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Enhancement of Mechanical Properties and Wear Resistance of Epoxy: Glass Fiber, Basalt Fiber, Polytetrafluoroethylene and Graphite

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ABSTRACT
Enhancements of mechanical properties and wear resistance of epoxy using bi-directional fibers (E-glass and basalt) and fillers namely polytetrafluoroethylene (PTFE) and graphite has been systematically investigated in this study. Fiber reinforced epoxy (G-B/E) filled with PTFE and graphite (2%, 4%, and 6%) were fabricated using hand layup technique followed by compression molding. Interlaminar shear strength, tensile, and flexural properties were determined to evaluate the effectiveness of PTFE and graphite fillers on the mechanical properties. The dry sliding wear behavior was assessed by using a pin on disc apparatus under different loads and different sliding distances. Results show that both fillers improved the mechanical properties, and the improvement is more pronounced with the incorporation of graphite filler. The enhanced performance of filler filled G-B/E composites is due to better adhesion and good dispersion of particulates in the epoxy matrix providing increased surface area for strong interfacial interaction and better load transfer. The wear test results indicate that addition of PTFE and graphite in G-B/E hybrid composites have a significant influence on wear behavior under varied sliding distance/loads. Further, it was found that PTFE filled G-B/E composites exhibited lower specific wear rate as compared to unfilled and graphite filled G-B/E hybrid composites. In addition, scanning electron microscopy images of the mechanical test failed specimens of selected specimens have also been reported. The most important concept of this paper is to strength the importance of integrating fibers and functional fillers in the design of wear resistant polymer matrix composites.

Key words: *G-B/E composites, Fillers, Mechanical properties, Wear, Scanning electron microscopy.*

1. INTRODUCTION

Over the past decades, polymer matrix composites are made and most widely used for structural applications in the aerospace, automotive, and chemical industries, and in providing alternatives to traditional metallic materials [1]. The features that make composites so promising as industrial and engineering materials are their high specific strength, high specific stiffness, and opportunities to tailor material properties through the control of fiber and matrix compositions. Composites are developed for superior mechanical strength and this objective often conflicts with the simultaneous achievement of superior wear resistance [2]. As a result of this, these materials are found to be used in mechanical components such as gears, cams, wheels, impellers, brakes, clutches, conveyors, transmission belts, bushes, and bearings. In most of these services, the components are subjected to tribological loading conditions, where the likelihood of wear failure becomes greater.

Basalt is a natural material that is found in volcanic rocks. When used as (continuous) fibers, basalt can reinforce a new range of composites. It can also be used in combination with other reinforcements (e.g., basalt/carbon). Since deep studies on this material are only recent, in the last 10 years, number of researchers has been investigating properties and behavior of various composites made of continuous or short basalt fibers [3-8]. The advantages make basalt fibers a promising alternative to glass fibers as reinforcing the material in composites when considering that the price of basalt fibers lies between that of E and S-glass and that it is continuously dwindling as new market opportunities [9]. Therefore, over the last year's basalt fibers have been studied extensively as reinforcement in thermosetting matrices [10-12]. Fiore *et al*. [13] demonstrate the feasibility of use of basalt fibers in substitution of glass one. To this aim, hybrid composites were manufactured by means of ply substitution techniques and tested by three-point

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bending and tensile tests. Moreover, this solution was then applied to a naval bulkhead demonstrating that, considering costs, environment impact, and mechanical performances, this kind of material could substitute the traditional glass fiber composites in naval application. De Rosa *et al*. [14] confirmed that using the stronger basalt fiber at the top and bottom of the glass laminate improved the post-flexural strength of the hybrids. However, it is difficult to transfer the conclusions from one hybrid to the other, as there is currently no theoretical framework available to assess the importance of the various material parameters.

Apart from fiber reinforced composites, the composites made from both fiber/filler reinforcement performed well in many practical situations. The use of fillers in the matrix provide increasing load withstanding capability, reduced coefficient of friction, improved wear resistance, and thermal properties.

The question of why fibers and fillers usually improve the wear resistance of a polymer matrix has been the subject of intense study in recent years Zhang *et al*. [15] studied dry sliding friction and wear behavior of PEEK and PEEK/SiC composite and concluded that the influences of SiC fillers in the composite effectively reduce the plough and the adhesion between the two relative sliding parts. Suresha *et al*. [16] described the role of SiC and graphite on friction and slide wear characteristics in glass-epoxy composites by adding them separately. They stated that the influence of these inorganic fillers has a significant role in reducing friction and exhibited better wear resistance properties.

