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Influence of Zirconia Particles on Mechanical and Dry-Sliding Wear Characteristics of Glass-Basalt Fiber Reinforced Composites

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***Abstract*—Fiber reinforced polymer composites (FRPCs) are utilized as a part of all sort of advanced engineering structures like aircraft, ships, boats and, helicopters, cars, sporting goods, chemical processing equipment etc. In the area of composites the fiber strengthened composite comprising of one fiber is utilized for long time. The outcomes would have showed up for certain region. This is because that utilization of single fiber comprising of restricted property. To beat this issue the utilization of another fiber is made. This outcome as hybrid composites. Hybrid polymer composite material offers the manufacturer to get the required properties by the choice of matrix and fiber. This work concerns the development of glass-basalt hybrid fiber composite with and without Zirconia (ZrO_2) fillers. All the composites were fabricated by hand layup technique. The mechanical characterises such as tensile strength and modulus, three point bending strength and modulus and hardness have been investigated as per ASTM standards. The wear test was done by utilising pin on disc apparatus over various loads (10 and 20 N) and different sliding distances (1000, 2000, 3000 and 4000 m). From the experimental investigations, it has been noticed that loading of ZrO_2 filler to glass basalt hybrid-fiber reinforced composites shows superior tensile and hardness characteristics compared to plain composites. The wear test results shows that addition of ZrO_2 filler in G-B/E hybrid-composites have significant effect on wear characteristics under different sliding distance/loads. Again, it was noticed that 4 weight % of filler loading indicates lower wear as compared to neat GB-E hybrid composites. Scanning electron microscopy (SEM) images of the failure composites revealed various aspects of the failure region. The failure of the tensile and flexure fractured surfaces have also been reported.**

***Index Terms*— Fiber-reinforced polymer composites, Zirconia, Scanning electron microscopy.**

I. INTRODUCTION

Now a days, the researchers are focusing on the invention of new stronger, tougher, lightweight structural materials which aids application on aircraft, automobiles and wind turbine large blade structures [1]. Reinforcing two or more fibers into a single polymeric matrix increases the performance and leads to new system in materials called hybrid-composite material with different material characteristics [2]. This is a

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major challenge that can be met through an understanding of the relationships between materials architecture and mechanical response. The advantages and limitations of fiber hybridization of various mechanical properties for carbon/carbon/epoxy and glass/carbon composites were studied using rule of mixture. None of the mechanical properties, except the fracture energies indicates positive sign of hybrid effect[3]. Manders and Bader [4] noticed the effects of hybridization and strain failure enhancement is upto 50% for the composites glass fiber/carbon fiber/epoxy. The strain failure in the carbon phase elivated as the relative composition of carbon fiber was decreases and as the carbon was more uniformly distributed. Yerramalli and Waas [5] have considered hybrid composite of carbon/ glass with overall fiber volume fraction of 30%. Under the static and dynamic loading rates splitting and kinking failures were noted while loading the hybrid laminates. As a consequence, from past several years basalt is used as reinforcement in thermoset matrix and several work has been done from various authors [6–8]. De Rosa et al. [9] shows that flexural strength of the hybrid composite can be increased by placing basalt fiber at the top and glass fiber at the bottom of the laminate. Apart from fiber reinforced composites, the laminates prepared from both fiber-filler reinforcement performed well in many practical situations. The inclusion of fillers in the resin, shows many combinations that increase load carrying capacity, decreased coefficient of friction, increases wear resistance and thermal properties. Suresha et al. [10] described the role of sic and Gr particles on friction and dry-sliding wear characteristics in glass–epoxy composites by adding them separately. They found that the effect of these fillers shows reducing friction and increased wear resistance characteristics under dry sliding conditions. The current work focuses on the study of dry-sliding wear and mechanical behavior of glass–basalt hybrid fiber reinforced epoxy composite with and without zirconia fillers (2, 4 and 6 wt. %).

