BIOMECHANICAL PROPERTIES OF HYBRID KEVLAR/LINEN/EPOXY COMPOSITE FOR BONE PLATE APPLICATIONS

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Abstract - *Tibia fracture is mainly treated using rigid metallic bone plates which may result in "stress shielding" leading to bone resorption and implant loosening. This work aims to develop a Kevlar/Linen/Epoxy hybrid composite material for use as an orthopaedic Tibia fracture plate, instead of the common steel and titanium metal plates. The Kevlar/Linen/Epoxy composite would have properties similar to that of human cortical bone, there by having potential application as a Tibia fracture plate. The composite material used here is a "sandwich structure" in which mats of Kevlar are attached to both outer surface of the linen core, which results in a unique structure compared to other composite plates for bone plate applications.*

This study was conducted to evaluate the mechanical properties of the newly developed material. Mechanical properties were evaluated using experimental analysis of the proposed material which included tensile, flexural, and hardness tests. The specimens are prepared by means of hand lay-up process considering ASTM D 3039, ASTM 790 and ASTM D785 *standards.*

***Key Words*: stress shielding, bone resorption, *implant loosening,* hybrid composite, sandwich structure**

1. INTRODUCTION

Trauma is a major cause of death and disability in both developed and developing countries. The World Health Organization (WHO) predicts that by the year 2020, trauma will be the leading cause of years of life lost for both developed and developing nations. Bone fractures occur if the load on the bone exceeds the strength of the bone itself, caused by motor vehicle accident for example. Almost 80% of the accident victims suffer fractured bones.

Orthopaedic surgeons have been using metallic bone plates for the internal fixation of humerus bone fractures. Apparently, metallic prostheses, which are generally made of stainless steel and titanium alloys, cause some problems like metal incompatibility, corrosion, magnetism effect, anode-cathode reactions, including a decrease in bone mass (osteopenia), increase in bone porosity (osteoporosis), and delay in fracture healing (callus formation, ossification). Due to insufficient bone growth, refractures after the removal of the prostheses are also widely reported. It was also found that the difference in the elasticity of a metallic implant and bone may cause loosening of the implant.

In recent years, composite materials have been considered for biomedical applications (such as Fracture fixation mechanisms like as plates and intramedullary nails) since they have mechanical and biological similarities to the human tissue. Composites have some advantages, such as being radiolucent in X-ray radiography and compatibility with modern medical imaging like MRI and CT scans. The introduction of rigid plates had by far the greatest impact on plate fixation of fractures. However, it led to cortical porosis, delayed bridging, and refractures after plate removal. An efficient fixation device must have mechanical properties close to the bone plate in order to allow some levels of axial movements between fracture ends while stabilizing the fracture site by minimizing the unfavorable fragments' motions. Therefore, the fixation mechanism must fully tolerate the torsional and bending loads (high bending and torsional stiffness) while being axially flexible.

This work is part of an ongoing program to develop a new Kevlar fiber/linen/epoxy (KF/flax/ epoxy) hybrid composite material for use as an orthopaedic long bone fracture plate, instead of a metal plate. The purpose of this study was to evaluate the mechanical properties of this novel composite material. The composite material has a "sandwich structure"in which two thin sheets of KF/epoxy were attached to each outer surface of the linen/epoxy core, which resulted in a unique structure compared to other composite plates for bone plate applications. Mechanical properties were determined using tension, three- point bending, and Rockwell hardness tests

2. COMPOSITE MATERIAL PREPARATION

Hybrid composite specimens of Kevlar fibre, linen fibre and epoxy resin made by using Hand Lay-up technique. A mild steel mold is used for the fabrication of composite specimen. The mold is coated with wax for the easy removal of the sample. At first the Kevlar fibre and linen fiber fabrics of required size are cut so that they can be deposited on the template layer by layer during fabrication. Epoxy L-12 resin is used as a matrix and mixed with hardener K-6, the solution was mixed with 10:1 by weight percentage. Two OHP sheets are used at the top and bottom of the mold to give smooth surface finish. Brush and roller are used to impregnate fiber fabrics and also to avoid air entrapped. Linen fiber fabric is placed over the Kevlar fabrics with resin layer in between in the mold up to the required thickness of specimen. Brush and roller are used to impregnate fiber mats and also to avoid air entrapped. Now the mold is placed in the compression molding machine. Approximately 70 kgF pressure is applied on the mold and it is allowed to cure at room temperature for 24 hours.

