Experimental Investigation and Prediction of Mechanical Properties of a Composite Material for Bone Plate Application

R. M. Deshmukh, Prof. S. S. Kulkarni

***Abstract*— Metallic implants have been used widely in a lot of orthopaedic applications. Titanium, Ceramics, medical grade titanium and other metal alloys are inserted in large bones designed as artificial joints. Plates and bars are also attached to bones in order to facilitate healing of fractured bones. The disadvantages of metal implants however are corrosion and the release of ions, so there is need for finding new orthopaedic materials like composites, which have a closer density to the natural bone too. This work is part of the manufacturing and processing of carbon fiber/epoxy composite and the assessment of its mechanical properties. Mechanical properties are estimated by ASTM standard methods. Results are resented according to evaluation of composite performance mechanically and show the best choice of composite parts in order to improve future use of orthopaedic bone plate applications.**

Index Terms—Fracture fixation, Hand layup manufacturing process, Orthopaedic bone plate, Mechanical Properties.

I. Introduction

Composite materials have replaced metallic materials in various engineering applications in a number of industries including transportation, aerospace, pressure vessel and others. One area where there has been growing interest in the use of composite materials is medical implants [5]. Some of the advantages of composite materials are their lightweight, low density and high strength to weight ratio. Most importantly, composite materials superior to other types of materials is their flexibility to be manipulated to achieve certain desired properties that cannot otherwise be achieved by the elementary constituent materials on their own. The properties of composite materials are determined by the properties, ratios, and orientation of their constituent parts. A composite martial typically consists of a bonding material called the matrix, and one or more reinforcing materials called the fibers [2]. Fixation of long bone fractures with clinically available metal plates may be limited because of a mismatch between the stiffness of the metal plate and the bone. This mismatch can result in "stress shielding", which leads to more load transfer to the plate instead of the bone, thereby resulting in bone resorption and eventual implant loosening. Thus, designing a bone plate with mechanical properties close to cortical bone can reduce the negative effect of "stress shielding"[2]. In this regard, composite materials having mechanical properties close to the bone plate have been suggested as an alternative to metals for designing bone plate.

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II. Experimental Methodology

A. Materials and Methods

Selection of Material for Preparation of Specimen:

1. Reinforcement Material
   - Plain weave Bi- Woven Carbon Fabre
2. Epoxy Resin
   - LY556
3. Hardener
   - HY 951

. The hand lay up process is a simple method which is adopted for the manufacture of the laminated composites, a mould can be used for this hand lay up process the mould can be as simple as a flat sheet or a flat surface before the layup is done the surface is thoroughly cleaned by applying some chemical agents such as acetone and to this surface a release agent like wax or oil or petroleum jelly is applied to insure the laminated pert does not adhere to the mould part[8]. The reinforcing material plain weave bi-woven carbon fibres are cut into required size and are laid on the flat surface of the mould. The fibres of the required size are laid along the required direction as per the design requirements. The resin that is LY556 and hardener HY 951 are mixed in the proportions as recommended by the manufacturer in the required proportions that is in the proportions of 10:1 as suggested by the manufacturer is mixed thoroughly and is applied on the laminated surface to be laminated. The resin is spread evenly on the reinforcing fibres; the resin is squeezed evenly on the surface using a roller and compressed thoroughly with the roller itself. The reinforcing fibres are stacked one above the other and the above mentioned procedure is repeated repeatedly. The laminated composites are allowed to cure for 24 hours. These laminated composites are post cured at a temperature of 1200c for 2 hours to ensure the even distribution of the resin and to ensure the proper percolation of the matrix into the reinforcing material. The laminate is ready and this laminate is cut into required size as per ASTM standard and subjected to various tests.