II. EXPERIMENTAL

A. Materials

Fibers used in the present study are basalt fabrics, 360 g/m^2, plain-weave, tex 330, from Nickunj Pvt Limited, and E-Glass fabric, 360 g/m^2 , plain-weave, tex 330 (Suntech Ltd.). Table 1 shows the basic mechanical characteristics of used basalt as well as E-glass. The resin adopted in the present study is an epoxy (LY556) is a bifunctional one and the hardener used is HT972 is a solid, aromatic amine. The resin and hardeners were supplied by M/s. Huntsman Advanced Materials, Mumbai. The wt. % of glass and basalt in the final composites were listed in Table 2.

B. Preparation of Composite Laminates

The weight percentage of epoxy resin and hardner used is in the ratio of 100:28. Hand lay-up fabricating method is used to produce the composites. The stacking sequence is placing glass and basalt fibre one over the other with the resin mix well and distributed uniformly between the fabrics to obtain hybrid reinforced composites. A Teflon sheet is applied on the finished laminate. To obtain constant thickness of the prepared laminate, a 3 mm spacer is used. The whole assemblage is appressed in a hydraulic press at exactly pressing temperature and pressure of 100^0 C and 0.5 MPa. The prepared laminate has a size L X B X H, 500mm X 500mm X 3 mm respectively was kept in a hot air oven for 2hours at nearly a temperature of 120^0 C. To obtain particles filled fiber reinforced composites Zirconia powder is mixed with a familiar weighed quantity epoxy resin. The details of the prepared final composites are listed in Table 2.

TABLE I. BASIC MECHANICAL PROPERTY OF THE BASALT AND GLASS

Properties	Basalt	E-glass
Filament diameter (µm)	17	7
Density (g/cc)	2.8	2.54
Tensile strength (MPa)	4800	3200
Elastic modulus (GPa)	90	70
Elongation at break (%)	3.15	4.0
Maximum service temp. (oC)	650	460o C

TABLE II. COMPOSITION OF MATRIX, FIBER AND FILLER OF PREPARED COMPOSITES

Sample code	Matrix wt. %	Wt. %	Filler wt. %
G-E	45%	55% (Glass)	-
B-E	45%	55% (Basalt)	-
GB-E	45%	55% (50% Glass-50%Basalt)	---
GB-E+2ZrO_2	43%	55% (50% Glass-50% Basalt)	2% Zirconia
GB-E+4 ZrO_2	41%	55% (50% Glass-50% Basalt)	4% Zirconia
GB-E+6 ZrO_2	39%	55% (50% Glass-50% Basalt)	6% Zirconia

C. Mechanical characterization

Tensile test was done according to ASTM D 638 using a universal testing machine (Lloyd makers). The composite plates were prepared in the form of dog-bone shape by using water jet cutting machine. Average value of five tested specimens was reported here. The test was done at a crosshead speed of 5 mm/min at room temperature. Flexural (three-point bending) test was done according to ASTM D790. A pin-on-disc wear test setup was used for the dry-sliding wear experiments (asperASTMG-99standard). The test was done on a track diameter of 50mm for a stated test duration, related load and sliding velocity. The specimen surface should be perpendicular to the contact surface. The weight loss of the specimen was measured by using an electronic digital weighing machine with an accuracy of 0.0001g. The weight loss was then converted into wear volume using the measured density data. Fractography examination for the tensile and bending failure specimens were seen using Scanning Electron Microscope (SEM), JEOL model 6390.

III. RESULTS AND DISCUSSION

Tensile strength of the composites depends upon various parameters like the strength of the fiber, strength and chemical stability of the resin, interaction between fiber and matrix and also the fiber length. Fig. 1 indicates line graph of load versus elongation curves of different prepared fiber reinforced laminates. In this case tensile load keep on increases linearly as the displacement increases till fracture of all the samples. As tabulated in Table 3 using both glass and basalt fiber (GB-E) exhibits the tensile strength 240 MPa which is about 6% and 9% greater than the unfilled composites. This is because of positive interaction between glass and basalt and also the good interfacial joining between the fiber and matrix. Further adding of zirconia fillers into GB-E laminates increases the tensile strength and modulus. Inclusion of 6wt. % of zirconia into GB-E composite shows superior tensile strength and modulus compared to all the prepared laminates, this is because uniform particle distribution and good polymer/filler integrated adhesion for efficient stress transfer.