3. TESTING OF KEVLAR/LINEN/EPOXY COMPOSITE

A number of experimental techniques have been developed to find mechanical behavior of engineering materials. In this study tensile, flexural and hardness test are used to find the mechanical properties of Kevlar/linen/epoxy composite material.

Table 1: Test standards and specimen dimensions.

Experiments	Test Standard	dimensions (mm)
Tensile	ASTM D3039	250 X 25 X 5
3 Point flexural	ASTM D790	150 X 13 X 5
Hardness test`	ASTM D785	1^2

3.1 TENSILE LOAD TEST

Tensile Load Test is the most common type of test used for measuring the mechanical properties of materials. This test is widely used to provide a basic design information regarding material properties and is generally accepted test for material specifications. The major parameters obtained during the tensile load test are the tensile strength, yield strength, Elastic modulus , percent of increase in length and the percentage of reduction in area ,toughness, Poisson‟s ratio etc. can be found out using this technique.

In this test, a specimen is fixed between the jaws of the testing machine before loading. The specimen used is approximately uniform over the length within which elongation measurements are done (gauge length). Tensile specimens are developed according to the ASTM standards. The cross section of the specimen is rectangular in shape. The change in gage length of the sample as tensile loading proceeds is measured from a sensor attached to the sample (called an extensometer) or by the change in actuator position (stroke or overall change in length).

The specimen thickness is also an important parameter in the tensile test. The load that must be applied to produce a gauge section failure decreases as the specimen thickness decreases. In the case of composite materials, accurate measurement of tensile strength is very much difficult and this can be addressed through the improved specimen design and careful fabrication of the specimen. The tensile strength of the laminate was measured by the ASTM standard ASTM D3039 .The Tensile test setup is shown in the figure 1

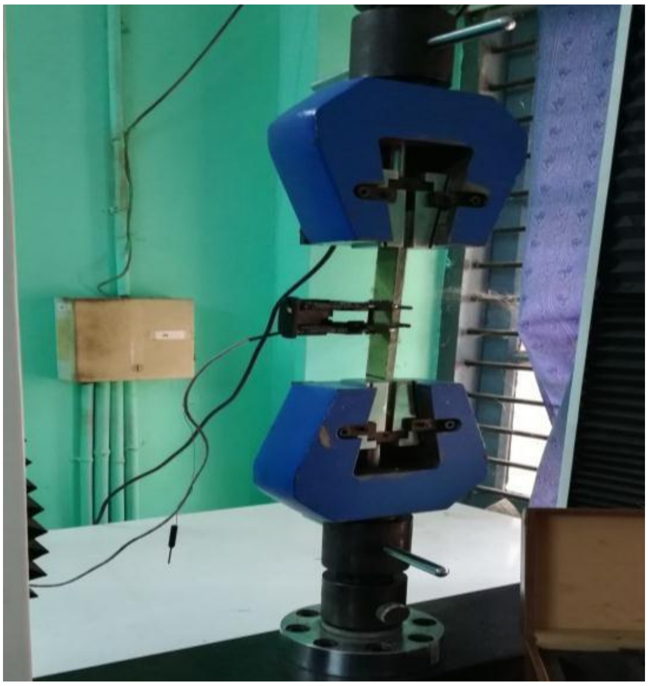

Figure 1: Tensile test setup

The tensile loading is done to the specimen until it fractures. During the test, the maximum load is recorded. By using an x-y recorder, a load elongation curve is plotted in order to find the tensile behavior of the material. An engineering stress-strain curve is also obtained along with the load-deflection curve and the required mechanical parameters can be obtained by studying on this curve. The strain is measured by using an extensometer with a gauge length of 250mm. The ultimate tensile strength is calculated using the eqn.

$$\sigma = \frac{P_{max}}{A}$$

Where P_{max} = maximum load during the tension test

A =Area of the specimen

3.2 FLEXURAL TEST

The three point bending flexural test provides values for the bending modulus Ef, flexural strength σf, flexural strain εf and the flexural (bending) stress-strain response of the material. However, the results of the testing method are sensitive to specimen and loading geometry along with strain rate which are certain disadvantages of this method.

