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# FRICTION AND WEAR OF POLYMERIC MATERIALS FILLED BY OIL AND REINFORCED BY NANOCARBON TUBES

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## ABSTRACT
**The present work investigates the possibility to introduce new self-lubricating polymeric materials for dry sliding bearing applications. The proposed polymeric composites are consisting of high density polyethylene (HDPE), low density polyethylene (LDPE) and polystyrene (PS) filled by paraffin oil and reinforced by carbon nanotubes (CNTs). Experiments were carried to test the frictional properties of the proposed composites at dry sliding conditions.**

**The experiments showed that filling HDPE, LDPE and PS by paraffin oil and reinforcing them by CNTs can decrease the friction coefficient and increase wear resistance significantly. This may be referred to the presence of oil in multipores inside the polymer matrix, where they work as reservoirs of oil from which it leaks up to the sliding surface and causes friction decrease, where the contact will be between partially polymer composites/steel and oil/steel due to the mixed lubrication regime offered by the oil film. Besides, oil film can isolate the contacting asperities of the sliding surfaces from excessive wear, where high shear tearing and transfer of polymer to the steel surface were diminished. The self-lubricating mechanism of CNTs during sliding depends on the rolling movement of the CNTs, where they change friction and shear stress into rolling. This mechanism can be achieved when the nanotubes can have the medium in which they can move freely. Presence of oil can provide this facility that decreases both friction and wear.**

## KEYWORDS
**Friction, wear, polymeric materials, paraffin oil, nanocarbon tubes.**

## INTRODUCTION
**The tribological properties of carbon nanotubes (CNTs) have little research attention, [1 - 7]. It was 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. Favorable tribological properties of a CNTs filled polytetrafluoroethylene composite were due to the high strength and high aspect ratio of the CNTs. It seems 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. 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.**

**The influence of reinforcing epoxy by CNTs and filling by different types of vegetables oils (olive, corn, sunflower, sesame, almond and paraffin oil) on the friction coefficient and wear resistance was investigated, [8]. Based on the experimental results, it was found that a significant decrease in friction coefficient was observed with increasing the CNTs content. Oils can be ranked due to their effect in decreasing μ at 0.6 wt.% CNTs content approximately as follows corn, almond, paraffin, sesame, sunflower, and olive oil. On the other hand, it was noticed that there is significant decrease in wear loss values. However, studies on the tribological properties of CNT–polymer composites have been relatively fewer.**

**Carbon nanotubes have been used in various fields of applications in recent years due to their high physical, chemical, and mechanical properties, [11]. One of these fields is composite materials in which CNTs are added to a matrix not only as reinforcement but also to obtain other physical and chemical properties such as electrical conductivity and corrosion resistance. Carbon nanotubes are specially introduced into polymer matrices like epoxy to fabricate polymer matrix nanocomposites which presents a new generation of composite materials, [12]. Increase in strength and Young's modulus of fabricated double-walled carbon nanotubes/epoxy nanocomposites was reported at nanotube content of 0.1 wt. %. The effect of dispersed multi-walled carbon nanotube (MWCNT) on the enhancement of elastic modulus in an epoxy system was investigated, [13]. In recent years, [14 - 20], researchers have focused their attention on tailoring polymer Nano composites by filling Nano dimension materials as filler. This has exhibited better mechanical, thermal, optical and electronic properties as compared to that of macro composite because of molecular level interaction between filler and polymer. The influence of multi-walled carbon nanotubes (MWCNTs) on the hardness and wear of polymethyl methacrylate (PMMA) reinforced by MWCNTs of 0.1, 0.2, 0.3, 0.4 and 0.5 wt. % contents was investigated, [21]. Based on the experiments, it is observed that the hardness of hot cured composites increased while wear decreased by increasing MWCNTs content unlike the cold cured composites,. In addition to that, it is shown that wear of hot cured composites decreased by increasing normal loads also unlike cold cured composites where wear increased by increasing normal loads. From this study, it can be concluded that hot cured composites are better than cold cured composites as denture base materials.**

**In the present work, the influence, of oil content impregnating the matrix of the tested polymers that reinforced by CNTs, on the friction and wear is investigated.**

## EXPERIMENTAL

**Experiments were carried out using pin-on-disc wear tester. It consists of a rotary horizontal steel disc driven by variable speed motor. The details of the wear tester are shown in Fig. 1. The test specimen made of the proposed composites is held in the specimen holder that fastened to the loading lever. Friction force can be measured by means of the load cell. The steel disc was fastened to the rotating disc. Its surface roughness was about 3. 2 μm, $R_a$. Test specimens were in the form of cylindrical pins of 6 mm diameter. Tests are carried out under constant sliding velocity of 2.0 m/s and 1.2,**

**1.8 and 2.4 N applied load. Every experiment lasted 5 minutes. All measurements were performed at 30 °C and 10 % humidity.**

