ADHESIVE WEAR AND FRICTIONAL BEHAVIOR OF RICE HUSK FILLED GLASS/EPOXY COMPOSITES

Abstract: Low density, high strength and modulus, high corrosion resistance, and self-lubricating properties are the few important properties which make polymer composites a potential candidate for tribological applications. Development of new materials and their tribological study is still being explored to solve many industrial problems. The present research endeavor aims at development of new tribo-material in order to minimize the specific wear rate and coefficient of friction. The present study experimentally explores the wear and frictional performance of glass fiber reinforced polymer composites filled with rice husk. The dry sliding wear tests are carried out on pin-on-disc wear test machine at ambient conditions. Tests are conducted for sliding speeds of 1 and 2 m/s by applying normal loads of 10, 20 and 30 N. The weight loss and friction force is measured by varying the sliding distance 1000 to 3000 m. Further, the worn surface morphology is examined by using scanning electron microscope (SEM) to analyze the wear mechanism.

Key words: Glass/epoxy laminates, Rice husk, Specific wear rate, Coefficient of friction, SEM.

1. INTRODUCTION

The tribological study of polymers is more vital than the metals and alloys because the energy spent during sliding is transformed into heat energy which results in rise in local temperature at the interface of the rubbing surfaces. This temperature rise has a significant effect on the tribological performance of polymer and polymer based composite materials [1-4]. The use of polymer composites cannot be avoided because these materials have superior physical and mechanical properties as compared to the conventional materials [5,6]. These materials can be used in making different mechanical components such as gears, cams, wheels, bearings, bushes and clutches. The study of tribological behavior of such sliding components is highly decisive as wear is a very common phenomenon that can be observed when they are subjected to high load and temperature [7-9]. The wear resistance and coefficient of friction of polymers can be significantly improved by reinforcing fibers. Further the tribological properties of the polymer composites can be notably enhanced by incorporating filler materials. Ahmed et al. [10] experimentally investigated the effect of various ceramic fillers on dry sliding wear behavior of jute-epoxy laminated composites. The results reveal that on addition of small amount of filler materials, the wear resistance of jute fiber reinforced epoxy composite improved significantly. It was also observed that Al2O3 filled composite laminates has better wear resistance than SiC filled laminates. Chauhan et al. [11] conducted experiments to study the tribological performance of pure vinylester, glass fiber reinforced vinylester and glass fiber reinforced vinylester filled with SiC under dry and water lubricated sliding conditions. Their results show that on incorporation of glass fiber and SiC particles to the vinylester polymer, the wear characteristics enhanced considerably in both dry and water lubricated sliding conditions. Srivastava and Wahne [12] found that the particulate fillers significantly improve the mechanical properties and as well as wear resistance of the E-glass fiber epoxy composites. This is because fillers in particle form enrich the bonding strength between the fiber and the epoxy resin. Moreover, addition of filler materials in different weight fractions has a notably significant effect on reducing wear and frictional properties of the random E-glass fiber composites.

Due to the growing environmental awareness, the use of lignocellulosic materials such as rice husk, wood flour, jute, sisal, nettle and bagasse has grown tremendously [13-15]. Furthermore, these materials...
introduce some advantages over conventional materials which include low density, low cost, non-abrasive properties, reasonable strength, biodegradation and renewable nature. Easy availability and high silica content are the two main factors which has attracted many researchers to study the tribological property of rice husk filled polymer composites [16]. The major constituents of rice husk are 32% cellulose, 21% hemicelluloses, 22% lignin and 15% mineral ash. The mineral ash comprises of 96.34% SiO₂, 2.11% K₂O, 0.45% MgO, 0.2% Fe₂O₃, 0.41% CaO and 0.08% MnO₂ [17]. Moreover, rice husk is a low-cost bio-based by-product which is one of the major agricultural wastes for the agro processing industry. The large amount of production of rice which is approximately 600 million tons per year is the only source of production of such waste material. The amount of production of rice husk waste depends upon the production of rice which is nearby 20 wt.% of the total amount of rice production [18]. The literature confirms many applications of rice husk such as electricity generation, particle boards, light weight concrete, rice husk fueled steam engines, building materials, as filler material in various polymers, but, its tribological investigation is on nascent stage [19]. The studies on rice husk filled glass-epoxy composites for improving the specific wear rate and coefficient of friction (COF) are scanty. Therefore, an attempt has been made in the present work to improve the tribological behavior of glass/epoxy composites by using rice husk as the filler material.

2. MATERIALS AND METHODS

2.1 Tribo Materials Used

Composite laminates were prepared by conventional hand lay-up technique in chrome plated mild steel mold (560 mm × 460 mm) at room temperature. The mold is specially designed to produce 4 mm thick laminate sheet. The laminates possess six layers of woven boron free EC-R glass fiber mats of 610 GSM manufactured by Owens Corning Fiber Glass, USA. Epoxy resin LY556 and hardener HY 951 were used as the matrix materials. The resin and hardener is mixed and stirred mechanically in a ratio of 10:1 by weight. The rice husk is used in a proportion of 5% of the weight of glass fibers, whereas, the weight percentage of glass fiber varies in the range of 50 - 55 %. The length of the rice husk filler varies from 4-5 mm. Specimens of suitable dimension are cut using a diamond cutter. The specimens of size 30 × 10 × 4 mm³ were prepared for the test.

