

FRICITION AND WEAR OF POLYMERIC COMPOSITES FILLED BY OILS

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ABSTRACT

The present work discusses experimentally the performance of proposed polymeric nanocomposites filled by vegetables and paraffin oils as well as carbon nanotubes (CNT) to be used as bearing materials. Two groups of test specimens were prepared. The first group included high density polyethylene (HDPE), low density polyethylene (LDPE), polystyrene (PS) and polyamide (PA12) that were mixed with 5.0 wt. % paraffin oil and 0.6 wt. % CNT and molded. The second group was PA12 that filled by various kinds of vegetables oils of 5.0 wt. % content and 0.6 wt. % CNT as well.

The proposed nanocomposites were introduced to enable the bearing to overcome the boundary lubrication condition, whereas every two mating surfaces are in contact with each other experience asperities partially. In that condition, CNT can probably improve the self lubricating properties when the oil film is difficult to be formed on the contact area. Besides, oil contained in the pores flows to the surface due to the heat generated by friction and forms an oil film, where the pressure generated by the hydrodynamic action separates the two sliding surfaces and carries the load. Presence of oil inside the polymeric matrix of the nanocomposites makes the bearing operates for relatively longer time without further lubrication.

Based on the experimental results, it was found that, significant decrease in friction coefficient and wear was observed for the proposed nanocomposites due to their self-lubrication performance. Also an improvement of the tribological properties has been attained. The improvement was attributed to the strengthening effect and self-lubricating mechanism of CNT as well as the presence of vegetables oils that facilitated the rolling motion of CNT. Besides, filling PA12 by vegetables oils caused significant decrease in wear values. Sesame oil can be recommended to fill PA12 nanocomposites.

KEYWORDS

Friction, wear, polymeric nanocomposites, bearings.

INTRODUCTION

Polymeric composites are extensively used as bearing surfaces. In extreme working conditions, it is needed to develop the self-lubricating polymeric materials. Several attempts were carried out to accomplish that objective. Polyamide (PA6) filled by vegetables oils such as (olive, flax seed, almond, castor, camphor, cress, black seed, lettuce, sesame, and sun flower) in content up to 10 wt. %, were tested, [1, 2]. It was concluded that, friction coefficient (μ) decreased as the oil content increased. Whereas the oil transfer from the specimen to the contact surface forming oil film. The oil film was responsible for the friction decrease. The minimum value of friction coefficient was observed for flax seed oil. In recent researches, LDPE and PA12 as matrix materials were reinforced by graphene nanoplatelets (GNPs) and were impregnated by paraffin oil. Friction and wear of the suggested composites were investigated, [3, 4]. It was found that LDPE/GNPs and PA12/GNPs nanocomposites had lower coefficient of friction and wear than those of the unfilled LDPE and PA12.

HDPE, polypropylene (PP), PS were reinforced by polytetrafluoroethylene (PTFE) fibers and filled by vegetable oils of 10 wt. % were tested, [5]. The PS and PE specimens filled by glycerin oil displayed a decrease in the μ with increasing oil content. Regarding the PP composites filled with corn oil, it manifested a slight friction increase. The results of the PP specimens demonstrated a consistent trend. The least value of μ (0.07) was offered by PE filled by 7.5 wt. % glycerin oil and 20 wt. % PTFE. This value recommends those composites to be used as bearing materials. The relatively lower friction values exhibited by PE filled by glycerin oil are due to its quite good lubricating property. On the other hand, PP composites revealed the lowest wear values.

Dry sliding and lubricated friction as well as wear behaviors of PA and HDPE blend were studied, [6, 7]. It was found that the PA specimen showed the highest μ , while HDPE displayed the lowest. The friction of PA blended by HDPE decreased. The wear and friction properties of PA66, polyphenylene sulfide (PPS), and PTFE were studied, [8]. The results proved that friction properties could be gotten better by oil lubrication. The anti-wear properties of PPS and PTFE were enhanced by oil lubrication. It was observed that the high elasticity was found to be useful to form a transfer film responsible for a low and stable μ , [9 - 11]. The results manifest the friction behavior in seawater is stable, [12], μ of PTFE was slightly lower and the wear was somehow higher than those in distilled water.