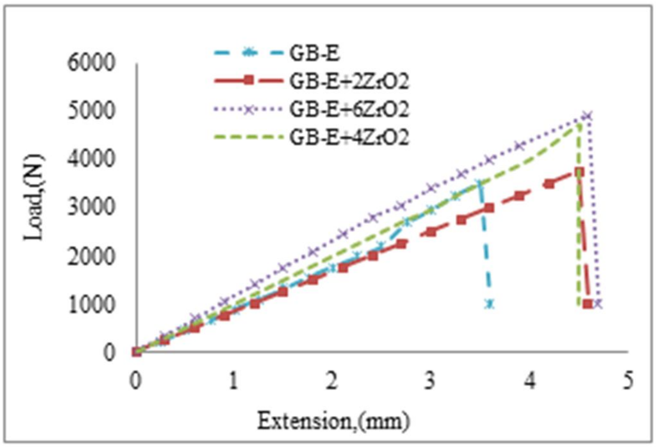

Figure 1. Load v/s displacement of plain and ZrO_2 filled GB-E composites

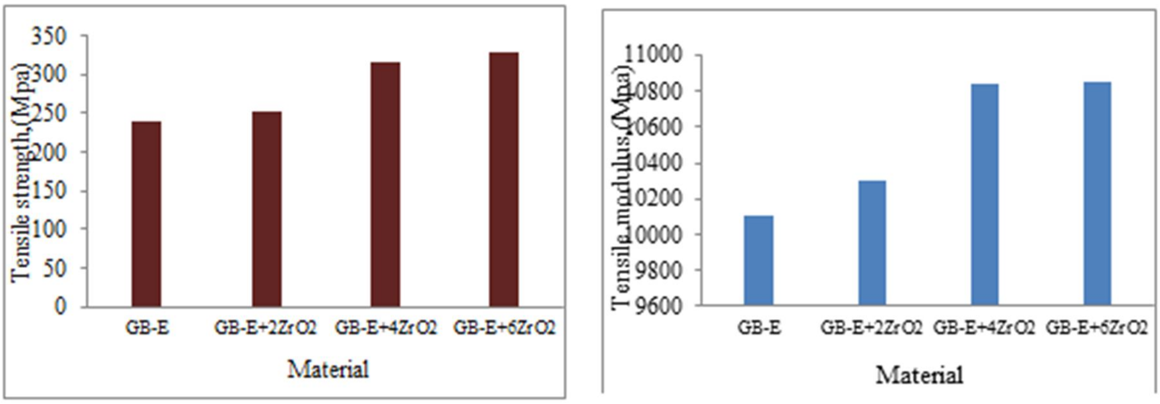

Figure 2(a and b). Tensile strength and modulus of prepared composites

TABLE III. MECHANICAL PROPERTIES OF PREPARED LAMINATES

Composites	Tensile strength MPa	Tensile modulus GPa	Flexural strength MPa	Flexural modulus GPa	Hardness
G-E	230	10.67	198.4	15.4	21
B-E	221	10.63	209.5	16.1	19
GB-E	240	10.8	201	15.7	22
GB-E+2 ZrO2	251.2	11.1	219.8	16.4	23
GB-E+4 ZrO2	315.1	12.4	190.6	18.3	23
GB-E+6 ZrO2	327.6	12.8	194.2	15.8	26

Fig. 3 shows the load-deflection curves of all the prepared samples under 3-point bending load. From the Fig. 4 it is observed that GB-E+2ZrO_2 composites showing major flexural strength comparison to pure basalt reinforced composites and lower compared to higher loading of fillers. This can be explained, because of fracture in basalt composites occurs in the compressed section, while in glass laminates failure occurs in the whole section. Same result was also observed by Wittek and Tanimoto [11]. The GB-E with zirconia particle composites exhibits a sudden load rise, the peak maximum load, and disastrous failure. From Fig. 4, it is also seen that addition of zirconia content up to 6% weight to the composites the flexural strength is low due to large filler in the composites damages matrix continuity, less volume of fiber and increased voids in the composites. Further 2% zirconia grains filled GB-E composite displayed the maximum flexural strength compared to all the samples.

