Investigation of bending properties of E-Glass fiber reinforced polymer matrix composites for applications in micro wind turbine blades

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Abstract. Polymer matrix composites are divided into thermoplastic or thermosetting polymers reinforced with organic or inorganic fiber. Use of composites is increasing in the field of engineering applications due the fact that they are satisfying the required mechanical properties. The present study is made on Sandwich composite with E-Glass fiber reinforced Epoxy composite skin and Balsa wood core. E-Glass fiber reinforced composite is an immensely versatile material due to its light weight, inherent strength, weather resistance, finish and also due to variety of surface textures. Though carbon fibers are more rigid then eglass fiber, we choose e-glass for its lower cost and are better suited to extreme flex patterns. The composite consist of E-Glass fiber, epoxy resin namely Ly556 and Hardener 951. E-glass is a low alkali glass with a typical nominal composition of SiO2 54wt%, Al2O3 14wt%, CaO+MgO 22wt%, B2O3 10wt% and Na2OK2O less then 2wt%. Some other materials may also be present at impurity levels. Tensile test, compression test and three point bending test etc. has to be carried out to better understand the mechanical properties of composite material. In this study three point bending test is discussed. This study is done keeping in mind the use of E-Glass fiber and epoxy resin composite in micro wind turbine blade.

1. Introduction

Due to depleting fossil fuels in world, the search for alternate sustainable source of energy has increased. Examples of which is energy from sun, wind, geothermal etc. Also, as the price of the fossil fuel is increasing, there is an urgency to find a reliable solution to the ever increasing energy needs. This has resulted in lot of research and development taking place in the field of sustainable energy. Composite material is increasingly being used to manufacture components used in field of sustainable energy sector due to its advantages of being light weight and better strength to weight ratio. The properties of polymer composite can be modified using fibers to suit the high strength and high modulus requirements. The advantages of continuous fiber (e.g. carbon fiber, glass fiber) reinforced polymer matrix composites are well known. The thermosetting polymer like epoxy resin is widely used in applications, like matrix for fiber reinforced polymer composites, coating, structural adhesives and other engineering applications. Epoxy resins are known for its excellent structural and thermal properties, better chemical and corrosion resistance, low shrinkage on curing and also its ability to be processed under different conditions. The present work is precursor to the development of micro wind turbine blades. Blades are an important component of a wind turbine, E-Glass fiber reinforced composite is selected for the construction of the blade as it is less expensive compared to other fibers, is also better suited for extreme flex patterns, have a better strength to weight ratio compared to metals like aluminium and better weather resistance

2. Methodology and experimental procedure

The objective is to investigate the behaviour of E-Glass fiber reinforced composite material specimens under a bending test. This experiment is used to determine the material properties due to bending and is used in a wide range of engineering applications. One aim of this study was to determine the characteristic of the material when subjected to bending loads keeping in mind the use of the E-Glass fiber for micro wind turbine blade.

3. Fabrication of Composite Specimen

Figure 1. E-Glass fiber

Figure 2. E-Glass fiber specimen preparation

Figure 3. Specimen for bending test

The specimen for the 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 Epoxy composite. Balsa Wood is the core for the bending specimen. The balsa wood is used as core due to its properties that make it ideal for sandwich composite construction. Balsa wood is compatible with different types of manufacturing processes like wet lamination to prepreg construction. Balsa does not get affected by styrene or long resin gel thus making it better suited for infusion applications also. Balsa is also available with a coating which minimizes the resin absorption and increases the bond strength and thus improves the weight savings. This composite specimen mainly consists of E-Glass fiber, epoxy resin Ly556 and Hardener 951. E-glass is a low alkali glass which consists of SiO_2 54wt%, Al_2O_3 14wt%, CaO+MgO 22wt%, B_2O_3 10wt% and Na_2OK_2O less then 2wt% other than this some other materials may also be present as an impurity. 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-1. In a unidirectional (UD) fiber lamina majority of fibers run in one direction.

Table 1. Layups and Orientation.