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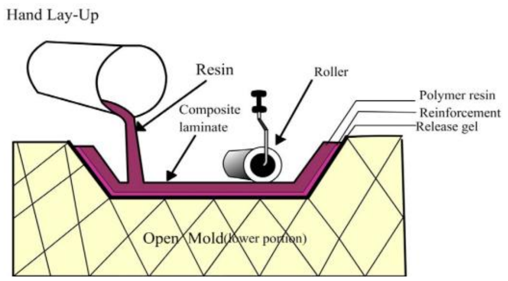

Fig.1 Hand Layup Method [13]

Table.1: Details of Composite Prepared

Sample No.	Composite Material	Fibre Orientation in Deg.	Laminate Thickness in mm
A	Carbon/ Epoxy	$0/90^0$	4
B			5
C	Carbon/ Epoxy	$\pm45^0$	4
D			5

B. Experimental Tests and Investigation

The composite laminates were subjected to various loads and computer controlled UTM. The specimens were clamped and tests were performed. The tests were closely monitored and conducted at room temperature. The load at which the complete fracture of the specimen occurred has been accepted as breakage load.

Fig. 2 Tensile Specimen

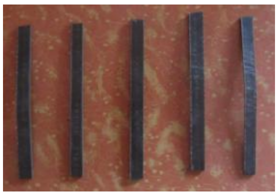

Fig. 3 bending specimen

Tensile Test

Figure 4 shows the specimen being mounted on the tension test rig. The tension test is conducted as per ASTM 638 standard. The specimen is loaded gradually the loading was done at a controlled rate, the load at yield point is noted down. Further the specimen was loaded till the specimen fails. The load at yield point was recorded. This is repeated for different specimens.

Fig. 4 Specimen subjected to Tension Test on UTM.

Three Point Bendind Test

The following types of specimens were prepared as recommended by the ASTM D790 standards. The various specimens prepared for the flexural tests are as listed bellow in the figure it can to understand that there are carbon fibre reinforced polymer laminates with two different fibre orientations that is $0/90^0$ and $\pm45^0$, further the laminates are manufactured for two different thickness 4mm and 5mm.

Fig. 5 Three point bending test

Barcol Harness Test

The hardness of resins is an indication of the level of cure. Hardness increases as cure progresses until a maximum for the resin type is reached. The Barcol hardness test method is used to determine the hardness of both reinforced and non reinforced rigid composites and to determine the degree of cure of resins and composites. The Barcol hardness test obtains a hardness value by measuring the penetration of a sharp steel point under a spring load. Specimens for the Barcol Hardness Test are prepared and tested according to ASTM D2583.

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Fig.6 Hardness Test Fixture

III. RESULT AND DISCUSSION

The characterization of the composites reveals that the effect of thickness and orientation on the mechanical properties of composites. The properties of the composites with different thicknesses and orientations are investigated by tensile test, bending test and hardness test. The effect of laminate thickness and orientation on the tensile, flexural and hardness properties of the material is tabulated bellow and also shown it by graphs for better understanding.

Table 2: Results of tensile test, bending and hardness test

Thick-ness (mm)	Orienta-tion $(^0)$	Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)	Hardne-ss
4	0-90	377.49	60.62	51
5	0-90	368.94	240.19	51
4	$\pm45^0$	46.94	107.85	59
5	$\pm45^0$	72.59	175.57	56

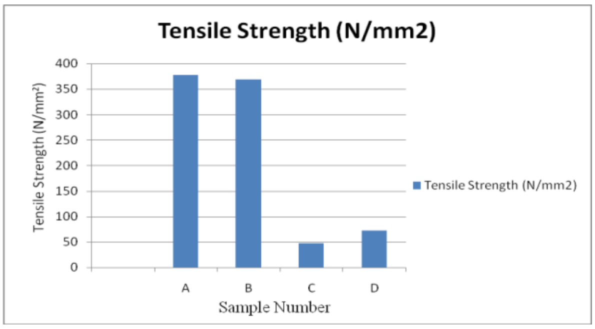

Fig.7 Graphical results of tensile strength

Inferences from above results:

- The tensile strength is superior in case of 90 degree orientation.
- More force is required for fracture of Carbon fibre reinforced composite in case of 90 degree orientation.
- Tensile strength is minimum in case of ±45 degree orientation as compared to 90 degree orientation