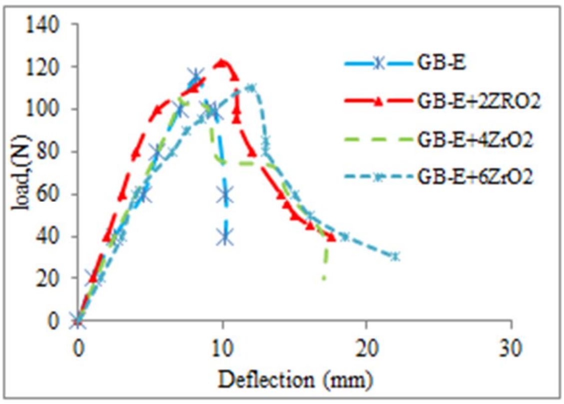

Figure 3. Typical load as a part of deflection of filled and unfilled GB-E composites

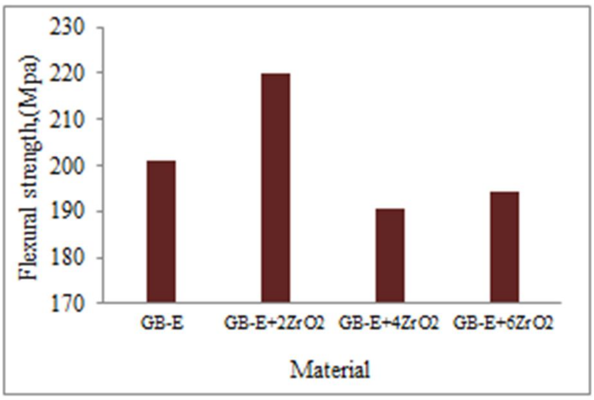

Figure 4. Flexural strength of filled and unfilled GB-E composites

Wear analysis

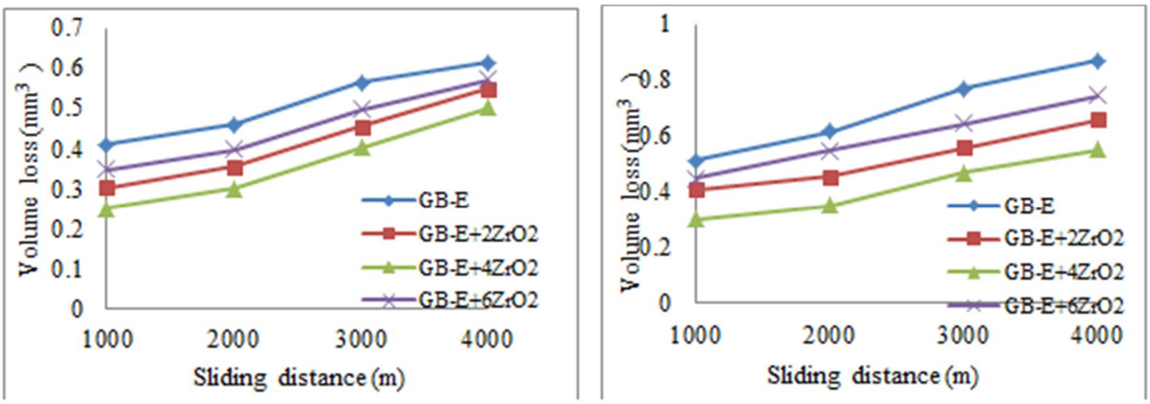

Fig. 5 Wear volume loss of plain and filled GB-E samples at (a) 10 N and (b) 20 N

