DESIGN OF BI-AXIAL TESTING MACHINE

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Abstract—The knowledge of a materials ability to safely sustain a load before breaking has been of paramount importance to man ever since structures were first built. The strength of material under tension has long been regarded as one of the most important characteristics required for design, production quality control and life prediction of industrial plant. In recent years advanced composite materials are increasingly used in almost every industrial branch and the components manufactured from these composite materials are usually subjected to complex loading that leads to multi-axial stresses and strain fields. A bi axial testing machine which describes the mechanical behavior of an isotropic sheet material is presented. Mechanisms controlling each other independently impose a tensile stress on a plus shaped cruciform. The sample design has been optimized to reach the highest possible isotropic biaxial strain field. The isotropic nature of fibrous materials has led us to develop an optical method to measure in-plane displacements. The apparatus described herein is designed for the performance of biaxial stretching tests on flat cross-shaped specimen. It can be used with a conventional uniaxial tensile testing machine. The device converts the machine from one that exerts a uniaxial force to one that applies a system of forces in two perpendicular directions.

Index Terms - structures, composite materials, complex loading, multi-axial stress and strain fields.

I. INTRODUCTION

The Knowledge of a material's ability to safely sustain a load before breaking has been of paramount importance to man ever since structures were built. It is difficult to conceive that the qualitative ranking of softwoods, hardwoods and stone were unknown in the Neolithic time, and the Greek, Egyptian, Roman and Norman civilizations clearly had an understanding of material strength perhaps purely based on experience .However it is not until the Renaissance period in the 16th century that documentary evidence from the writings of Leonardo Da Vinci are found, which show that quantitative methods were employed to measure the differences in the material properties, Timoshenko (1953) and Gray (1988). The strength of material under tension has long been regarded as one of the most important characteristics required for design, production quality control and life prediction of industrial plant. The tension test is one of the most commonly used tests for evaluating materials. In its simplest form, the tension test is accomplished by gripping opposite ends of a test item within the load frame of attest machine. A tensile force is applied by the machine, resulting in the gradual elongation and eventual fracture of the test item. During this process , force-extension data, a quantitative measure of how the test item deforms under the applied tensile force, usually are monitored and recorded. When properly conducted, the tension test provides force-extension data that can quantify several important mechanical properties of a material. These mechanical tests determined from tension tests include, but are not limited to the following: Elastic deformation properties, such as the modulus of elasticity (Young's Modulus) and Poison's ratio, Yield Strength and Ultimate tensile strength, Ductility properties such as elongation, reduction in area strain -hardening characteristics. These material characteristics from tension tests are used for quality control in production, for ranking performance of structural materials for evaluation of newly developed alloys, and for dealing with the static-strength requirements of design. The results of tensile tests are used in selecting materials for engineering applications. Tensile properties frequently are included in material specifications to ensure quality. Tensile properties often are measured during development of new materials and processes so that different materials and processes can be compared.

