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Effect of CNTs on the Wear and Friction Performance of Carbon Fibre Woven Fabric Reinforced Epoxy Resin Composites

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Abstract Multi-walled carbon nanotubes (MWCNTs) filled carbon fibre woven fabric reinforced epoxy resin composites were fabricated by hand lay-up method. The tribological properties of the composites were investigated systematically using reciprocating wear and friction machine under different sliding conditions. Experimental results show that the friction force, wear loss and friction coefficient significantly increases with increase of load at fixed sliding time whereas wear loss reduces sharply with increase of sliding time at fixed applied load. However, sliding temperature gradually reduces and stabilized after 5 min. The worn surfaces of the composites were examined by scanning electron microscope (SEM). The friction and wear of the MWCNT filled carbon fabric composites result indicates that the wear and friction coefficient increases with increasing applied load.

Keywords Carbon Fibre Woven Fabric, MWCNTs Particles, Epoxy Resin, Friction Force, Friction Coefficient, Wear

1. Introduction

Carbon nanotubes (CNTs) have been recognized as a potential candidate for the reinforcement of polymeric composites due to their many excellent physical, mechanical and functional properties, and extremely high aspect ratios. Depending on the area of applications, CNT/polymer composite can be classified into structural and functional composites [1-3]. For structural applications, much improved mechanical properties are explored based on the high modulus, tensile strength and strain to fracture, and excellent damping characteristics of CNTs. The degree of improvement of CNTs on mechanical properties of composites totally depends on the dispersion and interfacial adhesion of CNTs in the composites [4-6].

The incorporation of CNTs with conventional micro-scale fibre reinforcements in a common polymer matrix can be achieved by modifying the matrix resin or the fibre reinforcement using CNTs. Various techniques have been used for CNTs dispersion into polymer matrix, which include shear mixing, calendaring, extrusion, ultrasonication and ball milling [7]. One of the major problems is that the viscosity of CNT modified matrix increases dramatically with increasing CNT content, even with a very small content below 1 wt%, leading to severe agglomeration of CNTs in the bulk of composite. The highly viscous and CNT agglomerated resin systems cannot be processed using conventional composite method [8, 9]. Therefore, conventional approach of mixing CNTs with a polymer epoxy resin require before the fibre reinforcements.

Due to attractive application of epoxy resin in many fields, the demand for the wear resistance of epoxy resin is becoming strict because epoxy resin displaying a lower wear resistance [10]. The combination of epoxy resin with inorganic particles has become an attractive approach to improve the wear resistance of epoxy resin to meet the demand of automotive industries.

Hence, CNTs as reinforcement can be used in the epoxy resin to improve the mechanical properties of epoxy resin [8]. Since, multi-walled carbon nanotubes consists of hollow rolled-up graphite-like structure, resulting in self-lubricating property of MWCNTs, which makes MWCNTs promising candidates as antifriction and abrasion resistance material. Many groups have reported friction and wear behaviour of CNTs/epoxy resin composites [11-14]. They reported that the friction coefficient and wear rate of MWCNTs/epoxy resin composite gives lower value compared to pure epoxy resin. The wear rate decreased with the increase of MWCNT loading [13].

Carbon fibres exhibit self-lubricating properties due to the composition of various graphite planes. Compared with short carbon fibres or continuous carbon fibres, the carbon fabric shows better load-carrying capacity and tribological properties due to the properly aligned structure. The carbon fibre reinforced friction material shows lower wear rate than

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glass fibre and asbestos fibre reinforced composites within the temperature range of 100-300°C. The friction coefficients of carbon fibre reinforced plastic composite (CFRP) increases as friction temperature increases from 100 to 300°C due to fibre thinning and pull-out [15-17].

The modification of tribological behaviour of carbon fabric polymer composite by the addition of micro or nano filler material has been introduced to be quite encouraging. Many researchers studied the effect of solid lubricants and nanoparticles on the tribological properties of carbon fabric composites [18-20]. Among the various inorganic fillers, potassium titanate wisker (PTW) has been considered to be a promising reinforcement for the wear resistant composites. The small size and high ratio of length to diameter of PTW are very useful for reinforcing polymer [20]. To the best of my knowledge, there is hardly any work reported on the tribology of MWCNT filled woven carbon fabric reinforced epoxy resin composites.

