International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 01 | Jan - 2022 ISSN: 2582-3930

Development and Mechanical Testing of Carbon Fiber Reinforced Polymer Matrix Composites for Micro Wind Turbine Applications

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Abstract - In this century, composites have been discovered to be the most promising and discriminating material accessible. Composites reinforced with synthetic or natural fibres are becoming more popular as demand for light weight, high strength materials for specialized applications grows are on the rise in the market. In the current work Carbon fiber Reinforced Polymer Matrix Composite material is developed aiming wind turbine blade applications. This research demonstrates the successful development of a carbon fibre reinforced Epoxy matrix composite that can be utilized to make micro wind turbine blades and is very cost effective thanks to the utilization of a simple hand lay-up approach. The peak elongation varies from 12.248 mm to 14.417 mm, and the tensile strength varies from 939.472 N/mm2 to 960.910 N/mm2. It was observed that the Compressive Strength varies from 8.992 N/mm2 to 46.895 N/ mm2 and peak elongation varies from 1.808 mm to 3.462 mm. In three-point bending test, the peak load was found to be 509.96 N. Due to the presence of carbon fibre reinforcement, the bending strength of polyester resin has been greatly increased.

Keywords: Composite Materials, Micro Wind turbine

1. Introduction

The development of new materials with improved strength, stiffness, density and cost-effectiveness has been demanded by the industrial rapid growth [4]. Composite materials have emerged as one of the materials with better properties that may be employed in a variety of applications [1-3]. A composite material is made up of two or more constituent materials with significantly diverse physical or chemical properties that, when combined, provide a material with distinct qualities from the separate components. The fundamental components remain separate and distinct inside the finished structure. Natural or synthetic fibres are widely used in the fabrication of composite materials in a variety of industries, including construction, mechanical, automotive, aerospace, biomedical and marine [5-6].

Energy consumption has increased as the world's population and civilization have grown. Simultaneously, environmental consciousness has emerged as a serious environmental issue in the global marketplace. Oil, coal, wind, gas, hydro energy and other types of energy are all major sources of energy on the planet [7-10]. The development of the wind energy concept was prompted by an increasing desire to use renewable energy sources. Wind energy is a prominent renewable energy source that can assist in addressing the world's energy issues. Wind turbines or mills have been created to transform the kinetic energy of the wind into mechanical or electrical energy [11]. Wind turbine development for power generation is an exciting promise. One of the most significant components of a wind turbine is the rotor blades [12].

The primary criterion for selecting materials for wind turbine blades is that they must be strong and rigid, have a low density, and have good fatigue strength [13]. The blade's strength must be sufficient to bear the force acting on it without fracture, as well as rigid enough to avoid striking the tower during extreme loading circumstances. For the construction of wind turbine blades, the wind turbine industries are concentrating on the development of low weight, cost-effective, and environmentally friendly materials [12]. The choice of appropriate blade materials is critical in determining the eventual efficiency of a wind turbine blade.

Ganesh R Kalagi et al., [12] The application of natural fibre reinforced polymer composites in wind turbines, as well as the requirements for the composites, their properties, constituents, manufacturing technologies, and defects, are discussed in this research paper. Promising future directions for the composite materials are also discussed. V. García et al., [14] studied the suitability of basalt fibers on wind turbine blade applications using computation techniques. He concluded that, composite materials are an excellent replacement for metals in wind turbine applications. Sharma Set al., [15] studied the suitability of carbon-glass fiber reinforced composites for wind turbine blade applications. The authors concluded that the strength of composite is 160% higher than the conventional materials. Based on the literature study, it is observed that very less work has been carried out on carbon fiber composites. In the current work Carbon fiber Reinforced Polymer Matrix Composite material is developed aiming wind turbine blade applications.

2. Experimental Methods and Materials

This section describes the various materials and apparatus used in the experiment. The procedure for creating composite materials is also outlined.