The tribological behavior has been well developed for the polymethyl methacrylate polymer (PMMA), [13, 14]. Friction and wear of PE, PA, POM, PTFE, and bakelite bearings were investigated. The most wear resistance had occurred in PA bearings, [15]. The average μ value showed that PA reinforced by aramid fibers generally had the lowest values. The polyimide (PI) composites filled with carbon fibers were selected to study the friction and wear properties [16]. The tribological behavior of a carbon nanotube reinforced polyamide (PA6) composites was investigated, [17]. The results demonstrate that CNT enhanced wear resistance and decrease friction coefficient of PA6, due to the self-lubricating effects of CNT on PA6 matrix.

The friction and wear behavior for polyethylene terephthalate with PTFE (PET/PTFE) was studied, [18]. Friction and wear of acetal and nylon was carried out, [19]. The adherence of polymeric transfer film into the steel surface was explained. The relatively limited adherence on stainless steel was explained, [20], on the bases of its lower surface energy and lower friction. CNT have extensive research attention in engineering applications, [21 - 23]. Composites reinforced by CNT developed properties, [24 - 26]. It was found that addition of 1.0 wt. % of CNT to polymer matrix increased tensile modulus up to 42 % and the strength up to 25 %, [27 - 33]. It has been reported that addition of CNT to polyimide increased the resistance to scuffing and adhesion.

In the present experiments, friction coefficient and wear of HDPE, LDPE, PS and PA12 filled by paraffin oil and CNT, as well as PA12 filled by CNT and different types of vegetables oils will be investigated.

EXPERIMENTAL

Experiments were carried out by use of pin-on-disc wear tester, Fig. 1. Friction test period was 600 seconds under constant sliding velocity of 1.0 m/s and 20 N load. The test specimen, in the form of cylindrical pin, had 10 mm diameter and 30 mm height. The diameter was reduced to 5 mm to contact the friction disc, Fig. 2. The first group of test specimens was made of thermoplastic polymers such as high-density polyethylene (HDPE), low-density polyethylene (LDPE), polystyrene (PS) and polyamide 12 (PA) of 50 – 80 μm particle size. They were mixed with 5.0 wt. % paraffin oil and 0.6 wt. % CNT. The mixture was molded in the die and heated up to 110 $^{\circ}\text{C}$, Fig. 3.

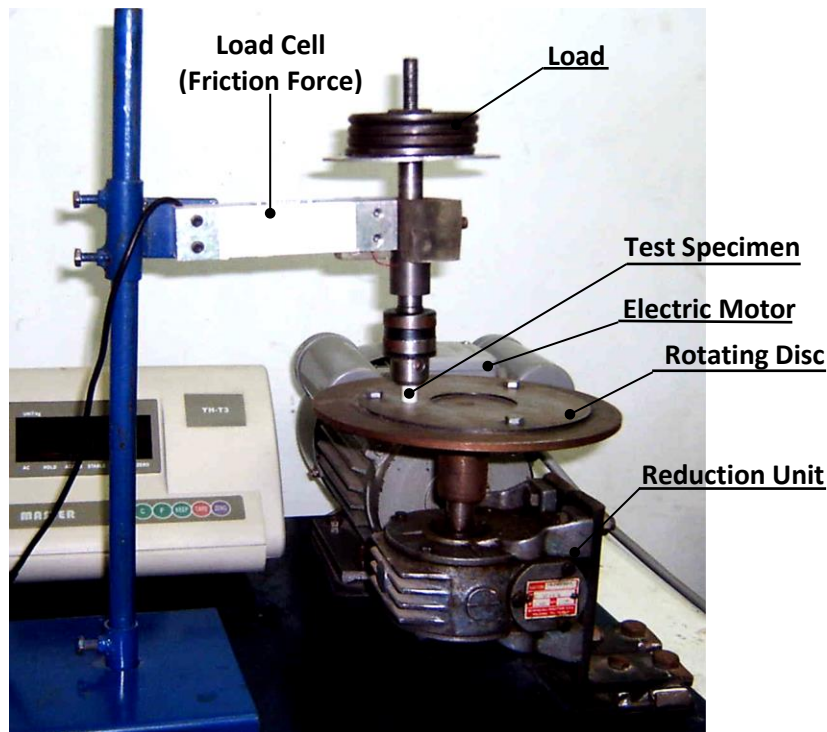


Fig. 1 Arrangement of friction test rig.

