

Evaluation of Mechanical & Thermal Properties of Glass Fiber, Carbon Fiber/Epoxy Composites

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ABSTRACT

Composite material plays a vital role as it is a combination of two or more materials that results in better properties than those of the individual components used. Major proportion of engineering materials consists of composite materials. Composite materials have been used in vast applications ranging from day-to-day articles to highly sophisticated applications. This present investigation is to study the mechanical and thermal properties of Glass fiber-epoxy resin (GFER), Carbon fiber-epoxy resin (CFER) composite system which is being manufactured by hand layup and vacuum bagging method. The Glass and Carbon fiber used in this investigation are 200GSM (Grams per Square Meter) and having orientation of (0° - 90°). The composite samples are made in the form of laminates. The mechanical (Tensile strength & Flexural Strength) and thermal (Thermal Conductivity) properties are studied for all samples. The base/matrix material used for all these composite samples is liquid based Diglycidyl ether of Bisphenol-A (DGEBA) and Acid based Anhydride hardener system. The tensile and flexural samples were prepared as per ASTM standard and corresponding values are tabulated and discussed.

Keywords: Glass Fiber, Carbon Fiber, Epoxy Resin, Tensile Strength, GFER & CFER Composite material

I. INTRODUCTION

Composite material is a combination of two or more materials, whose properties are superior to those of the constituent materials acting independently. Fiber-reinforced polymer composites are usually manufactured by embedding stiff and strong fibers into a relatively less stiff and compliant, polymeric matrix. The primary role of the fibers is to provide strength and stiffness to the composite [1]. Typical reinforcing fibers used are glass, carbon and aramid, with fiber diameters in the range of 6-14 μ m. The role of the matrix material i.e. Epoxy resin is to hold the fibers in their position, protect the fibers from abrasion and the external environment (such as chemicals or moisture) and transfer load between fibers. Matrix material for polymeric composites can be either thermosets or thermoplastics [2]. Thermoset resins usually consist of a low-molecular weight resin system and a compatible curing agent (also called a hardener). When the resin and hardener are mixed they form a low viscosity liquid that undergoes a chemical reaction to form three-dimensional cross-linked structures, resulting in an insoluble solid phase that cannot be reprocessed on reheating.

The attainment of good mechanical properties in a composite material depends crucially upon the efficiency of stress transfer from the matrix to the fiber, which requires optimization of the adhesion of the fiber to the matrix. To promote the fiber-matrix adhesion, different surface treatments/coupling agents are applied to the fiber surfaces to provide chemical bonding with the polymeric matrix. Silane type coupling agents are normally applied to glass fiber surfaces during manufacture while carbon fibers are surface treated by oxidation and aramid fibers are usually treated with an epoxy finish. The adhesion between fiber and matrix occurs during the processing of composites. The processing parameters control the properties and therefore the quality of the composites.

The use of composites filled with fiber in epoxy system has gained significant importance in the development of thermosetting composites. One of the most important focuses in achieving this goal is to develop a new material, which possesses a strength-to-weight ratio that far exceeds any of the present materials. Epoxy resin remains the most important matrix material used in the high-performance transportation systems. When epoxy combines with carbon fibers, it results in advanced

composites, which have sound-specific properties such as impact, hardness, tensile strength and modulus and other properties.

II. SAMPLE PREPARATION & EXPERIMENTATION

i) Materials

Epoxy, one of the most widely used insulating materials in the electrical industry is used as the base/matrix polymer material in the present study. One of the advantages of these particular epoxy resins is that they do not contain any fillers and they have a low initial viscosity. For preparing a sample using these epoxy resin (Diglycidyl ether of Biphenyl-A (DGEBA) type epoxy resin CY205) and hardener (Acid anhydride hardener HY905), 100 parts by weight of the CY230 resin is mixed homogeneously with 10 parts by weight of the HY951 hardener respectively with some proportion of flexibilizers DY040 & accelerator DY061[3]. For reinforcement material purpose Carbon Fiber of 200GSM 2x2 twill woven (HinFab™HCT200C) and E-Glass Fiber of 100GSM plain weave fabric (HinFab™HinfabHGP116E) are used along with processing materials such as Peel ply fabric, Perforated sheet, Breather sheet, Bagging sheet, sealing tape, flow tube, flange etc. during fabrication of samples with vacuum bagging technique.

