EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 16, No. 3, July 2019, pp. 48 - 62 ISSN 2090 - 5882
(Received March 21. 2019, Accepted in final form June 15. 2019) www.egtribjournal.com

TRIBOLOGICAL PROPERTIES OF EPOXY REINFORCED BY RANDOMLY ORIENTED CHOPPED CARBON FIBERS

Ramadan M. A.

Mechanical Engineering Department, Faculty of Engineering, Helwan University, Helwan, EGYPT.

ABSTRACT
This article discusses the influence of filling epoxy by chopped carbon fiber and various kinds of oil (olive, corn, sunflower, glycerin and paraffin) on the friction and wear. Different concentrations of each oil (2, 5, 10 wt. %) were added to epoxy resin in addition to 2 wt. % chopped carbon fiber. Experiments were conducted using pin on disc test rig. The tests were carried out at constant speed (0.93 m/sec), constant load (6.5 N) and constant running time (300 sec) at room temperature. The worn surfaces of tested specimens were observed using scanning electron microscope. The results revealed that reinforcing epoxy by chopped carbon fiber has significantly affected the friction behavior and wear resistance. Moreover, addition of green oils (olive, corn, sunflower and glycerin) and mineral oils (paraffin) to epoxy/carbon fiber composites enhanced the friction and wear properties.

KEYWORDS
Green oils, chopped carbon fiber, epoxy, wear, friction.

INTRODUCTION
Nowadays, carbon fiber (CF) is used as reinforcement of polymer composites for the application of aerospace, Bearings and railway transport systems, due to the fact of its high strength, creep resistance and excellent stiffness, [1-4]. Zhang et al, [5] developed short cut carbon/polyimide composites and studied the impact of fiber oxidation on the tribological properties. Midan [6] developed carbon fiber/phenolic resin composites and have an impact on strength and hardness have been observed to increase with increasing carbon fiber content.

Composites formed via including nano-scale particles to a polymer matrix results in enhancing the tribological properties, [7, 8]. Carbon fiber reinforced polymer composites were investigated, [9]. The tribological and mechanical properties were improved.

Recently, the use of epoxy resin (EP) has increased due to its sturdy adhesion, good dimensional stabilities and high mechanical properties, [10, 11]. Also, their tribological

behavior proved higher improvement at different reinforcement fillers. Modifying of epoxy matrix composites with lubricant is the key factor to minimize the friction and wear in many studies detected bearing applications, [14-18].

In the current work, the effect of addition of different kinds of oils with different concentrations to epoxy composites reinforced by chopped/random oriented carbon fiber on the friction and wear was studied.

EXPREMENTAL

The pin-on-disc was used to conduct the experiments under ambient and dry conditions at room temperature. It was designed and fabricated to measure the coefficient of friction displayed by the test specimen (pin) and disc surface. A steel disc of hardness (269 HB) and size of (170 mm diameter ×10 mm thickness) was used as counterpart and driven by an electric motor which provides rotational motion of (140 r.p.m). The Schematic illustration of pin-on-disc wear test is shown in Fig. 1. The experimental conditions were as follow: constant sliding velocity (0.93 m/sec), constant normal load (6.5 N), and constant running time (300 seconds). The load cell was used and connected to digital indicator to detect the friction force. The friction coefficient was calculated using the equation, F_f/F_n where F_f is the measured friction force and F_n is the normal load exerted on the pin by the testing machine's dead weight. The wear was measured via weight loss of specimen utilizing an analytical balance of precision 0.00001 g. To ensure the accuracy and reliability of the data, each experiment was repeated three times.

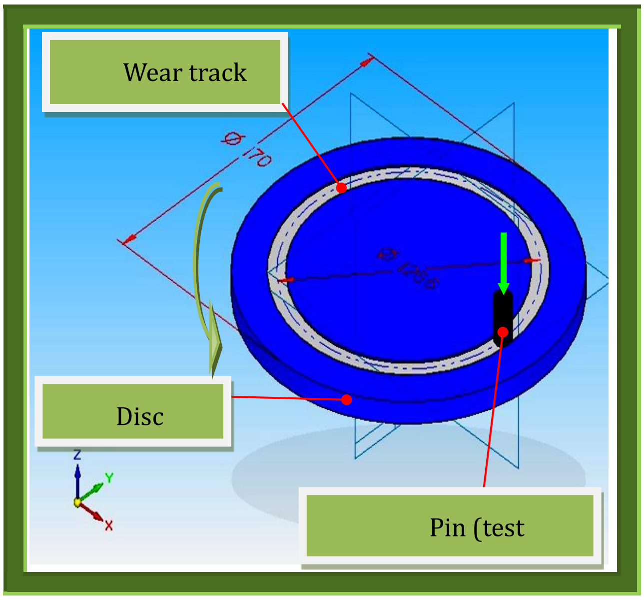


Fig. 1 Schematic illustration of pin-on-disc wear test.

Six types of carbon fiber/epoxy composites were used as test specimens in the experiments. Epoxy was reinforced by random oriented chopped carbon fibers and filled by olive, corn, sunflower, glycerin, paraffin oils, while the last group was oil free, Fig 3. Different concentrations of each oil type (2, 5, and 10 wt. %) had been added to modify the carbon/epoxy composites. The concentration of carbon fiber was (0.5, 1 and 2 wt. %). The carbon fiber diameter was about 7.5 µm , Fig. 4. Table 1 shows ingredients of the test specimens.

Table1, illustration of test specimen's contents

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

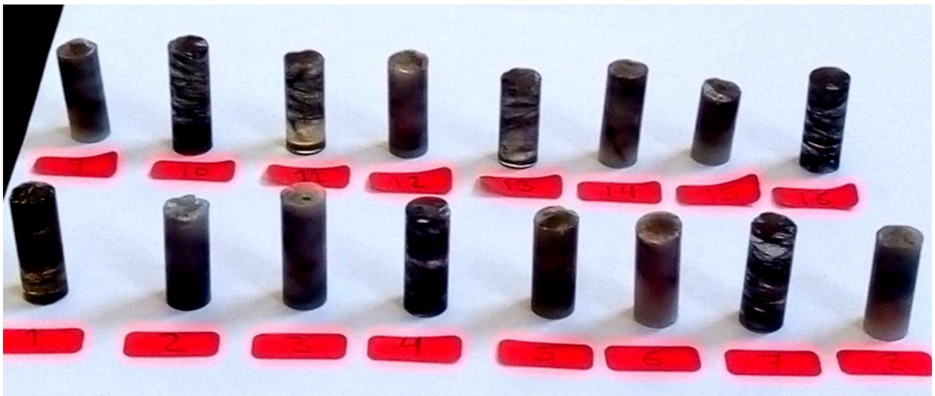


Fig. 2 Test specimens.

