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Investigation of Compression properties on E-Glass fiber reinforced polymer matrix composites used for micro wind turbine blades

Sachidanand Singh[1], Dr. Hanumantharaju H.G[2]

[1]*Department of Mechanical Engineering, UVCE, Bangalore, INDIA*
[2]*Associate Professor, Department of Mechanical Engineering, UVCE, Bangalore, INDIA*

Abstract: The main goal of this work is to understand the mechanical behaviour of composites to compression loads. A unidirectional (UD) fabric of E-glass fiber is the most common reinforcement in composite structural applications which exhibits excellent strength, modulus, resistance to water degradation and corrosive environments, durability, good and a quantitative and qualitative analysis is conducted on this model and the results are validated. An experimental test sample made of the E-Glass/Epoxy-resin composite is subjected to uniaxial compression test. The experimental results are validated with the multiscale mechanical model built. The FEA (Finite Element Analysis) is being utilized and the results obtained are validated through experimental approach. With such validated numerical model, application in micro wind turbine blade would result in faster prototype development.

Keywords: Compressive strength, Composite material, Micro wind turbine, E-Glass fiber, FEA, Orthotropic Material, Numerical methods, Macrostructure, Microstructure.

INTRODUCTION

Composite materials are being used as structural elements for engineering applications in aerospace, automobile, and mechanical domains. However, these composites have some disadvantages related to the matrix dominated properties which often limit their wide applications [1]. To utilize composite materials in any application, the material being used needs to be fabricated in hundreds of numbers to test and characterize them for a statistical estimation of the elastic behaviour. Such an experimental process is time consuming, and the cost of experimentation also escalates. One of the solutions for these problems is to pre-design the composite materials using numerical models.

A detailed literature study [2- 13] illustrate that the glass fiber composites have a lot of potential in numerous advanced sectors such as automotive, structural, aerospace and marine applications.

In this paper, E-Glass fibre reinforced polymer matrix composite (epoxy-resin: Ly556 and Hardener 951) is modelled using FEA method (Finite Elements used at micro and macroscale), implementing a hierarchical multiscale modelling scheme. A representative volume element (RVE) is used to model the E-Glass/Epoxy-resin composite at microscale consisting of the uniaxial fibres embedded in epoxy-resin polymer matrix. The material properties derived from the microscale finite element analysis is applied to the nodal points of the elements of the macroscale finite element model. E-glass is a low alkali glass with a typical nominal composition of SiO_2 54wt%, Al_2O_3 14wt%, CaO+MgO 22wt%, B_2O_3 10wt% and Na_2OK_2O less than 2wt% other than this some other materials may also be present as impurity.

A unidirectional (UD) fabric is one in which the majority of fibers run in one direction only. The Epoxy resin Araldite LY556 and Hardener HY951 combination gives laminate with excellent water resistance and very low cure shrinkage; hence the laminates of this epoxy are dimensionally stable and practically free from internal stresses. Araldite LY556 is an epoxy resin based on Bisphenol-A suitable for high performance composite FRP applications like Filament Winding, Pultrusion and Pressure Moulding etc. Hardener HY951 an aliphatic primary amine and is used if curing is to take place at room temperature or within shorter time duration, at 50° to 120° C. The properties of the materials are listed in Table 1.

Table 1. The ingredients of matrix system

Ingredients	Trade Name	Chemical name	Density (g/cm^3)
Epoxy Resin	LY 556	Diglycidal Ether of bisphenol A (DGEBA)	1.16
Hardener	HY 951	Triethylenetetramine (TETA)	0.95

METHODOLOGY AND EXPERIMENTAL PROCEDURE

The objective of this study is to compare the behaviour of E-Glass/Epoxy composite material specimens under a compression test with the finite element analysis result. This study will help to determine the material properties of E-Glass fiber which is used in a wide range of engineering applications. The understanding from this study will help in the further development of the micro wind turbine blade.