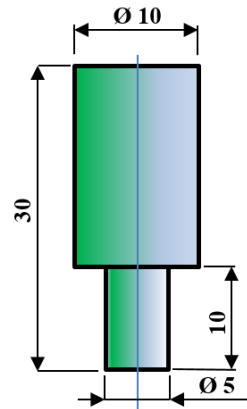


Fig. 2 Dimensions of the tested composites.

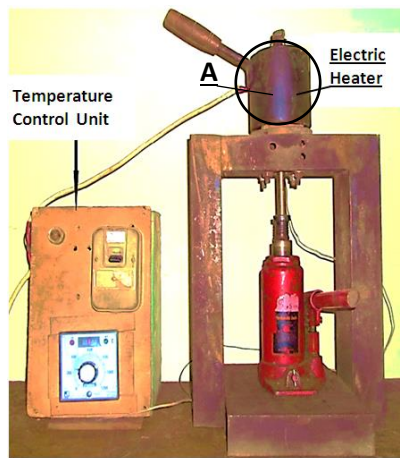


Fig. 3 Preparation of the tested composites.

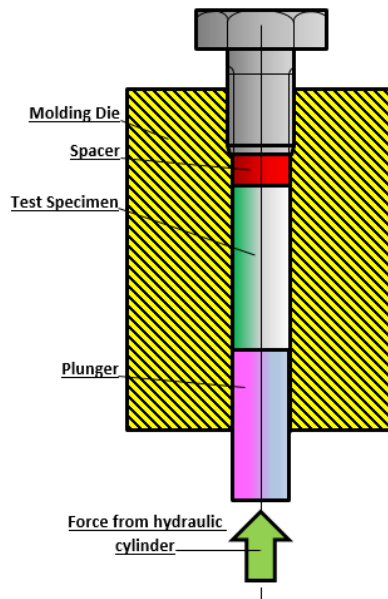


Fig. 4 Details of the molding die (A).

The second group was prepared from PA12 filled by NCT of 0.6 wt. % content and 5.0 wt. vegetables oils (olive, corn, sun-flower, sesame, almond, castor, camphor, cress, flax seed, black seed and lettuce) as well as paraffin. The tests were conducted under dry conditions at room temperature.

RESULTS AND DISCUSSION

Friction coefficient displayed by the tested polymers filled by paraffin oil and CNT is shown in Fig. 5, where unfilled polymers showed the highest friction values. Among them, HDPE displayed the lowest values followed by LDPE, PS and PA 12. Test specimens filled by CNT showed friction decrease due to CNT self-lubricating mechanism during sliding. Further friction decrease was observed for test specimens filled by oil. The friction decrease may be attributed to the oil stored in the pores inside the polymer matrix that experienced boundary-lubricating film. The mechanism of lubrication depends on the presence of low shear oil film formed on the sliding surfaces that separates the contacting asperities. The pores were working as oil reservoirs feeding oil into the friction surface. The variation of the friction coefficient with the type of the polymers can be explained on their triboelectrification that controls the adhesion of oil molecules into the polymeric surfaces. The trapped oil inside the pores leaked to the surface by the action of the frictional heat forming oil film on the contact area and leading to significant friction decrease. Besides, oil film prevented polymer transfer into the steel surface. Due to the relative friction increase, it can be concluded that PA 12 transfer and adherence into the steel surface was more effective than the lubricating effect of the oil film.

