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COMPARATIVE PERFORMANCE OF FRICTION COEFFICIENT DISPLAYED BY POLYMERS FILLED BY VEGETABLES OILS

Ibrahim A. S., Khashaba M. I. and Ali W. Y.

Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT.

ABSTRAC
The present work investigates the friction coefficient of polymers filled by vegetables oils such as almond, camphor, castor, cress, flax seed, black seed, lettuce, olive, sesame and sun flower oils in content up to 10 wt. %. The polymers are polyamide 6 (PA), high density polyethylene (PE) and polyvinyl chloride (PVC). The friction coefficient displayed by the tested polymers is investigated at constant load and velocity when sliding against steel.

Experiments showed that friction coefficient displayed by the tested polymers filled by the tested vegetables oils decreased with increasing oil content. The minimum values of friction coefficient were observed at 10 wt. % oil content for PA composites filled by camphor, castor, cress, flax seed, black seed, sesame and sun flower oils. PE composites filled by almond, lettuce and olive oils showed the lowest friction values. The friction decrease may be attributed to the oil stored in the pores inside the polymer matrix which experienced boundary lubricating film of low shear interfacial layer formed on the sliding surfaces and easily removed by the shear instead of the contacting asperities. Those pores were working as reservoirs feeding oil into the contact surface. The minimum friction values recommend using 10 wt. % oil filled PA as bearing material in dry sliding condition.

KEYWORDS
Friction coefficient, PA, PE, PVC, vegetables oils, steel.

INTRODUCTION
Polymer composites are widely used as bearing surfaces. Several trials were exerted to introduce new self-lubricating polymeric materials for bearing applications, where external lubricant such as oil or grease can be excluded and the design can be simplified and maintenance cost can be reduced. Polymeric composites consisting of polyamide (PA6) filled by different types of vegetables oils such as (almond oil, camphor oil, castor oil, cress oil, flax seed oil, black seed oil, lettuce oil, olive oil, sesame oil, and sun flower oil) in concentration up to 10 wt. %, were tested, [1]. It was found that, as the oil content increased friction coefficient decreased. It seems that friction decrease was displayed due to oil transfer from the specimen to the counterface forming a thin layer which was responsible for the friction decrease. The minimum value of friction coefficient (0.15) was observed for flax seed oil specimens, at 10 wt. % oil content and 30 N normal load.

Proposed polymeric composites consisting of high density polyethylene (PE), polypropylene (PP) and polystyrene (PS) and filled by fibres of polytetrafluoroethylene (PTFE) in concentration up to 25 wt.% as well as different types of vegetables oils such as corn oil, olive oil, paraffin oil, glycerin oil, castor oil and sun flower oil in concentration up to 10 wt.% were tested, [2]. PP composites filled by corn oil showed slight friction increase. Besides, friction coefficient displayed by PS and PE specimens filled by glycerin oil decreased with increasing oil content, while friction coefficient displayed by PP specimens showed consistent trend. It was noted that, PE filled with 7.5 % glycerin oil and 20 wt. % PTFE displayed the minimum value of friction coefficient (0.07). This friction coefficient values recommend those composites to be used as bearing materials. PE filled by glycerin oil displayed relatively lower friction values due its common known good lubricating property. PP composites showed the lowest wear values.

Among the self-lubricating materials the so-called engineering polymers have increasing importance, [4]. Dry sliding and lubricated friction and wear behaviors of polyamide (PA) and ultra-high molecular weight high density polyethylene (UHMWPE) blend were studied, [2]. It was observed that, PA specimen demonstrated highest friction coefficient, while UHMWPE displayed the lowest in both dry-sliding and lubricated sliding test. The friction of PA could be sufficiently decreased by blending with UHMWPE. The friction and wear properties of polyamide 66 (PA66), polyphenylene sulfide (PPS) and polytetrafluoroethylene (PTFE) sliding against themselves under dry sliding and oil-lubricated conditions were studied, [5]. Experimental results showed that friction properties of the three sliding combinations could be greatly improved by oil lubrication, where the antiwear properties of PTFE and PPS were improved by oil lubrication.

An investigation of the tribology of three thermoplastic polymer composites based on polytetrafluorethylene, polyethylene terephthalate and polyamide, that are considered to be used as sliding bearings in nanopositioning, was carried out, [6]. It was observed that, the high Young's modulus was found to be beneficial for the formation of a thin transfer film responsible of a low and stable coefficient of friction. Novel poly(phthalazinone ether sulfone ketone) (PPESK) resins have become of great interest in applications such as bearing and slider materials. Dry sliding wear, of polytetrafluoroethylene (PTFE) and graphite-filled PPESK composites against polished steel counter parts, was investigated, [7]. It was found that friction coefficient and wear rate of the PPESK composites decreased gradually with addition of fillers. Results showed the excellent dry tribological characteristics of the modified UHMWPE/steel rubbing pair compared with the pure UHMWPE/steel rubbing pair, [8]. It was suggested that the modified UHMWPE could be used in dry friction conditions with a relatively high sliding velocity. The influence of sea water composition on the tribological behavior of PTFE was studied, [9]. Results show that the friction process in sea water was relatively stable, the friction coefficient and the wear rate of PTFE were slightly lower and a little larger than those in distilled water, respectively.

Wear and friction simulator with metal cylinder on flat polymer was developed to analyze the tribological behavior of tibial insert used in Total Knee Replacement (TKR), [10]. Tests were first carried out with polymethyl methacrylate polymer (PMMA) for which the tribological behavior has been well developed. High density polyethylene (HDPE) was also characterized. In fact HDPE has been firstly used in the tibial insert

before the use of ultrahigh molecular weight polyethylene (UHMWPE). High performance engineering polymers ensure desired properties for journal bearings and give good tribological results, [11]. Tribological behaviors of polymer based PE, PA, POM, PTFE, and Bakelite bearings were investigated and evaluated. As a result, the highest wear resistance had occurred in PA and POM bearings, [12]. It was observed that the average friction coefficient showed that the PA46 + 15% aramid fibres generally had the lowest values compared to the other types of samples. The friction and wear properties of the polyimide (PI) composites filled with differently surface-treated carbon fibers (20 vol. %), sliding against GCr15 steel under oil-lubricated condition, were investigated, [13]. Experimental results revealed that the treatment largely reduced the friction and wear of CF reinforced PI (CF/PI) composites.

