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FRICTION AND WEAR OF CARBON FIBER REINFORCED EPOXY

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ABSTRACT
The current article discusses the effect of filling epoxy by continuous and aligned carbon fiber in addition to different kinds of oil (olive, corn, sunflower, glycerin and paraffin) on friction and wear. Each oil type was added with different concentrations (2, 5 and 10 wt. %) into epoxy beside constant concentration of carbon fiber, (4 wt. %). Wear tests were performed using pin-on-disk tester at constant load (6.5 N), constant running time (300 sec) and constant speed (0.93 m/sec). To explore the pertinent mechanisms, the worn surfaces of the tested specimens were analyzed via scanning electron microscope. The results reported that reinforcing epoxy by continuous and aligned carbon fiber has significantly affected the friction and wear properties. Furthermore, filling carbon/epoxy composites by vegetables and mineral oils has promoted the tribological properties.

KEYWORDS
Vegetables oils, Continuous carbon fiber, epoxy, wear, friction.

INTRODUCTION
Owing to their high specific strength and stiffness in addition to having excellent chemical and thermal resistance and lowering wear in adhesive situations, fiber reinforced polymer composites are being used in high stress, excessive temperature and high speed applications, [1 - 3]. Friction and wear are essential issues in these applications, [4]. Some researcher investigated friction and wear characteristics of glass fiber reinforced polymer composites under dry and oil-lubricated sliding conditions, [5 - 7]. The results proved that coefficient of friction and wear had been much less in oil lubricating sliding in contrast with dry sliding.

Carbon fiber reinforced polymer composites showed remarkable development in the latest years, [8 - 10]. Sung-Won Yoon Studied the validation of the usage of carbon/PEEK composites as alternatives to the metal based materials for artificial hip joints, [11]. The author evaluated the effect of fiber ply orientation on the tribological behavior of carbon/PEEK composites. The results showed that the friction coefficient was relatively large when the carbon fiber oriented at (0˚) and speed of 2.5 m/s. The wear behavior of carbon reinforced phenylene sulfide was improved, [12]. Further

improvements in wear resistance of carbon/polymer composites were reported, [13 - 15]. Due to the strength, stiffness and thermal conductivity of carbon fabric, carbon epoxy woven composites are prominent wear resistant material, [15]. The tribological properties of the carbon/epoxy woven composites have been observed to be affected by oil absorption.

The current paper highlights the effect of modifying the continuous, aligned carbon fiber/epoxy composites with different concentrations of different oils on the friction and wear.

EXPREMENTAL

The test rig used to conduct the experiments was pin –on- disc machine. The load cell was located in a suitable position in which be able to measure the friction coefficient between test specimen and disc surfaces as shown in Fig. 1, while a digital screen was used to detect the values of friction force. More details regarding pin-on-disc specifications and experimental condition are shown in Table 1. The friction equation $F_f = \mu F_n$ was utilized to calculate the friction coefficient, μ where F_f is the measured friction force and F_n is the normal force. On the other aspect, wear was measured by weight loss using high precision weight balance, 0.0001 g.

The test specimens were epoxy reinforced by continuous and aligned carbon fiber and filled by vegetables and mineral oils. The test specimens were classified into six groups:

1. Epoxy reinforced by carbon fiber and filled by olive oil,
2. Epoxy reinforced by carbon fiber and filled by corn oil,
3. Epoxy reinforced by carbon fiber and filled by sun flower oil,
4. Epoxy reinforced by carbon fiber and filled by glycerin oil,
5. Epoxy reinforced by carbon fiber and filled by paraffin oil,
6. Epoxy reinforced by carbon fiber, oil free for comparisons, as shown in Table 2. Each oil type had been added to the carbon/epoxy composites with different concentrations (2, 5, and 10 wt. %) at constant carbon fiber concentration, 4 wt. %. To study the effect of carbon fiber contents, different concentration of carbon fiber, (1, 2 and 4 wt. %) were used. The average diameter of carbon fiber was about 7.5 μm, as shown in Fig. 2. To assure the reliability and accuracy of the experimental data, each experiment was reiterated three times.

