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TRIBOLOGICAL BEHAVIOR OF EPOXY REINFORCED WITH CARBON NANOTUBES AND FILLED BY VEGETABLES OILS

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ABSTRACT
The present work investigates the influence of reinforcing epoxy by carbon nanotubes and filling by different types of vegetables oils (olive, corn, sunflower, sesame, almond and paraffin oil) on the friction coefficient and wear resistance. Carbon nanotubes of 0.25, 0.5, 0.75 and 1 wt. % content are added to epoxy matrix mixed by 10 wt. % of vegetable oils. Based on the experimental results, it was found that a significant decrease in friction coefficient was observed with increasing the CNT content. Oils can be ranked due to their effect in decreasing μ at 0.6 wt.% CNT content approximately as follows corn , almond , paraffin, sesame , sunflower , and olive oil. The friction reduction ratios were 93, 72, 67, 51, and 42 % respectively. On the other hand, it was noticed that there is significant decrease in wear loss values. Oils can be ranked due to their effect in decreasing wear at 0.6 wt. % CNT content as follows sesame, corn, paraffin, sunflower, almond and olive. The wear reduction ratios were 66, 60, 50, 43, 40 and 33 wt. % respectively. This indicates that sesame oil gives the best wear resistance among the tested vegetable oils.

KEYWORDS
Carbon nanotubes (CNT), epoxy, wear, vegetables oils.

INTRODUCTION
Owing to their unique mechanical, electrical and thermal properties, carbon nanotubes (CNTs), both single and multiwalled, have attracted extensive research attention worldwide, [1 - 3]. It has been found that composites reinforced by CNTs can have very improved properties, [4 - 6]. For example, it was reported that adding 1.0 wt. % of CNTs to a polymer matrix brought about an increase of tensile modulus and strength of up to 42 and 25 %, respectively, [7].

However, studies on the tribological properties of CNT reinforced polymer composites, [8 - 12] have been relatively fewer. Zoo et al., [8], reported that an addition of 0.5 wt. % CNTs to ultrahigh molecular weight polyethylene could significantly reduce the wear loss of the composite but increase its friction coefficient. It was considered that this was mainly caused by the increased shear strength of the composite. An et al., [9], acknowledged an improved wear and mechanical properties of alumina-based composites containing CNTs up to 4 wt. %, though without a mechanism explanation. Chen et al., [10], believed that favorable tribological properties of a CNT filled polytetrafluoroethylene composite were due to the high strength and high aspect ratio of the CNTs. They commented that the CNTs might have been released from the composite during sliding, which then prevented direct contact of worn surfaces and hence reduced both the wear rate and friction coefficient. However, no direct evidence was given. Cai et

al., [11], reported that the contribution of CNTs in a polyimide composite was to restrain the scuffing and adhesion of the polyimide matrix in sliding, providing a much better resistance than the neat polyimide. Lim et al., [13], concluded that Raman spectra could not characterize the difference between a worn and an unworn surface of CNTs and carbon/carbon composites because the spectra were nearly the same.

EXPERIMENTAL

Epoxy used in experiments was Jotafloor SF Primer. Epoxy matrix was filled by carbon nanotubes of 0.25, 0.5, 0.75 and 1.0 wt. % content. The content of vegetables oils (olive, corn, sunflower, sesame, almond and paraffin oil) was 10 wt. %.

The test specimens were molded in a die shown in Fig.1, all dimensions in mm. Wear test was carried out on the test rig shown in Fig. 2. Vertical load was applied by weights of 2, 4, 6, 8 and 10 N. Friction force was measured using load cell mounted to the loading lever and connected into digital monitor display. The test specimen was held in the specimen holder which sliding on a horizontal base with an electrical driving mechanism to move specimen in a reciprocating motion. The test was conducted under dry conditions at room temperature.

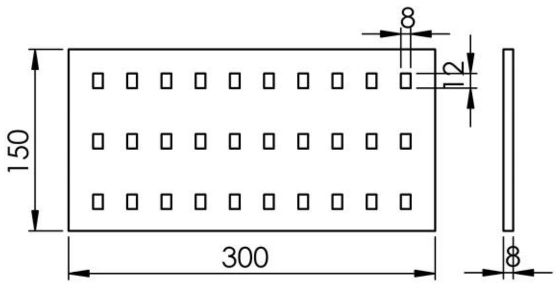

Fig.1 The molding die.

