.

4.1 NETTING TYPE ANALYSES

A planar mat of fibres, subjected to tensile strains in two directions at right angles to each other and to a shear strain between these directions has been considered (26).

This model is based upon the following assumptions :

a. No effect of the binder phase

b. long, straight, thin fibres

c. load applied only at the fibres ends, and

d. no bending stiffness for the fibres.

Composite Young's modulus equation (detailed in the Appendix-A) for this model is

$$E_c = (1/3)\, E_f V_f \qquad \text{.....................(1)}$$

where,

E_f = Young's modulus of fibre

V_f = Volume fraction of fibre

4.2 STRENGTH CHARACTERISTICS OF A SINGLE FIBRE

Most of the reinforcing fibres are brittle with a wide scatter in their tensile strength values. Statistical theories of brittle fracture are mostly based on the Griffith fracture theory (27). It is assumed that the strength of brittle material is limited by the presence of microcracks, or flaws, distributed throughout the specimen. If it is further assumed that the flaws are distributed in a random manner and are noninteracting (28), then the fibre may be divided into a chain of '1' links, each of unit length. When the stress at the root of a microcrack in any link reaches the theoretical cohesive strength, fracture ensues. It is thus evident that the most severe crack, or flaw, determine the failure of the entire fibre. In other words, statistical theories are based on the concept of the "weakest link", according to which the strength of a chain of '1' links equals the strength of the weakest link.

Coleman (29), using the weakest link showed that the cumulative distribution function $G_1(\sigma)$ of classical fibres is of the Weibull (30) type. The Weibull probability density function f(x) (detailed in the Appendix - B) is given by

$$f(x) = \alpha \beta x^{\beta-1} \exp(-\alpha x^{\beta}) \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where $x \geqslant 0, \beta > 0 \sim$ shape parameter, and $\alpha > 0 \sim$ characteristic parameter.

The Weibull distribution function may also be employed to characterize the fibre strength behaviour under quasistatic loading in an approximate manner, by postulating the distribution parameters α and β as functions of the strain rate '$\dot{e}$' (31). The following relations were established for these parameters on the basis of tests on 2 in. gage length S-glass filaments (mean diameter d_f = 0.00 485 in) at various strain rates

$$\ln(-\ln \alpha) = -0.029 \ln \dot{e} + 3.398 \quad \ldots\ldots\ldots\ldots \quad (a)$$

$$\ln \beta = -0.028 \ln \dot{e} + 0.863 \quad \ldots\ldots\ldots\ldots \quad (b)$$

where $\dot{e}$ has been non-dimensionalized with respect to $\dot{e}_o$ = 1 per min.

From the cumulative distribution function (detailed in the Appendix-C), the following quantities, may be calculated in a straight forward manner :

$$\sigma_f = (\alpha l)^{-1/\beta} \, \Gamma(1+1/\beta) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

$$\psi_f/\sigma_f = \left[\frac{\Gamma(1+2/\beta)}{\Gamma^2(1+1/\beta)} - 1 \right]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots \text{(4)}$$

where Eq.(3) gives the average strength and Eq.(4), the coefficient of variation. Here $\Gamma(x)$ denotes the gamma function of x.

Equation (3) predicts a linear relationship between log (σ_f) and log (l) as shown in figure 6.1. The slope of the straight line $[\log(\sigma_f) - \log(l)]$ yields the value of $-1/\beta$. Knowing the parameter α, the parameter β may be obtained through use of Eq. (3).

4.3 TENSILE STRENTH DISTRIBUTION OF LARGE BUNDLES

A bundle made up of a large number 'N' of parallel fibres, all of equal length 'l' is considered. The fibres are assumed to be clamped at the ends, such taht all the unbroken elements have the same strain. The fibres remain elastic up to the point of rupture. It is evident that if there was no dispersion in the length of the fibres, the strength of the bundle would be equal to that of all its individual components. However, since there is a distribution of fibre strengths, the problem is more complex. It was first considered by Daniels (32).

In Daniels' analysis, it was assumed that when a fibre breaks, the load it was carrying is instantaneously distributed equally among the surviving fibres. Fibre bundle strength and standard deviation equations, according to Daniels' theory, are

$$\sigma_B = (\alpha l \beta)^{-1/\beta} \, e^{-1/\beta} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

$$\psi_B = (\alpha l \beta)^{-1/\beta} \left[e^{-1/\beta} (1 - e^{-1/\beta}) \right]^{-1/2} N^{-1/2} \quad \text{(6)}$$

CHAPTER- V

DESCRIPTION OF EXPERIMENTAL PROCEDURE AND PREPARATION OF SPECIMEN

5.1 Tensile test of tossa jute (Corchorus Olitorius) fibre :

Tossa jute are classified into six grades. These are namely BTSPL, BTA, BTB, BTC, BTD and BTE grades, where B means Bangladesh and T stands for work "Tossa". For sampling, two bales of BTA grade jute were spread out on the floor. Ten reeds were taken at random from them. Then 15" length were cut from the middle portion of the reeds. From these reeds, two bundred filaments were taken out. These were then cut at 15 cm lengths. These filaments were the test specimens.

The study was conducted on these jute fibres using an Instron Testing m/c model of TM-M of BJRI at a cross-head speed of 5 mm per min. Load and elongation at break were automatically recorded on the chart from which strength and strain at break were calculated.

Fifty specimens were tested for each of the three different gage lengths (10 cm, 5 cm and 1 cm). The rates of straining were 0.05 mm/mm/min, 0.1 mm/mm/min,0.5/mm/mm/min, for gage lengths 10 cm, 5 cm, and 1 cm respectively. The data of different gage lengths are summarized in Tables 5.1, 5.2 and 5.3.

5.2 Tensile test of jute fibre bundle :

For sampling, one bale of BTA grade jute was spread out on the floor. Ten reeds were taken at random from the bale. From these reeds forty fibres were taken out for each specimen. These were then cut at 15 cm lengths. These bundles were the test specimen.

Experiment was conducted on these bundles using an Instron testing m/c of model TM-M at a cross-head speed of 5 mm/min. Load & elongation at break were automatically recorded on the chart from which strength and strain at break were calculated. Ten specimens were tested each of gage length 10 cm. The experimental data are summarized in Table 5.4.

5.3 Tensile test of jute yarns :

Samples of length 15 cm were cut from reel of BTA grade jute. These yarns were the test specimens. Experiment was conducted on jute yarn using an Instron Testing machine model 1026 of BUET at a cross-head speed of 50 mm/min. Loads at break were automatically recorded on the chart. Elongation at break was also recorded. In this investigation ten specimens were tested, each of gage length 10 cm. The experimental data are summarized in Table 5.5.

5.4 Tensile test of jute yarn-bundle :

Samples, each of 20 cm length and 2.75 cm width, were cut from carpet backing cloth of BTA grade jute. There were ten longitudinal yarns in each sample. Samples of 5 x 2.75 cm each, were also cut from glass mat. The matrix was then prepared by mixing thoroughly in a container with a stick, while carefully avoiding the entrainment of excessive air, 500 grams of Epolac G-774TSY(unsaturated normal polyester resin) 15 grams of Cobalt Nepthanete, and 5 grams of methyl ethyl ketone peroxide. Glass mats were wetted with this liquid resin, and placed on both sides of the ends of the samples. Sheets of polythene were placed on them and rolled thoroughly to wet out the mat and to remove entrapped air. These were cured slowly at room temperature.

Transverse yarns were then isolated from the samples. The test length was 10 cm. The yarns were equally spaced in the specimen.

Experiment was conducted on these bundles using an Instron Testing machine, model 1026, at a cross-head speed of 50 mm/min. Load at break was automatically recorded on the chart, from which strength at break was calculated. The experimental data are given in Table 5.6.

5.5 Tensile test of jute mats :

Same procedure as was discussed in section 5.4 were adopted except that the transverse yarns were not isolated from the samples. The test data are summarized in Table 5.7.

5.6 Tensile test of jute mat reinforced composites :

Samples 25 x 45 cm were cut from mat of BTA grade jute, then weighed and recorded. The matrix polyester was then prepared by mixing ingredients thoroughly in a container with a stick, in the proportions listed in Table 5.8., while carefully avoiding the entrainment of excessive air.

Unilayer and multilayer of jute mat reinforced plastics were made by hand lay-up method. These were cured slowly at room temperature. These composite sheets were weighed. Specimens each of length of 25 cm and width of 2.76 cm were cut from these sheets. All surfaces and edges of these specimens were filed, and the filed surface were finished with finer abrasive papers. A ten layer of glass mat reinforced composite sheet was made by hand lay up method for tabs.

After curing at room temperature, tabs of 38 x 25.4 x 5 mm were cut from this sheet and filed all the cut surfaces. Tabs were then attached to the ends of the jute reinforced plastic specimens, with Aica adhesives. The dimensions of the test specimens were according to the standard of ASTM D 3039 -76 as shown in figure 5.1.

Tensile tests have conducted on the above specimens using an Instron Testing machine at a cross-head speed of 50 mm/min. Test was performed at room temperature. Load at break was recorded on the chart. The extension at or as near as possible to the point of rupture of the specimen was measured and recorded. Load and deformation at different intervals of time were also measured and recorded. Ten specimens were tested at each volume fraction of jute. Experimental data for jute reinforced composite specimens are given in Table 5.9.

5.7 Tensile Test of Polyester Resins :

A sheet of 200 x 200 x 6 mm of pure resin, according to the proportions listed in Table 5.8, was made. After curing at room temperature, specimens were cut from this sheet by a metallic die, according to the standard of ASTM D 638- 77a as shown in figure 5.2. All surfaces of the specimens were filed, and the filed surfaces were finished with finer abrasive cloths.

Tensile test was conducted on the above specimens using an Instron Testing machine at a cross-head speed of 50 mm/min. Test was performed at room temperature. Load at break was automatically recorded on the chart. The extension at or as near as possible to the moment of rupture of the specimen was measured and recorded. Load and deformation at different intervals of time were also measured and recorded. Ten specimens were tested. Experimental data for pure resin specimens are summarized in Table 5.10.

5.8 Flexural test of jute mat reinforced composites :

Sheets of varying thickness ranging 1.5 mm to 1.9 mm, 4cm long and 15 cm wide of different jute mat volume fraction of jute reinforced plastics and pure resins were made by hand lay-up method. The matrix had the same proportion of resins as listed in Table 5.8. These were cured at room temperature for two days. Specimens of length 40 mm, and width 12.9 mm were cut from these sheets. Then all surfaces of the specimen were filed, and the filed surfaces were finished with finer abrasive cloths.

Test was conducted on the above specimens utilizing a "Flexural Modulus Measuring Apparatus" as shown in the figure 5.3. At first the mean thickness (d) of each specimen over its full width at the mid-section was measured and recorded. From the specimens, the one which had the mean thickness nearest to the mean of the mean thickness of the specimens was selected. The deflection equivalent to an induced strain of 0.2% for this specimen from the following equation was calculated :

$$D = \frac{0.21505}{d} \quad \text{..............} \quad (1)$$

where,

D = deflection of the specimen at its mid point, mm

d = thickness of the specimen, mm

The specimen was placed centrally on the supports and then the load beam was placed on the specimen. The gauge adjusting screw was turned in a clockwise direction until the proximity switch was functioning.

The bezel locking screw was loosened and the dial gauge bezel was turned so that " zero " coincides with the position of the pointer.

Loose weights were applied to the centre of the beam progressively. As each weight was added, the gauge adjusting screw was turned clock wise until the red light came on. When sufficient weights had been added to cause movements of 2D as indicated on the gauge the applied load 'W' was recorded. The remaining nine specimens were tested similarly, applying load 'W' as quickly as possible. Exactly one minute after the completion of loading, the resultant deflection D to the nearest 0.002 mm was recorded.

The elastic modulus for each specimen was calculated from the following equation.

$$E = \frac{L^3 W}{4d^3 Db} \qquad \text{............} \quad (2)$$

where,

b = Specimen width, mm

L = Specimen span length, m.m.

W = Load, Newton

d = Specimen thickness, m m.

D = Deflection of specimen, m m.

The experimental data of jute mat reinforced composite and pure resin specimens are summarized in Table 5.11.

5.9 Fatigue test of jute yarn composites :

A glass mat reinforced mold was prepared for the purpose of making test specimens according to the standard of Terco Company as shown in figure 5.5. Then a random sample, 20 cm long, 0.752 m m. mean diameter of BTA grade jute yarns was placed in the bottom half of the mold and the yarns were subjected to tension. The top of the mold was then placed above the bottom and the two sections were clamped. Prior to placement of yarns, the mold had been cleaned thoroughly and subsequently, its surface were evenly coated with a thin coat of Mold Release Wax.

The matrix polyester was then prepared by mixing thoroughly in a container with a wooden stick, while carefully avoiding the entrainment of excessive air, 25 grams of Epolac G. 774 TSY, 0.5 grams of Cobalt Nepthanete and 0.25 grams of Methyl Ethyl Ketone Peroxide. The resin was then injected into the mold. The mold was cured at room temperature for two hours. It was then opened and the specimen was removed carefully. After this, the composite specimen was placed in the open space for post curing for two days. In this way five specimens, for each volume fraction of jute yarns, were made. Five specimens of pure matrix were also made. A photograph of the specimen is shown in fig. 5.5. The effective span length of the specimen was 100.5 mm, the mean diameter of the composite was 7.5 mm.

Experiments were conducted on both resins and composite specimens, utilizing the Fatigue testing machine Terco MT 205.

The test specimen was passed through the locking nut and was inserted in the bearing on the loading device, which was on a level with the gripping shaft. The test specimen was introduced into the shaft and the locking nut was tightened. The load was set at 5 N.

Theloading device has a microswitch which on fracture of the test piece, cut off the power supply to the motor. The microswitch has a reset button which is pressed to restart the machine. The cycle counter was set at zero before the machine was started in each case. After the test piece had fractured, the part gripped in the shaft was removed by knocking the wedge shaped mandrel through the hole in the shaft. The test was repeated with other test specimens. Five specimens were tested for each volume fraction of jute. The life of the test specimen, was expressed in number of loading cycles, recorded automatically.

5.10 Water absorption test of jute mat composites :

Jute mat reinforced composite sheets of different volume fraction of jute mat and a pure polyester resin in the proportion, listed in Table 5.8, were made according to the procedure discussed in section 5.6. Specimens of 76.2 mm long and 25.4 mm. wide were cut from these sheets, according to ASTM D-570, and weighed. After weighing, these specimens were placed in a container of distilled water in such a way that specimens entirely immersed and rested on edges. At the end of twenty four hours, the specimens were removed from water one at a time, wiped off water from all the surfaces with a dry cloth, and weighed immediately. Percentage increases in weight due to immersion were calculated and recorded. Ten specimens were tested at each volume fraction of jute and pure resin.

5.11 Hardness test of jute mat reinforced composite :

Jute mat reinforced composite sheets of differnt volume fraction of jute and a pure polyester resin were made according to the procedure discussed in section 5.6. Specimens were cut according to ASTM D-2240. The sample had a diameter of 3 cm and a minimum thicness of 6 mm; thiner specimen were placed layer upon layer until this minimum thicness had been achieved. The test was performed according to standard ASTM D-2240-68, using Zwick Hardness Tester on Shore D.

Tests were performed on each sample at three different locations. When performing the tests, the hardness tester was applied to the sample in a shock and vibration free manner and depressed until the contact surface of the tester touched the surface of the sample under test. The shore D hardness number was recorded. Ten samples were tested for each volume fraction of jute. A photograph of Zwick Shore D Hardness Tester is shown in figure 5.4.

CHAPTER=VI

EXPERIMENTAL RESULTS AND COMPARISON

6.1 JUTE FIBRES:

Fifty specimens were tested for each of the three different gage lengths. The values of Weibull parameter were calculated, using the mean experimental fibre strength values for three different gage lengths, and equation(2) of chapter IV. Experimental and theoretical results in comparison with 0.00485 in mean diameter S-glass fibre of 38.5 mm gage length are summarised in Table 6.1 (20). Average tensile strength of jute fibre versus fibre length are shown in figure 6.1 together with values for other fibres(33).

