THE EFFECT OF ADDITION OF NANOFILLERS ON THREE-BODY ABRASIVE WEAR BEHAVIOR OF UNIDIRECTIONAL GLASS FIBER REINFORCED EPOXY COMPOSITES

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ABSTRACT

The Influence of nanofillers on three-body abrasive wear behavior of unidirectional glass fiber reinforced epoxy composites was emphasized using rubber wheel abrasion test rig (RWAT). For better understanding, the glass-epoxy composite with three different nanofillers was used (GE, GE+silica, GE + alumina + silica, GE + silica + alumina + alumina trihydrate). Wear studies were carried out for different abrading distance viz. 250, 500, 750, and 1000 m and 20 and 40 N applied loads using 212 µm silica sand as abrasive. Addition of nanofillers like alumina, silica, and alumina trihydrate increased the wear resistance. Abrasive wear rates were reduced as the abrading distances increased.

Keywords: Glass-Epoxy, Three-Body Abrasive Wear, Wear Volume, Specific Wear Rate.

1. INTRODUCTION

With the development of new and advanced materials, use of polymer matrix composites (PMCs) is becoming more common. Its superior and distinctive qualities such as high specific strength and modulus, good corrosion, thermal and electrical resistance properties enhance its utility in the end applications. Numerous applications have been allocated for these PMCs in automotive and aerospace industries. Therefore, the mechanical and tribological behaviour of these materials should be studied systematically. The five different types of wear are abrasive wear, adhesive wear, surface fatigue, fretting wear and erosion wear [1]. Among the wear types, abrasive wear situation come across in vanes and gears, in pumps handling industrial fluids, sewage and abrasive-contaminated water, roll neck bearings in steel mills subjected to heat, shock loading; chute liners abraded by coke, coal and mineral ores; bushes and seals in agricultural and mining equipment, have been received increasing concentration. Abrasive wear is typically categorized by the contact environment and the type of contact. The contact type defines the abrasive wear mode. In general there are two types of abrasive wear i.e. two-body abrasive wear and three-body abrasive wear.

Many scientists have studied the abrasive wear behavior of polymer based composite materials. Ranganatha et al. [2] investigated three-body abrasive wear of Al₂O₃ filler on carbon fiber reinforced polymer composites. The material used in this study was fabricated by using hand layup technique. They observed that abrasive wear loss decreases with increase in the percentage of alumina to the composites. Ravikumar et al. [3] investigated the effect of particulate fillers on mechanical and abrasive wear behavior of polyamide 66 (PA66)/polypropylene (PP) nanocomposites. All particulate-filled PA66/PP composites were prepared by using twin screw extrusion followed by injection molding. The results indicate that addition of nanoclay short carbon fiber in PA66/PP has significant influence on wear under varied abrading distance/loads. Further, it was found that nanoclay filled PA66/PP composites exhibited lower wear rate compared to short carbon fiber filled PA66/PP composites. In addition, the worn surface morphology of the samples was also discussed. Chand et al. [4] studied the three-body abrasive wear of short glass fiber polyester composite. They observed
that the abrasive wear of the composite shows dependence on all the test parameters like applied load, sliding speed and abrasive particle size. The size of the abrasive particle and applied load tends to increase abrasive wear volume of the composites, whereas wear rate tends to decrease with increasing sliding velocity at constant applied load and particles of size ranging between 200–300 µm. Harsha and Tewari [5] investigated the abrasive wear of glass fiber reinforced polysulfone composites. They observed that their wear resistance deteriorated because of fiber reinforcement. With an increase in glass fiber percentage, the elongation at break decreased. This is a controlling factor for abrasive wear performance. Patnaik et al. [6] investigated parametric optimization of three-body abrasive wear behavior of bidirectional and short Kevlar fiber reinforced epoxy composites. They observed that theoretical values of specific wear rate are calculated based on the given wear model and further compared it with experimental specific wear rate values. The error values for bi-directional Kevlar fiber reinforced epoxy composites lies in the range 0-8%. Whereas, for short Kevlar fiber reinforced epoxy composites error lies is in the range of 0-5%. Suresha et al. [7] studied the Three-body abrasive wear behavior of particulate filled glass–vinyl ester (G–V) composites, observing that abrasive wear volume increases with increase in abrading distance/loads for all the samples. However, the SiC-filled G–V composite showed better abrasive wear resistance. Abrasive wear rate is higher in unfilled G–V composites.

The aim of the present study was, therefore, to investigate the three-body abrasive wear behavior of unidirectional glass fiber reinforced epoxy composite with and without nanofillers (alumina, silica, and alumina Trihydrate).

2. EXPERIMENTAL DETAILS

2.1 Materials

Unidirectional glass fiber reinforced epoxy composites with three different compositions of nanofillers (GE, GE + silica + alumina, GE + silica + alumina+ alumina trihydrate) were fabricated to study the three-body abrasive wear behavior. Manufacturing technique used was pultrusion process. Unidirectional glass fibers were used as reinforcing material and epoxy as matrix. Secondary reinforcements include fillers like silica, alumina, and alumina trihydrate of nanosize and are added to improve the abrasion resistance of the glass-epoxy composite. The compositional details and the final composites manufactured are listed in Table 1.

