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Dry sliding wear of recycled carbon fiber reinforced epoxy composites

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ABSTRACT – In this paper, the role of as-received (rCF-AR) and cryogenic treated (rCF-T) recycled carbon fiber (rCF) reinforcements were investigated on the tribological behavior of epoxy composites by using a micro pin-on-disc tribotester apparatus under dry sliding condition. The wear behavior of the composites was analyzed based on three different sliding velocities at a constant load and constant sliding distance. The results showed the reinforcement effect of rCF-T as compared to rCF-AR has enhanced the wear resistance of epoxy composite, which are attributed by the improved adhesion between the treated rCFs and epoxy matrix.

1. INTRODUCTION

The current trend of carbon fiber reinforced thermoset polymer composite material has formed a very important class of tribo-engineering materials in non-lubricated condition. This is particularly due to their lightweight as compared to conventional materials. In addition, carbon fiber improved mechanical and tribological properties of epoxy composites [1]. Due to their advantages, this has posed the approaching needs to recycle and reuse the non-biodegradable carbon fiber composites' waste in the landfills.

A composite's wear performance is determined by the interfacial adhesion of the fiber/matrix. Therefore, the cyclic cryogenic treatment was introduced to promote strong interfacial bonding between the fibers and the matrix as reported by researchers [2, 3]. The treatment has proven to shell off remnant of epoxy resin as well as the weak amorphous carbon layer along the recycled carbon fiber surface [3], leading to increase surface roughness of the fibers that provide more active sites for better adhesion of the fiber with the freshly introduced matrix [4].

In this study, the wear behaviors of as-received and cryogenic treated recycled prepeg carbon fiber reinforced epoxy composites are compared at different sliding velocities at a constant load to understand the effect of the reinforcements on the wear mechanisms of composites.

2. METHODOLOGY

2.1 Materials

Thermoset liquid epoxy resin made from Bisphenol-A and Epichlorohydrin cured by modified liquid amines used in this study as the matrix polymer was supplied by Chemrex Corporation Malaysia. As received (rCF-AR) and cryogenic treated (rCF-T) are used for the study. rCF-T was prepared by immersing rCF-AR carbon fiber in liquid nitrogen for 3 minutes and then exposed to the room temperature until the rCFs temperature reached 22 to 24 ºC for 25 times .The surface morphologies of the rCFs were observed using scanning electron microscope (SEM). The average diameter of the recycled carbon fiber is approximately 7.6 µm with an average fiber length of about 90 µm.

2.2 Fabrication of Epoxy Composites

The rCFs were homogeneously dispersed in epoxy resin through ultrasonic dispersion for 10 minutes using an ultrasonicator (UP100H, Hielscher). After dispersion, the mixtures were then added with a hardener followed by mechanical stirring at 99 rpm under vacuum for 10 minutes in Vacuum Casting Machine. The well-mixed composites were then flowed into silicone mold pattern in the vacuum environment. The composites were left to cure at room temperature for 24 hours. The composition of the composites: EP/rCF-AR (epoxy reinforced as-received rCFs) and EP/rCF-T (epoxy reinforced treated rCFs) was 90 wt. % of epoxy resin and 10 wt. % of rCFs.

2.3 Wear Test

Micro pin-on-disc tribotester (CM-9109, Ducom) as per ASTM G99 was utilized for the dry sliding wear experiments at room temperature to study the wear behavior of the composites. The counter-body of the wear disc is made of EN-31 steel hardened with an average initial surface roughness of 0.2 µm and hardness of 58-60 HRc. The tests were carried out at a constant load of 16 N with three sliding velocity of 0.4, 0.7 and 1.0 m/s under sliding distance of 21,579 m. After each wear test, the difference between the initial and final weight of the specimen was noted as a measure of wear loss to calculate the specific wear rate of the composite. For each composition, the specific wear rate was obtained by taking the average of three calculated values. After wear test, wear debris was collected for analysis.

2.4 Morphology Observation

The worn surfaces and wear debris were examined using scanning electron microscope (Evo 50, Carl Zeiss) to reveal the influence of fibers on the corresponding wear behavior and to understand the possible wear mechanism.