The friction and wear behavior of carbon nanotube reinforced polyamide 6 (PA6/CNT) composites under dry sliding and water lubricated condition was comparatively investigated, [14]. The results showed that CNTs could improve the wear resistance and reduce the friction coefficient of PA6 considerably under both sliding conditions, due to the effective reinforcing and self-lubricating effects of CNTs on the PA6 matrix. The friction and wear behaviour for polyoxymethylene homopolymers (POM-H) and polyethylene terephthalate with teflon additives (PET/PTFE) was compared, [15]. An extensive investigation, of polymer gear (acetal and nylon) friction and wear behavior, was carried out, [16]. It was found that the surface temperature was the dominant factor influencing the wear rate and an initial relationship between gear surface temperature and gear load capacity has been established and further developed. The effects of resin content on the wear of woven roving glass fibre-epoxy resin and glass fibre-polyester resin composite materials were examined, [17]. Glass fibre–epoxy resin composites generally showed higher strength and minimum wear when compared with glass fibre–polyester resin composites materials. The better adherence of a polymer transfer film onto a steel counterface was explained by higher attractive forces resulting from its high surface energy, while there was little adherence on stainless steel counterfaces in accordance with its lower surface energy and lower friction, [18]. After sliding of UHMWPE/carbon, no wear debris was observed as its higher toughness allows for tearing of the surface without particle detachment.

In the present work, friction coefficient, displayed by PA, PE and PVC filled by the tested vegetables oils in content up to 10 wt. % when sliding against steel, was 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 pin made of the tested composites is held in the specimen holder that fastened to the loading lever. Friction force can be measured by means of the load cell, fastened to the rotating disc of 3.2 μm, R_a surface roughness. Friction tests were carried out under constant sliding velocity of 2.0 m/s and 30 N load and lasted for 600 seconds. All measurements were performed at 25 ± 5 ºC and 30 ± 10 % humidity.

The test specimen, in the form of a cylinder, was 10 mm diameter and 30 mm height. The diameter was reduced to 5 mm to contact the friction disc, Fig. 2. The polymers used in the present work were PA, PE and PVC. The polymer granulates, of 30 – 50 μm particle size, were mixed with different types of vegetables oils in contents of 1, 2, 4, 6, 8,

and 10 wt. %. The vegetables oils were almond, camphor, castor, cress, flax seed, black seed, lettuce, olive, sesame and sun flower oils. The mixture was compressed in the die and heated up to 110 °C by using hydraulic jack, Fig. 3.

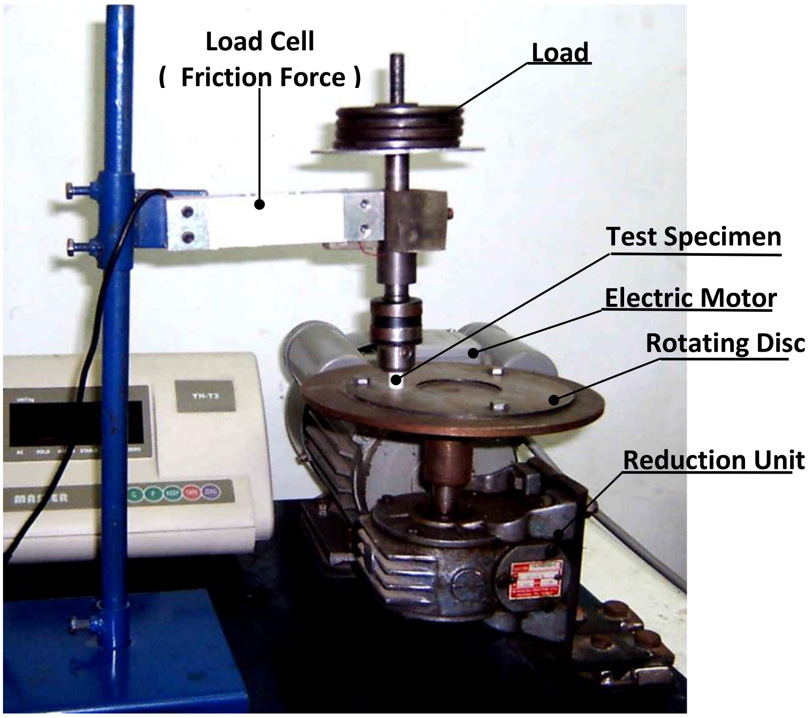

Fig. 1 Arrangement of friction test rig.

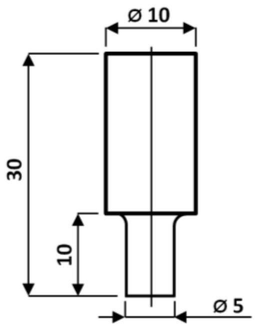

Fig. 2 Dimensions of the tested composites.

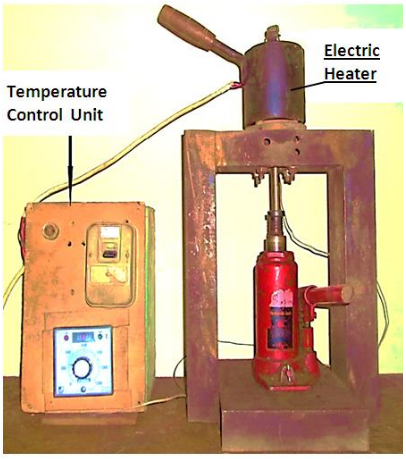

Fig. 3 Preparation of the tested composites.