II. COMPOSITE MATERIAL:

Composite materials, often shortened to composites or called composition materials, are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct at the macroscopic or microscopic scale within the finished structure.
A substance consisting of two or more materials, insoluble in one another, which are combined to form a useful engineering material possessing certain properties not possessed by the constituent, is called a "composite material".
Many of the modern industrial applications and technology required materials with superior properties that cannot be met by conventional monolithic material, such as metal alloys, ceramics, and polymers. Considering the principle of the combined action, better properties can be obtained bythe combination of two or more distinct materials. Accordingly, material properties combinations have been, and yet being extended by the development of the composite, which is a multiphase material that exhibits a proposition of the properties of the forming phases so that a better combination of properties is obtained. Composites may have different properties that its constituent do not possess, such as impact resistance being high for HPPE composites.
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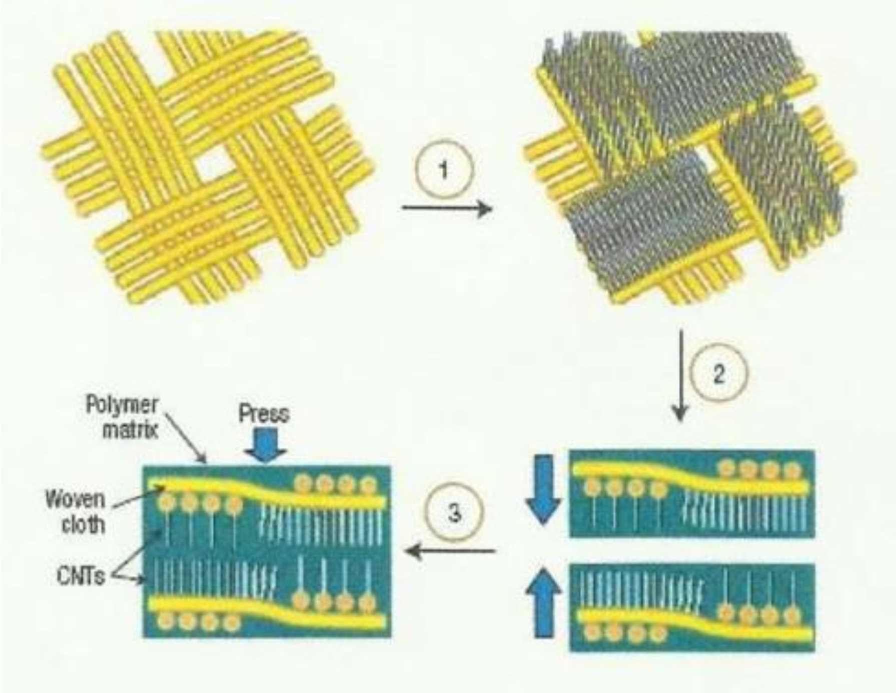

Figure 1: (1) :Aligned Nano tubes grown on the fiber cloth ;(2) Stacking of matrix infiltrated CNT –grownfiber cloth (3) 3-D Nano composite plate fabrication by hand lay-up

Composite materials that exist today can be categorized into five major classes, which include:-
1. Ceramic Matrix composites (CMCs)
2. Metal matrix composites (MMCs)
3. Intermetallic matrix composites (IMCs)
4. Carbon carbon composites (CCCs)
5. Polymer matrix composites (PMCs).

