Comparative study of tribological behavior of MWCNTs filled HFRP and unfilled HFRP composites under different sliding parameters and different sliding environment

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Abstract. Industrial application of Hybrid Fiber Reinforced Polymer Composites (HFRP) is increasing day by day. HFRP composites have many advantages such as lightweight, high specific strength etc. which make HFRP composites a suitable material in aerospace industry. This paper compares the tribological properties of HFRP composites and HFRP composites doped with multi-walled carbon nanotubes (MWCNTs) fabricated by vacuum bagging process under different loads and different environments. The experiment was performed on a pin on disc type tribometer with HFRP samples and steel disc of hardness 60 HRC acting as a counter surface. Experimental results depict that addition of MWCNTs improves tribological behavior of the composite. In addition to that morphology of specimens was examined by optical microscope.

Keywords: Hybrid composite, MWCNTs, tribology, glass fiber, carbon fiber

1. Introduction

Nowadays to improve the product performance and reduce the cost of manufacturing composite material are used which are made of at least two distinct materials. As the application of composites increases, research is being carried out on varieties of composites e.g. metal matrix composites (MMC), ceramic matrix composites (CMC), polymer matrix composites (PMC) etc. [1].Singh et al. [2] found that metal matrix composites have better tribological property compared to metal alloy. Polymer matrix composites find its application in many industries such as aerospace industries; where the component used should not only be light in weight but also have high strength. Due to easy process ability, high aspect ratio, low friction coefficient, polymer matrix composites (PMCs) is preferred over conventional materials. In fiber reinforced polymer composites the most widely used polymer matrix by researchers is epoxy. Epoxy resins have crossed linked molecular structure which prevents the formation of the transfer film and because of this restriction wear resistance of epoxy resin is low. So by selecting the right type of fibers or fillers the epoxy-based composites can have excellent tribological properties [3]. Synthetic fibers (glass, carbon) are most widely used in aerospace industry due to properties like light weight, high specific strength, low moisture absorption. To enhance mechanical and tribological properties of single FRP composites and reduce its limitations hybridization process is used [4].

MWCNTs (multi-walled carbon nanotubes) are widely used as filler material because of good mechanical and thermal properties [5]. Agarwal et al. [6] found that tribological behavior of glass fiber reinforced polymer composites depends on surrounding environment, sliding velocity and normal load. In case of glass fiber reinforced polymer composites tribological properties shows poor result in dry environment in comparison to the oil lubricated environment [7]. As tribological properties of PMCs vary with variation in environment and working parameters so in order to find wear and friction behavior, it is necessary to evaluate the values at a specific environment and at specific working parameters [8]. Guermazi et al. [9] investigated the abrasive wear behavior of different FRPs (fiber reinforced polymer) composite and found that abrasive wear in case of glass fiber is more in comparison to carbon fiber and behavior of hybrid composite lies between them. Jagannatha et al. [10] in their paper concluded that an increase in weight percentage of carbon fiber in glass/carbon epoxy hybrid composite improves its mechanical properties. Wang et al. [11] also investigated the friction and wear behavior of GF/CF/UHMWPE composite under two different environments and found that hybrid composites had the best antifriction characteristics.

In this paper, the tribological behavior of HFRP composites and MWCNTs doped HFRP composites were compared under different loads of 40N, 70N and 100N and under dry and oil lubricated environment. A constant sliding speed of 4.52 m/sec was used during the experiment. The tribological behavior of both composites was compared on the basis of weight loss, specific wear rate and friction coefficient.

2. Materials and Method

2.1 Material

The test specimens were prepared by using glass fiber and carbon fiber as reinforcement, epoxy resin as matrix material. Epoxy resins (viscosity 300cp) was mixed with hardener (K-6) procured from Atul Limited, Gujarat, India. The hardener and epoxy was mixed in the ratio 1:10 by weight. In this experiment carbon nanotubes were provided by United Nanotech Innovations Pvt Ltd. (Bengaluru, India). The bi-directional glass fabric (600GSM); bi-directional woven roving carbon fabric (600 GSM) used for the experiment was supplied by MS Industries (Kolkata, India) and Hindustan Fiber Glass Industries, India respectively.