2.2 Test Procedure

Dry sliding wear test is conducted on a pin-on-disc wear tribometer (Ducom India TR20LE) as per ASTM G 99. The counter body is a disc (140 mm × 8 mm) made up of ground hardened steel (EN-31, 64 HRC, average surface roughness, Ra = 0.361 µm). The contact surface of all specimens is polished with an emery paper of 800 grit size to ensure proper intimate contact between the specimens and counterface. Before the test, both the rotating disc and specimens are cleaned with acetone. The average surface roughness value of sliding surface of the specimen was Ra = 1.1 µm. The surface roughness of the specimen is measured by using Mitutoyo SJ-401 surface roughness tester. The weight of the specimens is measured by using high precision electronic balance Shimdzu-AUW220D with an accuracy of 0.0001 g.

Wear tests are performed on pin-on-disc tribo-test machine (Figure 1). Tests are conducted at varying sliding speeds (1, 2 and 3 m/s) under applied normal loads of 10, 20 and 30 N and sliding distances of 1000, 2000 and 3000 m. The weight difference is measured before and after the test for all specimens. The weight difference gives the weight loss of the composite specimen during a particular sliding experimentation. The wear performance is expressed in terms of specific wear rate. The specific wear rate, Wr of the specimens can be calculated using equation (1). Each value reported is the average of three specimen tests.

\[ W_r = \frac{\Delta w}{(\rho DFN)} \]  
(1)

Where, \( \Delta w \) = Mass loss during test duration (gm); \( \rho \) = Density of the specimen (gm/mm³); \( D \) = Sliding distance (m); and \( F_N \) = Applied normal load (N).

As the disc starts rotating, rubbing starts between the specimen and the disc, the control unit continuously monitors the friction force. The value of the friction force is recorded to compute coefficient of friction, by using equation (2).

\[ \mu = \frac{F}{F_N} \]  
(2)

Where, \( F \) = Measured frictional force (N); and \( F_N \) = Applied normal load (N).

2.3 Worn Surface Analysis

The worn surface morphology of the specimens is examined by using scanning electron microscope (LEO 435VP). The electrical conductivity of the specimen is enhanced before the photomicrographs are taken. To enhance the conductivity, a thin film of gold is coated.
using sputter coater (BALTEC SCD 005).

3. RESULTS AND DISCUSSION

3.1 Specific Wear Rate

The variation of specific wear rate with applied normal load, sliding distance and sliding speed is presented in Figures 2-4. Figures 2-4 reveals that specific wear rate decreases with an increase in applied normal load for all the specimens. However, specific wear rate initially increase with sliding speed and drops beyond sliding speed of 2 m/s. The results also depict that the highest specific wear rate is obtained at sliding speed of 2 m/s under the applied normal load of 10 N and sliding distance of 1000 m. The highest specific wear rate is measured with a value of $11.48 \times 10^{-8}$ mm$^3$/N-mm. The lowest specific wear rate measured is $1.28 \times 10^{-8}$ mm$^3$/N-mm which is obtained at a sliding speed of 3 m/s and sliding distance of 3000 m on application of 30 N normal load. It has also been observed that the specific wear rate increases at the beginning of the experiment. This is probably due to the fact that initially only the specimen and rotating disc are in contact with each other which results in asperities physically interlocking into the crevices. Now, as the disc starts rotating, even on application of small amount of load, the asperities deform plastically due to shearing. As a result, weight loss is too high at the starting of the experiment. The specific wear rate gradually drop-down with an increase in applied normal load because as the normal load increases the pressure at the interface of specimen and counterface becomes high. Due to this high pressure the debris deposited on counterface transferred back onto the specimen rubbing surface which act as a shield and protect the specimen from severe wear. Moreover, at higher load the film generation is more frequent when compared with low load application. Apart from this, sometimes fillers decompose and produce some reaction products which improve the bonding between transfer film and counterface and hence enhance the wear resistance [20]. A similar finding is reported by Yousif [21] where the wear characteristic of the neat polyester is highly improved by reinforcing coir fibers under dry sliding condition. The identical specific wear rate behavior is observed when sliding distance vary from 1000 to 3000 m for all specimens under various loads and sliding speeds. The specific wear rate increased when the sliding speed is increased from 1 m/s to 2 m/s and then decreases in spite of increase in sliding speed for sliding distance of 1000 m and 2000 m. The wear rate increases with the sliding speed because at higher speed, disc rotational speed becomes high which results in high temperature generation at the interface. When the temperature reaches to the softening point of polymer, fiber-matrix and filler-matrix debonding starts which in turn results in easy shearing of fiber or filler. But the specific wear rate reduced when sliding speed is increased from 2 m/s to 3 m/s because at this speed range, the formation of film transfer layer is very fast which finally stick to the specimen mating surface. The highest wear loss for specimen was observed at sliding speed of 2 m/s, applied normal load of 10 N and sliding distance of 1000 m, which is 9.8% and 7.9% higher when compared with sliding speed of 1 and 3 m/s under the same load application.