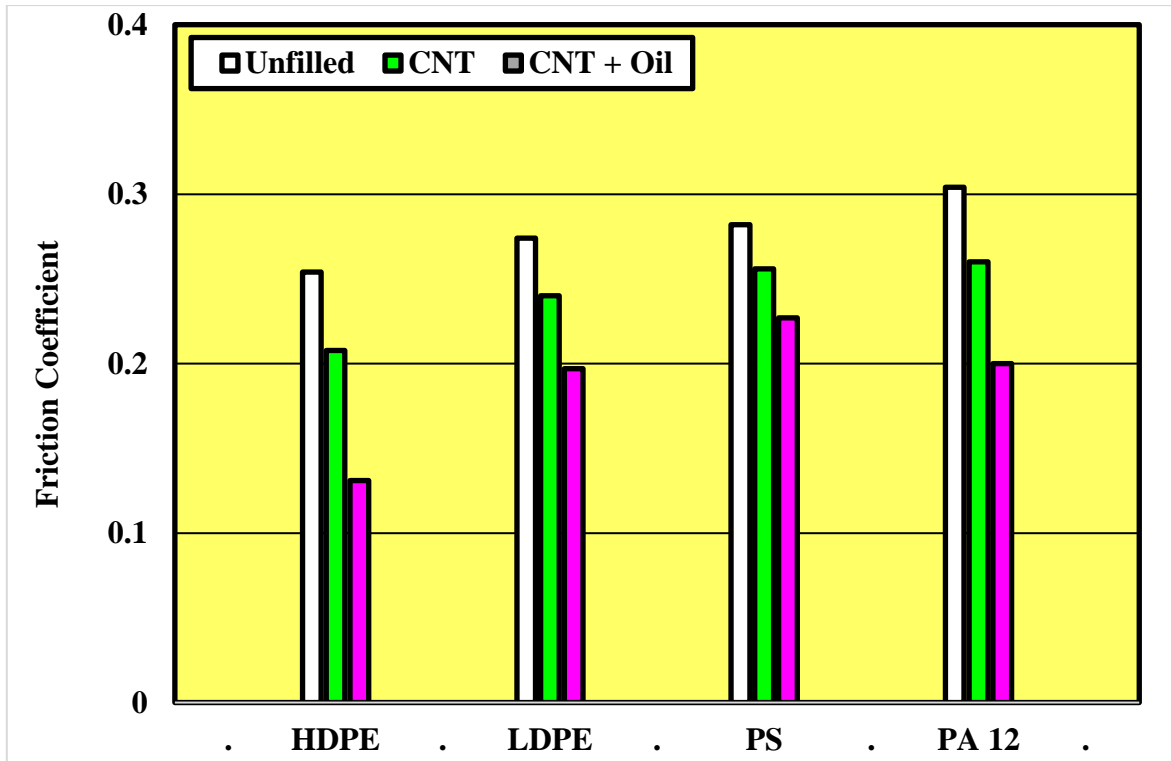


Fig. 5 Friction coefficient displayed by the tested thermoplastic nanocomposites.

Considering the triboelectrification of the sliding surfaces and according to triboelectric series, when PE and PVC surfaces are sliding on steel, the surface of steel gains positive charge, while PE and PVC gain negative one. PA gains positive charge and steel has negative one. Due to the electric static charge (ESC), the two mating surfaces attract the polar molecules of vegetables oils to their surfaces forming multilayers of the oil molecules separating the two materials, [1]. Consequently, the lubrication regime changes from boundary to mixed lubrication, where oil polar molecules are adhered to the charged mating surfaces due to the ESC. Consequently, friction coefficient decreased due to the adhesion of the oil molecules to the contact surfaces and the increase of the oil film thickness caused by accumulation of the oil molecules formed by adhering to each other.