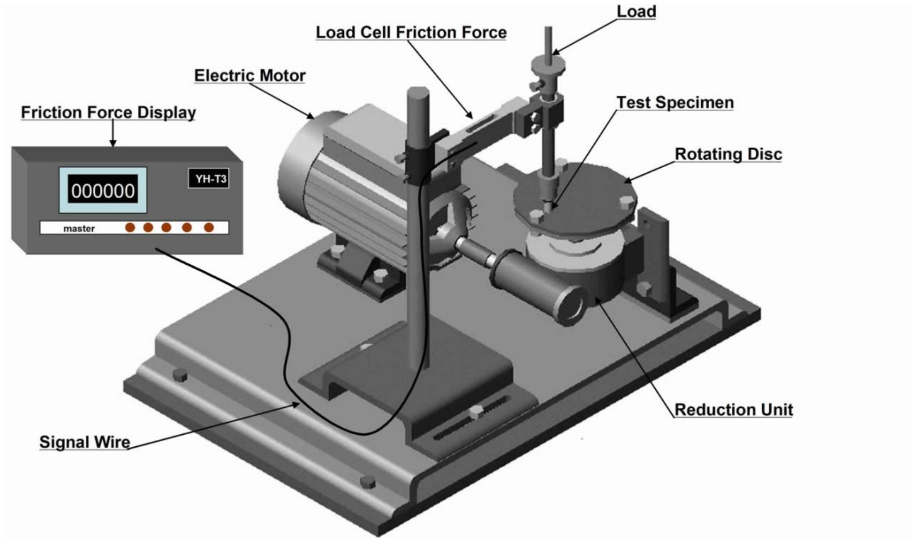


**Fig.1. Arrangement of test rig.**

**The test specimen in the form of a cylinder is 10 mm diameter and 70 mm height. This diameter was reduced to 6 mm to be in contact to the friction disc. The tested polymeric materials were high density polyethylene (HDPE), low density polyethylene (HDPE) and polystyrene (PS). Those polymers were filled by carbon nanotubes (CNTs) and paraffin oil. All these constituents were molded in a die at 150 °C temperature by using hydraulic press. CNTs were added to polymer in different contents (0.2, 0.4, 0.6, 0.8 and 1 wt. %) while oil contents were 1, 2, 3, 4 and 5 wt. %.**

## RESULTS AND DISCUSSION

**Friction coefficient displayed by polymers sliding against steel at 1.2 N load is shown in Fig. 2. HDPE displayed the lowest friction values, while PS gave the highest ones. Friction coefficient slightly decreased with increasing oil content. The same trend was observed at 1.8 and 2.4 load, where the relationship between friction coefficient and oil content is shown in Figs. 3 – 4. This may be referred to the presence of oil in multipores inside the polymer matrix, where they work as reservoirs of oil from which it leaks up to the sliding surface and causes friction decrease. Presence of oil decreases friction coefficient due to the film formed on sliding surface, where the contact will be between partially polymer composites/steel and oil/steel due to the mixed lubrication regime offered by the oil film.**

**It seems that friction decrease was displayed due to oil transfer from the specimen to the counterface forming a thin layer. The decrease of friction coefficient was attributed to the adhesion of oil molecules into the sliding surfaces. It was proved that the oil is trapped in pores after solidification of the polymer. Those pores are working as reservoirs feeding the oil into the sliding surfaces and forming oil film on the contact surfaces. The film was fed by the oil stored inside the pores in the polymer matrix. The strong adhesion of the oil molecules experienced boundary lubricating film in which a low shear interfacial layer was formed on the sliding surfaces and easily removed by the shear instead of the contacting asperities. It is worthy to mention that due to the polarity of paraffin oil, the adhesion of its molecules into the sliding surfaces will be relatively**

stronger, where polar molecules will form multilayers, which strengthen the adhesion of oil into the sliding surfaces.