2.1 Development of Composite Material

Hand lay-up technique is used to fabricate the composites at room temperature. This technique has multiple advantages and it is also economical for short production and prototype making. In this technique, the required ingredients of epoxy resin LY556 and hardener 951 are thoroughly mixed and the mixture is then constantly agitated in a basin. Carbon fibres are manually placed in the open mould. Carbon fiber lamina is shown in fig 1. The resulting mixture is brushed evenly over the glass plies. The Vacuum bag is mounted on the open mould as to remove the extra resin that builds up during hand laying process (Fig 2). The bag is pushed by atmospheric pressure. The pressure on the laminate removes trapped air, extra resin and compacts the laminate resulting in a higher fibre reinforcement percentage. Fig. 3 shows the developed composite material.

Table.1: Ingredients of matrix system

Ingredients	Trade Name	Chemical Name	Density (gm/cm3)
Epoxy Resin	LY556	Diglyodal Either of Bisphenol A	1.16
Hardener	HY951	Tri ethylene tetra mine	0.95

Figure 1: Carbon fiber lamina

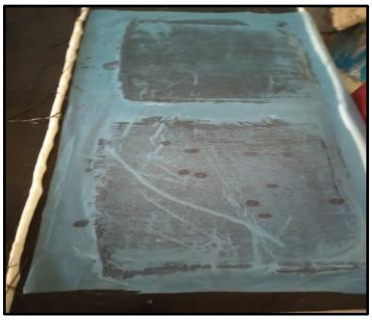

Figure 2: Carbon laminate in vacuum Bag

Figure 3: Composite Material

2.2 Tensile test.

A UTM is used to perform a tensile test (Universal Testing Machine). The force required to break the composite specimen is measured, as is the distance the specimen extends or elongates to achieve that breaking point. Table 2 lists the parameters for tensile test specimens.

Table 2: Details of tensile test specimen

Type of test	Tensile
Shape	Rectangle(flat)
Width	31.95 mm
Thickness	3.1 mm

Figure 4: Tensile Test Specimen

Table 3. Lay Up and Orientation

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

The specimen used for the tensile test is having 6 layer of carbon fiber reinforced composite lamina having zero degree orientations. The dimensions used for the preparation of tensile test specimen are 250mm length x 25mm width x 3.30 mm thick. The layup orientation for tensile test specimen is shown in table 3. The developed specimen for tensile testing is shown in Fig 4.

2.3 Compression test.

After removing the created composite specimens from the mould, specimens of compression test appropriate dimensions were prepared in accordance with ASTM requirements. A water jet cutting equipment was used to cut the test specimens. Figure 5 depicts the dimensions utilized in the production of compression test specimen. The compression strength is measured using a universal testing machine (UTM). A rectangular cross-section bar is attached to a wedge clip and loaded by moving the cross head. Deflect the specimen until it ruptures or a maximum strain of 5 percent is attained, whichever comes first. Three test specimens are subjected to compression testing. The findings of the tests are discussed in detail in the next section. Fig 6. Shows the developed compression test specimen.

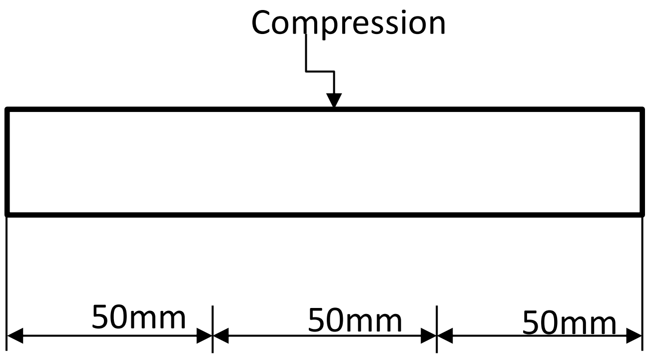

Figure 5: Compression test specimen dimensions.

Figure 6: Compression test specimen.

2.4 Bending test.

The flexural test setup is shown in Figure 8. Flexural strength refers to a material's capacity to resist deformation under load. It's a three-point bend test that results in inter-laminar shear failure most of the time. According to ASTM D790, this test is performed with UTM. This information is typically utilised to make decisions about the materials to employ for various parts that must support loads without flexing. Bending test specimen and its dimensions are shown in Fig 6 and 7 respectively.

