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INVESTIGATION OF 3 POINT BENDING PROPERTIES ON E-GLASS FIBER REINFORCED POLYMER MATRIX COMPOSITES USED FOR MICRO WIND TURBINE BLADES

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Abstract: The main goal of this work is to understand the mechanical behaviour of composites to three point bending 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 fatigue life and it is easily available and cheaper. A multiscale numerical model is prepared 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 three point bending 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.

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

Introduction

Sandwich panels are an important composite structure in aerospace applications as well as in high performance automobiles, boats and wind turbines. Typically a sandwich panel is comprised of a low stiffness, low density inner core enclosed by two stiff outer skins. The outer skins are either made of metal sheet or composite made up of fiber, matrix and the core can be made of honeycomb, balsa wood and foams. In case of this study the outer skin is made of unidirectional E-Glass fabric, Epoxy resin Araldite LY556 matrix materials and Hardener HY951. Matrix surrounds the fibers, acting as load transferring medium and thus protecting those fibers against chemical and environmental attack.

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 fatigue life and it is easily available and cheaper. 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.

Figure 1: E-Glass fiber reinforced ploymer composite specimen

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[1-2]. 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

Table 2: Material Property of Glass Fiber Reinforced PolymerComposite for FEM

Property	Value	Unit
Density	1664	kg/m^3
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	
Shear Modulus XY	5000	MPa
Shear Modulus YZ	3846.2	MPa
Shear Modulus XZ	5000	MPa

Table 3: Material Property of Balsa Wood for FEM

Property	Value	Unit
Density	120	kg/m^3
Young's Modulus X Direction	5295.2	MPa
Young's Modulus Y Direction	79.428	MPa
Young's Modulus Z Direction	79.428	MPa
Poisson's Ratio XY	0.3	
Poisson's Ratio YZ	0.3	
Poisson's Ratio XZ	0.3	
Shear Modulus XY	195.92	MPa
Shear Modulus YZ	19.588	MPa
Shear Modulus XZ	19.588	MPa

In order to gather insight and information, the literature research is done. Thereafter, two types of analyses are done; experimental analysis and Finite Elements Method (FEM) analysis.

The Balsa specimens are all cut out of one single panel, in order to ensure overall equality in properties.

The 3 point bending test is followed by the finite element analysis to authenticate the material property that will be used for the further development of the micro wind turbine blade. Table 2 and table 3 shows the E-glass epoxy and Balsa wood material property used in the analysis.

Procedure and assumptions that are used for the Analysis:

- The Analysis will be carried at room temperature.
- CAD for the FEA work is prepared as per the ASTM standards.
- Orthotropic material property is used for both E Glass and Balsa wood Core.
- For better result Geometric Non-Linearity is used in the analysis as this is a thin sheet of sandwich composite.
- Transient structural analysis was carried out to simulate the three Point Bending test.
- All analysis results are presented in the SI units.

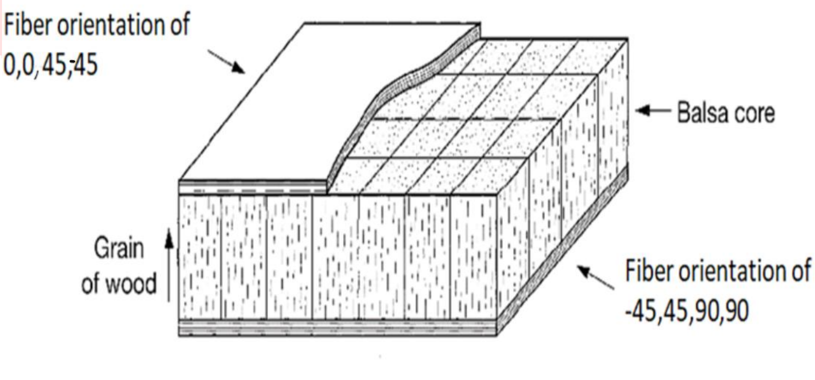

Figure 2: Fiber orientation

FABRICATION OF COMPOSITES

The specimen for the three point bending test is a sandwich composite structure, having core made of Balsa wood and the skin made of 8 layer of E-Glass fiber reinforced composite. Balsa Wood is the core for the bending specimen. End-grain balsa is a structural core with properties that make it ideal for sandwich construction. It is compatible with all types of manufacturing processes from wet lamination to prepreg construction. Balsa is not affected by styrene or long resin gel, hence making it well suited for infusion applications. Balsa is also available with a coating that minimizes resin absorption increasing bond strength and maximizing the weight savings. The skin core (E-Glass fiber reinforced composite) contains 8 layers and orientation that wrap the central balsa core in the way as shown in the table-4.

