Wear and frictional study of MWCNT doped glass fiber reinforced polymer composite under different sliding conditions

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Abstract. Glass fiber reinforced polymer composites are a proven and successful alternative that have numerous advantage over traditional reinforcement method, giving material a longer service life. In this paper experimental investigation is done on GFRP/epoxy doped with 3 wt % of MWCNTs (multi-walled carbon nano tube, diameter of order nanometer). The aim of this research is to evaluate the feasibility of GFRP doped with MWCNT under different sliding conditions (a) dry (b) lubricated at three different loading conditions and sliding speeds. The sample was prepared by hand layup technique followed by vacuum bagging. The experiment was performed on a pin on disc type tribometer (TR-20, made by DUCOM) with a steel disc of HRC-60 acting as the counterface. Experiment shows that the wear rate increases with increasing in normal load. It was also observed that the wear rate and the coefficient of friction is minimum in lubricating conditions and maximum in dry environment. Morphology was examined with the help of FESEM analysis of MWCNT doped GFRP.

Keywords: GFRP; carbon nanotube; Wear; FESEM; Pin on disc

1. Introduction
Over the years, composites have been largely used for various applications like automobiles, aerospace and chemical industries. The features of the composites like high specific strength, low weight, High stiffness increase their application in industries and engineering materials,[1]. Composites are heterogenous in nature composed of two or more distinct phases (matrix and reinforcement phase) with different physical and chemical properties which when combine give properties superior to the properties of the individual component. These material forms an intimate contact between them on the macroscopic level. The matrix phase also called the discontinuous phase can be classified into polymer matrix composite, metal matrix composite and ceramic matrix composite. In recent times, Polymer matrix composites have gained much more importance then any other composite materials. A distinct advantage of Polymer matrix composites over other materials is that, It has high performance resin system, high stiffness, high strength, high resistance to chemical corrosion and scratching. Polymer matrix composites can be reinforced plastics and advanced composites, which include fibres and matrix that have attracted demands in many industrial applications. The fibers reinforced polymers can be
formulated by using different types of fibres that can be natural (khenaf, hemp, jute etc) or synthetic (glass, carbon, graphite, aramid etc)[3]. Besides these fibres, the FRP can also be developed by reinforcing fillers. These fillers may be organic, inorganic or nanofillers. The addition of filler material in the composite brings a lot of changes in the molecular and supermolecular structure. These helps to enhances the strength, toughness, shrinkage, creep and chemical resistance of the matrix[21]. Besides this, Nanofillers have been more popular in recent times because of its optical, electrical mechanical and magnetic properties[4,5] Visco studied that when 0.4 wt% of carbon nanotube is added to epoxy, then the flexural, wetability , calometric and electrical properties of EP have enhanced [18]. Rawat and Singh have determines the effect of varying the % of CNT on the impact resistance in their paper.[21]. Nowadays, the PMC have increased its demand in many applications where sliding wear characteristics is important. So, It becomes necessary to investigate the effect of working conditions, load, speed on the GFRP in order to increase its performance like high load carrying capacity, better lubrication, better life etc in various applications. most of the studies have been done in different environments like water, saline water, acidic, oil dry in order to have better knowledge of the performance of the carbon and glass fibers reinforced polymers.[10,11,12,15,17,22].

Many researches have been done to investigate the sliding wear characteristics of GFRP [10]. El-teyeb [7] showed the wear and frictional effect of GFRP under dry sliding condition. His study showed improvement in the wear characterization under dry sliding conditions. Sandeep aggarwal[22] in his paper have investigated the effect of different working environments on GFRP reinforced with epoxy resin. He demonstrated that the loading conditions, speed have highly influenced the wear and friction behaviour of GFRP doped with epoxy resin. He also investigated that the value of Coefficient of friction for GFRP is maximum in dry followed by lubricated condition. Kishore[19] in his study conclude the effect of velocity and load on the sliding wear characterization of GFRP with different fillers. Hameed stated that when the load on the fibers increased, there will be an increase in the glass transition temperature[26].

The present study has been done to develop a GFRP composites. The aim of the study is to carry out wear tests on pin-on-disc under different environmental conditions with variable loads and speeds. These study investigate the effect of MWCNT(multiwalled carbon nanotubes) reinforcement on the tribological behaviour of Glass Fiber Reinforced Polymer