Concerning to specimen preparation, the epoxy resin was prepared by adding the epoxy to the hardener with mix ratio (2:1) respectively and slow stirring. The oil was added to epoxy resin by stirring then the carbon fibers were chopped into 5 mm length and mixed randomly with the epoxy resin in a plastic container then stirring the mixture manually for 5 min. The molds used were commercial syringes without needle of size 9 mm diameter and 22 mm long, [7]. The mixture was drawn and left for 24 hours at room temperature for curing. After that, the top nozzle of syringe was cut and specimen was easy ejected from the molds by the ejector.

Fig. 3 Test specimen free of oil.

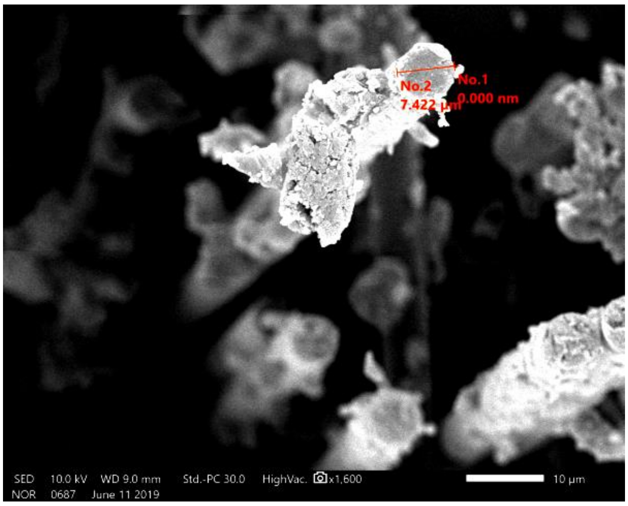


Fig. 4 Specification of carbon fiber average diameter.

RESULTS AND DISCUSSION

Effect of carbon fiber content on friction and wear

This section discusses the effect of filling epoxy with different concentrations (0.5, 1 and 2) wt. % of chopped carbon fiber on the friction and wear. Figure 5 illustrate the relation between friction coefficient and carbon fiber content for epoxy/carbon fiber composites. The friction coefficient increase from 0.61 (without carbon fiber) to 0.81 (at 0.5 wt. % CF). This attributed to the high strength of carbon fiber. With increasing the carbon fiber content, the friction coefficient decreases. The friction coefficient decreased from 0.81 at 0.5 wt. % carbon fiber to 0.61 at 2 wt. % carbon fiber. This could be ascribed to the carbon film that formed between the sliding surfaces and serving as a self-lubricant subsequently reducing the coefficient of friction. The effect of carbon fiber content on wear is shown in

Fig. 6. It is clearly shown that the wear significantly deceases with increasing the carbon content. The transferred film of carbon deformed at the sliding surface is highly accountable for such decrease.

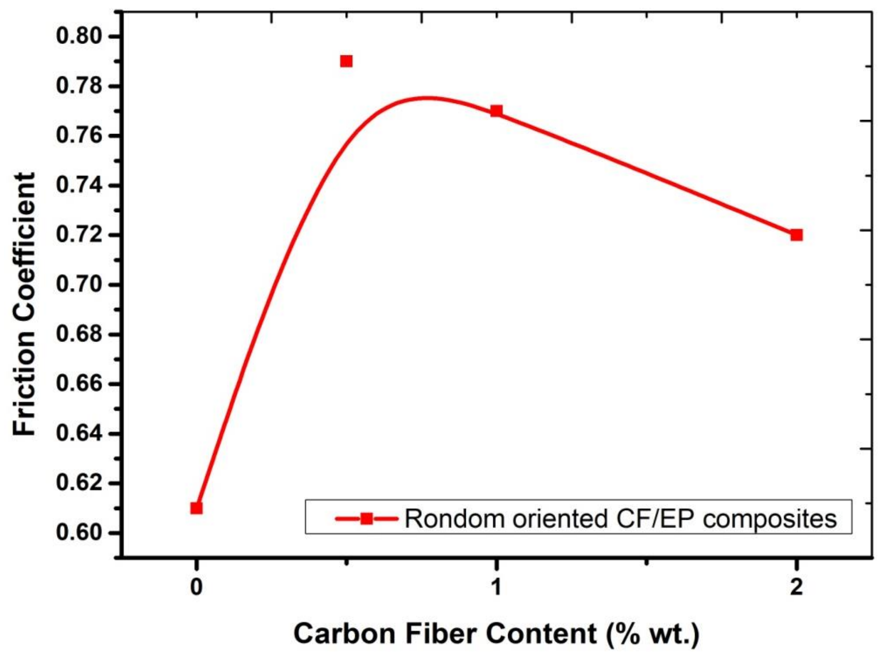


Fig. 5 Friction coefficient of epoxy composites filled by chopped carbon fiber.

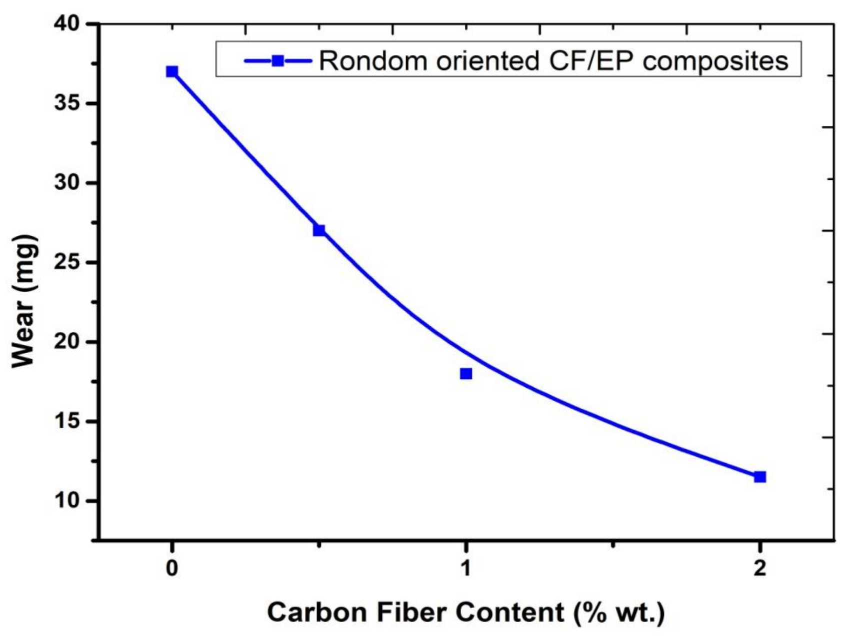


Fig. 6 Wear of epoxy composites filled by chopped carbon fiber.