Table 1, specifications of pin-on-disc wear test

pin-on-disc parameters	Specifications
steel disc hardness	**269 HB**
steel disc size	**170 mm diameter ×10 mm thickness**
rotational speed	**140 r.p.m**
running time	**300 seconds**
sliding velocity	**0.93m/sec**
normal load	**6.5 N**
Wear track	**126.6 mm**

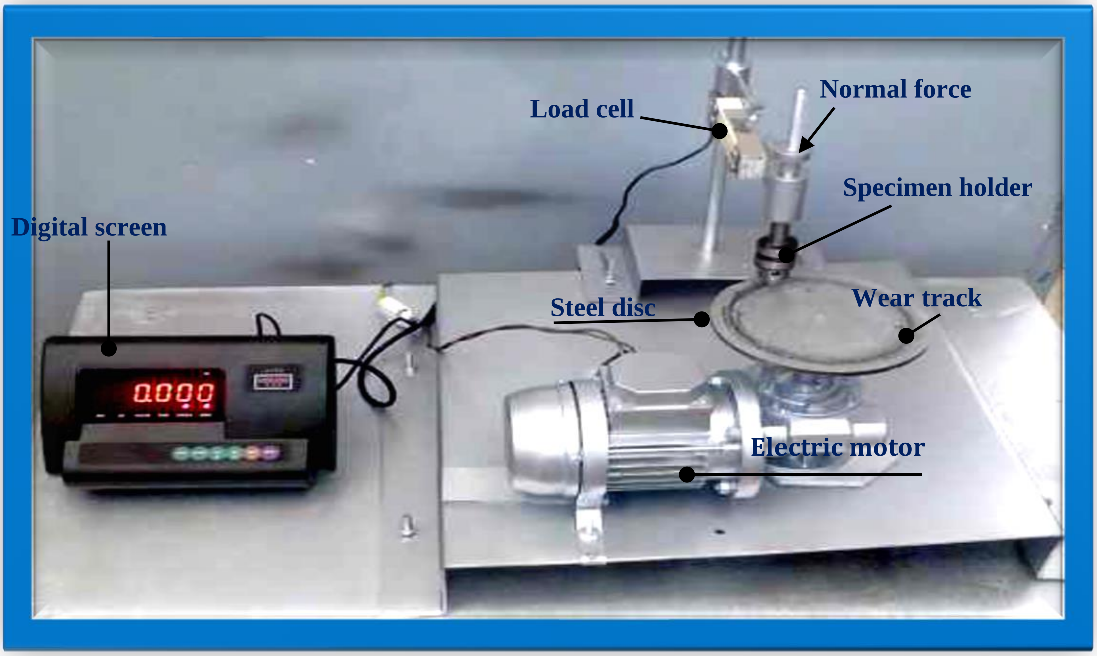


Fig. 1 Configuration of pin-on-disc machine.

With regard to specimen preparation, the molds used were commercial syringes of size 9 mm diameter and 22 mm long without the top nozzle, [10]. There are five steps for specimen preparation:

1. Carbon fibers were cut into 20 mm length and put into set and located vertically into the core of the syringe by adhering the set to the center of piston seal,
2. Preparing the epoxy resin by adding the epoxy to the hardener with mix ratio (2:1) respectively and slow stirring,
3. Oil was added to the epoxy resin then stirring the mixture manually for 5 min,
4. The mixture was drawn by syringe (without nozzle) and injected in the mold around the fiber and left in vertical position for 24 hours at room temperature for curing,
5. Finally, the specimen was easy ejected from the molds by the syringe piston. Illustration diagram of specimen preparation steps is shown in Fig. 3.