2. Experiment
2.1 Material
In the present study, Experiments have been done on glass fiber reinforced polymer. The composite specimen is prepared by reinforcing glass fiber in epoxy resin material. (Atul limited, Valsad, Gujarat, India) has supplied the epoxy resin L-12 and hardener K-6. In this experiment woven roving E-glass Fabric was used supplied by Hindustan fiber glass industries india at a very reasonable rate. The glass fiber reinforced polymer was prepared by using 8 layers of woven plymer E-glass, which are stacked in the order of [0/90°],[0/45°],[0/90°],[0/45°],[0/45°],[0/90°],[0/45°],[0/90°]. The glass fiber reinforced polymer is doped with 3 wt% of MWCNT, which is prepared by the CVD process. 3wt% of MWCNT is added in acetone. This mixture is then ultrasonically stirred for 2 hrs. This process further continues by stirring the mixture of MWCNT with the help of magnetic stirr for 30 mins at 75°C. The formed mixture is the evaporated at 50°C for 24 hrs, for the proper sepration of acetone. The hardener K-6 is added in the mixture in the ratio of 10:1 and then proper mixing is done for 10 mins. Finally the composite specimen is prepared by the hand lay up technique where the mixture was applied according to the stacking order required. The pressure used was 700 mm of Hg for 24 hrs. The composite specimen prepared was of thickness 8mm approximately. The specimen prepared was cut in a sample of 8 mm × 8 mm. This prepared sample was then glued to the aluminium pins with the help of an adhesive.
2.2 Testing procedure

Glass fiber reinforced polymer doped with 3 wt% of MWCNT was prepared. The composite specimen obtained have size of 100 mm × 100 mm which were cut into 18 samples. Each samples have thickness of 8 mm. Experiment were done on the samples glued with the aluminium pins with the help of the adhesive. Before gluing the sample the weight of each sample has been measured. The aluminium pins were of diameter of 8 mm.

Wear tests were conducted on a wear tester, a pin on disc machine – made by DUCOM, Banglore that can handle load up to 1000 N and 10 m/sec speed. It was desired that the prepared sample should have even contact with the rubbing surface. So, before starting the experiment, a hardened steel disc of surface (0.5 – 0.6) mm was used to rubbed the sample pins against it to make an even contact. The load used for this rubbing process is same to the load on which the wear test were performed.

Later on the wear tests were conducted on pin on disc, in which steel disc of En 31 and the hardness 60 HRC act as the counterface. Before starting the experiment the sample were weighed to measure the initial weight. After the experiment has been performed the sample were cleaned with the acetone and then dried. After this process, the sample pins were held in the pin holder and rubbed over the steel disc at three different sliding speed of 2.93 m/s (track diameter 80 mm, sliding time 900 sec, sliding distance 2638 m), 3.66 m/s (track diameter 100 mm, sliding time 900 sec, sliding distance 3298 m) and 4.39 m/s (track diameter 110 mm, sliding time 900 sec, sliding distance 3958 m).

The experiment was conducted on three different loads of 50 N, 100 N and 150 N. After the experiment, the rubbed pins was again cleaned by the same process dried and then weighed. The least count of the weigh measuring device is 0.01 mg. The same method of testing is done on all the samples at different track diameters and different loads respectively.

After measuring the test conducted samples before and after the experiment, it was found that some amount of weight loss take place. The temperature of the disc increased and a small amount of colour change of steel disc surface and generation of noise also take place. Increase in the coefficient of friction and some marks of abrasion of disc have been also found.

The wear tests on different track diameters sliding speeds and loads were performed in dry and lubricated sliding environments. The oil which act as the lubricating medium in these experiment was SAE-20 engine oil, posses kinematic viscosity of 25-30 cst at 50 °C. Before starting the lubricating environment experiment two drops of lubricated oil were pat on the steel surface, further oil at a flow rate .02 ml/min were poured during the experiment .After performing the experiment on the samples in the lubricated environments, the 600 grade Sic emery paper was used to clean the steel surface. The formula used for calculating the wear loss is

\[ K_o \left( \frac{mm^3}{N.m} \right) = \frac{\Delta m}{\rho L d} \]

Here, \( \Delta m \) is the weight loss in kg.

\( \rho \) the density in kg/mm\(^3\), L is the load in N and d is the sliding distance in m.
3 Results and Discussion

3.1 Weight loss
In this present research, the effect of the normal load, sliding speed, track diameter and lubricating medium is determined by calculating the weight loss of the sample. The weight loss is measured by calculating the difference between the initial and the final weight of the sample. The manner in which the weight loss of the GFRP composite is affected by the various parameters like sliding speed, sliding distance and the sliding environments is shown in the fig:2.

The sliding speed for which the weight has been measured was 2.93 m/s, 3.66 m/s and 4.39 m/s. It has been concluded from the fig:2 that after performing the experiments, with the increase in the normal loads, acting on the samples, the weight loss for all the GFRP composites have been increased.

The GFRP specimens were tested in dry and lubricated medium. It was demonstrated from the samples that the value of coefficient of friction for GFRP specimen is lower in case of lubricating medium as compared to the dry sliding medium. It was also found out that in case of dry sliding when the load is increased the amount of wear of the GFRP specimen is much more then when the experiment were tested in the lubricating medium at the same load.

