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ABRASIVE WEAR OF POLYESTER COMPOSITES

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ABSTRACT
The present work discusses the friction coefficient and wear of polyester composites sliding against dry rough steel surface. Polyethylene (PE) fibres were used to reinforce polyester in order to increase wear resistance of the tested composites. Vegetable oils such as almond, olives, cress, sesame and baraka oils were added to polyester during moulding.

Based on the experiments, it was found that the results confirmed good tribological performance of the vegetable oils as filling materials in the polyester matrix, especially in terms of the low coefficient of friction. This effect is proportional to the amount of polar groups and double bonds in their fatty acids, related to increased adsorption and shear strength at the interface. Friction coefficient of polyester composites filled by the tested vegetables oils decreased with increasing oil content, where minimum friction values were displayed by composites containing 9.0 wt. % oil content. Increasing PE fibres decreased friction content. As the PE fibres content increased friction decreased due to strengthening effect of the PE fibres which were responsible for the retarding epoxy transfer into steel surface. Besides, wear of polyester composites filled by the tested oils decreased down to minimum then increased with increasing oil content. Besides, reinforcing the tested composites by PE fibres significantly decreased wear. The lowest wear was displayed by composites filled by 6.0 wt. % almond oil and reinforced by 3.0 wt. % PE.

KEYWORDS
Abrasive wear, friction, wear, polyester, PE fibres, vegetables oils.

INTRODUCTION

Polyester composites like polymers are sensitive to abrasive wear. The increased use of polyester composites in many of tribological applications such as automotive and agricultural machinery as well as chemical industries highlights the necessity of developing their abrasive wear resistance. It was found that filling polyester fibres by oil and reinforcing by polyethylene fibres decreased friction coefficient, [1]. Composites free of oil displayed the highest friction and wear. Composites containing olive oil displayed higher friction and lower wear than that containing almond oil. This behaviour can confirm the higher wear protection due to the stronger surface interactions between the polar molecules and the sliding surfaces displayed by olive oil. Beside, wear of polyester composites filled by sesame, cress and baraka oils decreased down to minimum then increased with increasing oil content. The minimum wear values were displayed by composites filled by 3.0 – 6.0 wt. % oil content.

Polyester composites were reinforced by agricultural fibres such as banana core, coconut coir, straw and palm leaves to replace glass fibres. The agricultural fibres have some advantages over traditional reinforcement materials such as glass fibres in terms of cost, density, renewability, abrasiveness and biodegradability. The experimental results revealed that reinforcing polyester by agricultural fibres decreased friction coefficient and wear. Thermosetting polymers were

used in the processing of natural fiber composites. Polyester matrices [2 - 8] were more widely used compared to epoxy [9 - 11]. The increased interest in the various natural materials for reinforcement has paved the way for increased research activities in the field. Reinforcing friction materials by natural fibres showed significant enhancement in mechanical and tribological properties, [12, 13]. Reinforcing phenolic resins by fibres enables them to overcome the high brittleness and cure shrinkage that prevents the widespread application of resins.

The influence of filling polyester–glass fibre composites by paraffin and glycerine oils on their friction and wear was investigated, [14], where significant reduction in friction coefficient and wear was observed. Besides, epoxy filled by oil displayed significant reduction in friction, where minimum values reached 0.1, [15 – 20]. It seems that oil occupied infinite number of very small pores in epoxy matrix, where it flew on the sliding surface and provided thin film of lubricant. This proposed mechanism of lubrication changed the dry sliding into lubricated one.

Elastohydrodynamic lubrication (EHL) film thickness in a space ball bearing was measured by electrical capacitance and resistance, and transients of oil film and lubricant breakdown were observed, [21]. With different oil-impregnated polymer retainers, which were employed as oil supply resources, degradation was restricted to some degree, even lubricant breakdown disappeared and a steady state of the oil film was produced. A long term space ball bearing demanded both the lowest driving torque and a steady state oil film, which depended on a strictly controlled oil supply from oil-impregnated retainers.