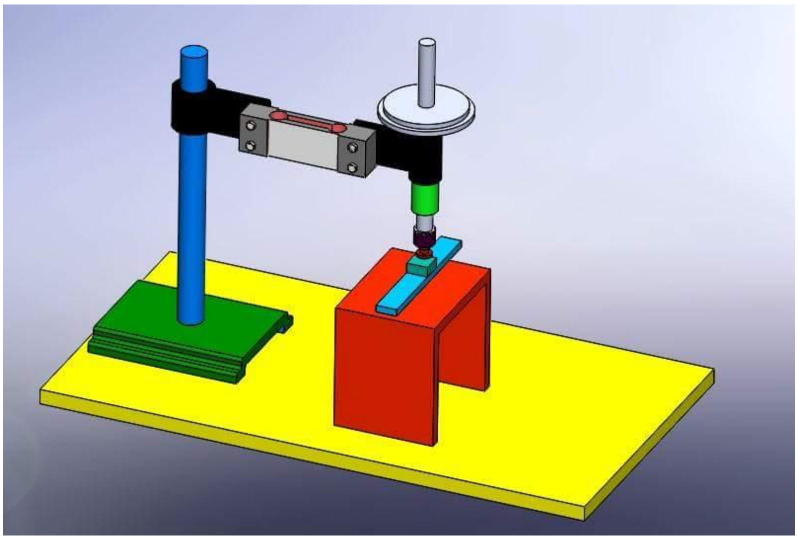

Fig. 2 Arrangement of the wear test rig.

RESULTS AND DISCUSSION

The effect of oil type and CNT content on the friction coefficient is shown in Figs. 3 - 9. Wear test was carried out on the test rig shown in Fig. 2. Vertical load was applied by weights of 2, 4, 6, 8 and 10 N. Friction force was measured using load cell mounted to the loading lever and connected intto digital monitor display. The test specimen was held in the specimen holder which sliding on a horizontal base with an electrical driving mechanism to move specimen in a reciprocating motion. The test was conducted under dry conditions at room temperature.

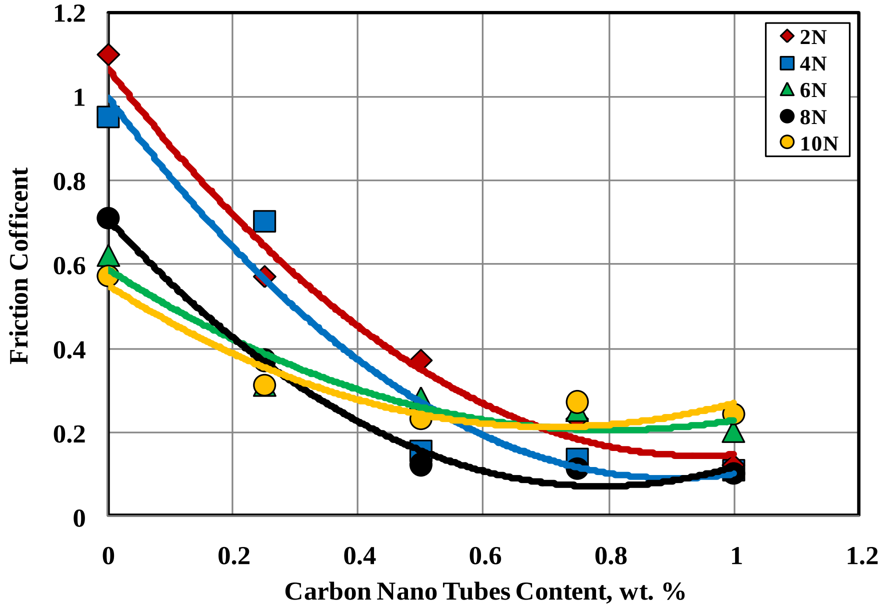

Fig. 3 Friction coefficient of composites filled by CNT and olive oil.

The relationship between friction coefficient and CNT content for olive oil is shown in Fig. 3. As shown from figure, a decrease in friction coefficient was observed with increasing CNT content. This may be attributed to CNT self-lubricating mechanism during wear. Also, it can be noticed that friction coefficient decreased with increasing normal load. It is observed that there is a slight increase in friction coefficient for CNT content above 0.8 wt. %, this behavior can be explained on the bases that the percentage of aligned CNT normal to the contact surface increases with the increase of CNT content.

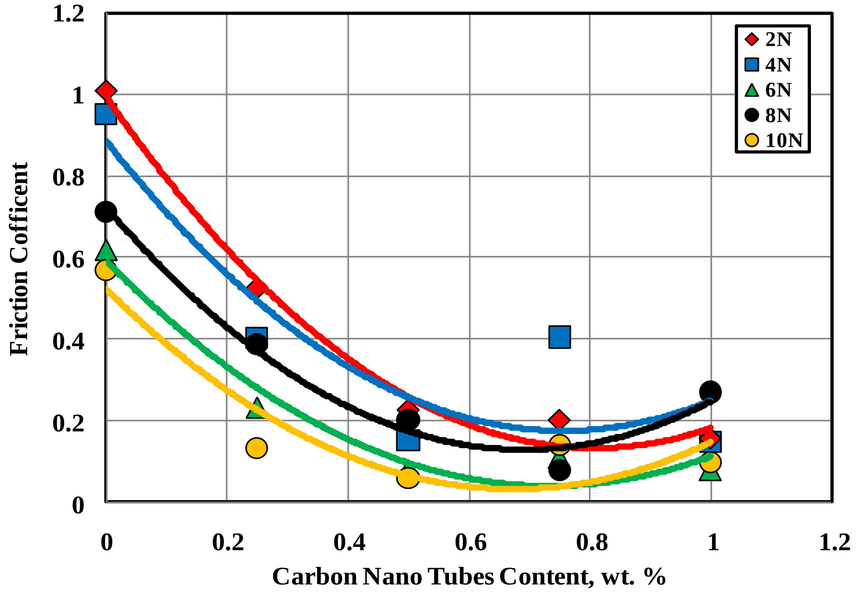

Fig. 4 Friction coefficient of composites filled by CNT and corn oil.