TABLE 4: Layup and Orientation

Layer	Material	Orientation (degree)
1 (top layer)	E-Glass UD fibers	0
2	E-Glass UD fibers	0
3	E-Glass UD fibers	+45
4	E-Glass UD fibers	-45
Central Balsa Wood Core	-	-
5	E-Glass UD fibers	-45
6	E-Glass UD fibers	+45
7	E-Glass UD fibers	90
8 (bottom layer)	E-Glass UD fibers	90

Fabrication of the composites is done at room temperature by hand lay-up techniques. The required ingredients of resin and hardener are mixed thoroughly in a basin and the mixture is subsequently stirred constantly. The E-Glass fibers are positioned manually in the open mold. Mixture so made is brushed uniformly, over the glass plies. Then the vacuum bag is mounted on the mold, 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 [3]. Abrasive water jet Machining is used for cutting the specimen to get a smooth, precision cut surface.

The matrix alone is relatively weak and has low elastic modulus, i.e., it bends and stretches easily. However it is very stable chemically and constitutes an excellent matrix for the composites. The E-Glass fibers provide the strength and stiffness; their modulus of elasticity may be 50 times greater than that of the matrix. Since E-Glass fibers can withstand much higher tensile stress before strain and yielding occurs, they take most of the load when composite is stressed.

The prepared sandwich composite materials were taken out from the mold and then specimens of suitable dimensions were prepared from the composite slabs for three point bending tests according to ASTM D7264 standards. The dimensions used for the preparation of bending test specimen are shown in figure 3. The specimen for 3 point bending test is shown in figure 4.

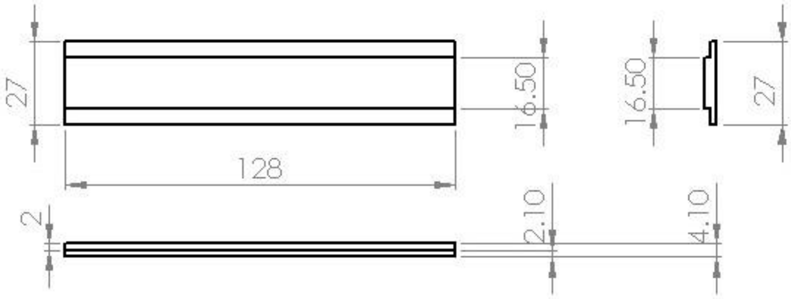

Figure 3: Bending test specimen dimensions (in mm)

Figure 4: Three Point Bending test specimen

BENDING TESTING

A universal testing machine (UTM) is used to test the bending 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 bending test. Machines have a computer interface for analysis and printing of output.

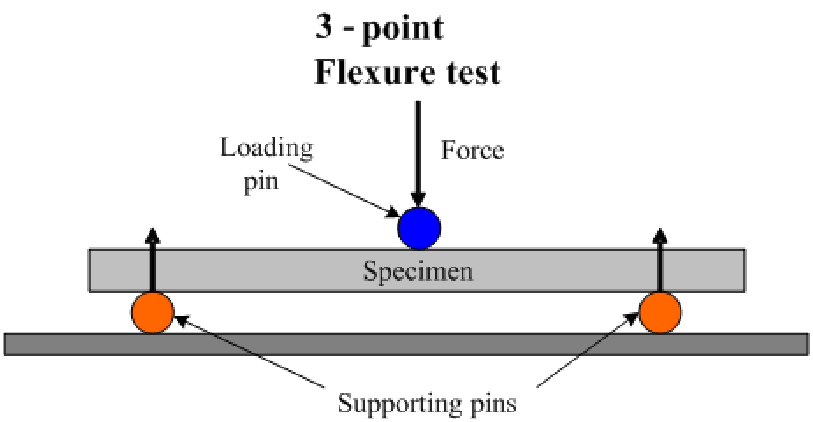

Figure 5: Three point bending Arrangement

A bar of rectangular cross section rests on two supports and is loaded by means of loading nose midway between the supports. The specimen is deflected until rupture occurs in the outer surface of the test. The three point bending arrangement used for the bending test is shown in figure 5.

