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Characterization of Compression Properties of Glass/Epoxy Laminates with and Without Graphite Particulate Filler

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Abstract : *Composites have been used extensively in application such as aerospace, automotive and chemical. Therefore, there is a need for further studies on the properties of these materials. This work presents the results of compression tests on the mechanical properties of composite materials. The laminates were fabricated by dry hand lay-up technique. The approximate volume fraction of the laminate is; 65% of glass fiber, 27% of epoxy resin added with 3% of graphite particulate filler and 8% of hardener. The composite specimens were tested for compressive property determination. The compressive properties such as compressive strength, compressive load and elastic modulus were investigated by using fuel instruments and engineers' private limited (FIE) machine in accordance with ASTM standards. Based on the results obtained, the longitudinal E11, transverse E22 and shear modulus G12 of 56.44 GPa, 9.0425 GPa and 6.1648 GPa for glass fiber/epoxy laminates, respectively, while the ultimate longitudinal XL, transverse XT and shear tensile τ0 strengths of 643.994MPa and 34.3598 MPa for glass fiber/epoxy laminates, respectively. The results from this series of tests have been presented and compared with results from analytical equations. Specimens were examined under scanning electron microscope (SEM) to study the microstructure of the fracture surfaces of samples.*

Keywords: *Composites, Compression test, Dry hand lay-up technique, FIE.*

1. INTRODUCTION

In order to of estimate strength and stiffness, structural materials are subjected to mechanical testing. Tests aimed at evaluating the mechanical characteristics of fibrous polymeric composites are the very foundation of technical specification of materials and for design purposes [1].There has been a remarkable growth in the large-scale production of fiber and/or filler reinforced epoxy matrix composites. Because of their high strength-to-weight and stiffness-to-weight ratios, they are extensively used for a wide variety of structural applications as in aerospace, automotive and chemical industries [2]. The many uses of these materials in space and aeronautical industry-related applications are well known [3]. Use of inorganic fillers dispersed in polymeric composites is increasing. Fillers not only reduce the cost of the composites, but also meet performance requirements, which could not have been achieved by using reinforcement and resin ingredients alone. Unfortunately, graphite does not possess very good mechanical properties and is often either easy to cleave (natural graphite in pencil lead) or very brittle (diamond like carbon coatings or glassy carbon). In order to improve the mechanical properties of pure graphite, carbon–carbon (C–C) or carbon–polymer (C–Polymer) composites have been produced. A large number of patents describe various methods of producing such composites. C–C composites are generally produced when a mixture of graphite particles and an organic binder is heat treated at temperatures up to around 2800 degree C [4- 5].It is reported that the mechanical and thermo mechanical properties of composites filled with micron-sized filler particular are inferior to those filled with nanoparticles of the same filler [6]. Composite materials in the context of high performance materials for structural applications have been used increasingly since the early 1960s; although materials such as glass fiber reinforced polymers were already being studied 20 years earlier. Initially conventional test methods originally developed for determining the physical and mechanical properties of metals and other homogenous and isotropic construction materials were used. It was soon recognized however that these new materials which are non homogenous and anisotropic (orthotropic) require special consideration for determining physical and mechanical properties [7]. The uses of composite structures have proliferated recently to include a large number of new applications. Once only used for specialized parts or secondary members, composites are now considered to be competitive with other materials in many applications. The fact that composites in general can be

custom tailored to suit individual requirements have desirable properties in corrosive environment; provide higher strength at a lower weight and have lower life-cycle costs has aided in their evolution. Also it provides a good combination in mechanical property, thermal and insulating protection. These qualities in addition to the ability to monitor the performance of the material in the field via embedded sensors give composites an edge over conventional materials. So to understand the behavior of the composite materials under different loading conditions and because composite materials are produced by different manufacturers, studying the mechanical and physical properties becomes vital [8]. The focus here is to expand the general understanding of these materials to illustrate the importance of knowing the mechanical properties and to show the ease with which this information can be gained through simple laboratory tests. Specifications given by manufacturers are often average values for an entire product line and not a specific item. This is a source of error when considering small test samples cut from product sample. Further much of the specific information is not published in manufacturers literature which requires the user to conduct the tests himself to determine the exact information. Accurate mechanical properties of the composite materials are essentially important because they provide the fundamental materials parameters in the design of composite structures under different loading modes. In this work material characterization test of the coupon for glass/epoxy laminate with graphite particulate filler used in the current project was carried out. The objectives of this project work are to present processing techniques of analysis of test methods, and test procedures to determine compressive properties and strength data for composite materials. All the test methods presented are based on the American Society for Testing and Materials (ASTM). These tests are useful for engineers who desire to extend their expertise into experimental characterization of anisotropic materials.