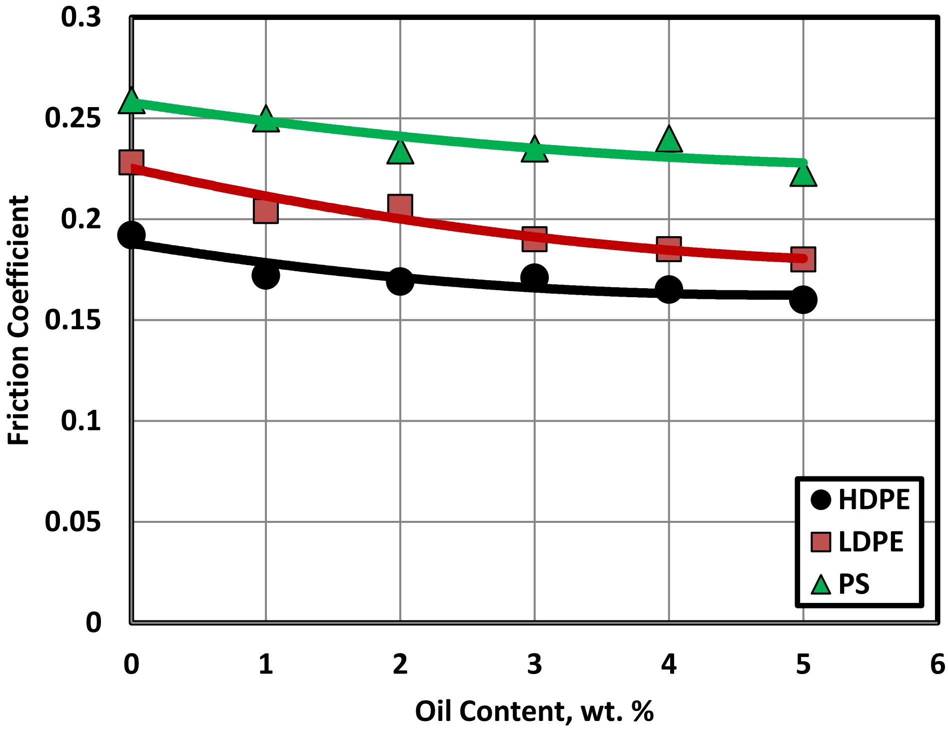


**Fig. 2 Friction coefficient displayed by polymers sliding against steel at 1.2 N load.**

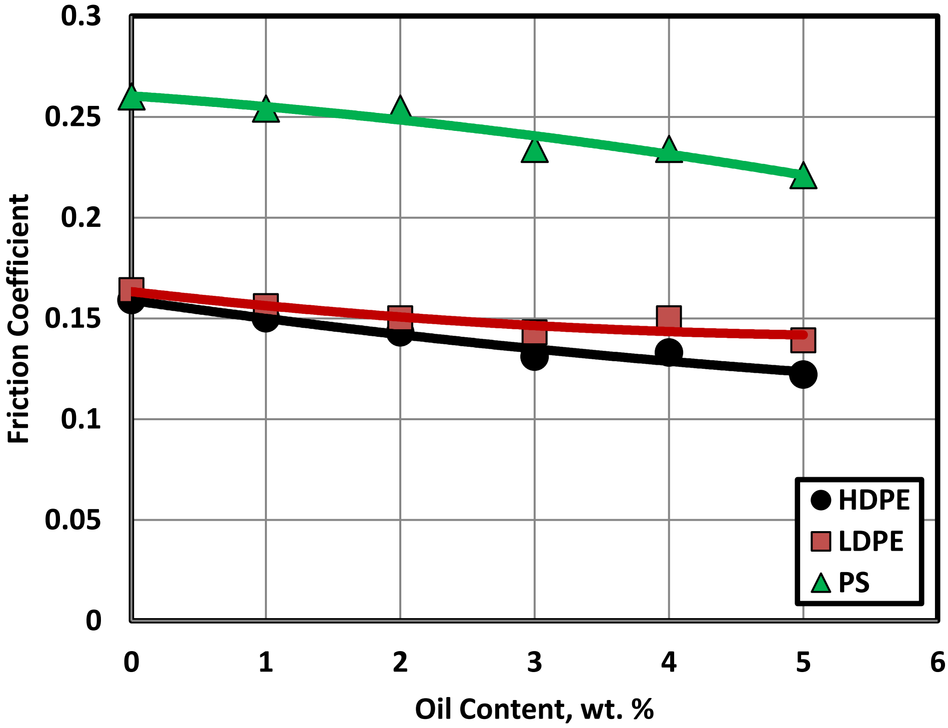

**Fig. 3 Friction coefficient displayed by polymers sliding against steel at 1.8 N load.**

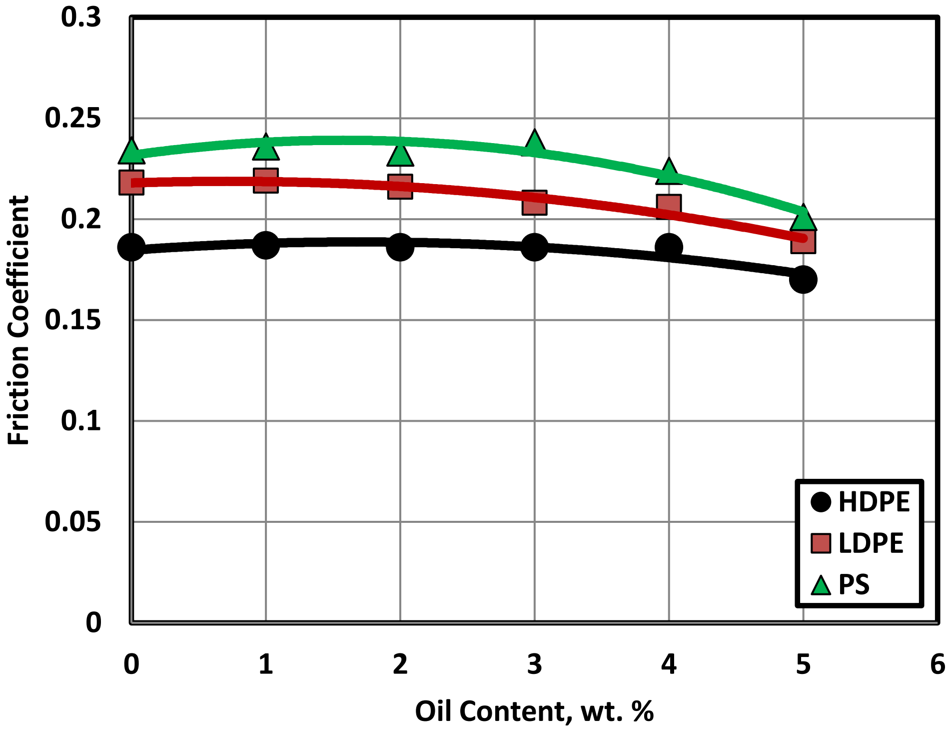