![Fig. 2. Variation of specific wear rate with input parameters for sliding distance of 1000 m.](image1)

![Fig. 3. Variation of specific wear rate with input parameters for sliding distance of 2000 m.](image2)

![Fig. 4. Variation of specific wear rate with input parameters for sliding distance of 3000 m.](image3)

3.2 Co-efficient of Friction

In order to study the frictional performance of the developed composites lainates, the average coefficient of friction ($\mu$) is plotted against the applied normal load under different sliding velocities and distances. The friction force is measured by transducer mounted on the lever arm. Friction force data are recorded by using a microprocessor controlled data acquisition system. The friction force is recorded periodically after every 30 seconds during the sliding test. The average coefficient of friction for all specimens decreased with an increase
in applied normal load for sliding speed of 1 and 3 m/s as presented in Figure 5 to Figure 7, respectively. But, at sliding speed of 2 m/s specimen experienced an opposite trend in coefficient of friction with increase in applied normal load. The higher value of coefficient of friction with normal load is attributed to the formation of high amount of debris and exposure of fiber and filler materials. The other factors that may result in higher value of coefficient of friction are embedding of filler particles at the interface between the specimen and counterface, rubbing of third body particles, rupture due to irregular surfaces and delamination due to sticking of filler particles. To clarify the decreasing trend of coefficient of friction, it is observed that increase in normal load leads to rise in temperature at interface of the rubbing surfaces (specimen and counterface). Again, this increased temperature causes thermal degradation of polymer because polymers become soft with rise in temperature. This type behavior of polymer matrix results in weaker adhesive bonding between fibers/fillers and polymer, which in turn results in formation of back film transfer and smooth shearing of fiber or filler. These are the few common causes of decrease in coefficient of friction. The least value of coefficient of friction recorded is 0.17 which is obtained at sliding speed of 3 m/s, applied normal load of 30 N and sliding distance of 1000 m.

Fig. 5. Variation of coefficient of friction with input parametrs for sliding distance of 1000 m.

Fig. 6. Variation of coefficient of friction with input parametrs for sliding distance of 2000 m.

Fig. 7. Variation of coefficient of friction with input parametrs for sliding distance of 3000 m.

3.3 Scanning Electron Microscopy

Figures 8-10 represents the morphology of the worn surfaces at different normal loads for sliding speed of 1 m/s and sliding distance of 1000 m. Figure 8 manifest severe wear loss at applied normal load of 10 N, where fiber fracture, matrix breakage and debris formation are the common damage forms. Moreover, filler pull out is detected which appeared as deep grooves in the SEM image. Figure 9 indicates the surface morphology of the worn sample where less damage is observed in terms of debris formation and fiber fracture that is obtained at applied normal load of 20 N. Figure 10 shows surface damages of the specimen when specimen is subjected to 30 N load. A mild wear is observed at higher load application which includes back film transfer, microcracks and patches of thin polymer film that is formed over the fibers due to plastic deformation of polymers which shields the composite surface and contributes to higher wear resistance. Tayeb et al. [22] found that deposition of fiber fragments on soft polyester might be the one reason of lower mass loss of chopped glass fiber reinforced polyester while sliding in anti-parallel orientation.

Fig. 8. SEM micrograph of the worn specimen under a constant applied normal load of 10 N, sliding speed of 1 m/s and sliding distance of 1000 m.
Fig. 9. SEM micrograph of the worn specimen under a constant applied normal load of 20 N, sliding speed of 1 m/s and sliding distance of 1000 m.

Fig. 10. SEM micrograph of the worn specimen under a constant applied normal load of 30 N, sliding speed of 1 m/s and sliding distance of 1000 m.

4. CONCLUSIONS

In the present study, friction and wear performance of glass fiber reinforced polymer composites filled with rice husk is experimentally investigated. From the results and discussion the following conclusions can be drawn:

1. The specific wear rate of the rice husk filled glass-epoxy composites decreased with increase in applied normal load. The lowest specific wear rate for rice husk filled laminate composite reported with a value of $1.28 \times 10^{-8}$ mm$^3$/N-mm which is obtained at applied normal load of 30 N, sliding speed of 3 m/s and sliding distance of 3000 m.

2. The coefficient of friction for all the specimens decreased with increase in applied normal load except at sliding speed of 2 m/s. The minimum coefficient of friction calculated is 0.17 that can be found at applied normal load of 30 N, sliding speed of 3 m/s and sliding distance of 1000 m.

3. The worn surface morphology of the specimens displayed that back film transfer and debris formation are the main reasons of low wear rate. The debonding of fibers, matrix cracking, fiber breakage and ploughing in the resinous region are also observed.

4. Results show that the wear properties of the developed composites are much more profound to variation of applied normal load than the sliding speed.

5. REFERENCES


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