RESULTS AND DISCUSSION

Friction coefficient displayed by the tested polymers filled by almond oil specimens, Fig. 4, slightly decreased with increasing oil content. The minimum value of friction coefficient (0.21) was observed at 10 wt. % oil content for PE composites. The friction decrease may be attributed to the oil stored in the pores inside the polymer matrix which experienced boundary lubricating film of low shear interfacial layer formed on the sliding surfaces and easily removed by the shear instead of the contacting asperities. Those pores were working as reservoirs feeding oil into the contact surface.

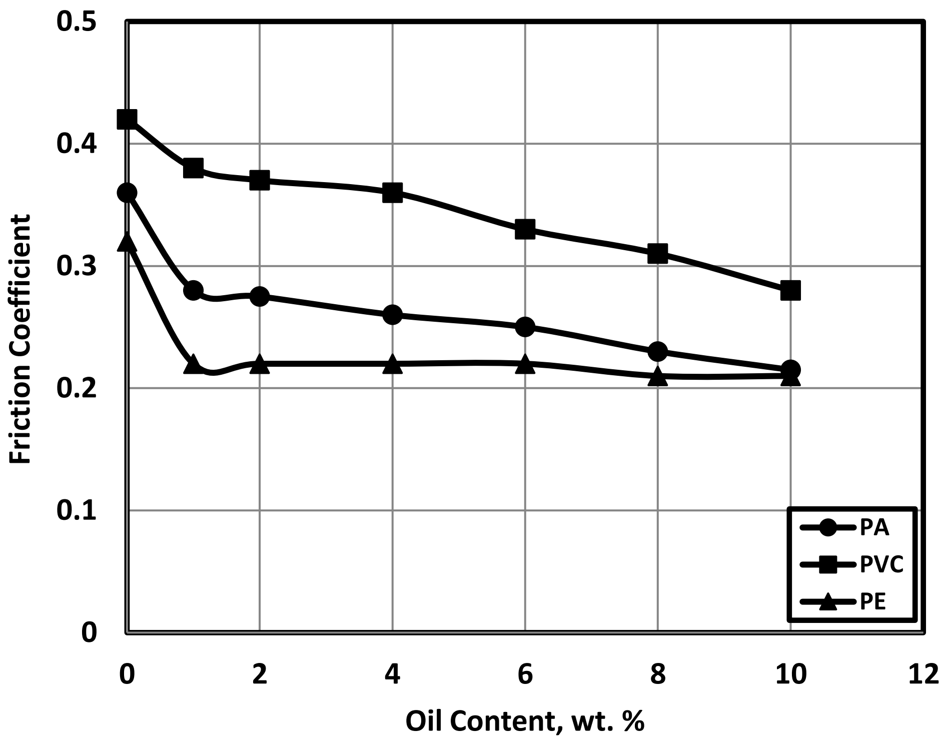

Fig. 4 Friction coefficient displayed by the tested polymers filled by almond oil.

Friction coefficient displayed by the tested polymers filled by camphor oil slightly decreased with increasing oil content, Fig. 5. It seems that friction decrease was due to the oil transfer from the specimen forming thin layer covered the sliding surface. Values of friction were relatively lower than that displayed by almond oil. PA showed the lowest friction values.

Figure 6 shows the effect of oil content on the friction coefficient displayed by the tested polymers filled by castor oil. It can be seen that friction coefficient decreased with increasing castor oil content. Values of friction coefficient were relatively higher than that observed for almond and camphor oils filled composites. PA showed the lowest friction followed by PE and PVC.

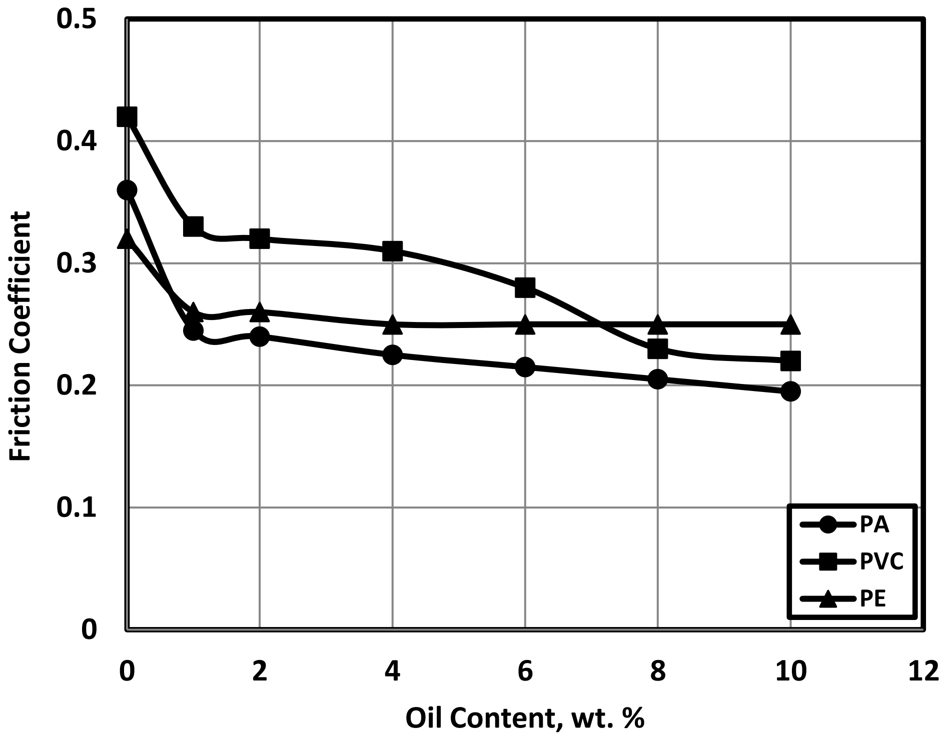

Fig. 5 Friction coefficient displayed by the tested polymers filled by camphor oil.

