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Friction and Wear behavior of Glass Fiber Reinforced Polymer Composite (GFRP) Sliding under Dry Environmental Condition with Variable Parameters

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Abstract—*This paper presents the friction and wear behavior of GFRP (glass fiber reinforced polymer) composites fabricated by vacuum bagging process (glass fiber reinforced with bis phenol epoxy resin). Composites were experimentally investigated under dry sliding environment. Wear tests were conducted on a pin on disc type tribometer and EN31 steel as counter body sliding under dry environment ,the loads and sliding velocities varied from 40 N to 120 N and 2.5 m/s to 3.14 m/s respectively. A complete distance of 1.507 km and 2.827 km was attained. Experimental results depict that coefficient of friction and rate of wear increases with increase in velocity and normal loads for dry environment. Results also shows wear rate increases with increase in sliding distance. FESEM analysis of the worn surfaces reveals that the high wear in dry environment results from an easy separation of fibers from the polymer matrix under high friction which leads to bending of fiber at the end.*

Keywords*: Tribology, Sliding Wear, Polymer Matrix Composite, Wear resistance.*

1. INTRODUCTION

There is tremendous use of composite materials since ancient times. Almost in every industry composite plays an important role ,it is mainly used in automobile and aircraft industries for manufacturing of various products [1] and some of these do require an understanding of their tribological characteristics also. Composites are more preferred over other materials due to their higher strength to weight ratio and other characteristics.

Epoxy when reinforced with glass fiber and mixed with hardener enriches the properties of epoxy, yet the glass-fiber-reinforced polymer (GFRP) category needs more and more research for enhancing its usage in light of its promise in terms of engineering application capabilities[2]. Being comparatively of lower density and easily shapeable these may be prepared into different sequences of stacking to attain high strength and stiffness for heavy loadings [2-3]. Some additional mechanisms noted are fiber pull out, pealing of the resin, matrix wear associated to fiber separation, deformation of the edges of the wear track and shear deformation of the fibers. Prior research by other investigators has shown that when the polymer resins are reinforced with glass, carbon or any other fiber, the wear rate depends on various parameters like size, shape, materials etc[4].

2. EXPERIMENTAL DETAILS

2.1 Composite fabrication

Composite specimens were prepared using glass fibers and epoxy resin matrix material, (Epoxy resin L-12 and Hardener K-6. GFRP is a good engineering material with high impact strengths; moldable, high strength to weight ratio and that is also desirable in commercial applications due to lower cost.

The GFRP epoxy resin composite plates having dimensions 270mm×320mm×4mm were prepared by the vacuum bagging process (Fig.2). To attain 4 mm nominal thickness, eight layers of glass fabric were used. We used a stacking sequence, $[0^\circ/ \pm45^\circ/ 90^\circ]_s$. During wear and friction experiments the surface which was in contact with steel disc having a 0° fiber orientation.

2.3 Experiment

Sliding Friction and wear tests were performed using pin on disc apparatus (Make: Ducom, Bangalore, India).Counter disc used was steel disc of EN31 hardened to 60HRC having Ra values between 0.2 to 0.3.The loads and sliding velocities varied from 40N to 120N and 2.5m/s to 3.14m/s respectively. A complete distance of 1.507km and 2.827km was attained with two different speeds and track diameter. All sets of experiments were conducted two times in the same manner and average weight loss was taken for calculation of specific wear rate.

$$K_0 \text{ (mm3/Nm)} = \Delta m/\rho L d \qquad (1)$$

Where Δm is the weight loss in kg, ρ the density in kg/mm3, L the load in N and *d* the sliding distance in m(Table 1 &2)

Table 1

$\rho=1.7842\text{x}10^{-6}$ kg/mm^{3,}N=600 rpm

ΔT=600sec,track dia = 80 mm, v=2.5133 m/s

Load (N)	Weight loss (Δm)	Sp. Wear rate (k_0)	Coefficient of friction
Dry 40	2.34 mg	1.99 x10^{-5}	0.21
Dry 80	5.57 mg	2.51 x10^{-5}	0.24
Dry 120	9.8 mg	2.98 x10^{-5}	0.40