Table 6.1 Experimental results of tensile strength and Young's modulus of jute fibre, in comparison with S-glass fibre (20).

Rate of straining	Elastic modulus of jute fibre kg/mm^2		Elastic modulus of glass fibre• kg/mm^2	Tensile strength of jute fibre kg/mm^2		Tensile strength of glass fibre• kg/mm^2	Values of Weibull parameters		Theoretical values for strength and standard deviation. kg/mm^2	
mm/mm/min	Mean	S. D	Mean	Mean	S. D	Mean	α	β	Mean	S.D
0.05	3865.59	370.22	16671.72	36.75	6.215	166.7	5.445161×10^{-10}	4.581529	36.751	2.435
0.1	4177.16	379.5		41.554	6.365				42.75	2.832
0.5	4189.20	131.34		60.747	1.322				60.748	4.025

• Straining rate of glass fibre was 0.0265 mm/mm/min.

6.2 JUTE FIBRE BUNDLE

As the specimens were loaded individual fibres fractured at random level of loading, well below the failure load of bundles. The theoretical bundle strength and standard deviation were calculated, using the equations (4) and (5) of chapter IV, and the values of Weibull parameters from Table 6.1.

Experimental values of bundle strength and standard deviation, in comparison with theoretically calculated values, and also in comparison with 0.00485 in meandiameter S-glass fibre bundle of 38.5 mm gage length, are summarized in Table 6.2 (20).

Table 6.2 Experimental and theoretically calculated values of jute bundle strength and standard deviation, in comparison with S-glass fibre bundle.

Rate of strainning, mm/m.m/min	Tensile strength of jute fibre, kg/mm^2		Theoretical values for strength and S.D., kg/mm^2		Tensile strength of glass fibre, kg/mm^2	
	Mean	S.D.	Mean	S.D.	Mean	S.D
0.05	19.286	2.443	22.204	1.733	85.82	25.11

* Rate of Straining of S-glass fibre bundle was 0.0265

6.3 JUTE YARNS

Ten specimens were tested at a straining rate of 0.5 mm/mm/min. Experimental results are summarized in Table 6.3.

Table- 6.3. Experimental results of tensile strength and Young's modulus of jute yarns.

Rate of straining mm/mm/min	Tensile strength kg/mm^2		Young's modulus kg/mm^2	
	Mean	S.D	Mean	S.D.
0.5	14.411	1.255	610.95	11.52

6.4 JUTE YARN BUNDLES

Ten specimens were tested at a straining rate of 0.5 mm/mm/min. Experimental mean tensile strength and standard deviation values are summarized in Table 6.4.

Table- 6.4 Experimental results of tensile strength and standard deviation of jute yarn bundles.

Rate of straining mm/mm/min	Tensile strength, kg/mm^2	
	Mean	S. D
0.5	10.452	1.5519

6.5 JUTE mats :

Ten specimens were tested at a straining rate of 0.5 mm/mm/min. Experimental mean tensile strength and standard deviation values are summarized in Table 6.5.

Table- 6.5 Experimental results of tensile strength and standard deviation of jute mats.

Rate of straining mm/mm/min	Tensile strength, kg/mm^2	
	Mean	S. D
0.5	15.0312	1.9061

6.6 JUTE MAT REINFORCED COMPOSITE :

Ten specimens were tested at each volume fraction of jute at a straining rate of 0.394 mm/mm/min.Theoretical results of Young's modulus of composites based upon the rule of Netting-type analysis are given in Table-6.6.

Experimental results in comparison to 0.00485 in mean diameter S-glass fibre composite of V_f = 0.0895, at a straining rate of 0.66 mm/mm/ min. , gage length of 38.5 mm are given in Table 6.6(20) Mean tensile strength of jute reinforced composite versus gross fibre volume fraction are shown in figure 6.2 Young's modulus of composite versus volume fraction of jute, in comparison with glass fibre are shown in figure 6.3. Mean breaking strain of composite versus volume fraction of jute are shown in fig. 6.4.

6.7 PURE RESIN

Ten pure resin specimens were tested. Experimental results are summarized in Table 6.7.

Table - 6.6 Experimental and theoretical results of Young's modulus and tensile strength of jute mat reinforced composite in comparison with S-glass fibre reinforced composite.

Rate of Straining mm/mm/min	V_f	Young's modulus of jute reinforced composite, $kg/m.m^2$		Young's modulus, E_c, based upon Netting type prediction, kg/m using.		Tensile strength jute reinforced composite, kg/mm^2		Tensile strength of S-glass reinforced composite, V_f=0.0895, kg/mm^2	
		Mean	S.D.	E_f	E_y	Mean	S.D.	Mean	S.D.
0.3937	0.142	43.0349	1.7005	182.97	28.92	1.9987	0.128	196.26	27.364
"	0.168	52.3336	2.0552	216.47	34.21	2.3849	0.104		
"	0.178	54.3885	1.3122	229.35	36.25	2.5467	0.090		
"	0.202	61.5860	1.2122	260.28	41.137	2.9017	0.066		
"	0.208	63.257	0.781	268.01	42.36	2.9929	0.078		

Table- 6.7 Experimental results of tensile strength and Young's modulus of pure polyester resin specimens.

Rate of straining mm/mm/min	Tensile strangth kg/mm2		Young's modulus kg/mm^2	
	Mean	S.D	Mean	S.D
1.0	1.104	0.034	15.276	0.511

6.8 FLEXURAL MODULUS :

Ten specimens were tested at each volume fraction of jute. Experimental mean flexural modulus and standard deviation of jute mat reinforced composite are summarized in Table 6.8. Flexural modulus versus volume fraction of jute are shown in fig. 6.5

Table-6.8 Experimental results of mean flexural modulus and standard deviation of jute mat reinforced composite and pure resin.

Volume fraction of jute	Flexural modulus, N/mm^2	
	Mean	S. D
0.0	80.494	0.929
0.0602	160.95	5.246
0.0802	183.407	6.602
0.108	219.365	7.395
0.128	242.422	5.43
0.208	347.817	5.58

6.9 WATER ABSORPTION :

Ten specimens were tested at each volume fraction of jute mat and a pure resin. Experimental results on jute mat reinforced composite and pure resin, are summarized in Table 6.9. Weight increase due to immersion in water, %, versus volume fraction of jute are shown in fig.6.6.

Table- 6.9 Experimental values of weight increase due to immersion in water and standard deviation of jute mat reinforced composite and pure resin.

Volume fraction of jute V_f	Weight increase due to immersion in water, %	
	Mean	S. D
0.0	1.555	0.044
0.142	2.828	0.063
0.168	3.148	0.086
0.202	3.60	0.083
0.208	3.689	0.041

6.10 HARDNESS

Ten specimens were tested at each volume fraction of jute mat reinforced composite and pure resin. Experimental results of shore-D hardness number and standard deviation are summarized in Table 6.10. Shore-D hardness number versus volume fraction of jute are shown in Fig.6.7.

Table - 6.10 Experimental results of shore-D hardiness number and standard deviation of jute mat reinforced composite and pure resin.

Volume fraction of jute	Shore-D hardness number	
	Mean	S. D
0.0	45	1.76
0.142	55	2.33
0.168	60	1.45
0.178	61	1.82
0.208	62	1.75

6.11 FATIGUE :

Five specimens were tested at each volume fraction of jute mat reinforced composite and pure resin. Experimental values of fatigue life, in cycles of loading and standard deviation are summarized in Table 6.11. The load was 5 Newtons. Fatigue life, in cycles of loading versus gross fibre volume fraction are shown in figure 6.8.

Table 6.11 Experimental results of fatigue life and standard deviation, of jute yarn reinforced composite and pure resin, at load of 5 N.

Volume fraction of jute	Fatigue life, in cycles of loading	
	Mean	S. D
0.0	356	56
0.033	946	58
0.079	2474	96
0.1245	3878	220
0.1495	4672	363
0.224	7524	513

CHAPTER - VII
DISCUSSION AND CONCLUSIONS

7.1 Introduction :

Some mechanical properties of jute, polyester resin, and jute reinforced plastics have been determined experimentally. And the experimental results are correlated with theoretical values. The important points are summarized in this chapter and possible extension of the present work for continuation of the research is discussed.

7.2 Discussion of results :

It is observed that the mean experimental value of jute fibre strength decreases while increasing the test gage length. This is due to the value of strength of the weakest link in the fibre. As the gage length decreases, the total number of links in the fibre also decrease, and the strength value of the weakest link may be more. There is also a reduction in the mean experimental value of Young's modulus of jute fibre, while increasing the test gage length from 1 cm to 10 cm. But it is observed from figure 6.1 that the mean strength of jute fibre increases almost linearly with decreasing gage length. The theoretically calculated strength compares well with the experimental strength, but the theoretically calculated standard deviation is nearly one and half times greater than the sample standard deviation. The S-glass strength is nearly four and half times greater than the strength of jute fibre. The S-glass Young's modulus value is about $4\frac{1}{4}$ times greater than the mean experimental value of Young's modulus of jute fibre.

The mean experimental fibre bundle strength compares well with that calculated from Daniels' theory (32). But the bundle strength is much smaller than the fibre strength of both jute and glass fibres. This is due to the dispersion in the strength of the fibres.

The mean values of experimental jute yarn strength and Young's modulus are much smaller than those of jute fibres. This is due to the discontinuities of the fibres in yarn. The mean experimental jute yarn strength is greater than the mean experimental jute yarn bundle strength.

The mean experimental value of jute mat strength is about one and half times greater than the mean experimental jute yarn bundle strength. This is due to the transverse yarns in the mat by which the strength increases.

It is observed that the experimental values of Young's modulus of jute mat reinforced plastics are greater than the theoretically calculated values on the basis of Netting-type analysis. But if a constant $K = 1.5$ is taken into account for discontinuities of the fibres and multiplied by the results obtained on the basis of Netting type analysis, the results obtained compare well with the mean experimental results. The mean experimental strength of jute mat reinforced plastics increases with increasing volume fraction of jute in the composites. But the value of strength of composite is less than the strength of jute fibre.

It is observed that the experimental values of flexural modulus, fatigue life, hardness, and percentage increase in weight due to immersion in water, increase with increasing volume fraction of jute in composites as shown in figures 6.5,6.6,6.7 and 6.8.

7.3 Conclusions :

The following conclusions can be drawn as a consequence of the present research work :

1. As jute absorbs much resin, there is a limitation of increasing the vlume fraction of jute in composite. The maximum volume fraction of jute is in composite 0.208. The composite has some voids when the volume fraction of jute is more than 0.208.

2. The experimental values of mean tensile strength, Young's modulus, fatigue life, hardness number, flexural modulus, and water absorption of jute mat reinforced plastics increase almost linearly with increasing volume fraction of jute in the composite.

3. The experimental value of mean breaking strain of pure polyester resin is decreased approximately by 96% when 0.208 volume fraction of jute mat is used as a reinforcing material.

4. The experimental values of mean tensile strength and Young's modulus of jute mat reinforced plastics containing 0.208 volume fraction of jute mat are approximately 2.75 times greater than pure polyester resin. So jute may be used as a reinforcing material.

5. The experimental value of mean flexural modulus of jute mat reinforced plastics containing 0.208 volume fraction of jute is approximately 4.82 times greater than pure polyester resin.

6. Experimental values of mean shore-D hardness number and percentage weight increase due to immersion in water of jute mat reinforced plastics containing 0.208 volume fraction of jute are approximately 1.37 and 2.37 times greater than polyester resin respectively.

7. Experimental value of mean fatigue life of jute yarn reinforced plastics containing 0.224 volume fraction of jute is approximately 21 times greater than polyester resin.

8. Experimental value of mean tensile strength of jute fibre is approximately 2.45 times greater than jute mat. So it is better to use jute fibre as a reinforcing material.

7.4 Extension of the present work :

The study of the mechanical behaviour of jute reinforced plastics has been presented in this work. Due to relatively limited amount of measurements performed for mechanical behaviour of jute reinforced plastics, several questions regarding the mechanical properties are yet to be solved. It is not possible to reach definite conclusion regarding the effect of strain rate on mechanical properties of jute reinforced plastics. This answer may be reached only by conducting a large number of tests at various strain rates. As a direct extension of the present work, the following suggestions may be made for continuation of the research.

1. Experimental study of the elastic behaviour of unidirectionally continuous jute fibre reinforced plastics.

2. Experimental study of strength characteristics of jute fibres under dynamic loading.

3. Experimental study of the mechanical behaviour of hybrid composites, consisting of two or more types of reinforcing fibres, one of them being a jute fibre within a common matrix.

APPENDICES

APPENDIX- A

NETTING TYPE ANALYSES

A planar mat of fibres subjected to tensile strains e_{11} and e_{22} in two directions at right angles to each other (Fig. 1) and to a shear strain γ_{12} between these directions has been considered.

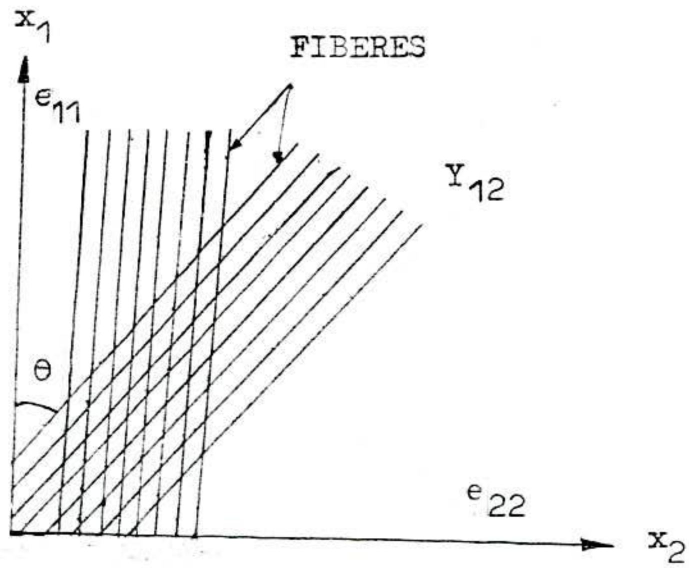

Fig. 1. Planar mat of fibres.

The strain of a fibre inclined at an orbitrary angle 'θ' to the direction x_1 is

$$e_{11} \cos^2\theta + e_{22} \sin^2\theta + \gamma_{12} \sin\theta \cos\theta \quad \dots \quad \dots \quad (1)$$

Let f(θ) be the distribution function, that is, the fraction of fibres inclined at angle 'θ' to the direction x_1 in the unit width transverse to their direction, such that

$$\int_0^{\pi} f(\theta)\, d\theta = 1 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (2)$$

The fractions of fibres intersecting lines of unit width perpendicular to the directions x_1 and x_2 are then $f(\theta) \cos\theta$ and $f(\theta) \sin(\theta)$ respectively.

