Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 3, Issue 2; January-March, 2016 pp. 50-53

http://www.krishisanskriti.org/Publication.html

Experimental and Finite Element Analysis of Flexural Strength of Glass Fiber Reinforced Polymer Composite Laminate

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Abstract—*The Glass Fiber Reinforced Polymer (GFRP) is used for several industrial purposes where it is required to exhibit good Flexural behavior. The flexural strength of composite is very essential property to make it as a good structural component. In the present work Glass Fiber/Epoxy resin composite laminate of eight layer is fabricated with the help of vacuum assisted hand lay-up technique of orientation [0/90, ±45, ±45, 0/90]. Three point bend test was performed for Flexural Strength according to ASTM D790 standard. The test was carried out on the Hounsfield Universal Testing Machine (UTM) of capacity of 50 KN. The Finite Element Analysis for Flexural Strength was also studied with the help of FEA software ANSYS Mechanical APDL to validate the experimental results with that of FEA software. When compared Finite Element Analysis software results showed the good agreement with the experimental results.*

Keywords*: Glass Fiber reinforced polymer, Flexural Strength, Finite Element Analysis, ANSYS.*

1. INTRODUCTION

Fiber-reinforced composite materials provide ample scope and receptiveness to the design changes, materials and processes. Their strength to weight ratio, stiffness, cost effectiveness and easy availability of raw materials, make them the obvious choice for a wide variety of commercial and industrial applications like electronics, furniture, power industry, oil industry, and in many industrial products such as power transmission shafts etc. The major structural application areas include aircraft, space, automotive and sporting goods, marine and infrastructure.

Flexural strength is very important whenever the composite material is subjected to the compression loading. There are many methods which can be used to measure flexural strength but this also comes with great deal of confusion as which method will be best to use. The test should be simple giving the pure flexural properties which require no special devices and can be used on presently available machines. The three point test method has been widely used to characterize the flexural strength of the fiber reinforced composites. In this method a beam of certain dimension is placed under simply supported conditions and line load is applied at the center of the specimen.

H.ullah et.al. [1] Studied the damage initiation, progression and interaction in GFRP woven laminates subjected to large deflection bending. Flexural and tensile tests were carried out to characterize the material behavior. A series of simulations were performed to study the onset, progression and interaction of inter-ply and intra-ply process under three point bending. R. santhanakrishnan et.al. [2] Studied the fabrication and flexural properties of GFRP composite sandwich structures stitched and un-stitched. The flexural strength and deflection of fabricated specimen were determined through the three point bending test. M.C. serna et.al. [3] Studied the different response under tension and compression of unidirectional carbon fiber laminates in a three point bending test. Agnieska bondyra et.al. [4] Studied the glass fiber polyester layered composite of the mixed sequence composed alternately of laminas reinforced with e-glass plain woven fabric. And also develops FE modelling and simulation of composite plate made of GFRP using FE code MSC. Marc. Praveen Kumar et.al [5] studied the effect of specimen dimension of flexural modulus of isotropic and FRP composites and validated with the help of ANSYS software. In the present work, the flexural strength of the GFRP composite laminate is characterized with the help of three point test method and afterword's it is validated with the help of ANSYS 14.5 software.

2. EXPERIMENTAL DETAILS

2.1 Laminate fabrication

In the present work, a plain woven glass fabric is used as reinforcement. Glass fiber is strong and lightweight material. Although strength of glass fiber is less than carbon fiber but is less brittle and cheaper than the carbon fiber. The matrix used is epoxy resin with hardener. When combined both matrix and reinforcement is used to form composite material. Glass fiber/Epoxy resin composite laminate of eight layer is fabricated with the help of vacuum assisted hand lay-up technique of orientation [0/90, ±45, ±45, 0/90]. At first eight layer glass fiber sheet was cut out. A hardener resin mixture was prepared with ratio of 10:1. The hardener resin mixture was impregnated with the help of paint brush of size 2 inches and the cylindrical roller was used to force the matrix through fibers and to get flat laminate. For further consolidation vacuum bagging technique is used. In this process the laminate was placed in the sealed boundary with nozzle arrangement. Nozzle arrangement creates vacuum in the sealed boundary and the extra resin was soaked by the breather material placed onto the laminate and after reaching the certain amount of pressure the nozzle was removed and the laminate was cooled under certain load for 24 hours at lab temperature.

Specimen was prepared from the GFRP composite laminate of the size of 280 X 17O mm as shown in fig 1 The specimen was cut with the help of the hex blade from the large size laminate. The size of the specimen was taken as per ASTM D790 in which length of the specimen was 140 mm, width 30 mm and thickness 3.9 mm as shown in fig 2.

Fig. 1: Fabricated laminate

Fig. 2: Finished Specimen

The mechanical properties of glass/epoxy laminated plates were determined under static loading conditions according to the ASTM standards as shown in Table 1.0 Here, E1, E_2 and E_3 are Young's modulus; G_{12}, G_{13} and G_{23} are the shear modulus corresponding to the 1–2, 1–3 and 2–3 planes respectively and μ_{12}, μ_{13} and μ_{23} are the corresponding Poisson's ratios.