2.2 Preparation of specimen and testing procedure

HFRP and MWCNTs doped HFRP composite plates having dimension 100mm×100mm×4mm were prepared by hand lay-up technique followed by vacuum bagging process. Four layers of carbon fiber and four layers of glass fiber were used in order to attain a thickness of 4 mm. In order to prepare hybrid composites all the layers were cut to the required size and these layers were put one over the other with a stacking sequence of $[(0°/90°)_{Carbon}/ (-45°/+45°)_{Glass}/ (-45°/+45°)_{Carbon} / (0°/90°)_{Glass}]_s$ and prepared epoxy resins put in between the layers with the help of a brush. For the preparation of MWCNTs doped HFRP composites, proper mixing of CNTs with epoxy resin was ensured and for that first, the CNTs were ultrasonically mixed with acetone having high purity for 2h, then mixed with epoxy resins in 3 wt. %. Further separation of acetone from the solution was done by heating the solution to 75°C then evaporating in vacuum at 50°C for 24 hours. During the entire mixing process, continuous stirring of the solution is necessary. Now with the help of vacuum bagging technique, the air entrapped in the specimens was removed from the composite. Vacuum bagging technique also promotes flow ability of epoxy resin and these results in the decrease in curing time. The specimens are kept at 1 atmospheric pressure for 30 minutes, during this time extra resins come out of the specimen. Finally, a weight of 40 N is applied for next 36 hours at atmospheric condition. The entire process was done with dust, contaminant-free environment. Any abnormalities present in the plates were checked by naked eye. For testing a total of 12 samples of HFRP and 12 samples of MWCNTs doped HFRP composites were prepared. Specimens of size 8mm×8mm×4mm were cut as shown in figure 1 (a) and glued to aluminum pins of 8 mm diameter.

Figure 1 (b) shows the pin-on-disc type tribometer (TR-20, made up by DUCOM, Bangalore) which was used to find the tribological behavior of HFRP samples. Steel disc (En 31) of hardness 60

HRC (R_a value 0.2 to 0.5 μm) was used as the counter surface. For investigating the behavior of the hybrid composite, the surface 4mm×8mm (figure 2)) was allowed to slide against the steel disc. The samples, as well as steel disc, were first cleaned with acetone and dried at room temperature. Samples were then weighed before performing the experiment, on a balance with least count of 0.01mg. The experiment was performed at 40N load and the dry environment by rubbing the neat HPRP samples (area of 32mm^2) at constant sliding speeds 4.52m/s (track diameter 120 mm, sliding time 840sec, sliding distance 3800m) against the steel counter surface. After experiment samples were cleaned with acetone and weight of the samples were again measured with the help of balance. The same procedure was repeated for 70N, 100N load and oil lubricated environment. The same experimental procedure was applied for MWCNTs doped HFRP composite. SAE 20 (kinematic viscosity 25-30cSt at 50degree centigrade) was used as oil with constant flow rate of 0.02ml/min. In order to calculate the precise value of weight loss all sets of experiment was conducted two times and taking average of the two values. ASTM (D3039) standard was used to perform the entire test during the experiment.

The specific wear rate may be given by following equation

$$K_0\left(\frac{mm^3}{Nm}\right)=\frac{\Delta m}{\rho LD} \qquad (1)$$

Where Δm ≡ weight loss (kg), ρ ≡ density (kg/mm^3), L ≡ load (N), D ≡ rubbing distance (m).
Friction coefficient was evaluated by using the following formula

$$\mu=\frac{F}{N} \qquad (2)$$

Where F is the frictional force and N is the normal force.

(a)

(b)

Figure 1: (a) HFRP Samples glued to aluminum pin; (b) Pin-on-disc tribometer (TR-20)