This study focuses on the evaluation of the mechanical and dry sliding wear behavior of glass-basalt hybrid fiber reinforced epoxy composite with and without fillers such as graphite and polytetrafluoroethylene (PTFE) (2, 4, and 6 wt.% each).

2. EXPERIMENTAL

2.1. Materials

Two types of reinforcement used in the present study are basalt fabrics, 360 g/m^2, plain-weave (warp 5F/10 mm, weft 5F/10 mm), tex 330, from Nickunj Pvt. Limited, and E-Glass fabric, 360 g/m^2, plain-weave (warp 5F/10 mm, weft 5F/10 mm), tex 330 (Suntech Fibers Ltd.). The matrix used is an epoxy (LY556) is a bifunctional one that is diglycidyl ether of bisphenol-A, and the high-temperature hardener HT972 is a solid, aromatic amine, *viz*., 4,4'-diamino diphenyl methane. The resin and hardeners were kindly supplied by M/s. Huntsman Advanced Materials, Mumbai. The wt.% of glass and basalt fibers in the formulations was varied and is listed in Table 1.

2.2. Preparation of Composite Laminates

The epoxy resin is mixed with the hardener in the ratio 100:28 by weight. Dry hand lay-up technique is employed to produce the composites. The stacking procedure consists of placing glass and basalt fabric one above the other with the resin mix well spread between the fabrics to obtain hybrid fiber reinforced composites. A porous Teflon film is placed on the completed stack. To ensure uniform thickness of the sample a spacer of size 3 mm is used. The mold plates have a release agent smeared on them. The whole assembly is pressed in a hydraulic press at pressing temperature and pressure of 100°C and 0.5 MPa. The laminate so prepared has a size 500 mm × 500 mm × 3 mm was kept it in a hot air oven at a temperature of 120°C for 2 h. To prepare the particulate filled fiber reinforced composites graphite and PFTE powder (average particle size of about 10 μm) is mixed with a known weighed quantity of epoxy resin.

2.3. Mechanical and Wear Characterization

Tensile testing was performed according to ASTM D 638 using a universal testing machine (Kalpak Instruments). The test was conducted at a crosshead speed of 2.5 mm/min at room temperature. Flexural (three-point bending) test was carried out according to ASTM D790. The average of at least five measurements of each laminate sample is reported here. The crosshead speed was maintained at 2.5 mm/min. The interlaminar shear strength (ILSS) was evaluated in accordance to ASTM D 2344. A span-to-depth ratio of 4:1 and a cross-head speed of 2.5 mm/min were used.

A pin-on-disc wear test apparatus was used for the dry sliding wear experiments (as per ASTMG-99 standard). The test was conducted on a track of 50 mm

Table 1: Weight percentage of matrix, fiber, and filler of prepared composites.

Sample code	Matrix wt. %	Fiber wt. %	Filler wt. %
G-E	45	55 (Glass)	-
B-E	45	55 (Basalt)	-
GB-E	45	55 (50 Glass-50 Basalt)	-
GB-E+2 Gr	43	55 (50 Glass-50 Basalt)	2 graphite
GB-E+4 Gr	41	55 (50 Glass-50 Basalt)	4 graphite
GB-E+6 Gr	39	55 (50 Glass-50 Basalt)	6 graphite
GB-E+2 PTFE	43	55 (50 Glass-50 Basalt)	2 PTFE
GB-E+4 PTFE	41	55 (50 Glass-50 Basalt)	4 PTFE
GB-E+6 PTFE	39	55 (50 Glass-50 Basalt)	6 PTFE

PTFE: Polytetrafluoroethylene

diameter for a specified test duration, applied load, and sliding velocity. The surface of the specimen was perpendicular to the contact surface. The surfaces of both the specimen and the disc were cleaned with a soft paper soaked in acetone before the test. The initial and final weights of the specimen were measured by using an electronic digital balance with an accuracy of 0.0001 g. The difference between the initial and final weights is the measure of weight loss. The weight loss was then converted into wear volume using the measured density data. The specific wear rate parameter provides a more comprehensive measure of the wear loss characteristics of the materials.

3. RESULTS AND DISCUSSION

3.1. Mechanical Characterization

Figure 1 shows typical tensile load versus displacement curves of glass fiber, basalt fiber, and unfilled and filled hybrid (glass-basalt) fiber reinforced epoxy composites. Here, the load linearly increased with increasing displacement until reaching failure of all the samples.