In this work, friction coefficient and wear of MWCNT filled woven carbon fabric reinforced epoxy resin composites have been studied with the variation of applied load and time. The worn surfaces were examined by scanning electron microscope (SEM) to explain the wear mechanisms of CNTs filler in the woven carbon fabric and epoxy resin. It is believed that this result will provide the application of CNT filler in the woven carbon fabric composites for self-lubricating bearings.

2. Experimental Work

2.1. Materials and Specimen

Araldite (LY-556) 55%, hardener (HY-917) 49% and accelerator (DY-070) 0.28% were used as epoxy resin matrix obtained from Ciba Gaigy Ltd., Mumbai, India. MWCNT nanoparticle was used as fillers. This was procured from J.K. Impex Company, Mumbai with 99.5% purities. Woven carbon fabric (0/90^{o}) was obtained from Carbon Nexus, Institute of Frontier Materials, Deakin University, Geelong, Victoria, Melbourne, Australia. The material properties are listed in Table-1.

Firstly, 2 wt % of MWCNT nano filler was manually mixed with the resin (LY-556) separately. It is well known that nearly 2 to 3 weight percentage of MWCNT nano filler is dispersed uniformly in the polymer matrix, which has high mechanical properties [2]. Then nano filled resin was dispersed using a lab-scale three-roll-mill (EXAKT 120 Advanced Technology GmbH, Germany) process. This process was controlled by between introduction the of very high shear rate (up to 200,000 s^{-1}) throughout the suspension. The pre-dispersed suspension was then given batch wise onto the roll with dwell times of 2 minutes. The dispersive forces on the suspension were acting in the gap (5μm) between the rolls. After dispersion of the MWCNT with epoxy resin, the hardener (HY-917) in the weight ratio of 10:1 and accelerator were added in a vacuum dissolver in the mixture of MWCNT/resin, in order to avoid trapped air in the suspension. The mixture was placed in a vacuum chamber for 30 minutes to eliminate the bubbles introduced during the rolling process. Then dispersed mixtures were poured into the mould and allow curing the woven carbon fabric and MWCNT reinforced epoxy resin mixture for 24 hr. The fibre volume fraction was approximately 47% and the void content was less than 2%. After curing, specimens were prepared as per the ASTM G203-10 standard for the measurement of tribological properties.

Table 1. Material properties [2]

Material	Geometry	Elastic modulus, GPa
MWCNT 99.98%	Average Length = 2 μm Average Inner diameter = 6.5 nm Average Outer diameter = 40 nm	1000.0
Epoxy resin	-	2.0
Woven carbon fabric	Thickness = 0.50 mm, Fabric Direction =0/90^{o}	70

2.2. Friction and Wear Measurements

Wear and coefficient of friction was measured from reciprocating sliding wear and friction monitor instrument (TE-200ST). Reciprocating wear test was performed against high chromium steel ball having a 10 mm diameter with 3.3 Hz reciprocating frequency. The total stroke length was set at 3mm for all tests and was conducted for 10 min at a normal load 50N. The variation in coefficient of friction and temperature were obtained from the machine itself and the wear loss was measured with the help of electronic digital balance.

2.3. Morphological Observations

The morphological behaviour of MWCNT filled woven carbon fabric composites were observed through a scanning electron microscope (SEM). SEM samples were prepared into 10x10 mm sizes via a diamond cutter and placed on a SEM grid for the characterization of composite features. The samples were observed using a Hitachi HF-2000, 200kV SEM.

The carbon fibres are stacked and impregnated with phenolic resin using hand laying procedures. The mould is then warm pressed, cured and post-cured in a vacuum oven to obtain the carbon fibre reinforced plastic composites (CFRP). The open porosity of the matrix is nearly about 1% at this step.

3. Results and Discussion

3.1. Effect of Sliding Time on Friction and Wear

The sliding temperature, friction force, friction coefficient and wear loss with variation of sliding time of 2% MWCNTs filled woven carbon fabric reinforced epoxy resin composites at constant applied load 50N are shown in Figs.1-3. Fig.1 clearly shows the sliding temperature fluctuating within the range of 23.5 to 25.5°C with the increase of sliding time from 0 to 30 min.

