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Role of Natural and Synthetic Fillers on Erosive Wear Behavior of Basalt -Epoxy Hybrid Composite

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ABSTRACT*: An investigation was made to evaluate the effect of the incorporation of bio-based jatropha oil cake (JOC), Titanium dioxide (TiO2) and Clay on the erosive wear behavior of Basalt-epoxy (BE) hybrid composites. A Vacuum-Assisted Resin Infusion (VARI) technique was employed to obtain a filled and unfilled B-E composites. The effect of different impact velocities (20 and 40 m/s) and angle of impingement from 30^0 to 90^0 on the performance of the wear resistance of the composites were measured. The results of erosive wear losses, angle of impingement, and impact velocity and erosion rate of 3% of TiO_2 and JOC filled and unfilled B-E composites are analyzed and discussed. The worn surface features of unfilled and filled B-E composites were examined using Scanning Electron Microscopy (SEM).*
Keywords - *Erosive wear, Basalt, Epoxy, fillers, Vacuum Assisted Resin Infusion Technique, Wear Mechanism*

I. INTRODUCTION

Micromechanical interaction between original surface and solid particles causes a local damage of solid surface with progressive loss of materials. The fiber reinforced plastics (FRPs) composite parts, such as helicopter rotor blades, aircraft operating in desert environments, high-speed vehicles, water turbines, pump impeller blades, aircraft engine blades, missile components, canopies, radomes, and wind screens find extensive application in automotive and aerospace sectors. The surface of these composite parts will be impacted by the solid particles contained in the air, and those particles will destroy the original materials [1]. The widespread use of synthetic fiber (glass, carbon and aramid etc.) or synthetic filler (graphite, molybdenum disulfide, boron nitride, titanium carbide, silicon carbide ,Titanium dioxide etc.) reinforced polymer composites has been declining because of their high initial costs, their use in non-efficient structural forms and most importantly their adverse environmental impact. On the other hand, there is an increased use of natural fibers/fillers as reinforcement in plastics to substitute conventional synthetic fibers/fillers in some automotive and aerospace outer body components such as doors, bonnet, fuselage and engine cowling etc. These applications raise main concerns to study the potential of using natural fibers/fillers as reinforcement for polymers [2-4]. N.Mohan et al. [5-6] were studied natural and synthetic fillers in the thermo set polymers exhibit good load bearing capacity and improved sliding and abrasive wear resistance. The wear performance of natural and synthetic filler in glass-epoxy composites in abrasive wear situations were in the sequence is follows: SiC-G-E>JOC-SiC-G-E>JOC-G-E>G-E. In the light of above, the author has focused his attention on natural fibre/fillers in polymeric composites which are biodegradable in reinforced with thermosetting matrix and has considerable potential in the manufacture of composite materials, which is an added reason to investigate natural filler material for tribological applications. Natural fibers like flax, sisal, coir, hemp, etc., are becoming more popular because it has satisfactory strength properties along with a relatively low price and good biodegradability.

A disadvantage of these fibers is that the consistency of the fibers cannot be guaranteed; they are sensitive to the moisture content of the environment, and they do not adhere well to a polymer matrix under moist conditions [7]. Basalt fibers which extracted from common volcanic rock could be a good option for reinforcing with polymer matrices [8]. Its chemical composition is closely similar to glass; its basic components are SiO_2, Al_2O_3, CaO, MgO, K_2O, Na_2O, Fe_2O_3 and FeO [9] The positive features of good physical and mechanical properties, like high hardness, high strength, good wear resistance, color and shine of basalt fibres include sound insulation properties, excellent heat resistance, good resistance to chemical attack and low water absorption makes basalt as a suitable reinforcement for the tribological behavior of composites [10]. Basalt fibers have high chemical stability, non-toxic, non-combustible [11] and resistant to high temperatures .Basalt fibers can be used from $200^0$to 600^0C without any significant loss of mechanical properties [12, 13] .Moreover, their specific mechanical properties are better than, those of E-glass ones. Another important characteristic is the lower cost could make basalt as a suitable reinforcement to replace glass fibres in various transport applications [14]. However, no systematic efforts have been made to evaluate the potential of combination of organic and natural filler in volcanic fibers in multi-component composite materials in this respect. Hence in this work, four materials based on such fiber combinations were developed and evaluated for their erosive wear characteristics.

this research work deals with comparing the erosive wear performance of synthetic and natural fillers in natural Basalt fiber–Epoxy(BE) composites and to explore the possibility of using bio-waste material in epoxy matrix and thus opens new vistas to utilize locally available inexpensive natural jatropha waste product and produce a new candidate for tribo-material. The results and analysis are presented in the subsequent sections.