DISCUSSION OF THE WORK DONE

Results obtained from the 3 point bending test are presented in this section. The result from the test is shown in the table 5 and figure 6. Mechanical properties of Sandwich composite with E-Glass fiber reinforced composite skin and Balsa wood core are depending on the properties of the constituent materials (type, quantity, fiber distribution and orientation, void content). The findings presented here provide new insights into the development of sandwich composite structures with unique mechanical properties for a wide range of mechanical and structural applications. Bending is an important structural test because of variety of loading situations in service.

TABLE 5: Result from Three point Bending test

Specimen No.	Thickness (mm)	Maximum Displacement(mm)	Maximum Principal Stress (N/mm^2)	Reaction Force (N)
1	3.96	3.16	8.5	510
2	3.95	1.935	6.188	392.3
3	3.92	2.283	8.729	490.4

Figure 6: Test specimen after 3 point Bending Test

FE ANALYSIS

A Finite element model has been designed as per the dimensions mentioned in figure 3 and the fibers of the glass fiber reinforced polymer composites in the top and bottom layer are modelled using the commercial Ansys ACP tool and the orientation of the fibers are as mentioned in table 4. The complete finite element model designed for testing is as shown in the below figure 7.

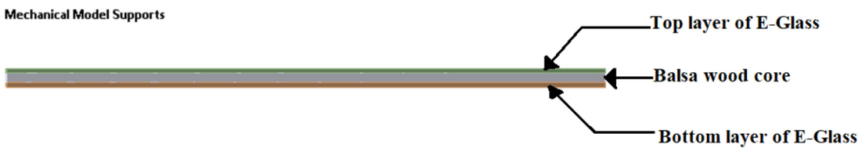

Figure 7: Sandwich Composite model

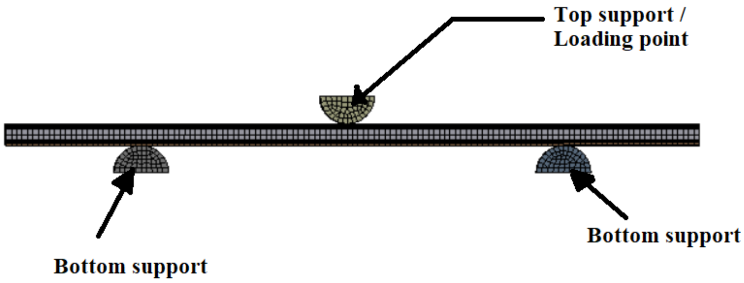

Figure 8: Meshed Sandwich model along with testing arrangement

Figure 8 shows the completely meshed sandwich model along with testing arrangement with 51903 nodes and 24497 elements. The bottom supports of the testing arrangement are fixed and the top support as shown in figure 9 and has been displaced as shown in figure 10.