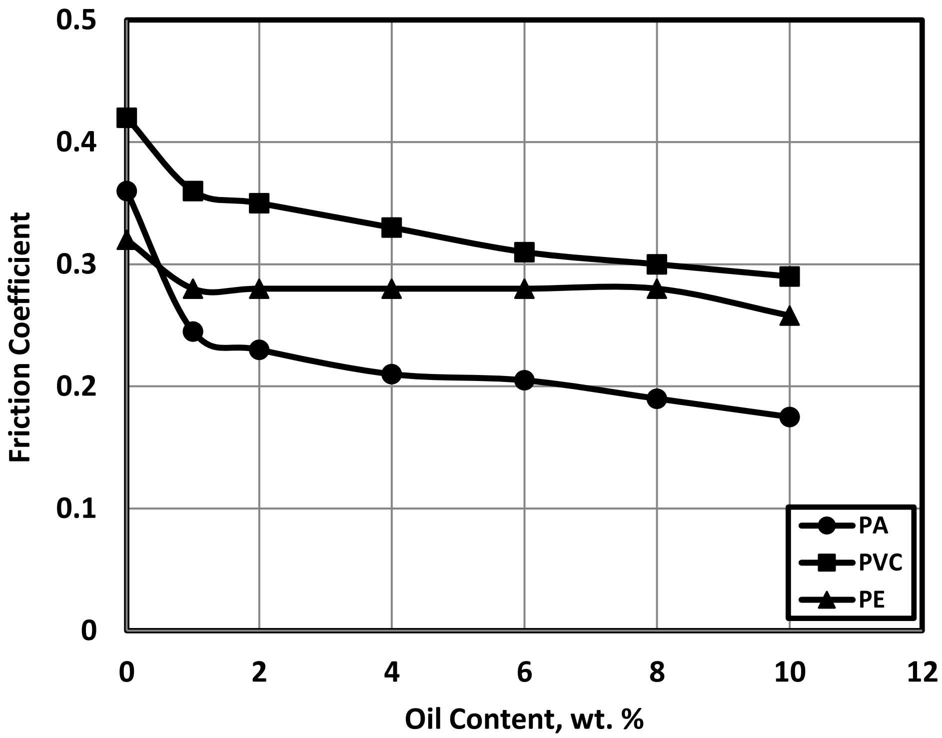

Fig. 6 Friction coefficient displayed by the tested polymers filled by castor oil.

Based on the triboelectric series, when PE and PVC and steel surfaces are pressed or rubbed together, the surface of steel usually becomes positively charged, while PE and PVC become negatively charged due to triboelectrification. While PA gains positive charge and steel has negative one. The intensity of the generated charge depends on the pressure and velocity of rubbing. Once charged, the two surfaces attract each other in dry contact. In the presence of polar molecules of vegetables oils, steel and the tested polymers attract the oil to their surfaces forming multilayers of the oil molecules separating the two materials, Figs. 7 and 8. This behavior would affect the contact and change it from dry to mixed lubrication. The oil molecules are stuck strongly to the charged steel and the tested polymer surfaces due to the electric bond. Besides, the generation of the electric static charges on the sliding surfaces homogeneously distributes the oil molecules over the contact area. Based on that behaviour, friction coefficient decreased in values depending on the adhesion force of the molecules to the contact surfaces which control the thickness of the oil film formed during sliding.

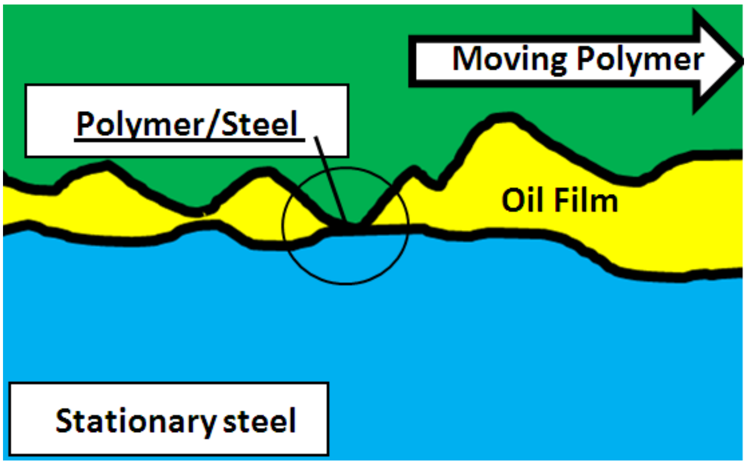

Fig. 7 Illustration of the tested polymers/steel contact.

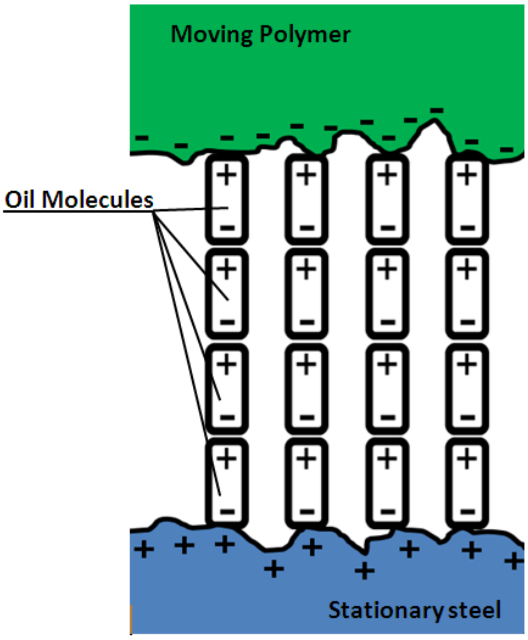

Fig. 8 Details of tested polymers/steel contact.