**Fig. 4 Friction coefficient displayed by polymers sliding against steel at 2.4 N load.**

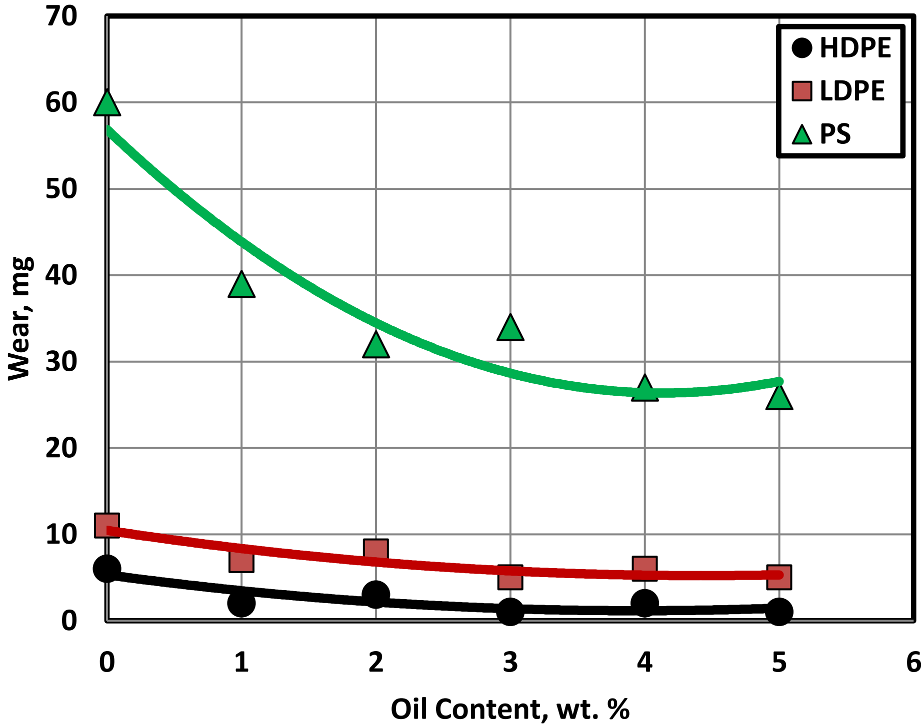

Fig. 5 Wear of polymers sliding against steel at 1.2 N load.

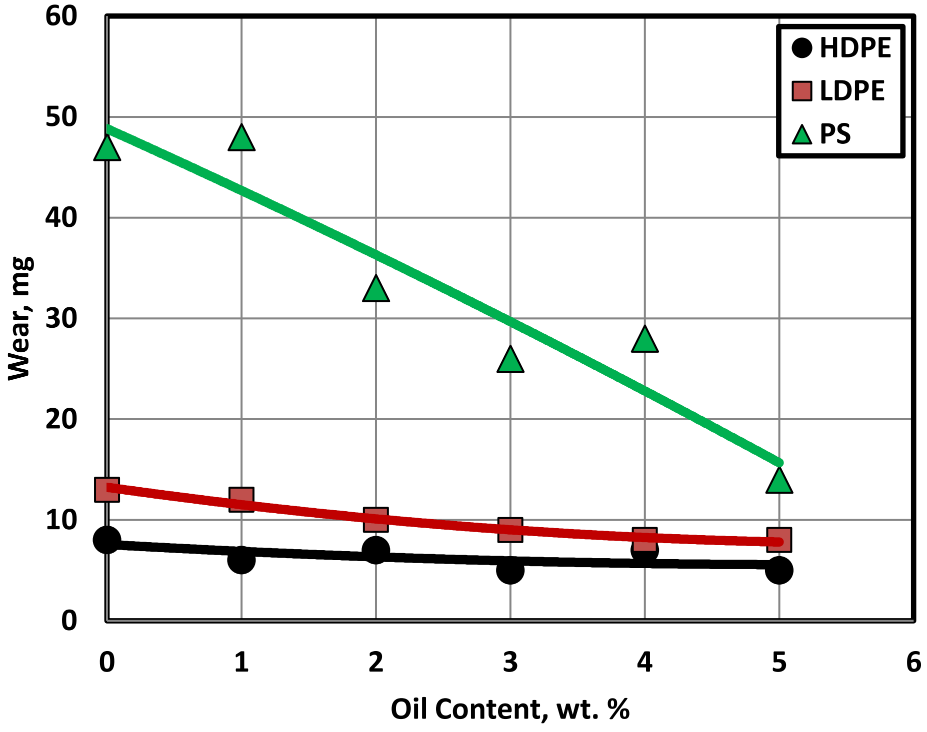


Fig. 6 Wear of polymers sliding against steel at 1.8 N load.