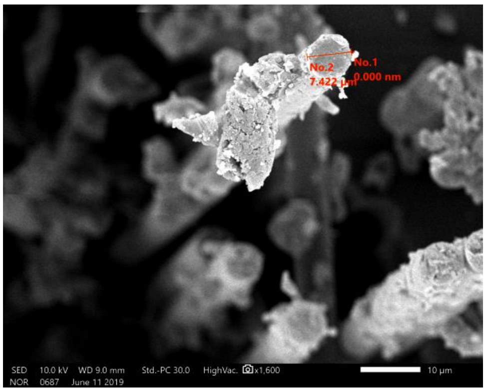
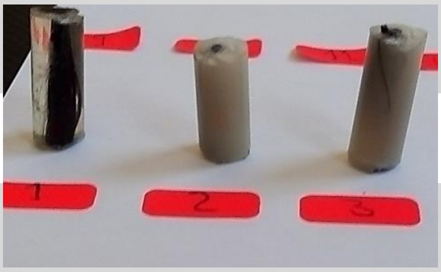
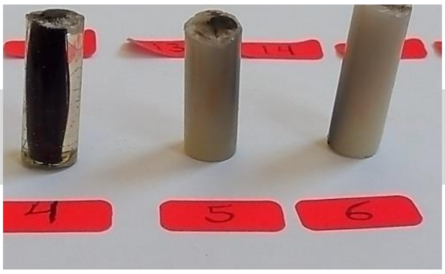
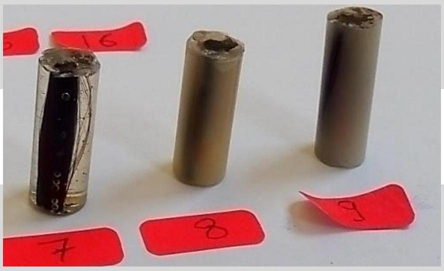
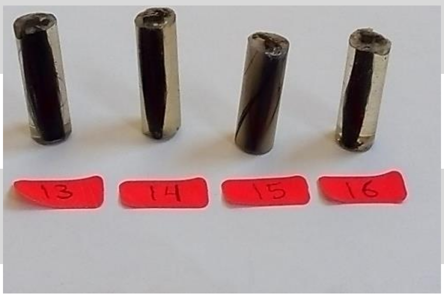


Fig. 2 Specification of carbon fiber average diameter.

Table2. Specification of the test specimens

Specimen No.	Specimen ingredient, wt. %	Specimen
1	**Epoxy + 4 wt. % carbon fiber + 2 % wt. olive oil**	
2	**Epoxy + 4 wt. % carbon fiber + 5 % wt. olive oil**	
3	**Epoxy + 4 wt. % carbon fiber + 10 % wt. olive oil**	
4	**Epoxy + 4 wt. % carbon fiber + 2 % wt. corn oil**	
5	**Epoxy + 4 wt. % carbon fiber + 5 % wt. corn oil**	
6	**Epoxy + 4 wt. % carbon fiber + 10 % wt. corn oil**	
7	**Epoxy + 4 wt. % carbon fiber + 2 % wt. sun flower oil**	
8	**Epoxy + 4 wt. % carbon fiber + 5 % wt. sun flower oil**	
9	**Epoxy + 4 wt. % carbon fiber + 10 % wt. sun flower oil**	
10	**Epoxy + 4 wt. % carbon fiber + 2 % wt. glycerin oil**	
11	**Epoxy + 4 wt. % carbon fiber + 5 % wt. glycerin oil**	
12	**Epoxy + 4 wt. % carbon fiber + 10 % wt. glycerin oil**	
13	**Epoxy + 4 wt. % carbon fiber + 2 % wt. paraffin oil**	
14	**Epoxy + 4 wt. % carbon fiber + 5 % wt. paraffin oil**	
15	**Epoxy + 4 wt. % carbon fiber + 10 % wt. paraffin oil**	
16	**Epoxy + 4 wt. % carbon fiber (free oil specimen)**	