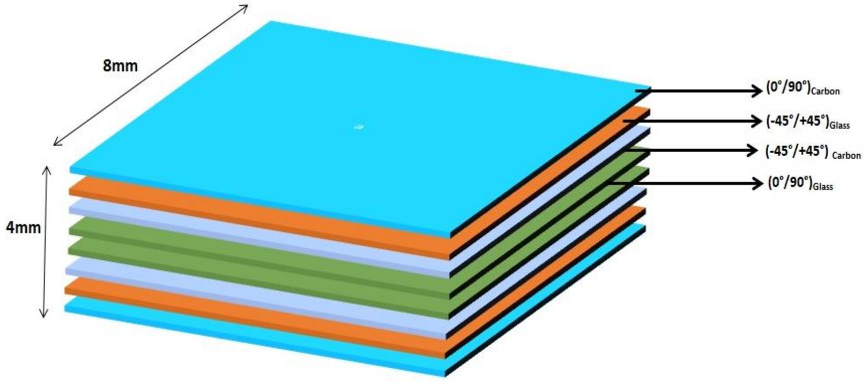


Figure 2: (a) Orientation of HFRP composite

3. Results and Discussion

3.1 Weight loss

Figure 3 (a) and (b) shows variations of weight loss with the load for HFRP composites and MWCNTs doped HFRP composites in dry and oil lubricated condition respectively. Parameters that mainly affect weight loss are applied normal load, surrounding environment, rubbing distance and sliding velocity [6]. Besides these factors weight loss in polymer matrix composites also depends on temperature rise. It was observed during the experiment, the temperature of specimen increases with the increase in load. This rise in temperature results in thermal softening of the epoxy matrix in the composites. The softened matrix layer and hybrid fibers embedded gets separated from the surface of the sample, this results in an increase in weight loss with the increment in applied load in both the surrounding environments and for both the composite materials.

Table 1: Weight loss (mg) under dry and oil lubricated condition for neat HFRP and MWCNTs filled HFRP composites under varying load

Surrounding environment	Load	Weight loss (mg) neat HFRP	Weight loss (mg) CNTs doped HFRP
Dry	40 N	7	1.9
Dry	70N	13.5	5
Dry	100N	21.3	8
Oil	40N	3	1.1
Oil	70N	7.1	2
Oil	100N	11.4	4.1

Table 2: Specific wear rate under dry and oil lubricated condition for neat HFRP and MWCNTs filled HFRP composites under varying load

Surrounding environment	Load	Specific wear rate(K_0 $*10^{-5}$) (mm^3/Nm) neat HFRP	Specific wear rate(K_0 $*10^{-5}$) (mm^3/Nm) CNTs doped HFRP
Dry	40 N	2.593623	0.618217
Dry	70N	2.85829	0.930148
Dry	100N	3.15681	1.041766
Oil	40N	1.111583	0.35810
Oil	70N	1.503243	0.372059
Oil	100N	1.68956	0.533905

But in MWCNTs doped HFRP composites weight loss is low in comparison to neat HFRP composite. Addition of CNTs improves mechanical properties as well as the thermal conductivity of HFRP composites and these results in faster heat dissipation from the contacting surface. This finally results in less thermal softening and hence, lesser wear. Also, high heat carrying capacity of oil causes

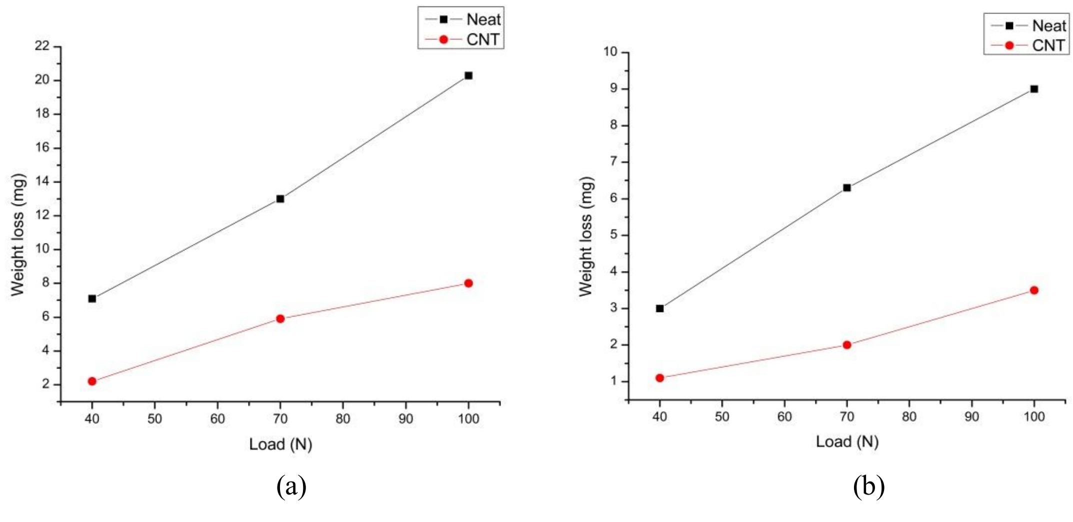
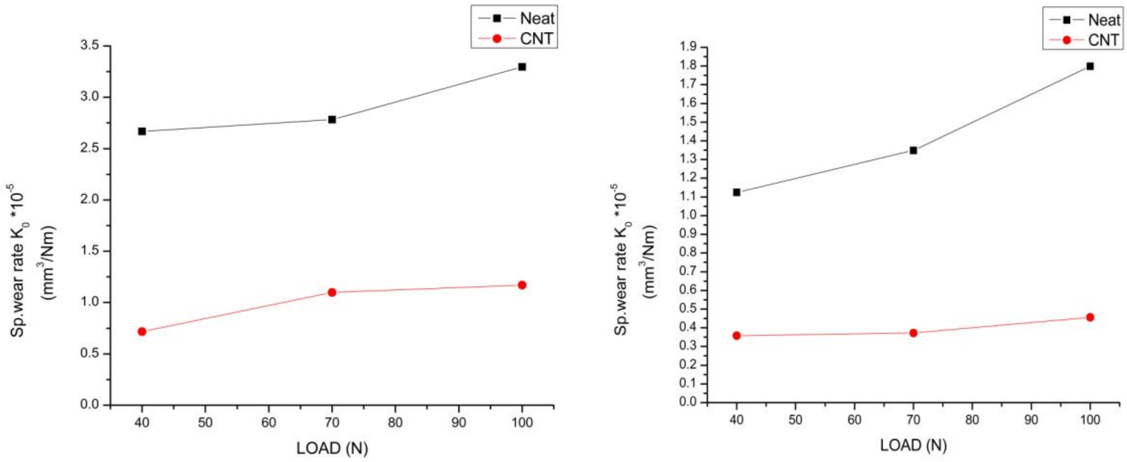