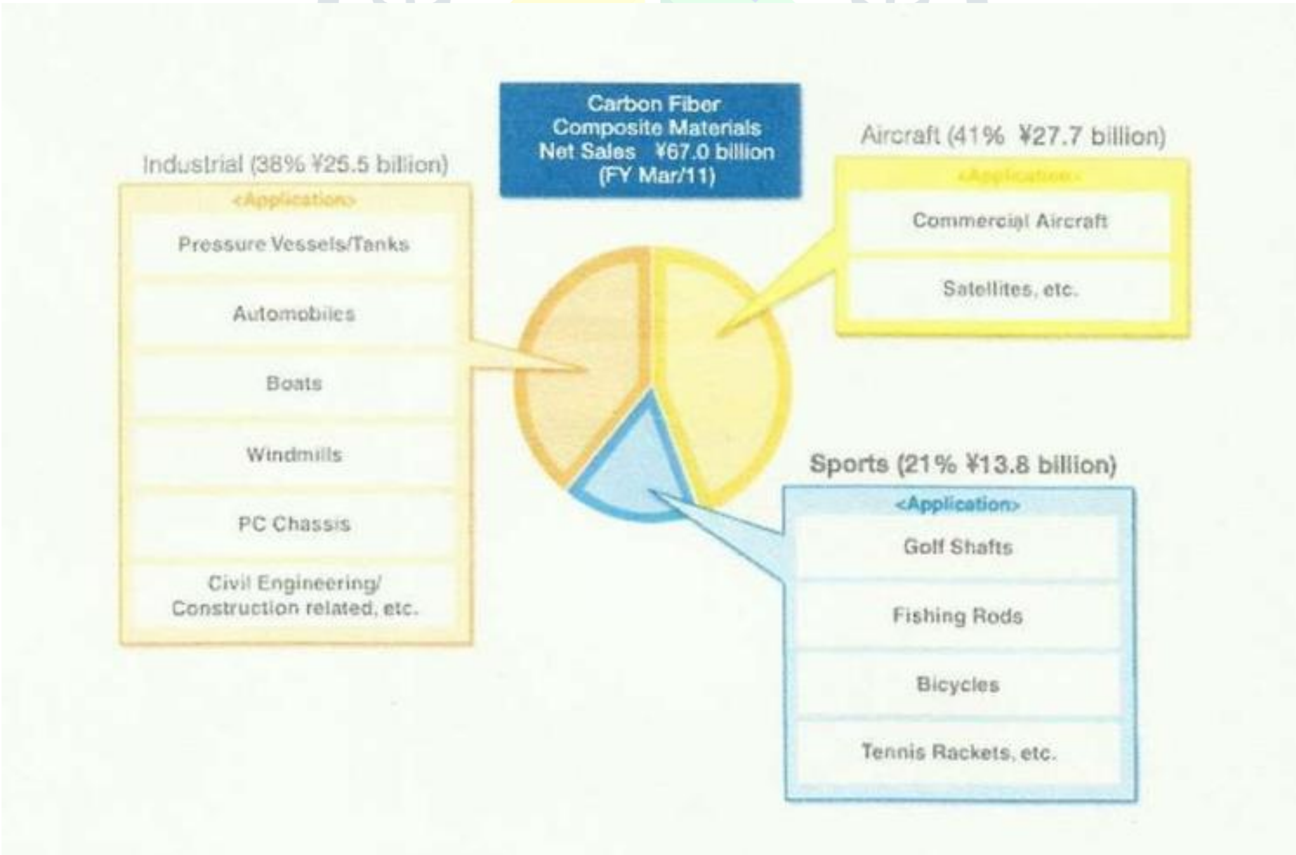

Figure 2: Applications of Composite materials

Composite materials have several advantages over traditional engineering materials, which make them attractive for many industrial applications. Composite materials have superior mechanical properties like high specific stiffness, high specific strength, high fatigue strength, and good impact properties. They can easily act as "smart" materials, that is, they can provide in-service monitoring or online process monitoring with the help of embedded sensors. Unlike most metallic materials, they may offer high corrosion and chemical resistance. Besides, the composite material provides good dimensional stability and design flexibility, they are appropriate for near net shape processing, which eliminates several machining operations and thus reduces process cycle time and cost.
Composites are also used in several design applications. Composite can be designed for different types of loading. For design purpose, it is vital to clarify the mechanical responses of composites to the mentioned loading types. As a result, studies are being carried out to determine the mechanical behavior of composite structures under different loading condition.

III. GENERAL STRUCTUREOF COMPOSITE:

The general structure of fiber-reinforced composites can be divided into three type's three parts: reinforced fiber, the matrix resin, and interfacial region that join the fiber and resin. By alternating the types and ratios of fiber and matrices the properties of the composite can be tailored to match the requirement of the end user.

3.1 Fiber and Matrix properities

Fiber Properities :

Carbon, glass and Aramid fibers are the main fibers used in polymer matrix composites .The choice of fiber and its specific properties are designed to complement a specific matrix; the addition of fibers in different volumes allow.

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IV. TESTING OF COMPOSITE MATERIAL:

The production of the (residual) strength of fiber-reinforced composites using failure criteria is not easy because of the different failure modes and their complex interaction that may occur. During the last fifty years, the failure behavior of the fiber-reinforced composite was studied intensively and various failure criteria were proposed. These criteria can generally be divided into two groups: (1) mechanistic criteria, which take into account the different modes of failure and which are mainly based on micro-mechanical models and (2) Empire criteria, which produce the strength out of mathematical model without taking into account what's happening on the micro-mechanical level. A recent worldwide study, which compares for fiber reinforced composites, the currently used failure criteria with each other small number of biaxial experiments shows that both categories of criteria give only an acceptable prediction of failure for a very limited number of specific cases. Furthermore, the first group of criteria often seems to be too complicated for a real design problem while the second group is often too easy to be generally accepted.

The failure behavior of uni-axially loaded fiber-reinforced composites is different from biaxial loaded specimens full stop Moreover in real life applications fiber-reinforced composites components are usually loaded in more than one direction at once, that is, they are biaxially loaded. Consequently limiting the evaluation of a material characteristic to uni-axial coupon test may lead to misrepresentation of the behavior of a material in real construction. Indeed, using more realistic loading condition, introduction of biaxial conditions will lead to a more accurate representation of the expected behavior of the structure in-service.

