

Analytical and Numerical Investigation of a Composite Material Rod under Tensile Loading

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ABSTRACT: Composite materials have a long history of usage. Straw was used by the Israelites to strengthen mud bricks. Plywood was used by the ancient Egyptians to achieve superior strength and resistance to thermal expansion as well as to swelling. Now days, fiber-reinforced, resin-matrix composite materials that have high strength-to-weight and stiffness-to-weight ratios have become important in weight-sensitive applications such as aircraft and space vehicles. The key material properties for usual engineering applications are strength and stiffness. The fibers are stiff and have high strength and they are expected to carry the load to which the structure is submitted. The matrix has low strength and low stiffness and it gives the shape to the component and transfers the loads to fibers and between them. The usual design criterion for composite material is based on trying to align the fibers with most critically loaded directions of mechanical component. This paper based on an investigation to find out elastic constants and other mechanical properties of an orthotropic (glass epoxy) composite lamina theoretically and by finite element analysis because composite structure may not yield the exact results due to orthotropic or non linear behavior of composite material.

KEY WORDS: Glass epoxy, ANSYS, Fiber Volume Fraction, Modulus of Elasticity

I. INTRODUCTION

In composite material two or more distinct materials are combined together but remain uniquely identifiable in the mixture. The most common example is, perhaps, fiberglass, in which glass fibers are mixed with a polymeric resin. If we cut the fiberglass and after suitable preparation of the surface, when we look at the material, the glass fibers and polymer resin would be easy to distinguish. This is not the same as making an alloy by mixing two distinct materials together where the individual components become indistinguishable. There are many composite materials and while we may be aware of some, such a fiberglass and carbon epoxy, there are many others ranging from the mundane, reinforced concrete a mixture of steel rod and concrete (itself a composite of rock particles and cement), pneumatic tyres (steel wires in vulcanized rubber), many cheap plastic moldings (polyurethane resin filled with ceramic particles such as chalk and talc) to the exotic metal matrix composites used in the space program (metallic titanium alloys reinforced with SiC ceramic fibers), and in automobile, such as engine pistons (aluminum alloys filled with fibrous alumina) and brake discs (aluminum alloys loaded with wear resistant SiC particles).

Their precise beginnings are unknown, but all recorded history contains references to some form of composite material.

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II. MATERIALS AND METHODS

The materials used for the testing are glass fiber, epoxy resin and composite made from glass fiber and epoxy. The glass fiber and epoxy resin are commercially available in market. The composite material rods are prepared as per usual manufacturing process available in standard books on composite materials.

III. OBJECTIVE OF INVESTIGATION

To find suitability of a composite material by knowing its tensile strength for a mechanical application where it will be subjected to tensile loading following objectives are set;

1. To find out tensile strength of a glass epoxy composite material.
2. To study stress-strain behavior of a composite material in tensile loading.
3. To investigate theoretically and by finite element approach the behaviour of a composite material for different fibre volume fractions with same matrix composition and study of stress-strain curve of same.

IV. THEORITICAL ANALYSIS

At the outset of investigation work it becomes necessary to test glass fiber and epoxy for finding Young's modulus. This is because the material used for experimentation is commercially available material hence it becomes necessary to verify the true value of Young's modulus to be used for further work.

Testing Of Glass Fiber

Five glass fiber specimens were tested to find average value of Young's modulus. The sample calculations and stress-strain behavior of two such specimens are mentioned below.

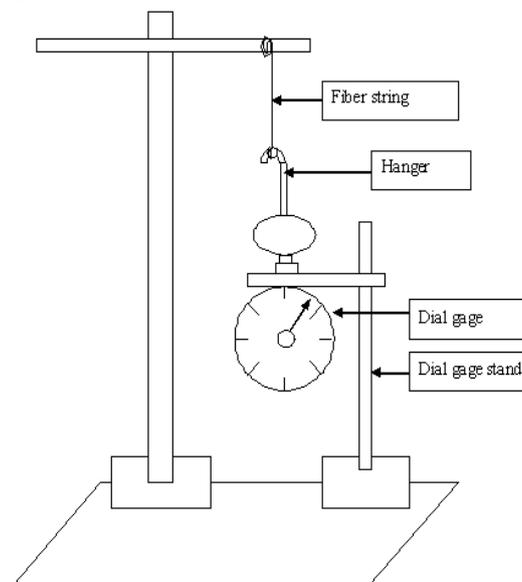


Figure 1 Experimental setup for fiber testing.

