SOLID PARTICLE EROSION OF BASALT FIBER AND GLASS FIBER-EPOXY COMPOSITE

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Abstract- The solid particle erosion behavior of unidirectional basalt and glass fiber reinforced epoxy composites has been characterized. The erosive wear of these composites have been evaluated at different impingement angles (30°-90°) and at three different impact velocities (23, 40, and 61 m/s). The particles used for the erosion measurements were steel balls with diameter of 300-500 mm. The basalt and glass fiber reinforced epoxy composites showed semi ductile erosion behavior, with maximum erosion rate at 60° impingement. As Compared to glass-epoxy composite, the basalt-epoxy composite shows good erosion resistance. The morphology of eroded surfaces was examined by using scanning electron microscopy (SEM). Possible erosion mechanisms are discussed.

Keywords- Basalt Fiber; Scanning Electron Microscopy (SEM); Solid Particle Erosion; Wear Mechanisms.

I. INTRODUCTION

Natural fibers have received great interest as reinforcing material for polymer-based composite because of the environmental issues in combination with their low cost and some intrinsic interesting properties (density, shape ratio, mechanical behavior). Many types of natural fibers like sisal, kenaf, hem, flax, coconut and banana have been studied and applied. However, vegetal fibers are very sensitive to thermal and hygroscopic load and show limited mechanical properties due to the fiber extraction system, the difficulty in fiber arrangement, the fiber dimension and the interface strength. There are situations where these composites may encounter impacts as well as abrasions from dust, sand, splinters of materials, and slurry of solid particles and consequently the material fails due to erosive wear. Examples of such applications are helicopter rotor blade, pump impeller blade, aircraft engine blade, pipeline carrying slurries and structural components operating in the desert environment. A wide variety of methods were adopted to protect materials from the nuisance of wear, including use of efficient materials, processing techniques and surface treatment of the exposed components. The characteristic restrictions of glass fibers such as bio-degradability, specific durability, and low wear resistance paves way for finding an alternate material for developing wear resistance polymers. Least attention has been devoted to the carbon fibers in tribological and mass applications due to its high cost. One possibility for improving the mechanical properties is basalt fiber (BF). BF is colloquially known as the “21st-century nonpolluting green material”. Basalt fiber is a new type of fiber prepared by drawing a natural ore, melted at a high temperature, through a platinum-rhodium alloy. It has numerous raw material sources, is inexpensive, and has excellent properties such as corrosion resistance, minimal moisture absorption and the ability to withstand high temperatures, provide thermal insulation, and absorb sound. Basalt fiber is also a cost-effective and high-strength material that has been widely used in road construction, buildings and other applications that require reinforcement. In general, the positive features of this new generation of basalt fibers include sound insulation properties, excellent heat resistance (better than glass), good resistance to chemical attack and low water absorption. Bin Wei et al mentioned that the interfacial property of basalt fiber-reinforced epoxy composite is better than glass fiber-reinforced epoxy composite even after sea water treatment. Visualizing the importance of polymer composites, lot of work has been done by various researchers. To evaluate the erosive wear resistance of polymers and their composites is therefore of substantial interest. From literature survey, it is evident that very little work has been reported on solid particle erosion studies of epoxy and their composites. The objective of the present investigation was to study the solid particle erosion characteristics of basalt and glass fiber reinforced epoxy composites under various experimental condition. Hence the present work focuses on the comparison of erosive wear behavior of B–E and G–E composite.

II. EXPERIMENTAL DETAILS

A. Materials
Basalt woven fabric 360 g/m² obtained from M/s. APS Austria. The basalt fabric diameters 18 µm was used as reinforcement. A bidirectional E-Glass woven fabric 360 g/m² was procured from M/s. Reva
Composites, Bangalore, India. Multifunctional 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°C is 1100 mPas and density is 1.15-1.20 g/cc. The hardener is a liquid and its viscosity is 50–80 mPa s and specific gravity is 1.59.

B. Fabrication of Composite Specimen

When the composite fabrication consists of mixing a known quantity of filler with epoxy resin using a high speed mechanical stirrer to ensure the proper dispersion of filler in the epoxy resin. The hardener was mixed into the filled epoxy resin using a mechanical stirrer. The ratio of epoxy resin to hardener was 100:40 on weight basis and the epoxy resin was manually applied onto the glass fabric and the resultant composites were fabricated using the VARTM process. The composites were cured at room temperature under a pressure of 14 psi for 24 hrs and it is post cured up to 3 hrs at 100°C. The glass/basalt Fiber to Epoxy ratio was 60:40. The Glass- Epoxy and Basalt-Epoxy composites were designated as G-E and B-E respectively. The laminate of dimensions 300 mm X 300 mm X 2.8 ± 0.2 mm was fabricated and the specimens for the required dimensions were cut using a diamond tipped cutter. Density of the composites specimens was determined using a high precision digital electronic weighing balance of 0.1 mg accuracy by using Archimedes principle.

C. Testing

The solid particle erosion experiments were carried out as per ASTM-G76 standard on the erosion test rig. It consists of air compressor, air drying unit, particle feeder, an air particle mixing and accelerating chamber. Dry compressed air is mixed with the particles, which are fed at a constant rate from a conveyor belt type feeder in the mixing chamber and then accelerated by passing the mixture through a converging nozzle of 3 mm diameter. The velocity of the eroding particles is determined using a rotating disc method. In the present study, silica sand was used as an erodent. Square samples of size 50 mm X 50 mm with 3.0 mm of thickness were utilized for erosion tests. Erosion wear was measured by the weight loss. The normalized erosion rate (Ws) was expressed in terms of Equation (1):

\[ W_s = \frac{W_c}{W_{fr}} \]

where, \( W_c \) is the loss in weight of the composite material and \( W_{fr} \) is the total weight of erodent (silica sand) used for erosion of each specimen. \( W_s \) is determined by weighing the sample before and after the erosive wear test using a digital electronic balance with 0.1 mg accuracy. Each of the erosive wear tests were performed twice and average wear values were calculated. The experimental details are presented in Table 1.