The tested polymers filled by cress oil showed slight friction decrease, Fig. 9, where friction coefficient drastically decreased with increasing cress oil content up to 2 wt. %. Further increase of oil displayed consistent friction trend. PA showed the lowest friction followed by PVC and PE.

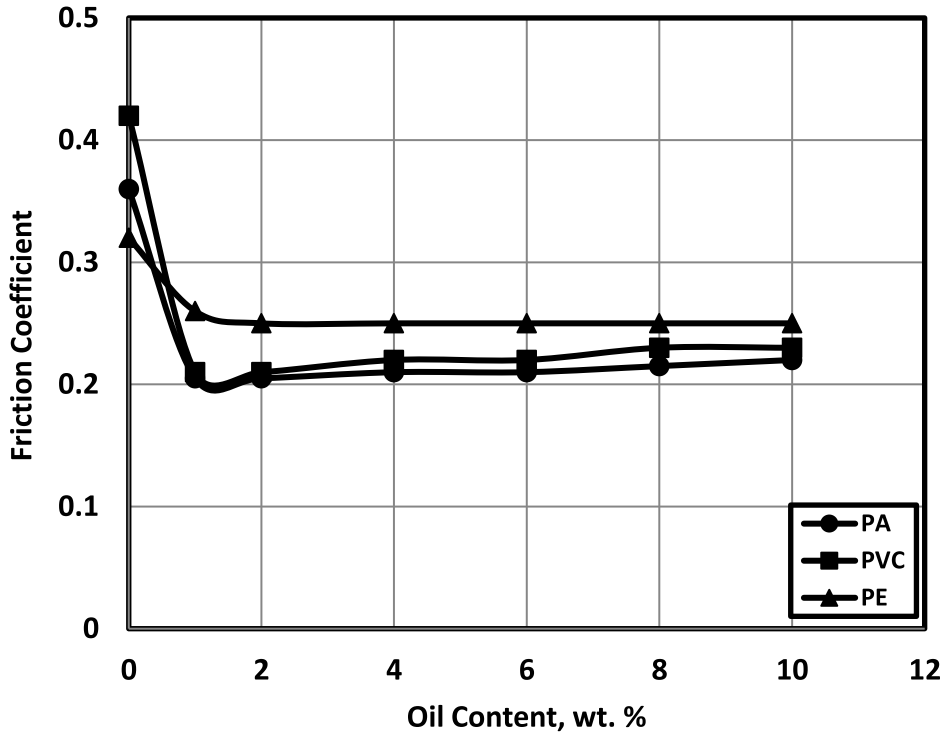

Fig. 9 Friction coefficient displayed by the tested polymers filled by cress oil.

The effect of filling the tested polymers by flax seed oil on friction coefficient is shown in Fig. 10. Drastic friction decrease was observed with increasing oil content up to 1 wt. % followed by slight decrease. PA displayed the lowest friction values followed by PE and PVC. The minimum friction value (0.15) recommends using 10 wt. % oil filled PA as bearing material in dry sliding condition.

Slight friction decrease was observed for the tested polymers filled by black seed oil with increasing oil content, Fig. 11. The minimum value of friction coefficient (0.25) was observed at 10 wt. % oil. The dependency of friction coefficient on the type of the polymers can be explained on the basis of their triboelectrification which controls the adhesion of oil molecules into their surfaces, where the trapped oil inside the pores was forced to be fed to the surface forming an oil film on the contact area leading to significant friction decrease. The tested polymers filled by lettuce oil specimens displayed relatively lower friction values than that observed for the above mentioned oils, Fig. 12, which confirmed the good lubricating properties of lettuce oil due to the relatively stronger adhesion of their molecules into the sliding surfaces.

The same trend was observed for the friction coefficient displayed by the tested polymers filled by olive oil, Fig. 13. Like all the tested composites, friction coefficient drastically decreased for oil content up to 1 wt. % then consistent trend was prevailing for further oil increase for PE and PVC, while PA showed slight increase with increasing oil

content. The decrease in friction might be from the presence of pores inside the the tested polymers matrix filled by oil which during friction leaked out to the sliding surface forming oil film, which would prevent polymer transfer into the steel counterface. It seems for PA the polymer transfer to the steel surface was more effective than the lubricating effect of the oil film.

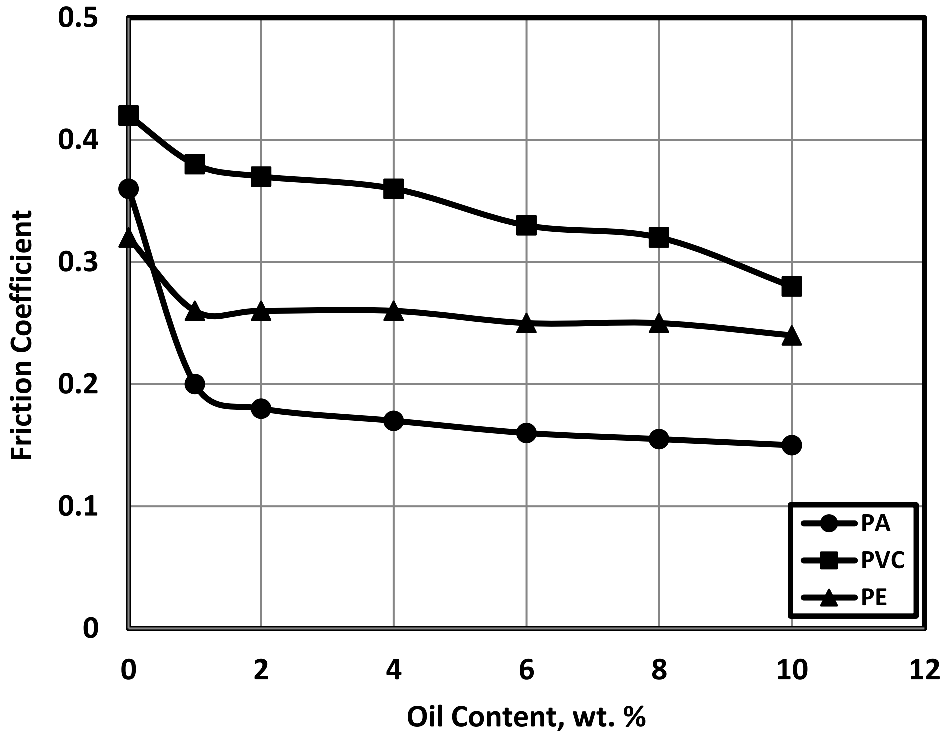

Fig. 10 Friction coefficient displayed by the tested polymers filled by flax seed oil.