Table 2

GFRP specimen $\rho=1.7842\text{x}10^{-6}$ kg/mm^3 ,

N=600 rpm , ΔT=900sec, v=3.1416 m/s

LOAD	WEIGHT LOSS(Δm)	Sp. Wear rate(k_0)	Coefficient of friction
Dry 40	5.5 mg	2.99 x10^{-5}	0.20
Dry 80	15.3 mg	3.25 x10^{-5}	0.24
Dry 120	28.7 mg	5.02 x10^{-5}	0.38

3. RESULTS AND DISCUSSION

3.1Wear and friction properties

Weight loss: Normal load, sliding distance and velocity of sliding are the main variables affecting the weight loss and friction. The weight loss in GFRP composite specimens was measured at 2.51 m/s and 3.14 m/s speeds and under 40N-120 N loads on dry environmental condition. The weight loss for all the composite specimens normally increased with the increase of normal loads at both of the constant sliding speeds of 2.51 m/s and 3.14 m/s, when the values of normal loads were increased from 40 to 120 N as can be easily seen from Fig. 1(a) and 1(b).

During experiment it was observed that the specimen temperature had also increased with increase in normal load. Glass fibers embedded got more easily separated from the surface of the samples, and as a result, the weight loss increased with an increase in load and sliding speeds.

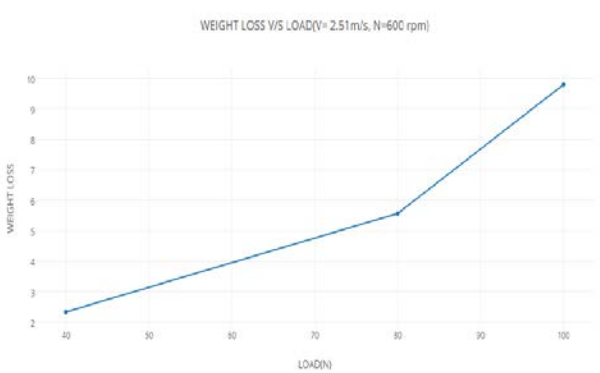

Fig. 1(a)

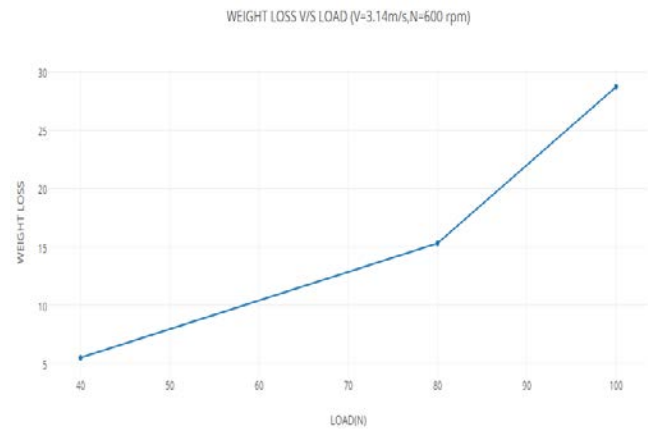

Fig. 1(b)

Specific wear rate:

The wear mechanism of GFRP composite has two modes: the polymer matrix wear, which include matrix plastic deformation and cracks in the matrix and the fiber wear, which involve fiber sliding wear, fiber cracking, fiber rupture, and fiber pulverization.