1st layer (top layer) – UD fibres	0 degree
2nd layer – UD fibres	0 degree
3rd layer – UD fibres	+45 degree
4th layer – UD fibres	-45 degree
Central Balsa Wood Core	-
5th layer –UD fibres	-45 degree
6thlayer – UD fibres	+45 degree
7th layer – UD fibres	90 degree
8th layer(bottom layer) – UD fibres	90 degree

Fabrication of the composite specimen for the bending test is done at room temperature by a process known as hand lay-up. The required materials for the fabrication like resin and hardener are mixed thoroughly by stirring it constantly. The E-Glass fibers are positioned manually as per the requirement in an open mold. Mixture so made is brushed uniformly, over the laid E-Glass fibers in the open mold. The vacuum bag is mounted on to the mold, vacuum bag helps to remove excess resin that may be present due to the using of open-molding process like hand lay-up technique. When the air is removed from the vacuum bag, atmospheric pressure exerts a force on the bag. This pressure on the laminate removes any entrapped air, excess resin, and also compacts the laminate, resulting in a higher percentage of fiber reinforcement [1]. Abrasive water jet machining process is used for cutting the specimen to get a smooth, precision cut surface.

The epoxy resin alone bends and stretches easily. However it is very stable chemically and constitutes an excellent matrix for the composite manufacturing. The E-Glass fibers provide good structural strength and stiffness, their modulus of elasticity is almost 50 times higher than that of the epoxy resin. E-Glass fibers can withstand much higher tensile stress before strain and yielding occurs also they take maximum load when composite is stressed.

The prepared sandwich composite material was taken out of the mold after curing and then the specimen as per required dimensions was prepared from the composite sheet for three point bending tests as per the ASTM standards. The test specimens were cut by water jet cutting machine. Four identical test specimens were prepared for three point bending test [2-3]. E-Glass fiber is shown in Figure 1 E-Glass fiber specimen preparation is shown in Figure 2 and Figure 3 shows the specimen for bending test. The dimensions for making the 3 point bending test specimen are shown in Figure 4.

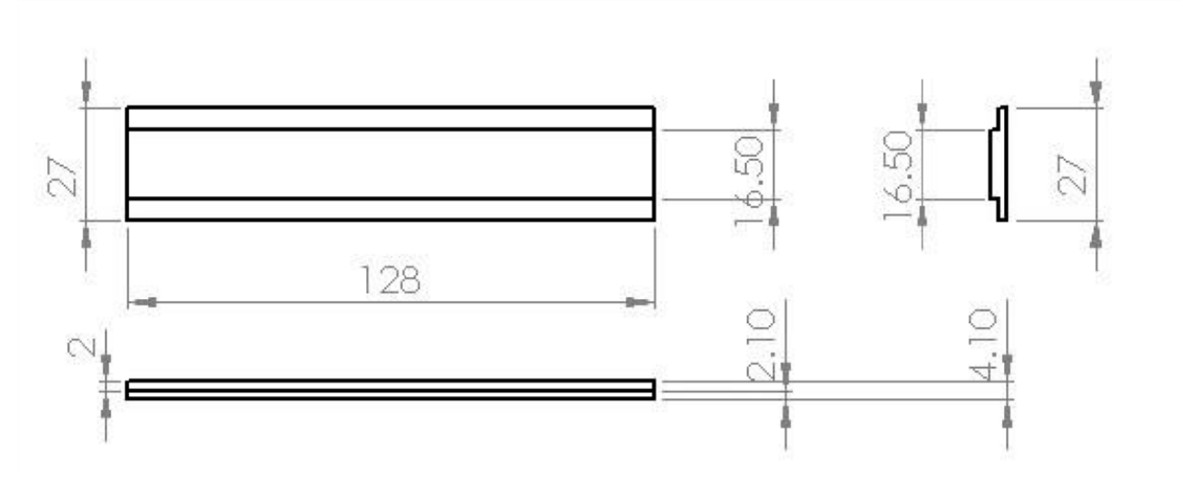

Figure 4. Bending test specimen (in mm)

The simple form of vacuum bagging a flexible film (PVA, nylon or polyethylene) is placed over the wet layup, the edges are sealed, and a vacuum is created to remove void from the specimen. A batter form of vacuum bagging places a release film over the laminate, followed by a bleeder ply of fiber glass cloth, non-woven nylon, polyester cloth, or other material that absorbs excess resin from the laminate. A breather ply of a non woven fabric placed over a bleeder ply, the vacuum bag is mounted over the entire assembly. Pulling a vacuum from within the bag uses atmospheric pressure to eliminate voids and force excess resin from the laminate. The addition of pressure will results in high fiber concentration and provides better adhesion between layers of sandwich construction. When laying non-contoured sheets of PVC foam of balsa into a female mold, vacuum bagging is a technique which ensures proper secondary bonding of the core to the outer laminate. In the Figure 5 Vacuum bog molding process is shown used for the sandwich composite specimen.