3. Results and Discussions

In the current study, carbon Fiber Reinforced Polymer Matrix Composite material is developed with an intention of micro wind turbine application. The developed composite material is subjected to Mechanical characterization. The properties like tensile strength, Compression strength and flexural strength are determined and presented. Each test is repeated two times to ensure uniformity.

Figure 7: Three point bending test specimen

Figure 8: Three point bending test

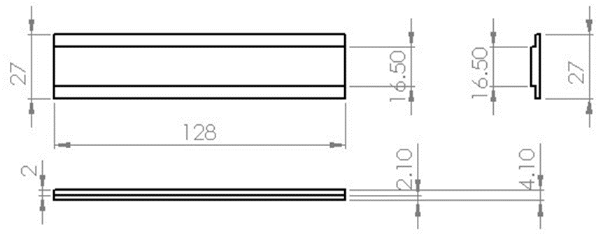

Figure 9: Bending test specimen dimensions.

3.1 Tensile Strength

Results obtained from the tensile test are presented in this section. The result from the test is shown in the table 4 and figure 10 and 11 shows the tensile test results of two different specimens of same type. Two specimens are tested at the time to ensure repeatability and accuracy of the results. Carbon fibre reinforced composites have a greater ultimate tensile strength because carbon fibre has a higher strength and behaves like an elastic material under tensile loading. The use of carbon fibre mat reinforced polymeric composite greatly increased the composite's ultimate tensile strength.

In case of specimen 1, the peak load was observed to be 95.08 kN and elongation at peak load was 14.417 mm and corresponding tensile strength was found to be 960.910 N/mm2. In case of specimen 2, the peak load was observed to be 93.05 kN and elongation at peak load was 12.248 mm and corresponding tensile strength was found to be 939.472 N/mm2.

The maximum variation in peak load was found to be 2.13% between the two specimens. In case of elongation the variation was found to be 15.04% and in case of tensile strength it was found to be 2.23%. Fig 12 shows the tensile test specimens after deformation.

Graphs describes typical load vs. deflection of the specimens. Curves for the specimens show linear behaviour until failure.

Table 4: Result from Tensile Testing

Specimen No.	Thickness (mm)	Width (mm)	Peak Load (kN)	Elongation at Peak (mm)	Tensile Strength N/mm²	Break load (kN)
1	3.1	31.92	95.08	14.417	960.91	95.08
2	3.1	31.95	93.05	12.248	939.47	93.05

