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# A comparative study of wear and friction characteristics of glass fibre reinforced epoxy resin, sliding under dry, oil-lubricated and inert gas environments

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ABSTRACT

GFRP are used for wear-critical industrial components that must perform in a variety of surrounding environments. Friction and wear characteristics of glass fibre reinforced polymer composites were experimentally investigated under three different sliding environments, (a) dry sliding, (b) oil-lubricated sliding and (c) sliding in inert gas (argon). The counterface used in these experiments was En 31 steel hardened to 60 HRC, and two sliding velocities and three normal loads were used. Results show that sliding in inert gas (argon) provides the maximum value of coefficient of friction followed by dry sliding and oil-lubricated sliding in descending order. FESEM analysis of the worn surfaces reveals that the high wear in inert gas (argon) results from an easy separation of fibres.



## 1. Introduction

Composite materials have been used by the mankind since ancient times; e.g. straws were used in bricks to enhance the strength and structural properties. The researches with superior reinforcing fibres in a base of polymer or epoxy resin materials has emerged as a low cost, easily shapeable, composite material, that for several applications may be the best alternative amongst the materials available due to superior characteristics such as high impact strength and amenability to low cost manufacturing, having higher strength to weight ratio and also less overall cast etc. Thus various uses of composite materials have emerged in automobile and aircraft industries e.g. cams, seals, shafts, gears, bushes, etc [1–3] and some of these do require an understanding of their tribological characteristics also.

Even though the epoxy resin polymer reinforcement with fibres improves the tribological characteristics of epoxy resins, occasionally it may make them poor as well [2]. A number of previous investigations [2,4–6] emphasised on wear and friction characteristics of polymer fibre reinforced composite materials. Amongst the operating conditions, the temperature of surface may have importance in study of the tribological behaviour of certain polymer composites [1,7,8]. However, very few studies have been done till now on these aspects [8,9]. Because the application of composite materials is increasing day by day in applications where sliding wear characteristics are important, so it is desirable to have better knowledge about the tribological behaviours of these fibres reinforced polymers and epoxies, under various conditions of working.

Moreover, though a wide range of materials has been manufactured till now, yet the glass-fibre-reinforced polymer (GFRP) category needs more and more research for enhancing its usage in light of its promise in terms of engineering application capabilities. These are comparatively more expensive, but, make for a superior material for a variety of engineering uses [10–12]. 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 [14]. Such composite materials consist of epoxy resin and reinforcement selected as per the required mechanical property suiting the applications [15,16]. The known common mechanisms of wear for FRP composites are: fibre–matrix debonding, matrix fracture, and fibre breaking [10–15]. Some additional mechanisms noted are fibre pull out, pealing of the resin, matrix wear associated to fibre separation, deformation of the edges of the wear track and shear deformation of the fibres. Thus application of FRP composites in mechanical parts with adequate wear resistance in actual service conditions would require a high knowledge of and research onto the friction and wear characteristics.

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It is a well-known fact that a gaseous atmosphere may highly influence the friction and wear performance of steels to other contact materials. Friction and wear behaviour of steel and other metals are governed partially by the oxygen ($O_2$) adsorption and the formation of oxide layers which is relatively supportive of the sliding condition in comparison to pure non-oxidised metal surfaces, where adhesiveness is much higher and cold welding may occur. But findings show that the effects of gaseous environment on tribological characteristics in case of polymer composites to steel or metal contact varies and is different in different studies and therefore factors, such as adhesion, friction of oxidised metal surfaces, etc. causing more wear have been already recognised [23–28].

However, due to the complexity and the sensitivity of the gas-lubricated systems, the results from these studies do not apply to every gas-lubricated combination. The adsorption of gas molecules and the chemical change of the contact surfaces substantially determine the behaviour of each metal differently, therefore, the friction and wear behaviour of gas-lubricated systems are highly related to the operating conditions and material combination. Furthermore, findings obtained from different researches, using gases as lubricating medium at non-lubricated metal contacts, often show different response and can even appear contradictory when applying different operating conditions (gas pressure, contact pressure, temperature and other contact dynamics, etc.) or using different material combination. Furthermore, in research using Argon (Ar) and Nitrogen ($N_2$) atmospheres, friction and wear of different metal alloys and bearing steels higher than in an air atmosphere [29].

Prior research by other investigators has shown that when the polymer resins are reinforced with glass, carbon or other hybrid fibres, the wear rate of polymers sliding against steel is reduced; though, the performance is influenced by parameters such as the matrix composition, amount, shape, size, the type and angle of orientation of the fibres, and the testing parameters such as speed of sliding, load and environment [17–22].

