Effect of MWCNT on the Tribological Behavior of GFRP Composites under dry sliding condition

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Abstract :

Tribological behavior of a material is dependent on various factors. This paper investigates the effects of doping percentage of MWCNTs in GFRP composites on their wear and friction characteristics. Materials having different concentrations of MWCNTs (i.e. 0 wt.%, 0.5 wt.%, 1 wt.%, 1.5 wt.%, and 2 wt.%) were rubbed against a counter surface of steel (En-31) having a hardness of 60 HRC and average surface roughness of 02-0.5 ¼m. The experiments were performed on pin-on-disc type tribometer under dry sliding with constant sliding velocity, constant sliding distance and different loading conditions. The observations were compared on the basis of weight loss and specific wear rate to determine the wear characteristics, while the coefficient of friction to determine the friction behavior. All the results were further examined with FESEM analysis.

Keywords: MWCNTs; GFRP; Wear; Friction; Dry sliding condition.
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1. Introduction

at affordable cost. Fiber reinforced polymer (FRP) materials are used in almost every field of advanced engineering structure such as aircraft, helicopters, spacecraft, boats, ship, automobile, sports goods, chemical processing equipment[2]. Increasing application of FRP material influenced researchers to study the friction and wear behavior and to improved wear resistance. Tribological behaviors of polymer composite are different from well understood tribological properties of metals and ceramics. For fiber reinforced polymer matrix composites of material removal under dry sliding condition is dominated by generally four wear mechanisms, viz., matrix wear, fiber sliding wear, fiber fracture and interfacial debonding [3].

The tribological properties of polymers are commonly improved by addition of different reinforcing filler and solid lubricant fillers, commonly reinforcing filler include glass fiber, carbon fiber and solid lubricants include MoS2, graphite, polytetrafluoroethylene(PTFE), SiO2, etc [4]. Thermoset epoxy resins are widely used as matrix materials for composite structures application because they exhibit low shrinkage, higher mechanical properties, easy fabrication, excellent chemical and moisture resistance[5]. Epoxy resins polymer reinforced with glass fiber provided the higher mechanical as well as tribological properties[5]. Nevertheless, further incorporation of CNTS in glass fiber reinforced polymer composite exhibit lower coefficient of friction and wear rate as compared GFRP composite. CNTs have high thermal conductivity and layer structure which help in self-lubrication. Bobbili and Madhu [6] reported that GFRP with CNT showed lower coefficient of friction, wear rate and mass loss and this parameter reduced with increased of CNT weight percentage. Srivastava [7] revealed that friction coefficient and wear rate is dependent on the applied load. Their result showed the friction coefficient and wear loss increased with increase of applied load. Nevertheless, incorporation MWCNT improved the wear resistance of the woven carbon fabric reinforced epoxy composite.

2. Experiment

2.1 Material Specification

This investigation consists of comparison of tribological characteristics of epoxy resin matrix with neat GFRP composite and MWCNTs doped GFRP composite which consist MWCNTs concentration of 0.5 wt. %, 1 wt. %, 1.5 wt. % and 2 wt. %. The epoxy (L-12) along with hardener (K-6), both provided by Atul Industries Pvt. Ltd., India, was used. Bi-directional woven E-glass fibers of 600 gsm were used as primary reinforcements while pristine multi-walled carbon nano-tubes (MWCNTs) of length 1-10 ¼m and diameter 5-20 nm were used as secondary reinforcement.

2.2 Material Fabrication

Laminate composites were fabricated using hand layup technique followed by the vacuum bagging process. All the samples were symmetric laminates having eight glass fabrics layer stacked in the sequence of [(0o/90 o)/ (-45o /+45o)/ (-45o /+45o)/ (0o /90o)]s. For neat GFRP composite, firstly epoxy resin was mixed with hardener in the ratio of 10:1. The solution was then applied on the glass fiber woven using a brush to accomplish the desired stacking sequence. The excess resin was removed using a roller after application of solution to each layer. For further removal of excess resin, vacuum bagging was used at the pressure of 650 mm of Hg for 35 minutes. After this, a load of 40 kgf was applied for 24 hours. Samples of dimensions 6mm x 6mm were cut from the laminate composites.

For composites doped with MWCNTs, firstly, the MWCNTs were dried at 60oC for 40 minutes. Dried MWCNTs were then mixed with epoxy resin in the required weight percentage (i.e. 0.5, 1, 1.5 and 2 wt. %) using probe ultrasonicator for homogeneous dispersion for 45 minutes. After proper mixing, hardener was mixed in the ratio of 10:1 and the solution was further mixed using ultrasonicator for 10 minutes. The solutions of epoxy, hardener and each concentration of MWCNTs were used to prepare laminates in the similar fashion as described previously. The samples of the same size (i.e. 6mm x 6mm) were cut and were glued to the aluminum pins of diameter 6mm (Fig. 1(a)).