The relationship between friction coefficient and CNT content for corn oil, Fig.4, has the same trend observed for olive oil. This may be referred to the same mechanism of friction. Presence of oil in multipores inside epoxy matrix, where they work as reservoirs of oils and leak up to the sliding surface is responsible for friction decrease. Presence of oil decreases friction coefficient due to the film formed on sliding surface, where the contact will be between partially epoxy composites/emery paper and oil/emery paper due to the mixed lubrication regime offered by the oil film.

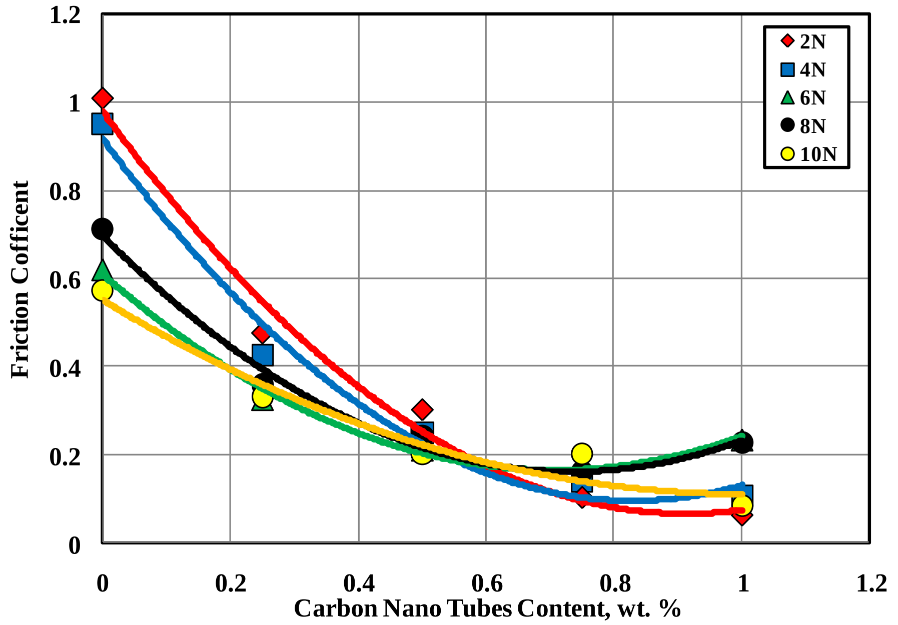

Fig. 5 Friction coefficient of composites filled by CNT and sunflower oil.

It can be noticed that friction coefficient values displayed by sliding of composites filled by sunflower oil, Fig. 5, were higher than that observed for corn oil. As shown, the lowest friction coefficient value is 0.06 at 2 N normal load and 1.0 wt. % CNT content. This value is different compared to that observed for corn oil (0.07) at 8 N normal load. For olive oil, μ is 0.1 at the same normal load. This may indicate that corn and sunflower oils have better friction properties than olive oil.

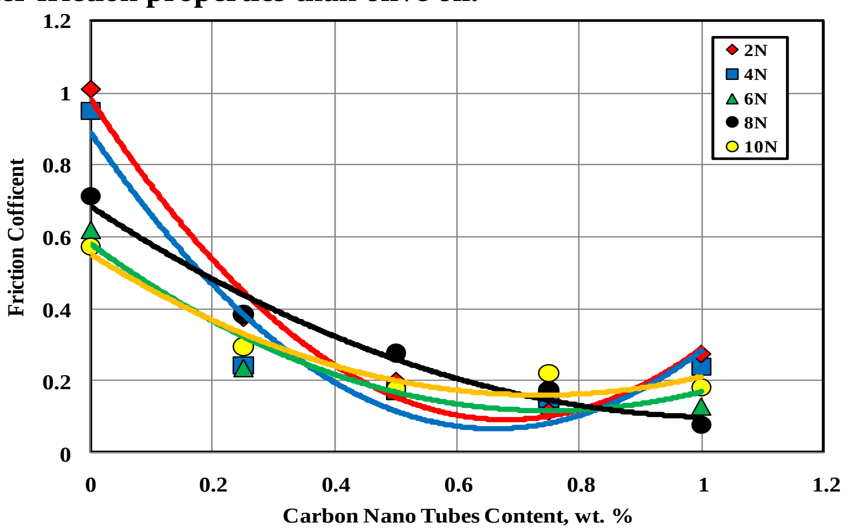

Fig. 6 Friction coefficient of composites filled by CNT and sesame oil.

