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Comparative investigation on the wear and friction behaviors of carbon fiber reinforced polymer composites under dry sliding, oil lubrication and inert gas environment☆

Sandeep Agrawal[a]*, K. K. Singh[b], P. K. Sarkar[b]

[a]Department of Mechanical Engineering Hidustan college of science and technology Farah, Mathura -281122, India
[b]Department of Mechanical Engineering Indian School of Mines Dhanbad, Jharkhand -826004, India

Abstract

CFRP (Carbon fibre reinforced polymer) composites are applicable for different engineering machinery to perform in different types of adjoining environments. Tribological properties of CFRP composites were examined experimentally and compared in three types of environmental conditions, (i) dry condition, (ii) oil-lubricated condition and (iii) inert gas (argon). A steel disc of En 31 with hardness of 60 HRC was used as the counterface. The experiment was done at different sliding speeds and different normal loads. It was observed from the results that sliding in an inert gas environment gives the highest value of friction coefficient followed by dry sliding and oil-lubricated sliding. SEM study of the wornout surfaces shows that the greater wear during inert gas environment results due to an easy detachment of fibres from matrix material.

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Keywords: wear; CFRP composite; Gas atmosphere; friction.

1. Introduction:

Lighter in weight and with excellent engineering properties, composites are replacing most of the metal parts of aeronautics. In 1969, carbon composites were newly applied in this area and used to aircraft brakes extensively, because of their outstanding wear and friction characteristics, particularly at elevated temperatures. Due to lower

* Corresponding author. Tel.: +919997688001; fax: +91565246634.
E-mail address: san197012@rediffmail.com

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wear they are preferably suitable to all the aircraft brakes during take-off and landing [1–3]. In early 1980s, the use of CFRP composites was increased to Formula 1 brakes. On the other hand, these materials have not been applied to other vehicles, because of their high cost and lower temperature ranges.

The use of polymer composites, with oil lubrication or accumulation of dust and other contaminants with lubricant is a very important aspect of study [4–10]. However, most of the researchers have published their studies on the tribological study of FRPs sliding against steel in dry conditions, and few of them have investigated the tribological behaviour in other environmental conditions. As far as the role of transfer films during sliding between contacts, it is generally supposed that the transfer film provide a soft polymer surface from the debris. As most of the polymer composites are self-lubricated, the transfer film may act as a lubricant so that the friction coefficient is much lesser in comparison to that between metal and metal [11]. Tanaka [5] and Evans [6] investigated that the application of lubricant into a polymer composite–metal sliding normally lowers the friction coefficient, but wear may be increased.Tanaka also observed that the quantity of released polymer into oil lubrication was same as in dry sliding [5].

Lancaster [4, 8] has investigated the tribological characteristics of different type of CFRP composites sliding against steel in oil and other fluids and observed that the wear of CFRP composites as well as other composites under oil- lubricated condition was normally lesser than in the dry sliding. Yamada and Tanaka [12] investigated the tribological characteristics of various PTFE-based composites against steel during oil- lubricated sliding and observed that the wear rate of PTFE-based composites highly decreases during oil lubrication. It is also found by them that the lesser wear of composites during oil- lubricated sliding was due to lower transfer of material.

Wang et al. [13, 14] has given the results that oil might decrease the coefficient of friction nanometer Si3N4 filled PEEK but with the surrender of a large decrease in wear resistance, and nanometer SiC as a filler highly improve the wear resistance of PEEK under oil- lubricated sliding with a even, and a persistent film was formed on the surface of the counterface. This work is done mainly to investigate the friction and wear properties of CFRP composites, and to study the effect of different environmental conditions i.e. dry, oil-lubricated and argon on wear and friction when sliding takes place against a stainless steel counterpart.