Effect of modifying carbon fiber/epoxy composites with defferent oil types on friction and wear

This section is devoted to report the tribological properties resulting from adding green oil (olive, corn and sunflower) in addition to another different oils (glycerin and paraffin) into random oriented carbon fiber/epoxy composites. The concentration of carbon fiber was constant 2 wt. % during this study. Figure 7 shows the friction properties of carbon fiber reinforced epoxy composites modified by olive oil. It is obviously shown that the friction coefficient decrease with increasing oil concentration inside the composites. This could be ascribed to the fact of oil's role in decreasing the coefficient of friction and due to the increase of oil film at the sliding surface. The composites comprise 10 wt. % olive oil demonstrated 40 % reduction in friction coefficient compared to the oil free composites. The friction coefficient of composites filled by random chopped carbon fiber and corn oil is shown in Fig. 8. The composites have 10 wt. % of corn oil revealed friction coefficient value of (0.59) lower than those of free oil composites (0.72). In the other word, the composites filled by 10 wt. % corn oil displayed friction coefficient reduction of 18%. The effect of corn oil in reducing friction coefficient is lower than olive oil effect. This may be attributed to the relatively high viscosity of olive oil compared to corn oil.

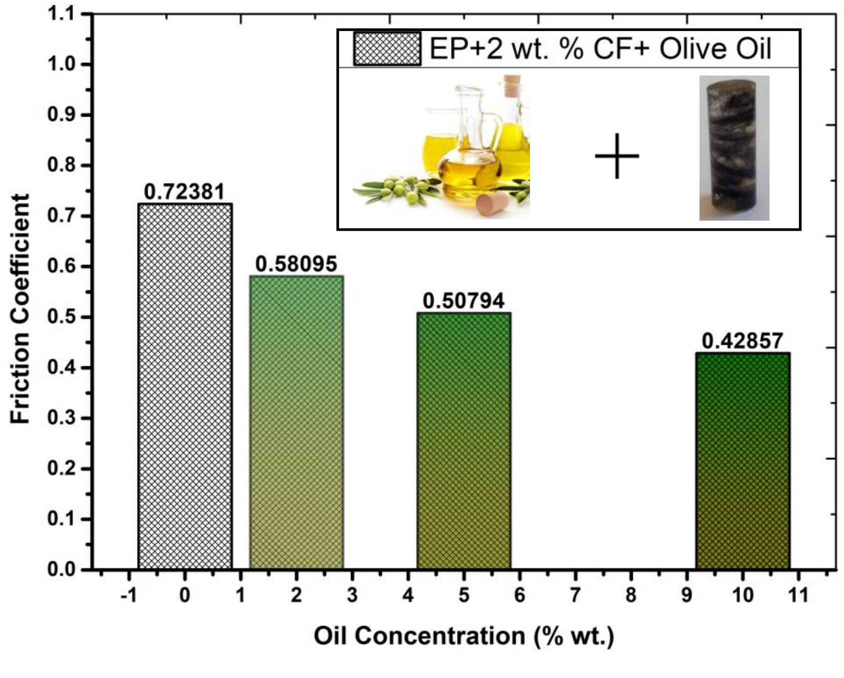


Fig. 7 Effect of adding olive oil as a modifier to epoxy reinforced by 2 wt. % chopped carbon fiber on friction coefficient.

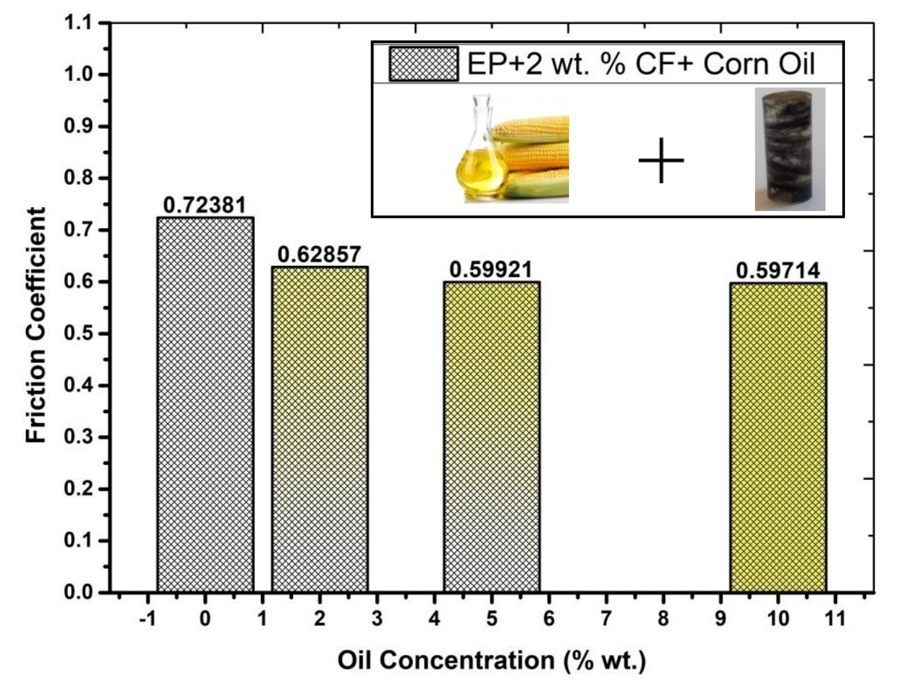


Fig. 8 Effect of adding corn oil as a modifier to epoxy reinforced by 2 wt. % chopped carbon fiber on friction coefficient.

