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CHARACTERIZATION OF EPOXY RESIN REINFORCED WITH ECO-FRIENDLY VEGETABLE OILS

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ABSTRACT

This work aims to study the mechanical and tribological properties of different epoxy composites are performed. The epoxy matrix was adopted in this work as a base material, while the eco-friendly vegetable oils (castor, palm and rocca) are performed as filler materials. The hardness values, stress-strain curve, friction coefficient, wear resistance and topography of worn surfaces, via optical 3D, are adopted via conducting the experiments. The results show that the hardness enhanced with 11.4% % with filling content 12.5wt. %of palm. The epoxy matrix dispersed with 12.5%, 10% and 10% for castor, palm and rocca, respectively, give the lowest friction coefficient and wear rate among the other compositions.

KEYWORDS

Castor, Palm, Rocca, Epoxy, Friction, Wear.

INTRODUCTION

Polymers are essential materials used in everyday items such as rubber, plastic, resins, and adhesives [1 - 3]. Many polymers have been developed with nano fillers for various purposes [4 - 6]. Life would be much more difficult without polymers. Epoxy refers to both the cured product of epoxy resins and the epoxide functional group. It has many uses, including metal coatings, electronics, high tension electrical insulators, fiber-reinforced plastic materials, and structural adhesives [7 - 11]. In recent years, nanocomponents have emerged as a new type of material that enhances the performance of composites by introducing new features and unique interactions between materials [12 - 14]. Nanocomposite polymers consist of a base resin and fillers with at least one dimension in the nanometer range [15, 16]. These nanocomposites have superior mechanical and thermal properties compared to traditional composites due to the high density of micrometer fillers in relation to the low mass of the polymer matrix [17, 18]. As a result, polymer nanocomposites can improve mechanical properties while remaining lightweight [19, 20]. As a result, polymer nanocomposites can improve mechanical properties while remaining lightweight [21, 22].

Researchers have added additives to epoxy to improve its properties, including mechanical, tribological, electrical, and thermal qualities [23, 24]. The addition of block-copolymer (BCP) and core-shell rubber (CSR) to epoxy composites has been shown to increase fracture toughness significantly by 268% and 200%, respectively [25]. Adding graphene nanoplatelets to epoxy thermosets has also been found to enhance fracture toughness and shear strength by 142% and 252%, respectively [26].

Researchers have sought to improve the mechanical and tribological behavior of epoxy by adding different weight fractions of nano-graphene. It was found that increasing the graphene weight fraction up to 5 wt. % enhanced compressive stress and decreased the specific wear rate and friction coefficient significantly by approximately 50% and 60%, respectively, [28]. The addition of TiO_2 to epoxy has also been shown to decrease the specific wear rate and improve wear resistance, impact strength, and toughness [29]. Researchers have studied the effect of incorporating Al_2O_3 into an epoxy matrix at different weight fractions. It was found that 1 wt. % Al_2O_3 can improve the mechanical and tribological characteristics of the composite [30, 31]. However, increasing the Al_2O_3 weight fraction to 3% caused a deterioration in all composite properties due to agglomeration of the additives within the matrix. A low loading fraction of 0.4 wt. % Al_2O_3 has been shown to improve the mechanical and tribological properties of epoxy composites [32 - 34].

Hybrid composites are currently gaining popularity as advanced construction and structural materials that offer a balance between cost-effectiveness and improved performance. These materials are created by combining two or more different types of fibers within a common matrix or reinforcing polymer blends. Hybrid composites have the potential for use in a variety of industrial applications [35 - 38]. Bio-based epoxy resins have been developed using vegetable oils as a raw material, [39 - 41]. Vegetable oils are readily available, low-cost, and biodegradable, making them an ideal choice for creating flexible resins that can be used in a variety of industrial products such as adhesives and biodegradable biomaterials. Epoxy/clay nanocomposites made from castor oil were created with 1, 2, and 3 wt. % filling content. The resin matrices were examined using techniques such as FTIR, NMR, XRD, SEM, and TEM [42].

The performance characteristics of the nanocomposites showed significant improvements in tensile strength, impact, and thermal stability when compared to their original systems. Mesua ferrea L. seed oil-based epoxy/clay matrix was used as bio composites Research showed that incorporating 5 wt% of nano-clay into the pristine polymer resulted in significant improvements in various properties, including tensile strength, scratch hardness, adhesive strength, and thermal stability [44 - 46]. The tribological performance of vegetable oil-based epoxy/CNTs matrix was also evaluated, revealing that incorporating nano-hybrid oil and CNTs into the epoxy matrix led to a significant improvement in wear resistance [47 - 48].

This study aims to investigate the tribological and mechanical properties of eco-friendly vegetable oil-based epoxy composites. The tribological properties were

evaluated by measuring the friction coefficient and wear rate, while the wear mechanism was determined by analyzing the worn surfaces. The mechanical properties were assessed by examining the stress-strain curve and hardness.

EXPERIMENTAL

Materials and Specimens Preparation

In this study, KEMAPOXY 150 epoxy resin from CMB Group in Egypt was used as the base material, mixed with natural oils (castor, palm and rocca). Specimens were prepared by adding varying percentages of natural oils and mixed at 300 rpm for 10 minutes. The matrix was created by mixing components A and B in a 2:1 ratio at 300 rpm for 3 minutes. The inter-bonding strength of the matrix depends on the proportion of hardener and stirring speed. The oil was added in percentages of 2.5, 5.0, 7.5, 10, and 12.5% by weight. The mixture was then poured into cylindrical molds and left to cure for 7 days at room temperature. The steps of epoxy nanocomposites are displayed in Fig. 1.