For sesame oil, Fig. 6, the lowest friction coefficient value observed is 0.078 at 8 N normal load and approximately 1.0 % CNT content. It can be noticed that there is a slight increase in friction coefficient values after 0.8 wt. % CNT content. Sesame oil gives lower frictional values than olive oil.

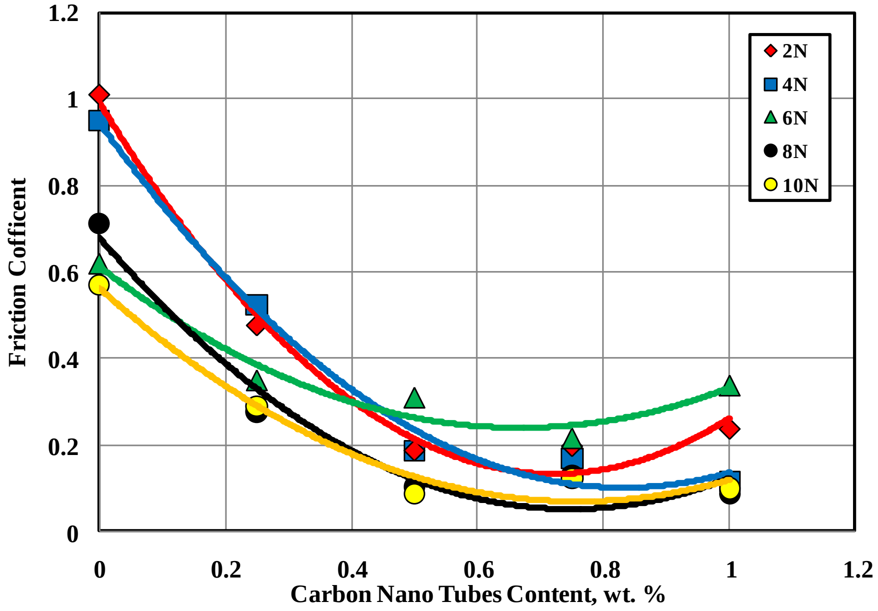

Fig. 7 Friction coefficient of composites filled by CNT and almond oil.

The friction coefficient values for almond and paraffin oils are shown in Figs. 7 and 8 respectively. It can be noticed that paraffin oil gives the lower value approximately at 0.75 wt. % CNT content especially for high normal loads. There is a slight increase in friction coefficient values after 0.8 wt. % CNT content.

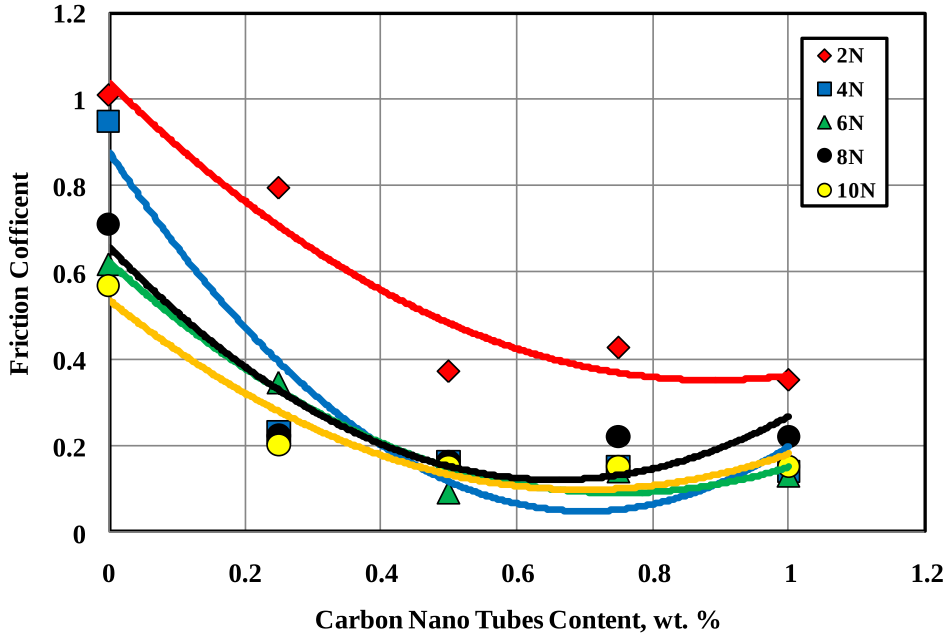

Fig. 8 Friction coefficient of composites filled by CNT and paraffin oil.

In order to evaluate the role of oil in reducing friction coefficient, comparative performance of friction coefficient is shown in Fig. 9. It can be noticed that there is

drastic decrease in friction coefficient values. Oils can be ranked due to their effect in decreasing μ at 0.6 wt.% CNT content, where corn, almond, paraffin, sesame, sunflower, and olive oils are ranked due to their superiority in reducing μ . The friction reduction ratios were 93, 72, 67, 51, and 42 % respectively.