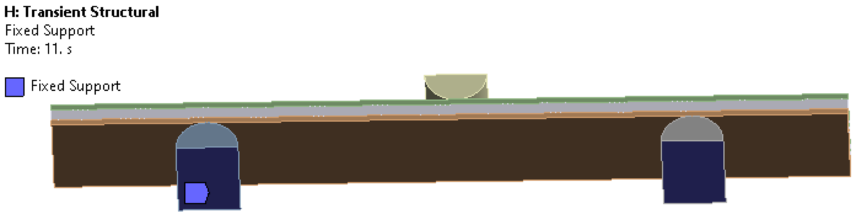

Figure 9: Fixed support applied to the bottom supports

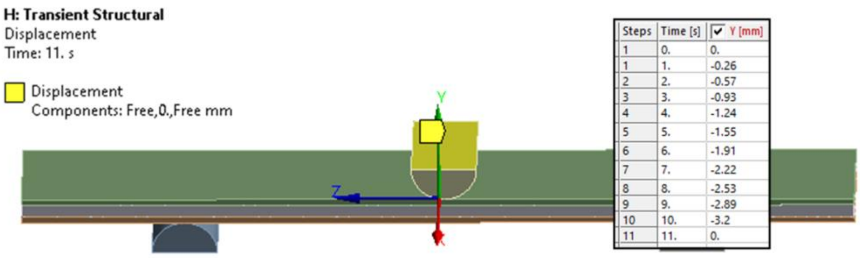

Figure 10: Displacement applied to the top support

After applying the constraints and making sure that the contacts are appropriate between the three layers of the body along with the supporting elements, the transient analysis is performed leading to the following results.

With the application of step wise displacement, for the maximum displacement of 3.2 mm the maximum principal stress obtained is 7.686 N/mm^2 and the reaction force obtained is 450.03N as shown in figure 11 and 12.

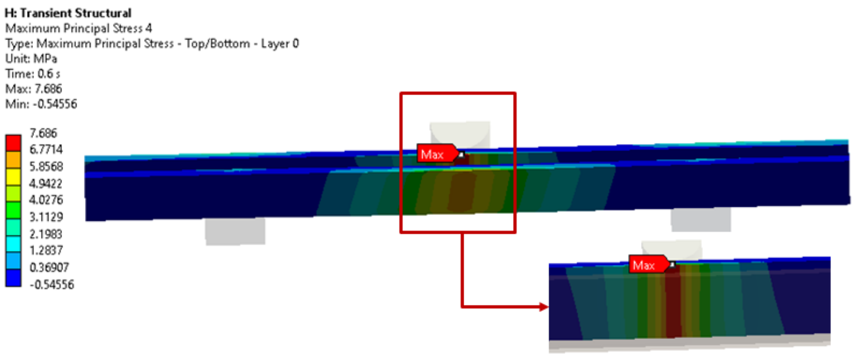

Figure 11: Maximum Principal Stress of 7.686 N/mm^2

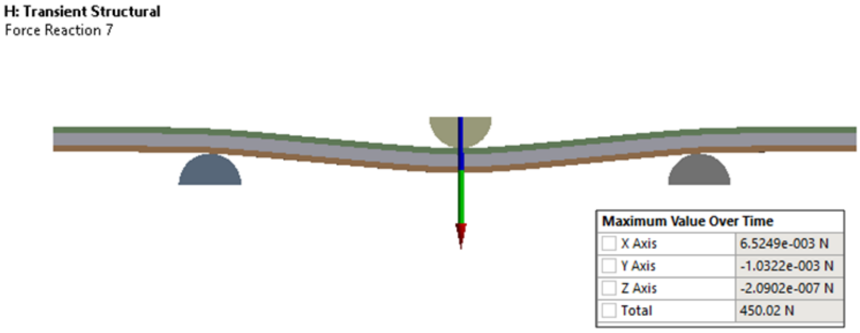

Figure 12: Reaction force of 450.03 N

CONCLUSIONS

Due to the depleting fossil fuel in the world, the search for alternate sustainable source of energy has increased, examples of which are energy from sun, wind, geothermal etc. Also as the price of the fossil fuel are increasing the urgency to find a reliable solution to the ever increasing energy needs, this study is done keeping in mind the use of Sandwich Composite in micro wind turbine blade.

This experimental investigation of mechanical behaviourur of sandwich E-Glass fiber reinforced Epoxy composite with Balsa wood core leads to the following conclusions:

- It was found that in physical testing for maximum displacement varies from 1.935 mm to 3.16 mm, the reaction force varies from 392.3 N to 510.0 N leading to the average reaction force of 464.233 N and the maximum principal stress varies from 6.188 N/mm^2 to 8.729 N/mm^2 leading to an average principal stress of 7.8 N/mm^2.
- Also from the FE analysis, we obtain closest results for the same displacement of 3.2mm with the maximum principal stress of 7.686 N/mm^2 and the reaction force of 450.03 N.
- It is observed that the percentage error in case of maximum principal stress is found to be 1.46% and in case of reaction force it is found to be 3.05%.

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