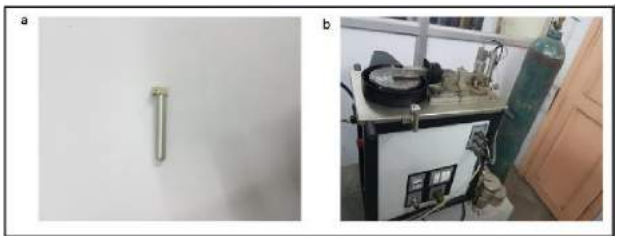


Fig.1 (a) specimen glued with Al pin (b) pin on disc machine

2.3 Tribological Testing

The tests were performed on pin on disc (TR-20) by DUCOM. The parameters which could affect the wear and friction behavior of materials are pair of sliding materials, temperature, sliding environment, sliding distance, sliding velocity and normal load. In this study, the experiment was performed in dry environment condition at room temperature. The test materials are described previously and counter surface used was steel disc (En-31) having hardness of 60 HRC and average surface roughness of 0.2-0.5 ¼m. The disc was cleaned with acetone so as to remove any wear debris or dust. Normal load applied to each kind of material is 20N, 40N, 60N, and 80N. Sliding distance (H”942 m) and sliding velocity (H”1.57 m/s) are kept constant by keeping rpm (600 rpm) and sliding time (600 seconds) constant. Each specimen was weighed before and after the experiment. The sliding direction was kept parallel to the fiber orientation. The wear and friction characteristics of specimen were determined by weight loss, specific wear rate and coefficient of friction.

3. Results and Discussion

3.1 Weight Loss

Weight loss is one of the prime factors to be considered while determining wear characteristics of a material. Weight loss (or wear) is dependent on many factors such as temperature, normal load, sliding velocity, sliding speed, sliding environment. However in this study, factors such as sliding environment (dry), sliding

speed, sliding distance and temperature were constant. So weight loss was dependent on normal load. Fig.2 (a) shows weight loss with respect to normal load for different samples. Wear in CFRP composite occur due to thermal softening of the laminates. It was observed that temperature of the disc was higher for the higher loads. Higher value of normal load leads to higher actual contact area, which results in more rubbing and generating more heat. This leads to more thermal softening and hence, more weight loss. It may also be observed from Fig.2 (b) that weight loss decreases with the introduction of MWCNTs. Furthermore, with the increment in MWCNTs concentration, the weight loss decreases for a given value of normal load. This is because MWCNTs increases the cohesive nature of the material, resulting in less adhesive wear. Also, MWCNTs increases compressive strength of the sample, leading to decrease in actual contact area for the given value of normal load.

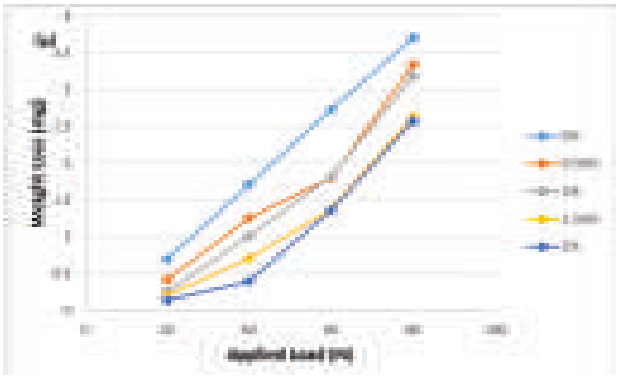


Fig. 2(a) weight loss as a function of applied load for different MWCNT concentrations.

Fig.2 (b) weight loss as a function of MWCNT wt.% for different for load

3.2 Specific Wear Rate

Specific wear rate is one of the factors determining the wear characteristics more precisely as compared to weight loss. By definition, the specific wear rate of a material is the volume loss of material, per unit of normal load, per unit of sliding distance. It may be expressed as

$$Specific\ Wear\ Rate\ (K_s) = \frac{\Delta m}{\rho * L * d}\left(\frac{mm^3}{N-m}\right)$$

where,

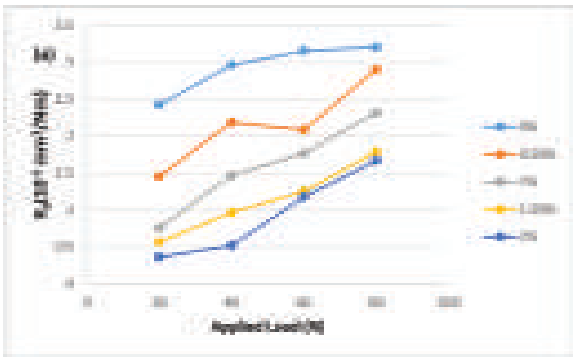
$_{\triangle}$m ≡ mass loss (kg)

ρ ≡ density of the sample (kg/mm3)

L ≡ normal load (N)

d ≡ sliding distance (m)

From Fig.3 (a), it may be observed that with the increment in normal load, the value of specific wear rate increases. It is known that with the increment in load, weight loss increases. From the formula above, it may be noted that both numerator (weight loss) and denominator (load) increases with the increment in normal load. So as per the observations, the increased value of specific wear rate determines that rate of increment of weight loss is higher than that of change in value of normal load. Also, it is observed from the Fig.3 (b) that with the increment in concentration of MWCNTs, the values of specific wear rate decreases for a given value of normal load. It is due to the decreased weight loss and rests all the other factors being same with the increment in MWCNTs concentration, similar trend was also reported by the author [6].