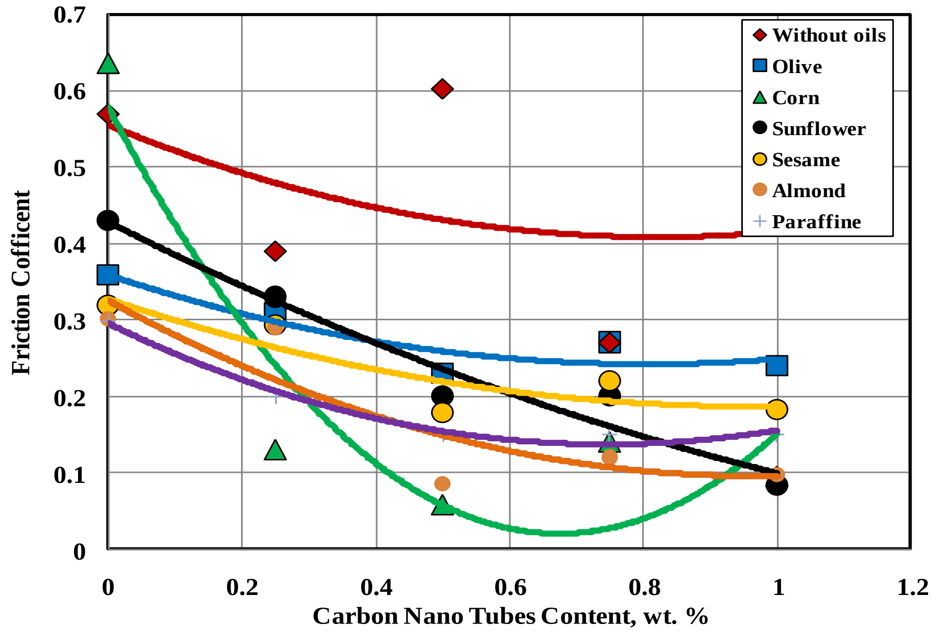

Fig. 9 Friction coefficient of composites filled by CNT and the tested types of oils.

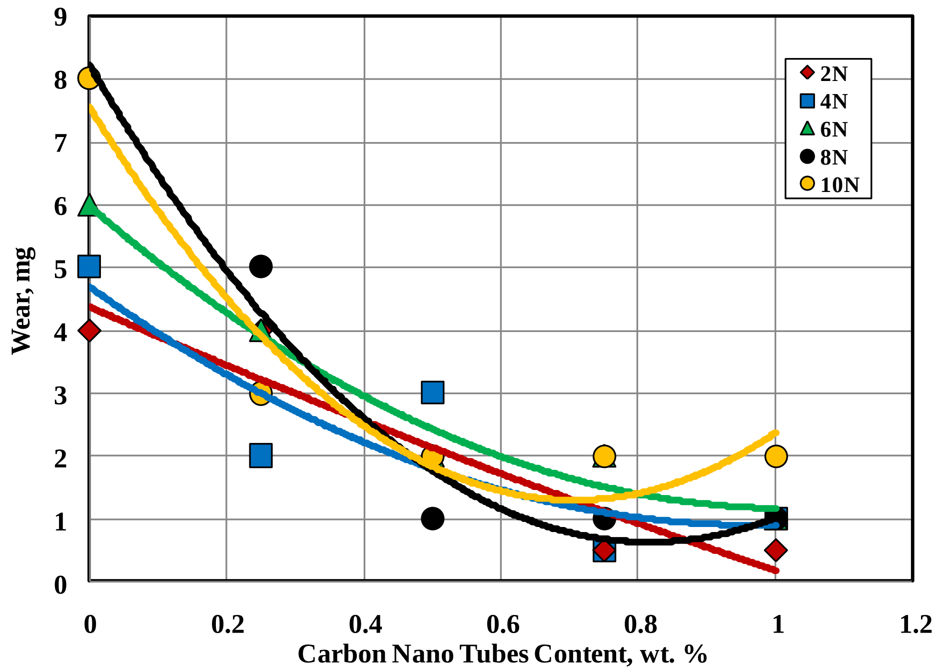

Fig.10 Wear of composites filled by CNT and olive oil.

Wear in the presented work is represented by weight loss. The relationship between wear loss and CNT content for olive oil is shown in Fig. 10. It is noticed that a decrease in wear loss was observed with increasing the CNT content. This behavior is attributed to the increase of wear resistance of composites because of CNT. It can be noticed that there is a slight increase in wear after 0.8 wt. % CNT content. The improvement of the wear resistance of composites was due to the CNTs reinforced epoxy matrix from wear.

Figure 11 displays the relationship between wear loss weight and CNT content for corn oil, where the same trend was observed as for olive oil. Presence of oil decreases wear due to the film formed on sliding surface. As shown from figure that the lowest value of wear was observed at 0.65 wt. % CNT content. It is noticed that wear values are lower than that observed for olive oil, which makes corn oil have a better wear resistance than olive oil.