Biodegradable oils can replace mineral oils to solve the problem of pollution of the natural surroundings caused by mechanical systems. Natural biodegradable oils possess good anti-wear properties and low friction, [22]. The conventional lubrication mechanisms based on physical and chemical adsorption, where the polar molecules play a key role in interactions with the sliding surfaces, the best tribological performance is expected for vegetable oils, which consists of a considerable amount of fatty acids with unsaturated bonds, [23]. Moreover, when using oils with additives the wear was significantly lower and the adhesion was eliminated. This was true for all types of oil, which clearly indicates that additives were predominantly responsible for the wear protection. Efficiency of the lubricant depends on the strength of the fluid film and consequently on the adsorption on the sliding surfaces. Increasing the polar functionality in vegetable oil structure has a positive impact on wear protection resulting from stronger adsorption potential on metal surface as well as greater lateral interaction between the ester chains.

Vegetable oils are renewable resources, environmentally friendly non-toxic fluids, biodegradable and have no health hazards. The triacrylglycerol structure of vegetable oil makes it an excellent candidate for potential use as a base stock for lubricants and functional fluids, [24]. It was observed that wear resistance of lubricated surfaces can be significantly improved by the formation of a stable tribochemical film, [25]. This film can be applied on the sliding surfaces through the polar action of vegetable oil. Several attempts were based on the development of structurally modified bio-based fluids to improve their use as industrial base oils.

In the present work, the effect of filling polyester composites by vegetable oils and reinforced by polyethylene fibres on their friction and wear when dry sliding against steel surface. Five types of vegetable oils, i.e., almond, olive, sesame, cress and baraka oils that posses different polar and saturation characteristics were used.

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 test specimen is held in the specimen holder fastened to the loading lever. Through load cell, where strain gauges are adhered, friction force can be measured. Friction coefficient was determined as the

ratio of the friction force, measured by the deflection of the load cell, and the normal force. The load is applied by weights. The counterface in form of a steel disc, of 100 mm outer diameter, is fastened to the rotating disc. Its surface roughness was about 7.6 µm, R_a. Test specimens were prepared in the form of a rod of square cross section of 5 × 5 mm and 30 mm length.

The tested materials were unsaturated polyester resin G154TB. The PE fibres of 0.5 mm diameter were used to reinforce the polyester matrix in concentrations of 1.0, 2.0, and 3.0 wt. %. The concentration of the constituents was considered relative to the gross weight of the test specimen. Test specimens were prepared by moulding. The composites were prepared by the deposition of the fibers in a rectangular mold and its physical impregnation with the liquid resin. At the end of the stratification, the mold was left for 24 h. The curing was done at room temperature for 24 hours.

The tested oils were added to polyester composites before molding at concentration ranging from 0 and 9 wt. %. After well mixing of polyester components A & B, oil was added to the mixture and remixing was achieved. Then PE fibres were added to the polyester matrix. The friction surface of the test specimens was finished by steel mesh before test, where the surface roughness was approximately 7.6 µm.

RESULTS AND DISCUSSIONS

Friction coefficient of polyester composites filled by almond oil and sliding against steel surface is shown in Fig. 1. Friction decreased with increasing oil content, where minimum friction values were displayed by composites containing 9.0 wt. % oil content. Increasing polyethylene fibres decreased friction content. This decrease was due to the lower friction values experienced by polyethylene. The highest friction was displayed by composites free of oil. The friction reduction might be attributed to the high number of oil pores inside the polyester matrix. As the surface layer removed by the action of wear the oil got out from the pores and covered the sliding surface forming lubricant layer that was responsible for the friction decrease. The results of friction coefficient are more indicative and support the quite good lubricity of almond oil.