2. EXPERIMENTAL PROCEDURE

2.1. Specimen details

The approximate volume fraction of the laminate is; 65% of glass fiber, 27% of epoxy resin added with 3% of graphite particulate filler and 8% of hardener. The compression test were performed in order to measure the mechanical properties well as the damage resistance properties of glass/epoxy laminates with graphite particulate fillers. The specimen geometry and the reference standard are summarized in Table 1.

Table 1 Specimen Dimension

Test Item	Length(mm)	Width(mm)	Remarks	Refere nce
Compres sion Test	122.59	12.54	Tablength;36. 58mm	ASTM D 3039

2.2. Specimen preparation

The laminate used in this study was manufactured by dry hand lay-up technique. E-glass plain weave roving fabric, which is compatible to epoxy resin, is used as the reinforcement. To make the glass/epoxy laminates with graphite particulate filler, graphite powder mixed into a weighed quantity of the resin was smeared on at 2000C for 2 hr. while making the lay-up. About 3 wt. % of graphite powder in resin was introduced; the laminate was made by pressing the lay-up in a compression unit operated at about 0.4MPa to yield about 2mm thick laminates. The stacking procedure consists of placing the fabric one above the other with the resin mix well spread between the fabrics. A porous Teflon film is placed on the completed stack. Use of spacers of about 2mm thickness helped in obtaining laminates of the required thickness following final curing. The mold plates have a release agent smeared on it. The whole assembly is pressed in a hydraulic press and allowed to cure for a day at room temperature. After remolding, post curing was done at 1200 C for 2 hours using an electrical oven. The laminate so prepared has a size 122mm X 12mm X 2 mm. The laminate so prepared has a size 150 x 75 x 2 mm. Finally from the composite laminate prepared, according to ASTM standards, the test sample was cut to size 120 mm x 12 mm x 2 mm with the help of a diamond tipped cutter. Aluminum plates with edges angled at 60 degree were attached with epoxy adhesive on both ends of all composites.

2.3. Testing equipment

Compressive test is performed in order to compare the compressive properties as well as the failure resistance properties of glass/epoxy laminates with graphite particulate filler made from ASTM D 3039.

The following equipment is,

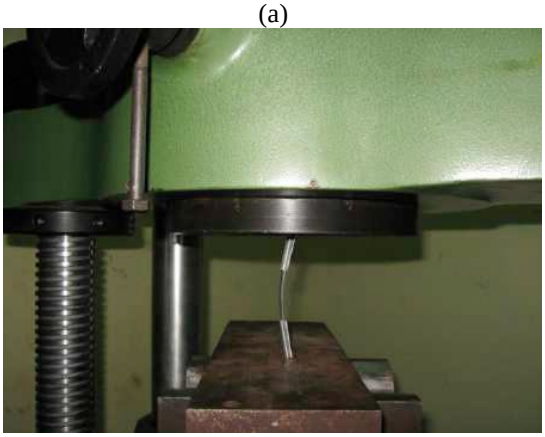
1. Hydraulic universal testing machine (UTE – 60) and data acquisition system.

2.3.1 Hydraulic universal testing machine and data acquisition system

There are many types of testing machines. The most common are universal testing machines, which test materials in tensile, compression or bending. The Max.capacity of this hydraulic universal testing machine is 600 kN. The primary use of the testing machine is to create the stress-strain diagram. Once the diagram is generated, a pensile and straight edge or computer algorithm can be used to calculate yield strength, young's modulus and compression strength.

The electromechanical machine uses an electric motor, gear reduction system and one, two or four screws to move the crosshead up or down. Crosshead speed of the testing machine was 8 mm/min, based on the compression test method for glass/epoxy laminates with graphite particulate filler. Fig.1 shows the hydraulic universal testing machine with data acquisition system.