Table 1.0: The mechanical properties of the composite laminate

Young's Modulus, E1	19.1 GPa
E2	19.1 GPa
E3	6.72 GPa
Poisson's Ratio, µ12	0.17
µ23	0.28
µ13	0.28
Shear Modulus, G12	3.5 GPa
G23	2.06 GPa
G13	2.06 GPa

2.2 Three point bend test method

Flexural properties like flexural strength can be find with the help of three point bend test method according to the ASTM D790 standards [6]. In this test a composite laminate of rectangular cross section is placed under simple supported conditions and the load is applied at the center of the laminate.

Flexural strength is also known as the bend stress. It is the materials ability to withstand the deformation under bending loads. The flexural strength represents the highest bearing capacity of material at its moment of rupture. For a rectangular composite laminate under compressive in three point test mode it is given by the equation [7],

$$\sigma\text{uf} = \frac{3PL}{2b\,h^2}$$

Where,

σ_{uf}, flexural strength

P, is the load in N at the fracture point

L, is the length of the support span

b, Width of the rectangular section

h, Thickness of rectangular section

2.3 Test Procedure

The three point bending test was conducted on HOUNSFIELD Universal Testing Machine (Fig. 4 and Fig. 5) of capacity 50 KN at department of mechanical engineering Indian School of Mines, Dhanbad. In the three point bend test specimen was held over two cylindrical support under simple supported conditions and one cylindrical head was moving downward at speed of 1 mm/min at mid span of the specimen to apply the load.

As per ASTM D790 standard the span length between two cylindrical supports should be taken as $\frac{s}{h} = \frac{16}{1}$, where s is the span length and h is the thickness of the laminate. Set up for three point bend test can be seen in fig. 3

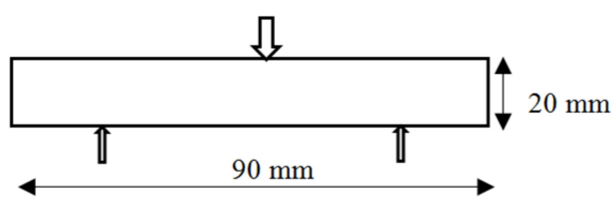

Fig. 3 Three point bending setup

Fig. 4: UTM machine **Fig. 5 Specimen during testing**

3. FINITE ELEMENT ANALYSIS

Finite element method one of the general procedure used now a days for solving complex problems. It has now become easier to use finite element method with the help of software. For performing finite element analysis the material was considered as orthotropic in nature and boundary and loading conditions were applied as according to the experimental procedure.

The composite laminate specimen were analyzed for flexural strength by using ANSYS 14.5 software. The composite laminate of 8 layers was modelled with orientation of [0/90, ±45, ±45, 0/90]. In ANSYS Mechanical APDL14.5 model of eight layers and the dimensions 140 mm X 30 mm can be seen in the fig 6. The thickness of each lamina was 0.4875 mm. Hence total thickness of the laminate was 3.9 mm. The element type was selected as 8-node, SHELL281 multi-layered shell element. SHELL281 element has six degrees of freedom per node i.e. translations in nodal x, y and z-directions and rotations about nodal x, y and z-axes. The orthotropic properties were assigned to the composite laminate as given in the table 1.0. All layers of the panel were meshed by 8 Node Shell 281 as shown in fig. 7. In the software and the common nodes were merged. Simply supported boundary conditions were applied and the compressive load was applied at center of the laminate along the y-axis.