Let E_f is the fibre modulus, and V_f is the fibre packing density, i.e., the ratio of fibre volume to the volume of the composite. The stresses are

$$\sigma_{11} = E_f V_f \int_0^{\pi} (e_{11} \cos^2\theta + e_{22} \sin^2\theta + \gamma_{12} \cos\theta \sin\theta) \cos^2\theta \, f(\theta) d\theta \; ..$$

$$\sigma_{22} = E_f V_f \int_0^{\pi} (e_{11} \cos^2\theta + e_{22} \sin^2\theta + \gamma_{12} \cos\theta \sin\theta) \sin^2\theta \, f(\theta) \, d\theta \quad ..(2)$$

$$\tau_{12} = E_f V_f \int_0^{\pi} (e_{11} \cos^2\theta + e_{22} \sin^2\theta + \gamma_{12} \cos\theta \sin\theta) \sin\theta \cos\theta \, f(\theta) \, d\theta$$

Alternately equations(2) can be recoritten as

$$\sigma_{11} = C_{11} e_{11} + C_{12} e_{22} + C_{16} \gamma_{12}$$

$$\sigma_{22} = C_{12} e_{11} + C_{22} e_{22} + C_{26} \gamma_{12} \quad .... (3)$$

$$\tau_{12} = C_{16} e_{11} + C_{26} e_{22} + C_{66} \gamma_{12}$$

where

$$C_{11} = E_f V_f \int_0^{\pi} \cos^4\theta \, f(\theta) \, d\theta$$

$$C_{16} = E_f V_f \int_0^{\pi} \cos^3\theta \sin\theta \, f(\theta) \, d\theta$$

$$C_{22} = E_f V_f \int_0^{\pi} \sin^4\theta \, f(\theta) \, d\theta \quad ...... (4)$$

$$C_{26} = E_f V_f \int_0^{\pi} \sin^3\theta \cos\theta \, f(\theta) d\theta$$

$$C_{12} = E_f V_f \int_0^{\pi} \cos^2\theta \sin^2\theta \, f(\theta) \, d\theta$$

The elastic constants C_{ij} for the composite may be calculated in a simple manner. For the isotropic, two dimensional case with a random distribution of fiber, the distribution function $f(\theta)$ used is

$$f(\theta) = \frac{1}{\pi}, \; 0 \leq \theta \leq \pi \quad .... \quad .... \; ..... \; (5)$$

Then using the WALLIS' integration formulas, which are

a) $$\int_0^{\pi/2} \sin^n\theta \, d\theta = \int_0^{\pi/2} \cos^n\theta \, d\theta = \frac{(n-1)(n-3) \; ...... \; (2) \text{ or } (1)}{n\,(n-2) \; ....(3) \text{ or } (2)} W$$

where $W = \pi/2$ if 'n' even and $W = 1$, if 'n' is odd.

b) $$\int_{0}^{\pi/2} \mathrm{Cos}^{n}\theta \ \mathrm{Sin}^{m}\theta \ d\theta = \frac{[(n-1)(n-3)..(2)\mathrm{or}(1)]\ [(m-1)(m-1)..(21\ \mathrm{or}(1)]}{(m+n)\ (m+n-2)\ ....(2)\ \mathrm{or}\ (1)} T$$

where $T = n/2$, if both 'm' and 'n' are even; otherwise

$T = 1$

We can easily find out the elastic constants, which are as follows.

$$C_{11} = C_{22} = (3/8)E_f V_f \ ; \ C_{12} = (1/8)\ E_f V_f$$

$$C_{16} = C_{26} = 0$$

From theory of elasticity (Hooke's law)

$$E = \frac{\sigma}{e}$$

$$E_c = \frac{\sigma_{11}}{e_{11}} = \frac{C_{11}e_{11}+C_{12}e_{22}}{e_{11}} = C_{11} + C_{12}\ \frac{e_{22}}{e_{11}} \quad ....(i)$$

And $$E_c = \frac{\sigma_{22}}{e_{22}} = \frac{C_{12}\ e_{11} + C_{22}\ e_{22}}{e_{22}} = C_{22} + C_{12}\ \frac{e_{11}}{e_{22}}$$

or $$e_{11}/e_{22} = (E_c - C_{22})/C_{12} \quad .... (ii)$$

From equations (i) and (ii) we have

$$E_c = C_{11} - (C_{12}^{2} / C_{22})$$

$$= (3/8)\ E_f V_f - (8/64)\ (1/3)\ E_f V_f$$

$$= (1/3) E_f V_f \quad .... (6)$$

APPENDIX-B

WEIBULL DISTRIBUTION

The Weibull probability density function f(x) changes its shape with the distribution parameters. It can adopt anywhere from exponential to highly skewed shapes. The probability density function f(x) is given by

$$f(x) = \alpha \beta x^{\beta-1} \exp(-\alpha x^{\beta}) \quad \ldots \quad \ldots \quad \ldots \quad \ldots (11)$$

where $x \geqslant 0$, $\beta > 0 \sim$ shape parameter, and $\alpha > 0 \sim$ characteristic parameter.

The cumulative distribution function F(x), corresponding to f(x) of Eq.(1), is

$$F(x) = 1 - \exp(-\alpha x^{\beta}) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots (2)$$

The wide range of possible shapes for the Weibull probability density function is shown in Fig. 1.

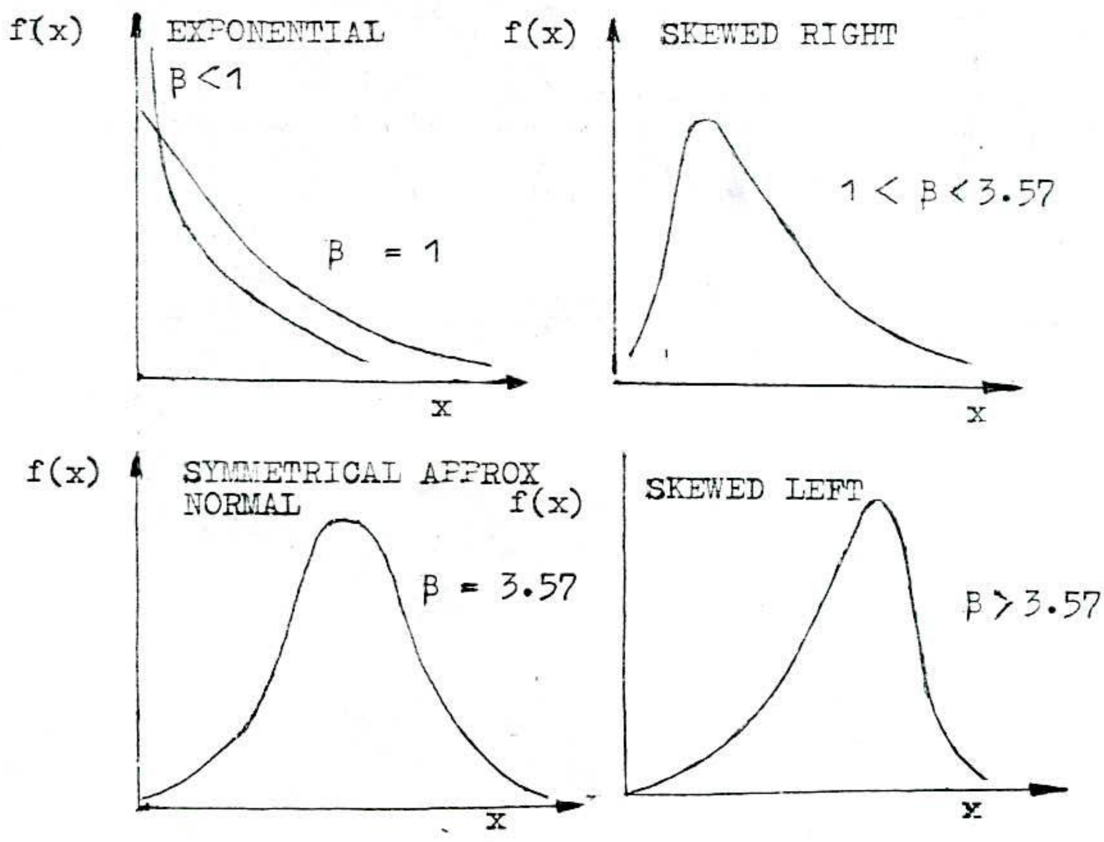

Fig. 1. Weibull probability density curves.

APPENDIX-C

STRENGTH CHARACTERISTICS OF A SINGLE FIBRE

Mathematically, if $G_1(\sigma)$ and $G_l(\sigma)$ denote the probability that the strength of the fibers of length unity and 'l', respectively, does not exceed 'σ', the weakest link hypothesis yields

$$1 - G_l(\sigma) = [1 - G_1(\sigma)]^l \quad \ldots \ldots \ldots \ldots \ldots (a)$$

Equation (a) implies that the probability of the survival of a fiber of length 'l' subjected to a stress 'σ' equals the probability that all of the 'l' links of unit length survive under the applied stress.

Apart from the weakest link hypothesis, the following two "self-evident" statements may be made regarding the cumulative distribution function $G_l(\sigma)$:

a) The fiber strength in greater than zero regardless of the fiber length l.

b) $G_l(\sigma)$ is a monotonically increasing function of σ. Whenever 'l' in Eq.(a) is large, and $G_1(\sigma)$ differs appreciably from zero, the right hand side of the equation will vanish. According to the second "self-evident" statement above, small $G_1(\sigma)$ corresponds to small σ. Thus, the form of $G_l(\sigma)$ for large 'l', is governed by the behavior of $G_1(\sigma)$ as 'σ' approaches zero. One must further assume that $G_1(\sigma)$ is well behaved near the origin, such that

$$\lim_{\sigma \to 0} G_1(\sigma) = \alpha \sigma^\beta \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots (b)$$

where α and β are positive constants. he Weibull distribution is derived from a slightly more general hypothesis than Eq.(b). One assumes that for all $x > 0$,

$$\lim_{\eta \to 0} \left[\frac{G_1(\eta x)}{G_1(\eta)}\right] = x^\beta \quad \ldots \ldots \ldots \ldots \ldots \ldots (c)$$

Where η is any positive variable.

The quantity η_l is determined such that

$$G_1\ (\eta_l) = 1/l \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (d)$$

and a new random variable 'Z_l' is defined such that

$$Z_l = \eta_l \min\ (\ x_1,\ \dots,\ x_i, \dots,\ x_l)\ \dots \quad \dots \quad \dots\ (e)$$

where $x_1,\ x_2,\ \dots,\ x_l$ denote the strengths of the 'l' links of unit length comprising the fiber. Also note that as $l \to \infty$, $G_1\ (\eta_l) \to o$, and hence $\eta_l \to 0$. The probability that Z_l is greater than some fixed quantity 'X' is

$$P\ \left\{Z_l \geqslant X\right\} \quad = \left[1 - G_1(\ \eta_l x)\right]^{l} \quad \dots \quad \dots \quad \dots \quad \dots\ (f)$$

substituting $\eta = \eta_l$, one obtains from Eqs.(c) and (f), for large 'l',

$$\lim_{l \to \infty} P\left\{Z_l > x\right\} = \lim_{l \to \infty} \left\{1 - G_1\ (\ \eta_l)\ x^{\beta}\right\}^{l} \quad \dots \quad \dots \quad (g)$$

Substitution of Eq.(d) in Eq.(g) results in

$$\lim_{l \to \infty} P\left\{Z_l > x\right\} = \lim_{l \to \infty} \left[1 - (1/l)\ x^{\beta}\right]^{l} = \exp\left\{-\ x^{\beta}\right\} \dots\ (h)$$

Reversing the scale, $\sigma = \eta_l^{-1}\ x$, and noting that

$$P\left\{Z_l > x\right\} = P\ \left\{\min\ (x_1,\ \dots\dots,x_l) > \sigma\right\}$$

and

$$P\left\{\min\ (x_1, \dots\dots x_1)\ >\ \sigma\right\} = 1 - G_l\ (\ \sigma\ )$$

we see that Eq.(h) yields

$$G_l\ (\ \sigma\ ) = 1 - \exp\left\{-\ (\ \sigma/\eta_l)^{\beta}\right\} \quad \dots \quad \dots \quad \dots \quad \dots (i)$$

when Eq.(b) is applicable, $\eta_l \sim (\alpha l)^{-\ 1/\beta}$, and Eq. (i) becomes

$$G_l(\ \sigma\ ) = 1 - \exp\left\{-\ l\alpha\, \sigma^{\beta}\right\} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (j)$$

The above relation is the Weibull cumulative distribution function. Here, α and β are independent of the length 1, and are referred to as the distribution parameters.

From the cumulative distribution function, Eq.(j), the following quantities, may be calculated in a straight forward manner :

$$\sigma_f = (\alpha 1)^{-1/\beta} \; \Gamma(1+1/\beta) \quad \ldots\ldots \; \ldots\ldots \quad (k)$$

$$\psi_f / \sigma_f = \left(\frac{\Gamma(1+2/\beta)}{\Gamma^2(1+1/\beta)} - 1 \right)^{1/2} \quad \ldots \; \ldots \; \ldots \quad (1)$$

Where (k) gives the average strength and (1) the co-efficient of variation.

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LIST OF TABLES FOR TEST DATA

Table- 5-1. Tensile test data of jute fibres of gage length 100 m.m.

Specimen No.	Diameters of fibre mm^2 (d_f)	Ultimate load, grams (W)	Strain at failure %	Tensile strength of fibre $(\sigma)_f$ kg/mm^2	Elastic Modulus of fibre E_f kg/mm^2
1	0.047	47	0.68	27.090	3983.85
2	0.049	56	0.82	29.696	3621.53
3	0.047	61	0.89	35.159	3950.52
4	0.050	58	0.85	29.539	3475.20
5	0.046	91	1.32	54.756	4148.22
6	0.046	47	0.68	28.280	4158.95
7	0.044	57	0.83	37.487	4516.49
8	0.046	59	0.86	35.501	4128.08
9	0.050	84	1.23	42.780	3478.11
10	0.046	49	0.71	29.484	4152.71
11	0.048	63	0.92	34.851	3784.25
12	0.049	65	0.95	37.465	3943.70
13	0.048	65	0.94	35.920	3821.31
14	0.049	68	0.99	36.060	3642.43
15	0.046	67	0.97	40.315	4156.21
16	0.048	64	0.93	35.367	3802.98
17	0.045	68	0.98	42.755	4362.82
18	0.050	69	1.00	35.141	3514.14
19	0.047	75	1.09	43.229	3965.96
20	0.050	70	1.02	35.650	3495.16
21	0.045	71	1.03	44.641	4334.17
22	0.048	72	1.04	45.270	4352.95
23	0.049	62	0.90	32/878	3653.14
24	0.05	66	0.96	33.613	3501.40
25	0.045	52	0.75	32.695	4359.40
26	0.046	57	0.82	34.298	4182.68
27	0.049	54	0.78	28.636	3671.27

Table-5-1. Tensile test data of jute fibres of gage length 100 m.m.

Specimen No.	Diameter of fibre m m (d_f)	Ultimate load, grams (W)	Strain at failure %	Tensile strength of fibres $(\sigma)_f$, kg/mm^2	Elastic Modulus E_f kg/m m^2.
28	0.048	48	0.70	26.525	3789.40
29	0.046	59	0.85	35.501	4176.64
30	0.051	74	1.07	36.229	3385.46
31	0.047	67	0.97	38.618	3981.23
32	0.045	58	0.84	36.468	4341.44
33	0.052	85	1.24	40.024	3227.75
34	0.046	47	0.68	28.28	4158.94
35	0.050	84	1.22	42.780	3506.62
36	0.052	88	1.28	41.431	3237.25
37	0.050	86	1.25	43.799	3503.95
38	0.045	58	0.85	36.468	4290.36
39	0.046	67	0.98	40.315	4113.80
40	0.050	63	0.92	32.085	3487.57
41	0.040	59	0.86	35.501	4128.08
42	0.049	61	0.88	32.348	3679.91
43	0.052	79	1.15	37.1989	3234.67
44	0.048	82	1.19	45.315	3807.98
45	0.048	59	0.86	32.604	3791.24
46	0.044	61	0.88	40.117	4558.81
47	0.045	47	0.68	29.551	43 5.84
48	0.050	77	1.12	36.257	3237.25
49	0.049	91	1.32	46.346	3511.05
50	0.049	89	1.30	47.196	3630.48

Table-5-2. Tensile test data of jute fibres of gage length 50 m.m.