ii) Surface Functionalization of Glass/Carbon-fibers

Strong interfaces between matrix and fiber are needed to achieve high performance, because the interface usually is the weakest point of the composite. A silane coupling agent was used to improve the interface and adhesion between the inorganic filler and polymer binder. The particle surface modification was performed with an epoxide-functionalized silane coupling agent, namely γ -glycidoxypropyltrimethoxysilane (GPS).

iii) Sample Preparation

The specimens/samples for testing flexural strength, tensile strength and for measurement of thermal conductivity used for experimentation were prepared by a process called Pre-preg and vacuum bagging technique.

A pre-preg system is a pre-impregnated sheet of a combination of the reinforcing fibers and the resin matrix (with hardener). In a pre-preg, the resin is advanced to a B-stage condition in which it is a semi-solid (represents a partially cured state) at room temperature, which melts and flows during the cure cycle. The B-staged resin normally contains some tack or stickiness to allow it to adhere during the lay-up operation. With reference to the manufacturing of pre-preg-based composites, the unidirectional prepreg laminas are stacked-up or laminated with the fibers in the required orientation. This is carried out either manually or by a lay-up machine which places the individual plies of the pre-preg in the required orientation directly onto the tool surface. The laminated pre-preg is then vacuum bagged with release film and breather cloths. The vacuum bagged pre-preg laminate is placed inside the autoclave where a combination of heat, pressure and vacuum consolidates and cures the laminate.

Figure 1 shows a typical autoclave cure cycle for pre-preg-based composites. With reference to the figure, the vacuum is applied before the heating stage of the cure cycle and maintained throughout the cure cycle. During the heating cycle, initially the viscosity of the resin decreases, and this allows the entrapped air between the laminas to escape by the application of the vacuum. The pressure applied on the pre-preg stack will consolidate the laminate. During the isothermal stage of the cure cycle, the temperature and pressure are kept constant. In this dwell period, the polymerization of the resin takes place by an exothermic reaction; this increases the viscosity of the resin rapidly.

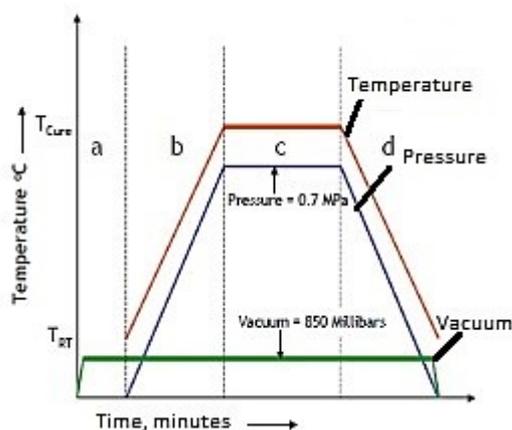


Figure 1. Typical cure cycle for pre-preg-based composites. a) Vacuum application, b) heating cycle, c) isothermal cure and

d) Cooling Cycle

As the reaction proceeds, the molecular weight of the resin increases by linking several chains to form a three-dimensional cross-linked network. This transformation from viscous liquid to elastic gel is known as the gel point. The degree of cure determines the amount of cross-linking in the resin. This degree of cure of the resin determines the composite's performance. After the dwell period, the cool-down stage of the cure cycle commences by gradually reducing the temperature and pressure. At the end of the cure cycle, the part is left to cool down to room temperature. The above steps of converting low molecular weight viscous resin to a high molecular weight solid by a polymerization process is also called curing hence the name cure cycle.

III. Experiments

Flexural Strength Measurement

Flexural strength and modulus were evaluated using Universal testing machine (UTM), M/s DAK Systems make with a crosshead speed of 2.5mm/min and 50 kN load cell. The three-point bending test system was used for all samples. In each case, five samples were tested and the average value tabulated in Table 1.0. Furthermore the sample sizes 100 x 20 x 4 mm³ were cut and tested in accordance with ASTM D7264 standard [4] as shown in Figure 2.0.