So, it was concluded that the wear of the GFRP specimen is largely depends on the normal load, sliding speed, sliding distance and the sliding environments. Temperature has also been considered an important factor in the wear of the polymer. During the experiment when the specimen keeps on rubbing against the steel disc, it was observed that there is a certain rise in the temperature of the specimen, with the increase in the sliding velocity, due to which the layer of the epoxy resin matrix get softened and attained some depth. The attained depth by the epoxy layer matrix largely depends on the increment in the temperature. This increment in the temperature can cause the separation of the glass fibres and the epoxy layer matrix from the samples, that result in the weight loss of the GFRP specimen, which mainly because of the thermal softening of the layers. Thermal softening of the specimen take place, when the temperature is increased which leads to the wear of polymers.
3.2 Specific wear rate
The specific wear rate is largely dependent on the normal load, the medium of sliding and the sliding velocity. The fig:3 shows the effect of the various factors on the wear rate. The fig:3 shows the specific wear rate in dry and lubricating medium. It has been demonstrated from the fig that when the specimen is experimented in the dry sliding, the specific wear rate is more in comparison to the lubricated medium, the decrement in the specific rate is considerable in case of the lubricating medium.

There are two modes of occurrence of wear in case of polymers. First is matrix cracking, in which plastic deformation of the matrix or cracks in the matrix take place and the second is fibers wear in which the fiber debonding, fiber pull out and fiber bridging take place.

During the experiment when the sample is rubbed against the surface, a transfer layer gets formed over the steel surface acting as the counterface. This formation of the transfer layer over the sliding surface plays a very important role in the behaviour of wear take place. When the transfer layer formed over the metallic surface, the adhesion between the the GFRP composite and the metallic counterface get reduce and then this transfer layer will act as the hindrance between the contact surface of the GFRP composite and the metallic surface.

3.3 Coefficient of friction
The factors affect the coefficient of friction mainly is normal load, sliding velocity, sliding distance and the sliding environment. The fig:4 shows the effect of these parameters on the coefficient of friction. It has been found out that during the starting period of experiment, there is no change in the coefficient of friction, but as soon as the normal load and the sliding velocity increases, there is an increase in the coefficient of
Friction takes place. It has been demonstrated in the fig:4 that the coefficient of friction attained in case of dry sliding is higher than the lubricating medium.

![Figure 4: Coefficient of friction v/s normal load for track diameter (a) 80 mm; (b) 100 mm; (c) 110 mm](image)

### 3.4 FESEM

After the experiment has been performed on all the GFRP specimens, the worn surfaces were tested under FESEM in order to obtain the FESEM micrographs at track diameter of 80 mm at three different loads of 50 N, 100 N and 150 N respectively in oil and dry environments. The FESEM analysis were done on the worn surfaces of the selected of GFRP doped with MWCNT at lower magnification of 300 X. The fig 5. Shows the FESEM micrographs of worn surfaces in oil conditions. It can be seen that in fig 5.(a) when the load is low (50 N), there are little marks of micro cracks in the matrix, but in fig 5 (b) and (c) when the load increased to 100 N and 150 N, there is a little increase in the damage of the fiber or can be say that there is a little much more deterioration of the fiber-matrix take place.

![Figure 5: FESEM images of samples tested in oil lubricated condition at track diameter of 80 mm for load of (a) 50 N (b) 100 N (c) 150 N](image)

Fig 6. Shows the FESEM micrographs of the worn surface at track diameter of 80mm at different loads of 50 N, 100N and 150 N in dry condition. It can be seen from the fig 6.(a) that when the load is 50 N formation of the fractured fibers is noticed and also because of the sliding thrust the repeated bending also take place that cause debonding of the fiber but as the load is increases from 50 N to 150 N in case of dry sliding at the same track diameter there is much more fiber separation due to the deterioration of adhesion between the fiber matrix. So it can be seen from the obtained FESEM micrographs that in case of dry
Environment, with the increase in the loads more fractured of the fibre matrix take place as compared to the oil environment at the same track diameter.

Figure 6: FESEM images of samples tested in dry condition at track diameter of 80 mm for load of (a) 50 N (b) 100 N (c) 150 N

4 Conclusion
1. The coefficient of friction has minimum value in case of lubricated medium, the formation of transfer layer in case of lubricated medium contributed towards the lower value of coefficient of friction.
2. In case of dry sliding the coefficient of friction is higher than in comparison to the lubricating medium.
3. When the normal load and the sliding velocity is increased there is an increment in the value of the wear rate take place.
4. The property of oil to form a transfer layer over the metallic surface helps to reduce the wear rate and gives better results.
5. When the normal load, sliding speed and sliding distance increased, the weight loss also increases. The weight loss in case of dry sliding is more than in comparison to lubricating medium. This is due to the thermal softening which occur as the result of rise in temperature.
6. The FESEM micrographs of the worn surfaces in oil and dry conditions shows that at lower value of the load little micro cracking of the matrix take place, but when the load is increased, much more fiber separation take place.

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