2. Experimental:

2.1.1 Materials and preparation of samples:

A balanced plain woven carbon fabric of 600 gsm with 18 yarns per 2.5 inch along the warp direction and the weft direction (figure 2.4) was used in fabrication of laminates. It was purchased from Eastern Engineering & Trading Co., India. The density of carbon fiber was 1860 kg/m3. Thermosetting resins, such as polyester, phenolic, polyamide, epoxy, etc., are frequently used as the matrix material. However, epoxy is preferred most over other matrix materials for the advantages of its structural applications as other matrix materials generally have certain drawbacks, such as high shrinkage, low strength, etc. In the present work, bisphenol-A based thermosetting epoxy (L12) and N, N'-Bis (2-aminoethyl) ethane-1,2-diamine room temperature hardener (K6), supplied by Atul Ltd., Gujarat, India, were used for impregnating the fabric. There are various techniques for fabrication of FRP laminates, each having its advantages and disadvantages. We used vacuum bagging technique in order to get better fiber volume fraction, high stiffness-to-weight ratio and strength-to-weight ratio. The CFRP composite plates with a size of 270mm×320mm×4mm were made by using vacuum bagging technique. To obtain 4 mm thick laminates, eight numbers of carbon fabric layers were used with a stacking order, $[0^\circ/\pm45^\circ/90^\circ]_s$. The complete process of laminate preparation was completely cut off from dust, grease or other particulates that may create problem during the process. The laminates were cured at ambient conditions for 48 hrs. For any defects these prepared plates were checked thoroughly by naked eyes. By gluing CFRP pieces of 8mm×8mm×4mm to aluminum pins of 8mm diameter, specimen pins were prepared.

2.1.2 Testing Procedure:

The tribological characteristics of CFRP composites sliding against steel disc were evaluated over a machine named as wear tester (a pin-on-disc type) supplied by DUCOM, Bangalore (India). Before starting the experimental observations, sample pin (8mm×8mm×4mm) was slide to the steel disc having surface roughness as 0.5–0.6μm, to obtain the uniform surface of sample for a smooth contact.

This disc was then replaced by a steel disc of En 31 hardened to 60 HRC. Before experiment, the weight of all the samples was measured after washing them with acetone bath and drying with the help of a hot air dryer. The sample was then rubbed over the steel disc at two different speeds of 2.51 m/s (600 Rpm at 80 mm track diameter) and 3.14 m/s (600 Rpm at 100 mm track diameter). A total distance of 1.507 km and 2.827 km was completed by sliding the samples for 600 seconds and 900 seconds. Later the pin was again washed, dried and weighed by an electronic balance which can measure as much lower to 0.01 mg. All the experiments were repeated two times in the same manner. All set of experiment was conducted at 40N, 80N and 120N loads.

These experiments were repeated in dry, oil-lubricated and argon gas environmental condition at 40N, 80N and 120N loads at room temperature. Engine oil SAE 20, having kinematic viscosity of 25–30 cSt at 50 ◦C was used for the lubrication of the disc surface. Before starting the slide, two drops of lubricating oil were dropped over the steel disc. Later on the oil was poured at a flow rate of 0.02 ml/minute. During inert gas sliding argon gas of very high purity was used. During sliding, 0.025 bar of gas pressure was applied at a rate of 1.5 Lit/minute. To find out the accurate weight loss, final weight of the samples was measured after cleaning with acetone and drying.

The specific wear rate was calculated using the equation,

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

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.

3. Results and Discussion:

3.1Wear and friction properties:

The main parameters affecting the wear and friction are normal load, lubrication, sliding distance, and speed of sliding. The effects of these parameters on wear of CFRP composites are shown in Figs. 1(a - c). The weight loss of CFRP composite specimens was measured at 2.51 m/s and 3.14 m/s speeds and under 40N-120 N loads on the selected environmental conditions and shown in Fig. 1(a-c). The loss of weight for composite specimens generally rose with the rise of normal loads at both velocities of 2.51 m/s and 3.14 m/s, when normal loads were raised from 40 to 120 N.