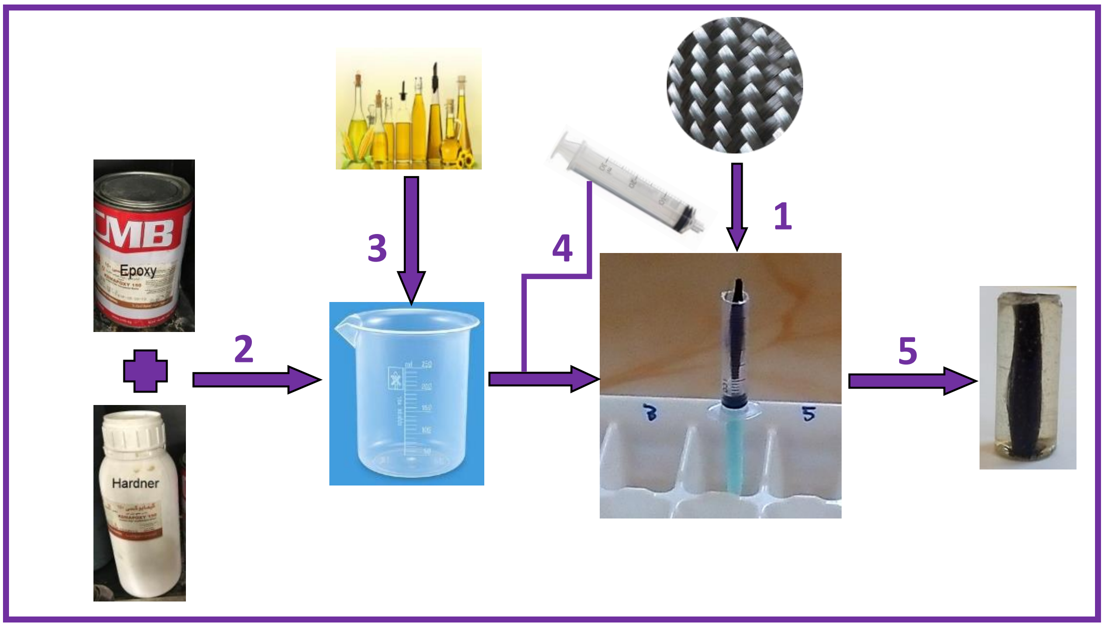


Fig. 3 Illustration diagram of specimen preparation steps.

RESULTS AND DISCUSSION

Influence of filling carbon/epoxy composites by different vegetables oils.

The tribological properties of carbon/epoxy composites filled by vegetables oils (olive, corn and sunflower) were reported in this section. Meanwhile, the carbon fiber contents were kept constant, 4 wt. % during this study. The experimental results of friction coefficient were plotted against oil concentration as shown in Fig. 4. It is clearly shown significant decrease in friction coefficient as the oil concentration increases inside the composites. This can be interpreted to the reality oil's function in diminishing friction coefficient and may be due to the boost of oil film at the sliding surface. The composites have 10 wt. % of corn oil, displayed 31% reduction in friction coefficient compared to free oil composites. Whilst the composites comprise 10 wt. % of sunflower oil exhibit friction coefficient reduction of 25 %. The maximum friction coefficient reduction was presented by composites containing 10 wt. % of olive oil due to the high viscosity of olive oil compared to sunflower and corn oils. Figure 5 shows the wear resistance of epoxy filled by 4 wt. % continuous carbon fiber and different vegetables oils (olive, corn and sunflower). It is obviously demonstrated that the wear diminished in accordance with oil content increase. This might be because of the possibility of expanding the oil film at sliding surface as oil contents increase. The polarity of epoxy is more than that of fluorocarbon polymers. This implies that the surface-free energy values of epoxy matrices are relatively high and their receptivity to adhesive bonding are therefore high, [16].

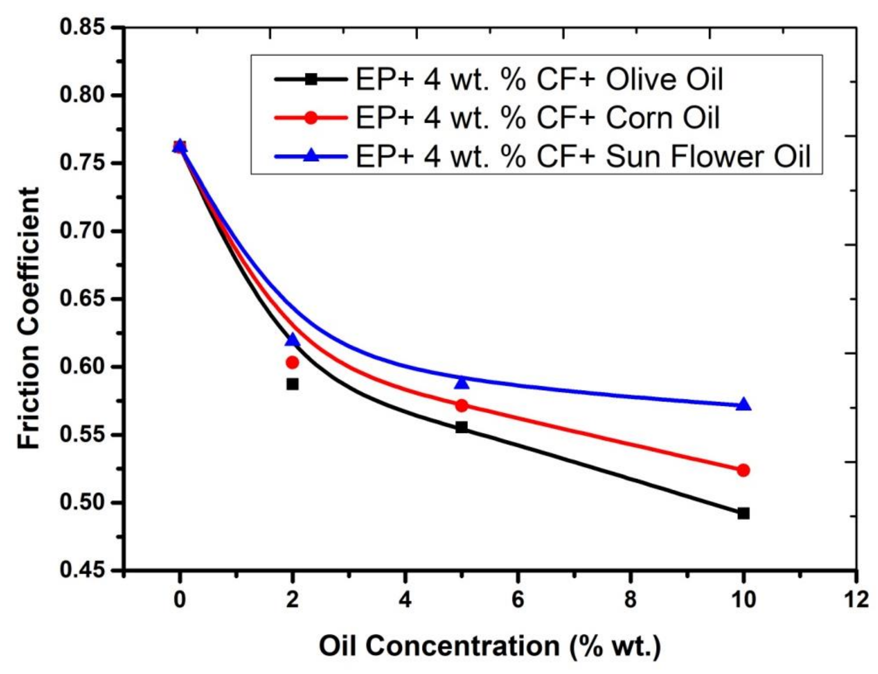


Fig. 4 Friction of epoxy composites filled by 4 wt. % carbon fiber and different vegetables oils.