II. COMPOSITE PREPARATION

2.1 MATERIAL USED:

Basalt woven fabric 360 g/m^2 obtained from M/s. APS Austria. The basalt fabric diameters 18 μm was used as reinforcement. Munltifunctional epoxy-Bisphenol A-epichlorohydrin (MY 740) and cyclo aliphaticamine (HY 951) (room temperature cure system) were obtained from M/s. S& S POLYMERS, Bangalore, India. The resin is a clear liquid, its viscosity at 25^{0}C is 1100 mPa s and density is 1.15-1.20Kg/m^3. The hardener is a liquid and its viscosity is 50–80 mPa s and specific gravity is 1.59. The commercially available TiO2(20-76ηm), Clay(20-36 ηm) powder was procured from M/s Sigma Aldrich, Bangalore, India and JOC(size 50-70 μm)

2.2 FABRICATION OF COMPOSITE:

Known quantity of filler was mixed with epoxy resin using a high speed sonicater for the proper dispersion of filler in the epoxy resin, and then the hardener was mixed into the filled epoxy resin. The ratio of epoxy resin to hardener was 100:30 on a weight basis . A suitable mold was used for the fabrication. Mold was cleaned by using an acetone and it is pre-coated with a releasing agent (suitable wax) to facilitate easier removal of the part from the mold. The required dimension of fabrics is placed on a granite mold. On the top layer of the fabrics, a porous Teflon film and breather were placed. This Teflon film enables separation of the part from the vacuum bag and breather ensures uniform distribution of vacuum. A two sided insulated tape was placed all around the fabrics around the perimeter of the mold, an open spiral tubes were attached and connecting to a vacuum pump, which acts as an air channel from inside the mold when vacuum is applied. Air is evacuated by a vacuum pump and maintained at 0.0965Mpa of pressure, at room temperature up to 24 h. To improve the consolidation and reduces the voids and dry spots, the epoxy resin was manually smeared onto the fabric before going to VARTM. The panels were post cured at 100^{0}C for 3 h in a computer controlled oven.

2.3 TESTING OF COMPOSITE:

The solid particle erosion experiments were carried out as per ASTM-G76 standard on the erosion test rig [15]. The silica sand of size 150–280 μm is used as erodent. The normalized erosion rate (Ws) was expressed in terms of equation (1);

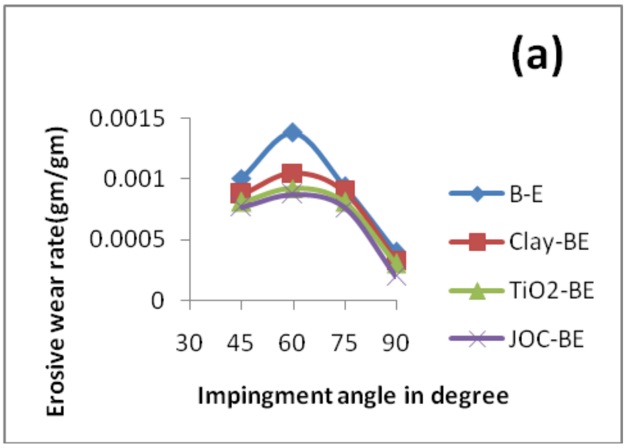
$$W_S = \frac{W_c}{W_{Er}} \; gm/gm \qquad (1)$$

Where, Wc is the loss in weight of the composite material and WEr is the total weight of erodent used for erosion of each specimen. Wc is determined by weighing the sample before and after the erosive wear test using a digital electronic balance, 0.1 mg accuracy. Each erosive wear test was performed twice and average values for wear loss were calculated. The experimental detail is presented in TABLE 1.

The graphical plots of erosion rate versus impingement angles at two different velocities of filled and unfilled composite systems are shown in Figures 1 (a)-(b).