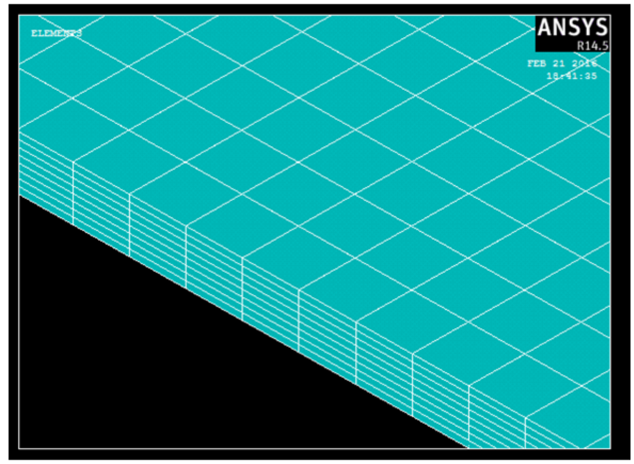

Fig. 6: GFRP laminate of eight layers

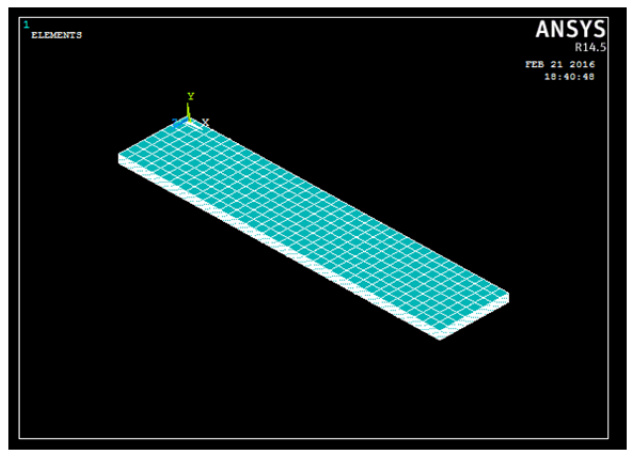

Fig. 7: Meshed GFRP laminate

4. RESULTS AND DISCUSSION

During the experiments, the load displacement diagrams for the specimen was plotted with the help of the digital output display attached to the UTM. The graph shows the Force VS Deflection. The graph shows the maximum force applied during the experiment and deflection occurred. The graphs can be seen in Fig. 8. The numerical results are obtained on ANSYS by using a command “General Post-processor”. The nodal solutions are obtained for bending stress it can be seen in Fig 9. The comparison between experimental and numerical results are shown in Table 2.0. It can be seen from this table that the results obtained from the numerical structural analysis are close to the experimental results (difference being less than 10%). This shows that there is a good agreement between the experimental and numerical results.

Table 2.0

Flexural Strength Experimental (Mpa)	Flexural Strength Numerical (Mpa)	Error %
290	272	6.2%

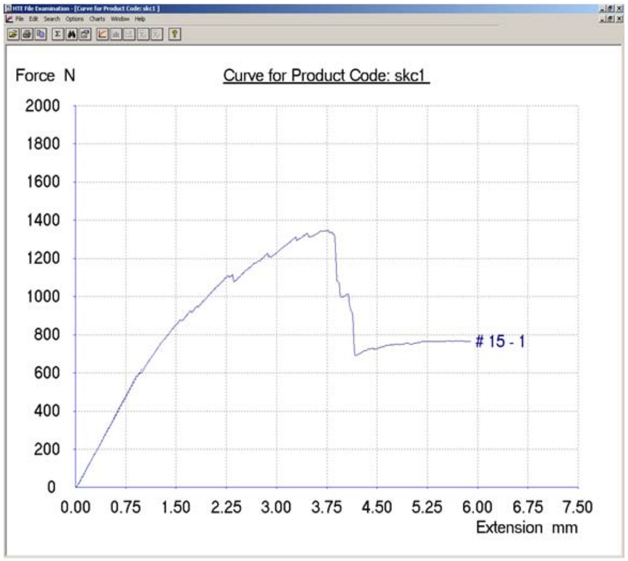

Fig. 8: Force VS deflection graph

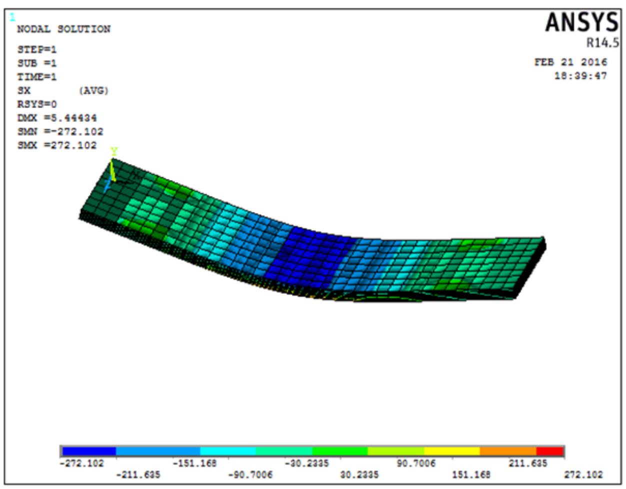

Fig. 9: Nodal solution for bending stress for X- component

5. CONCLUSION

The Flexural behavior of the composites is significant in reliability and safety of a number of mechanical components made of composites. The three point bend test was done to find the flexural strength of the glass fiber reinforced laminate and then experimental results were validate with the help of finite element software ANSYS Mechanical APDL 14.5 The three dimensional Finite element simulation was done to find Flexural strength to confirm the experimental results with the FEA results. From the results of this study, the following conclusions can be drawn:

- By comparing the experimental results with the results obtained numerically by ANSYS14.5, we can conclude that the results are within less than 10% error.
- While the result shows that there is less than 10% error that mainly because of the manufacturing defects mainly like conditions it was fabricated in or porosity, which changes the density of the laminate.

6. ACKNOWLEDGEMENT

The authors are be very thankful to Department of Mechanical Engineering, Indian School of Mines Dhanbad, India for providing the test facilities and support for carrying out the laboratory work.

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