(a)



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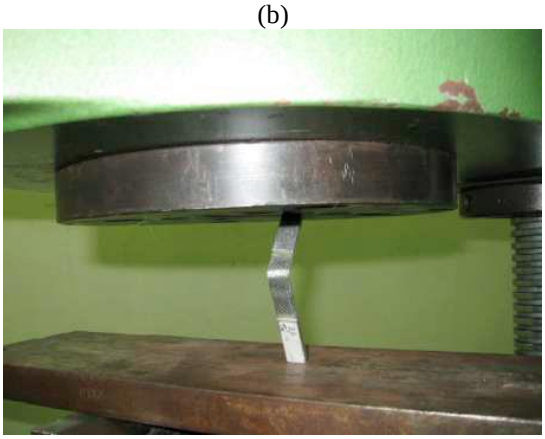
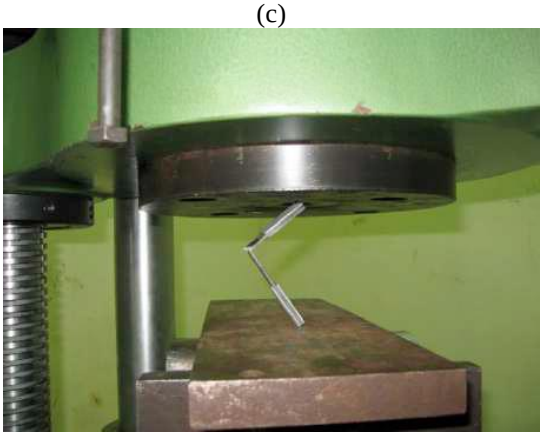


(c)



(d)

Fig. 1 (a,b,c,d) Hydraulic universal testing machine with data acquisition system and specimen set up.

2.3.2 Compression Test specimen

Compressive tests were carried out for the fabricated composite. To avoid stress concentration, before the experiment, aluminum plates with edges angled at 60 degree were attached with epoxy adhesive on both ends of all composites. The gauge length of the composite specimens was 50 mm. A strain gauge was fixed at the center of each specimen for measuring uniaxial strain and calculating Young's modulus. Fig.2 shows the compression test specimens 'dimensions.

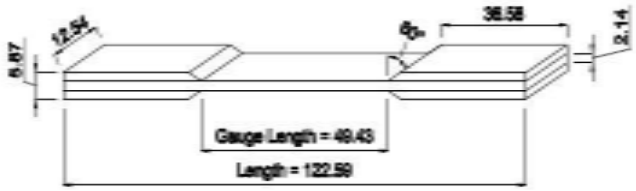


Fig. 2 Dimensions of compression test specimen

2.3.3 Procedure for compressive test

The compressive test consists of following step by step procedure.

1. Measure the compressive test specimen dimensions by using vernier calipers. E.g.: initial gauge length, total length, thickness and width.
2. Switch on the hydraulic universal testing machine and move the crosshead up and down.
3. Then give input to the data acquisition system E.g.: initial gauge length, thickens, width and cross sectional area.
4. The specimen can be set in between square jaw of the machine and tight the jaw by using hand wheel.
5. Set the load at zero Newton and apply small loads gradually. Now the specimen in loading condition.
6. Data acquisition system can plot load vs. displacement diagram and store the data of test up to failure.
7. When the peak load (maximum load) can reach, the data acquisition system can store the data.
8. Finally, the compression test specimen can failure and the data acquisition system can store peak load and maximum displacement of the specimen.
9. Loose the jaw by using hand wheel and remove the specimen from the machine
10. Switch off the machine and collect data from data acquisition system

Fig. 3 compression test specimen before and after tensile testing.

2.4. SEM examinations

The micromechanismes of compression failure were evaluated by examining the fracture surface of the compression specimen using a scanning electron microscope (SEM).

3. RESULTS AND DISCUSSION

3.1 Compression properties

Table 2 shows results of compressive test of glass/epoxy laminates with graphite particulate filler. The laminates with graphite particulate filler (3%) show compressive strength value.

Table 2 Compressive test of glass/epoxy laminates

Thickness(mm)	Width(mm)	CSA(mm^2)	Compression Load(kN)	Compression Strength(MPa)
2.14	12.54	26.84	1.29	48

Typical compressive load and stress– displacement curves for G-E laminates with graphite particulate filler is shown in Fig. 4. The curves represent a progression of behavior increasingly resistant to deformation. The experiment was performed under quasi-static compressive loading for glass-epoxy laminate up to final fracture. It has been observed that the laminated plate buckled globally until complete fracture occurred as expected. Fig. 3 shows the final deformed and damaged shape of the plate after the compression test. Figs. 4 show the comparison of load versus displacement curve for the glass-epoxy laminate plate, with different angle orientations.