Table 1: Erosion test condition

Test Parameters	
Erodent	Silica sand
Erodent size (μm)	150-280
Impact Velocity(m/s)	20and 40
Impact angle (degree)	45,60,75 and 90
Erodent feed rate(gm/min)	5.5
Test Duration (min)	3
Test temperature	RT
Nozzle to sample distance(mm)	10
Nozzle diameter(mm)	3



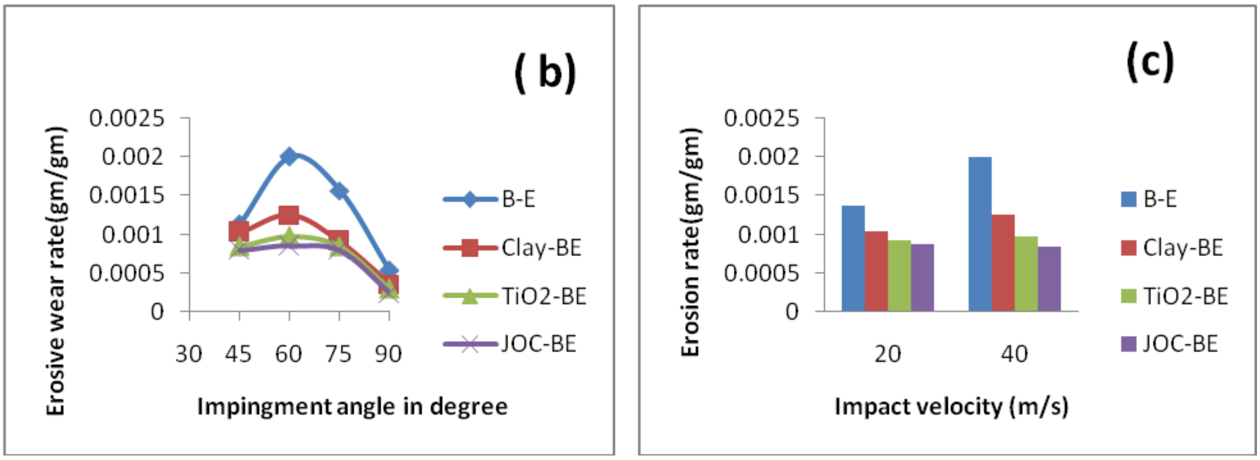


Fig.1 Erosion rate v/s angle of Impingement of composites at (a) V= 20 m/sec and (b) V=40 m/sec (c) Variation of erosion rate as a function of impact velocity at 600 impingement angle

III. RESULTS AND DISCUSSION

From Fig.1, it may be noticed that maximum erosion occurs at 60^0 impingement angle for all the composites tested and material shows semi ductile mode of attack and higher weight loss. Minimum erosion rate is observed at 450 impingement angle with lower weight loss.

From Fig.1c, it is obvious that erosion rate increases with increase in particle velocity. The erosion rate of JOC filled composite shows lower weight loss compared to Clay and TiO_2filled and unfilled composites. However, erosion rate is strongly affected by the variation of impingement angle of the particles and it is observed that erosion resistance offered by different composites is in the order of JOC-BE >TiO_2BE > Clay-BE > BE. The presence of rich ash and minerals in the Jatropha oil cake in BE composites provides good erosion resistance as compared to other synthetic fillers in Basalt-epoxy composites.

The influence of fibers / fillers on the wear resistance of clean polymer is more complex and unpredictable and mixed trends are reported [16]. The JOC filled B-E composite exhibited a low wear volume loss as compared to BE, Clay- BE and TiO_2-BE composite. Due to the presence of a small amount of unrestricted oil in JOC, may have acted as a lubricant and this may be the reason for the low erosive wear loss in JOC filled B-E composite as compared to that of the Clay- BE and TiO_2-BE filled and unfilled composite.