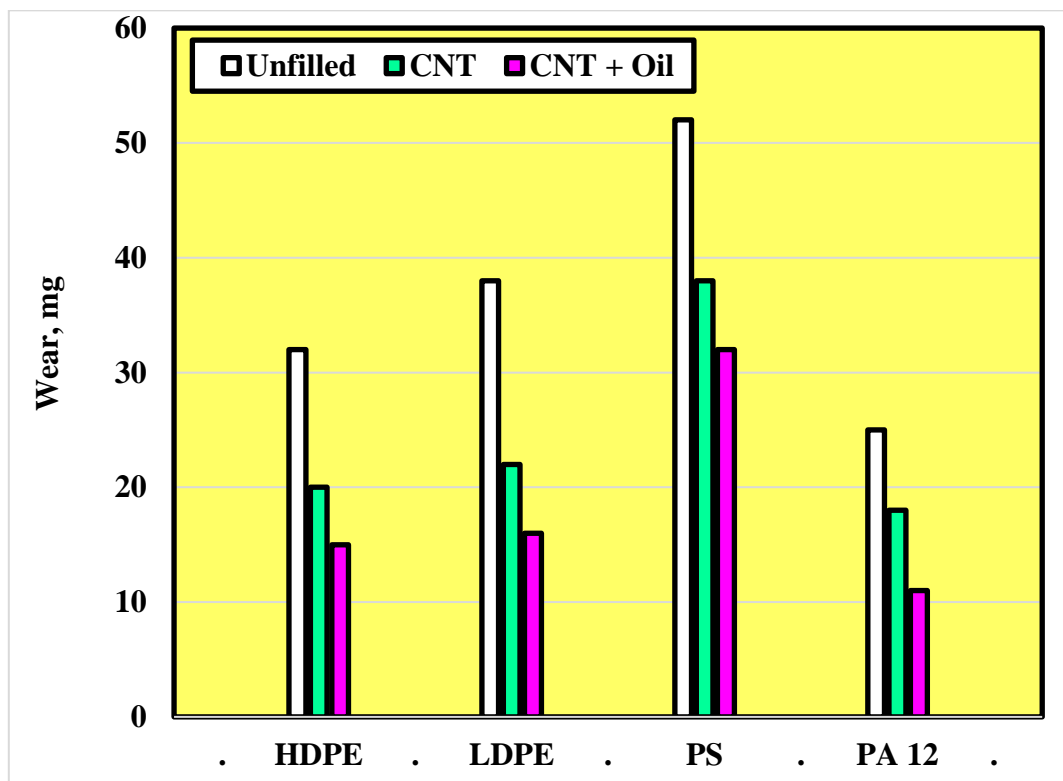


Fig. 6 Wear of thermoplastic nanocomposites.

The wear properties of the thermoplastic nanocomposites are illustrated in Fig. 6, where PA 12 displayed the minimum wear followed by HDPE, LDPE and PS. It is clearly shown that unfilled polymers showed the highest wear values, while filled polymers by CNT and oil displayed the lower wear. This behavior is attributed to the increase of wear resistance of composites because of CNT. Presence of oil decreased wear due to the film formed on sliding surface, where the rolling motion of CNT was facilitated and protected the sliding surfaces from further wear.

Effect of filling PA12 by vegetables oils and CNT is shown in Fig. 7, where significant decrease in friction coefficient was observed for filled nanocomposites. This can be

explained on the self-lubricating mechanism of CNT as well as the effect of oil. Presence of oil decreases friction coefficient due to the film formed on sliding surface, where the contact will be between partially PA12 composites/steel and oil/steel due to the mixed lubrication regime offered by the oil film. Drastic decrease in friction coefficient values was observed. Oils can be ranked due to their effect in decreasing friction coefficient in the order of flax seed, black seed, almond, castor, cress, sesame, lettuce, corn, camphor, olive, paraffin and sun-flower. Nanocomposites filled by oil and 0.6 wt.% CNT showed that almond, paraffin, corn, flax seed, sesame, sunflower, black seed, castor, olive, lettuce and camphor oils are ranked due to their superiority in reducing friction coefficient. The frictional behavior of the tested composites revealed that the role of vegetables oils is effective due to the molecule polarity. The majority of the specimens having vegetables oil showed their superiority on paraffin oil. Based on the limited heat stability of vegetables oils, they can be applied in conditions of relatively low sliding velocity such as bearings in robots.