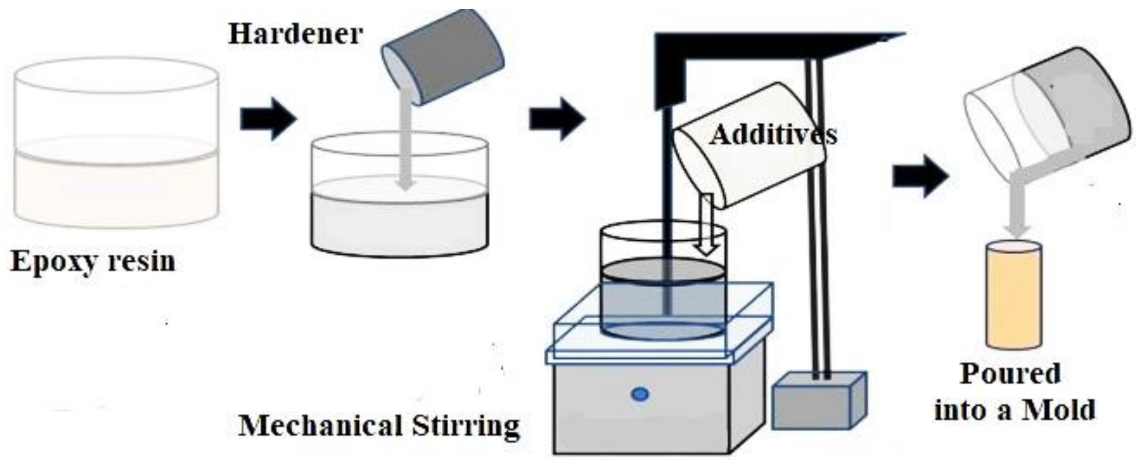

Fig. 1 Schematic diagram of epoxy sample preparation.

Experimental Equipment

The mechanical properties of the specimens were evaluated by measuring the stress-strain curve and hardness using a DFM-300KN uniaxial universal testing machine and a portable Shore D Durometer device. The tribological properties were assessed by measuring the friction coefficient, wear rate, and analyzing the worn surfaces using a pin-on-disk tribometer (as displayed in Fig. 2) and an electronic microscope (OLYMPUS BX53M).

The specimens were tested under dry contact conditions at 30°C and 55% relative humidity. Tests were conducted under five different normal loads at a sliding velocity of 0.25 m/s. The wear rate was calculated by measuring the weight loss after sliding the specimens against sandpaper for 3 minutes. The wear mechanism was analyzed by identifying wear tracks, grooves, voids, plastic deformation layers, and other defects on the worn surfaces.

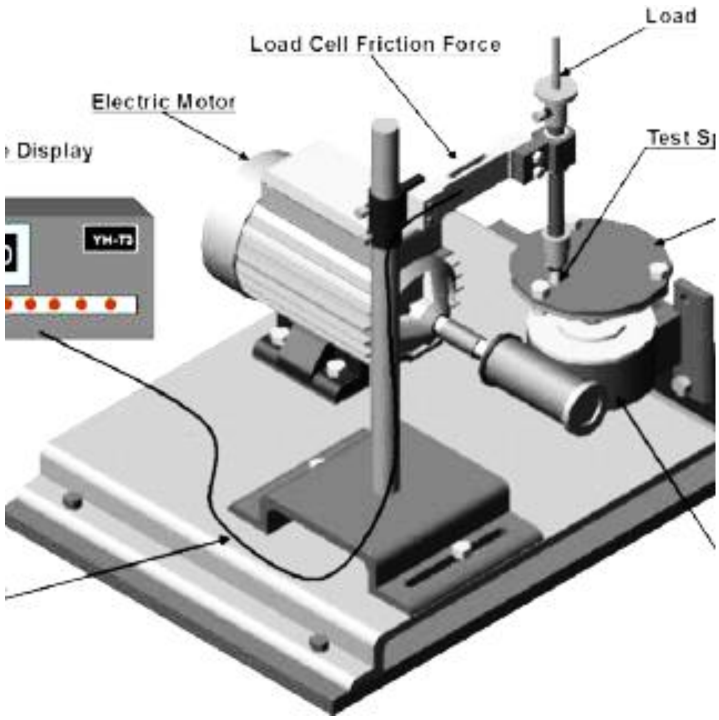

Fig. 2 Arrangement of tribometer test rig.

RESULTS AND DISCUSSIONS

Mechanical Characterizations of Epoxy Composites

In this section, the focus is on testing specimens to identify the effect of additives on the mechanical properties of the epoxy resin. The specimens are divided into two sets, the first set of specimens depends on filling with different natural oils. The best amount of content for different natural oils (paraffin, castor and rocca) is approved by examining the epoxy specimens.

The compressive test was adopted for all specimens to evaluate the strength of epoxy composites. Stress strain curves of epoxy specimens filled with different amount content of natural oils were displayed in Figs. 3 - 5. Figure 3 illustrates the stress strain curve of epoxy resin filled with castor oil. The results reveal that the presence of castor oil leads to an improvement in the strength of epoxy matrix, 12.5 % of oil. Furthermore, the breaking strain percentage was increased compared with pure epoxy sample. It can also be noticed that the breaking strain is constantly rising until the amount of filler is 10 % of the weight. While by increasing the castor oil content above this ratio, it was found that an amount of oil remains and does not mix with the resin. The specimens reinforced with palm oil were given in Figure 4. The results show that adding palm oil helps to improve the strength and breaking strain percentage of epoxy matrix. The best strength value was found for sample filled with 10 % of the weight. While the breaking strain percentage did not achieve any change with the increase in the amount of oil above 5 % of the weight. The rocca oil specimens were illustrated in Fig. 5. It can be observed from the figure that adding 2.5 % by weight of rocca oils helps to increase breaking strain percentage compared with the pure sample. Furthermore, high amount content of rocca oil has no effect on the breaking

strain but contributes to improving the epoxy matrix strength. Finally, it can be evident that adding oil to epoxy leads to increasing the strength and breaking strain percentage of the matrix.