From the result, it is observed that basalt fabric type shows an increase of 5% of the tensile strength when compared with glass fabric reinforced composites. Hybridization of glass and basalt fiber (GB-E) showed the tensile strength of 321.8 MPa, which is about 13.5% and 8.5% higher than the plain glass and plain basalt fiber reinforced composites as listed in Table 2. This is due to positive hybridization between glass and basalt and also the better interfacial bonding between the fiber and matrix. Further incorporation of graphite particles into GB-E composite increases the tensile strength and modulus. This may be due to good particle dispersion and strong polymer/filler interface adhesion for effective stress transfer. However, increase in addition of graphite and PTFE content up to 6% weight to the composites the tensile strengths and modulus is found to be less this is due to more filler material in the composites damages matrix continuity, less volume of fiber and more void formation in the composites. Flexural (3-point bending) tests were performed to check the effect of two different filler particles on the stiffness and strength of composites. Figure 2 shows the load-deflection curves of all the prepared samples under flexural loading. From Table 2, it is observed that GB-E composites showing higher flexural strength compared to pure basalt reinforced composites and lower as compared to pure glass fiber composite. This can be explained by the

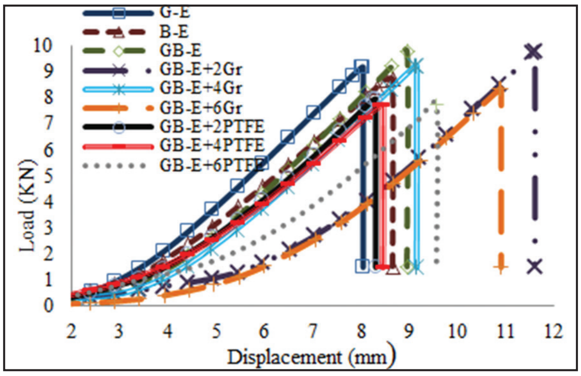

Figure 1: Typical load as a function of displacement of G-E, B-E and unfilled and filled GB-E composites.

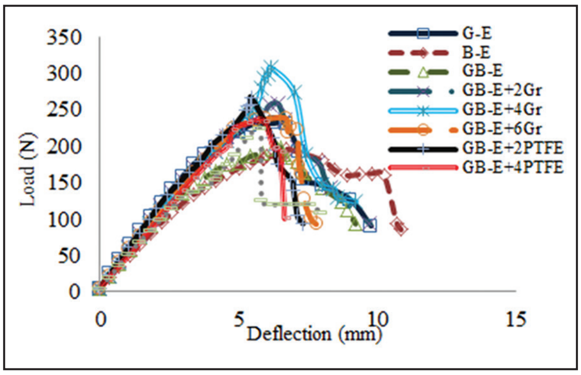

Figure 2: Typical load as a function of deflection of G-E, B-E and unfilled and filled GB-E composites.

Table 2: Mechanical properties of prepared composites.

Composites	Tensile strength MPa	Tensile modulus GPa	Flexural strength MPa	Flexural modulus GPa	ILSS MPa
G-E	283.33	19.6	334	20.9	13.36
B-E	297.15	20.6	244.4	14.7	11.95
GB-E	321.8	21.9	268.4	15.7	13.25
GB-E+2 Gr	335.7	23.3	359.9	23.3	14.2
GB-E+4 Gr	302.01	20.9	364.2	18.8	13.6
GB-E+6 Gr	323.58	22.4	347.8	19.6	13.9
GB-E+2 PTFE	262.6	18.2	304.1	16.7	12.08
GB-E+4 PTFE	266.4	18.5	331.8	22.487	11.79
GB-E+6 PTFE	267.34	18.565	290.3	17.587	8.8

ILSS: Inter laminar shear strength, PTFE: Polytetrafluoroethylene fact that failure in basalt laminates takes place in the compressed half section, while in glass laminates, the whole section is involved in the fracture process up to the tensile face. Similar behavior was also observed by Wittek and Tanimoto [17]. The GB-E with graphite particle composites showed a rapid load rise, the highest maximum load, and catastrophic failure. This means that the composite failed in a brittle manner. On the other hand, the GB-E showed a slow load rise, large yield displacement, and the lowest maximum load. This behavior suggests that the composite failed in a ductile manner because of the high elongation property of basalt fiber.

From the obtained result, it is also observed that addition of both graphite and PTFE filler particles enhances the flexural strength of GB-E composites. Flexural strength of GB-E laminates increased by 34%, 36%, and 30% for incorporation of 2%, 4%, and 6% graphite particles and also it is increased by 13%, 24%, and 8% for increasing wt.% of PTFE in GB-E composites. Graphite particles filled GB-E composite showed the highest improvement in flexural strength from all the samples. The increased flexural properties signify that graphite particles were homogeneously dispersed in the epoxy matrix.