Specimen No.	Mean diameter of fibre, d_f m m	Ultimate load, W grams	Strain at failure, %	Tensile strength kg/m m^2	Young's modulus E_f kg/m m^2
1	.048	72	0.96	39.788	4144.6
2	.047	73	0.99	42.076	4250.1
3	.046	63	0.86	37.988	4407.9
4	.049	64	0.83	33.939	4089.02
5	.047	75	0.87	43.229	4456.6
6	.046	62	0.90	37.306	4145.1
7	.049	76	0.98	40.302	4112.4
8	.045	79	1.06	49.672	4686.0
9	.047	69	0.90	39.770	4418.8
10	.048	84	1.09	46.420	4258.7
11	.049	70	1.00	37.12	3712.0
12	.048	84	1.10	46.42	4220.01
13	.046	71	0.92	42.722	4643.70
14	.047	88	1.14	50.72	4449.3
15	.046	91	1.16	54.75	4719.82
16	.047	89	1.10	51.29	4663.4
17	.047	93	1.14	53.60	4660.8
18	.048	95	1.15	52.50	4565.1
19	.046	97	1.05	36.70	3495.7
20	.047	61	0.85	35.159	4136.3
21	.045	61	0.88	38.354	4358.3
22	.046	58	0.78	34.91	4474.23
23	.050	57	0.76	29.03	3819.71
24	.049	73	0.96	38.71	4032.45
25	.047	76	0.98	43.805	4469.9

Table-5.2. Tensile test data of jute fibres of gage length 50 m.m.

Specimen No.	Mean diameter of fibre, d_f m m	Ultimate load, W grams	Strain at failure, %	Tensile strength kg/m m^2	Young's modulus E_f kg/m m^2
26	0.044	86	1.25	56.559	4524.7
27	0.049	80	1.04	42.423	4079.19
28	0.050	80	1.00	40.743	4074.36
29	0.052	74	0.96	34.844	3629.64
30	0.051	66	0.85	23.308	3800.97
31	0.043	81	1.18	56.466	4785.2
32	0.053	88	1.13	39.887	3529.90
33	0.050	82	1.17	41.762	3569.401
34	0.050	82	1.17	41.762	3569.401
35	0.051	82	1.16	40.14	3460.344
36	0.052	79	1.12	37.199	3321.339
37	0.050	67	0.87	34.122	3922.16
38	0.049	65	0.82	34.469	4203.56
39	0.048	62	0.80	34.262	4282.81
40	0.047	85	1.20	46.972	3914.333
41	0.046	70	1.20	42.120	4297.959
42	0.045	69	1.02	43.384	4253.333
43	0.045	67	1.03	44.063	4277.961
44	0.045	60	0.88	37.725	4286.931
45	0.044	58	0.96	38.144	3973.33
46	0.047	72	0.96	41.499	4322.81
47	0.048	76	0.94	41.999	4467.9
48	0.046	66	0.088	39.713	4512.8
49	0.045	67	0.92	42.127	4579.0
50	0.049	73	0.95	38.711	4074.90

Table-5.3. Tensile test data of jute fibres of gage length 10 m.m.

Specimen No.	Mean diameter of fibre, d_f m m	Ultimate load, grams	Strain at failure, %	Tensile strength kg/m m^2	Young's modulus E_1 kg/m m^2
1	.047	104	1.42	59.944	4221.40
2	.048	108	1.42	59.683	4203.02
3	.048	98	1.40	58.968	4191.64
4	.045	98	1.44	61.618	4279.01
5	.049	119	1.48	63.105	4263.85
6	.048	110	1.43	60.788	4250.90
7	.047	107	1.46	61.673	4224.178
8	.046	104	1.50	62.5788	4171.92
9	.049	117	1.51	62.044	4108.80
10	.047	105	1.48	60.52	4089.189
11	.046	101	1.45	60.773	4191.24
12	.049	112	1.44	59.393	4124.51
13	.045	95	1.38	59.732	4328.40
14	.047	106	1.55	61.097	3941.74
15	.048	112	1.51	61.893	4098.87
16	.049	115	1.54	60.9839	3959.99
17	.048	113	1.53	62.446	4081.43
18	.046	99	1.43	59.570	4165.73
19	.047	105	1.41	60.52	4292.198
20	.046	97	1.42	58.366	4110.28
21	.047	104	1.40	59.944	4281.71
22	.047	106	1.51	61.097	4046.15
23	.048	114	1.60	62.998	3937.275
24	.046	103	1.52	61.977	4077.43
25	.047	107	.43	61.673	4312.797

Table-5.3. Tensile test data of jute fibres of gage length 10 m.m.

Specimen No.	Mean diameter of fibre, d_f m m	Ultimate load, W grams	Strain at failure, %	Tensile strength kg/m m^2	Young's modulus E_f kg/m m^2
26	.045	105	1.45	60/52	4173.79
27	.046	100	1.49	60.172	4038.38
28	.050	121	1.53	61.6248	4027.76
29	.049	121	1.51	63.635	4213.56
30	.047	120	1.52	61.097	4019.56
31	.044	106	1.48	57.874	3910.41
32	.049	88	1.46	62.574	4285.89
33	.050	118	1.42	62.643	4411.47
34	.052	123	1.38	58.388	4231.01
35	.051	124	1.46	61.1899	4491.08
36	.044	125	1.45	59.189	4082.0
37	.052	90	1.42	59.80	4211.267
38	.052	127	1.38	60.271	4367.46
39	.050	128	1.46	61.1155	4185.99
40	.049	120	1.44	59.721	4147.29
41	.048	126	1.35	59.329	4394.74
42	.047	118	1.36	60.097	4418.89
43	.046	116	1.47	61.514	4184.62
44	.046	107	1.34	59.130	4412.68
45	.045	107	1.45	61.673	4253.31
46	.044	102	1.42	61.375	4322.18
47	.045	97	1.38	60.989	4419.49
48	.044	90	1.41	59.189	4197.80
49	.045	95	1.38	58.732	4328.40
50	.044	93	1.50	61.162	4077.46

Table- 5-4. Tensile test data of jute fibre bundles.

Specimen No.	Mean cross-sectional area of bundles mm	Ultimate load, W grams	Tensile strength $(\sigma)_B$ kg/mm
1	.065325	1440	22.04362
2	.0754296	1540	20.416381
3	.0664761	1420	21.361
4	.062211388	1180	18.967588
5	.08171282	1380	16.8884
6	.0760466	1200	15.779
7	.056745	1060	18.680
8	0.059446	1080	18.1677
9	0.06503882	1120	17.220
10	.06939778	1620	23.34368

Table- 5.5. Tensile test data of jute yarns.

Specimen No.	Mean cross-sectional area, A_y mm^2	Ultimate load, W, kg.	Strain at failure, %	Tensile strength kg/mm^2 $(\sigma)_y$	Young's modulus E_y kg/mm^2.
1	0.19635	3.00	2.5	15.278	611.155
2	0.2042	3.25	2.4	14.685	611.90
3	0.197135	2.75	2.3	13.949	606.51
4	0.2083	3.25	2.5	15.602	624.09
5	0.18085	2.75	2.5	15.197	607.88
6	0.1772	2.50	2.4	14.108	587.841
7	0.16982	2.25	2.2	13.249	602.24
8	0.1590	2.00	2.0	12.578	628.93
9	0.21237	2.50	2.7	16.48	610.395
10	0.19244	2.50	2.1	12.99	618.57

Table- 5-6. Tensile test data of jute yarn bundles.

Specimen No.	Mean cross-sectional area, A_{YB} mm^2	Tensile strength $(\sigma)_{yB}$ kg/mm^2	Ultimate load, (W) kg.
1	1.62597	10.45529	17
2	1.59	12.5786	20
3	1.52	12.50	19
4	2.042	8.81488	18
5	1.963495	9.1673	18
6	2.003	8.48726	17
7	1.84745	10.2844	19
8	1.9244	11.432	22
9	1.772	9.0293	16
10	1.69822	11.777	20

Tanle 5-7. Tensile test data of jute yarn mats.

Specimen No.	Mean cross-sectional area, A_{yM} mm^2	Ultimate load, W, kg.	Tensile strength $(\sigma)_{ym}$ kg/mm^2
1	1.963495	27	13.750
2	2.083	34	16.322
3	1.8095	30	16.579
4	2.1237	31	14.597
5	1.6982	30	17.665
6	1.772	31	17.494
7	1.62597	24	14.760
8	1.9635	26	13.2416
9	2.003	24	11.1982
10	2.083	29	13.922

Table-5.8. Matrix polyester molding compound formula.

Name	Weight, grams	Weight, %
Emolac G-240 FX (unsaturated flexible polyester resin)	6,000	72.82
Epolac G-774 TSY (unsaturated normal polyester resin)	2,000	24.27
Cobalt Nepthanete	160	1.94
Melhyl elthyl Ketone peroxide	80	0.97
Total	8240	100

Table- 5.9.1. Tensile test data of jute reinforced composites of V_f=0.142

Specimen No.	Mean cross-sectional area, Ac, mm^2	Ultimate load, W, kg.	Tensile strength $(\sigma)_c$, kg/mm^2	Young's modulus E_c kg/mm^2	Strain at failure
1	139.384	297	2.1308041	45.557	0.05315
2	146.358	291	1.9882753	43.386	0.05118
3	166.242	300	1.804598	43.927	0.055118
4	140.0934	315	2.2485	43.068	0.05118
5	153.81449	300	1.95040	43.3476	0.055118
6	156.989167	300	1.911096	44.493	0.055118
7	154.68599	315	2.036383	41.050	0.05118
8	158.72499	305	1.9215624	40.006	0.05315
9	153.064667	310	2.0252877	41.485	0.5118
10	149.961167	295	1.9671759	44.038	0.05315

Table- 5.9.2. Tensile test data of jute reinforced composites of $V_f = .168$.

Specimen No.	Mean cross-sectional area, Ac, $m.m^2$	Ultimate load, [illegible], kg.	Tensile strength $(\sigma)_c$, kg/mm^2	Young's modulus E_c $kg/m\text{-}m^2$	Strain at failure
1	162.0525	375	2.314064	50.940	.0433
2	169.84933	375	2.207839	50.4712	.0413356
3	154.6745	420	2.715379	49.264	.039370
4	155.61734	375	2.40975	55.087	.0433
5	167.67	410	2.445279	54.914	.0413356
6	159.68934	387.50	2.426586	53.682	.0413756
7	169.004	375	2.2188824	52.602	.0433
8	162.3999	380	2.339901	50.8312	.0412756
9	163.849	390	2.38044034	54.2572	.0413756
10	160.955333	385	2.3919679	51.2875	.0410756

Table- 5.9.3 Tensile test data of jute reinforced composites of V_f=0.178

Specimen No.	Mean cross-sectional area, Ac, mm^2	Ultimate load, kg.	Tensile strength $(\sigma)_c$, kg/mm^2	Young's modulus E_c kg/mm^2	Strain at failure
1	24.3936	62	2.54165	54.6659	0.03543
2	27.540288	69	2.50542	53.031	0.03137
3	26.47913	68	2.5680602	52.7585	0.0374
4	26.862176	70	2.605894	54.370	0.03137
5	27.70	69	2.49047	55.018	0.03137
6	25.8561	66	2.55258	54.0298	0.0374
7	24.062	60	2.493558	52.780	0.03543
8	24.892	64	2.5711	56.1224	0.0374
9	24.6927	64	2.591849	56.575	0.03543
10	26.7806	68	2.5391514	54.535	0.03137

Table- 5.9.4 Tensile test data of jute reinforce composites of $V_f = 0.202$

specimen No.	Mean cross-sectional area, AC, mm^2	Ultimate load, W, kg.	Tensile strength $(\sigma)_c$, kg/mm^2	Young's modulus E kg/mm^2	Strain of failure
1	51.4346	149	2.89688	61.7288	.02559
2	49.12848	140	2.84067	62.041	.02362
3	56.5372	156	2.75924	62.8966	.027556
4	53.4076	158	2.9583	61.8264	.02756
5	52.177	154	2.95148	63.284	.02756
6	48.62142	144	2.96165	62.688	.02559
7	48.0996	142	2.9522	58.6171	.02559
8	49.9317	147	2.944	61.043	.02559
9	52.593	150	2.85209	6.0369	.02559
10	50.486592	146	2.891856	60.372	.02559

Table- 5.9.5. Tensile test data of jute reinforced composites of V_f=.208

Specimen No.	Mean cross-sectional area, AC, mm^2	Ultimate load, W, kg	Tensile strength (σ) kg/mm^2	Young's modulus E kg/mm^2	Strain of failure
1	75.67	230	3.0395	62.937	0.0256
2	73.3212	220	3.000496	64.087	0.0256
3	72.712	225	3.0943998	62.878	0.0256
4	73.24178	227	3.0993239	64.157	0.0256
5	71.90	212	2.948539	63.588	.023622
6	72.64144	210	2.89091	62.939	.023622
7	72.0618	215	2.98355	63.445	.023622
8	71.624	205	2.862169	63.833	.023622
9	74.45136	222	2.981812	63.115	0.0256
10	72.23538	210	3.02829	61.535	.023622

Table- 5-10. Tensile test data of polyester resin specimens.

Specimen No.	Mean cross-sectional area, AC, mm^2	Strain of failure E	Ultimate load, W, kg.	Tensile strength (σ) kg/mm^2	Young's modulus E kg/mm^2
1	67.992	0.59	47	1.099	14.70
2	69.551	0.62	49	1.141	15.09
3	67.883	0.56	46.5	1.068	14.73
4	70.71	0.61	49	1.1157	15.55
5	75.75	0.64	54.5	1.1798	15.84
6	62.616	0.59	43	1.09188	14.37
7	70.328	0.58	48	1.0783	15.64
8	70.421	0.58	48	1.07694	15.62
9	70.5276	0.60	48.50	1.00278	15.59
10	70.356	0.615	47.50	1.09034	15.63

Table-5.11.1. Test data of flexural modulus of polyester resin.

Specimen No.	Thickness mm	Width m m.	Span length m m.	Load, W. Newton	Deflection mm	Flexural modulus N/mm^2
1	1.70	12.74	25.4	0.15	0.123	79.819
2	1.69	12.76	25.4	"	0.124	80.463
3	1.64	12.72	"	"	0.134	81.729
4	1.65	12.75	"	"	0.132	81.28
5	1.67	12.76	"	"	0.1287	80.299
6	1.71	12.72	"	"	0.121	79.85
7	1.62	12.78	"	"	0.138	81.955
8	1.66	12.80	"	"	0.130	80.73
9	1.72	12.72	"	"	0.120	79.118
10	1.70	12.76	"	"	0.123	79.695

Table-5.11.2. Test data of flexural modulus of composites, $V_f = 0.0602$.

Specimen No.	Thickness mm	Width mm	Span length mm	Load, W. Newton	Deflection mm	Flexural modulus N/mm^2
1	1.81	12.80	25.4	0.35	0.119	158.75
2	1.8034	12,85	"	"	0.1195	159.20
3	1.82	12.75	"	"	0.1182	157.822
4	1.81	12.75	"	"	0.118812	160.316
5	1.796	12. 80	"	"	0.120	160.95
6	1.73	12.78	"	"	0.125	173.35
7	1.67	12.82	"	"	0.148	162.259
8	1.6367	12.84	"	"	0.155	164.325
9	1.667	12.78	"	"	0.152	159.34
10	1.6934	12.85	"	"	0.150	153.192

Table 5.11.3. Test data of flexural modulus of composites, $V_f = 0.0802$.

Specimen No.	Thickness mm	Width mm	Span length mm	Load, W Newton	Deflection mm	Flexural modulus N/mm^2
1	1.8067	12.80	25.4	0.4	0.119029	182.425
2	1.834	12.78	"	"	0.117	177.658
3	1.7334	12.82	"	"	0.121	189.412
4	1.75	12.75	"	"	0.123	194.97
5	1.78	12.76	"	"	0.12	189.762
6	1.8167	12.80	"	"	0.118	180.95
7	1.85	12.84	"	"	0.116	173.76
8	1.8167	12.85	"	"	0.118	180.246
9	1.83	12.83	"	"	0.117	178.129
10	1.7867	12.82	"	"	0.120	186.757

Table-5-11.4. Test data of flexural modulus of composites, $V_f = 0.108$.