Glass fiber specimen-1

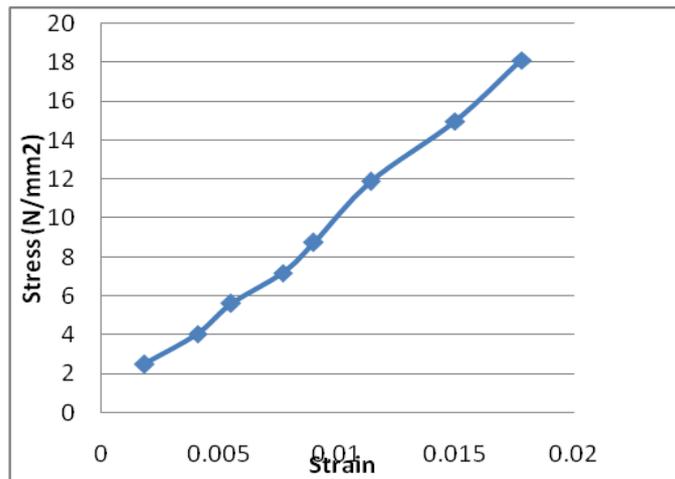
Specifications:- Initial length of glass-fiber = 195 mm, Diameter of glass fiber = 2mm, Area of glass fiber = $\pi/4 \times (2)^2$
= 3.141 mm²

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After testing the fiber specimen-1, corresponding values of stress and strain are found. And the graph of stress vs. strain is plotted.



Graph 1. Stress strain diagram for glass fiber specimen- 1

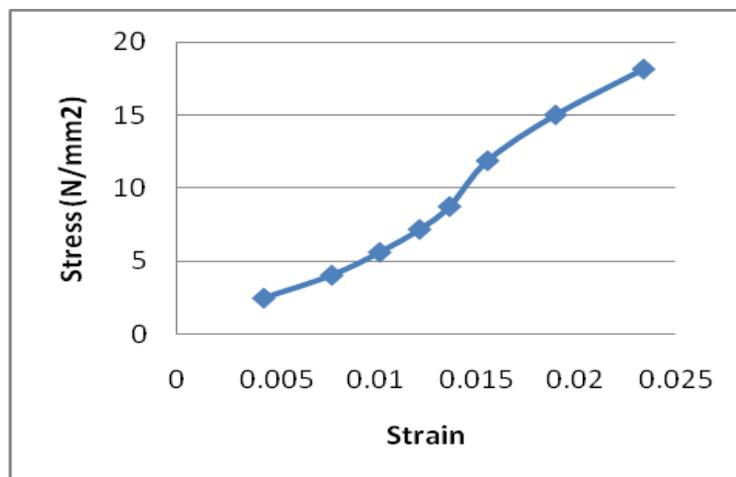
The value of E from graph is found by fitting a straight line using MINITAB software.
The value of E from graph is found by fitting a straight line using MINITAB software.
Average value of E using stress strain diagram and experimental results for fiber specimen 1 is 1198 N/mm².
Glass fiber specimen-2

Initial length of glass-fiber= 205 mm

Diameter of glass fiber = 2mm

Area of glass fiber = $\pi/4 \times (2)^2 = 3.141 \text{ mm}^2$

After testing the fiber specimen-2, corresponding values of stress and strain are found. And the graph of stress vs. strain is plotted.



Graph 2. Stress strain diagram for glass fiber specimen- 2

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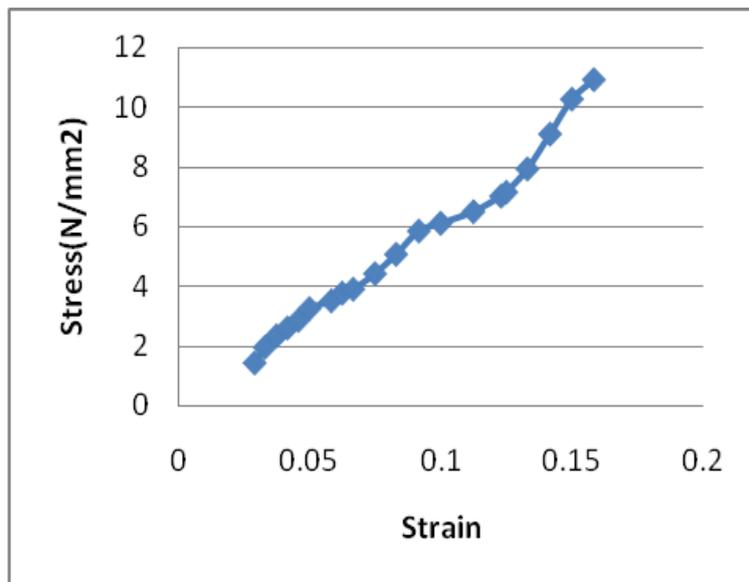
The value of E from graph is found by fitting a straight line using MINITAB software. Average E using stress strain diagram and experimental results for fiber specimen 2 is 708 N/mm². From results obtained for five fiber specimens average modulus of elasticity for glass fiber string is calculated which is equal to 953 N/mm².