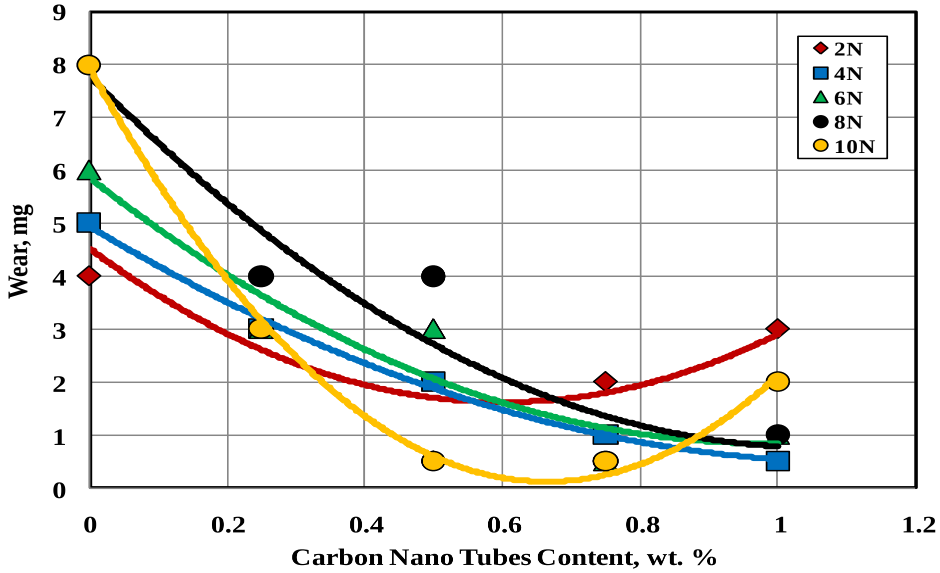

Fig. 11 Wear of composites filled by CNT and corn oil.

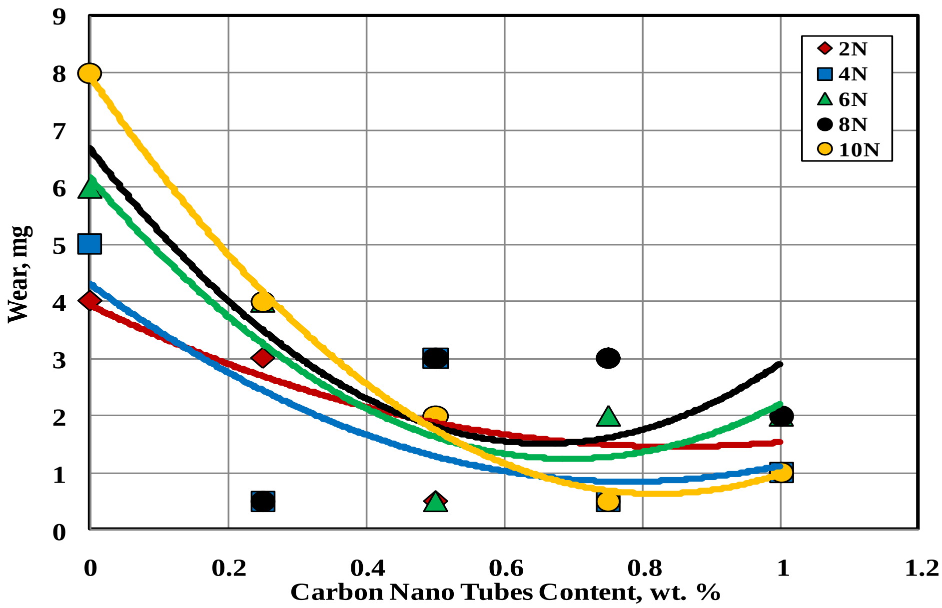

Fig.12 Wear of composites filled by CNT and sunflower oil.

Figure 12 presents the wear behavior for sunflower oil. As shown from figure, the lowest value of wear was observed at 0.75 wt. % CNT content. It is noticed that wear values are lower than that observed for olive oil, and higher than that observed for corn oil. This makes corn oil has better wear resistance than olive and sunflower oils.