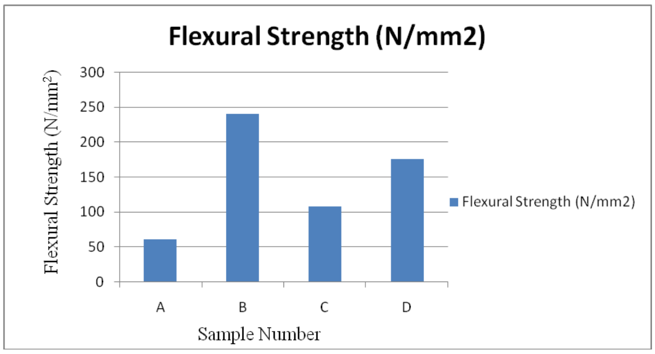

Fig.8. Graphical results of Flexural strength

Inferences from above results:

- The flexural strength is superior in case of 90 degree fibre orientation.
- More deflection is found in 45 degree orientation. The deflection is less in case of 90 degree orientation
- Flexural strength increases with thickness.

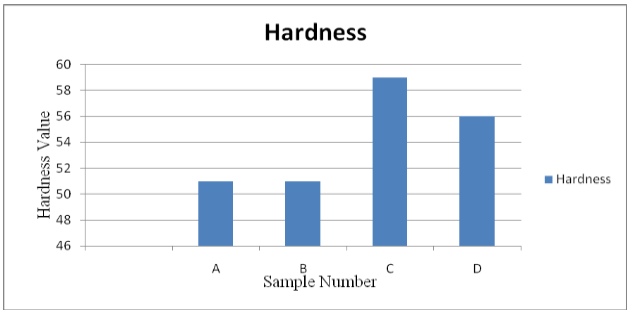

Fig.9. Graphical results of Hardness

Inferences from above results:

- The maximum hardness found in 45 degree orientation.
- Hardness value is not dependent on thickness.

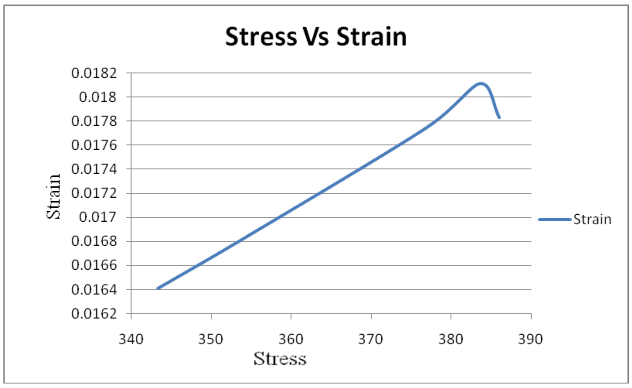

Fig. 8. Stress Vs Strain Graph

The stress vs strain curve was plotted by using experimental results. The X-axis indicates stress value and Y-axis indicate strain value.

Table 3: Comparison of CF/epoxy material properties with stainless steel and bone properties

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It is observed that the difference between Young's modulus of stainless steel and human cortical bone is more (five to six times greater than bone modulus). The moduli of current Carbon fiber/epoxy material have very close material properties to that of human cortical bone modulus. So the current material CF/epoxy is suggested as a compatible material for designing the bone plates.

Material	Tensile Strength (N/mm^2)	Bending Strength (N/mm)	Young's Modulus (GPa)	Hard -ness
Stainless Steel	715	302	193	95
Carbon Fiber Epoxy	46.94-377.49	60.62-240.19	6-21	51-59

IV. Conclusions

In this work, a carbon fiber/epoxy composite material was experimentally investigated as a potential composite material for making orthopaedic bone plates. Overall, the material was found suitable for bone fixation plates if designed correctly.

1) This study determined the mechanical properties of a new CF/epoxy composite material developed.

2) The results revealed that the composite material had higher mechanical properties in bending compared to tension(C&D type specimen). This phenomenon makes the material attractive for applications that need adequate bending stiffness while having lower axial stiffness, like long bone fracture plates.

3) Moreover, the failure stress in both tension and bending were high enough to carry clinical-type forces as occur in axial compression or bending. Based on the current results, the CF/epoxy composite has the potential to be used in orthopaedic fracture fixation.

4) The main emphasis of the work was on development, testing and characterization of these composites to know their suitability and adaptability for orthopaedic bone plate application.

5) Results obtained from present study compared with stainless steel material properties and can be used for design and development of bone plates.

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