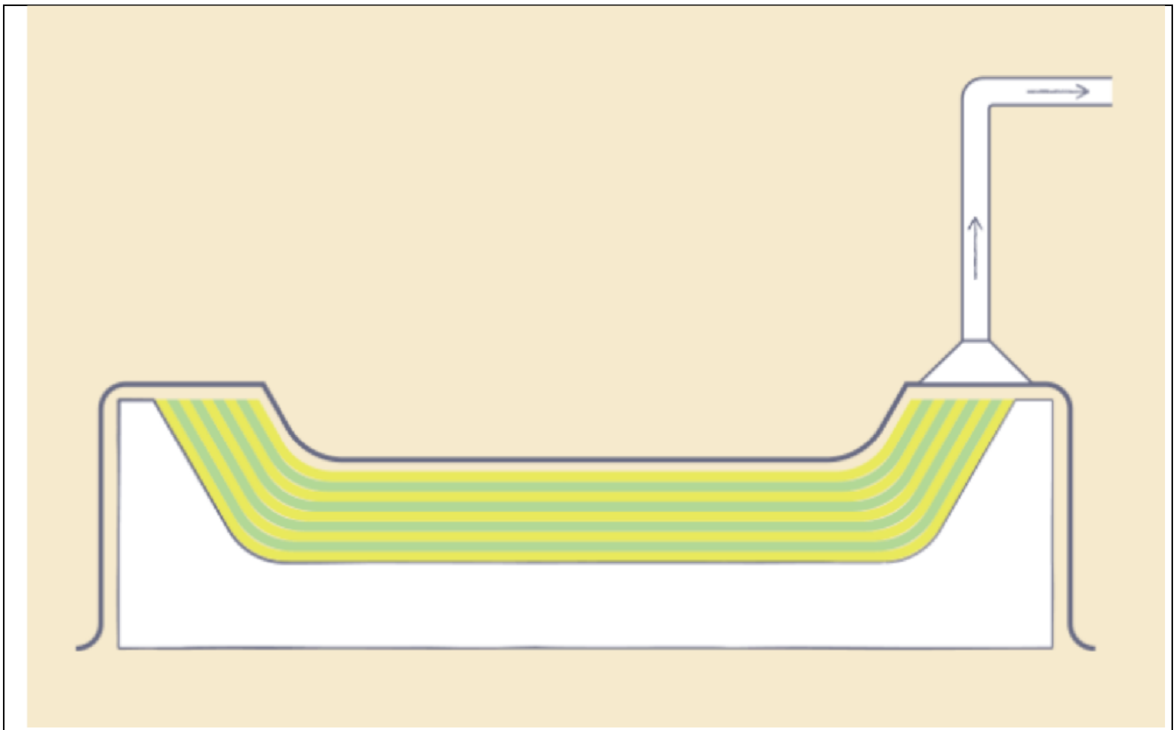

Figure 5. Vacuum bag molding process

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Figure 6. Abrasive Water Jet Machining

Water Jet Machining (WJM) and Abrasive Water Jet Machining (AWJM) are two types of nontraditional machining processes. In this process the mechanical energy of water along with abrasive phases are used to achieve material removal. This process belongs to mechanical group of nonconventional processes like Ultrasonic Machining (USM) and Abrasive Jet Machining (AJM). Water is pumped at very high pressure, 200-400 MPa (2000-4000 bar). The pressure is amplified using hydraulic cylinders of different cross-sections as used in “Jute Bell Presses”. When water at high pressure is passing through a suitable orifice (generally of 0.2- 0.4 mm dia), the potential energy of water is converted into kinetic energy, yielding to a high velocity jet (1000 m/s). Such high velocity water jet is used to machine thin sheets or foils of aluminium, leather, textile etc.

In pure WJM, tap water can be used for machining purpose. As the high velocity water jet is discharged from the orifice, the jet tends to entrain atmospheric air and flares out thus decreases its cutting ability. Hence, stabilizers (long chain polymers) that hinder the fragmentation of water jet are added to the water. In AWJM as shown in Figure 6, abrasive particles like sand (SiO_2), glass beads are added to the water jet to enhance its cutting ability by many folds.