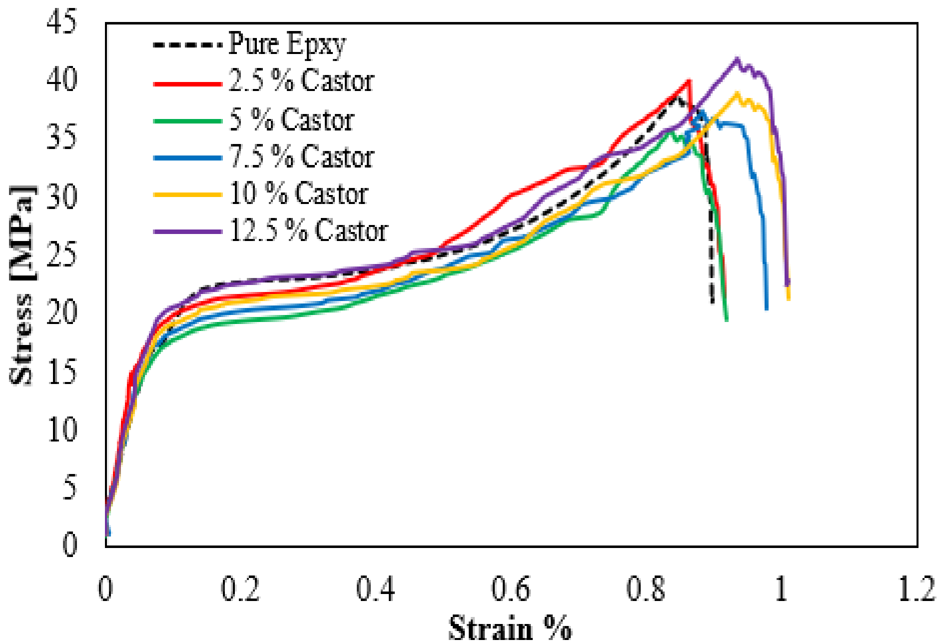

Fig. 3 Stress strain curve of epoxy resin filled with different filler content castor oil.

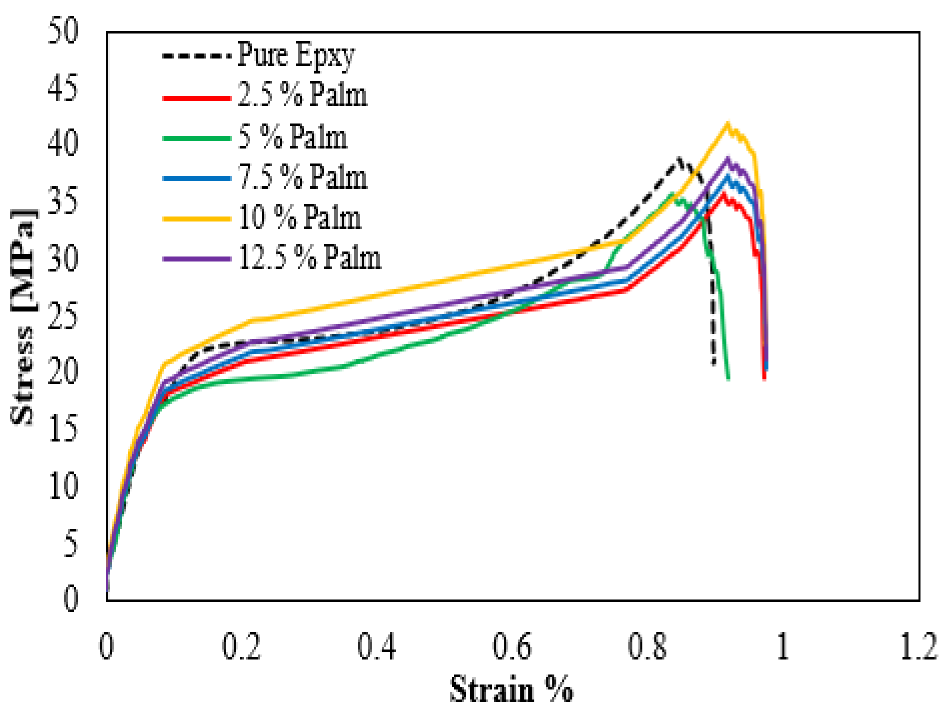

Fig. 4 Stress strain curve of epoxy resin filled with different filler content palm oil.

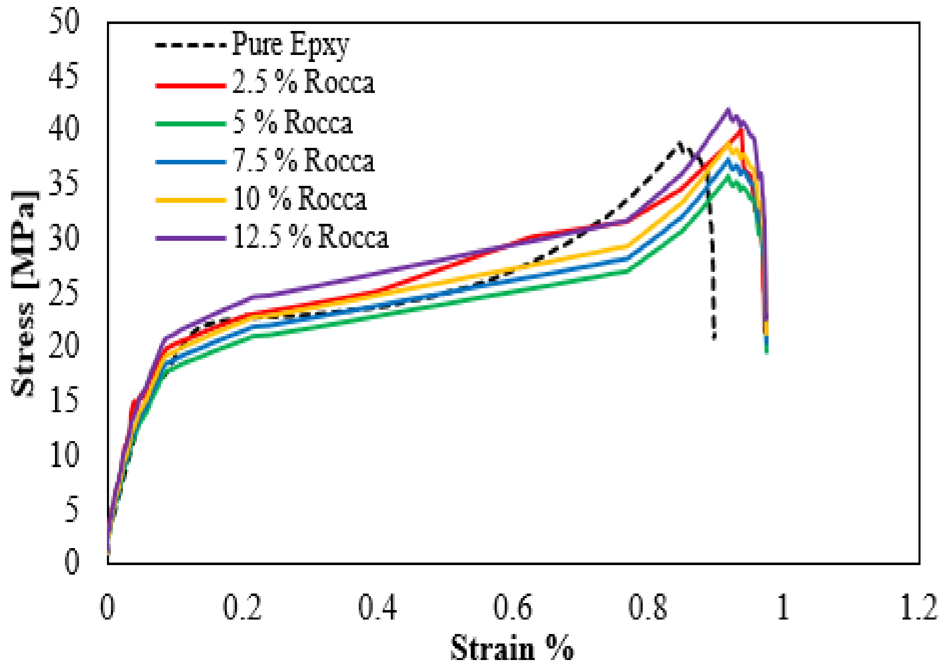

Fig. 5 Stress strain curve of epoxy resin filled with different filler content rocca oil.