Figure 2. Flexural Strength Measurement

Table 1. Flexural Strength of composite

S. No	Type of Fiber in the composite	Specimen No	Flexural Strength (N/mm ²)	Average (N/mm ²)
1	Carbon	CF1	1270	1218

2	Fiber (CF)	CF2	1150	932
3		CF3	1192	
4		CF4	1250	
5		CF5	1232	
6		Glass Fiber (GF)	GF1	
7	GF2		0991	
8	GF3		0870	
9	GF4		0905	
10	GF5		0953	

Tensile Strength Measurements:

Tensile strength was studied using an Universal testing machine (UTM), M/s DAK Systems make with a crosshead speed of 5 mm/min. Testing samples were prepared in dumb-bell shapes and these dimensions are 100 x 20 x 4mm³ based on the ASTM D3039 standard [5] as shown in Figure 3.0. In each case, five samples were tested and the average value tabulated in Table 2.0.



Figure 3. Tensile Strength Measurement

Table 2. Tensile Strength of composite

S. No	Type of Fiber in the composite	Specimen No	Tensile Strength (N/mm ²)	Average (N/mm ²)
1	Carbon Fiber (CF)	CF1	0937	972
2		CF2	0942	
3		CF3	0992	
4		CF4	1012	
5		CF5	0981	
6	Glass Fiber	GF1	0214	234
7		GF2	0224	

8	(GF)	GF3	0269
9		GF4	0291
10		GF5	0175

Thermal Conductivity Measurement

The thermal conductivity measurement was carried out by M/s C-Therm Technologies make, TCi-120 Thermal conductivity analyzer on a sample made from above Glass-fiber and Carbon-fiber/Epoxy resin composite system as shown in Figure 4.0. For each composition 3 samples (100mm length x 5 mm thickness) were tested and the test results are given in Table 3.0.



Figure 4. Thermal Conductivity Measurement

Table 3. Thermal Conductivity of composite

S. No	Type of Fiber in the composite	Specimen No	Thermal conductivity (W/m. K)
1	Carbon Fiber (CF)	CF1	0.455
2		CF2	0.462
3		CF3	0.471
6	Glass Fiber (GF)	GF1	0.420
7		GF2	0.415
8		GF3	0.422

IV. RESULTS & DISCUSSION

In the present investigation, glass fiber as well as carbon fiber reinforced with epoxy resin composite are fabricated and their mechanical and thermal properties are evaluated. The tensile strength and flexural strength are observed for 5 different specimen.

Following observations are made from the experimentation

- ✓ The measured Flexural strength of the Carbon Fiber and Glass Fiber composite materials are given in Table 1.0, from the test results it is clear that the

Flexural strength of the composite material made of Carbon fiber is varied from 1150-1270 N/mm² whereas for composite with Glass fiber it is varied from 870-991 N/mm². These results show that the toughening of epoxy matrix with a thermoplastic polymer was adequate in improving its mechanical property and probably its interface with the reinforcement. This result suggests that the used thermoplastic has high structural performance and good compatibility with epoxy and carbon fiber, improving consequently the interface among the components of the composite.

- ✓ From the test results of Tensile Strength as given in Table 2.0, the tensile strength of composite with Carbon fiber is varying from 942-1012 N/mm², whereas for glass fiber composite it is varied from 175-291 N/mm².
- ✓ The results obtained from the experiments show that tensile and flexural strengths of composites with 90⁰ of fiber orientation have the best performance. According to the tensile, CFRE composites were 21-24 % stronger than the GFRE composites, whereas from Flexural strength (three point bending) test results, the CFRE composites were 71-80% stronger than the GFRE composites.
- ✓ The thermal conductivity of Carbon fiber reinforced composite as well as Glass fiber reinforced composite materials are almost equal as given in Table 3.0.

V. CONCLUSIONS

Based on the experimental investigation and analysis, the following conclusions are drawn: the composite material reinforced with carbon fiber is having better tensile strength and flexural strength as compared to the composite material reinforced with Glass fiber. The thermal conductivity of Glass Fiber and Carbon fiber reinforced with epoxy resin system have almost similar values which will help in dissipation of heat generated in high voltage electrical systems.

VI. REFERENCES

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