A 30 % reduction in friction coefficient was exhibited by carbon fiber/ epoxy composites include sunflower oil as result of increasing the oil concentration up to 10 wt. %, Fig. 9. Whereas the value of friction coefficient for the composites filled by 10 wt. % sunflower oil was 0.51. The general trend for all composites at different types of oil is decreasing the coefficient of friction with increasing the oil concentration. This can be attributed to the self lubrication properties acquired by adding oil to the carbon fiber/epoxy composites. Where the oil exist in multipores inside the epoxy matrix and act as oil reservoirs and spill to the sliding surface resulting in friction coefficient reduction [17]. Figure 10 shows frictional properties of epoxy filled by carbon fiber and glycerin oil. It can be noticed that the friction coefficient decease as result of oil concentration increasing. With increasing up to 10 wt. % of glycerin oil concentration, the reduction in μ was 27 % from the reference oil free. Slight decrease in coefficient of friction was acquired by epoxy filled by carbon fiber and paraffin oil as increase of the oil concentration as shown in Fig. 11. The reduction in friction coefficient was 12.5 % at 10 wt. % oil concentration. The maximum ratio of friction reduction was obtained by epoxy filled by carbon fiber and olive oil. Whilst, the minimum ratio of friction reduction was displayed by composites comprise paraffin oil.

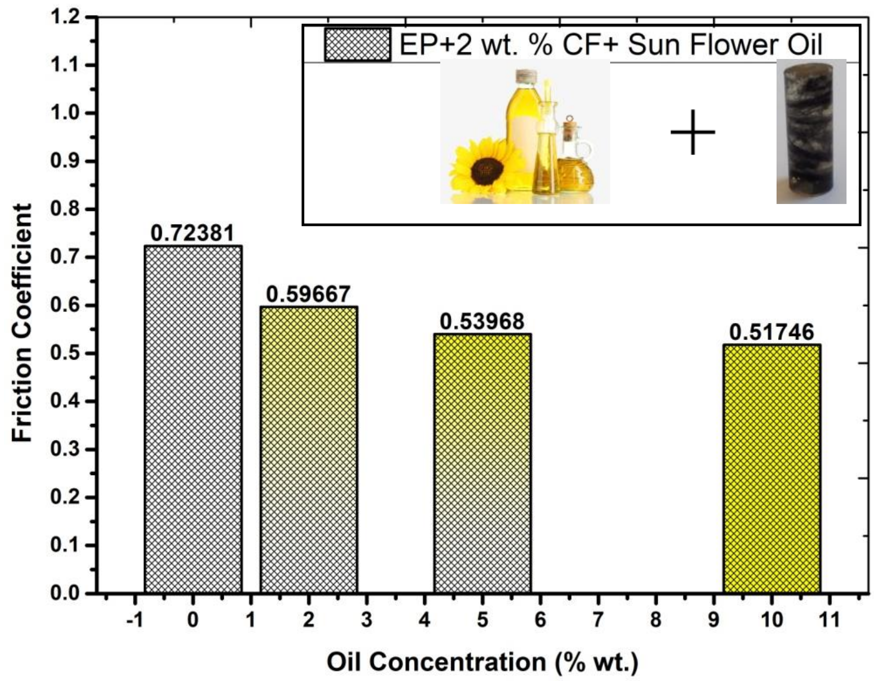


Fig. 9 Effect of adding sunflower oil as a modifier to epoxy reinforced by 2 wt. % chopped carbon fiber on friction coefficient.

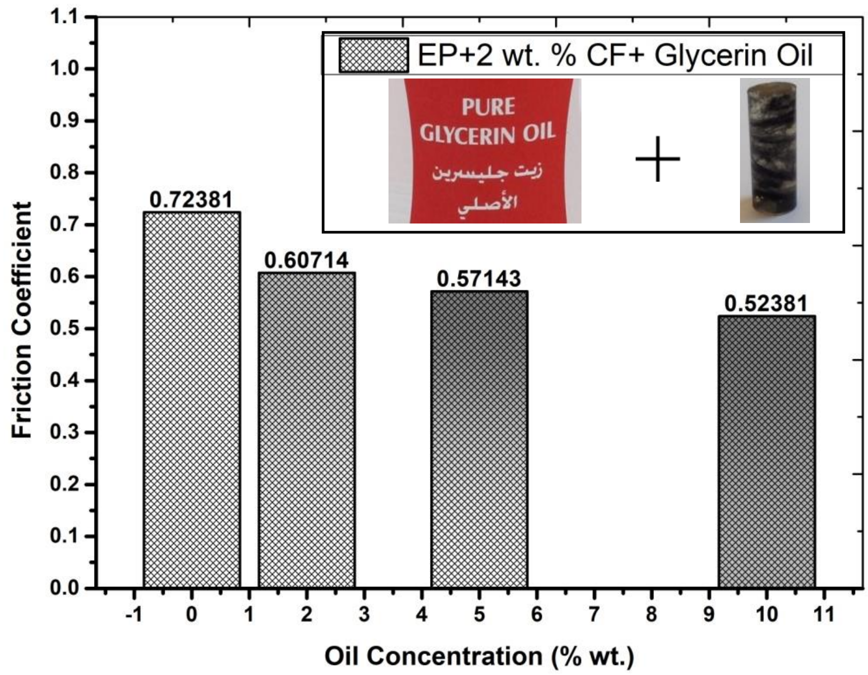


Fig. 10 Effect of adding glycerin oil as a modifier to epoxy reinforced by 2 wt. % chopped carbon fiber on friction coefficient.

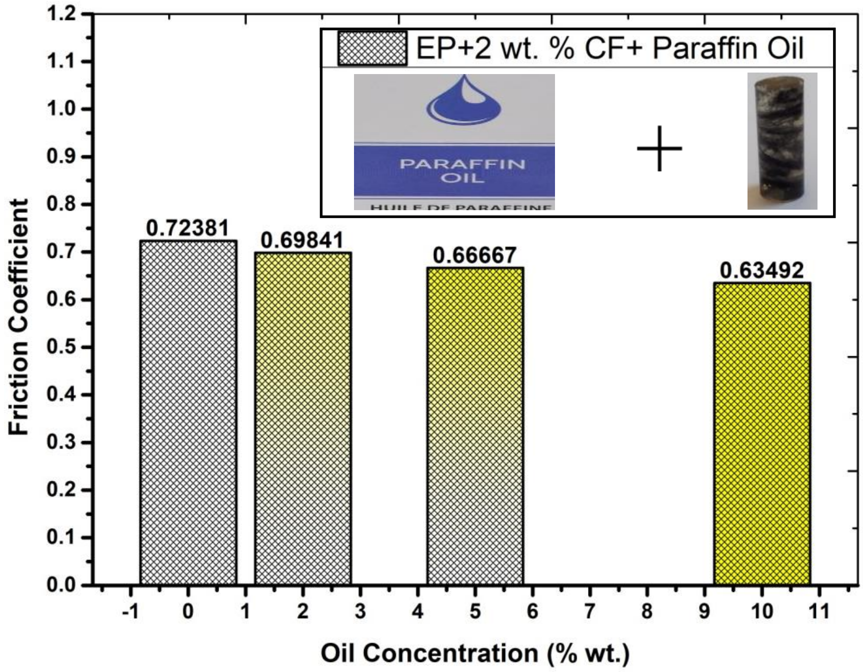


Fig. 11 Effect of adding paraffin oil as a modifier to epoxy reinforced by 2 wt. % chopped carbon fiber on friction coefficient.