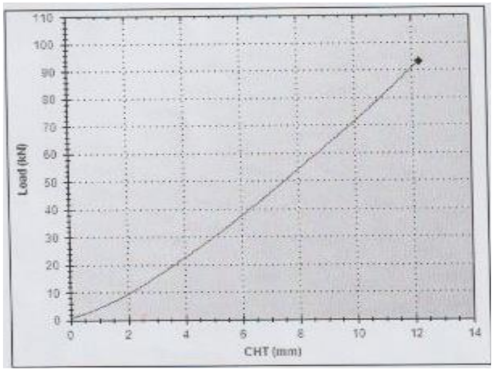

Fig 10: Tensile strength for specimen 1

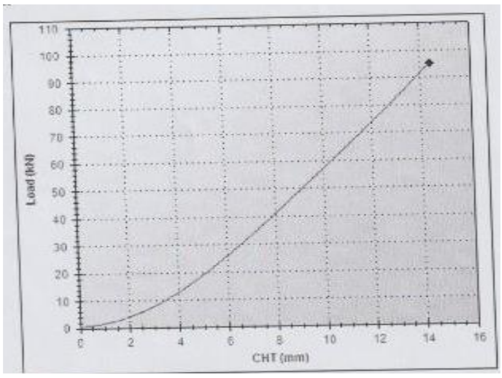

Fig 11: Tensile strength for specimen 2

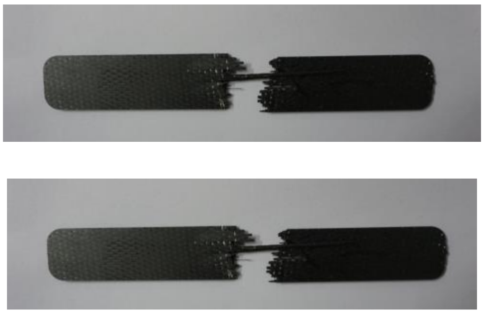

Fig 12: Tensile specimens after test

3.2 Compression Strength

Table 5: Result from compression Testing

Specimen No.	Thickness (mm)	Width (mm)	Peak Load (N)	Elongation at Peak (mm)	Compressive Strength (N/mm²)	Strain	Break load (N)
1	3.580	25.15	4138.6	1.892	45.965	0.024	980.7
2	3.670	25.04	4079.7	1.986	44.394	0.027	980.7

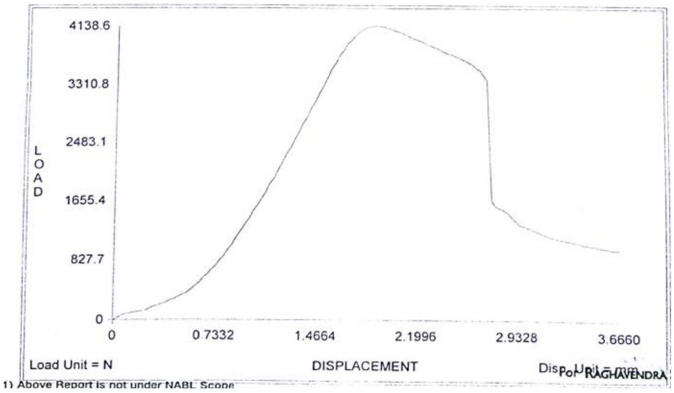

Fig 13: Compression strength for specimen 1

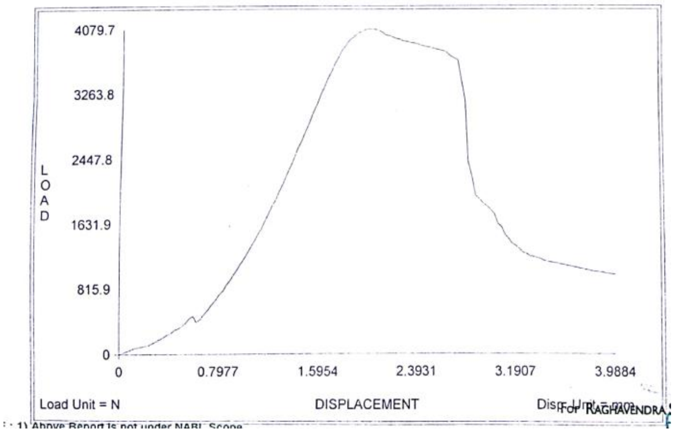

Fig 14: Compression strength for specimen 2

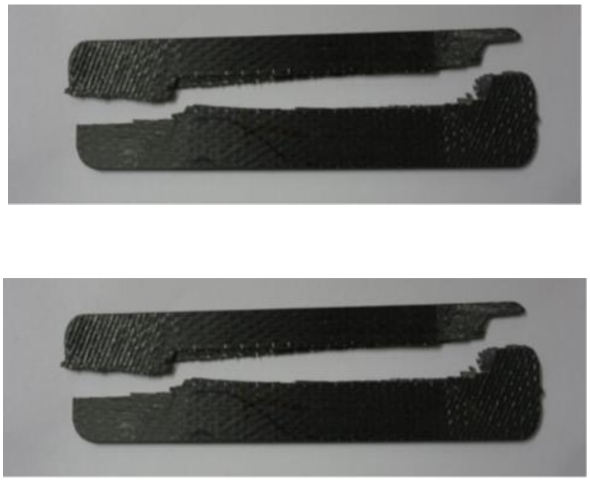

Fig 15: Specimens after test.