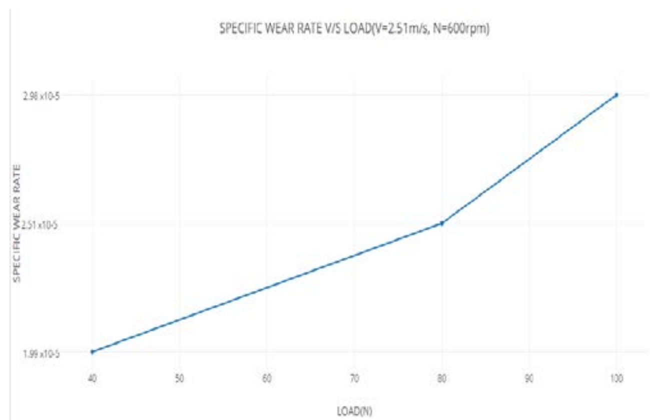

Fig. 2(a)

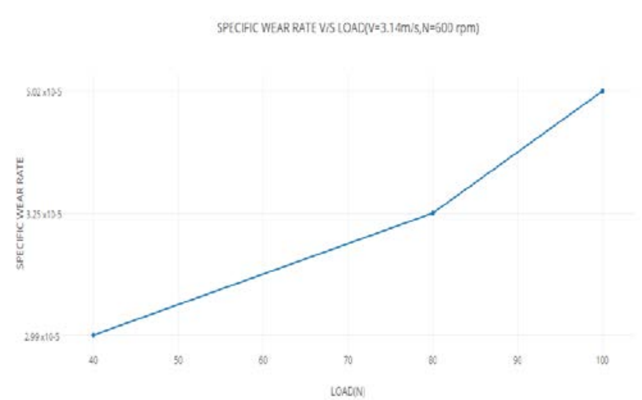

Fig. 2(b)

Coefficient of friction:

The obtained results of coefficient of friction are plotted in Fig. 7(a) and (b). The figure shows the deviations of coefficient of friction (average value at each experimental situation) with load and velocity of sliding under dry environmental conditions. Generally the coefficient of friction always increases if there is an increase in both load and sliding velocity. In dry sliding the relative motion of the mating surface does not permit the released soft debris (as in the inert gas sliding) to move out of the contact area. Up to a certain extent it allows a consecutive gathering of these wear debris over the contact surface of the GFRP laminate. Such wear debris is entrapped in between successive layers of composite.

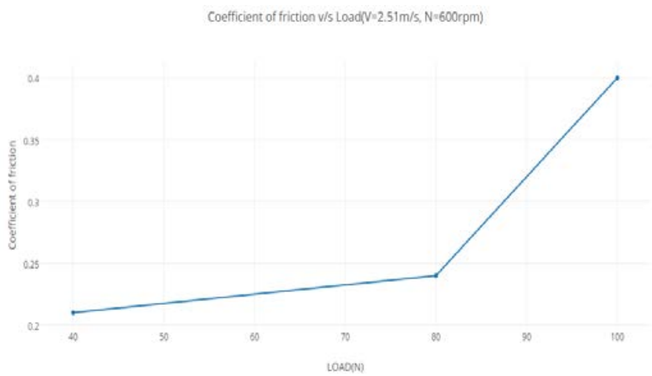

Fig. 3(a)

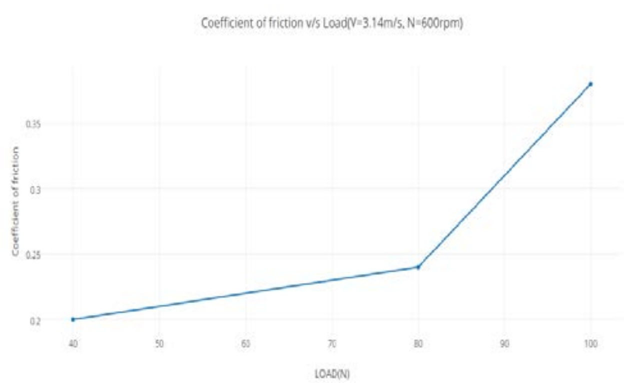

Fig. 3(b)

3.2 FESEM analysis of worn surface

Worn surfaces of composite samples were studied by FESEM analysis primarily to understand and get insights into the process of wear. The effect of normal load and sliding velocity were seen from the microscope and the level of damage was analyzed. Fiber and matrix damage increased with increase in normal load on fibers and could be well correlated with wear performance. It could be observed systematically that how wear thinning of fibers (which is responsible for wear resistance of composites) diminished with increase in normal load and how fiber fracture and random dispersion of fiber debris increased with increase in normal load.