Figure 3: (a) Weight loss of samples (in mg) v/s normal load (N) under dry condition for neat HFRP and MWCNTs doped HFRP composites at 4.52 m/s (b) Weight loss of samples (in mg) v/s normal load (N) under oil lubricated condition for neat HFRP and MWCNTs doped HFRP composites at 4.52 m/s

Lower temperature rise and therefore low weight loss in oil lubricated condition compared to dry lubricated condition for both the composites.

3.2 Specific wear rate:

In order to determine wear behavior, weight loss of each specimen itself is not sufficient. So we calculate specific wear rate. The variation of specific wear rate with respect to load for both composites under dry and oil lubricated condition is shown in figure 4 (a) and (b) respectively. As we increase the load specific wear rate also increases for both the materials. Due to severe plastic deformation of the matrix at higher load, dimension of wear particles increases in both the materials and this result in an increase in wear rate with the increment in normal load. From figure 3 (a) and (b), it is clear that specific wear rate of HFRP with pure epoxy is higher than that of MWCNTs doped HFRP for the same sliding conditions. It is due to the fact that graphite-like structure of carbon in MWCNT acts like a solid lubricant, which reduces the specific wear rate in MWCNTs, doped HFRP as compared to wear rate in HFRP with pure epoxy.



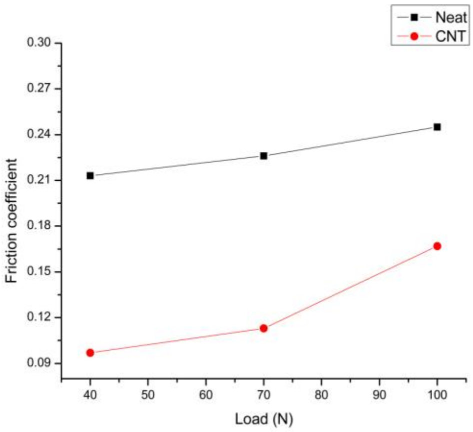
(a) (b)

Figure 4: (a) Variation in specific wear rate v/s normal load (N) under dry condition for neat HFRP and MWCNTs doped HFRP composites at 4.52m/sec (b) Variation in specific wear rate v/s normal load (N) under oil lubricate condition for neat HFRP and MWCNTs doped HFRP composites at 4.52m/sec