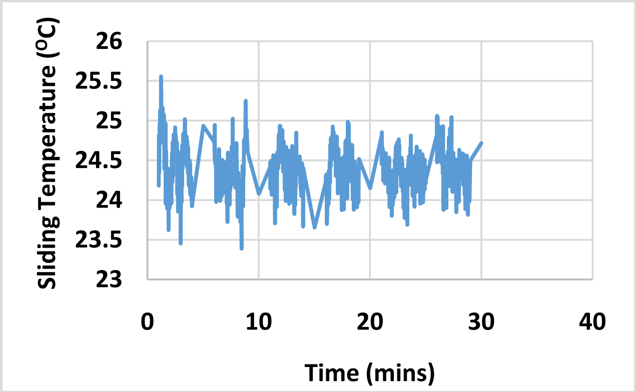

Figure 1. Variation of sliding temperature with time at constant load 50N

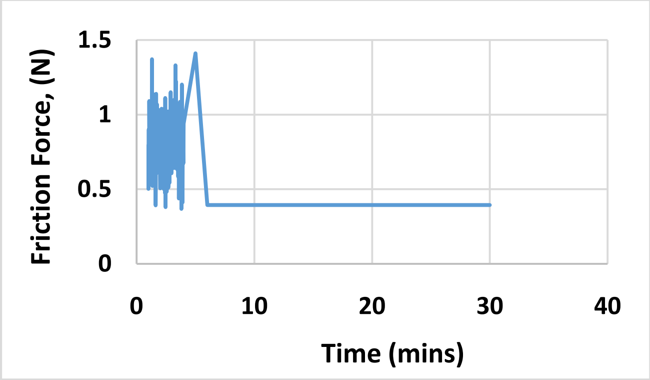

Figure 2. Variation of friction force with sliding time at constant load 50N

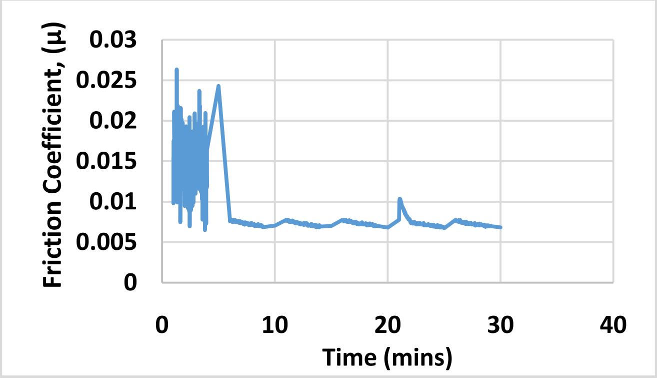

Figure 3. Variation of coefficient of friction with sliding time at constant load 50N

After 10 min, fluctuating temperature reduces in between 23.7 to 25.1°C and gets saturated because of the transfer of thick layer of debris film. The friction force is fluctuating in between 0.4 to 1.4N for short duration of time 5 min and then constant at 0.4N till the end of sliding time as shown in Fig.2. During this period, the friction coefficient varies in between 0.007 to 0.1 as can be identified from Fig.3. It can be seen that the wear loss decreased dramatically when experiments are progressed with the variation of sliding time at constant load 50N as can be identified from Fig. 4.

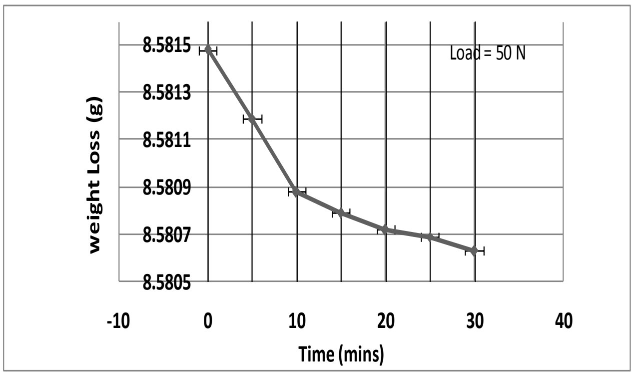

Figure 4. Variation of weight loss with time at constant load 50 N

3.2. Effect of Applied Load on Friction and Wear

Figs. 5-7 clearly indicate that the friction force, friction coefficient and wear loss increased with increase of applied load at constant 30 min sliding time. These figures show the gradual increase of friction force, friction coefficient and wear loss up to 70 N and then drastically increased till 80N load.