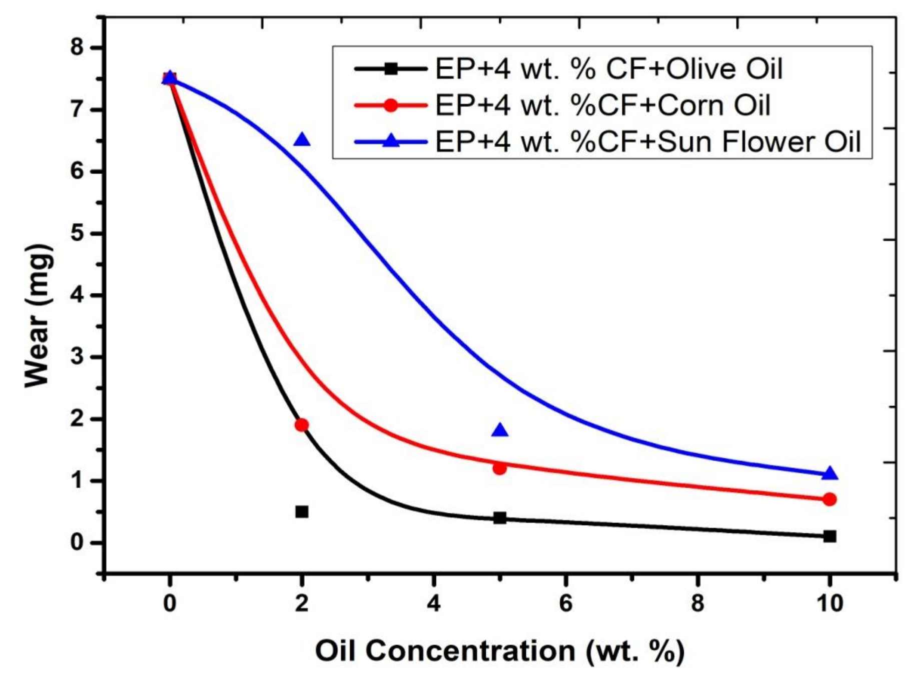


Fig. 5 Wear of epoxy composites filled by 4 wt. % carbon fiber and different vegetables oils.

The carbon/epoxy composites demonstrated lesser amount of wear when filled by olive oil, as indicated in Fig. 5, where composites have 10 wt. % of olive oil led to wear reduction of 98 % compared to oil free composites. While the wear reduction ratio came to 85 % and 90 % when filling the composites with 10 wt. % of sunflower and corn oil respectively. The results demonstrated that orienting of carbon fibers as continuous and aligned to the sample axis increased their strength and included oils increased the consistency of the sample thence weight loss diminished.

Influence of filling carbon/epoxy composites by different mineral oils.

This section is dedicated to report the friction and wear properties resulting from adding mineral oils (glycerin and paraffin) into continuous aligned carbon fiber/epoxy composites. The carbon fiber concentration was kept constant (4 wt. %) throughout this investigation. From analyzing the experimental results of carbon fiber composites modified by glycerin and paraffin oils shown in Fig. 6, it can concluded that paraffin has high impact in reducing friction than glycerin. Glycerin oftentimes used as lubricant because its high viscosity but its impact was contrary to expectations in this study. This is can be explained that the viscosity of glycerin may be decreased by polymerization whilst paraffin viscosity was not affected, [17]. Compared to oil free composites, carbon/epoxy composites have 10 wt. % paraffin oils exhibited reduction in friction of 37 % while those include 10 wt. % glycerin oils revealed friction reduction of 21%. Figure 7 exhibits the wear resistance of carbon/epoxy composites filled by different concentrations of mineral oils (glycerin and paraffin). It is clearly shown that weight loss decreased with increasing oil concentration. This is may be due to increasing the oil film thickness at the sliding surfaces as result of oil concentrations increase; moreover, oils assist on improving the adhesive bonding of composites. The composites comprise paraffin oil displayed higher wear resistance than those have glycerin oil. As discussed in the previous section, polymerization has high impact in detraction of glycerin viscosity subsequently reduce the adhesive bonding and wear resistance of composites. By modifying the carbon/epoxy composites with 10 wt. % of paraffin oil, the wear reduction ratio was 92 %. The wear reduction ratio constricted to 60 % when filling carbon/epoxy composites with 10 wt. % of glycerin oil.