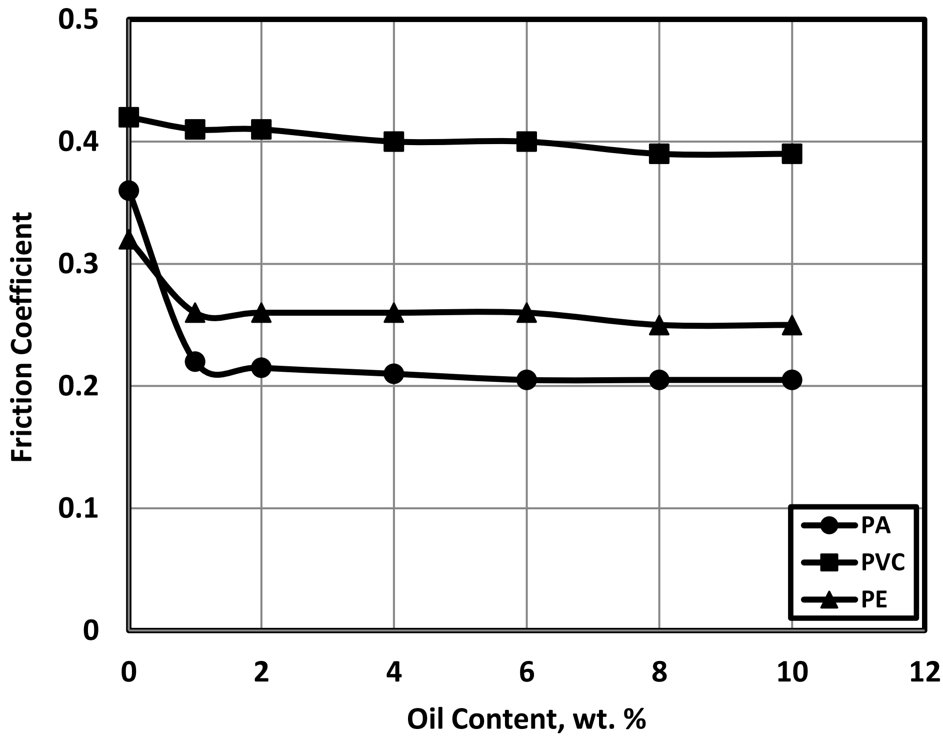

Fig. 11 Friction coefficient displayed by the tested polymers filled by black seed oil.

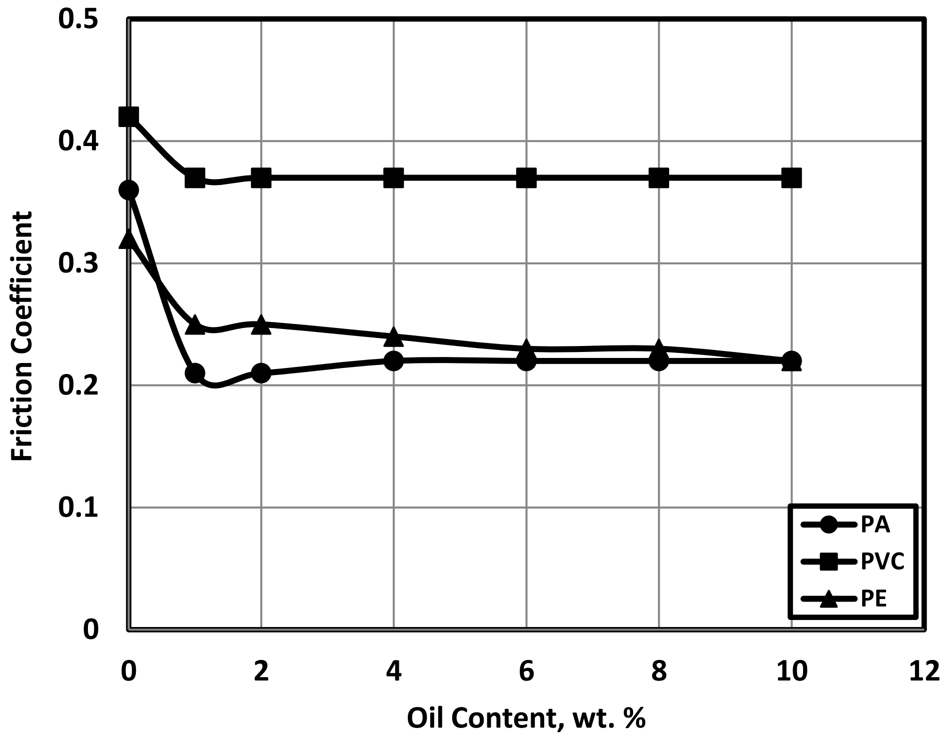

Fig. 12 Friction coefficient displayed by the tested polymers filled by lettuce oil.