V. BI-AXIAL TENSILE TESTING MACHINE:

In the present work of mechanical type, biaxial testing machine is designed and developed. The machine is designed to apply load up to 2500N.In this machine, load is applied by compressing springs and screw nut-mechanism. Worm-gear is used to apply the required Torque. Gears are fixed on the screw rod outside the fixed plate. The sliding plates have internal Threads to rotate the screw rod in it. Two studs are tightly fitted in the fixed plate and are kept loose in the sliding plates so that the sliding plate can easily move. Spring is kept in between the fixed plate and sliding plate.The strain gauge will be fixed on the specimen. When the load is applied the specimen along with strain gauge will get deformed. The deformed strain gauge will show change in resistance of its wire. The change in resistance of the strain gauge can be calibrated in terms of the induced strain in the specimen.

LITERATURE REVIEW

G. odegard, k. searles Presented in simple container model for the macro-mechanical predictions of the elastic-plastic behavior of woven-fabric/polymer-matrix composites was proposed. This model uses a scalar hardening parameter instead of an effective stress-strain relation to determine plastic strain increment. For simplicity, the stresses are expressed as invariants based on the material symmetry. It has been shown, by the use of experimental data for two different woven-fabric/polymer-matrix composite materials that the newly proposed model accurately describes the non-linear mechanical behavior for different in-plane biaxial stress states ranging from pure shear to pure tension.

Wen-pinlin, hsuan-teh hu Proposed the numerical constitutive model for a single layer of fiber reinforced composite laminates, including nonlinear stress-strain relation, mixed failure criterion, and post-failure response, is used to predict the ultimate strength of the composite laminates under biaxial tensile loads. The nonlinear constitutive law uses a variable shear parameter to model the nonlinear behavior of the in-plane shear.The onset Failure for individual lamina is determined by a mixed failure Criterion composed of the Tsai-Wu and the maximum stress criteria. After the initial damage occurs, the response of the lamina is described by brittle or degrading to the collapse of the entire laminate. The constitutive was tested against experimental data and satisfactory results are obtained. In addition, parametric studies for composite laminates with different laminate layups and under various biaxial tensile load ratios were presented.

Makris a, ramaultc Reported the behavior fiber-reinforced polymeric matrix composite laminates under static and cyclic in-plane complex stress states. a Horizontal biaxial loading frame and a special cruciform type were developed. The cruciform specimen is biaxially loaded in its plane using four independent servo-controls until keeps the center of the specimen at the same position during the test. For obtaining reliable biaxial failure data the design of the cruciform geometry is of paramount importance, also the accuracy of the measurement using both strain gauges and optical numerical full-field carried out. Finally will be shown a comparison between failure envelopes plotted using existing failure criteria and experimental data obtained from cruciform and beam specimens testing. The nonlinear shear stress-strain and transverse stress-strain behavior of the lamina were taken into account.

DESIGN OF BI-AXIAL TESTING MACHINE:

The biaxial testing machine is designed to test the glass fiber composite laminated under the load of 2500N. The load is transferred to the specimen through spring, power screw and gears. These components are designed to take the required load.