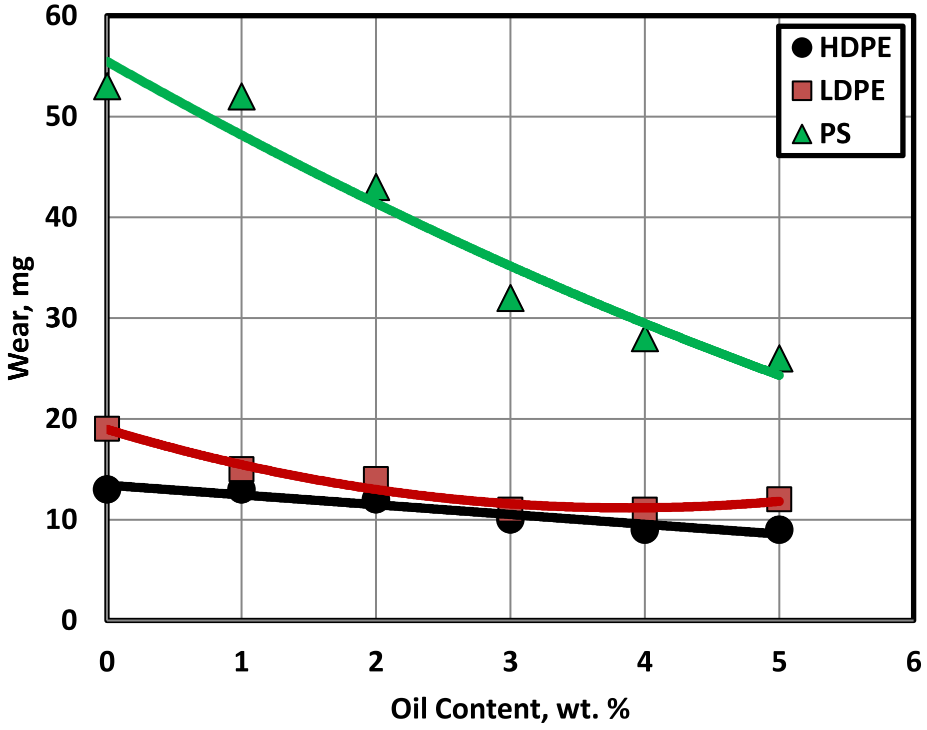


Fig. 7 Wear of polymers sliding against steel at 2.4 N load.

Wear of the proposed polymeric composites sliding against steel at 1.2, 1.8 and 2.4 N load is shown in Figs. 5 -7 respectively. Wear decreased with increasing oil content. The minimum wear values were presented by HDPE followed by LDPE, while PS displayed the highest wear values. It seems that, presence of oil provided the sliding surface by a uniform oil film that isolated the contacting asperities of the sliding surfaces from excessive wear. Besides, high shear tearing and transfer of polymer to the steel surface were diminished due to the oil film. Increase of oil content provided the sliding surfaces by a uniform oil film which would decrease wear. Wear decrease may be attributed to oil transfer from polymer matrix to the sliding surface forming a thin layer that decreases the shear force exerted at the sliding surfaces. The results of friction values observed in the experiments recommend HDPE composites to be used as bearing materials at dry sliding applications.

The relationship between friction coefficient and oil content is shown in Figs. 8 - 10. As shown, slight decrease in friction coefficient was observed with increasing oil content. This may be attributed to both of CNTs self-lubricating mechanism and oil during sliding. Also, it can be noticed that friction coefficient displayed lower values than that presented by composites free of CNTs. This observation can confirm that oil can decrease the effect of CNTs in raising friction coefficient.  This behavior can be explained on the basis that presence of oil enables CNTs to move freely, where the percentage of aligned CNTs normal to the contact surface decreases. It can be noticed that friction coefficient values displayed by sliding of composites filled by oil, Fig. 5, were higher than that observed for composites filled by oil and reinforced by CNTs. As shown, the lowest friction coefficient value is 0.16 for HDPE 0.6 wt. % CNTs content.