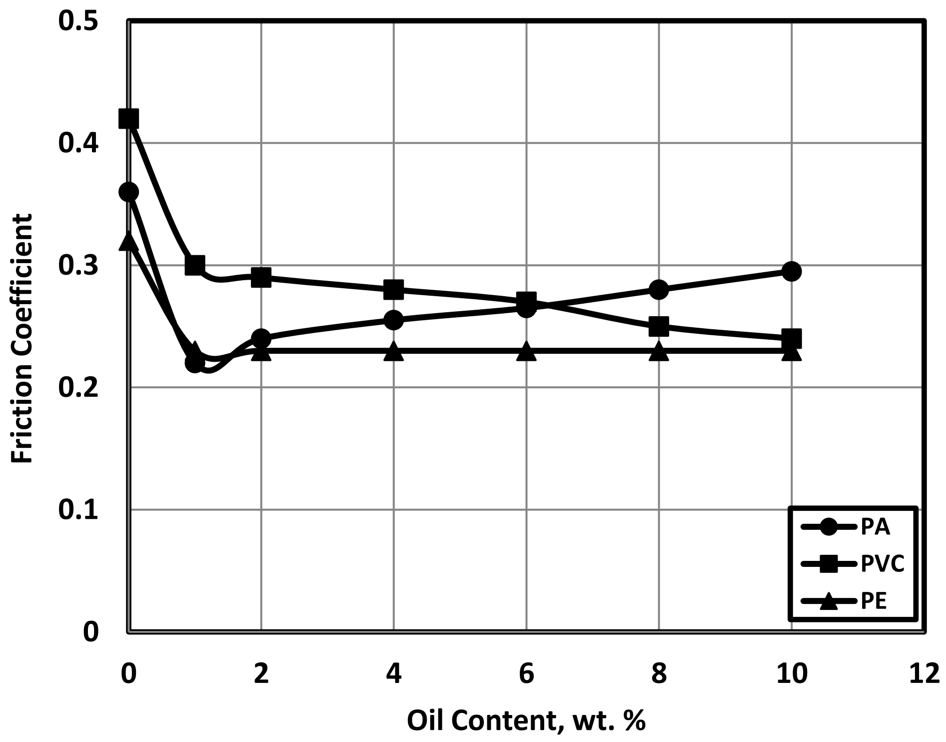

Fig. 13 Friction coefficient displayed by the tested polymers filled by olive oil.

Friction coefficient of the tested polymers filled by sesame oil showed slight decrease with increasing oil content, Fig. 14. It is seen that, PA displayed the lowest friction coefficient, while PVC showed the highest one. The minimum value of friction coefficient (0.18) was detected at 10 wt. % oil content for PA.

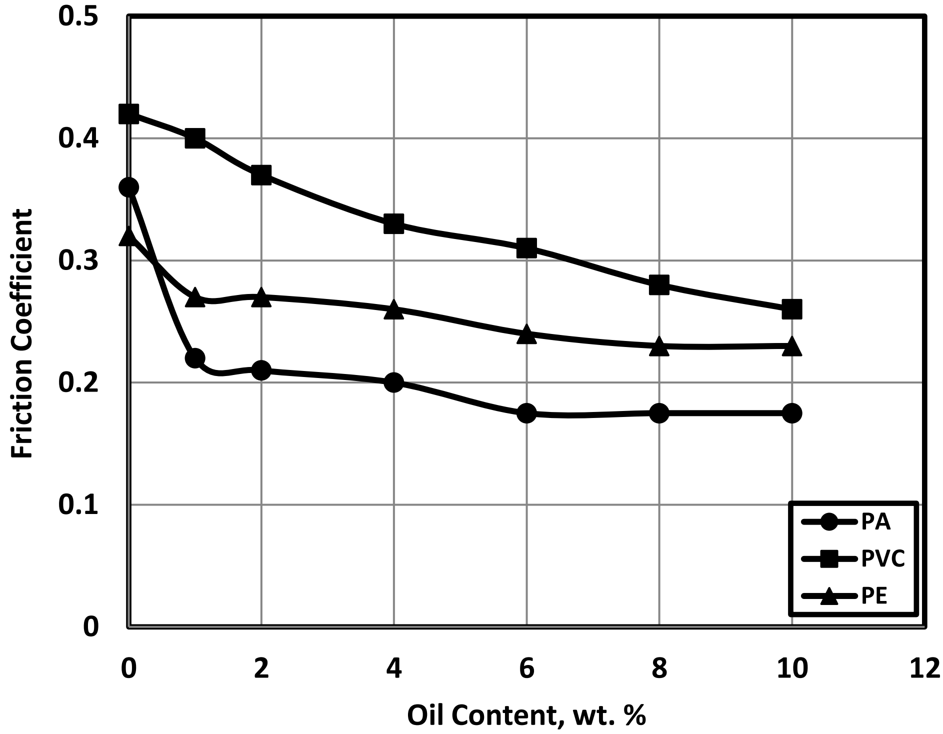

Fig. 14 Friction coefficient displayed by the tested polymers filled by sesame oil.