The wear resistance of epoxy filled by 2.0 wt. % chopped carbon fiber in addition to different concentrations of olive oil is shown in Fig. 12. It is visibly shown that the wear decreased in line with oil concentration increase. This may be due to the prospect of increasing the oil film at sliding surface as oil concentrations increase. In addition, epoxy has more polarity than polymers of fluorocarbon. This means that epoxy matrices have comparatively high surface-free energy values and are therefore more receptive to adhesive bonding [19].With increasing the olive oil concentration to 10 wt. %, the reduction ratio of wear attained 80%. The similar trend was obtained for epoxy filled by 2% wt. chopped carbon fiber and different concentrations of corn oil as shown in Fig. 13. Improvement of wear resistance was found as the corn oil concentration increase. The wear reduction ratio for specimens comprise 10 wt. % corn oil was about 70% whereas specimens contain 2 wt. % and 5 wt. % of corn oil observed reduction ratio of 30% and 52% respectively. Figure 14 exhibit the effect of modifying epoxy/carbon fiber composites with different concentrations of sunflower oil on the wear resistance. It is clearly observed that the wear resistance increasing as the concentrations of sunflower oil increase. This can be assigned to increasing the adhesive bonding as result of oil concentrations increase inside the composites. Epoxy composites filled by 2 wt. % carbon fiber and 10 wt. % sunflower oil reported 78% wear reduction compared to epoxy composites free oil.

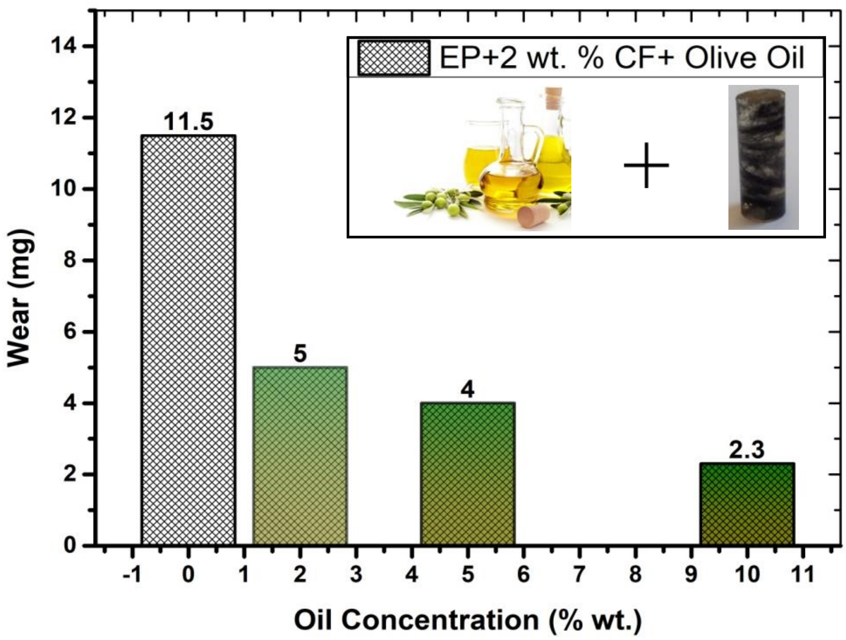


Fig. 12 Effect of adding olive oil as a modifier to epoxy reinforced by 2 wt. % chopped carbon fiber on wear.

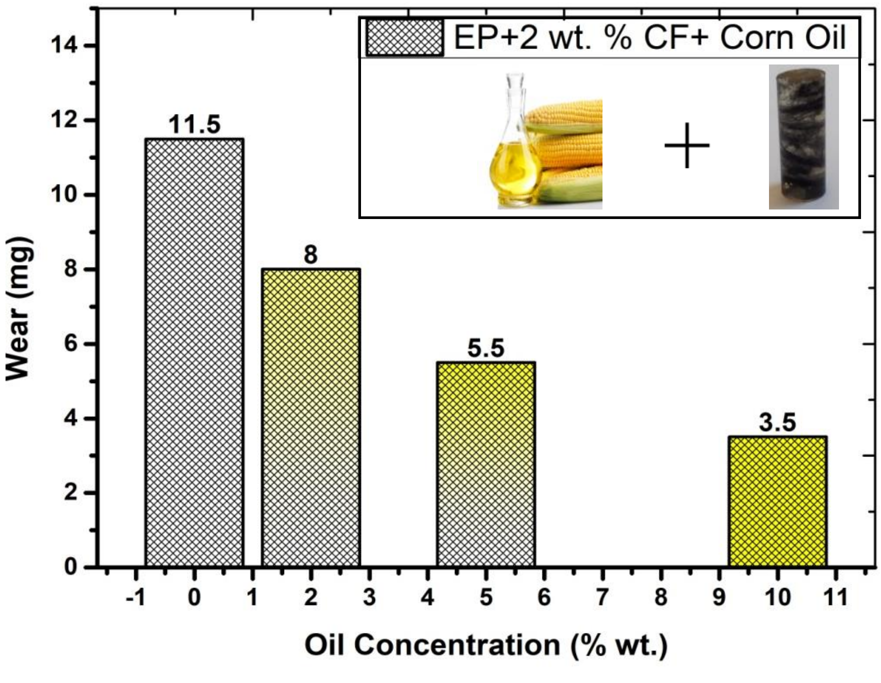


Fig. 13 Effect of adding corn oil as a modifier to epoxy reinforced by 2 wt. % chopped carbon fiber on wear.