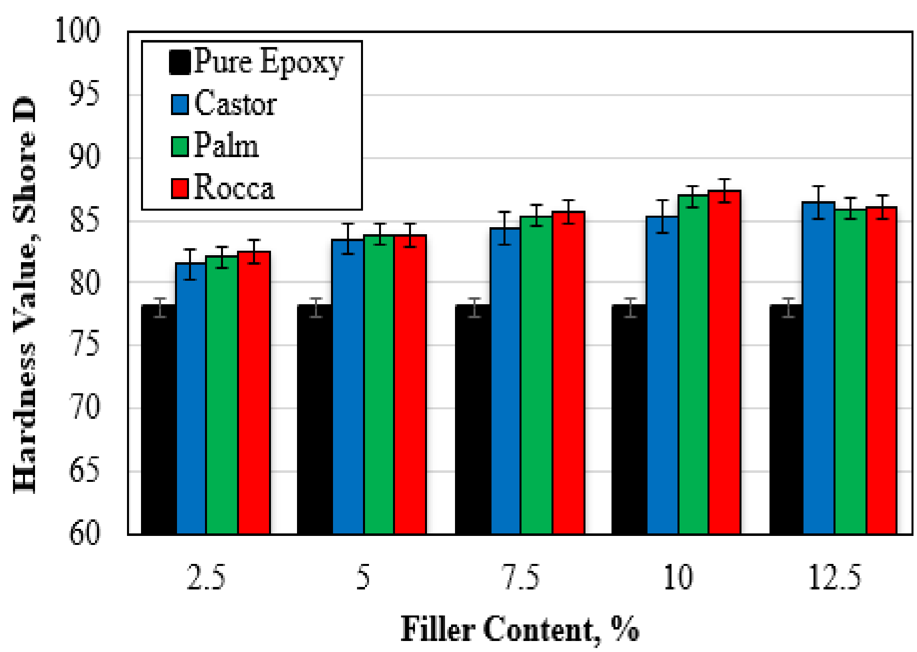

Fig. 6 Hardness shore D values of epoxy resin filled with different type natural oils.

Hardness values are performed to evaluate the performance of various additives within epoxy matrix via comparing with the pure sample. The experiments reveal that the pure epoxy sample gives a good hardness value up to 78 Shore D. It is seen that filling epoxy matrix with different natural oils, castor, palm and rocca helps to

improve the resin homogenous and strength the bonding, as shown in Fig. 6. The results show that the specimens reinforced with castor oil exhibit an enhancement of hardness value. The maximum hardness value of epoxy/castor oil specimens archives at filling content of 12.5 wt. %, 86.5 Shore D, with 10.9 % increasing compared to pure sample. The same observation is true with specimens filled with palm or rocca oils. Furthermore, the maximum hardness values are 86.9 Shore D for 10 wt. % of palm oil, 11.4 % improving, and 87.3 Shore D for 10 wt. % of rocca oil, with improving up to 11.9 %.

Tribological Properties of Epoxy Composites

The tribological performance of epoxy composites was evaluated through examining the friction coefficient and wear rate and scanning the worn surfaces. The topography of the worn surfaces was analyzed using 2D and 3D optical microscopic images. In addition to optical scanning, the epoxy composites were depicted using SEM technique to record more details of the contact surfaces of epoxy matrix.

The friction coefficient of epoxy specimens filled with natural oils was displayed on Figs. 7 - 9. The influence of adding castor oil with various filling content on the friction coefficient is illustrated in Figure 7. The results indicate that the dispersion of castor oil leads to reduce the friction coefficient. It can be observed that the minimum friction coefficient occurs with sample filled by 12.5 % by weight of castor oil. The friction coefficient reduces up to 28 % compared with the pure sample. Moreover, epoxy/palm composites are examined under the same conditions, as displayed in Fig. 8. The results evident that the friction coefficient low with increasing of palm oil content up to 10 %. While increasing the amount of filler gives a reverse effect and the friction coefficient returns to rise. However, the lowest friction coefficient occurs with sample filled by 10% by weight, 48 % of reduction. The friction coefficient of epoxy/rocca composites is illustrated in Figure 9. The same observation is repeated as happened in the case of palm oil. While the reduction of friction coefficient reaches up to 50% compared with free sample. Figure 10 gives a comparison between various oil types, castor, palm and rocca and free epoxy matrix. It can be found that filling content of 12.5 %, 10 % and 10 % for castor, palm and rocca, respectively, give the lowest friction coefficient among the other compositions. Thus, by comparing the best specimens of each type of oil, it may observe that the sample 10 % by weight of rocca has the best performance. It can be evident that filling epoxy matrix with oils contributes to forming a self-lubricating layer that leads to reducing the friction coefficient.

The wear rate of epoxy specimens dispersed with natural oils, castor, palm and rocca, was given on Figures 3.19 to 3.22. The effect of adding castor oil with various filling content on the wear rate is displayed in Figure 3.19. It was found that adding castor oil to epoxy matrix leads to wear rate go down. This may be due to the self-lubricating effect of the mixture. The results indicate that wear rate reduces with high filling amount of castor oil. However, the lowest wear rate value was given with 12.5 % filling amount of castor oil. Adding palm oil to epoxy matrix has the same effect, as depicted in Fig. 3.20. It may be observed that adding 10% filling amount of palm oil

leads to decrease the wear rate compared with pure epoxy sample. Moreover, rocca oil plays the same role in the wear resistance, as illustrated in Fig. 3.21. It was found that dispersion of 10% filling amount of rocca oil helps to lower the wear rate.