Specimen No.	Thickness mm	Width mm	Span length mm	Load, W Newton	Deflection mm	Flexural modulus N/mm^2
1	1.834	12.80	25.4	0.5	0.117	221.726
2	1.8734	12.83	"	"	0.120	202.354
3	1.8534	12.84	"	"	0.116	216.013
4	1.79.34	12.82	"	"	0.12	230.84
5	1.83	12.82	"	"	0.1175	221.887
6	1.8234	12.78	"	"	0.118	224.053
7	1.834	12.80	"	"	0.117	221.726
8	1.8367	12.76	"	"	0.117	221.442
9	1.8467	12.86	"	"	0.116	218.03
10	1.86	12.84	"	"	0.115	215.58

Table-5.11.5. Test data of flwxural modulus of composites, $V_f = 0.126$.

Specimen No.	Thickness mm	Width mm	Span length mm	Load, W Nuwton	Deflection mm	Flexural modulus N/mm^2
1	1.8367	12.80	25.4	0.55	0.11709	242.638
2	1.86	12.76	"	"	0.115	238.625
3	1.8	12.82	"	"	0.119	253.25
4	1.87	12.74	"	"	0.115	235.186
5	1.8634	12.80	"	"	0.115	236.58
6	1.8667	12.72	"	"	0.117	243.586
7	1.467	12.72	"	"	0.116	242.476
8	1.83	12.78	"	"	0.117	245.886
9	1.85	12.84	"	"	0.116	238.927
10	1.82	12.82	"	"	0.118	247.069

Table-5-11.6. Test data of flexural modulus of composites, $V_f = 0.208$

Specimen No.	Thickness mm	Width mm	Span length mm	Load, W. Newton	Deflection mm	Flexural modulus N/mm^2
1	1.74	12.80	25.4	0.70	0.124	342.97
2	1.72	12.75	"	"	0.12503	353.53
3	1.72	12.75	"	"	0.127	353.61
4	1.71	12.76	"	"	0.127	353.91
5	1.74	12.76	"	"	0.124	344.048
6	1.73	12.77	"	"	0.124	349.77
7	1.75	12.78	"	"	0.122	343.19
8	1.75	12.74	"	"	0.123	341.4684
9	1.76	12.72	"		0.121	341.7658
10	1.71	12.76	"	"	0.127	353.913

Table-5.12. Water absorption test data of jute reinforced composites.

Specimen No.	Volume fraction of jute V_f	Dry Weight grams	Wet weight grams	Percentage increase in weight
1	0.0	12.85	13.05	1.55642
2	"	12.80	13.00	1.5625
3	"	12.90	13.10	1.55038
4	"	12.60	13.80	1.5873
5	"	12.85	13.05	1.55642
6	"	12.80	13.00	1.5625
7	"	12.77	13.96	1.48786
8	"	12.84	13.05	1.63551
9	"	12.81	13.00	1.48321
10	"	12.75	12.95	1.56862
1	0.142	15.85	16.30	2.83911
2	"	15.75	16.18	2.73015
3	"	15.90	16.36	2.89308
4	"	15.92	16.24	2.78481
5	"	15.80	16.38	2.88944
6	"	15.92	16.27	2.84450
7	"	15.82	16.29	2.84090
8	"	15.84	16.31	2.83732
9	"	15.86	16.21	2.72496
10	"	15.78	16.34	2.89672

Table-5-12. Water absorption test data of jute reinforced composites.

Specimen No.	Volume fraction of jute V_f	Dry weight grams	Wet weight grams	Percentage increase in weight
1	0.168	13.85	14.29	3.17689
2	"	13.80	14.23	3.11594
3	"	13.90	14.35	3.23741
4	"	13.85	14.17	3.05454
5	"	13.82	14.25	3.11143
6	"	13.88	14.33	3.24207
7	"	13.78	14.21	3.12046
8	"	13.95	14.41	3.29749
9	"	13.70	14.12	3.06569
10	"	13.72	14.14	3.06122
1	0.202	4.60	4.77	3.69565
2	"	4.65	4.82	3.65591
3	"	4.85	5.00	3.71138
4	"	4.65	4.81	3.44086
5	"	4.80	4.98	3.54166
6	"	4.70	4.87	3.61702
7	"	4.55	4.71	3.51648
8	"	4.75	4.92	3.57894
9	"	4.68	4.85	3.63247
10	"	4.70	4.88	3.61702

Table-5.12. Water absorption test data of jute reinforced composites.

Specimen No.	Volume fraction of jute V_f	Dry weight grams	Wet weight grams	Percentage increase in weight
1	0.208	8.21	8.51	3.65408
2	"	8.15	8.45	3.68098
3	"	8.20	8.5	3.65853
4	"	8.24	8.545	3.70145
5	"	8.25	8.555	3.69696
6	"	8.30	8.61	3.73493
7	"	8.35	8.66	3.71257
8	"	8.28	8.59	3.74396
9	"	8.24	8.545	3.70145
10	"	8.18	8.475	3.60635

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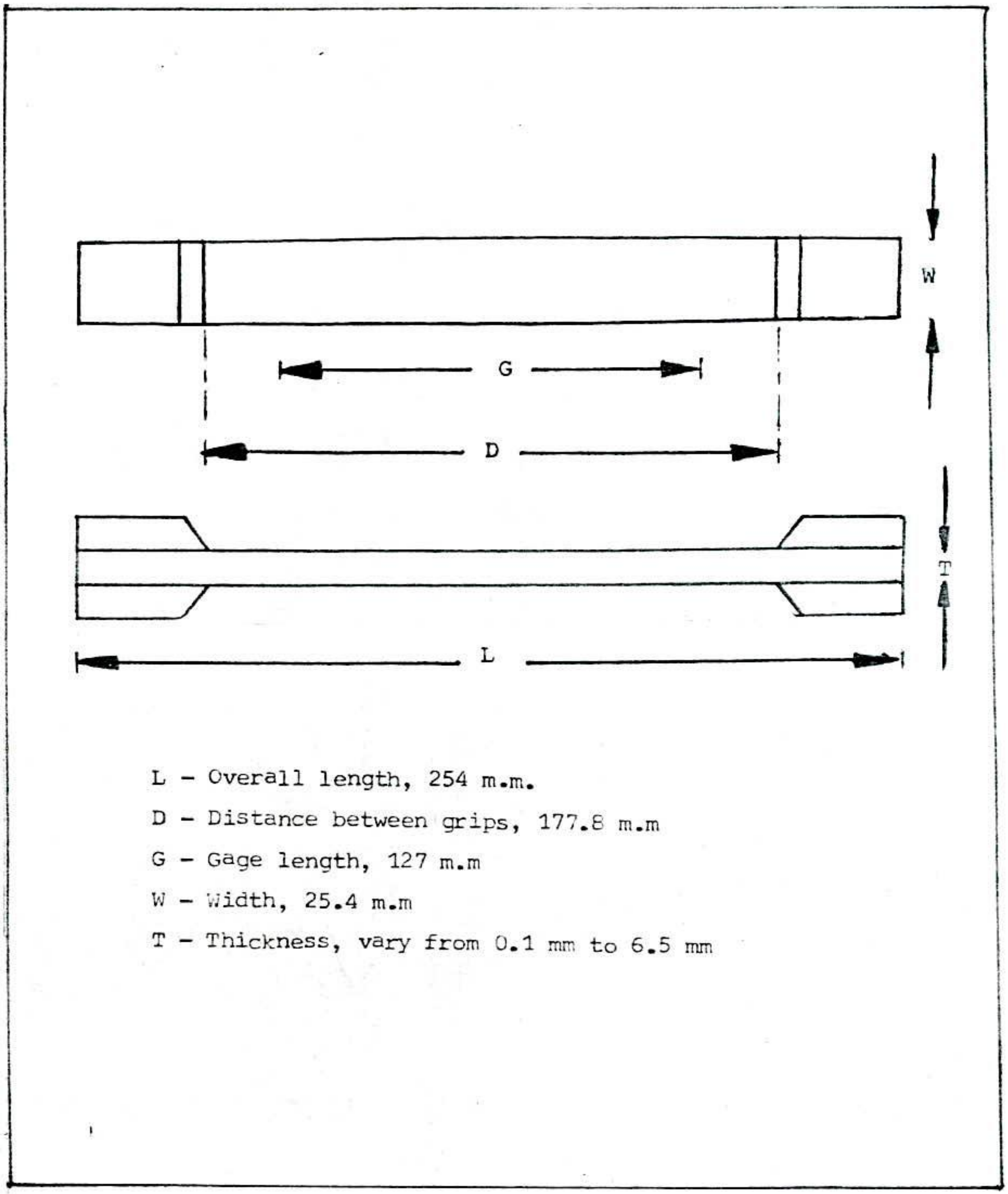
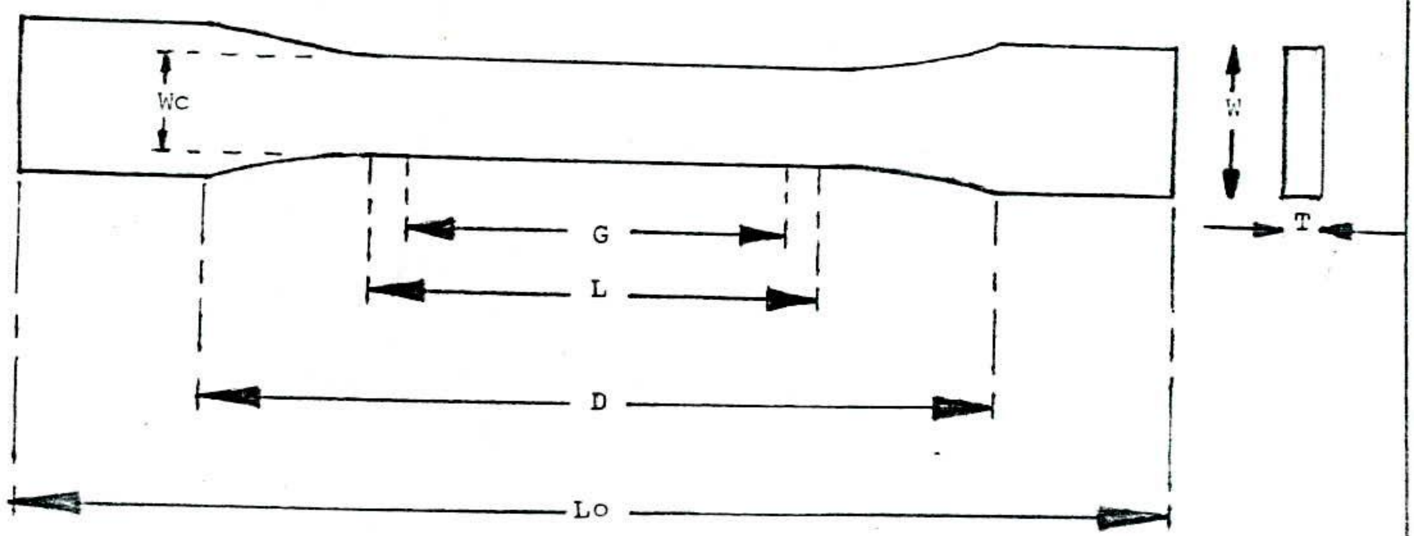


Fig. 5.1 Jute reinforced composite specimen **for tensile test.**



W - Width, overall	19 mm
Wc- Width of narrow section	13 ± 0.5 m.m
G - Gage length	150 mm
L - Length of narrow section	57 ± 0.5 mm
D - Distance bet^n grips	102 ± 0.5 mm
Lo- Length, Overall	152 mm
T - Thickness	6 ± 0.5 mm

Fig. 5.2. Polyester resin specimen for tensile test.

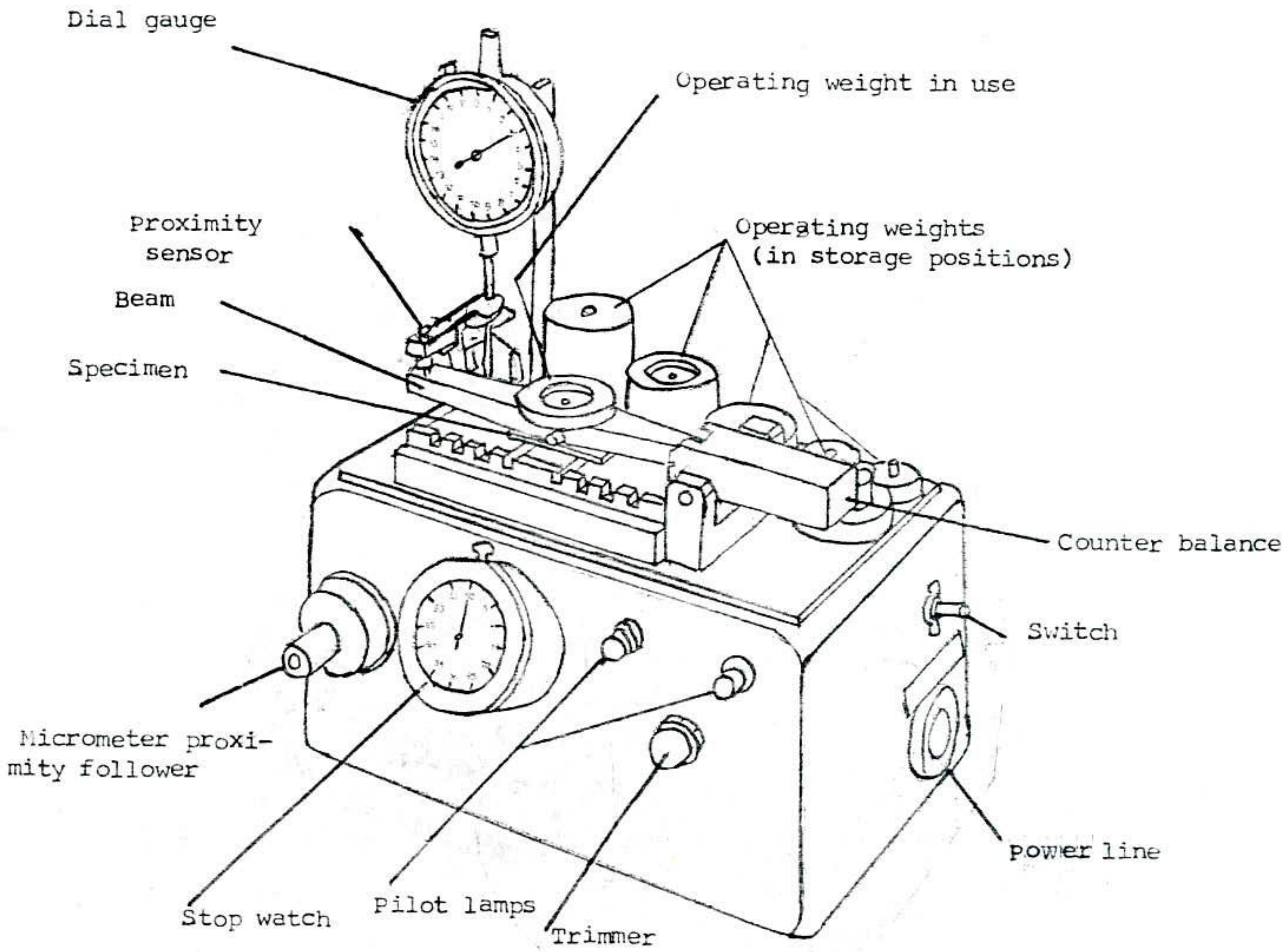


Fig. 5.3 A Sketch of Flexurul modulus measuring apparatus.