Composite specimen fabrication

Fabrication of the composites is done at room temperature by hand lay-up techniques. The required ingredients of epoxy resin LY556 and hardener 951 are mixed thoroughly in a basin and the mixture is subsequently stirred constantly. E-Glass fibers are positioned manually in the open mould. Mixture so made is brushed uniformly, over the glass plies. Then the vacuum bag is mounted on the mould, vacuum bag molding helps eliminate excess resin that builds up when structures are made using (open-molding) hand lay-up techniques. Atmospheric pressure exerts a force on the bag. The pressure on the laminate removes entrapped air, excess resin, and compacts the laminate, resulting in a higher percentage of fiber reinforcement. Vacuum Bagging process is shown in Figure 1b.

The E-Glass fibers reinforced epoxy composite specimens were developed using Vacuum bagging process and then specimens of suitable dimensions were prepared from the composite Laminate for different mechanical tests according to ASTM standards. The test specimens were sized by using water jet cutting machine as shown in Figure 1c. Compression test specimens were prepared according to ASTM D3410. Test specimen having dimension of length 150 mm, width of 25 mm and thickness of 2.8 mm. Two identical test specimens were prepared for carrying out Compression test. Figure.2 shows the sample test specimens. The specimen used for the compression test is having 6 layer of E-Glass fiber reinforced composite lamina having 0°/90°/0°/90°/0°/90° orientations. The dimensions of the compression test specimen for composite materials are prepared as per the ASTM standards.

Figure 1a. E-Glass fiber Lamina

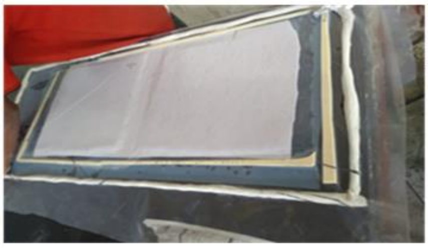

Figure 1b. Vacuum Bagging

Figure 1c. AJM Machining

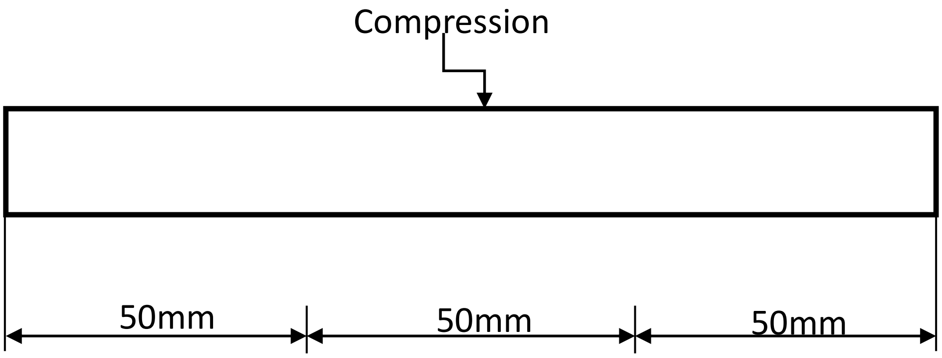

FIGURE 2. Composite test specimen dimensions (in mm)

Multiscale mechanical modelling

The dimension of the CAD model used for compression test simulation using FEA is same as that used for compression test (as per ASTM). Figure 3 shows the macroscale scale model and the finite element model of the CAD model. Commercial FEA tool Ansys is used for the compression test simulation. A two-dimensional model is used for the simulation. Fibre orientation and the layup are modelled in FEA as in test specimen. The orthotropic material property (with linear elasticity assumption) used for the macro structural analysis is obtained from micro structural study (with application of periodic boundary condition for constant material evaluation) as shown in table 3. Total element count is 3750 and total node count is 3926. The linear element is used for this analysis to reduce the computational time (explicit analysis requires more computation time). Since the geometry is rectangular plate, linear element is sufficient to capture the geometry appropriately. Ply thickness and orientation of the ply modelled in FEA are same as used in test specimen preparation. The CAD model of the specimen is constrained in all direction as shown in the Figure 5a as the bottom of the specimen is fixed as in test setup. The enforced displacement is applied as shown in the Figure 5b as in case of the testing specimen is pulled gradually until it breaks. Compression test is simulated using the explicit dynamic approach as the experimental tests are quasi-static in nature.