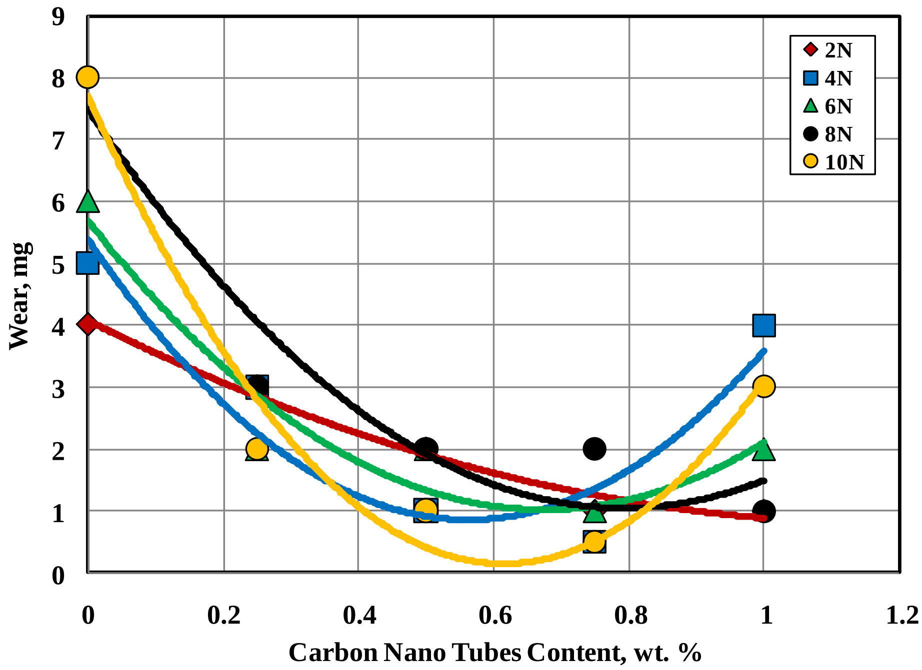

Fig.13 Wear of composites filled by CNT and sesame oil.

Results of wear of sesame oil are presented in Fig. 13. As noticed, the lowest value of wear was observed at 0.6 wt. % CNT content and there is significant increase in wear loss values beyond 0.75 wt. % CNT content. It is noticed that wear values are lower than that observed for olive, corn and sunflower oils, which makes sesame oil has the best wear resistance for all the tested oils.

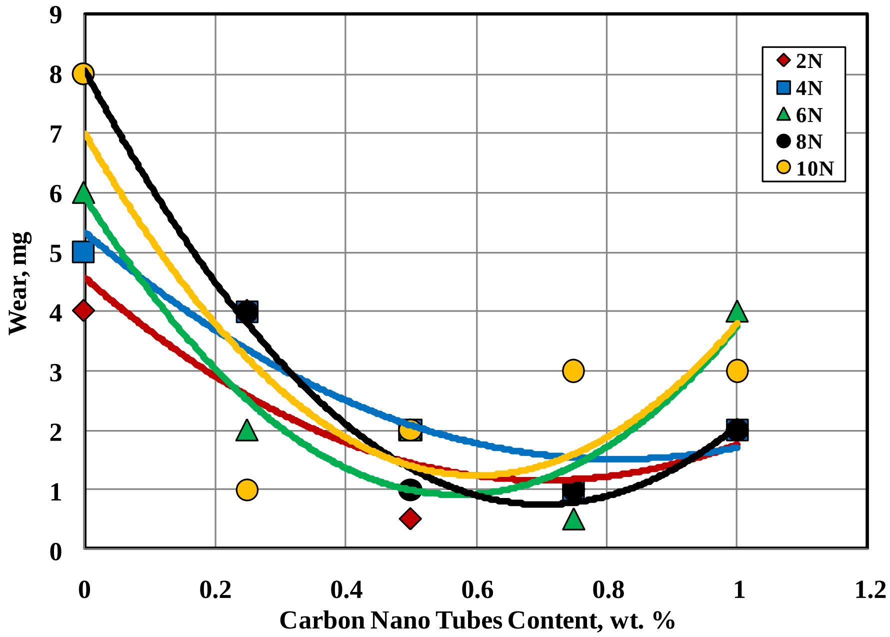

Fig.14 Wear of composites filled by CNT and almond oil.

Wear behaviour for almond oil is shown in Fig. 14, where the lowest value of wear was observed at 0.6 wt. % CNT content and there is a significant increase in wear loss values beyond this CNT content. It is noticed that wear values are lower than that observed for olive oil but higher than other oils.

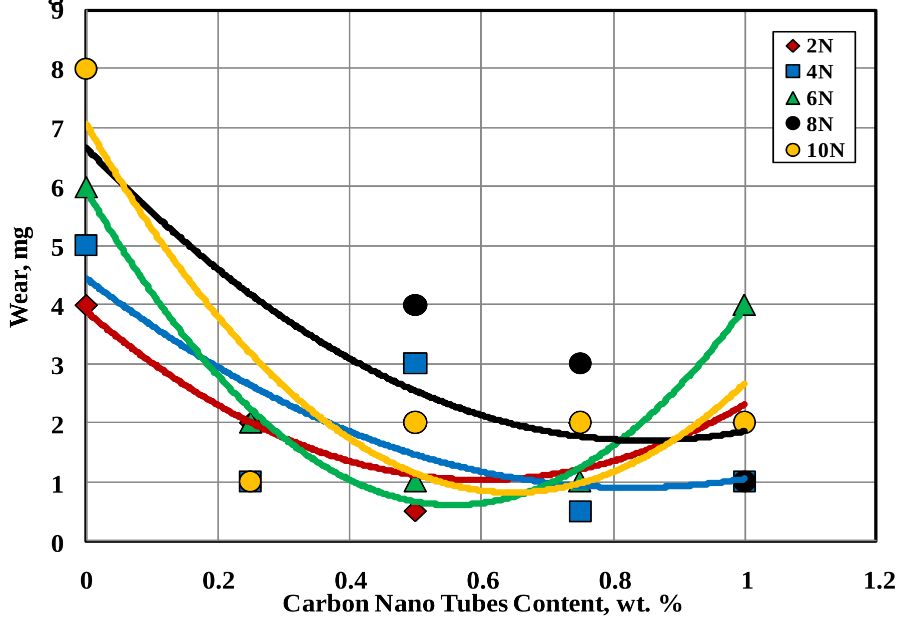

Fig.15 Wear of composites filled by CNT and paraffin oil.