Figs. 5 (a and b) shows the wear loss versus sliding distance for unfilled and ZrO2 filled GB-E composites at variant loads. From the above graph it can be seen that as the wear loss of all the prepared laminates increases with increase in the sliding distance and also wear volume depends on the applied load. It is seen that wear performance is improved for GB-E composite due insertion of ZrO2 filler. The results shows higher sliding nature of GB–E composite compared to particulate filled GB–E specimens. The phenomenon of reduced in wear rate is because of the nature of microparticles used. In the current study, GB– E composite was developed by hand layup technique followed by compression moulding 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 more matrix damage and the material removal rate is very high.

Fig. 5 (a and b) shows the comparison of wear for all the prepared laminates. It is seen that lower sliding distance shows more wear loss and low for higher sliding distances. This is because of fact that at minimum sliding distance minimum modulus resin was exposed to the steel disc and at major sliding distance maximum modulus fiber, both glass and basalt fiber was exposed to wear. These uncovered fibers, because of their unique properties, provide better resistance against the sliding wear. Thus, wear loss decreases with sliding distance. The ZrO2 filler was inspected to be beneficial to wear fulfilment and 4wt.% ZrO2 filler replete GB-E composites display better wear resistance compared to unfilled and filled GB-E composites at two distinguish loads.

IV. FRACTOGRAPHY

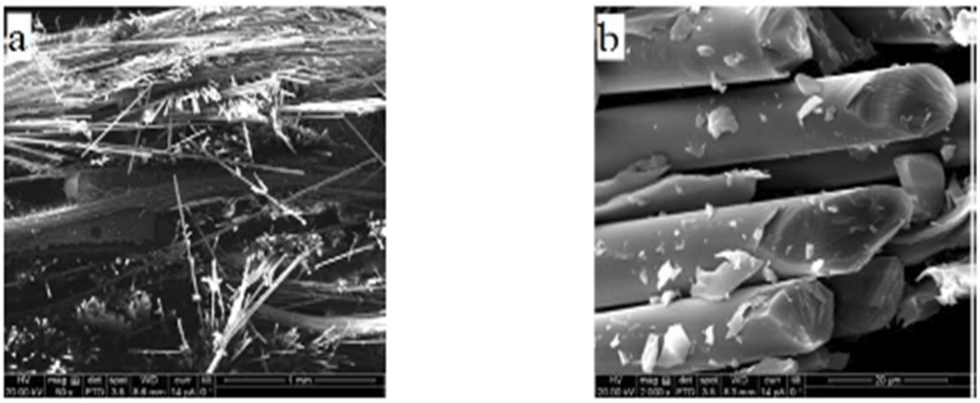

Figure 6. SEM images of tensile fractured surface of GB-E samples: (a) At 50X magnification; and (b) At 2000X magnification

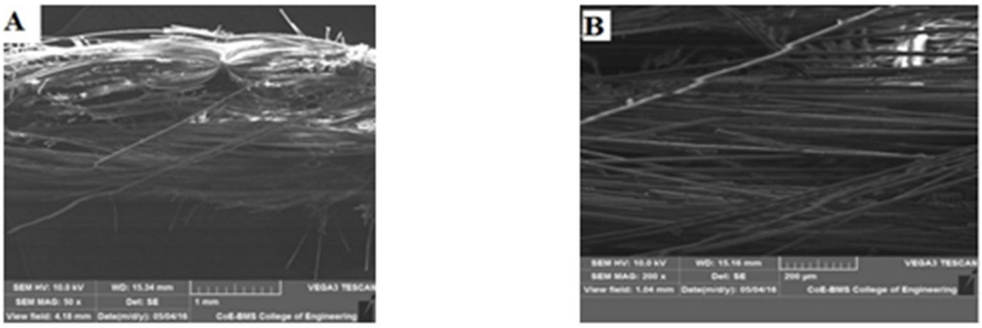

Figure 7. SEM images of tensile fractured surface of GB-E+6ZrO_2 samples: (a) At 50X magnification; and (b) At 200X magnification