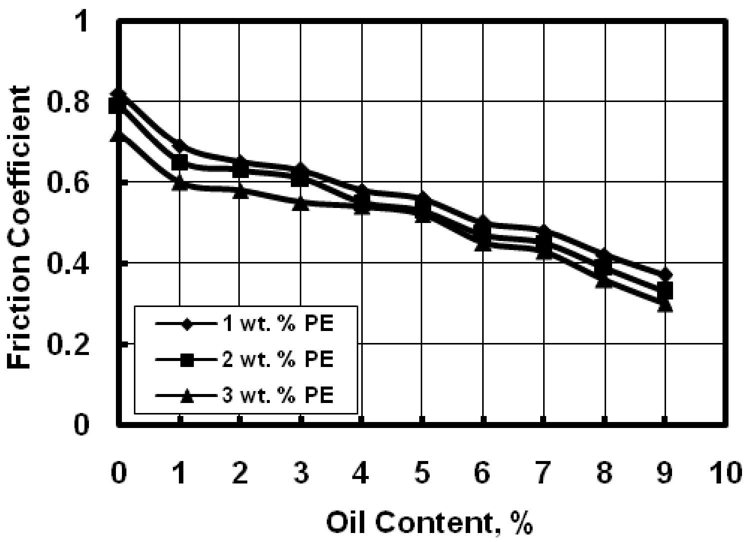

Fig. 1 Friction coefficient of polyester composites filled by almond oil and sliding against rough steel surface.

The effect of filling polyester by olive oil on the friction coefficient is shown in Fig. 2. Friction decreased with increasing oil content. The friction values were relatively higher than that displayed by composites filled by almond oil. Generally, the friction values were relatively higher than displayed by smoother steel counterface, [1]. This behaviour might be from the excessive polyester transfer into steel. In that condition the friction would be between polyester and polyester. Composites reinforced by 3.0 wt. % PE fibres showed lower friction coefficient due to the reinforcing action which was responsible for the decrease of polyester transfer.

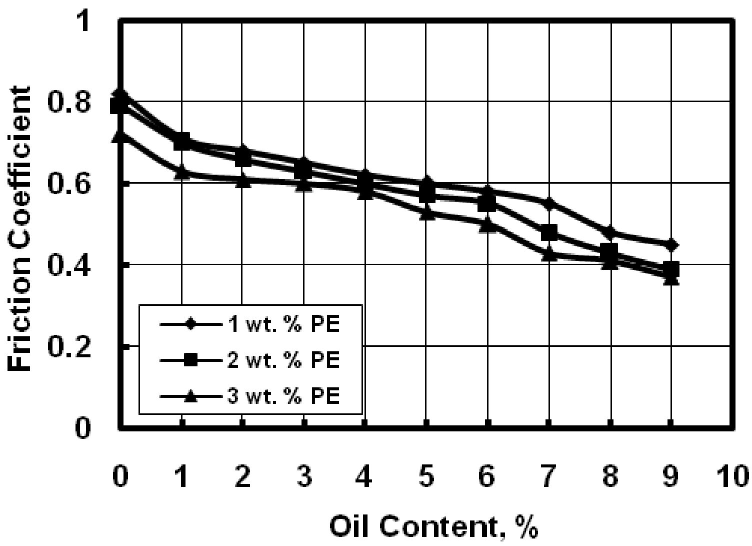

Fig. 2 Friction coefficient of polyester composites filled by olive oil and sliding against rough steel surface.

The same trend of friction decrease was observed for composites filled by sesame oil, Fig. 3. The friction values were relatively higher than that observed for composites filled by almond oil and lower that that observed for olive oil. Composites filled by 9.0 wt. % PE displayed the lowest friction values. It is illustrated that as the oil content increased friction coefficient decreased. It is necessary to determine the optimum oil based on the minimum wear vale.

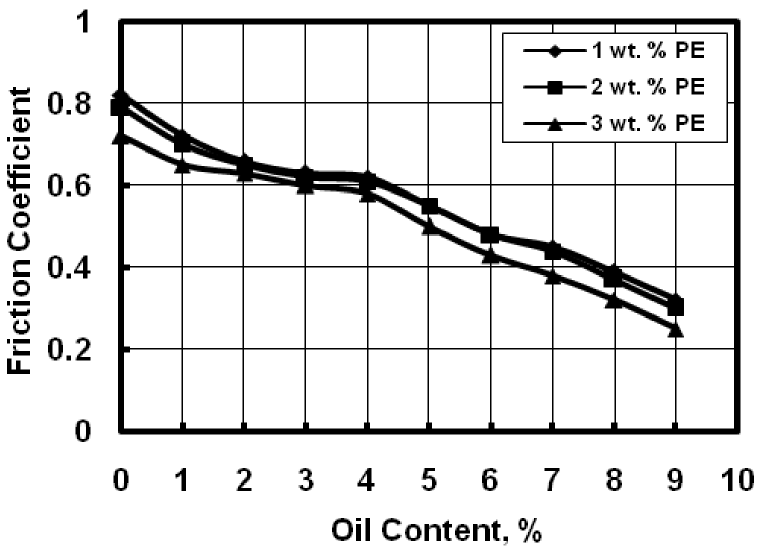

Fig. 3 Friction coefficient of polyester composites filled by sesame oil and sliding against rough steel surface.