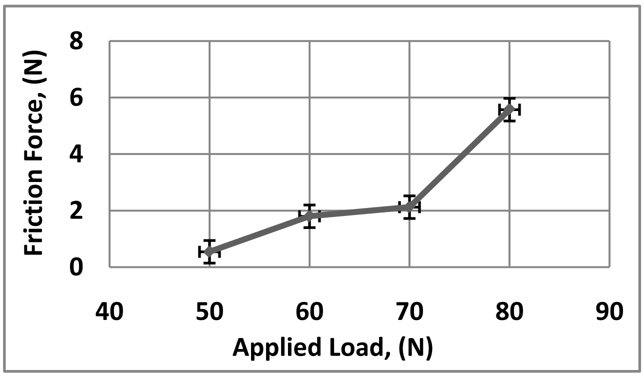

Figure 5. Variation of friction force with applied load at constant time 30 min

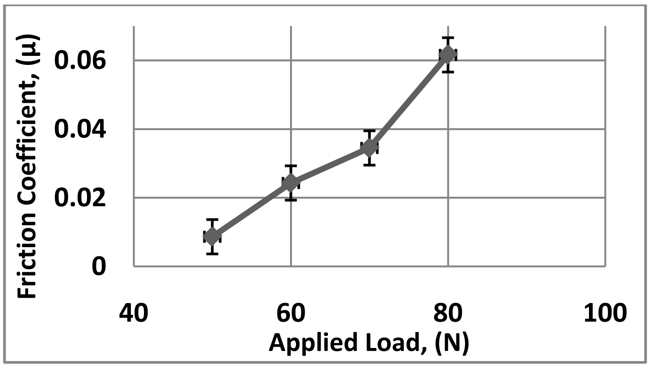

Figure 6. Variation of friction coefficient with applied load at constant 30 min

It can be found that the friction force (Fig.5), friction coefficient (Fig. 6) and wear loss (Fig. 7) increased rapidly after 70 N load because more whiskers are worn out of the woven carbon fabric and became abrasive, which deteriorated the wear resistance of the composite [11].

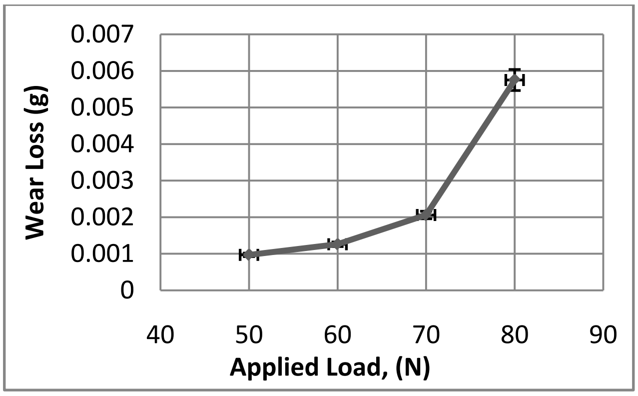

Figure 7. Variation of wear loss with applied load at constant time 30 min

These more wear debris and broken fibre fragments on the worn surface are appeared and can be identified from SEM micrograph as shown in Fig. 8. The friction coefficient of 2% MWCNT filled woven carbon fibre reinforced epoxy resin composite (0.08) is less than the pure epoxy resin (0.76) and woven carbon fibre (±45^{o}) reinforced epoxy resin composite (0.45), when sliding over the high chromium steel [8]. This reflects that the MWCNT particle reduces the friction coefficient. On the other hand, the higher applied load resulted in a high temperature rise at the counter face, which increases the friction force and friction coefficient as shown Figs. 5 and 6. The polymer surface was plasticized by the rising temperature and followed a decreasing in the carrying capacity of epoxy resin, and the epoxy resin can be detached off easily with MWCNT and carbon fibre, which might facilitate to increase the wear loss and friction coefficient. However, the MWCNTs nano filler reduced the wear loss and friction coefficient of woven carbon fabric reinforced epoxy resin composites [12]. The competitive effect on the wear loss and friction coefficient led to different results with the increasing of load. Under 50N, a lower friction force, friction coefficient and wear loss were obtained, and when the applied load is above 80N, a higher friction force, friction coefficient and wear loss were measured. Meanwhile, the effect of MWCNTs nanofiller on wear and friction coefficient of woven carbon fabric epoxy resin composite is very less compared to potassium whisker filled carbon fabric phenolic polymer composite. It indicates that the MWCNTs nanofiller act as a self-lubricating material [7].

3.3. Morphology of Worn Surfaces

In order to understand the morphology of the worn surfaces of the counterpart 2% MWCNT filled woven carbon fabric reinforced epoxy resin composite pins sliding against steel surface at load 80N and sliding time 30 min are shown in Figs. 8 & 9. It is seen that the debris formation and broken fibres take place. The worn surface is not smoother and visible as blocky fragments.