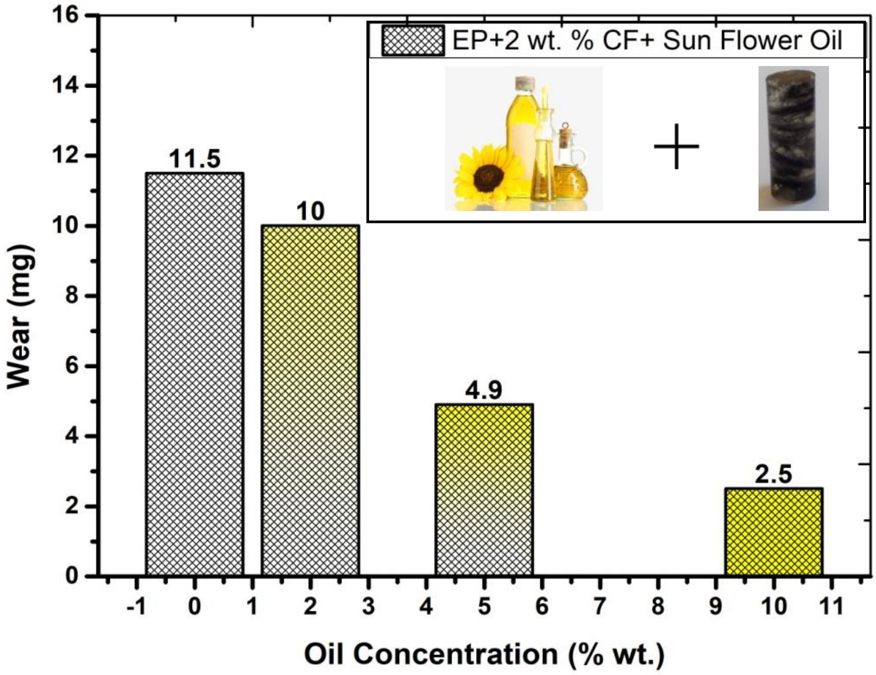


Fig. 14 Effect of adding sun flower oil as a modifier to epoxy reinforced by 2% wt. chopped carbon fiber on wear.

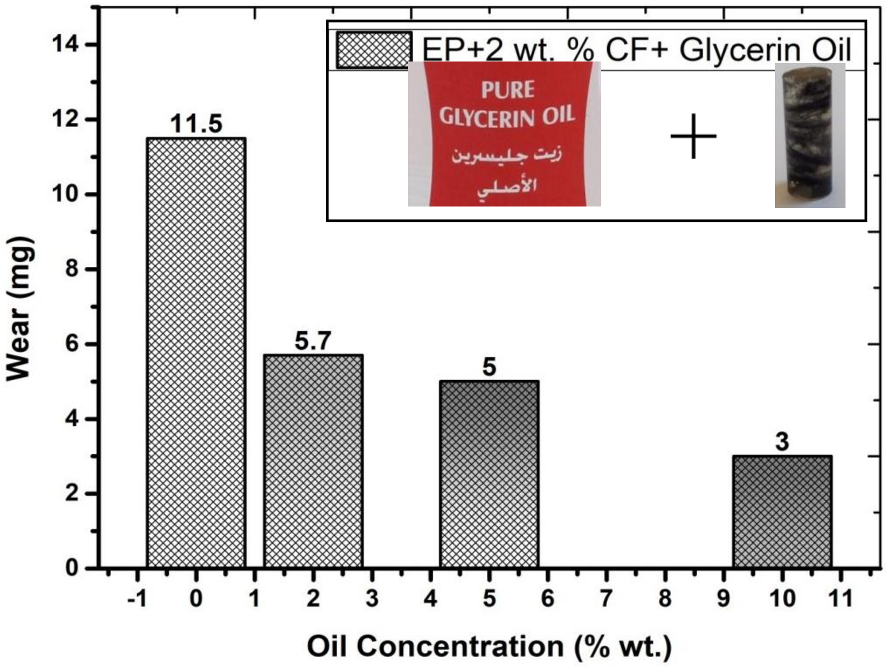


Fig. 15 Effect of adding glycerin oil as a modifier to epoxy reinforced by 2% wt. chopped carbon fiber on wear.

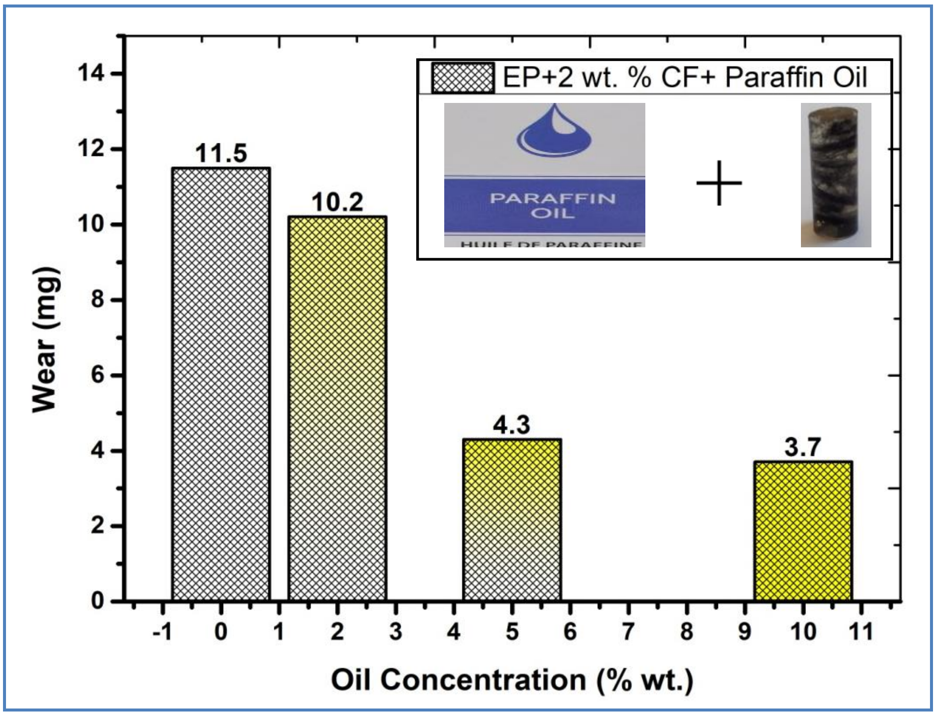
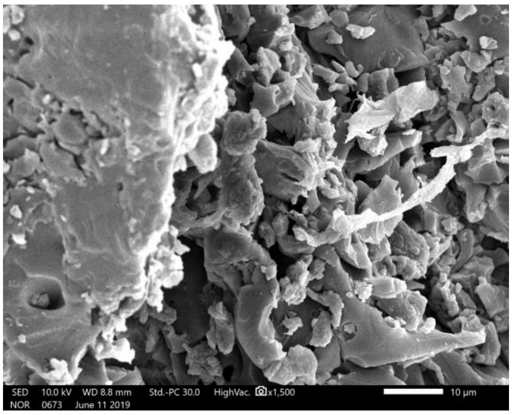


Fig. 16 Effect of adding paraffin oil as a modifier to epoxy reinforced by 2% wt. chopped carbon fiber on wear.