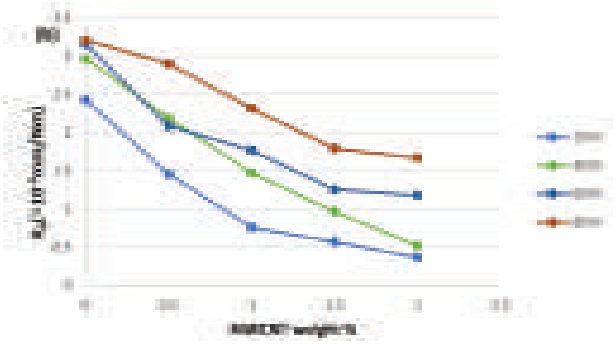


Fig.3 (a) Specific wear rate vs applied load at sliding velocity of 1.57 m/s

Fig.3 (b) Specific wear rate vs MWCNT concentration at sliding velocity of 1.57 m/s

3.3 Coefficient of Friction

Coefficient of friction may be used to analyze the friction behavior of sample. Friction results from the asperities at micro level. Fig.4 (a) shows that with the increment in load, the coefficient of friction increases. There are two common phenomenon governing the friction behavior one is increment in amount of glass fibers as wear debris and acting as solid lubricant, forming a tribo-film and thereby reducing the coefficient of friction, and one is more exposure of new surface due to removal of previous surface, leading to uneven profile of new surface, hence resulting in higher coefficient of friction. From the observation, it may be said that the later phenomenon is dominant in this experiment, resulting in higher coefficient of friction for higher loads[8]. It may be observed from Fig.4 (b) that with the increment in concentration of MWCNTs, the value of coefficient of friction reduces for a given value of normal load. This results from the graphite like structure of MWCNTs, reducing the coefficient of friction. It may also be noted that difference in coefficient of friction in neat GFRP and MWCNT doped GFRP is greater as compared to any two MWCNT doped sample of different concentration for a given load. It shows that introduction of MWCNTs results in better friction behavior, but magnitude of improvement in friction behavior is lesser with the increment of concentration of MWCNTs.

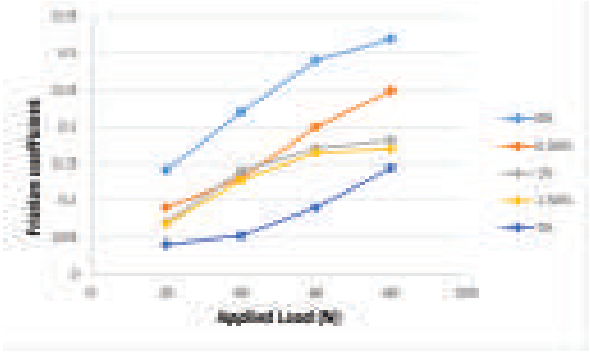


Fig.4 (a) Friction coefficient vs applied load at constant velocity of 1.57 m/s

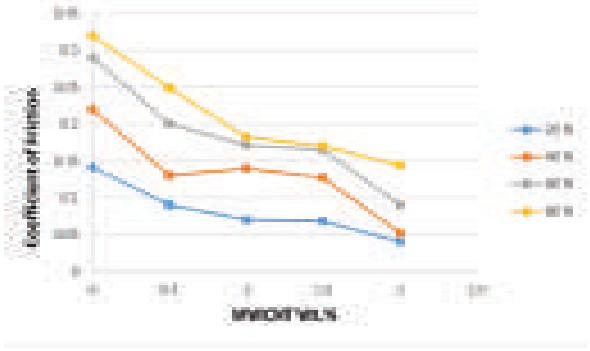


Fig.4 (b) Friction coefficient vs MWCNT concentration at constant velocity of 1.57 m/s

3.4 Field Emission Scanning Electron Microscope.(FESEM)

The FESEM of worn surface specimens of GFRP composite and MWCNT filled composite at working condition are detected. The SEM feature of GFRP composite subjected to load of 20 and 80 N and sliding velocity of 1.5m/s are shown in Fig.5 (a) and Fig.5 (b). At 20 N load, it was observed that there is less matrix material removal this is due to heat generated at the interface of tribo surface was lower caused lower thermal softening of the matrix and no fiber breakage are noticed. The SEM photographs support the glass fibers still closely adhere to the epoxy matrix which is reason to lower wear rate found at 20 N loading conditions. In Fig.5 (b), it can see that higher matrix material removal at 80 N and also debonding of fiber/matrix has been clearly recognized. Thus, wear rate increased with increased of applied load from 20N to 80N[9].