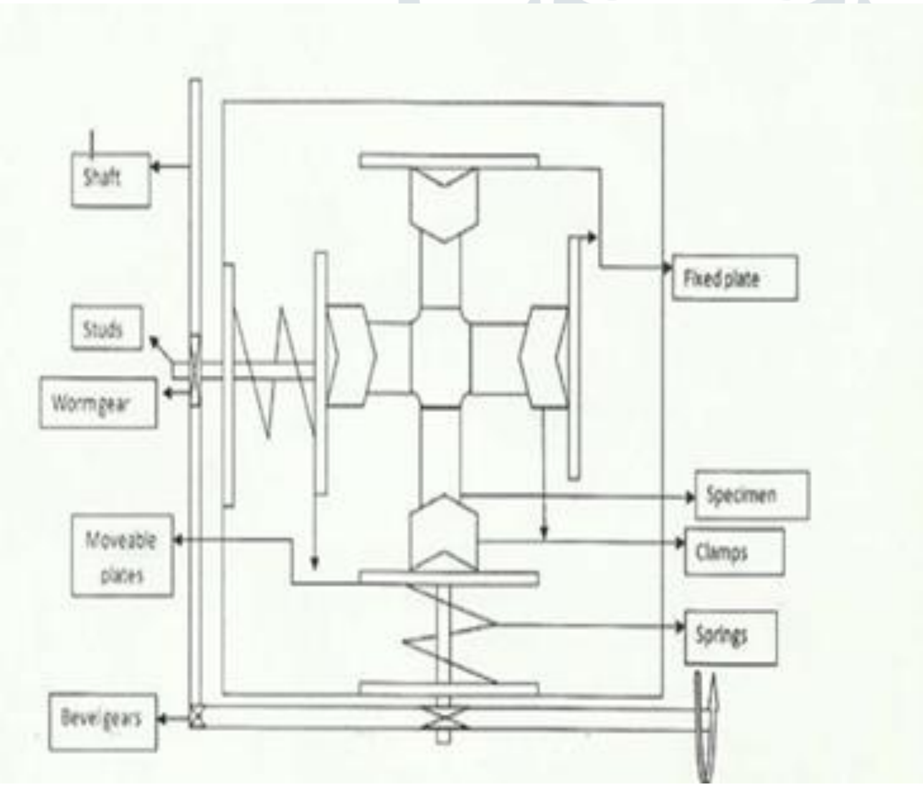

Figure 3: Biaxial Test Rig

3.1 Design of spring:

The material of spring is steel. Maximum tensile strength of the spring steel is 1775.5 MPa and modulus of rigidity is 79300 MPa. i.e.σ_{ult}=1775.5 MPa and G=79300 MPa
Permissible shear stress according to the the Indian Standard 4454-1981 is,
τ=0.5 ilt
τ=0.5×1775.5-887.75 MPa

Assuming spring index, C=6
The spring index is defined as the ratio of mean coil diameter to wire diameter
i.e.
c=D/d .... (3.1)
4C-10.615
Wahl stress factor, k = $\frac{4C-1}{4C-4} + \frac{0.615}{C}$ = 1.2525
Shear stress is given by $\tau = \frac{K8PC}{Hd2}$....... (3.2)
Where P=load applied = 2500 N and d=spring wire diameter
From equation (3.2)
Spring wire diameter d=8mm
So from equation (3.1)
Outer diameter of spring, D = Cd = 50mm
Assuming maximum deflection in spring, δ = 50mm
Deflection is given as $\delta = \frac{8PD^3N}{Gd^4}$
Therefore number of coil in the spring, N = 7
So number of active coils N_a = N+2=9
Solid length $N_a\, d$ = 72mm
It is assumed that will be a gap of 3mm between the consecutive coils when [the spring is subjected to the maximum force. The total number of coils is 9. Therefore total axial gap will be (9-1) × 3 = 21mm
Free length solid length + total axial gap + δ = 150 mm

3.2 Design of Gears:

The worm and worm gear provides the necessary torque to the power screw. The torque transmitted depends on the velocity ratio of the worm and gear.
Assuming velocity ratio as 48:1
Assuming x, the center distance between worm and wheel is to be 90mm.
Lead angle λ is given as
$\mathrm{Cot}^3\lambda$ = 48
Therefore λ = 15.4°
For velocity ratio of 48:1, no of starts n is I
I.e. n= Teeth of worm=T_W= I
Assuming module, rn = 3mm

Worm:
Axial pitch, Pa = ∏ m = 10 mm
Axial lead, 1=Pa n = 10mm
Diameter of worm,$D_w = \frac{1}{\pi tan\lambda}$ =39mm
Face length of worm, L=Pa (4.5 + 0.02T_W)
Depth of tooth, h= 0.623 Pa =43mm
Addendum, a=0.286 Pa = 2.86 full
L Outside diameter of worm, $D_{ow} = D_o$+2a = 45mm