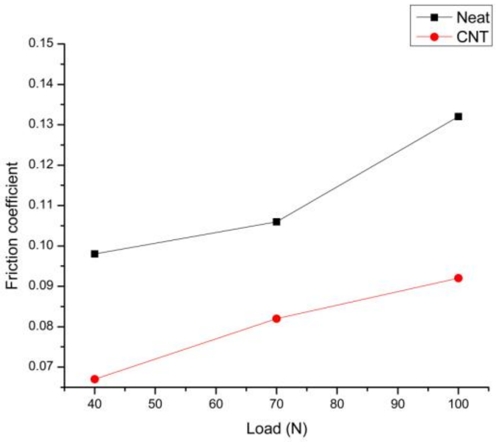
Experimental data also reveals that for both the material at all loads the value of wear rate is more in the dry environment compared to oil lubricated environment. This is because in oil lubricated condition a transfer film is formed over steel counter surface and it reduces the adhesive force between the surfaces, which results in reduction in ability of metallic particles present at the counter surface to plough soft polymer composite.

3.3 Coefficient of friction

The points shown in the graph of figure 5 (a) and (b) indicate mean value of the coefficient of friction at corresponding testing parameter. Factors mainly responsible for the increase in friction coefficient with load are breakage of reinforcement, plastic deformation of matrix etc. [12]. As per the observation, with an increase in load, the coefficient of friction for both dry and oil lubricated condition also increases. As load increases temperature increases and this leads to the formation of wear debris. As steel disc is rotating against the stationary samples it prevents the wear debris to remain over the contacting region and these results in new contact formation of fibers with steel disc. Therefore coefficient of friction increases as normal load increases for both the composites. In case of MWCNTs doped HFRP composites, CNTs present in the composite breaks out and form a carbonaceous film on the steel surface and this film act as a lubricating medium. Due to the formation of this layer nano composites have low friction coefficient compared to neat composite.



(a)



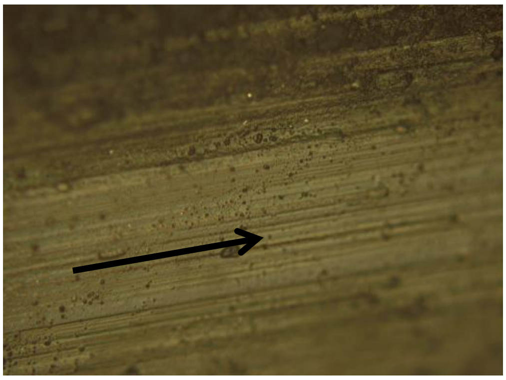
(b)

Figure 5: (a) Variation of Friction coefficient v/s load under (N) dry condition for neat HFRP and MWCNTs doped HFRP composites at 4.52m/sec (b) Variation of Friction coefficient v/s normal load (N) under oil lubricated condition for neat HFRP and MWCNTs doped HFRP composites at 4.52m/sec

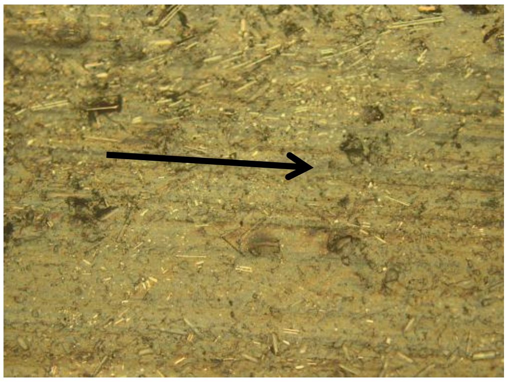
Again, higher accumulation of soft debris between fibers in oil lubricated condition results in lower value of friction coefficient compared to dry condition for both the materials.

3.4 Morphology

In order to analyze further the wear behavior and delamination of fibers, the worn surfaces of both composites under dry environment were studied by optical microscope. Figure 6-8 shows the micrographs of the specimens at 4.52 m/s in dry conditions. Images of the worn-out surfaces were taken at a magnification of 100x.The arrow lines indicate the direction of sliding. It can be observed from the micrographs that at low loads the worn surfaces are comparatively smooth for both the composites. But as load increases the damage of fibers and matrix also increases. At high loads, high accumulation of fiber debris can be observed on the counter surface. Due to three body abrasive effect on the counter surface, fiber debris and HFRP composites the wear resistance decreases with increase in load. Therefore, wear also increases and it can be observed from the micrograph. It can also be observed from the micrograph that surface damage in case of MWCNTs doped composites surface is lower compared to neat composite.