The abrasion mechanisms of 2% MWCNT woven carbon fibre composite are mainly due to adhesion wear and deformation of epoxy resin matrix. This indicates that the MWCNT particle is an effective method to decrease adhesion wear and improve the wear resistance [16]. From Fig. 8, it can be seen that the worn surface of the composite appears straight furrows, indicating that abrasive wear is the main wear mechanism of the composites under 80N load.

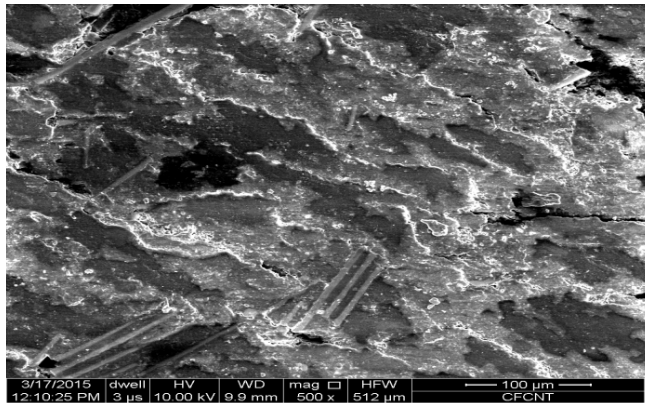

Figure 8. SEM image showing the wear surfaces and debris

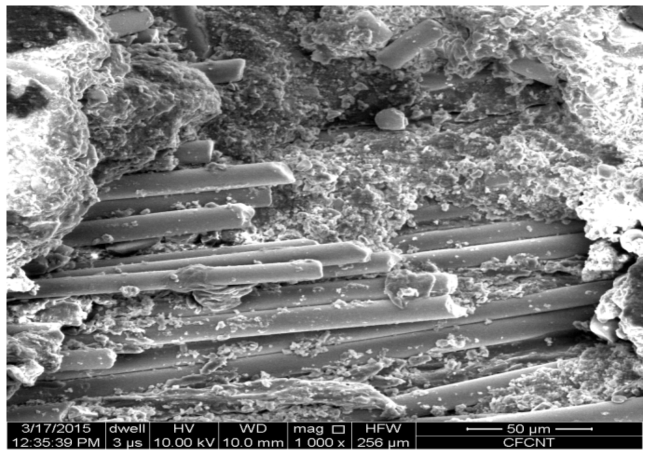

Figure 9. SEM image showing the worn surfaces, fibre fracture and debris

This indicates that the cracks are produced under the repeated shear force, making the surface of material to be spelled, which is appeared due to fatigue wear mechanism. During wear test, higher amounts of frictional heat are generated which caused degradation of the epoxy resin and weekend the fibre-matrix interface bond. However, MWCNTs nanoparticles increase the toughness and interface bond strength of fibre-matrix [2, 3]. Keeping sliding time constant, when we decrease the load to 60N, it yields a composite sample with good spread of the matrix, cracks in the matrix and fewer debris (Fig. 8). On the other hand, once the applied load progress, fibre deboneded, broken and crack propagated along sliding direction as shown in Fig. 9. With the increase of applied load, the epoxy resin decomposes and softens and melted, it increase the fibre debonding and fibre pull-out sufficiently under shear force as can be identified from Fig. 8. These results further demonstrated that CNTs filler act as barrier to resistance the worn surfaces in between fibre and steel, when composite pin sliding with the steel counter face in dry conditions, the formation of the transfer film is always thought to be an important factor to enhance the wear resistance of the epoxy resin composite [17]. The improvement in the transfer film contributed to a decrease in the friction coefficient and wear loss. The graphite particles transferred to the sliding surfaces and appeared in the form of thick debris as can be identified from Fig. 9.

4. Conclusions

This study investigated the effect of MWCNTs, applied load and sliding time on the friction and wear behaviours of woven carbon fabric reinforced epoxy resin composite. The sliding temperature, friction force, friction coefficient and wear loss are dependent on the applied load and sliding time. The friction coefficient and wear loss increased with increase of applied load. However, incorporation of 2% MWCNT increase the wear resistance and reducing the friction abilities of the woven carbon fabric reinforced epoxy resin composite. The woven carbon fabric filled 2% MWCNT epoxy resin composite exhibit the smallest friction coefficient and the wear loss compared to reported work [15, 20].

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