Worm Gear:
No of teeth, T_G=VR=48
Pitch circle diameter of gear, D_G = m T_G=150mm
Outside diameter of gear, $D_O = D_G$ + 0.8903 Pa=160 mm
Face width, b=2.15Pa + 5=30mm

3.3 Cast iron plates:

	FIXED PLATES	SLIDING PLATES
Number of plate	4	2
Length (mm)	140	140

Thickness (mm)	12	12
Height (mm)	113	93

Base plate: 760mm × 60mm × 6mm
Studs: Number of studs = 4 Length = 153 mm

- Bearing
- Cast iron plates
- Vice

3.4 Spring:
The spring has a wire diameter of 8mm, outer diameter 50mm and free length of 150mm, The stiffness of the spring is 57.8N

3.5 Power screws:
Square threaded power screws are in the machine to apply the load. Helix angles of the thread is 5 degrees the power screws have an outer diameter of 25mm, pitch 6mm and mean diameter 22mm. key slots were provided at one end t_J screw to fix the gear on it.

3.6 Studs:
Studs are of mild steel material. Its diameter is 15mm and length is 200mm. Two studs are fitted on both side of fixed plate and movable plate slide on these studs.

3.7 Worm and worm-wheel:
A worm drive is a gear arrangement in which a worm meshes with a worm gear to a spur gear, the worm wheel drive axes at 900 to each other.Bushes are provided in the gear to couple the gear with power screw. One end of the power screw is inserted in the gear and they are locked with the key.

3.8 Bevel gear:
Bevel gears are used when the axes of the two shafts intersect and the tooth bearing faces of the gears themselves are conically shaped. Bevel gears are most often mounted on shafts that are 90 degrees apart. Bevel gear is manufacture on the gear cutting machines. It has 20 tooth and outer diameter is 60mm.

3.9 Cast iron plates:
A total of six iron plates are employed in the machines of which 4 plates are fixed on the base plate and two plate slides. The four fixed plates have a width of 140mm, height 113mm and thickness 121mm. The sliding plates also have a width of 140mm and thickness 12mm but a height of 93mm.
Internal threading is done on the sliding plates and the threads are cut according to the threads of the screw rod. First the plates are drilled on the specified point then boring operation is done to enlarge the hole. The threads are cut by using “taps and die tools”.

Figure 4: Marking and Plate cutiing

4.0 Assembly of the components:

The tensile loading mechanisms are welded on the base plate. Two small plates are welded on the top of the sliding plates and two plates are welded on the fixed plate. These small plates are provided to fix the vices on it. The worm shaft is put inside in the bearing and they are welded on the bottom side of the plate. First the worm is meshed with gear then marking is done where the bearing cover is meeting the plates. Bevel gears are meshed and the two worm shafts are aligned properly. The bearing plates are welded to the base plate on the marked position.

Figure 5: Welding of Components

4.1 Fabrication of specimen:

A cruciform shaped fiber glass epoxy laminated is fabricated for testing in the bi-axial tensile machine. Resin L-12 (3202) is used as epoxy material. A 250×250mm cruciform is to be tested whose arms width is 25mm.
First a mould was taken according to the size of the specimen to be prepared then its surface was cleaned .Now FRP mat was cut in to the size of required dimension. PV was applied on the mould surface. To obtain good surface a thin plastic layer was used on the mould surface.
Resin and hardener was taken in the ratio of 10:1. 250 ml resin was taken in a measuring jug and 25ml hardener was taken in measuring jar. Resin and hardener was mixed in another jug and was applied on the mat surface using brush.
After joining all the mats, a plastic cover was put on the mat for good surface finish. To apply the forces required for bonding the laminated a heavy iron plate was kept on the laminated. It -is kept for 7-8 hours then iron plates is removed and a square shaped laminated is formed. Then it is cut with a high speed cutting tool to the required shape and size.

4.2 Installation of strain gauge:

Strain gauges are installed on the specimen for measuring the strain in the cruciform specimen. Three strain gauge of gauge factor 2 and 350 Ω are connected to form a rectangular rosette type combination.