4. Bending Testing

A universal testing machine (UTM) is used to test the bending strength of a specimen. A movable cross head 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 used for analysis and printing of output.

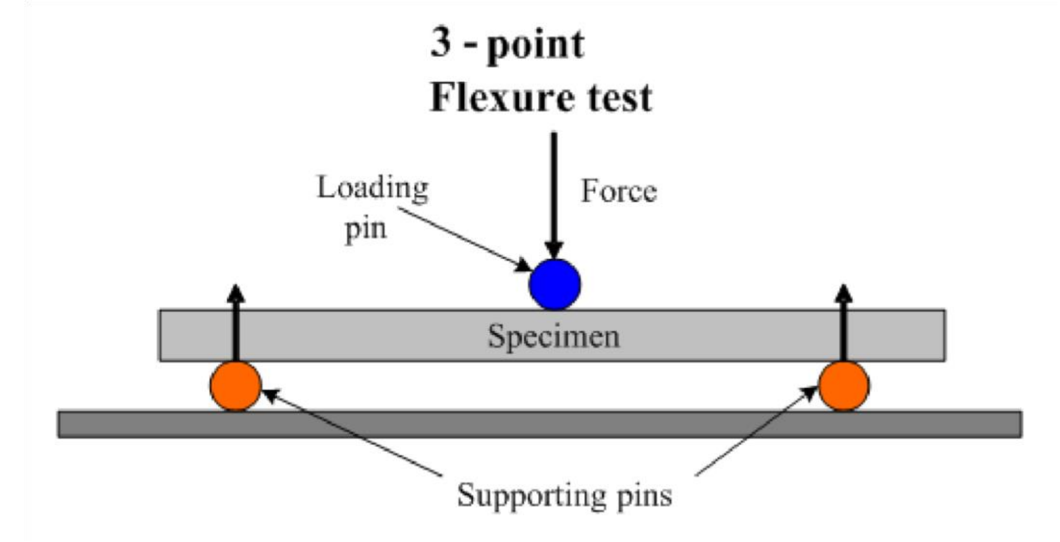

Figure 7. Three point bending Arrangement

The specimen rests on two supports and is loaded by means of loading nose midway between the supports. The specimen is deflected until it ruptures in the outer surface or until a maximum strain of 5.0% is reached, whichever occurs first. Bending test is carried for four test specimens. The results are discussed in next section. The three point bending arrangement used for the bending test is shown in Figure 7.

5. Results

Results obtained from the 3 point bending test are presented in this section. The result from the test is shown in Table 2 and Figure 6-7. Mechanical properties of Sandwich Composite with E-Glass fiber reinforced composite skin and Balsa wood core depend on properties of the materials used to make the specimen (material type, quantity, distribution of fiber and orientation, void present etc.). The findings of the testing here provide a new insight for the development of sandwich composite structures with unique mechanical properties having application in the field of use in micro wind turbine blades. Bending is an important structural test because of variety of loading situations in operation. Balsa wood is used instead of low density core material like foams due to higher toughness. During the 3 point bending test, there are three factors that dominate the resulting flexural strength of a specimen; the flexural strength of the matrix, the adhesion between fibers and matrix and the adhesion between laminates.

Table 2. Result from Three point Bending test

Specimen No.	Thickness (mm)	Peak load (N)	Break load (N)	Peak Displacement (mm)	Break Displacement (mm)	Peak Displacement %	Break Displacement %	Engg UTS (N/mm^2)	Strain
1	3.96	510	304.017	3.16	6.135	5.176	10.226	8.5	0.102
2	3.95	392.3	313.824	1.935	6.56	3.225	10.933	6.1888	0.109
3	3.92	490.4	264.789	2.283	6.992	3.805	11.654	8.729	0.117