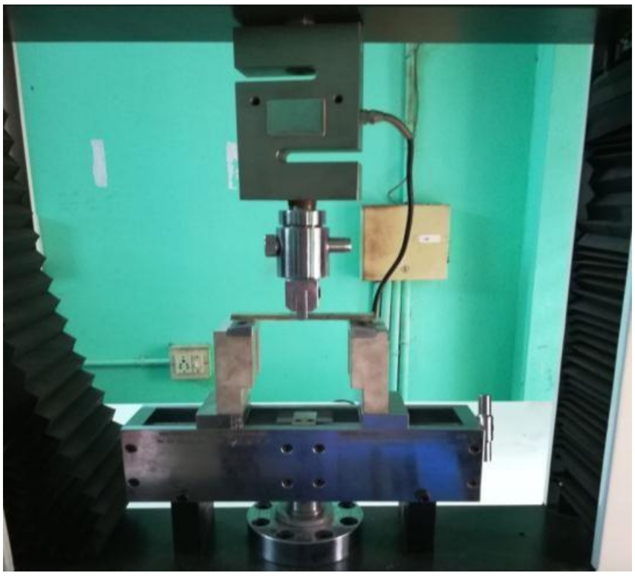

Figure 2: Flexural test

In the case of three point bend tests, flexural strength of composites is determined using ASTM D790 standards .The method for conducting the test usually involves a specified test fixture on a universal testing machine. The sample is placed at a set distance apart on two supporting pins and a third pin is provided for loading purpose lowered from above at a constant rate until failure of sample. . The specimen is deflected until rupture occurs in the outer surface of the test specimen or until a maximum strain of 5% is reached whichever occurs first. In 3 point bend test: If support span-to-depth ratio is greater than 16:1, the stress in the outer surface of the specimen for a simple beam can be reasonably approximated with the equation.

$$\sigma f = \frac{3P_{max}l}{2bd^2} \times \left[1 + 6 \times \left(\frac{D}{L}\right)^2 \times 4\left(\frac{d}{L}\right)\left(\frac{D}{L}\right)\right]$$

The flexural strain is calculated by the eqn.

$$\varepsilon f = \frac{6Dd}{L^2}$$

Where:

Pmax= Load at a maximum point on the load-deflection curve (N).
L= Support span (mm).
d= Depth of beam tested (mm).
D=Midspan deflection (mm).
b=Width of the beam tested (mm).
The midspan deflection of the sample can be obtained by eqn.

$$P_L = \frac{PL^3}{48EI}$$

E is the Flexural modulus.
I is the moment of inertia.

$$I = \frac{bd^2}{12}$$

Slope of the stress strain curve P/D can be obtained by eqn.

$$\frac{P}{D} = \frac{48EI}{L^3}$$

From the above relations, the flexural modulus can be calculated by eqn.

$$E_r = \frac{ml^3}{4bd^3}$$

Where m is the slope of the initial portion of the stress strain curve (P/D)

3.3 HARDNESS TEST

Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied. Some materials (e.g. metals) are harder than others (e.g. plastics). Macroscopic hardness is generally characterized by strong intermolecular bonds, but the behavior of solid materials under force is complex; therefore, there are different measurements of hardness: scratch hardness, indentation hardness, and rebound hardness. Hardness is dependent on ductility, elastic stiffness, plasticity, strain, strength, toughness, visco elasticity, and viscosity. Indentation hardness measures the resistance of a sample to material deformation due to a constant compression load from a sharp object; they are primarily used in engineering and metallurgy fields. The tests work on the basic premise of measuring the critical dimensions of an indentation left by a specifically dimensioned and loaded indenter. Common indentation hardness scales are Rockwell, Vickers, Shore, and Brinell.