Influence of carbon fiber content on friction and wear.

The effect of reinforcing epoxy by diverse concentrations (1, 2 and 4 wt. %) of continuous and aligned carbon fiber on friction and wear was debated in this section. As shown in Fig. 8, the friction and wear values were plotted contra carbon fiber content. 1 wt. % of carbon fiber gave rise to an increase in friction coefficient from 0.61 (without carbon fiber) to 0.81 (at 1 wt. % CF). This can be alluding to increasing the strength of epoxy when reinforced by 1 wt. % of continuous carbon fiber oriented aligned to the longitudinal axis of specimen. With increasing the carbon fiber content to 4 wt. %, the friction coefficient diminished to 0.76. As the cross sectional area of fiber sharing at the sliding surface, the increase in carbon fiber content led to increase in the total area of carbon fiber at sliding surface (summation of carbon fibers cross sectional areas), therefore the carbon film that formed between the sliding surfaces will increase as well.

The wear resistance was significantly enhanced as the carbon fiber increased. The wear reduction amounted to about 80 % as the carbon fiber concentration increased to 4 wt. %.

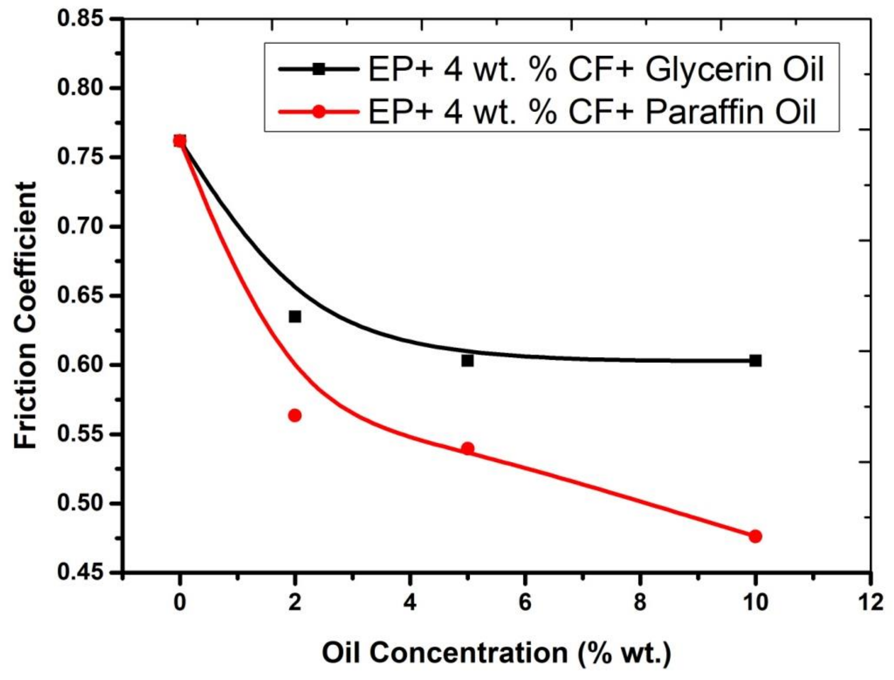


Fig. 6 Friction of epoxy composites filled by 4 wt. % carbon fiber and different mineral oils.