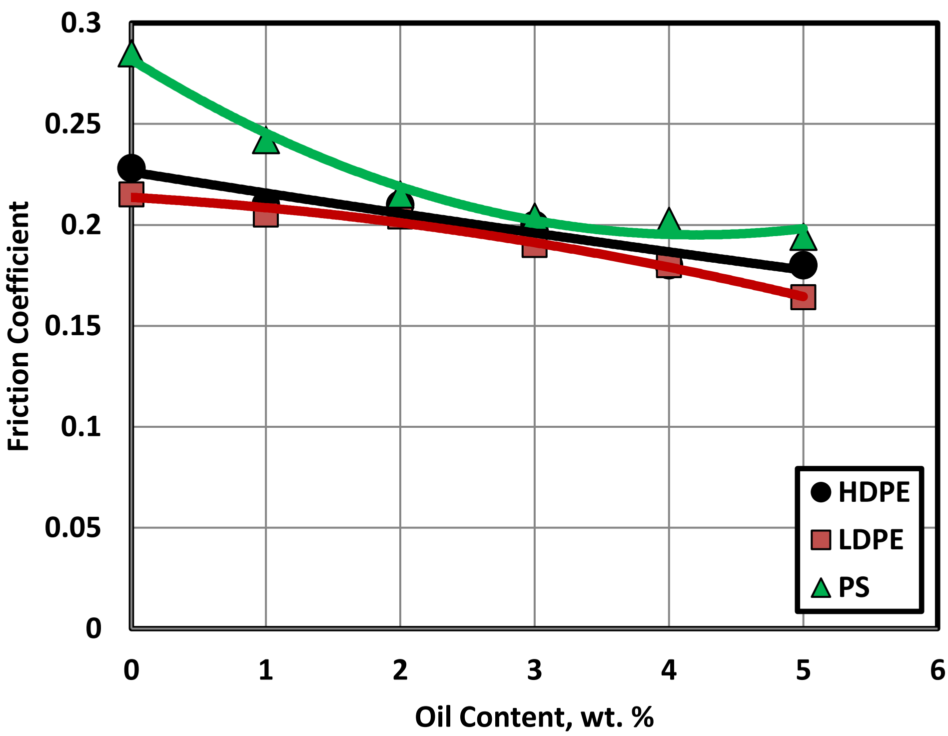


Fig. 8 Friction coefficient displayed by polymers reinforced by 0.6 wt. % CNTs and sliding against steel at 1.2 N load.

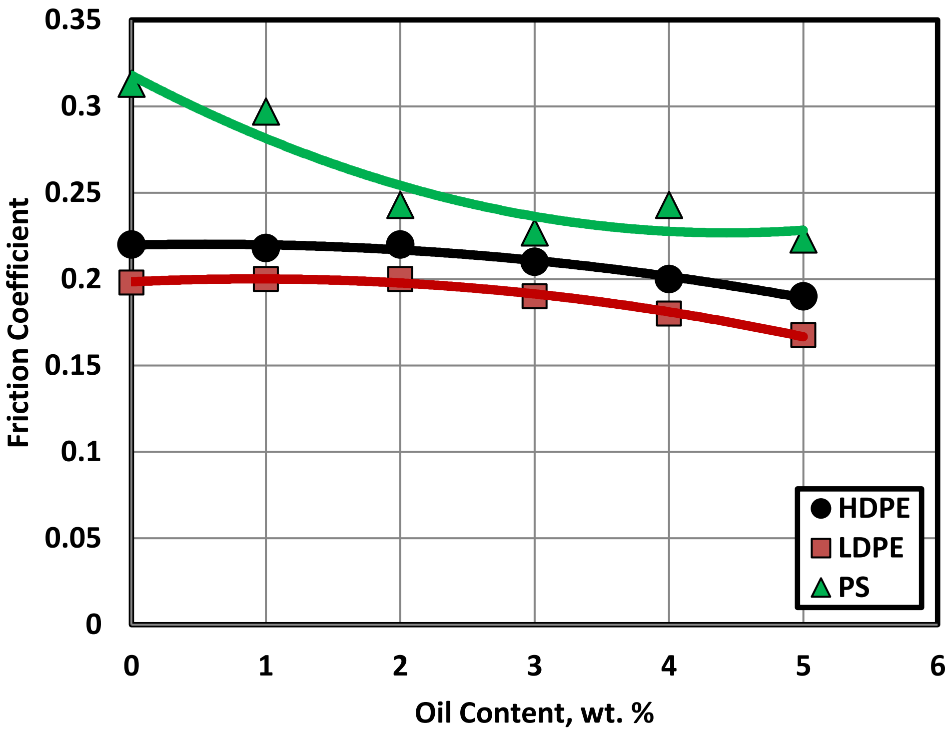


**Fig. 9 Friction coefficient displayed by polymers reinforced by 0.6 wt. % CNTs and sliding against steel at 1.8 N load.**