Testing of Epoxy model

Specifications of Epoxy Model

Length = 380 mm, Height = 13 mm, Width = 58 mm, Area = 13 X 58 = 754 mm², Initial length in U.T.M. = 120 mm.

After testing epoxy model under UTM, corresponding values of stress and strain are found. And the graph of stress vs. strain is plotted.



Graph 3. Stress Strain Diagram for Epoxy Model

The value of E from graph is found by fitting a straight line using MINITAB software. Average modulus of elasticity using stress strain diagram and experimental results is 66 N/mm².

Calculation of ‘E’ By Elasticity Approach

Table no.1 Specification of composite rods

Composite specimen No.	C/S area in mm ²	% of volume fraction
1	2070	3
2	1620	4
3	1534	5.5
4	1274	6

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[10] Average modulus of elasticity for glass fiber string which from experimental results is =953N/mm²

For epoxy material experimental value of modulus of elasticity is =66N/mm²

Theoretical Calculation of Modulus of elasticity for composite material by considering elasticity approach is as follows

Specimen-1

$$\text{Longitudinal Young's modulus } E_1 = E_f V_f + E_m V_m = 94.39 \text{ N/mm}^2$$

Specimen-2

$$\text{Longitudinal Young's modulus } E_1 = E_f V_f + E_m V_m = 102.11 \text{ N/mm}^2$$

Specimen-3

$$\text{Longitudinal Young's modulus } E_1 = E_f V_f + E_m V_m = 115.05 \text{ N/mm}^2$$

Specimen-4

$$\text{Longitudinal Young's modulus } E_1 = E_f V_f + E_m V_m = 118.49 \text{ N/mm}^2$$

V. NUMERICAL ANALYSIS

FE analysis by using ANSYS is carried in following sequence

1. Preferences: In preferences problem type or discipline is defined.

2. ANSYS Preprocessor: Model generation is done in this processor, which involves material definition, creation of solid model and finally meshing. Important tasks within this processor are:

- Specify element type
- Define real constants
- Define material properties
- Create the model geometry
- Generate mesh.

3. ANSYS Solution Processor: This processor is used for obtaining the solution for the element model that is generated within the preprocessor. Important tasks within this processor are

- Define analysis type and analysis option
- Specify boundary conditions.
- Obtain solution.

4. ANSYS general postprocessor: This processor consists of plotting of contours, vector display, deformed shape etc.

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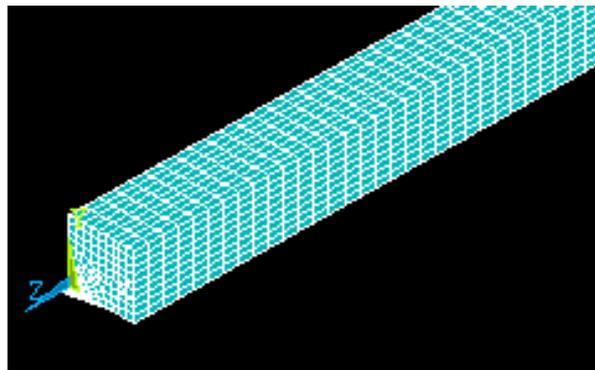


Figure 2. 3D FE Model for composite specimen

- After meshing the front area for the model, the three dimensional model is created. First model for matrix material is created by selecting material 2. Front area is extruded with length of extrusion equal to 80 mm. while extruding the no elements taken along the length of extrusion is 80. Front area of fiber is also extruded with equal number of elements and by selecting third material.