The CFRP specimens showed a lower value of friction coefficient and lower wear in oil lubricated condition, in comparison to argon and dry sliding environmental condition. The increase effect of normal load increased the wear with the load but not as high as in case of Argon or as in dry sliding. So the wear of polymer composites may be considered as a function of normal load, sliding speed, the temperature and the total sliding distance. The temperature of surface plays a significant part in the wear of polymer composites. The wear may be increased due to the occurrence of thermal softening, as the lesser the thickness of the soft layer generally lower will be the wear [15]. Results obtained from experimental observations also showed that on increasing the sliding speed and normal load the specimen temperature also increases. From Fig. 1(a) it may be seen that the “weight loss due to wear” is raised with rise of sliding speed and normal loads. The weight loss of all CFRP composite samples generally raised due to rise in normal load applied at the same sliding distance.

During the experimental observations it has been observed that the temperature of surface had also raised with a rise in normal load. The layer of the epoxy matrix of sample which became softened attaining more depth i.e. softened to a greater depth in proportion to the increment in temperature, consequently the carbon fibres implanted got more easily detached from the sample of the composite material, and consequently, the growth of wear takes place with an increment in load and sliding speeds, in all the three environmental conditions which is mainly because of the thermal softening of CFRP matrix.

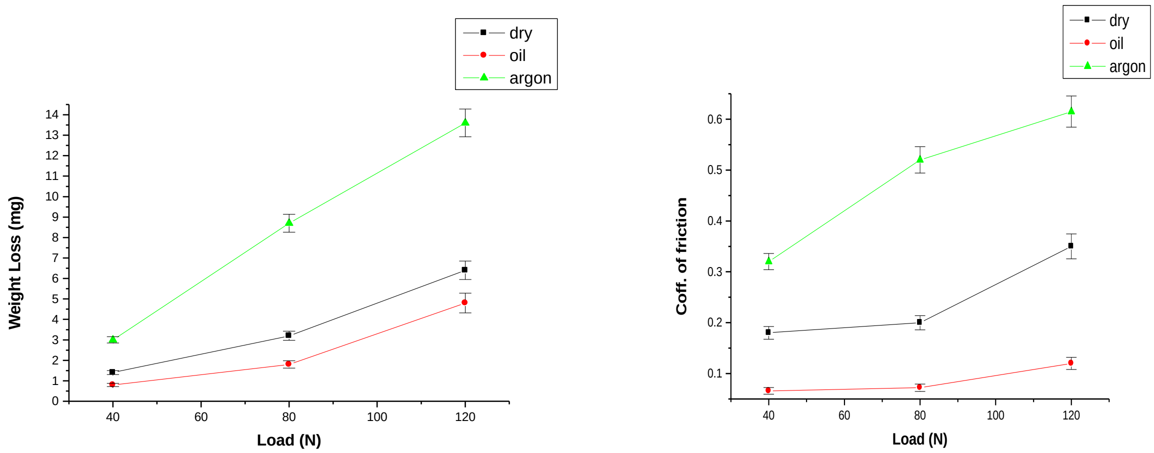

Fig. 1 (a) Weight loss v/s Load and Coefficient of friction v/s Load for CFRP, sliding under all three environmental conditions at 2.51 m/s and 1508 m.

3.2 FESEM analysis of worn surface:

The wornout surfaces were analyzed by SEM study mainly to understand the mechanism of wear. The images shown in Fig. 2 are shown in order of increasing wear rate (W_R). SEM images of surfaces of selected CFRP composites are shown in Fig. 2 at lower magnification (×300), and at higher magnification (×500). Marks of arrows are showing the direction of sliding.The effect of normal load and sliding environment, i.e. dry, oil-lubricated and inert gas i.e. argon gas to the damage of fibres by different mechanism or weakening in fibre–matrix bond due to fibre micro-cracking, micro-cutting leading to pulverization, removal from the matrix in the form of debris followed by either getting flew out from the surface causing positive wear or getting implanted in the matrix in random directions temporarily causing changes in coefficient of friction etc. can be clearly observed in SEM micrographs.