3. RESULTS AND DISCUSSION

Both the as received and cryogenic treated carbon fibers are shown in Figure 1. It is apparent that epoxy resins were removed from cryogenic treated recycled carbon fiber.

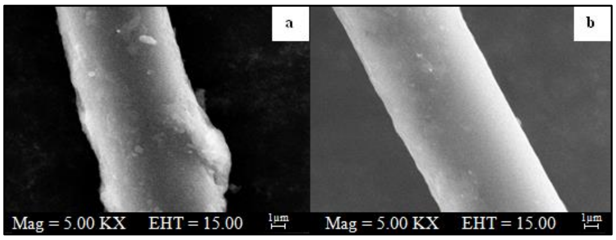

Figure 1 SEM surface morphologies recycled carbon fiber: a) as-received b) after cyclic cryogenic treatment.

The wear test results of the epoxy composites are presented in Figure 2.

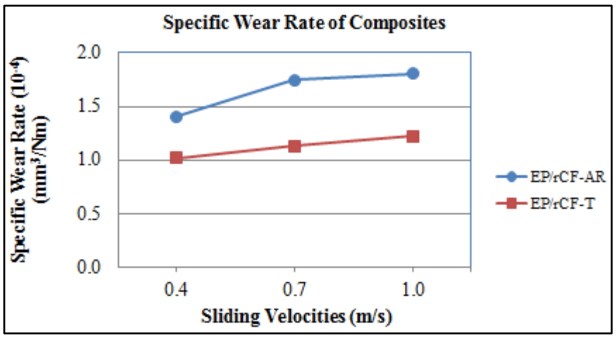

Figure 2 Specific wear rate of epoxy composites in conjunction with different sliding velocities with the constant load of 16 N and sliding distance of 21,579 m.

It is seen that the wear resistance of all EP/rCF-T composites improved significantly compared to EP/rCF-AR composites. The results revealed that the reinforcement effect of treated carbon fibers proven to be beneficial to improve the wear resistance, reflecting the importance of fiber/matrix interfacial bonding.

For EP/rCF-AR composites, fatigue wear is the main mechanism responsible for the material loss as shown in Figure 3(a). It also indicate that the particle/matrix interaction is not strong enough to resist the repeated shear loading during wear test [5]. When the breakage of epoxy matrix occurs, the fibers are easily being removed, because the local support of the matrix is missing [6]. Consequently, the specific wear rate is higher. Meanwhile, for EP/rCF-T composites, the worn surface become less coarse as shown in Figure 3(b), implying that that a major share of normal load was supported by the fibers. Therefore, fiber thinning, breakage and peeling off are the dominant wear modes. The fibers were always removed gradually and thus contributed to the enhancement of the wear resistance [6].

The depth of the peeled-off wear debris measurement further complies with the wear results. The wear debris measurements are shown in Table 2. The detached peeled-off large fiber debris of EP/rCF-AR could then act as third body abrasive that increases the wear rate of epoxy composites.

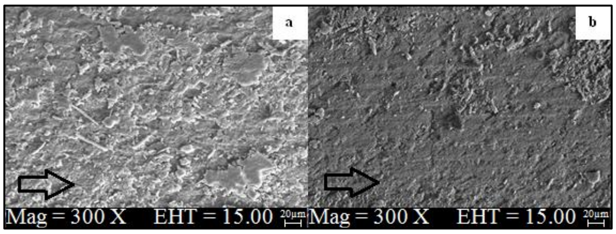

Figure 3 SEM morphologies of worn surfaces of a) EP/rCF-AR b) EP/rCF-T at 1.0 m/s with the constant load of 16 N and sliding distance of 21,579 m.

Table 2 Wear debris measurements.

Materials	**Depth (µm)**
rCF-AR	8.190 ± 0.27
rCF-T	6.546 ± 0.22

4. CONCLUSIONS

In this study, it can be concluded that the addition of cyclic cryogenic treated recycled carbon fiber is a valuable product worth to be reused in new composite material to serve as reinforcement as it improved the tribological feature of epoxy composite. This is due to the well-adhered recycled carbon fiber on the matrix.

5. ACKNOWLEDGEMENT

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