In this section, the results of the compression test are reported. Table 5, Figures 13 and 14, and Table 5 illustrate the results of the test. Figure 15 depicts the specimen following the compression test. Carbon fibre reinforced composites have a higher compressive strength because carbon fibre has a higher strength and behaves like an elastic material when loaded. The use of carbon fibre mat reinforced polymeric composite increased the composite's compressive strength substantially.

In case of specimen 1, the peak load was observed to be 4.138 kN and elongation at peak load was 1.892mm and corresponding compression strength was found to be 45.965 N/mm2. In case of specimen 2, the peak load was observed to be 4.079 kN and elongation at peak load was 1.986 mm and corresponding compression strength was found to be 44.394 N/mm2. The maximum variation in peak load was found to be 1.423% between the two specimens. In case of elongation the variation was found to be 4.73 % and in case of compression strength it was found to be 3.41%. Graphs describes typical load vs. deflection of the specimens. Curves for the specimens show linear behaviour until peak load.

3.2.1. Bending Test

Table 6: Result from Bending Test

Specimen	Thickness (in mm)	Peak load (in N)	Peak Displacement (in mm)	Break load (in N)	Break Displacement (in mm)	Strain
1	4.030	1098.4	1.570	509.96	4.854	0.08

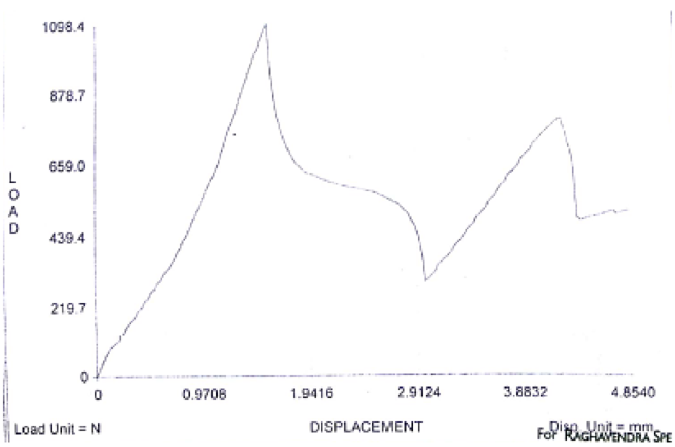

Fig 16: Bending test Result

Table 6 and fig 16 present the results of this experimental effort. The mechanical properties of carbon fiber-reinforced epoxy composites are determined by the constituent materials' properties (type, quantity, fibre distribution and orientation, void content). Three elements determine the resulting flexural strength of a specimen during the three point bending test: the matrix's flexural strength, the adhesion between fibres and matrix, and hence the adhesion between laminates. The values obtained have been analysed from available literature and an excellent agreement between test results has been observed. In case of bending test, the peak load was observed to be 1,098 kN and elongation at peak load was 1.570 mm and corresponding Break Displacement was found to be 4.854 mm. The strain at beak load was found to be 0.081. Fig 17 shows the specimen after test.

Fig 17: Specimens after test

4. Conclusions

In this study, carbon fibre reinforced composite specimens were developed using the vacuum bag method, and experimental evaluation of mechanical properties such as tensile, compression and bending tests of carbon fibre composites were successfully conducted according to ASTM standards. The following results are drawn from this experimental study of the mechanical behaviour of carbon fibre reinforced epoxy matrix composites:

- This research demonstrates the successful development of a carbon fibre reinforced Epoxy matrix composite that can be utilised to make micro wind turbine blades and is very cost effective thanks to the utilisation of a simple hand lay-up approach.
- The peak elongation varies from 12.248 mm to 14.417 mm, and the tensile strength varies from 939.472 N/mm2 to 960.910 N/mm2.
- It was observed that the Compressive Strength varies from 8.992 N/mm2 to 46.895 N/ mm2 and peak elongation varies from 1.808 mm to 3.462 mm.
- In three-point bending test, the peak load was found to be 509.96 N. Due to the presence of carbon fibre reinforcement, the bending strength of polyester resin has been greatly increased.

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