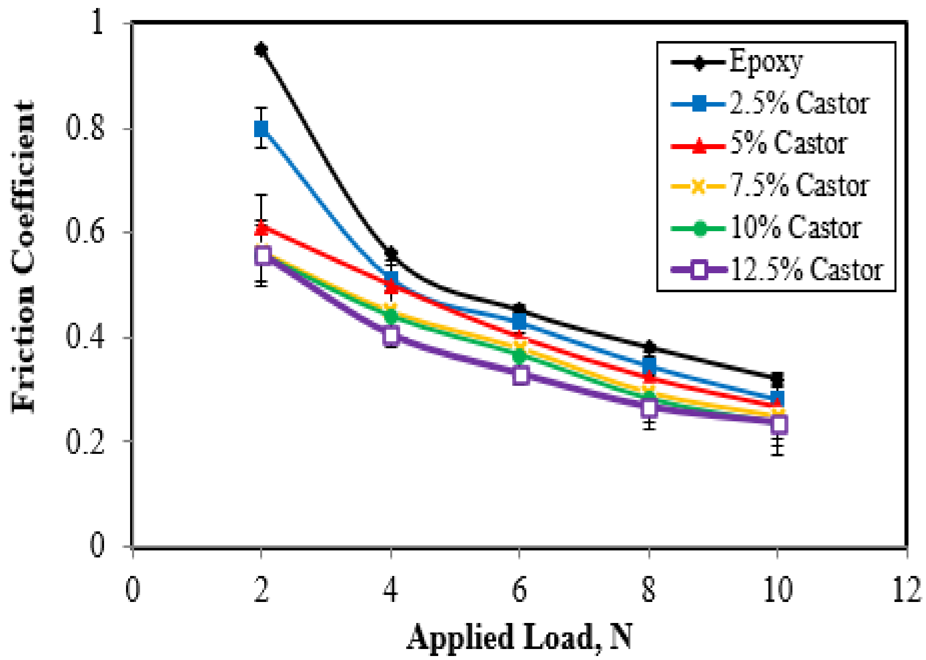

Fig. 7 COF of epoxy resin filled with different filler content castor oil.

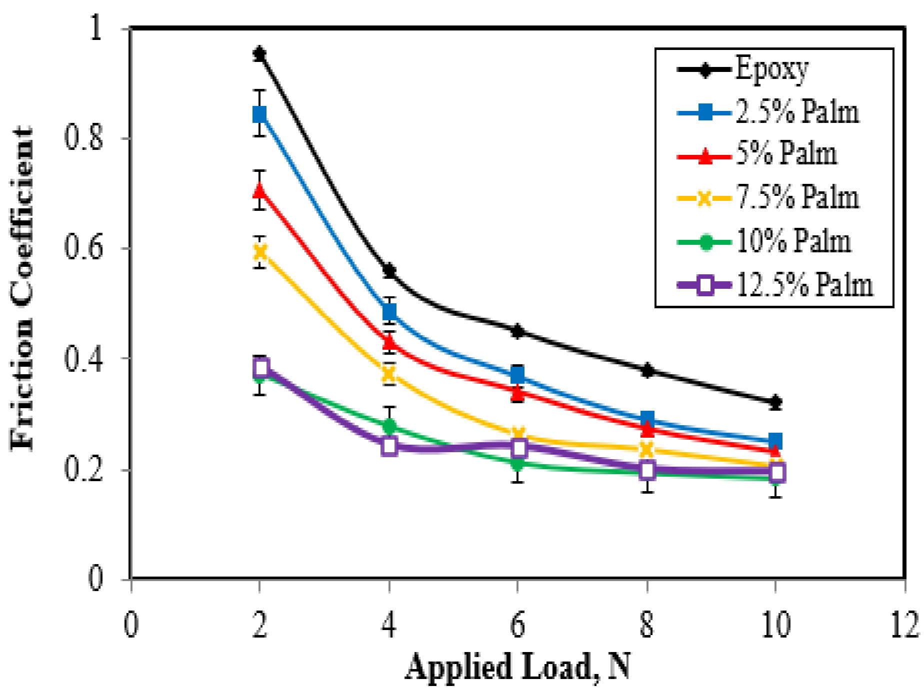

Fig. 8 COF of epoxy resin filled with different filler content palm oil.

Figure 3.20 gives a comparison between different types of epoxy/oil specimens to evaluate the wear resistance. The results indicate that specimens filled with rocca oil were given the lowest wear rate, which decreases by approximately 57 % compared with free epoxy matrix. Furthermore, adding castor and palm oils to epoxy matrix contributes to reducing the wear rate by about 42 % and 50 %, respectively. Finally, it can be evident that the presence of oil within the epoxy matrix plays an effective role in improving frictional performance and reducing wear.

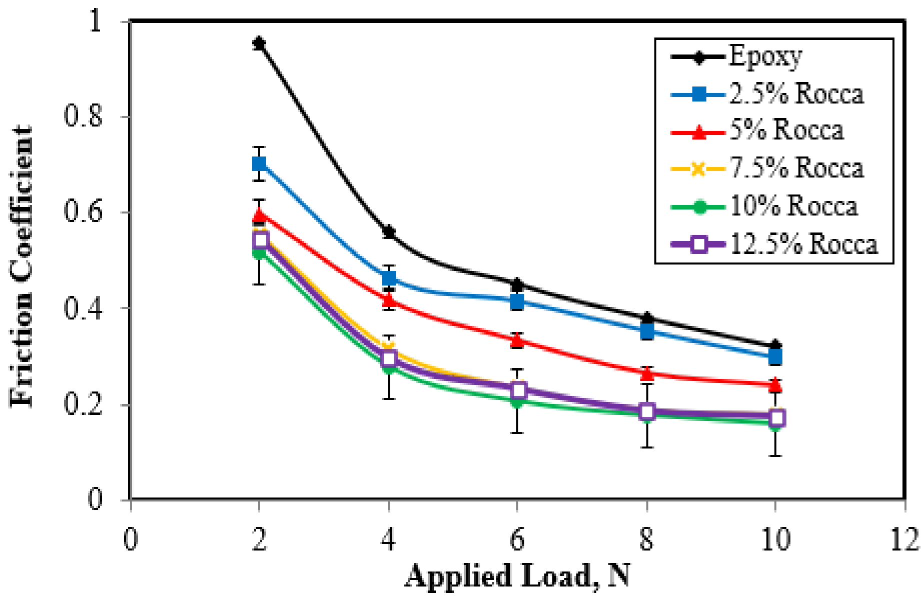

Figure 9 COF of epoxy resin filled with different filler content rocca oil.