The friction coefficient displayed by the tested composites illustrates the significant effect of the cress oil on decreasing friction coefficient, Fig. 4. As the PE fibres content increased friction decreased due to strengthening effect of the PE fibres which were responsible for the retarding epoxy transfer into steel surface. Friction coefficient represented relatively higher values than that observed for the almond, olive and sesame oils.

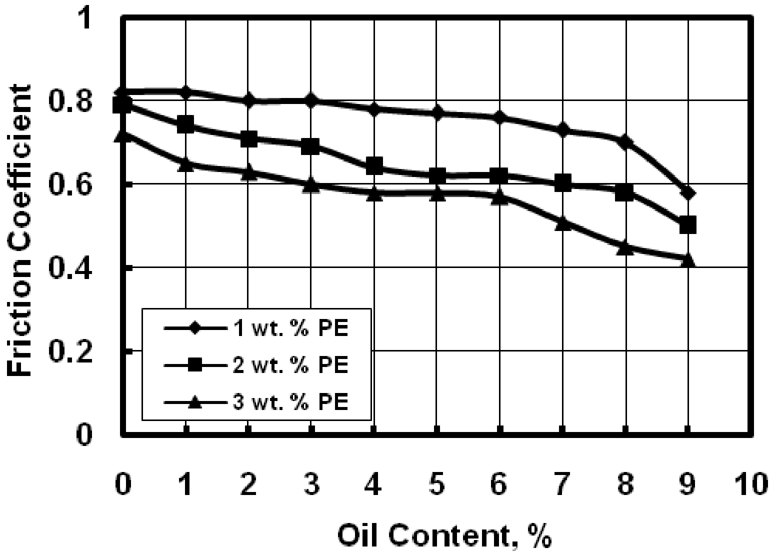

Fig. 4 Friction coefficient of polyester composites filled by cress oil and sliding against rough steel surface.

Based on the lubrication mechanisms of vegetable oils which depend on physical and chemical adsorption, baraka oil with its polar molecules, Fig. 5, showed a decreasing trend with increasing oil content. The effect of the PE fibres was insignificant for oil content ranging from 3.0 – 9.0 wt. %.

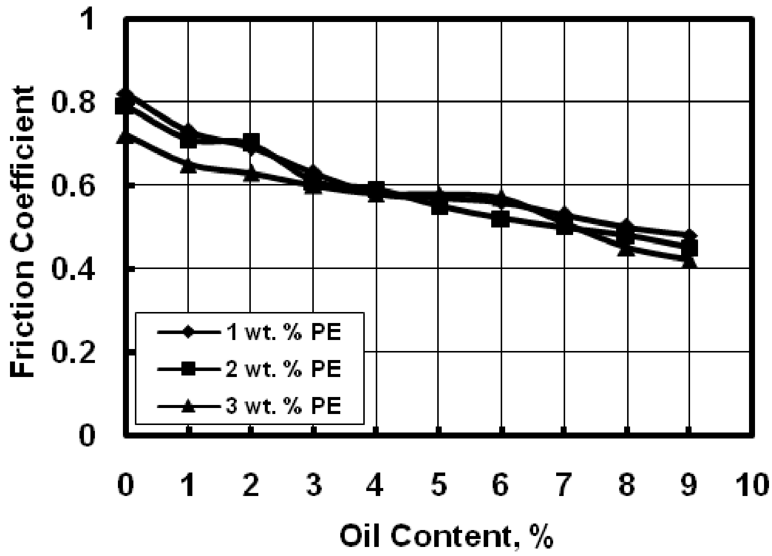

Fig. 5 Friction coefficient of polyester composites filled by baraka oil and sliding against rough steel surface.