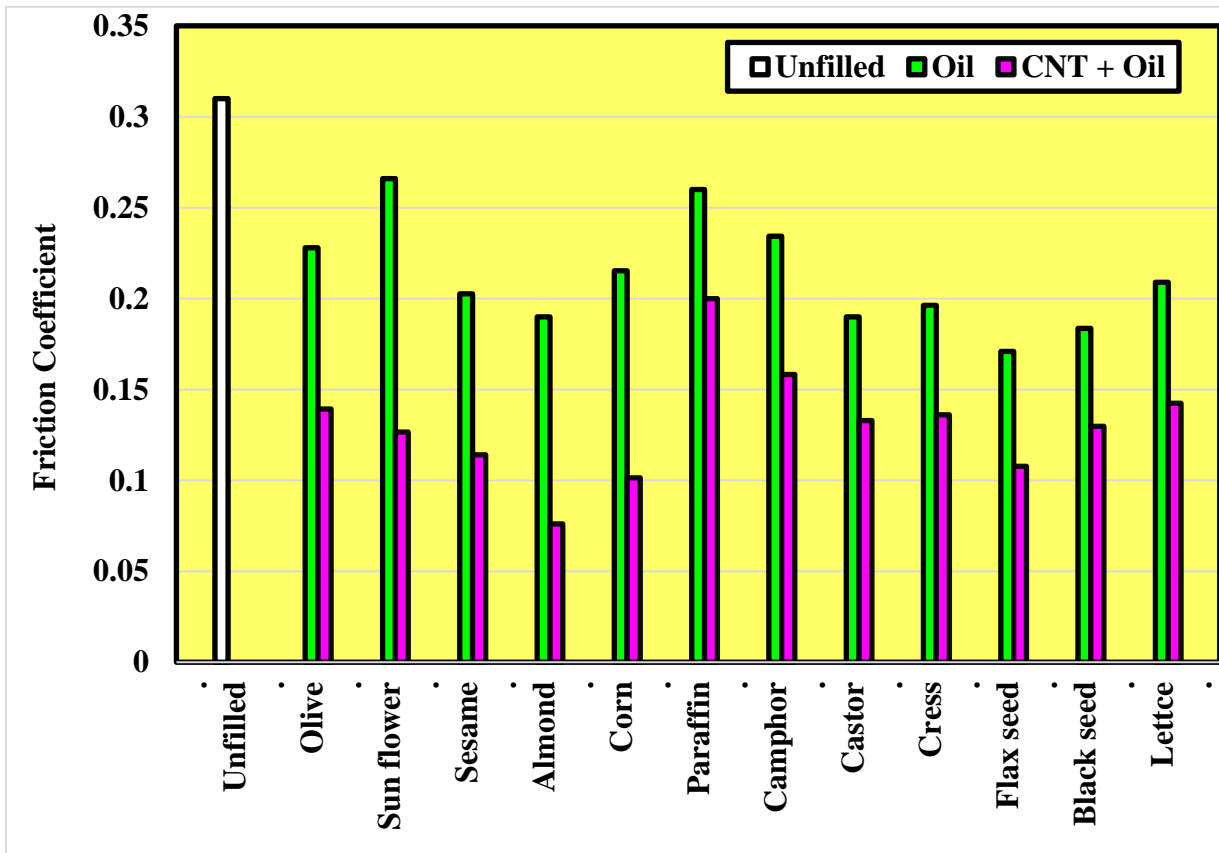


Fig. 7 Friction coefficient displayed by the tested PA12 nanocomposites.

Wear of the PA12 nanocomposites is shown in Fig. 8. It is noticed that drastic decrease in wear was observed for composites filled by oil, while further decrease displayed by nanocomposites filled by oil and CNT. The improvement of the wear resistance was due to the CNT reinforcing PA12. Presence of oil decreased wear due to the film formed on

sliding surface that prevented asperities contact. It is noticed that the lowest wear values were represented by nanocomposites filled by CNT and sesame oil followed by corn, almond and flax seed oils. Based on this observation, sesame oil can be recommended to fill PA12 nanocomposites. Besides, filling PA12 by vegetables oils caused significant decrease in wear values. Oils can be ranked due to their effect in decreasing wear for composites filled by 0.6 wt. % CNT as follows: sesame, flax seed, corn, almond, castor, cress, black seed, lettuce, olive, camphor, sun flower and paraffin. This observation indicates that sesame oil gives the best wear resistance performance. The addition of vegetables oils had excellent effect on the tribological behavior of PA12/CNT composites.