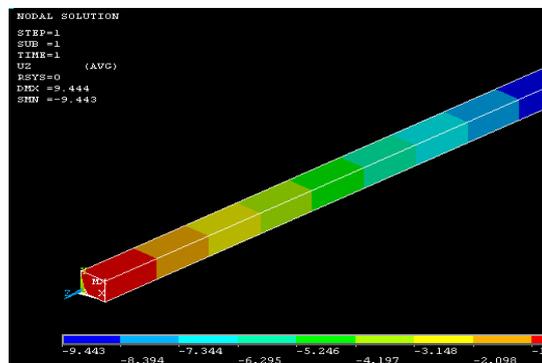


Figure 3. Deformation of specimen



Figure 4. Stresses in specimen

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Table no.2 Results from ANSYS

Composite specimen No.	Value of E from ANSYS in N/mm ²
1	91.25
2	103.28
3	107.045
4	113.08

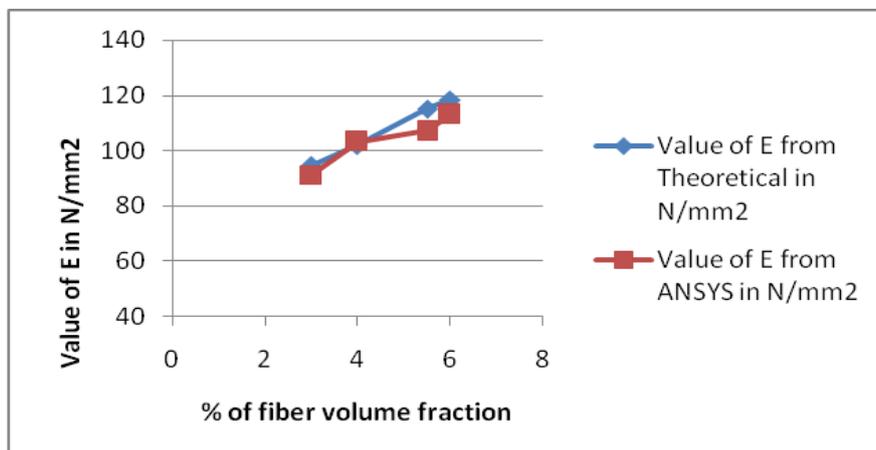
V. RESULTS AND DISCUSSIONS

In this present work, glass fiber string is made from fiber strand and it is tested for finding modulus of elasticity. Modulus of elasticity is found from experimental results and from stress strain graph and average value of both methods is considered. Five specimens of glass fiber are taken and average modulus of elasticity is considered from results of five specimens.

Composite material is prepared by using constituent materials as glass fiber and epoxy. Glass epoxy composite is tested in universal testing machine to find experimental modulus of elasticity. For the same composite material theoretical value of modulus of elasticity is calculated. Then finite element analysis of composite specimen is made and results obtained by these three methods are compared. Again three specimens with variation in percentage of fiber volume fraction and matrix volume fraction are prepared and elastic moduli for these three specimens are found by experimental, theoretical and finite element analysis method.

From the results, it is observed that, Percentage error in modulus of elasticity measured by experimental method as compared to calculated by theoretical formulae –12% it is because of error in experimentations.

Percentage error in modulus of elasticity by numerical method as compared to calculated by theoretical formulae – 1%. From those results it is observed that modulus of elasticity for composite material varies with fiber volume fraction and it increases with increase in fiber volume fraction. Following graph will show the variation of modulus of elasticity of composite material with fiber volume fraction. At zero volume fraction it is observed that modulus of elasticity of epoxy material is the modulus of elasticity of composite material and at 100% volume fraction of glass fiber modulus of elasticity of composite material is equal to modulus of elasticity of fiber.



Graph 4. Elastic moduli Vs Volume fraction of fiber

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VI. CONCLUSION

Attempts have been made to fabricate a composite material made of glass and epoxy material. Stress-strain curve for fiber and epoxy have been found out. Four test specimens of composite materials having different volume fraction of fibers have been tested in U.T.M. and stress-strain curve for each specimen is plotted. Modulus of elasticity for glass fiber string, epoxy and composite specimens found numerically and compared with theoretical values. Analysis of composite specimens is made by considering experimental values of modulus of elasticity.

The theoretically calculated modulus of elasticity by using micromechanics approach is compared with modulus of elasticity calculated from finite element analysis. From that it is observed that there is slight difference because of following reasons.

In finite element analysis by using ANSYS plane stress condition assumed but thickness of composite specimens is slightly more and axis symmetry is considered but specimens are not exact symmetric. This is done because of software problem, it is educational version and only 32000 node capacities therefore less number of elements are taken in longitudinal direction.

By considering all results there are some errors due to some experimental and software problems but in each type of analysis it is observed that by increasing number of fiber volume fraction, the modulus of elasticity of composite material increases.

The fibers, matrix and the composite material when loaded in tension are very much sensitive to strain rate and this is the reason for deviation between theoretical and theoretical values.

The fiber volume fractions of the specimens are near about 5 percent and efforts have to be made to build higher fiber volume fraction composites.

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