Table 1: Details of composite materials under study.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Composite designation</th>
<th>Matrix (wt %)</th>
<th>Fiber (wt %)</th>
<th>Filler (wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>GE</td>
<td>Epoxy (30)</td>
<td>Glass fiber (70)</td>
<td>--------------</td>
</tr>
<tr>
<td>02</td>
<td>GEF2</td>
<td>Epoxy (25)</td>
<td>Glass fiber (70)</td>
<td>Silica (2.5) + alumina (2.5)</td>
</tr>
<tr>
<td>03</td>
<td>GEF3</td>
<td>Epoxy (22.5)</td>
<td>Glass fiber (70)</td>
<td>Silica (2.5) + alumina (2.5) + alumina hydrate (2.5)</td>
</tr>
</tbody>
</table>

2.2 Three-body wear test

Three-body abrasive wear tests were conducted as per ASTM G-65 using sand/rubber wheel abrasion test rig (RWAT). The wear behavior mainly depends on type and size of abrading particles, abrading distance, speed of rotation, type of material.

![Photograph of the dry sand/rubber wheel abrasion test rig showing](image)

1) Nozzle, 2) Rubber lined wheel, 3) Specimen, 4) Silica sand, 5) loading arm and 6) deadweights
Tests were conducted at two different loads (20 N and 40 N) under four different abrading distances (250 m, 500 m, 750 m, and 1000 m) and at a constant speed of 200 rpm. Abrading particle used was 212 µm silica sand. Wear was measured in terms of mass loss and was converted to wear volume using density equation. Density of the composite was determined using rule of mixture. Specific wear rates were determined using the equation:

\[ K_s = \frac{V}{L \times D} \left( \frac{m^3}{Nm} \right) \]  

(1)

where, \( V \) is wear volume, \( L \) is the applied load and \( D \) is the abrading distance.

3. RESULTS AND DISCUSSION

3.1 Wear volume

Wear was measured in terms of mass loss and then was converted to wear volume using density equation. Figure 3a and 3b shows the wear volume of unfilled unidirectional glass fiber reinforced epoxy composite and nanoparticles filled GE composites for four different abrading distances (250 m, 500 m, 750 m, 1000 m) at 20 N and 40 N loads, using 212 µm silica sand as abrasive respectively. It is evident from the figures that wear volume increases linearly with increase in abrading distance. As compared to nanoparticles filled GE, unfilled GE composite showed maximum wear volume loss because of debonding at the fiber-matrix interface and fracture of fibers due to continuous sliding and rolling of abrasives [8].

![Figure 3a](image)

**Figure 3a:** Wear volume loss as a function of abrading distance of nanofiller filled GE composites at 20N

![Figure 3b](image)

**Figure 3b:** Wear volume loss as a function of abrading distance of nanofiller filled GE composites at 40N.
In contrast the addition of nanofillers improved the fiber matrix bonding, leading to reduced fiber-matrix interfacial debonding which in turn resulted in low wear volume loss (Figs. 3a and b). This is attributed to better interfacial adhesion between glass fibers and epoxy with nano fillers as compared to the adhesion between glass fibers and epoxy [9].

3.2 Specific wear rate

Figure 4a and 4b shows the specific wear rate for the unfilled GE composite and nanoparticles filled GE composites at 20 and 40 N loads repectively. It is very clear from the graph that irrespective of type of material specific wear rate has been reduced with increase in abradling distance. This is attributed to exposure of fibers to the abrading phase at higher abrading distances.

![Figure 4a](image)

**Figure 4a:** Specific wear rate as a function of abrading distance of nanofiller filled GE composites at 20 N

![Figure 4b](image)

**Figure 4b:** Specific wear rate as a function of abrading distance of nanofiller filled GE composites at 40 N

After the removal of matrix phase, the glass fiber which is harder than that of epoxy matrix offers higher wear resistance resulting in reduced wear rate at greater abrading distances. Maximum wear rate was recorded for the unfilled unidirectional glass fiber reinforced epoxy composite. With the addition of nano fillers like silica, alumina, alumina trihydrate, the specific wear rate of GE composite was significantly reduced. Maximum wear rate was found at 40 N loads. At 20 N load, wear rates were lower and length of scar was short at 20 N compared to scars at 40 N load [13]. Depth and length of the wear scar depends upon the applied load and type of polymeric materials. The wear scar has
three different zones: an entrance zone where abrasive particles first come into contact with specimen, central zone in which abrasive particle may roll as well as slide and an exit zone where abrasive particles leave the specimen. The wear rates of all the polymeric materials decreases with increase in abrading distance. Wear rates of unfilled GE did not show much variation with mass of abrasive at different loads. However, nanofiller filled GE composites (GE+Silica, GE + Alumina + Silica, GE + silica + alumina + alumina trihydrate) showed relatively high initial wear rate when the surfaces were new, and decreases to an almost a constant value with cumulative mass of abrasive.[10-12].

4. CONCLUSIONS

Addition of ceramic nanofillers like silica, alumina, and alumina trihydrate increased the wear resistance of the GE composite. Maximum wear rates and wear volume were recorded for unfilled glass epoxy composite because of fiber matrix interfacial debonding and fracture of unidirectional glass fibers by the continuous sliding of abrasive particles across the surface of the composite. Whereas, uniform dispersion and reduced abrasivity of nanofiller improved the abrasion resistance of GE composite. Wear volume increased with increase in abrading distance and load. Specific wear rate increased with increase in load and decreased with increase in abrading distance. Unidirectional long glass fibers helped in uniform distribution of load throughout the material resulting in steady state abrasive wear, thus leading to reduced wear rate.

5. REFERENCES