Zwick

Fig. 5.4 A photograph of Zwick Shore-D Harndess Tester

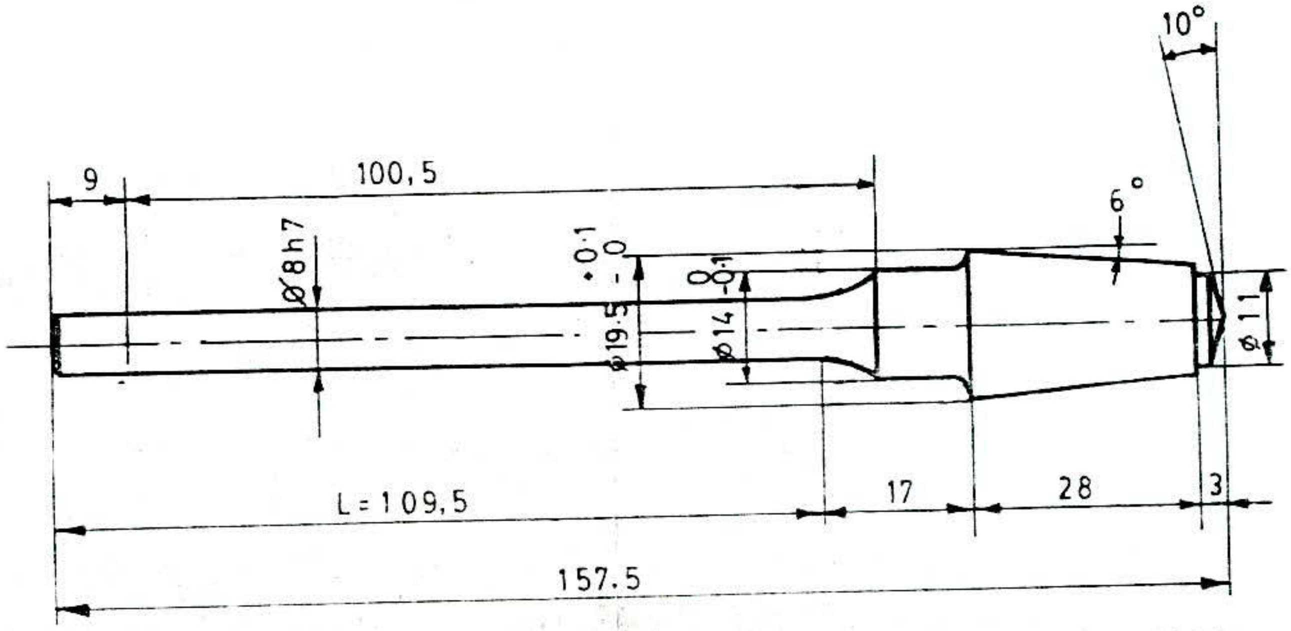


Fig. 5.5 Fatigue test specimen.

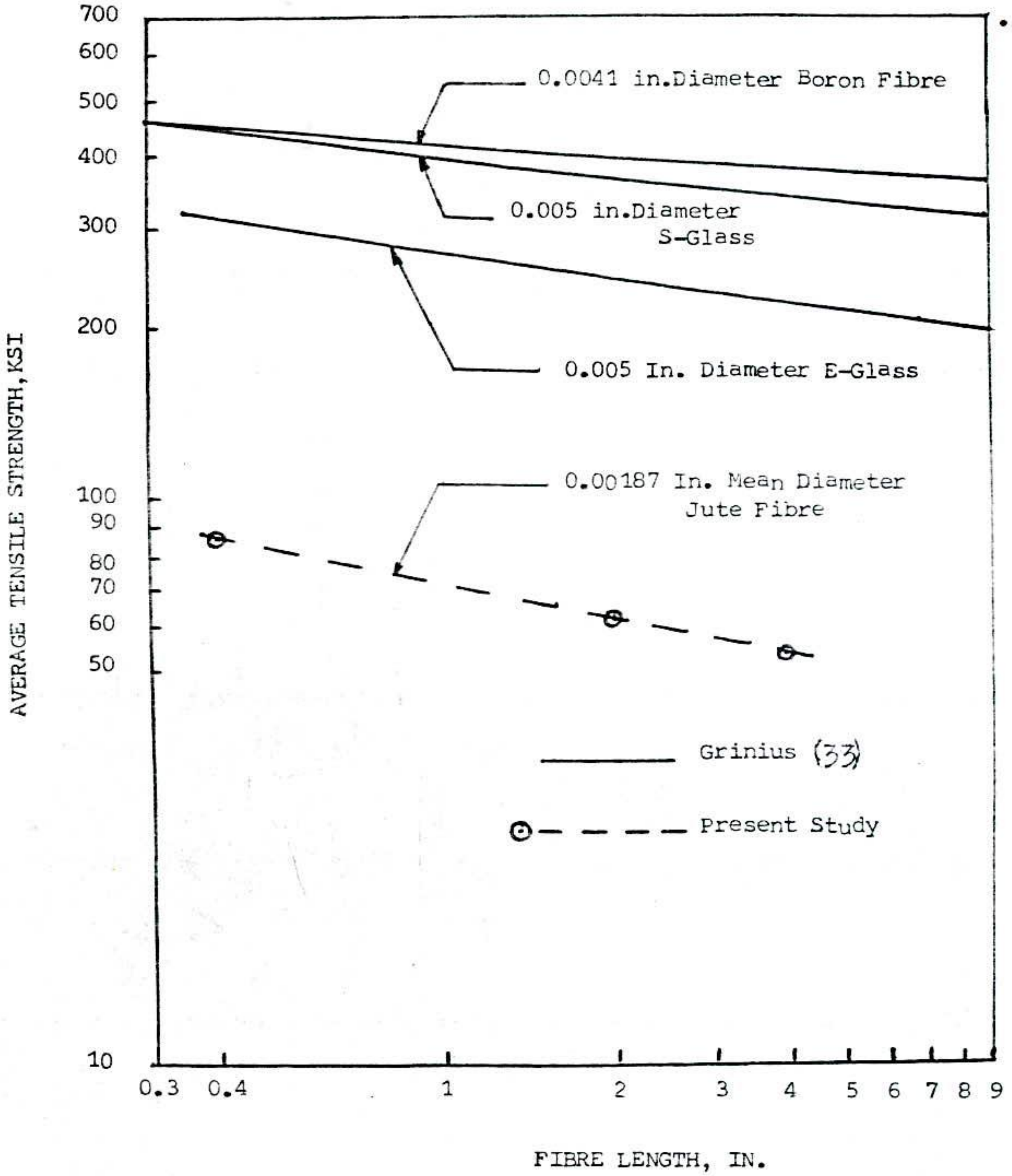


Fig. 6.1 Average tensile strength versus fibre length, logarithmic axes.

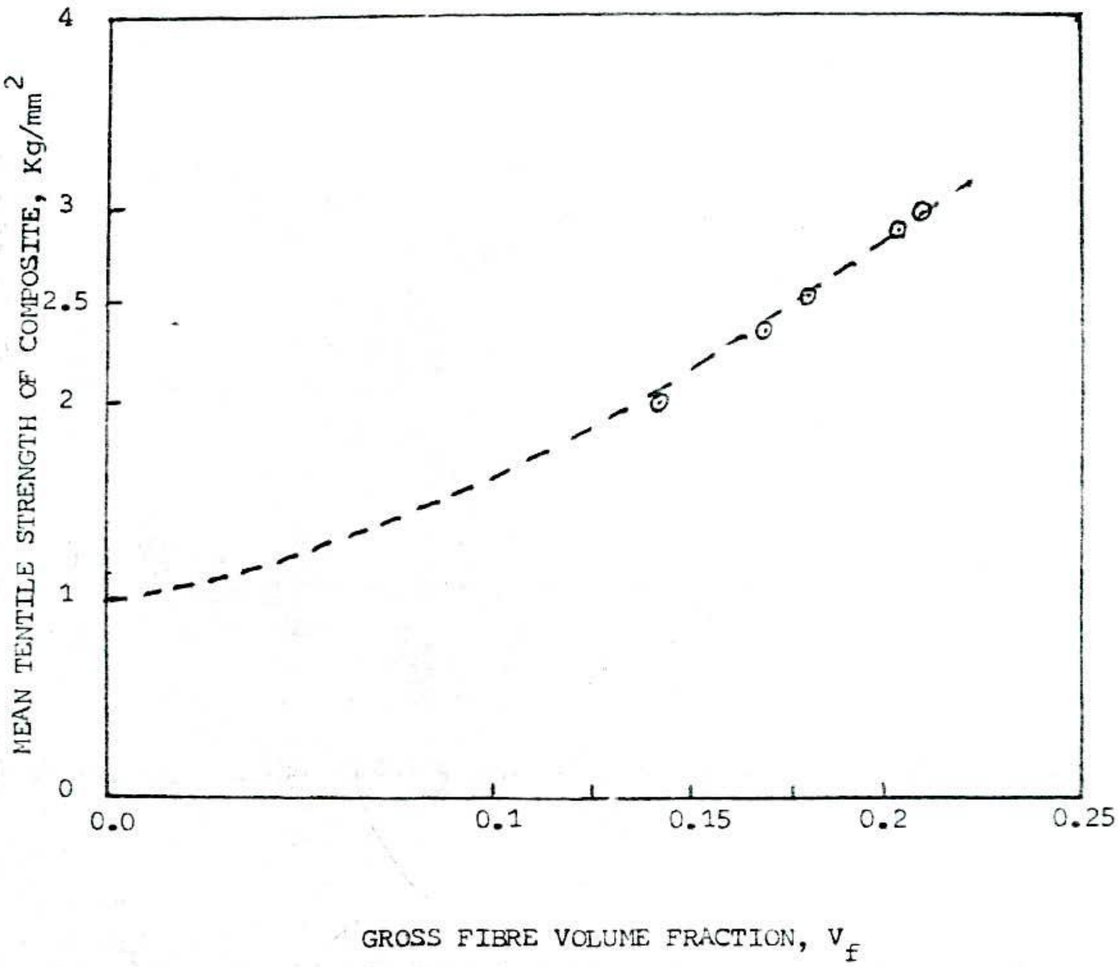


Fig. 6.2. Mean tensile strength of composite versus gross fibre volume fraction.

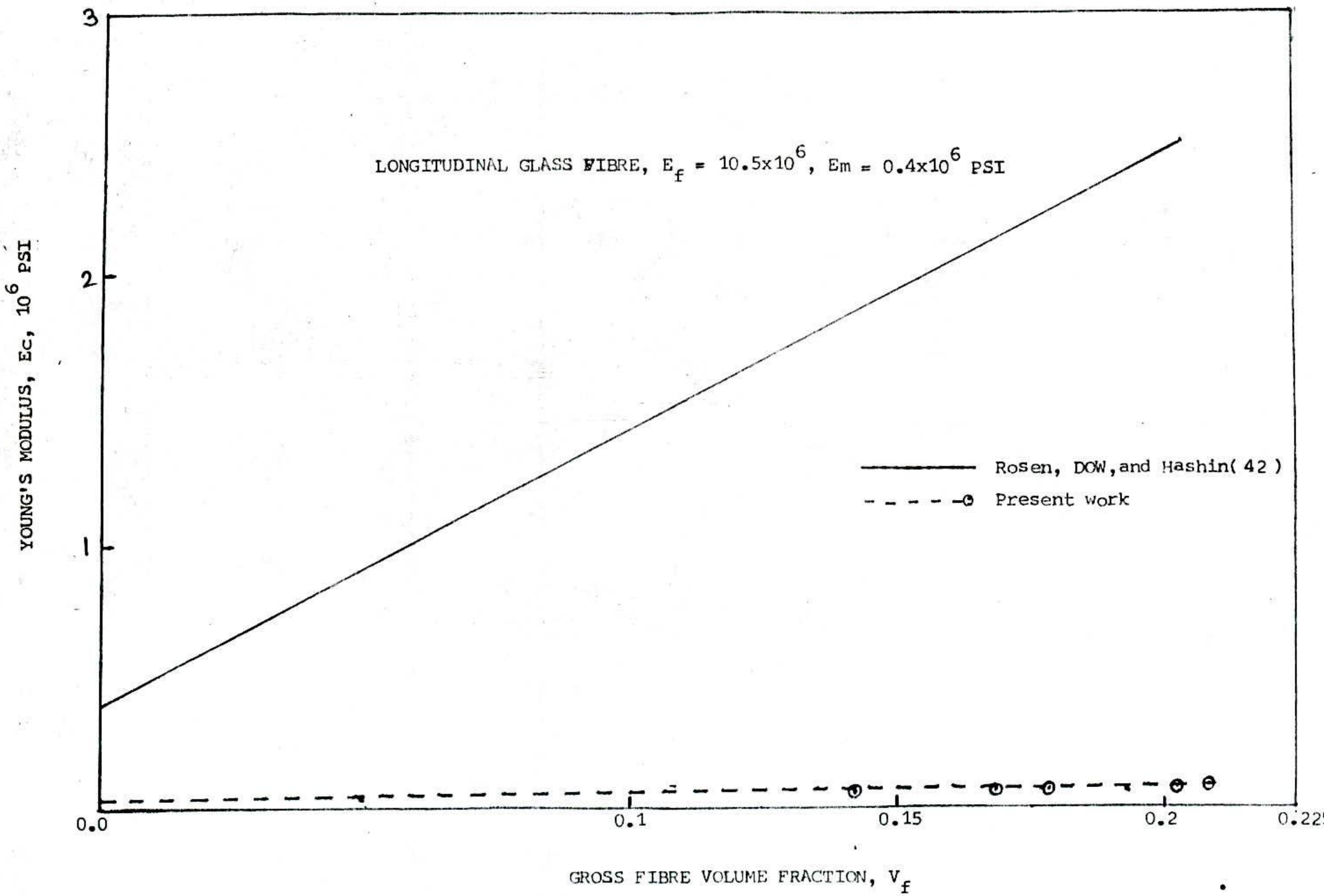


Fig. 6.3. Young's modulus of composite VS gross fibre volume fraction.

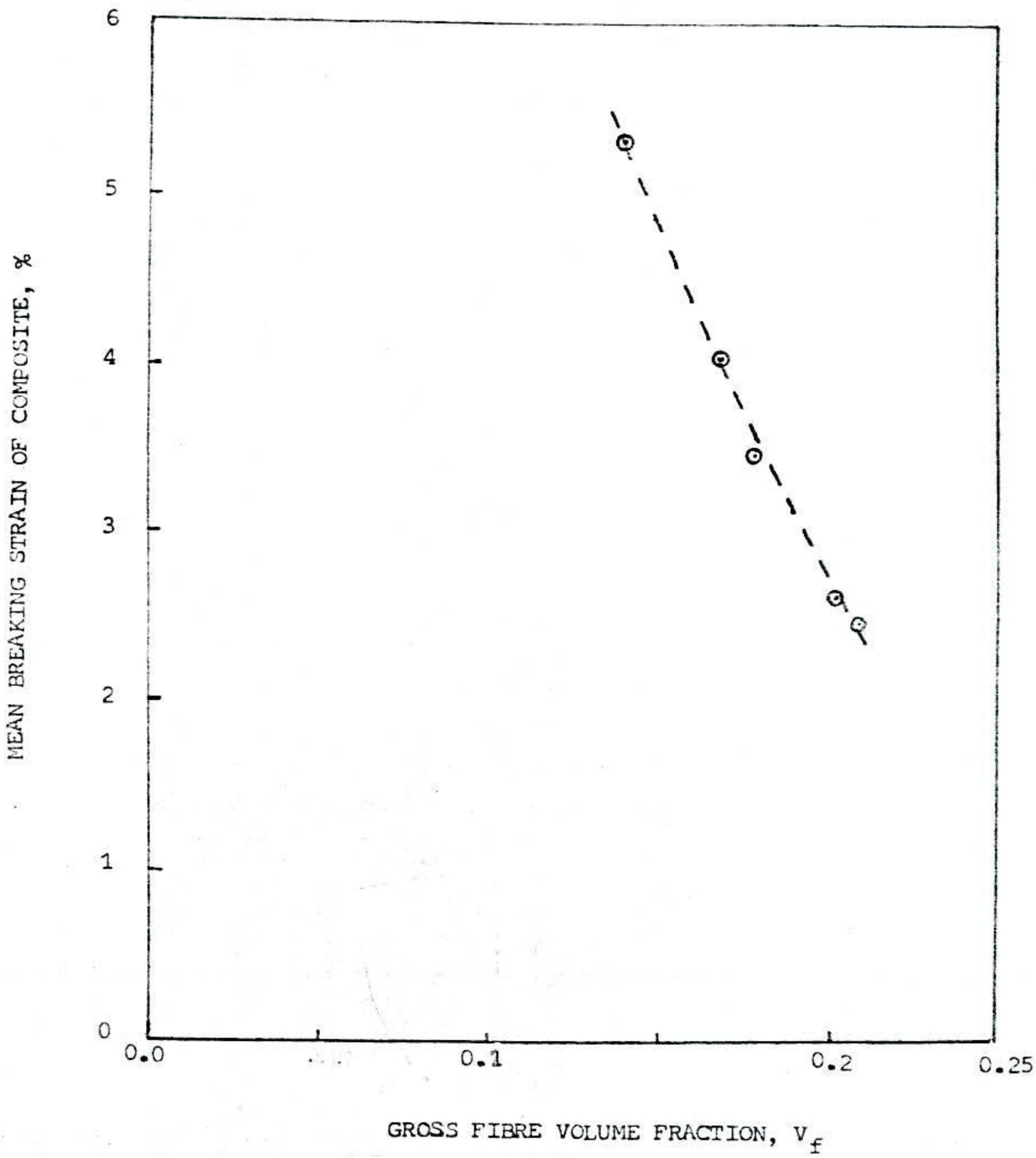


Fig. 6.4. Mean breaking strain of composite, in percentage VS gross fibre volume fraction.