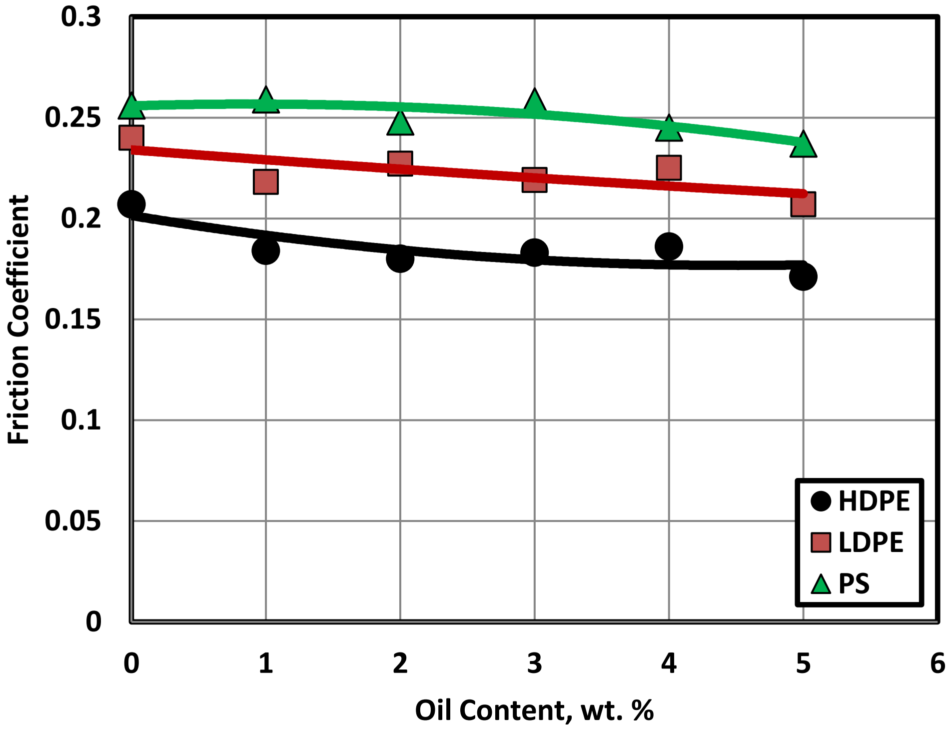

**Fig. 10 Friction coefficient displayed by polymers reinforced by 0.6 wt. % CNTs and sliding against steel at 2.4 N load.**