Figure 3: Rockwell hardness test

4. EXPERIMENTAL RESULTS

4.1 TENSILE TEST

Tensile testing was performed to determine the ultimate tensile strength and young's modulus of the prepared specimen. The tension test was performed as per the ASTM standard ASTM 3039.Stress -strain curves for each specimen were obtained from the data collected. The tensile strength and young's modulus of the Kevlar/linen /epoxy hybrid composite is shown in table 2.

Table 2: Result of tensile test

Material	Tensile strength (MPa)	Young's modulus(GPa)
Kevlar/linen/epoxy composite	208	34.74

Stress-Strain curves were obtained from the computer controlled UTM. Extensometer with a gauge length of 150 mm was mounted on the tensile test specimen to get the accurate strain during the tensile testing. The stress-strain curves obtained for specimens with varying Kevlar/linen layers are shown in figure 4.

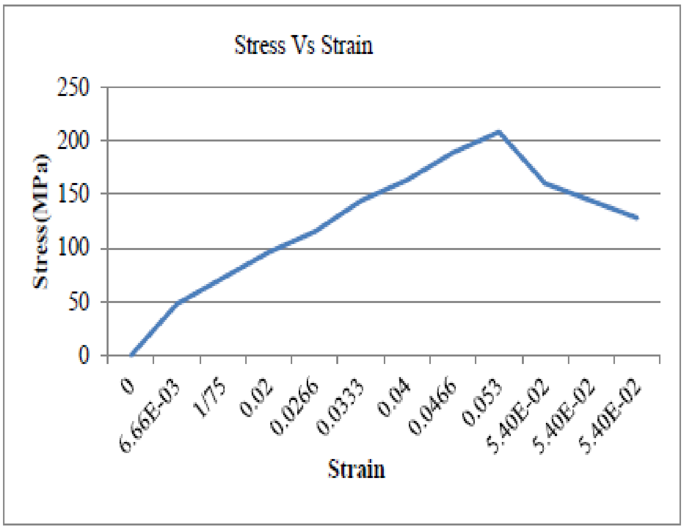

Figure 4: Stress- strain curve for Kevlar/ linen/ epoxy composite

All the specimens experienced brittle fracture. Failure for all specimens took place near the top grip with catastrophic failure accompanied by an abrupt decrease in stress after reaching a peak value. The tensile strength for the specimen is 208 MPa. In comparison with human cortical bone, the Kevlar/linen/epoxy composites have higher tensile strength. The Kevlar/linen/epoxy composites have a tensile strength of 208 MPa compared to the human cortical bone which has a tensile strength of 150 MPa.

4.2 FLEXURAL TEST

In the case of three point bend tests, the specimen was placed over the supports and the load is applied at the mid span of the specimen. Thus, creating a tensile stress at the lower portion and compressive stress at the upper portion of the specimen. Thus the load-displacement curves obtained from the system is used to calculate the flexural strength and the flexural modulus. Flexural strength of the specimen can be defined as the stress at which the specimen fails. Load-Cross head travel curve for Kevlar/ linen/ epoxy composite is shown in figure 5.