In order to extend that prior work, the present research is aimed at determining the effects of such testing parameters on wear rate of GFRP composite materials. Most of the prior findings are based on either randomly oriented or unidirectionally oriented fibre composites. Woven fabric reinforced composites are gaining popularity because of their balanced properties in the fabric plane as well as their ease of handling during fabrication. Hence, in the present research article, glass woven fabric reinforced epoxy composite material has been taken up for investigation with the intention of characterizing them for their wear behaviour. The wear behaviours of GFRP materials are experimentally evaluated under various normal loads, sliding velocities and sliding conditions and lubricating media such as dry, oil-lubricated and inert gas.

## 2. Experimental

### 2.1. Materials

In the experimental study, the composite specimens were prepared using glass fibres reinforcement in epoxy resin matrix material, (Epoxy resin L-12 and Hardener K-6 supplied by Atul Limited, Valsad, Gujrat, India). The glass fabric taken was a woven roving E-glass supplied by Hindustan Fibre Glass Industries, India and of an economical cost. Woven glass fabric was made of 600 GSM. (Continuous fibres need no spinning essentially; but in this case it was so). The Fabric is prepared by using the fibres by regular weave method. If fibres are not spun the fabric generally becomes denser, and exhibits lesser fibre flexure. Plain weave glass fibre include E-glass fibres of diameter 12–24 μm. Woven fabrics must be selected when higher shear strengths are essential along the plane of reinforced sheet. Unidirectional weaving usually has low shear strength than conventional weaving. GFRP is a good engineering material with high impact strengths; mouldable, high strength to weight ratio and that is also desirable in commercial applications due to lower cost.

### 2.2. Preparation of specimen

The GFRP epoxy resin composite plates having dimensions 270 mm × 320 mm × 4 mm were made-up by the vacuum bagging process. To attain 4 mm nominal thickness, eight layers of glass fabric were used. We used a stacking sequence, $[0°/\pm 45°/90°]_s$. During wear and friction experiments the surface which was in contact with steel disc having a 0° fibre orientation direction. All the layers of fabric were cut and placed one over another in the required sequence with the warp face down. The complete process was carefully isolated from dust, grease or other contaminants that may provide difficulty for bonding of layers during consolidation. The plates were cured at room temperature for 48 h. The prepared plates were checked by naked eyes for any abnormal surface defects. All plates were found without any form of surface defects and delaminations. Specimen pins were prepared by gluing GFRP pieces of 8 mm × 8 mm × 4 mm to aluminium pins of 8 mm diameter.

### 2.3. Testing procedure

Experiment was conducted on a wear tester; a pin-on-disc machine made-up by DUCOM, Bangalore (India) especially for high PV condition for 1000 N load and 10 m/s speed. Before experiment, specimen pin (8 mm × 8 mm × 4 mm) was rubbed against a hardened steel disc of surface roughness of 0.5–0.6 μm, to prepare the specimen for an even contact.

This rubbing for even contact was done under same load at which the experiment was conducted. Later on this rough disc was exchanged with a steel disc of En 31 hardened to 60 HRC and having *R*a values in between 0.2–0.3 μm. Before starting the experimental study, initial weight of pin was taken after cleaning it with acetone and drying. It was 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). The complete distance of 1.507 km and 2.827 km was attained by rubbing the pins for 600 s and 900 s to attain a considerable wear. Later on the pin was again cleaned by same method, dried and weighed with the help of a balance with a least count of 0.01 mg. All set of experiments was conducted two times in exactly the same manner and the precise value of weight loss was taken for calculating the specific wear rate. The experiment was repeated at 40 N, 80 N and 120 N loads. It was observed during the experiment that some of the parameters such as increase in coefficient of friction, increase in disc temperature, mark of abrasion on disc, a slight colour change in disc surface and noise generation at excessive loads actually occurred.

Experiments for adhesive wear studies were performed by sliding specimens under dry, oil-lubricated and argon gas atmosphere at 40 N, 80 N and 120 N loads at room temperature. All sets of these experiments were conducted as explained earlier and weight loss was measured after each experiment. The complete procedure was thus repeated for oil-lubricated and for inert gas i.e. argon medium sliding. The oil used for lubricating the disc surface during the experiments was SAE 20 engine oil, with a kinematic viscosity of 25–30 cSt at 50 °C. Prior to start of each experiment, two drops of lubricating oil were placed over the sliding surface. Further the oil was poured at a flow rate of 0.02 ml/min during