TABLE 2 a. Material Property E-Glass

Material Property E-Glass		
Density	2600	kg/m^3
Young's Modulus	85000	MPa
Poisson's Ratio	0.23	MPa

TABLE 2.b Material Property Epoxy

Material Property Epoxy		
Density	1160	kg/m^3
Young's Modulus	3780	MPa
Poisson's Ratio	0.35	MPa

TABLE 3. Material Property for Analysis

Material Property from microstructure Study		
Density	1664	kg/m^3
Orthotropic Elasticity		
Young's Modulus X Direction	32322	MPa
Young's Modulus Y Direction	9867.6	MPa
Young's Modulus Z Direction	9867.6	MPa
Poisson's Ratio XY	0.26392	
Poisson's Ratio YZ	0.60332	
Poisson's Ratio XZ	0.26392	

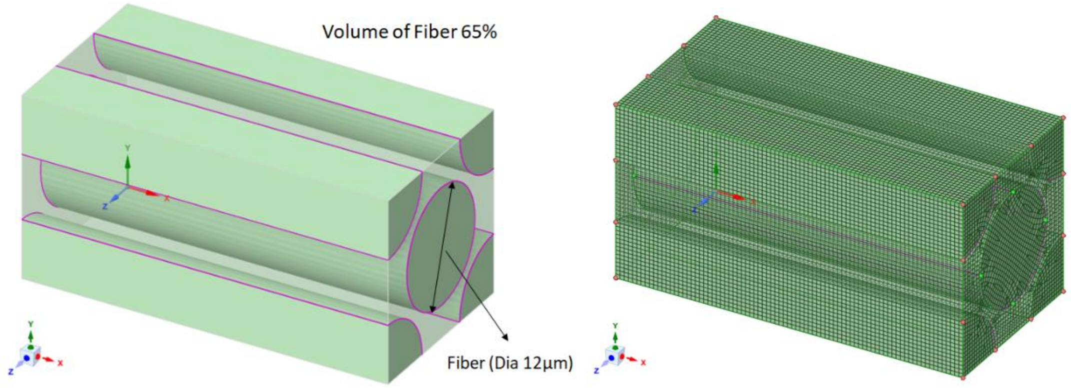

Figure 3. Representative Volume Element implemented at the microscale with E-Glass fiber and epoxy-resin

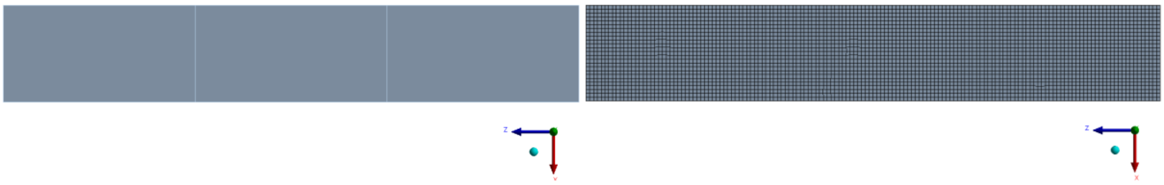

Figure 4 (a) Macroscale CAD model. (b) FE meshing for the CAD model

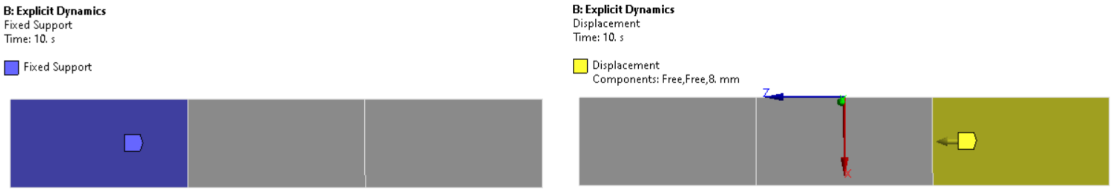

Figure 5 (a) Fixed Boundary Condition (b). Enforced displacement

Experimental method for validation

A universal testing machine (UTM) is used to test the compressive strength. A movable cross head is controlled to move up and down at a constant speed either using servo-hydraulic system or electromechanical system. A UTM with electromechanical system is used for compression test. Machines have a computer interface for analysis and printing of output.

Results and Discussion

3.1 Multiscale modelling outcomes

The maximum principal stress and the reaction forces are extracted after the solution in FEA. The maximum principal stress is 165.39 MPa as shown in figure 6 and the reaction force is 6.29 kN as shown in Table 4. It is observed that the maximum principal stress and reaction force from FEA is very close to the test result. The error for stress is 2% and for the force is 4%.