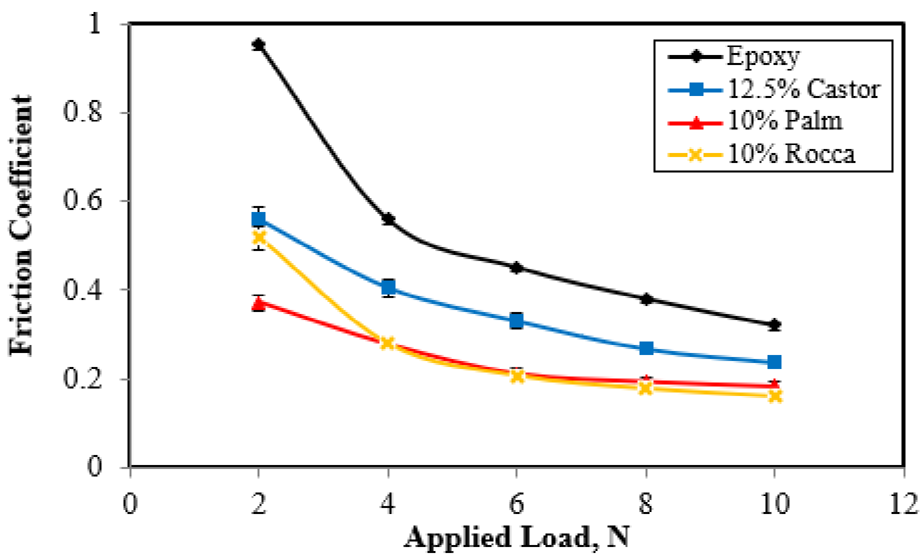

Fig. 10 Comparison of COF between epoxy resin filled with different oils.

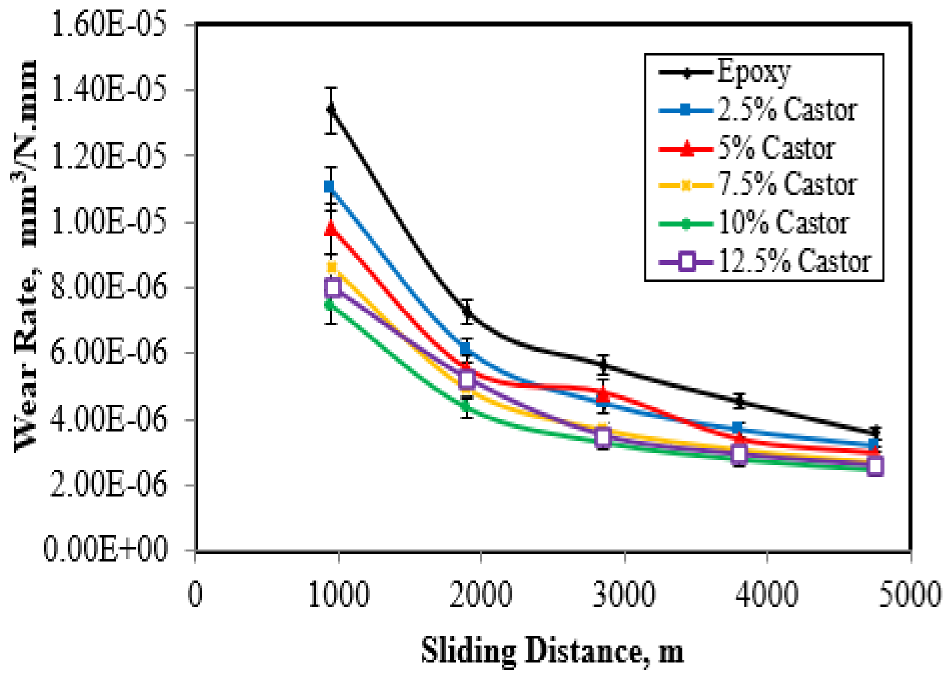

Fig. 11 Wear rate of epoxy resin filled with different filler content castor oil.

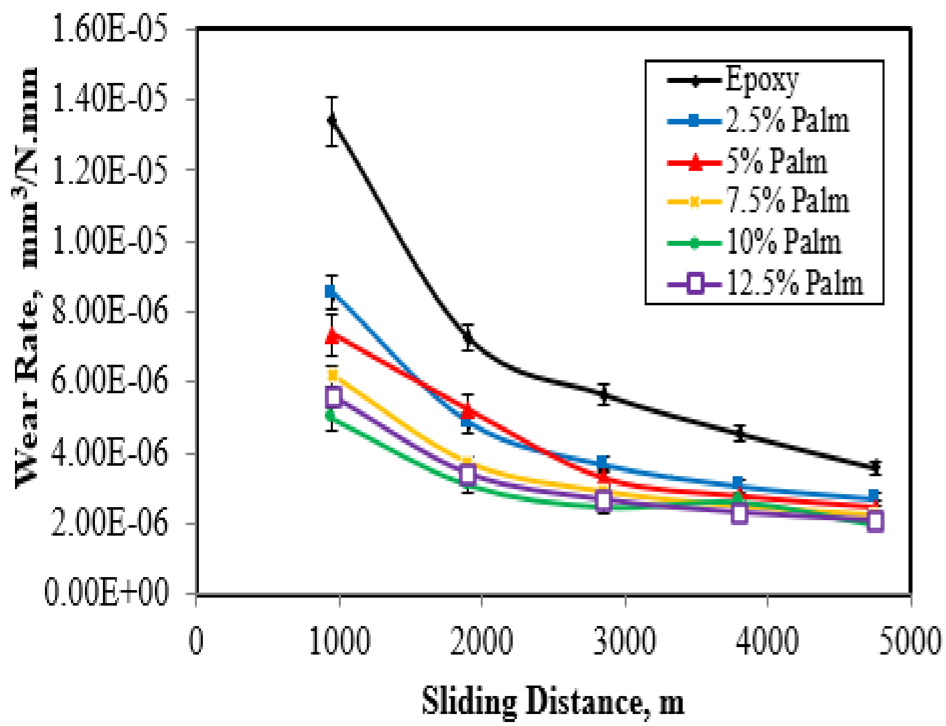

Fig. 12 Wear rate of epoxy resin filled with different filler content palm oil.