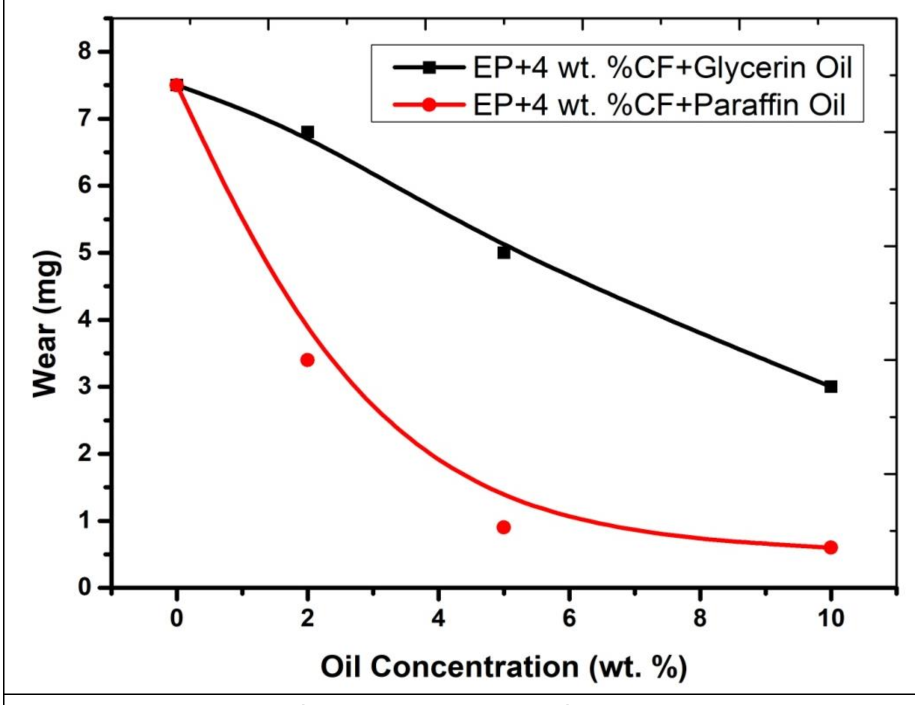


Fig. 7 Wear of epoxy composites filled by 4 wt. % carbon fiber and different mineral oils.

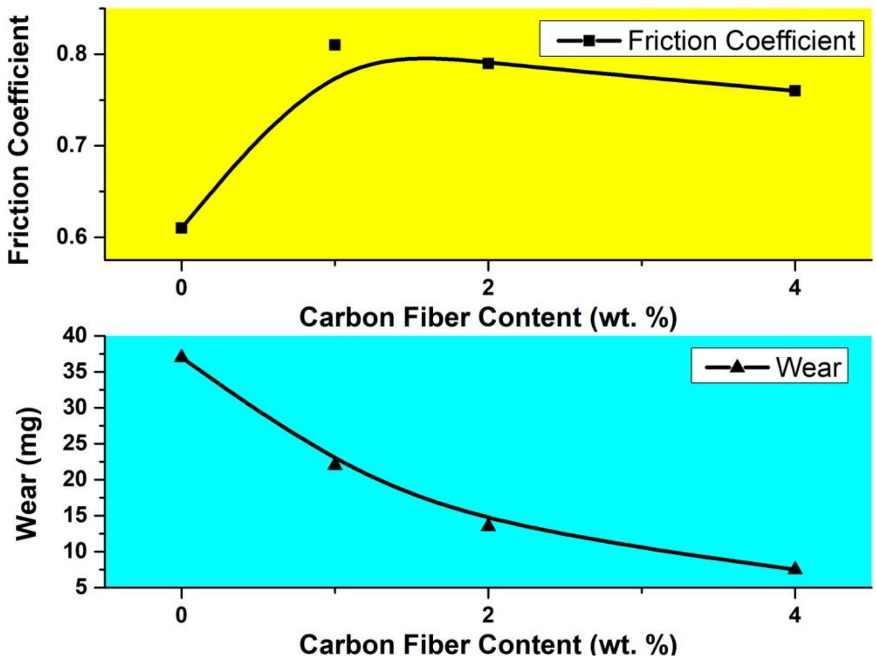
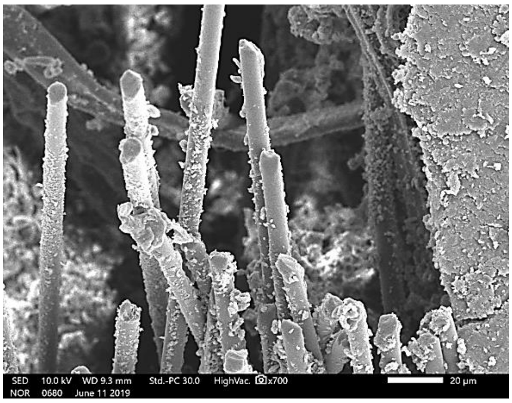
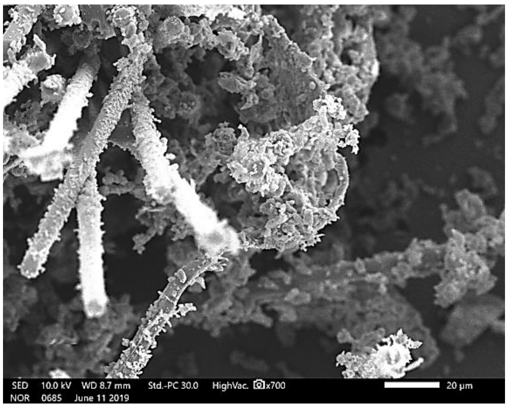