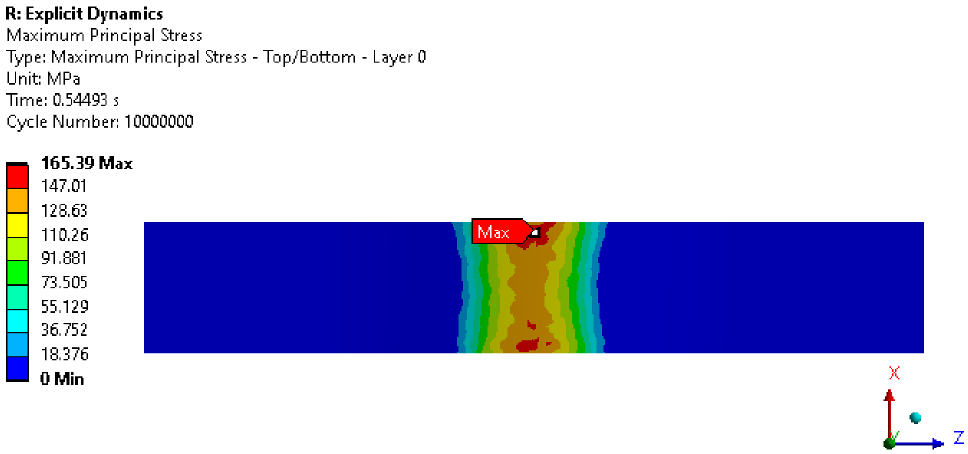

Figure 6. Maximum principal stress 165.9 MPa (N/mm^2)

TABLE 4. Reaction force at the fixed boundary condition location

Sl.No.	Time (s)	Force Reaction X (kN)	Force Reaction Y (kN)	Force Reaction Z (kN)	Force Reaction Total (kN)
1	1.18E-38	0.000	0.000	0.000	0.000
2	0.5	0.000	0.003	-6.504	6.504
3	0.54493	0.000	-0.017	-6.292	6.292

3.2 Experimental validation and comparison

Results obtained from the Compression test are shown from the**, Figure 6 and Table 4.** The findings presented here provide new insights into the development of composite structures with unique mechanical properties for a wide range of mechanical and structural applications. Study of composite specimen for Compression load is important from structural integrity point of view. Simple Digital Compression test

System is utilized to determine parameters such as stiffness & Strength for composite specimens. The average standard deviation for the maximum principal stress is 168.33 MPa and for peak load it is 6.56 kN. In Table 5 Compression strength and peak load of the E-Glass fiber-reinforced epoxy are shown for the applied load.

FIGURE 7. Test specimen after Compression Testing

TABLE 5. Result from Compression Testing

Specimen No.	Thickness (mm)	Width (mm)	Peak Load (kN)	Compressive Strength (N/mm^2)
1	2.8	25.0	6.463	164.18
2	2.7	25.0	6.657	172.48

CONCLUSIONS

In the present investigation E-Glass/Epoxy reinforced composite specimen compression test result are compared with the FEA result. The orthotropic material properties derived from the microscale finite element analysis is applied to the nodal points of the elements of the macroscale finite element model. A close correlation is observed between test result and the FEA result. The values obtained from test result and the FEA result has been analyzed and an excellent agreement between them is observed. Thus, FEA can be used for the development of micro wind turbine blade in future.

This experimental investigation of mechanical behaviour of E-Glass fiber reinforced Epoxy matrix composite leads to the following conclusions:

- The average maximum compressive strength from compression test is 168.33 N/mm^2 and from FEA Maximum principal stress 165.39 N/mm^2, which is very close enough to the experimentally obtained results (2% error) and the stress deformities is found in the same location as that of the experimental model also there is a qualitative comparison between test and FEA result
- Also the average peak load from the compression test is 6.56 kN and from FEA Reaction force is 6.29 kN. In this case also the test result and the FEA result are close (4% error).
- As the difference between test result and the FEA result is very less this material property can be used as a reference for the design of the micro wind turbine blade.

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