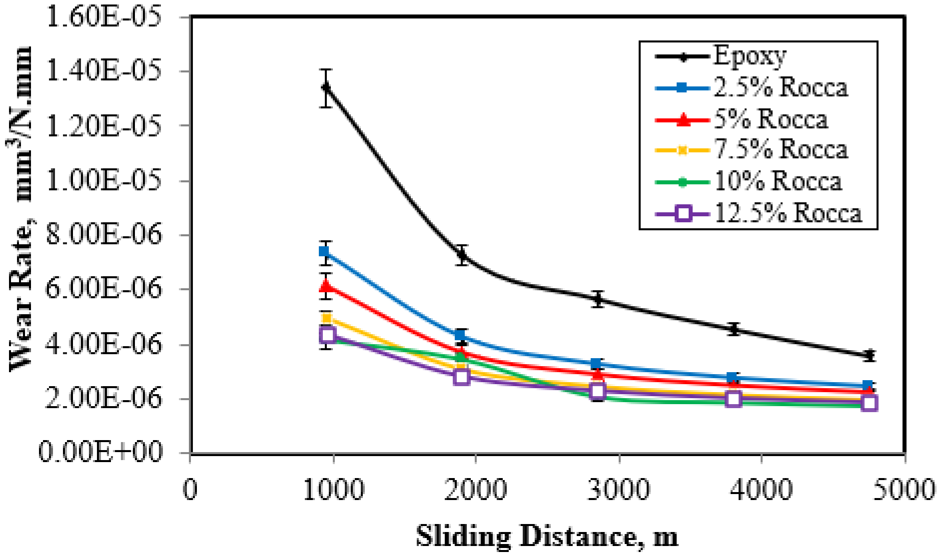

Fig. 13 Wear rate of epoxy resin filled with different filler content rocca oil.

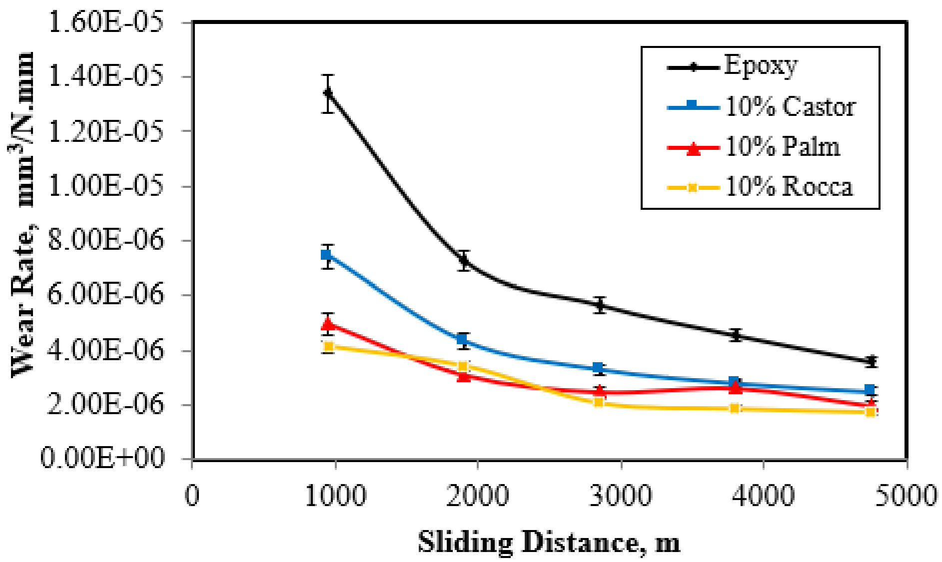

Fig. 14 Comparison of Wear rate between epoxy resin filled with different oils.

The worn surfaces of specimens were performed via optical microscopic images as illustrated in Figs. 15 - 17. The epoxy free sample displays a damaged surface with some wear track and grooves. This may be due to the free epoxy matrix being weaker. Figure 15 displays a clear shot of the worn surface epoxy matrix filled with castor oil, which is performed that the wear tracks and grooves formed through the contact area. It can be found that in the sliding area of specimens there were less marks shown in sample (A). Furthermore, it can be indicated that specimens containing castor oil exhibit less damage surface, therefore this may be due to the presence of oil which helps to improve wear resistance. In addition, the images of the specimens with a high amount of filling, sample (E), indicate the good spread of the oil through the epoxy

matrix. Which may lead to the formation of a self-lubricating film that improves tribological performance. Moreover, the same conclusion is suitable for the worn surface images of the specimens filled with palm and rocca oils as shown in Figs. 16 and 17, respectively.

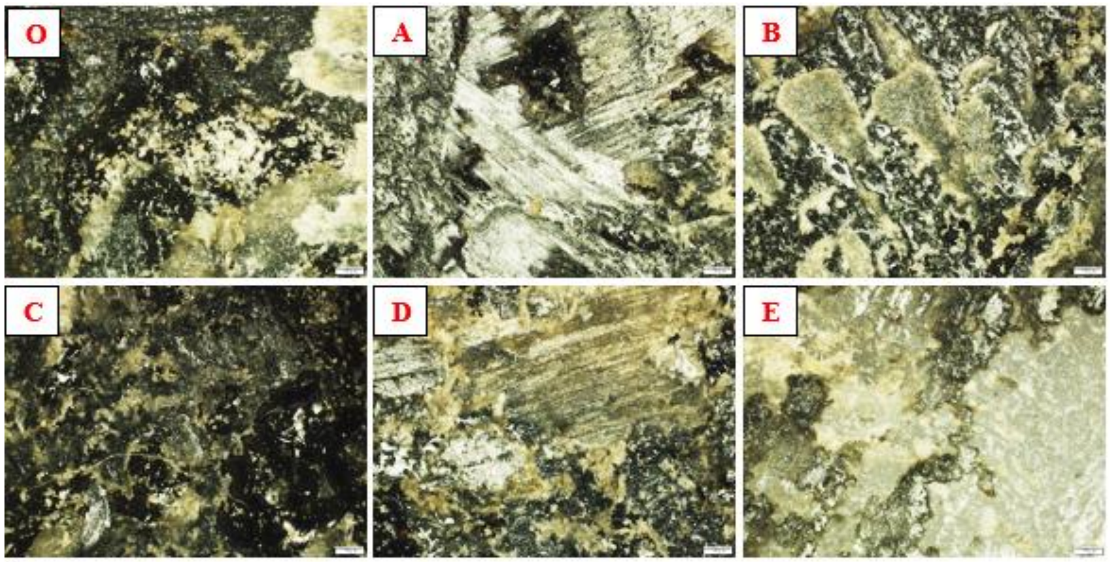

Fig. 15 Optical topography images of epoxy matrix filled with castor oil, (O) free epoxy matrix, (A) 2.5 % castor oil, (B) 5 % castor oil, (C) 7.5 % castor oil, (D) 10 % castor oil, and (E) 12.5 % castor oil.