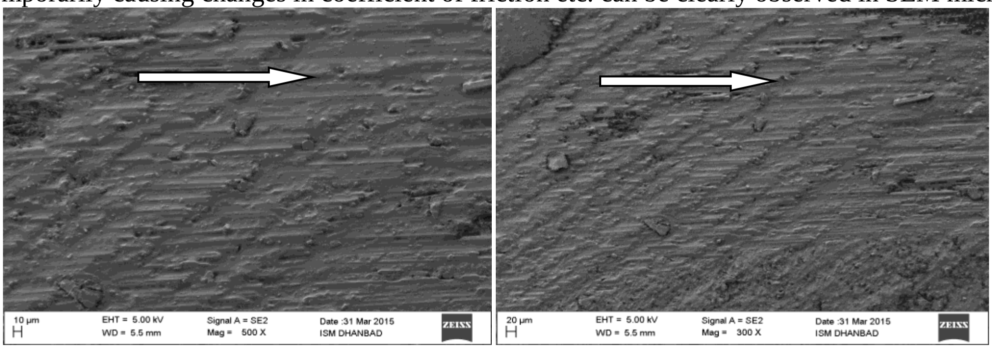

Fig. 2 (a) SEM image of wornout surface sliding dry,at 3.14 m/s and 40N.

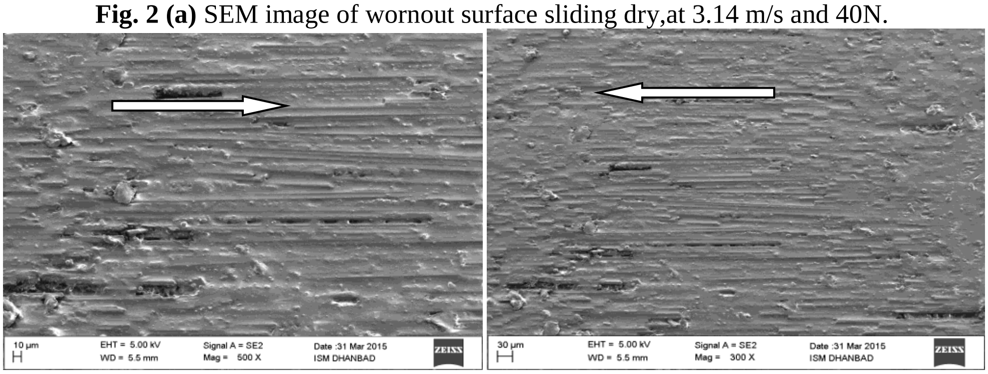

Fig. 2 (b) SEM image of wornout surface sliding dry,at 3.14 m/s and80 N..

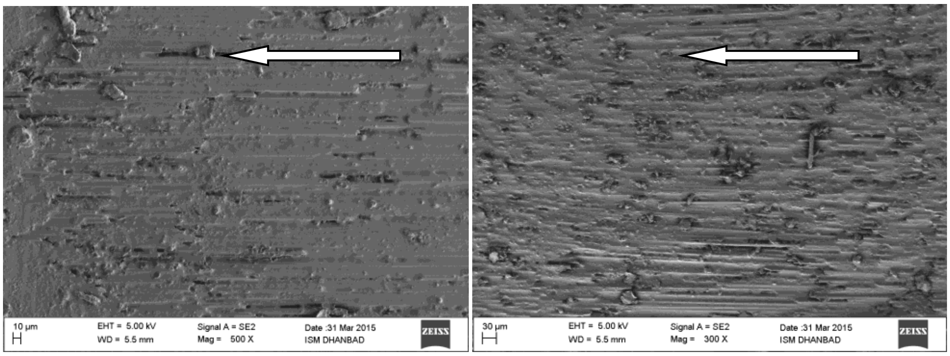

Fig. 2 (c) SEM image of wornout surface sliding dry,at 3.14 m/s and120 N.