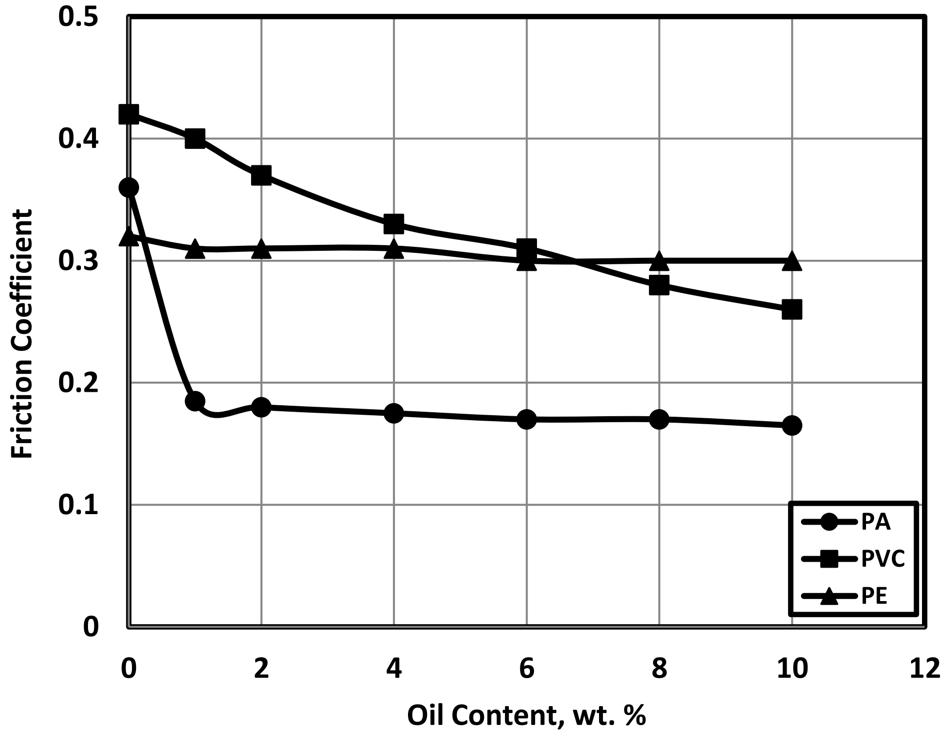

Fig. 15 Friction coefficient displayed by the tested polymers filled by sun flower oil.

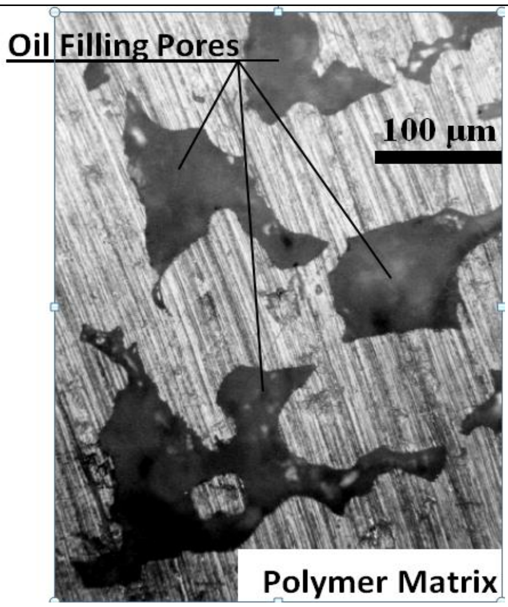

Fig. 16 Photomicrograph of the tested polymers matrix filled by oil.

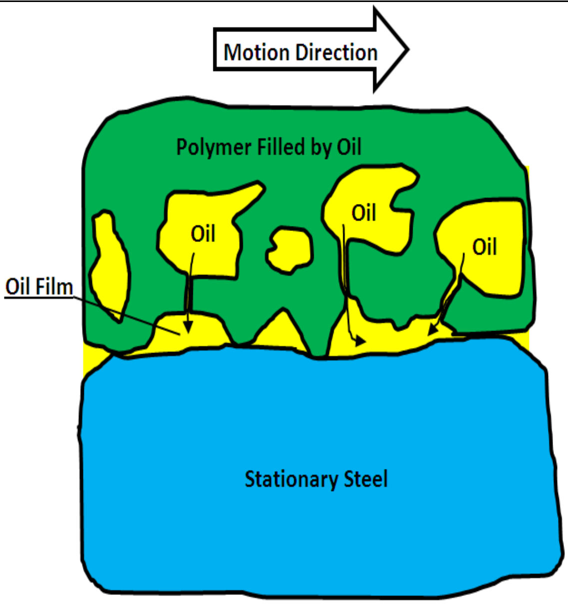

Fig. 17 Sliding of the tested polymers filled by vegetables oils against steel.

The lowest friction (0.17) was observed for PA filled by sun flower oil specimens, Fig. 15. The photomicrograph of the tested polymer matrix, Fig. 16, shows that the oil was trapped in pores after solidification of the tested polymer. Those pores were working as reservoirs feeding oil into the tested polymer surface. A sketch is shown in Fig. 17 illustrates the formation of oil film on the sliding surfaces. The film was fed by the oil stored inside the pores inside the polymer matrix. The strong adhesion of the oil molecules, known for vegetables oils, 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 was found that the nitrogen containing polymers such as polymers with pyridine, amine and amide groups like PA develop the most positive charge, while the halogenated polymers like PVC develop the most negative charge and the hydrocarbons like PE develop almost no charge, [19]. Based on the experimental results it was observed that PA displayed the lowest friction coefficient when filled with the majority of the tested oils followed by PE, while PVC displayed the highest friction. Further research should be exerted to reveal the effect of the static electric charge on the adhesion of the oil molecules into the sliding surfaces.

CONCLOSIONS

Friction coefficient displayed by the tested polymers filled by the tested vegetables oils decreased with increasing oil content. The minimum values of friction coefficient were observed at 10 wt. % oil content for PA composites filled by camphor, castor, cress, flax seed, black seed, sesame and sun flower oils. PE composites filled by almond, lettuce and olive oils showed the lowest friction values.

When PE and PVC and steel surfaces are pressed or rubbed together, the surface of steel usually becomes positively charged, while PE and PVC become negatively charged

due to triboelectrification. While PA gains positive charge and steel has negative one. Once charged, the two surfaces attract each other in dry contact. Steel and the tested polymers attract the oil to their surfaces forming multilayers of the oil molecules separating the two materials. This behavior would affect the contact and change it from dry to mixed lubrication. The oil molecules are stuck strongly to the charged steel and the tested polymer surfaces due to the electric bond. Based on that behaviour, friction coefficient decreased in values depending on the adhesion force of the molecules to the sliding surfaces which control the thickness of the oil film formed during sliding. The minimum friction values recommend using 10 wt. % oil filled PA as bearing material in dry sliding condition.

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