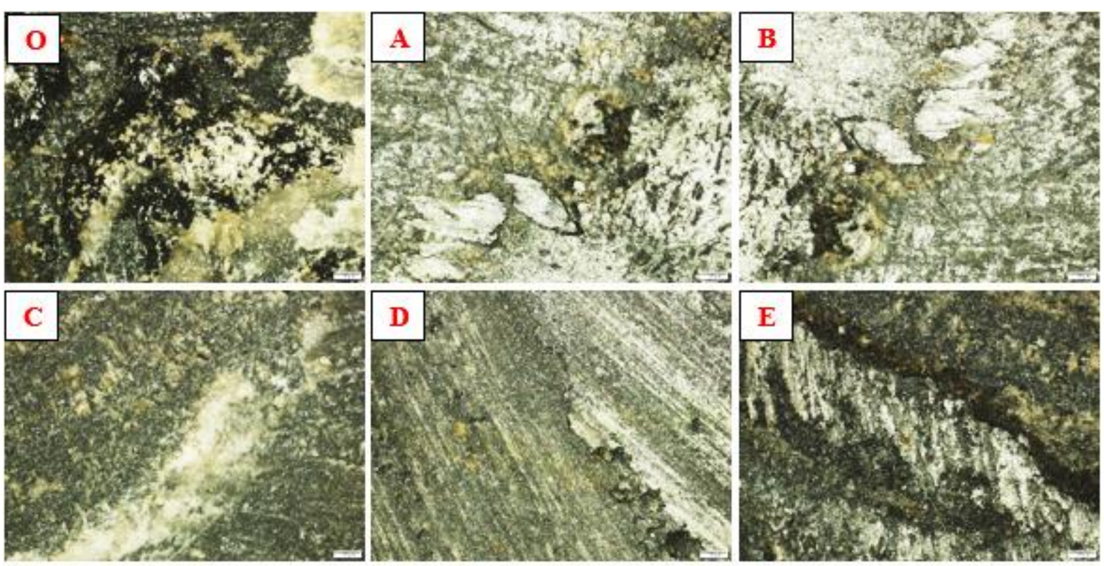

Fig. 16 Optical topography images of epoxy matrix filled with palm oil, (O) free epoxy matrix, (A) 2.5 % palm oil, (B) 5 % palm oil, (C) 7.5 % palm oil, (D) 10% palm oil, and (E) 12.5 % palm oil.

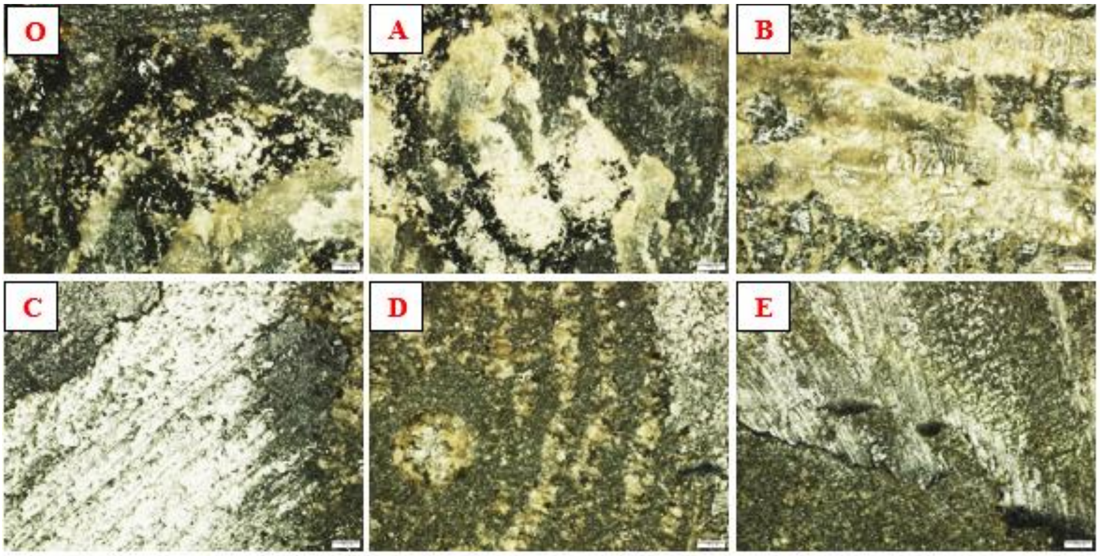

Fig. 17 Optical topography images of epoxy matrix filled with rocca oil, (O) free epoxy matrix, (A) 2.5 % rocca oil, (B) 5 % rocca oil, (C) 7.5 % rocca oil, (D) 10% rocca oil, and (E) 12.5 % rocca oil.

CONCLUSIONS

The current study targeted epoxy matrix to enhance its mechanical and tribological properties. Accordingly, many tests were carried out to evaluate the specimens features, therefore this study concluded the following points:

1. Filling the epoxy matrix with oil contributes to enhancing the mechanical and tribological properties of the oil.

2. High filling content of various oils, castor, palm and rocca give the best mechanical performance. Where, the strength and the breaking strain percentage of epoxy matrix increased.

3. The hardness enhanced with 10.9 % with filling content 12.5 wt. % of castor. Moreover, adding 10 wt. % of palm or rocca oil leads to rise the hardness value approximately 11.4 % and 11.9 %, respectively.

4. The epoxy matrix dispersed with 12.5 %, 10 % and 10 % for castor, palm and rocca, respectively, give the lowest friction coefficient and wear rate among the other compositions.

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