III. RESULTS AND DISCUSSION

The plot of Erosive wear rate as a function of impingement angle of G-E and B-E composites at 23, 40, and 61 m/s are shown in Figs. 1(a), 1(b) and 1(c) respectively. Fig 1(d) shows the variation of erosion rate at 60° impingement angle for the three different velocities. The angle of impingement is usually defined as the angle between the eroded surface and the trajectory of the particle immediately before impact. The most important factors influencing the erosion rate of materials are the impact angle, impact velocity, the size, shape and hardness of eroding particles. In the erosion study, weight loss was measured as a function of impingement angle. Ductile and brittle materials have shown significant difference in their response.

The behavior of ductile materials is characterized by maximum erosion at low impingement angles (15-30°). On the other hand, brittle materials show maximum erosion under normal Impingement angle (90°). Unlike the above two categories, the Reinforced composites are known to exhibit a semi ductile behavior with maximum erosion occurring in the range of 45-60°. A possible reason for the erosion behavior in the present study is that the glass and basalt fibers used as reinforcement for epoxy matrix are typically brittle materials, so that erosion is mainly caused by damage mechanisms such as micro-cracking or plastic deformation due to the impact of silica particle. Such damage is supposed to increase with the increase of kinetic energy loss. According to Hutchings, kinetic energy loss is maximum at an impingement angle of 90°, where erosion rates are maximum for brittle materials. In the present investigation, the peak erosion rate shifts to a larger value of impingement angle due to the brittle nature of carbon and glass fibers. It can be seen that the weight loss was maximum at 60° impingement angle for both materials. This is semi ductile erosion behavior. The erosion curves are similar for both G-E and B-E composite.

The lowest Erosion rate of gm/gm 0.4x10³ and 0.487 x10³ gm/gm was observed at 20 m/s for 30° impingement angle for B-E and G-E respectively and the highest wear volume loss of 5.01 x10³ gm/gm was observed at 60° for 61 m/s velocity of the particle for GE composite. As compared to G-E composites, the B-E composite shows good erosive wear resistance. This may be due to the interface between matrix material and glass fiber that would be mechanically
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Table 1. Erosion Test conditions

<table>
<thead>
<tr>
<th>Test parameter</th>
<th>Angular silica sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erodent size (µm)</td>
<td>150-280</td>
</tr>
<tr>
<td>Impingement angle (degree)</td>
<td>30, 45, 60, 75 &amp; 90</td>
</tr>
<tr>
<td>Impact velocity (m/s)</td>
<td>23, 40 and 61 m/s</td>
</tr>
<tr>
<td>Erodent feed rate (gm/min)</td>
<td>5.5</td>
</tr>
<tr>
<td>Test Duration (min)</td>
<td>3</td>
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<tr>
<td>Test temperature</td>
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</tr>
<tr>
<td>Nozzle to sample distance (mm)</td>
<td>10</td>
</tr>
<tr>
<td>Nozzle diameter (mm)</td>
<td>3</td>
</tr>
</tbody>
</table>

Fig. 1: Erosion Rate versus Angle of Impingement for the composite at (a) 23 m/s, (b) 40 m/s (c) 61 m/s and (d) Variation of Erosion Rate as a function of Impact Velocity at 60° Impingement Angle.

Fig. 2: SEM Images of Eroded Surfaces at a velocity of 23 m/s at 60° Impingement angle.
The worn surface features of the composites were examined using a scanning electron microscope (SEM). SEM approach is an effective approach to probe the wear mechanism of the composites.

The SEM features of the worn surfaces of B-E and GE composite samples for 60° impingement angle at lower and higher velocity are shown in Figs. 2 and 3. Erosion of thermo-set composites is a complex process involving matrix micro cracking, fiber matrix de-bonding, fiber breakage and material removal. At initial stage of erosion, there is a local removal of matrix material from the impacted surface, which results in exposure of fibres to the erosive environment, which is due to continuous repeated impact of solid particles on the surface of the specimen and there is damage to the interface between fibers and matrix.

Fig. 3 shows more damage to the interface between the fibers and matrix. It is observed that there is a separation and detachment of broken fibers from the matrix at higher velocity. In general, fibers in composites subjected to particle flow, break in bending. Because of the good mechanical properties of the basalt fiber, basalt-epoxy composite withstand more bending load. As compared to glass-epoxy composite; the Basalt-Epoxy composites shows less damage.

CONCLUSION

From erosive wear studies of Basalt-Epoxy and Glass-Epoxy composites, it was found that:
1) The influence of impingement angle on erosive wear of both composites exhibited semi-ductile erosive wear behavior with a maximum wear at a 60° impingement angle.
2) In comparison to B-E composite, G-E composite shows less erosion resistance. This may be due to different fiber or interface properties.
3) SEM studies of worn surfaces support the wear mechanisms of exposure of fibers, micro-cracking, micro-cutting and fiber-matrix de-bonding at higher particle velocity.

REFERENCES

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