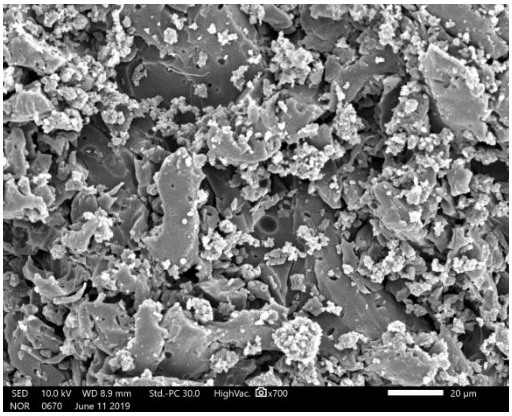
Adding different concentrations of glycerin oil to epoxy resin in addition to 2 wt. % carbon fiber was investigated to report their effect on wear resistance as shown in Fig. 15. The results showed improvement of wear resistance whenever glycerin oil concentration increased. The wear reduction increased to 73% as the concentration of glycerin oil increased to 10 wt. %. Also, paraffin oil was tested as a modifier to epoxy/carbon fiber composites as shown in Fig. 16. It is highly observed that the wear decreased with increasing the concentration of paraffin oil. The reduction ratio of wear for epoxy encloses 2 wt. % carbon fiber and 10 wt. % paraffin oil was 68 %. Composites contain olive oil displayed maximum reduction ratio of wear at all concentrations more than those contain corn, sunflower, glycerin or paraffin oil. This is may be due to the high viscosity of olive oil resulted in improvement of adhesive bonding moreover increase the wear resistance.

The worn surfaces of tested specimen were examined using scanning electron microscopy (SEM). Figure 19 shows SEM micrograph for worn surfaces of selected specimens after wear tests. Lot of fragments of epoxy at the contact surface were observed for epoxy/carbon fiber composites free of oil, as shown in Fig. 17a. This leads to severe increase in weight loss as shown in Figs. 12-16 at 0 wt. % oil concentration. The SEM micrograph of worn surface for epoxy/carbon fiber composites containing 10 wt. % olive oil is shown in Fig. 17b. The wear debris are plastically deformed and adhered on the matrix as the action of oil included in the composites and this help in decrease further wear. The worn surface of epoxy/carbon fiber composites filled by 10 wt. % corn oil is shown in Fig. 17c. The SEM micrograph displayed deep wear tracks resulting in increase in weight loss as shown in Fig. 13 at 10 wt. % corn oil. SEM image of epoxy/CF composites filled by 10% wt. sunflower obtained shallow wear tracks as shown in Fig. 17d. It is highly

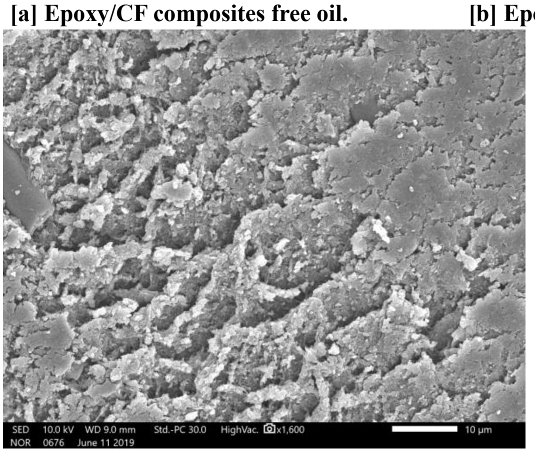
noticed that sunflower oil decreased the amount of fragments resulting in decrease in wear as shown in Fig. 14 at 10 wt. % sunflower oil. Regarding to worn surface of epoxy/CF composites filled by 10 wt. % glycerin oil; it is seemed to be covered with film-like layer as shown in Fig. 17e. A lot of wear debris was observed from the worn surface of epoxy/CF composites filled by 10 wt. % paraffin oil as shown in Fig. 17d. This explains the relatively high weight loss displayed for this composite as shown in Fig. 16 at 10 wt. % paraffin oil. Finally, the SEM micrographs were in a good agreement with wear results.



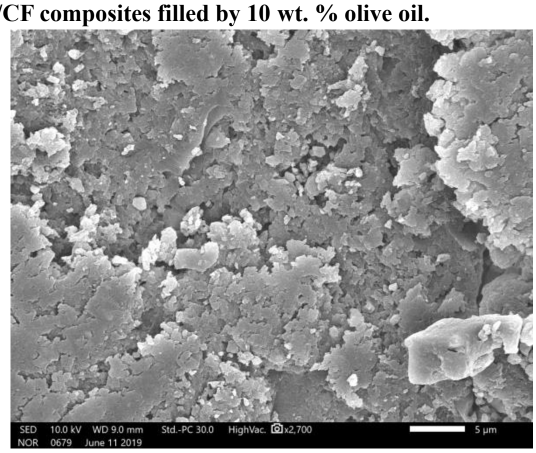
[a] Epoxy/CF composites free oil.



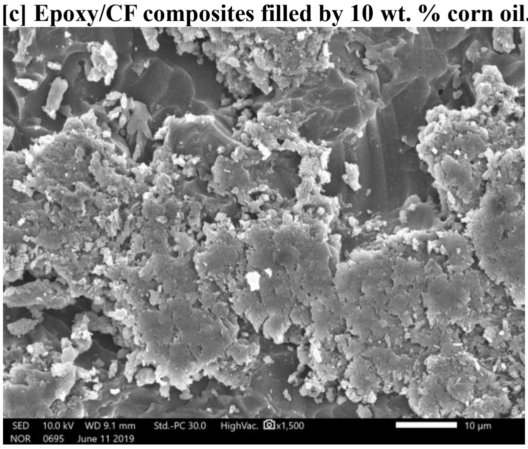
[b] Epoxy/CF composites filled by 10 wt. % olive oil.