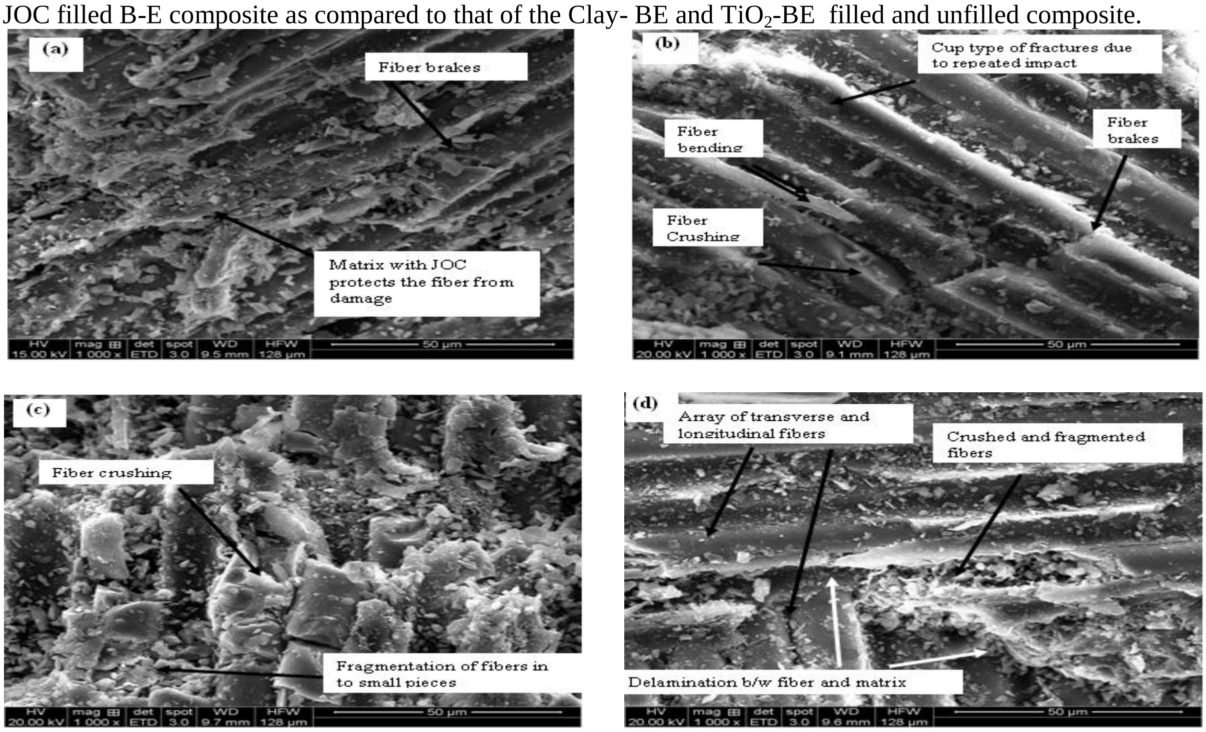


Fig.2 SEM image of eroded surface of (a) JOC-BE, (b) B-E, (c) Clay-BE and (d) TiO_2-BE composites sample

Fig.2a indicates eroded surface of jatropha oil cake filled Basalt-epoxy composites. At initial stage of erosion, there is a local removal of matrix material from the impacted surface, which results in exposure of fibers to the erosive environment, which is due to continuous and repeated impact of solid particles on the surface of the specimen and there is damage to the interface between fibers and matrix. The presence of jatropha particles in the matrix protects the fiber from damage and also resists further erosion. The wear debris consists of jatropha particles, resin matrix, basalt particles, silica erodent on the specimen surface and these mixtures on the specimen surface provide the synergetic effects and resist the erosion of hard silica erodent during erosion. Hence wear rate of JOC filled composites is lower as compared to all other composites.

Fig.2b shows the SEM image of unfilled Basalt-epoxy composites, Due to continuous action of sand particles on the surface of the unfilled composite specimen after local removal of matrix, the indentation of hard silica sand particles into the basalt fibers results in increased fiber fracture. It may be concluded that the effective removal of wear debris and increase in fiber-matrix debonding eventually lead to clean removal of matrix material with cup type of fractured fibers including fiber breaks in bending in the direction of erosion as evidently noticed on the eroded surfaces.

Fig. 2c shows the SEM image of eroded surface of clay-BE composite sample. The fibers have got fractured into small fragments and fiber debris was embedded in the plastically deformed matrix. As compared to JOC filled and unfilled basalt-epoxy composites, clay filled basalt-epoxy composites show more damage, the presence of hard powders in basalt-epoxy composites does not resist hard erodent, hence erosion rate of clay-BE composites is higher as compared to JOC filled and TiO_2filled BE composites.

Fig. 2d depicts eroded surface of TiO_2-BE composite sample. From the SEM image it was observed that after local removal of matrix, an array of fibers is visible, which is due to delamination between fibers and matrix resulting to crushed and fragmented fibers and broken fibers are easily detached from the eroded surface.. The adhering nature of filler in Basalt-epoxy composite does not show any increase in damage of fibers and matrix. A significant difference in damage was observed between unfilled and filled composite however JOC filled hybrid composites shows less damage of fiber and matrix**.**

IV. CONCLUSION

The erosive wear behavior strongly depends on impingement angle and the maximum wear rate is observed at 60^0 impingement angle. Incorporation of natural bio-waste based jatropa oil cake in Basalt-epoxy composite shows lower erosion rate as it restricts fiber-matrix debonding. Composite exhibits semi ductile behavior of erosion.

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