It is interesting to note that the laminate behave in a similar fashion whereby their behavior is almost linear before reaching the peak load. On the other hand, beyond that peak points of the load–displacement curves majority of the laminate experienced large displacements before fracture, which proved that these bi-woven laminates are able to absorb large amounts of energy before fracture. Table 2 summarizes the ultimate load and compression strength for the laminate size. The results have revealed that fiber orientation directly affects the distribution of load between the fibers and the matrix.

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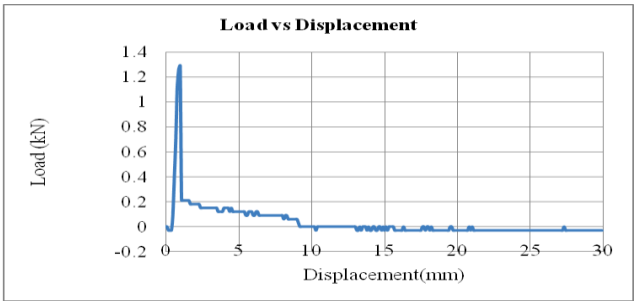

Fig. 4 load – displacement diagram

3.2 SEM analysis of the fractured specimens of laminate after tensile testing

Scanning electron microscopy (SEM) analysis was used for direct observation the failure of laminate surface, and particularly to examine the fiber-resin interface. Micrographs were taken of the surface of the tensile test samples. Figs. 5 and 6 Shows the SEM micrographs for glass/epoxy laminates with graphite particulate filler fracture after tensile loading. From the figures it is shown that a small gap has occurred between a fiber and matrix.

Although there is the presence of a small gap, which may due to the effect of the processing condition, generally that composite specimen shows good interfacial adhesion. The result is in agreement with the work of Suriani et al. [9]. There was no fracture on the matrix surface, which again points to the strength of the fiber/matrix interface. It was indicated that the loads are well distributed throughout the surface. Fibers are used as reinforcement and the matrix generally performs as a material that binds the fiber together. A good interfacial bond is required for effective stress transfer from the matrix to the fiber whereby maximum utilization of the fiber strength in the composites is achieved [10].

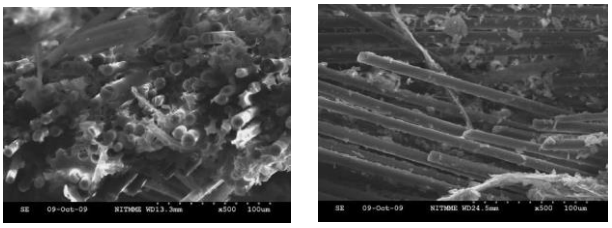

Fig.5. SEM micrographs for G-E laminates with graphite particulate filler fracture after compressive loading: (a)&(b).

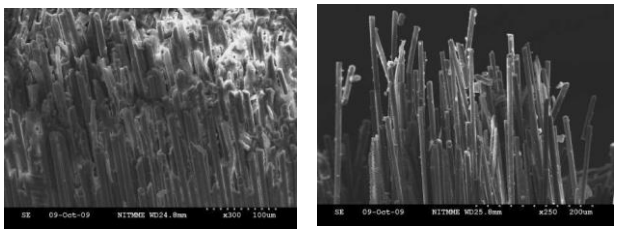

Fig.6. SEM-micrographs for G-E laminates with graphite particulate filler fracture after compressive loading: (c)&(d)

Two modes of fiber breakage were observed in the failed samples. One of them was from the fiber kinking, an example of which can be seen in Fig. 5where the warp tows kinked. This fiber kinking occurred close to the fracture surface, most likely at or near the time of final failure. As the warp fibers kinked, an additional localized load was developed which pushed the broken fibers into the neighboring fill tows (Fig. 6a). Another example of fiber breakage appeared to be a brittle fracture. These fiber fractures were observed at matrix cracks as shown in Fig. 6b, and were more frequent and wide spread than the fiber kinking failures. The final failure of specimen occurred when localized areas of damage merged, increasing the stress on neighboring undamaged areas. The increased stress accelerated the accumulation of damage until the specimen failed.

4. CONCLUSIONS

Compression experiment was conducted on glass/epoxy laminates with graphite particulate filler up to failure. The test results also show that different fracture modes were observed like brittle fracture of the matrix and breaking of the fibers gradually depending on the fiber orientation. An experimental study of the behavior of the bi-woven glass/epoxy laminate subjected to compressive load has been presented. The ultimate load of the bi-woven fiberglass laminate under compression load was found.

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