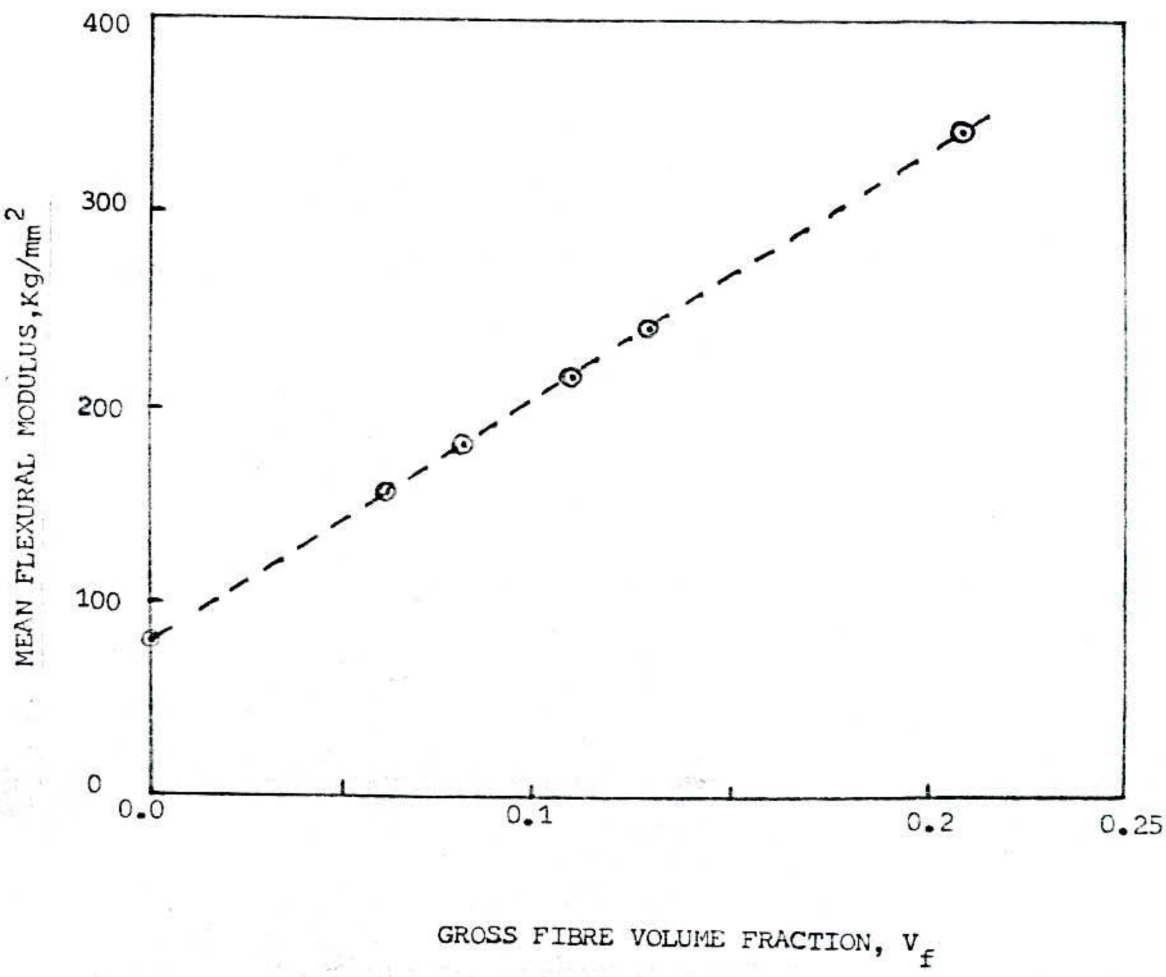


Fig. 6.5. Flexural modulus VS gross fibre volume fraction.

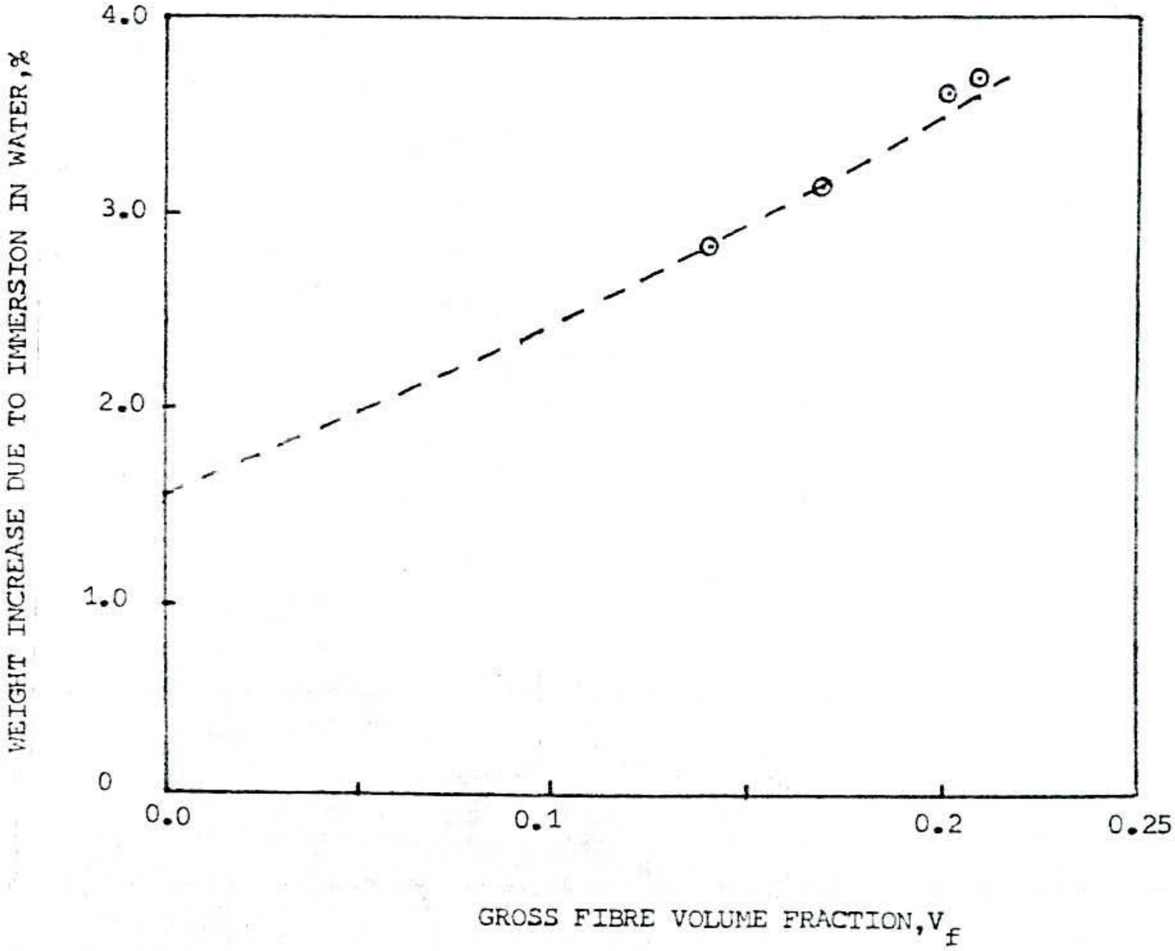


Fig. 6.6 Weight increase due to immersion in water, in percentage VS gross fibre volume fraction

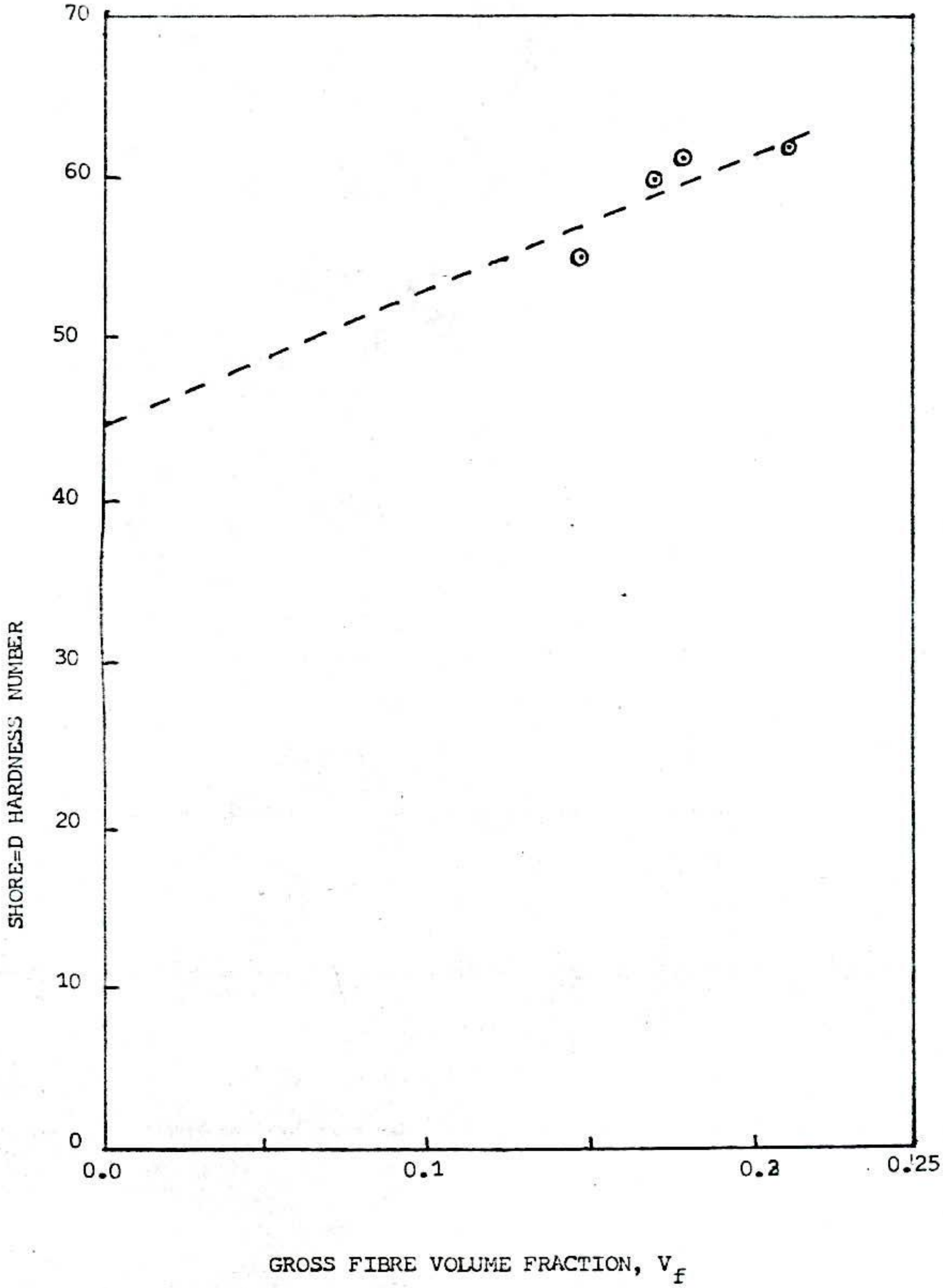


Fig. 6.7. Shore-D hardness number versus gross fibre volume fraction.

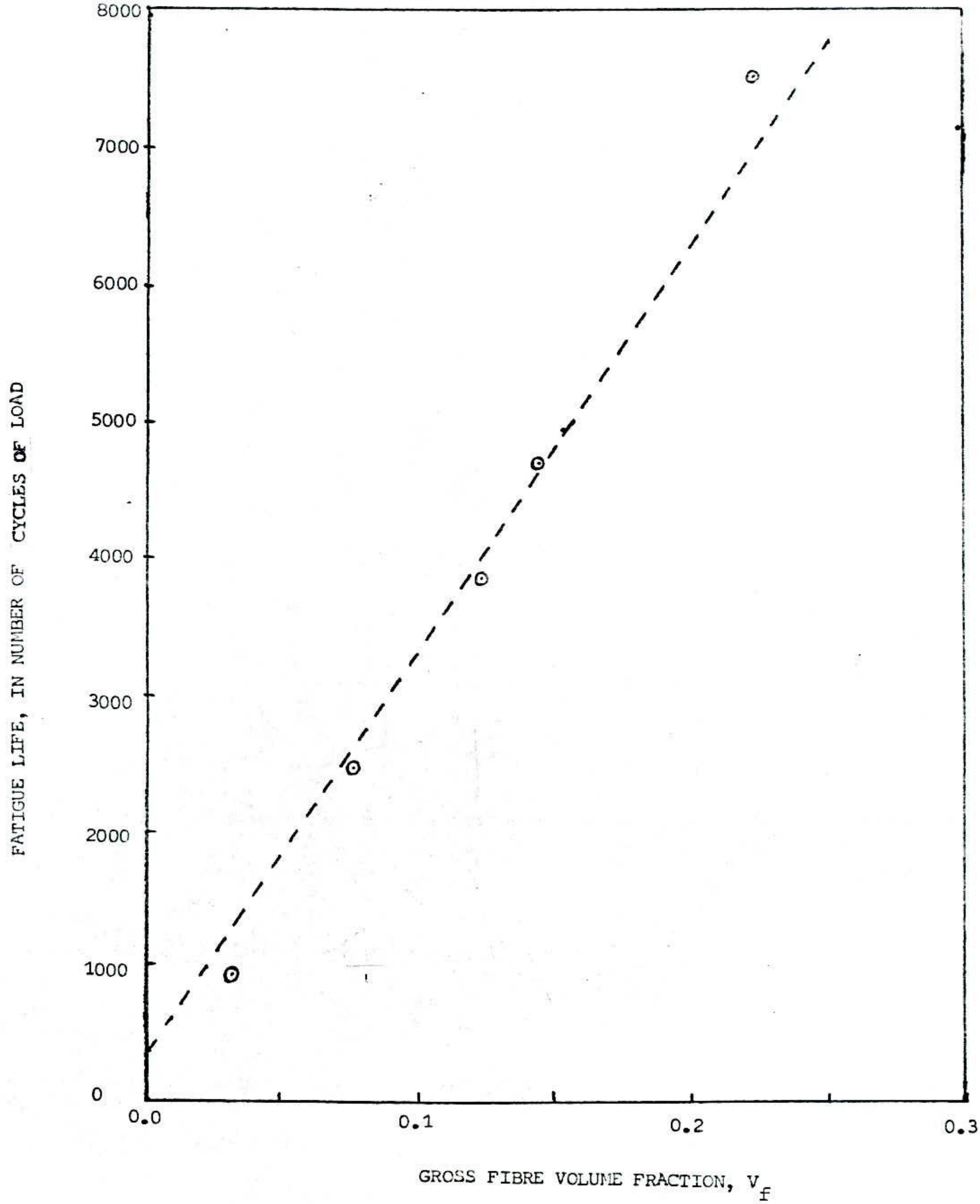


Fig. 6.8. Fatigue life, in cycles of loading VS gross fibre volume fraction, at load of 5 Newtons.