Table 2 shows that ILSS of GB-E composite is higher than that of pure glass and basalt fiber reinforced composites. This confirms that a good bond exists between the two different fibers and epoxy resin. Further with the incorporation of graphite particles in GB-E composite increases the ILSS, but in contrast a decrease in ILSS has been observed with increase in PTFE particles. It shows the better graphite particles dispersion in the epoxy matrix. From among the samples, GB-E+2Gr showed the best result in the improvement of ILSS.

3.2. Wear Analysis

Figures 3 and 4 show the wear volume as a function of sliding distance for unfilled GB-E and Gr and PTFE filled GB-E composites at different loads. Figure 5 is histogram showing specific wear rate (Ko) of unfilled GB-E and Gr and PTFE filled GB-E composites at higher load.

The wear data reveal that the wear volume tends to increase near linearly with increasing sliding distance and strongly depends on the applied load for all the composites tested. It was observed that the wear performance is improved for GB-E composite due inclusion of fillers namely Gr and PTFE. However, the wear performance of PTFE filled GB-E composite showed higher sliding wear resistance. Among the composites studied, the wear resistance trend occurred in the order: PTFE-GB-E > Gr-GB-E > GB–E for two different loads of 10 and 20 N. The variations in

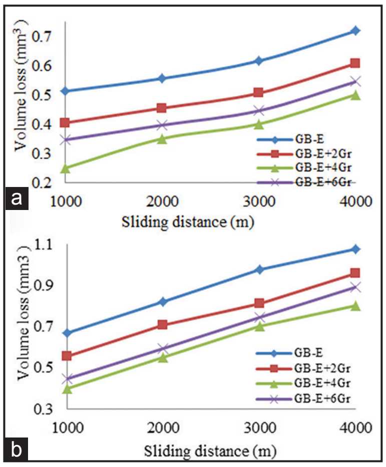

Figure 3: Wear volume loss of unfilled and graphite filled GB-E samples at (a) 10 N and (b) 20 N.

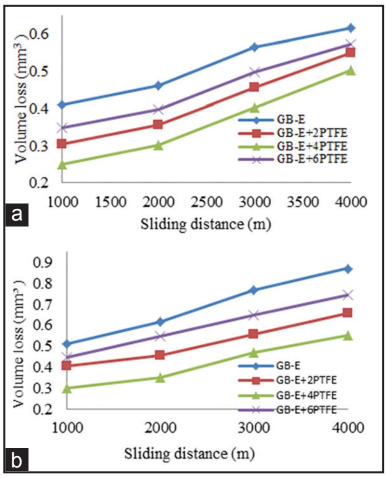

Figure 4: Wear volume loss of unfilled and polytetrafluoroethylene filled GB-E samples at (a) 10 N and (b) 20 N.

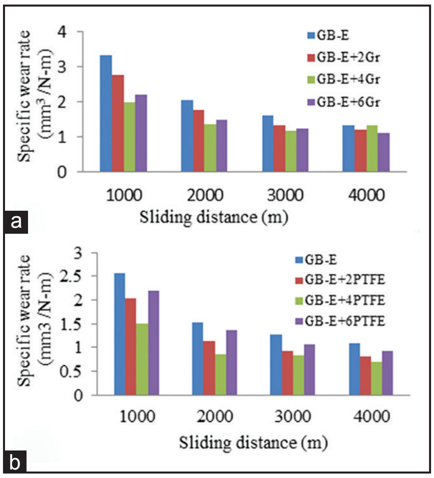

Figure 5: Variation in specific wear rate against sliding distance of unfilled GB-E and filled GB-E composites at 20 N.

the specific wear rate with sliding distance at 20 N load are shown in Figure 5a and b, respectively. The specific wear rate decreases with increasing sliding distance but increases with increase in applied load. The results revealed higher sliding nature of GB-E composite compared to particulate filled GB-E specimens. The phenomenon of a decrease in specific wear rate is due to the nature of microparticles used. In this study, GB-E composite was fabricated by hand lay-up technique followed by compression molding characterized by the resin rich top layer. Sliding wear tests were performed on as cast surface of the composite without disturbing its original surface.

Thus, in the initial stage of sliding, matrix is in contact with steel disc and has less hardness compared to that of hardened steel, resulting in severe matrix damage and the rate of material removal is very high. Similarly, when glass and basalt fibers are in contact with steel disc bi-directional fibers provide better resistance to the process of sliding.