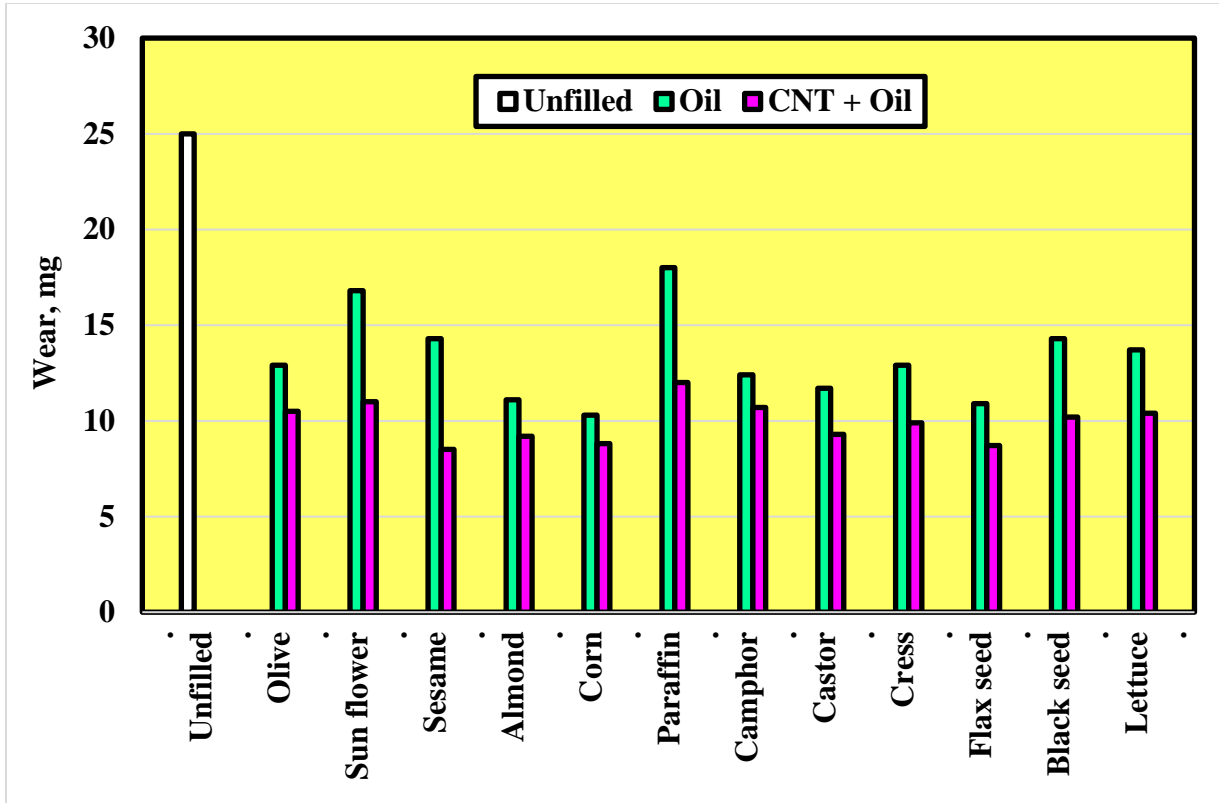


Fig. 8 Wear of the tested PA12 nanocomposites.

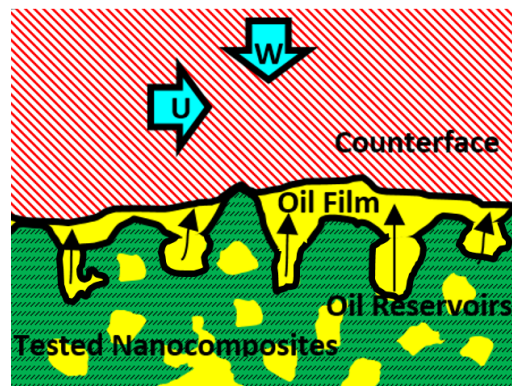


Fig. 9 Lubrication mechanism of the tested nanocomposites.

The lubrication mechanism of the nanocomposites is shown in Fig. 9, where the figure illustrates the mechanism of formation of oil film on the sliding surfaces. Oil trapped inside the pores went up to the sliding surface forming a film. The effective adhesion of oil molecules, known for vegetable oils due to their polar molecules, experienced boundary lubricating oil film on the sliding surfaces and separated the contacting asperities of the two mating surfaces.

CONCLUSIONS

1. Friction coefficient displayed by the tested polymers filled by paraffin oil and CNT showed drastic decrease compared to unfilled polymers. HDPE displayed the lowest friction values followed by LDPE, PS and PA 12.
2. Unfilled polymers showed the highest wear values, while filled polymers by CNT and oil displayed the lowest wear. PA 12 displayed minimum wear followed by HDPE, LDPE and PS.
3. Significant decrease in friction coefficient was observed for vegetable oil and CNT filled PA12 nanocomposites. PA12 nanocomposites filled by oil and 0.6 wt. % CNT showed that almond, paraffin, corn, flax seed, sesame, sunflower, black seed, castor, olive, lettuce and camphor oils are ranked due to their superiority in reducing friction coefficient.
4. Significant wear decrease was observed for composites filled by oil, while further decrease displayed by nanocomposites filled by oil and CNT. The lowest wear values were displayed by nanocomposites filled by CNT and sesame oil followed by corn, almond and flax seed oils.
5. Sesame oil can be recommended to fill PA12 nanocomposites.

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