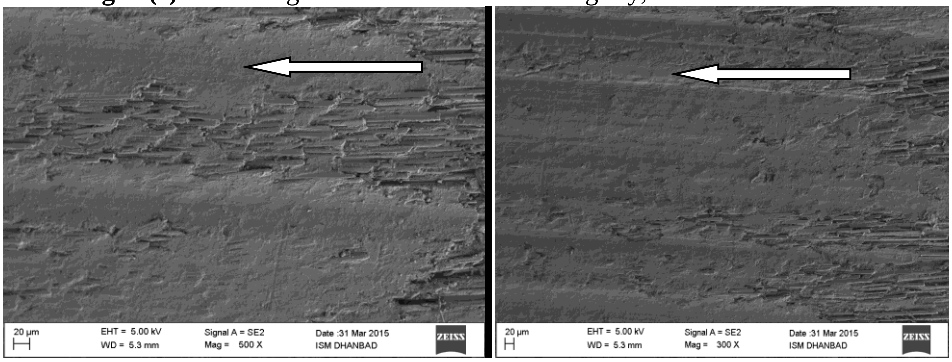

Fig. 2 (d) SEM image of wornout surface, oil-lubricated sliding at 3.14 m/s and 40 N.

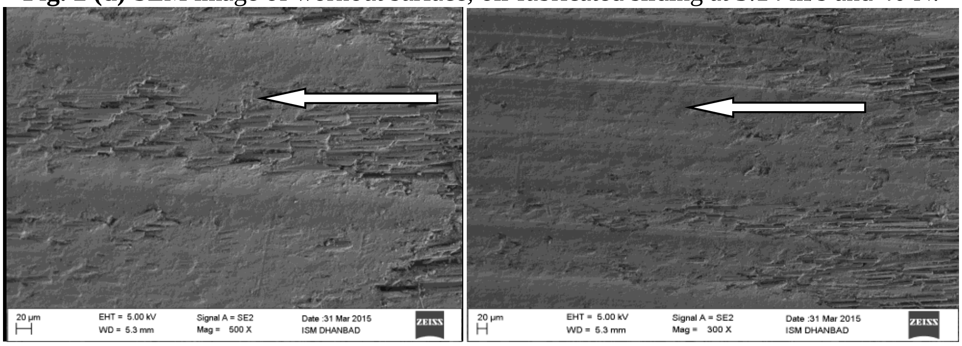

Fig. 2 (e) SEM image of wornout surface, oil-lubricated sliding at 3.14 m/s and 80 N.

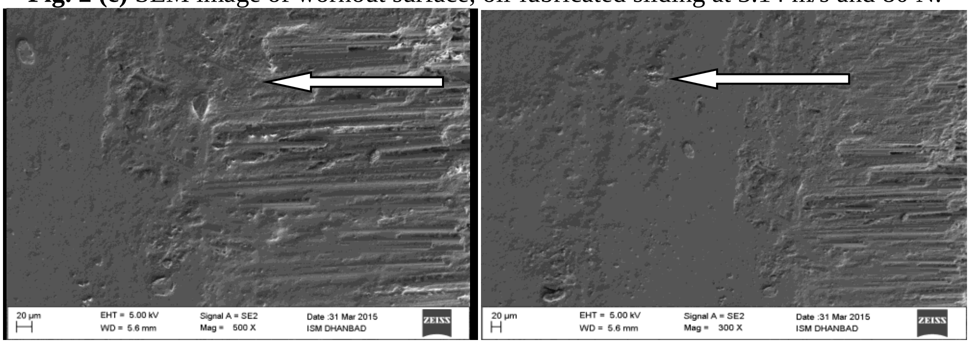

Fig. 2 (f) SEM image of wornout surface, oil-lubricated sliding at 3.14 m/s and 120 N.