Fig. 8 Friction and wear of epoxy composites reinforced by continuous and aligned carbon fiber.

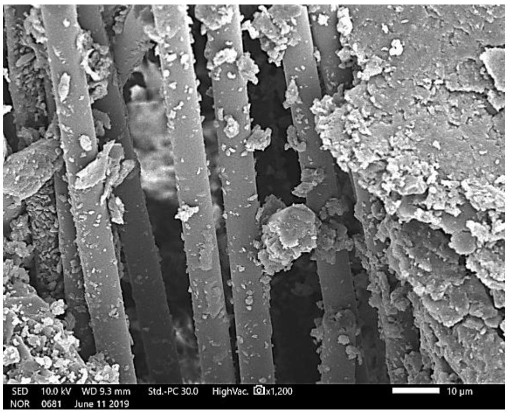


[a] CF/Epoxy composites free oil.



[b] CF/Epoxy composites filled by 10 wt. % sunflower oil.

[c] CF/Epoxy composites filled by 10 wt. % corn oil.



[d] CF/Epoxy composites filled by 10 wt. % glycerin oil.

[e] CF/Epoxy composites filled by 10 wt. % olive oil.

[f] CF/Epoxy composites filled by 10 wt. % paraffin oil.

Fig. 9 SEM micrographs of the worn surface of tested specimens.

Scanning electron microscopy was applied to examine the worn surfaces of the tested specimens. Figure 9 shows the SEM images of the worn surfaces for selected specimens. Figure 9a is SEM image of carbon/epoxy composites free oils that display severe wear on the worn surface. It is clearly noticed the debonding of epoxy matrix which generated due to degradation of specimen material. SEM micrograph of carbon/epoxy composites filled by 10 wt. % sunflower oils is shown in Fig. 9b. The SEM image showed mild wear as the adhesive bonding lost some of its cohesion. The worn surface of carbon/epoxy composites filled by 10 wt. % corn oils is shown in Fig. 9c. The SEM image displayed mild wear in a good agreement with the wear results as shown in Fig. 5. Figure 9d presents SEM image for carbon/epoxy composites filled by 10 wt. % glycerin. The image exhibited severe wear in a decent agreement with wear results shown in Fig. 7. Figures 9e and 9f demonstrated SEM images for carbon/epoxy composites filled by 10 wt. % olive oils and 10 wt. % paraffin oils respectively. The wear debris and chopped carbon fiber were plastically deformed at the worn surface and prevent further wear. Besides, it is clearly shown that olive and paraffin oils strongly enhanced the adhesive bonding of the composites. All SEM images agreed with the experimental wear results.

CONCLUSIONS

This study highlighted the influence of filling epoxy composites by continuous, aligned carbon fiber and different concentrations of different oils on the friction and wear. Based on the experimental results surveying, it can be concluded that:

1. Among five kinds of oils used to modify the carbon/epoxy composites, olive oil was observed to be the most convenient oil for enhancing the tribological properties of such composites.

2. Locating the carbon fiber in such continuous and aligned position improved the friction properties and enhanced the wear resistance.

3. Olive and paraffin oils have substantially improved the adhesive bonding of the composites.

4. Carbon/epoxy composites filled by olive oils achieved the maximum reduction ratios in regard with friction and wear.

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