For the purpose of comparison, the specific wear rate of all the samples has been shown in Figure 5a and b. It is seen that the specific wear rate for all the samples is high at lower sliding distance and low for higher sliding distance. This is attributed to the fact that at lower sliding distance low modulus matrix was exposed and at higher sliding distance high modulus fiber was exposed to wear. These exposed fibers, because of their high hardness values, provide better resistance against the sliding. Thus, the rate at which the material is removed with respect to the sliding distance decreases. Higher wear volume was noticed for GB-E composites compared to particulate filled GB-E composites. This is because the hard ceramic particles have high specific modulus compared to glass and basalt fiber and possesses higher hardness. The fillers such as Gr and PTFE was observed to be beneficial to wear performance and 4wt.% PTFE filler filled GB-E composites shows better wear resistance compared to unfilled and filled GB-E composites at two different loads.

3.3. Fractography

The scanning electron microscopy (SEM) micrographs in Figure 6a and b and Figure 7a and b showed the tensile fractured surface of GB-E and GB-E+2Gr composite systems, respectively. The fracture is due to delamination between the layers of the composite samples and fiber-pull out (Figure 6a). The SEM micrograph shown in Figure 6b indicates brittle fracture failure mechanism because as evident from the clean fibers on fractured surfaces. Other important failure mechanisms of composites such as fiber fracture and fiber-matrix debonding are also observed in SEM micrograph (Figure 6b). SEM characterization of the GB-E+2Gr fractured surface (Figure 7a and b) confirmed the presence of graphite particles on the surface of basalt and in the epoxy matrix showing the elemental components of graphite. This is a qualitative indication of a greater interfacial strength between the fiber filler and the matrix (Figure 7b).

4. CONCLUSIONS

Some important conclusions of this investigation are:

- The incorporation of micron-sized fillers improves the mechanical properties such as tensile strength/ modulus and flexural strength/modulus of GB-E composite. The improvement is more pronounced with the combined addition of graphite microfiller into the GB-E system
- The improved results are obtained with 2 wt.% and 6 wt.% of graphite filler loading in respect of tensile and flexural properties of GB-E composites. The tensile and flexural strengths show an increase of 5%, and 35%, respectively

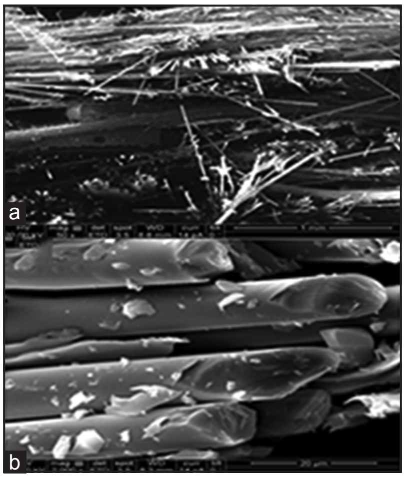

Figure 6: Scanning electron microscopy images of tensile fractured surface of GB-E samples: (a) At ×50 magnification; and (b) At ×2000 magnification.

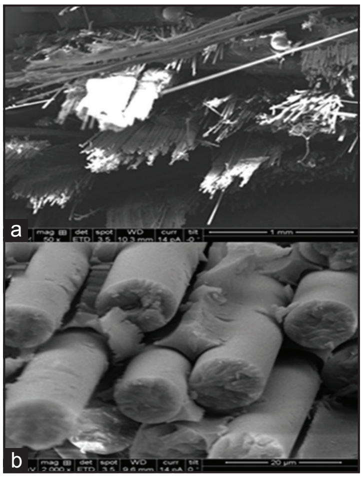

Figure 7: Scanning electron microscopy images of tensile fractured surface of GB-E+2Gr samples: (a) At ×50 magnification; and (b) At ×2000 magnification.

as compared to unfilled GB-E composite. The enhancements in mechanical properties are attributed to the good dispersion of particulates in the epoxy matrix which lead to high surface area for strong interfacial bonding, and better load bearing from hybrid fibers

- Specific wear rate increased with applied load at lower abrading distance and decreased with increasing abrading distance. PTFE filled GB-E composite showed better wear resistance as compared to that of unfilled GB-E and Gr filled GB-E composites
- The wear volume was less in the composite material with 4% PTFE filler as compared to that of graphite. Higher specific wear resistance (30%) was noticed for PTFE-GB-E composite than GB-E composite, due to high strength and good lubricating characteristics of filler.

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***Bibliographical Sketch**

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