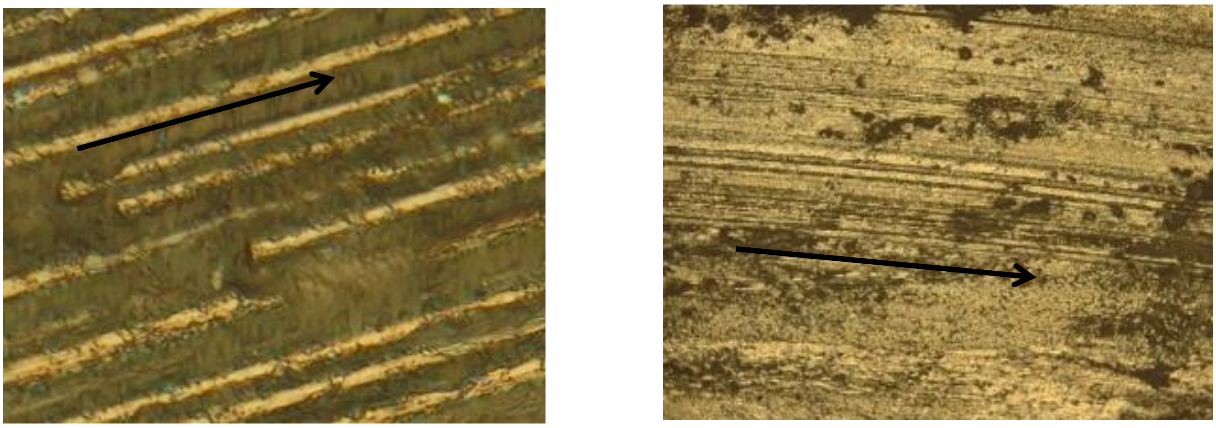


(a)



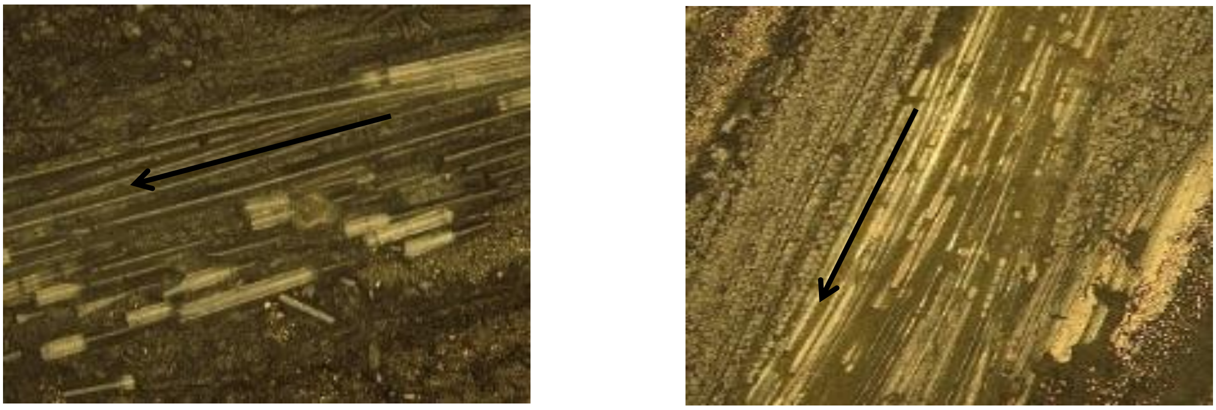
(b)

Figure 6: Worn surface of (a) neat HFRP and (b) HFRP doped with MWCNT sliding under dry environment at 40N



(a) (b)

Figure 7: Worn surface of (a) neat HFRP and (b) HFRP doped with MWCNT sliding under dry environment at 70N



(a) (b)

Figure 8: Worn surface of (a) neat HFRP and (b) HFRP doped with MWCNT sliding under dry environment at 100N

4. Conclusions

In this experiment tribological behavior has been investigated for neat and CNTs doped HFRP composites. Some of the important inferences that can be drawn directly from the investigation are as follows:

- The friction coefficient, specific wear rate and weight loss increases for both the composites with increase in loads.
- Friction coefficient, weight loss and specific wear rate for all the loads in oil lubricated condition are less in comparison to dry lubricated condition.
- MWCNTs doped HFRP composite shows better tribological properties compared to neat HFRP composites.

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