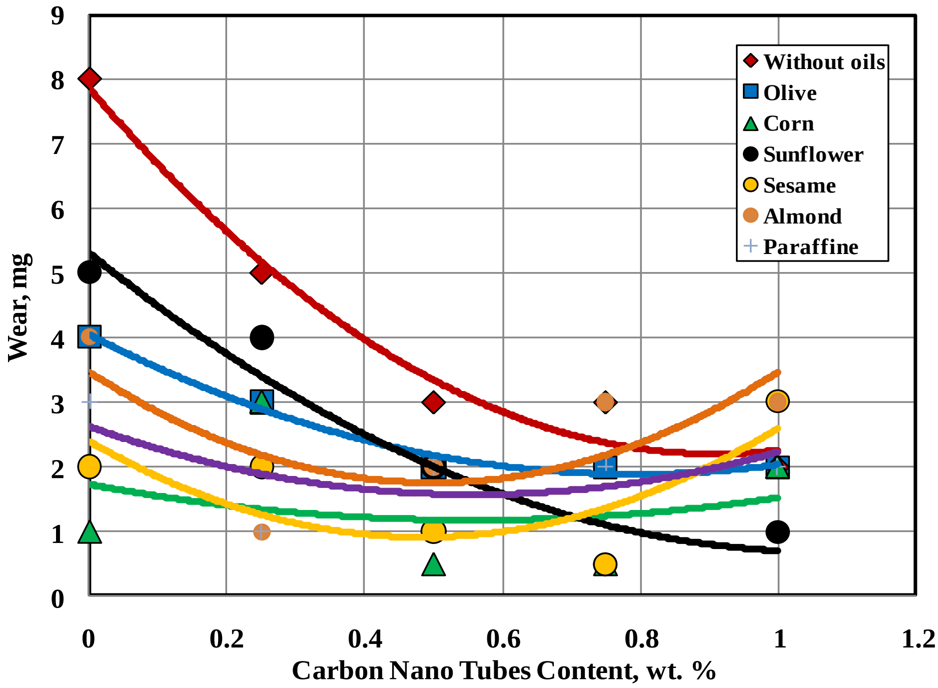

Fig.16 Wear of composites filled by CNT and different types of oils.

The relationship between wear loss and CNT content for paraffin oil is shown in Fig. 15. The lowest wear value was observed at 0.6 wt. % CNT content and there is a significant increase in wear loss values beyond this CNT content. It is noticed that wear values are lower than that observed for olive, almond and sunflower oils but higher than corn and sesame oils.

Figure 16 shows the comparative performance of wear loss. It can be noticed that there is a significant decrease in wear values. Oils can be ranked due to their effect in decreasing wear at 0.6 wt. % CNT content as follows: sesame, corn, paraffin, sunflower, almond and olive. The wear reduction ratios were 66, 60, 50, 43, 40 and 33 wt. % respectively. This indicates that sesame oil gives the best wear resistance performance. The addition of vegetables oils had excellent effect on the tribological behavior of epoxy/CNT composites.

CONCLUSIONS

In this study, the friction and wear behavior of Epoxy/CNT composites under dry sliding condition is investigated. From the experimental work, the following points can be concluded:

1. Significant decrease in friction coefficient was observed for composites filled by CNT which was attributed to the self-lubrication performance of CNTs.
2. Wear resistance of epoxy/CNT composites can be significantly improved by adding CNTs to the composite. This behaviour was attributed to the reinforcing effect and excellent thermal conductivity of CNTs. The wear rate of these composites decreases with increasing CNT content up to 1.0 wt. %.
3. Epoxy/CNT composites containing 0.6 wt. % CNT exhibited both the lowest wear rate and friction coefficient.
4. The improvement of tribological properties of epoxy/CNT composites is attributed to the strengthening effect and self-lubricating mechanism of CNTs.
5. The addition of vegetables oils has excellent effect on the tribological behavior of epoxy/CNT composites.
6. Oils can be ranked due to their effect in decreasing μ at 0.6 wt. % CNT content approximately as follows corn, almond, paraffin, sesame, sunflower, and olive.
7. Wear resistance of oils is displayed by sesame, corn, paraffin, sunflower, almond and olive, where wear reduction ratios are 66, 60 , 50 , 43, 40 and 33 % respectively.

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