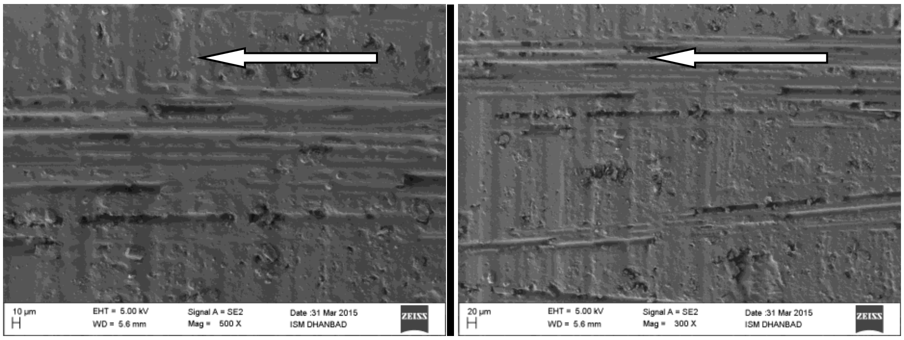

Fig. 2 (g) SEM image of wornout surface, argon medium at 3.14 m/s and 40 N.

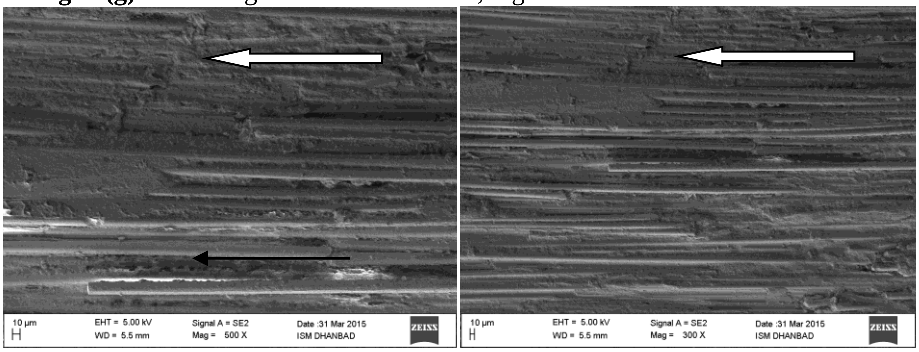

Fig. 2 (h) SEM image of wornout surface, argon medium at 3.14 m/s and 80 N.

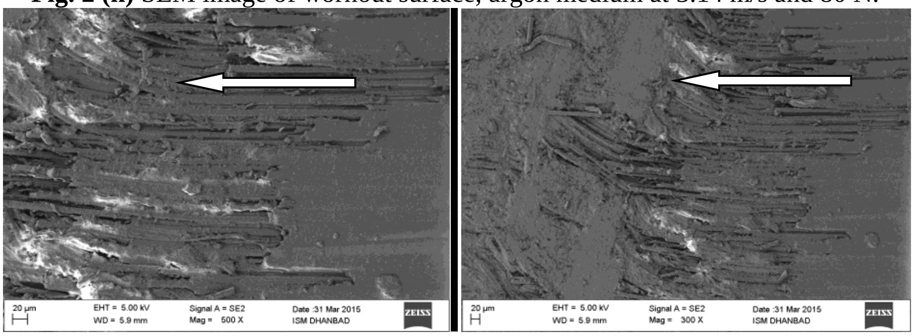

Fig. 2 (i) SEM image of wornout surface, argon medium at 3.14 m/s and120 N.

4. Conclusions:

After obtaining all the experimental results of wear and friction for the carbon fibre reinforced polymer (CFRP) composite, following conclusions can be made:

1. Normal loads, sliding speed and sliding environment highly affected the tribological behaviour of CFRP composite. Coefficients of friction and wear for inert gas argon environment are higher in comparison to other sliding conditions for all values of other parameters. This is because the new fibres made continuous contact to the counterface material, when the environment is argon gas.
2. The lowest value of friction coefficient is observed in oil-lubricated sliding because of the formation of a transfer film layer.
3. During dry sliding the values observed for friction coefficient are in between the other two sliding condition. These are due to continuous deposition of soft debris and forming a sort layer on the surface of rubbing.
4. The wear rate is increased due to an increment in normal load and velocity of sliding.

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