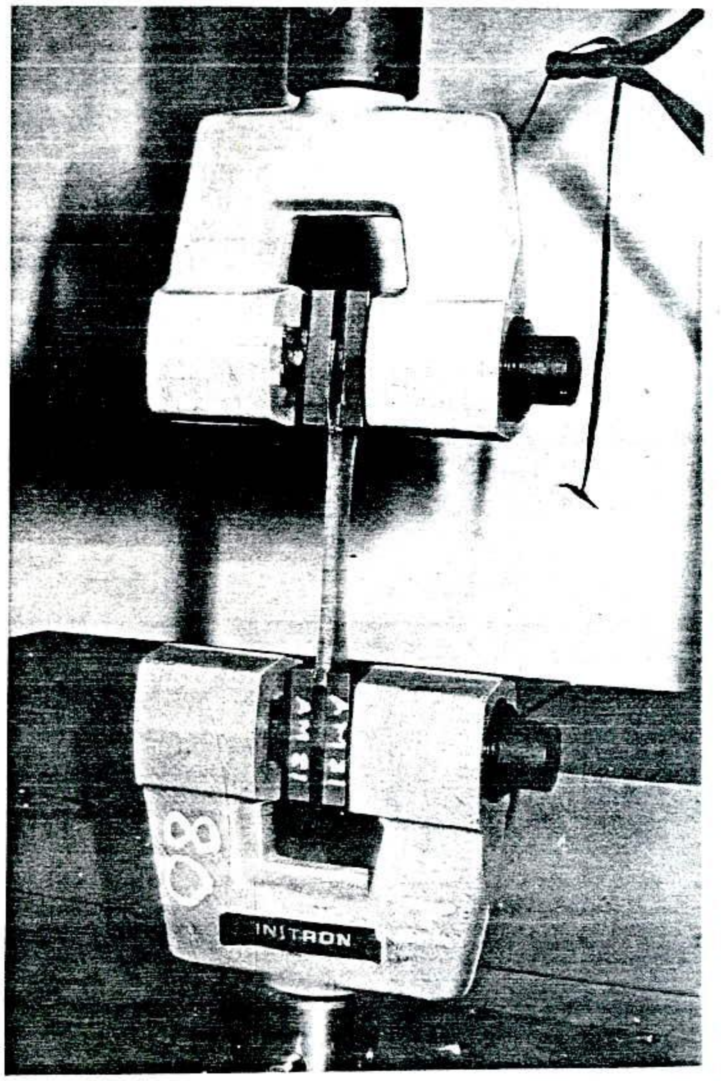


Fig. 7.1 Photograph of Gripping Set up for tensile test.

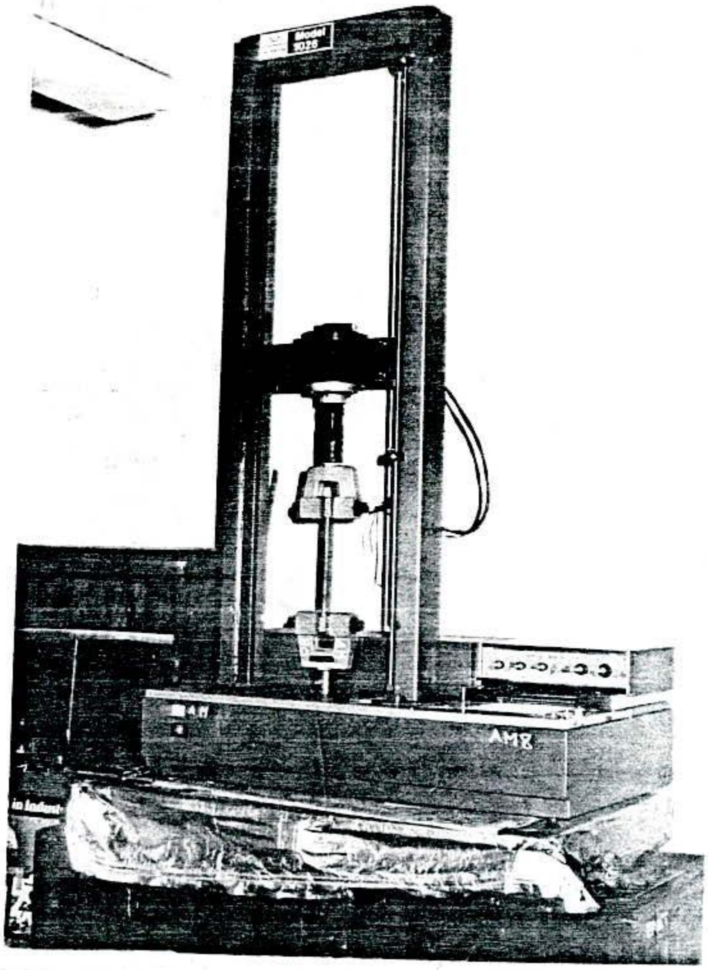


Fig. 7.2 Photograph of tensile testing machine with the specimen in position.

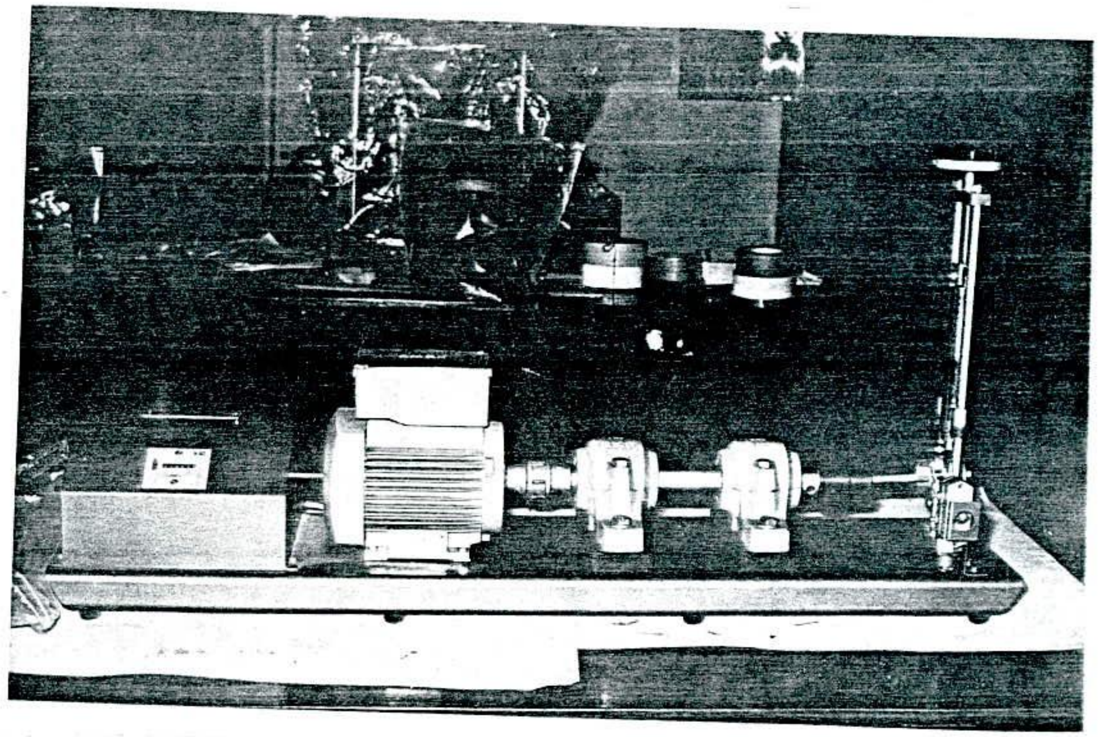


Fig. 7.3 Photograph of Fatigue testing machine with the specimen in position.

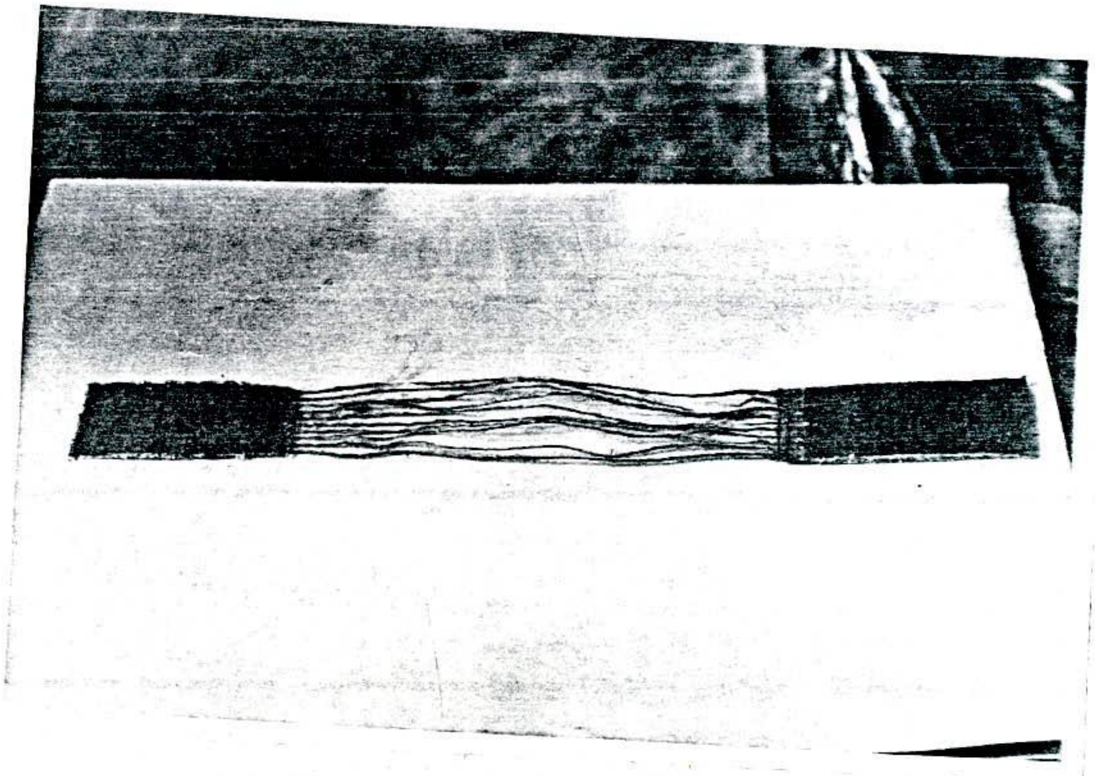


Fig. 7.4 Photograph of tensile test specimen of jute yarn bundle.

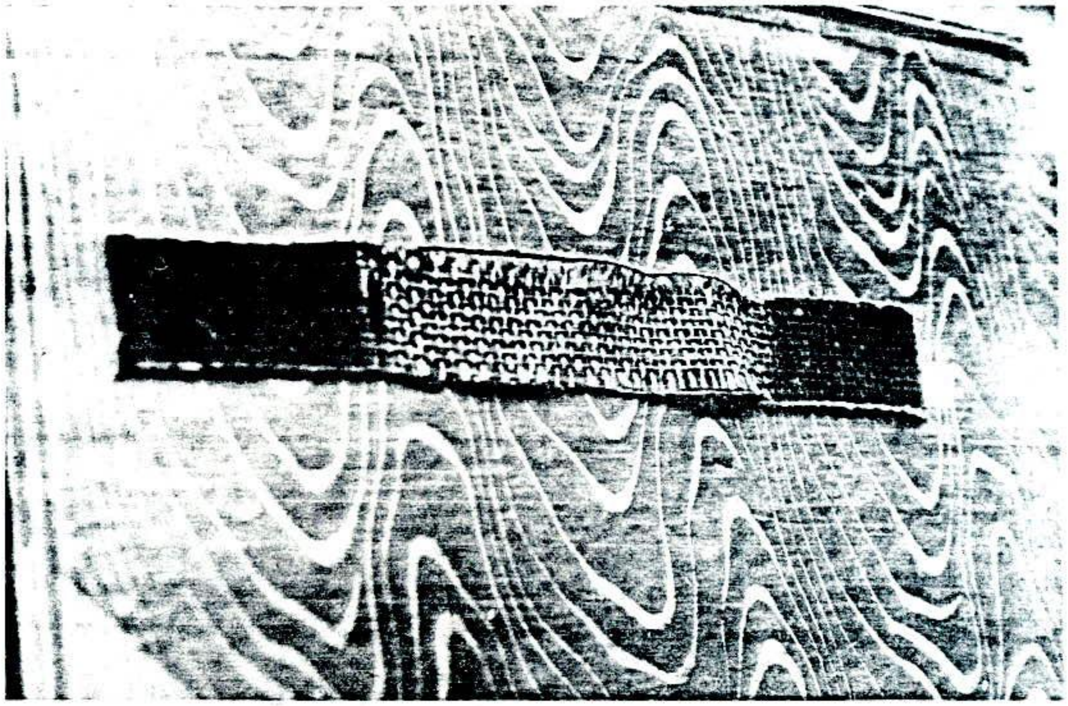


Fig. 7.5 Photograph of tensile test specimen of jute mat.

Fig. 7.5 Photograph of fractured tensile test specimen of pure resin.

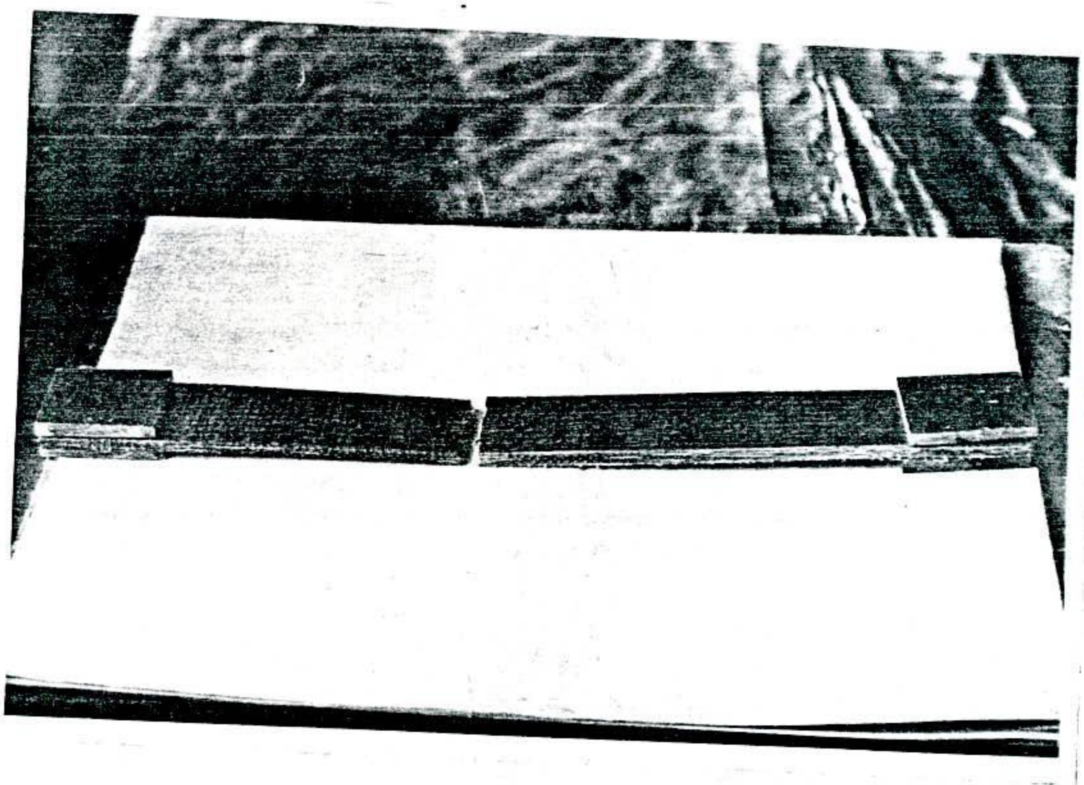


Fig. 7.7 Photograph of fractured tensile test specimen of reinforced plastics.

Fig. 7.8 Photograph of fractured fatigue test specimen of jute reinforced plastics.