4	3.9	362.9	254.982	1.986	10.302	3.31	17.17	5.558	0.172

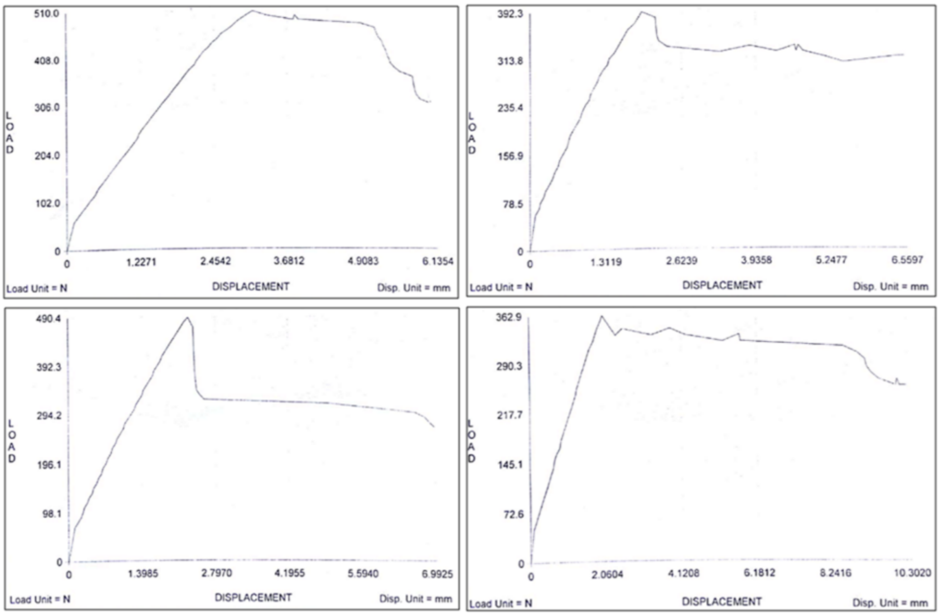

Figure 8. Load vs. Displacement Graphs of Three point bending from UTM

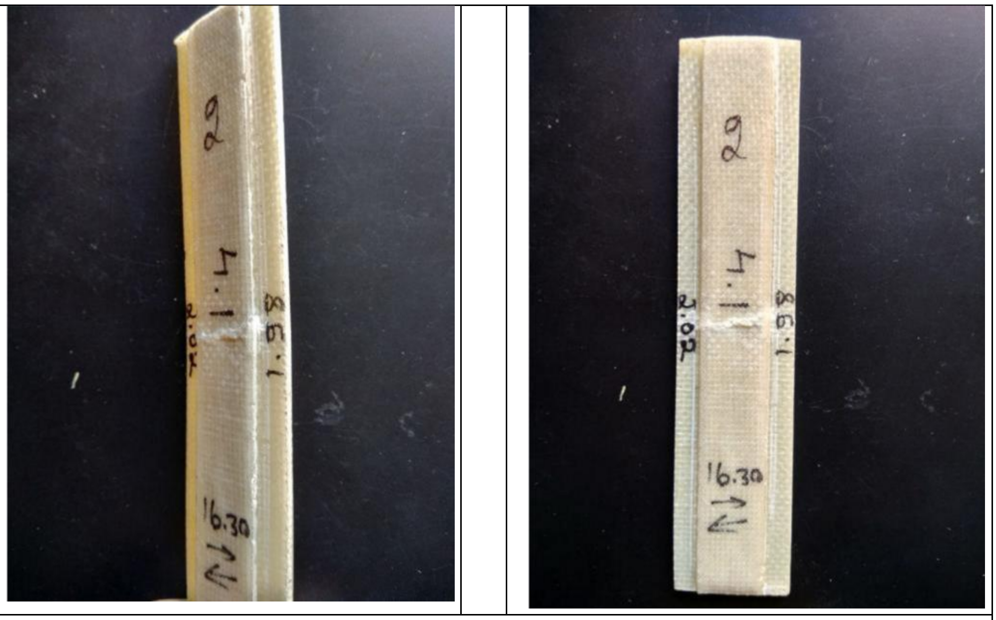

Figure 9. Test specimen after conducting the 3 point bending Test

6. 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 has resulted in lot of research and development taking place in the field of sustainable energy.

This investigation of Sandwich composite with E-Glass / Epoxy and Balsa wood core lead to the following conclusions:

- This work shows that micro wind turbine blade fabricated from sandwich E-Glass fiber reinforced Epoxy composite with Balsa wood core are very cost effective and can withstand loads that may cause bending.
- It was observed that the peak load while testing varies from 362.9 N to 510.0 N and peak displacement varies from 1.935 mm to 3.16 mm.

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