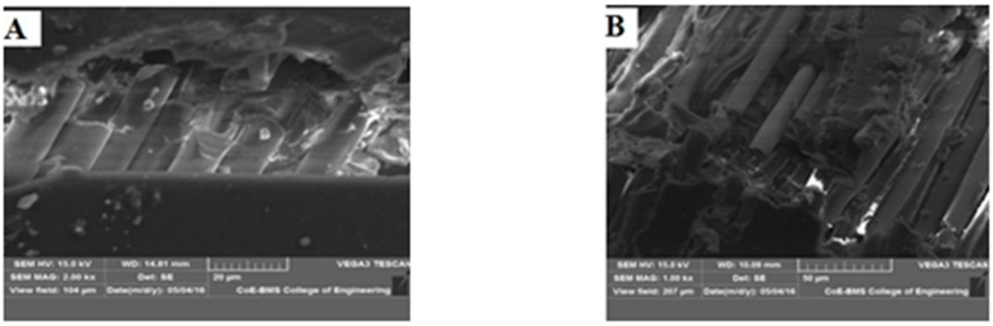

Figure 8. SEM images of flexure fractured surface of GB-E+2ZrO_2 samples: (a) At 50X magnification; and (b) At 200X magnification

The SEM micrographs in Fig. 6(a, b) and Fig. 7(a,b) displayed the tensile fractured surface of GB-E and GB-E+6ZrO_2 composite classifications, respectively. The fracture is mainly due to delamination between the layers of the composite specimens and fiber-pull out [Fig. 6(a)]. The SEM micrograph shown in Fig. 6(b) shows brittle fracture failure mechanism because as a fact from the clear on fractured surfaces. Other critical failure mechanisms of composites such as fiber fracture and fiber-matrix debonding are also observed in SEM micrograph [Fig. 6(b)]. SEM characterization of the GB-E+6ZrO_2 fractured surface [Fig. 7(a,b)] confirmed the presence of Zirconia particles on the surface of basalt and in the epoxy matrix showing the elemental components of Zirconia. Fig. 8(a,b) shows the fracture surfaces of GB-E+2 ZrO_2 of the present samples after flexural test. Some broken are observed in Fig. 8a, which relates to strong interfacial bonding with ZrO_2/epoxy matrix, i.e., less fiber pull-outs. A good bonding between resin and fiber and well impregnated ZrO_2 particles were observed in Fig. 8b. In Fig. 8b good fiber–matrix bonding was observed and the dispersed basalt hindered the crack damage in the matrix and glass from propagating leading to high flexural modulus.

V. CONCLUSIONS

Some important conclusions of this investigation are:
The incorporation of micron sized filler improves the mechanical properties such as tensile strength/modulus, flexural strength/modulus and hardness of GB-E composite. The improved results are obtained with 6 wt % and 2 wt. % of zirconia filler loading in respect of tensile and flexural properties of GB-E composites. The tensile and flexural strengths show an increase of 5%, and 8.5%, respectively as compared to unfilled GB-E composite. The enhancements in mechanical properties are attributed to the good distribution of particulates in the epoxy matrix which gives high surface area for strong inter surface bonding, and improved load bearing from hybrid. Typical failure of unfilled and filled GB-E composites under constant tension and flexure as shown that the fracture is in combination of an extensive amount of delamination, matrix cracking, partitioning of fiber bundles and breakage. However, in particulate filled GB-E composites, the fracture is associated with less matrix cracks, less breakage of fiber and the remains intact due to the good interaction between fillers in the composites.

Wear rate elevated with applied load at starting abrading distance and decreased with ending abrading distance. ZrO_2 filled GB–E composite displayed improved wear resistance as compared to that of unfilled GB-E composites.

The wear volume was less in the composite material with 4% ZrO_2 filler as compared to that of GB-E composites, due to high strength and good lubricating characteristics of filler.

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