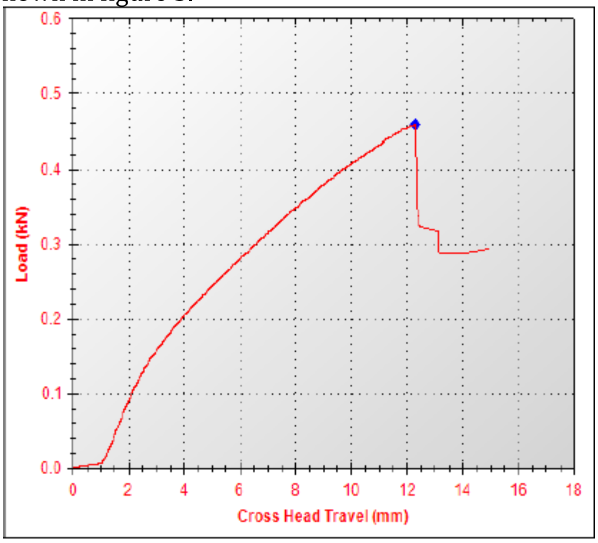

Figure 5: Load- Cross head travel curve for Kevlar/ linen/ epoxy composite

Table 3: Result of flexural test

Material	Flexural Strength (MPa)	Flexural Modulus (GPa)
Kevlar/linen epoxy	223.01	31.2

The above table shows the values of the flexural modulus and flexural strength. In comparison with human cortical bone, the Kevlar/linen/epoxy composites have higher flexural strength. The Kevlar/linen/epoxy composites have a flexural strength of 223 MPa compared to the human cortical bone which have a flexural strength of 210 MPa.

4.3 HARDNESS TEST

Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied. Rockwell E hardness tests were performed on 3 square shaped specimens each with a surface area equal to 1 in2 (i.e.,645mm2), based on the recommended dimensions in the ASTM standard ASTM D785-03 for Rockwell hardness test of plastics and electrical insulating materials. Rockwell E hardness tests were performed on 3 square shaped specimens each with asurface area equal to 1 in2(i.e.,645mm2), based on the recommended dimensions in the ASTM standard ASTM

D785 for Rockwell hardness test of plastics and electrical insulating materials. The Rockwell hardness number for the Kevlar/linen/ epoxy hybrid composite is 40 as shown in the table 4. Comparison of test results with commonly applied materials is shown in the table 5

Table 4: Result of hardness test

Material	Standard	Hardness number
Kevlar/linen/epoxy	ASTM D785	40

Table 5: Comparison of test results with commonly applied materials.

	Human Cortical Bone	Steel 316L	Titanium Alloy Ti-6Al-4v	KF/linen/ epoxy
Young's Modulus GPa	7–25	193	113	34.76
Ultimate Tensile strength MPa	50 –150	485	950	208
Flexural Modulus GPa	5-23			31.24
Flexural Strength MPa	35-283			223.01
Hardness number		95	36	40
Density g/cm^3	1.91	8	4.43	1.95

5. CONCLUSIONS

The experiments were conducted with Kevlar/Linen/Epoxy composite which was prepared by using hand lay-up process. The work determined the mechanical properties of Kevlar/Linen/Epoxy composite material. The mechanical properties of the developed composite specimen were evaluated via tensile, flexural and hardness tests.

The current study is the first to investigate the mechanical properties of Kevlar/linen/Epoxy hybrid composites for orthopaedic applications. The developed KF/Linen/Epoxy composite with Young's modulus of 34.76 GPa gives the hope of achieving an optimal design with mechanical properties much closer to that of cortical bone (7–25 GPa). This composite material will minimize stress shielding by allowing more load sharing as compared to conventional Titanium alloy Ti-6Al-4V (Young's modulus = 113 GPa) and stainless steel 316L (Young's modulus = 193 GPa). This composite material also has higher flexural modulus (Ef = 31.24 GPa) compared to cortical bone (Ef = 8 GPa) which prevents unwanted motion of the fracture site. It also has a low density of 1.95g/cm3 compared to the heavier metallic implants Titanium alloy (4.43 g/cm3) and Steel (8 g/cm3).

The developed material is significantly flexible compared to conventional metallic implants and has the considerably high strength needed to carry forces during daily normal activities. It can also counter unwanted motion of the fracture site due to its high flexural modulus and allow axial micro motion which enhances the remodelling of the callus at the fracture site. The low density of the same makes it a better candidate. So this hybrid Kevlar/Linen/epoxy composite can be used for potential application as fracture bone plates.

6. SCOPE OF FUTURE WORK

- Fatigue analysis of bone plate by using different bone plate material may be studied.
- Compare the biomechanical properties of Kevlar/linen/epoxy composite materials by varying the percentage of hybrid composite material may be evaluated.

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