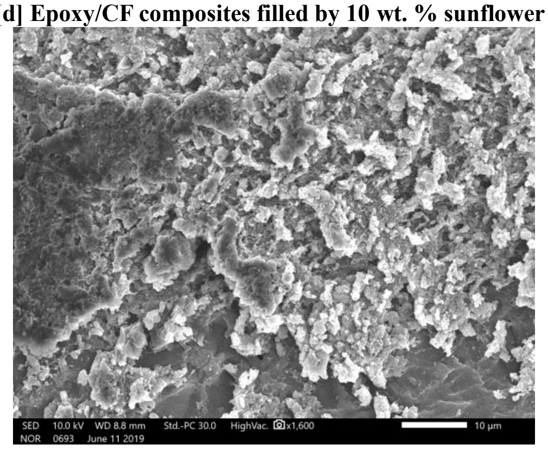
[c] Epoxy/CF composites filled by 10 wt. % corn oil.



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



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



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

Fig. 17 SEM micrographs of the worn surface of tested specimens.

CONCLUSIONS

The tribological properties of epoxy composites filled by chopped/random oriented carbon fiber and different kinds of oils were studied and the following conclusions were drawn:

1. Significant improvements in friction coefficient and wear resistance were observed for composites filled by chopped/random carbon fiber that were assigned to the high strength and self lubrication characteristic of carbon fiber.

2. The maximum reduction ratio of wear was observed for epoxy/carbon fiber composites contain 10 wt. % olive oil.

3. The maximum friction reduction ratio was obtained for epoxy/carbon fiber composites filled by 10 wt. % olive oil.

4. The friction reduction ratio due to addition 10 wt. % of olive, sunflower, glycerin, corn or paraffin oil to epoxy/carbon fiber composites were 40, 28, 27, 18 and 12.5 % respectively.

5. The wear reduction ratio due to filling epoxy/carbon fiber composites by 10 % wt. of olive, sunflower, glycerin, corn or paraffin oil were 80, 78, 73, 70 and 68 % respectively.

REFERENCES

1. Donnet J. B., Bansal R. C., "Carbon Fibers", Dekker, New York (1990).

2. Yasar I., Canakci A., Arslan F., "The Effect of Brush Spring Pressure on the Wear Behaviour of Copper–Graphite Brushes with Electrical Current", Tribology International, vol. 40, no. 9, pp. 1381-1386, (2007).

3. Jianxin Wang, Ruijun Zhang, Jiang Xu, Chao Wu, Peng Chen., 'Effect of the Content of Ball-milled Expanded Graphite on the Bending and Tribological Properties of Copper–Graphite Composites", Materials and Design, vol. 47, pp. 667–671, (2013).

4. Ma X.C., He G.Q., He D. H., Chen C. S., Hu Z. F., "Sliding Wear Behaviour of Copper–Graphite Composite Material for Use in Maglev Transportation System", Wear, vol. 265, no. (7-8), pp. 1087–1092, (2008).

5. Zhang X. R., Pei X .Q., Wang Q. H., "The Effect of Fiber Oxidation on the Friction and Wear Behaviors of Short-Cut Carbon Fiber/Polyimide Composites", Express Polymer Letters, vol. 1, no. 5, pp. 318–325, (2007).

6. Midan LI, Ruiying Luo, "Effect of Carbon Fiber Content on Mechanical and Tribological Properties of Carbon/Phenolic Resin Composites", 5th International Conference on Information Engineering for Mechanics and Materials (ICIMM 2015).

7. Ramadan M.A., Reda R., "CNTs, Al2O3 and SiO2 Reinforced Epoxy: Tribological Properties of Polymer Nanocomposites, Tribology in Industry, vol. 39, no. 3, pp. 357-363, (2017).

8. Ayman A. Aly, El-Shafei B. Zeidan, AbdAllah A. Alshennawy, Aly A. El-Masry, Wahid A. Wasel, "Friction and Wear of Polymer Composites Filled by Nano-Particles: A Review", World Journal of Nano Science and Engineering, vol. 2, pp. 32-39, (2012).

9. Andrey P. Vasilev et. al., "Mechanical and Tribological Properties of Polytetrafluoroethylene Composites with Carbon Fiber and Layered Silicate Fillers, Molecules, vol. 24, pp. 224, (2019).

10. Jin F.L., Li, X., Park S. J., "Synthesis and application of epoxy resins: A review", Ind. Eng. Chem. Vol. 29, pp. 1–11, (2015).
11. Odegard G.M., Bandyopadhyay A., "Physical aging of epoxy polymers and their composites", J. Polym. Sci. Polym. Phys., vol. 49, pp. 1695–1716, (2011).
12. Boopathi L., Sampath P.S., "Influence of Fiber Length in the Wear Behaviour of Borassus Fruit Fiber Reinforced Epoxy Composites" International Journal of Engineering Science and Technology, vol. 4, no.09, pp. 4119-4129, (2012).
13. Srinivas K., Bhagyashekar M. S., "Wear Behaviour of Epoxy Hybrid Particulate Composites", Procedia Engineering, vol. 97, pp. 488 – 494, (2014).
14. Nay Win KHUN, He ZHANG, Jinglei YANG, Erjia LIU, "Mechanical and Tribological Properties of Epoxy Matrix Composites Modified with Microencapsulated Mixture of Wax Lubricant and Multi-Walled Carbon Nanotubes", Friction, vol. 1, no. 4, pp. 341–349, (2013).
15. Yousif B. F., El-Tayeb N. S. M., "Wet Adhesive Wear Characteristics of Untreated Oil Palm Fibre-reinforced Polyester and Treated Oil Palm Fibre-Reinforced Polyester Composites Using the Pin-on-Disc and Block-on-Ring Techniques", Proc. IMechE, vol. 224 Part J, J. Engineering Tribology, (2009).
16. Shih-Chen Shi, "Tribological Performance of Green Lubricant Enhanced by Sulfidation IF-MoS_2", Materials, vol. 9, 856, (2016).
17. Badran H., Hasan M. K., Ali W. Y., "Tribological Behavior of Epoxy Reinforced with Carbon Nanotubes and filled by Vegetables Oils", KGK, vol. 11-12, pp. 38-42, (2017).
18. Chua K.W., Abdollah M. F. B., Mat Tahir N. A., Amiruddin H., "Potential of Palm Kernel Activated Carbon Epoxy (PKAC-E) Composite as Solid Lubricant: Effect of Load on Friction and Wear Properties", Jurnal Tribologi, vol. 2, pp. 31-38, (2014).
19. Kinloch A.J., "Adhesion and Adhesives: Science and Technology", Chapman and Hall, London, (1987).