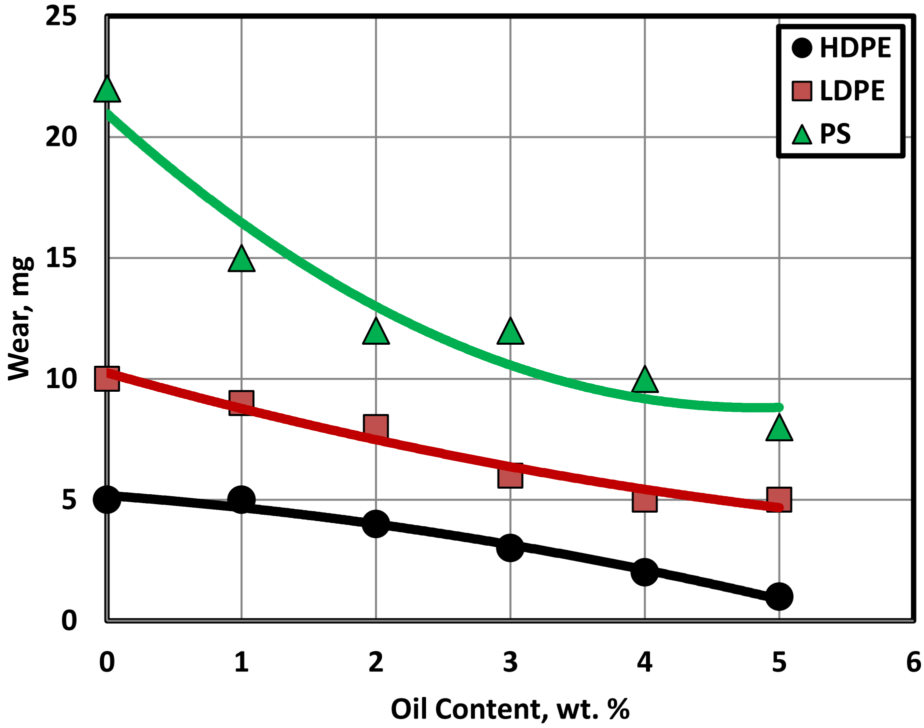


**Fig. 11 Wear of polymers reinforced by 0.6 wt. % CNTs and sliding against steel at 1.2 N load.**

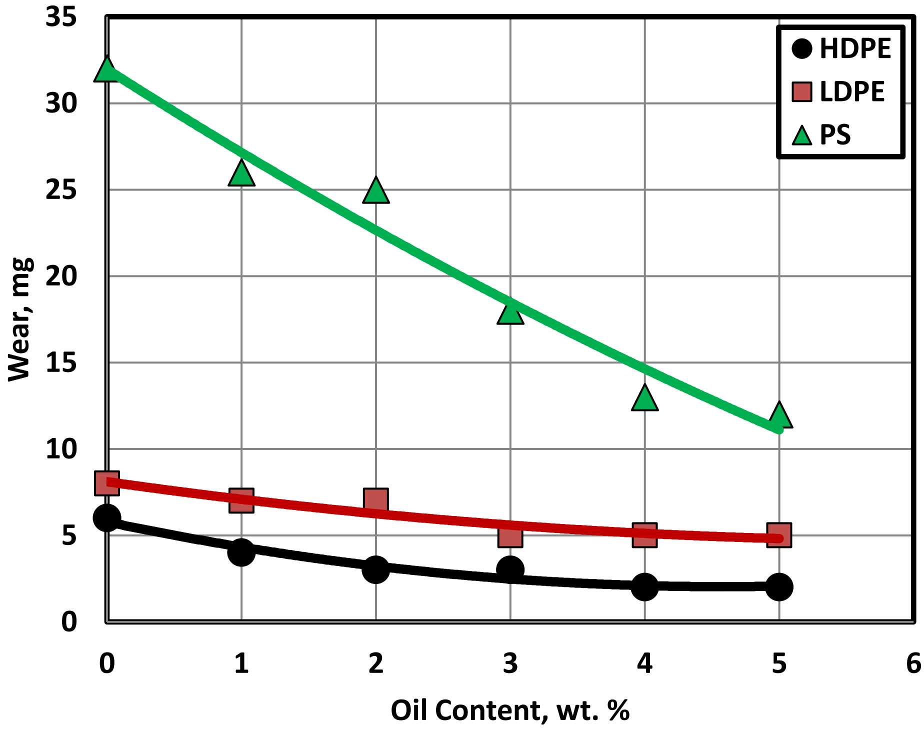

Fig. 12 Wear of polymers reinforced by 0.6 wt. % CNTs and sliding against steel at 1.8 N load.

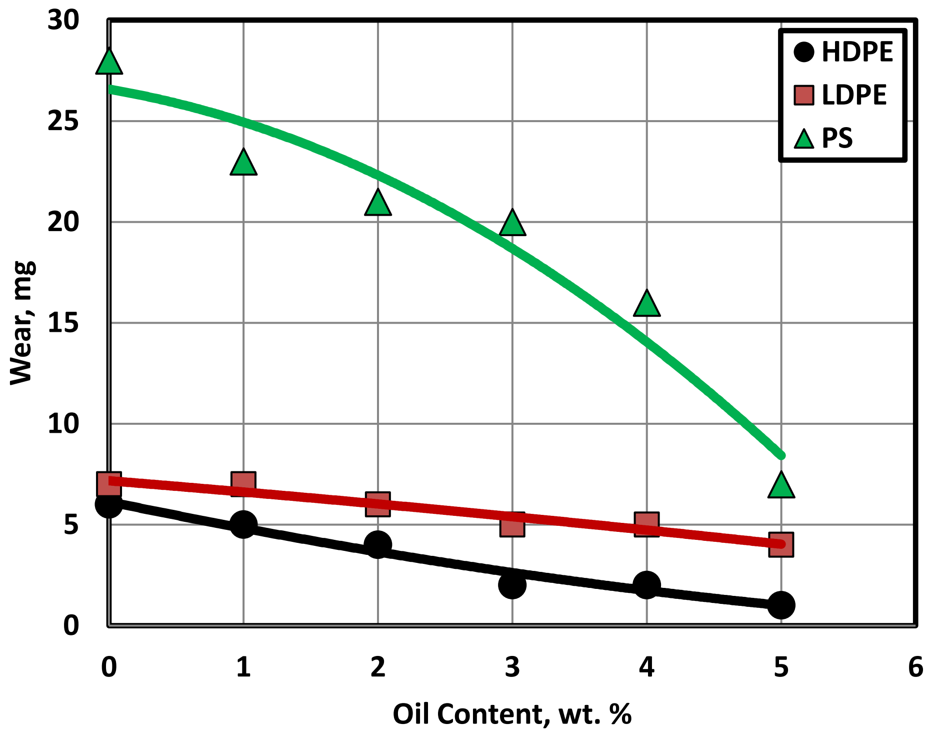


Fig. 13 Wear of polymers reinforced by 0.6 wt. % CNTs and sliding against steel at 2.4 N load.

The relationship between wear and oil content for composites reinforced by 0.6 wt. % CNTs is shown in Figs. 11 - 13. It is noticed that a drastic decrease in wear was observed with increasing oil content. This behavior is attributed to the increase of wear resistance of composites because of CNTs. The improvement of the wear resistance of composites was due to the CNTs reinforcing polymer matrix. Besides, 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 for HDPE. It is noticed that wear values were lower than that observed for composites filled by oil and free of CNTs. The self-lubricating mechanism of CNTs during sliding depends on the rolling movement of the CNTs, where they change friction and shear stress caused by sliding into rolling. This mechanism can be achieved when the nanotubes can have the medium in which they can move freely. Presence of oil can provide this facility that can decrease both friction and wear.

## CONCLUSIONS

1. Friction coefficient slightly decreased with increasing oil content. HDPE displayed the lowest friction values, while PS gave the highest values.
2. Wear of the proposed polymeric composites sliding against steel decreased with increasing oil content. The minimum wear values were presented by HDPE followed by LDPE, while PS displayed the highest wear values.
3. The results of friction and wear values observed in the experiments recommend HDPE composites filled by 5.0 wt. % oil to be used as bearing materials at dry sliding applications.

**4. Composites reinforced by NCTs and filled by oil displayed lower friction and wear values than that presented by composites free of CNTs because oil decreases the effect of CNTs in raising friction coefficient and increases the shear strength of the composites.**

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