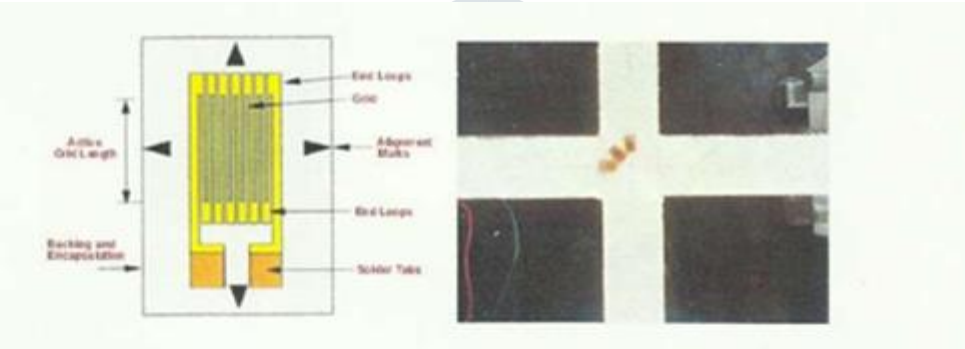

Figure 6: (a) Strain gauge (b) Strain gauge on specimen

4.3 Strain calculations:

The specimen is clamped in the vices. One arm of the Wheatstone bridge circuit is connected to strain gauge terminals. The circuit is balanced by varying resistance of rheostat. Then tensile load is applied on the specimen. Applied load is measured by the deflection occurred in the springs. The load causes changes in resistance of the strain gauge wire. This will bring deflection in the voltmeter.
Initial reading of the rheostat was taken when the strain gauge were unstressed.

Initial readings:

Rheostat reading for strain gauge 1 = 346 Ω
Rheostat reading for strain gauge 2 = 346.3 Ω
Rheostat reading for strain gauge 3 = 345 Ω
Resistance of strain gauge 1 R_{41}= 351.7 Ω
Resistance of strain gauge 2 R_{42}= 352.6 Ω
Resistance of strain gauge 3 R_{43} = 351.7 Ω
Now for a 5mm deflection in spring:
Load applied = deflection × stiffness of spring
= 5 × 57.8
= 289 N
Rheostat reading for strain gauge 1 = 272.8 Ω
Rheostat reading for strain gauge 2 = 272.8 Ω
Rheostat reading for strain gauge 3 = 270 Ω
Change in resistance of rheostat for 1^{st} strain gauge (ΔR_{21}) = 346-272.8
= 73.2 Ω
Change in resistance of rheostat for 2^{nd}strain gauge ($\Delta R_{22)}$ = 346.3-272.8
= 73.5 Ω9
Change in resistance of rheostat for3^{rd} strain gauge(ΔR_{23}) = 345-270
= 75 Ω
We know that from equation (3.1)
$\Delta R_4 = \Delta R_2$
Therefore,

Change in resistance of 1^{st}strain gauge (ΔR_{41}) =73.2 Ω
Change in resistance of 2^{nd}strain gauge (ΔR_{42}) =73.5 Ω
Change in resistance of 3^{rd}strain gauge (ΔR_{43}) = 75 Ω
From equation (3.4)
Strain in,
1^{st} Strain gaugeε_1 = 0.1041
2^{nd} Strain gaugeε_2 = 0.1042
3^{rd} Strain gaugeε_3 = 0.1066
From equation (3.5), principal strains are
ε_{max}= 0.1070 ε_{max} = 0.1036
If young's modulus (E) = 50 MPa and Poisson's ratio (V) = 0.225
Then from equation (3.6) Principle stresses are
σ_{max}= 6.86 MN/$m^2$$\sigma_{min}$ = 6.73 MN/m^2
From equation (3.7), maximum shear stress is
τ_{max}= 6.86 MN/m^2
The orientation of the principal stress is given by equation (3.8)
θ = 21.3

CONCLUSION:

The project explains the development of Bi-axial testing machine. Bi-axial tests can be performed on the materials which are generally stressed multi-axially in their operation.

1. The bi-axial test setup has been developed with the specification mentioned. Various machining operations have been performed for the manufacturing.
2. Fiber-glass epoxy cruciform laminated has fabricated and tested bi-axially. Changes in strain of the cruciform were recorded using strain gauge. Various mechanical properties of the cruciform specimen were obtained.

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