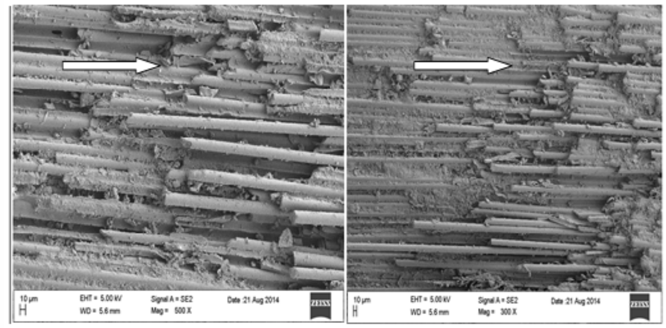

Fig. 8 (a): Worn surface sliding dry at sliding velocity 3.14 m/s under 40 N normal load.

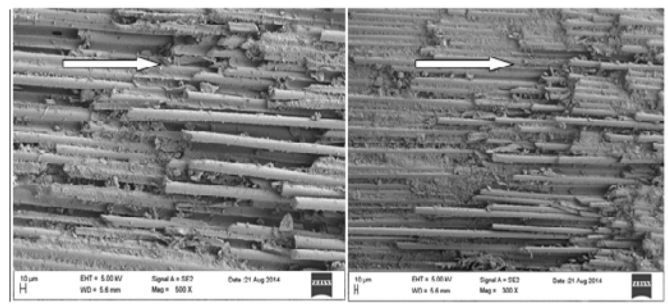

Fig. 8 (b): Worn surface sliding dry at sliding velocity 3.14 m/s under 80 N normal load.

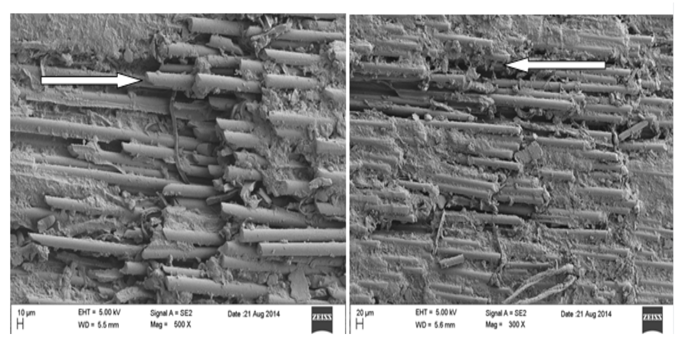

Fig. 8 (c): Worn surface sliding dry at sliding velocity 3.14 m/s under 120 N normal load

4. CONCLUSION

After observing all the results obtained out of friction and wear experiments for the glass fibre reinforced polymer (GFRP) composite taken into the experiments, the following conclusions can be drawn:

1. The coefficient of friction of the composites tested was in the range of 0.2-0.94 sliding against steel under three stated environmental conditions.
2. Friction and wear behavior of a GFRP composite material is highly affected by the normal loads, sliding velocity and distance covered. The greater wear rates obtained in this case also are due to the significant role of the softened component of epoxy resin due to higher heat generation.

3. In dry sliding the values obtained for coefficient of friction are lying in between the other two medium options. These are obtained because of a consecutive deposition of soft debris resulting to soften the process of rubbing. The fibers undergo a slight bending at ends resulting in an easy shear effect. As a consequence, lower values for wear rate are obtained.
4. Microscopic analysis of the worn surfaces reveals that the high wear rate results from an easy separation of fibers from the polymer matrix under high friction.
5. An increment in normal load and velocity of sliding has invariably led to increased wear rate.

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