Wear of polyester composites filled by almond oil and sliding against steel surface decreased down to minimum then increased with increasing oil content, Fig. 6. Reinforcing the tested composites by PE fibres significantly decreased wear. The lowest wear was displayed by composites filled by 6.0 wt. % almond oil and reinforced by 3.0 wt. % PE. The higher wear resistance offered by almond oil can be explained on the basis of the strong adsorption of the molecules of almond oil on the steel counterface by the physical and chemical adsorption, while

adherence of oil molecules to the polyester composites was exerted by electrostatic attractive force.

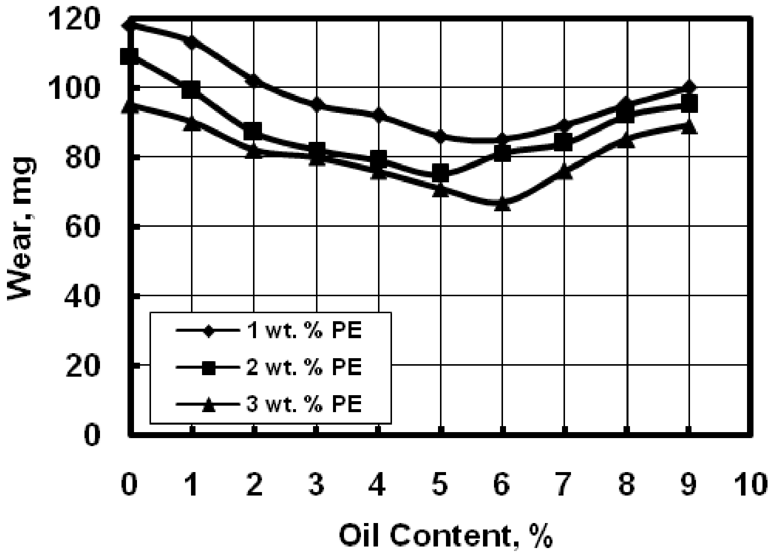

Fig. 6 Wear of polyester composites filled by almond oil and sliding against rough steel surface.

Wear displayed by polyester composites filled by olive oil and reinforced by polyethylene fibres is shown in Fig. 7. Wear recorded relatively the lowest values for composites reinforced by 3.0 wt. % PE. The behaviour can be explained on the basis that the brittle mode of polyester composites can be reduced by the ductile mode of PE. On the other hand, for the olive oil used, the friction was higher while wear decreased, which explains the higher wear protection due to the stronger surface interactions between the polar molecules and the sliding surfaces with the higher shear strength of the bonds. The higher friction coefficient coincides well with the lowest wear.

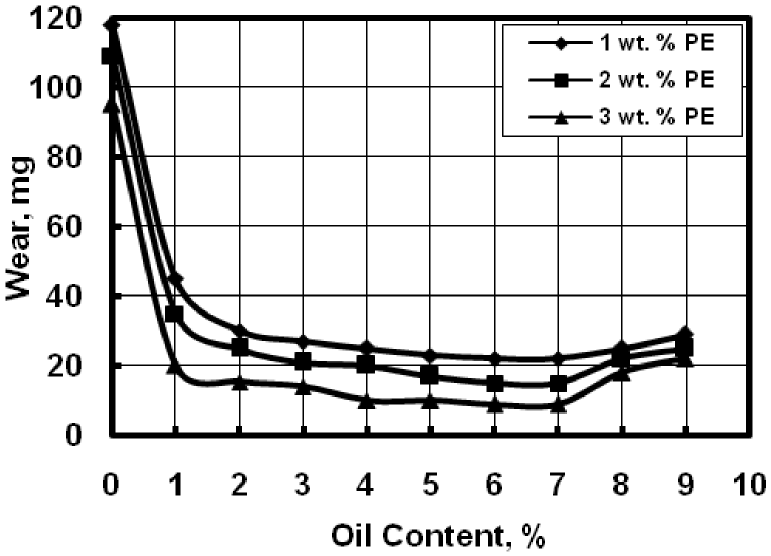

Fig. 7 Wear of polyester composites filled by olive oil and sliding against rough steel surface.

Wear of polyester composites filled by sesame oil and sliding against steel surface is shown in Fig. 8. Wear decreased down to minimum then increased with increasing oil content. The minimum wear values were displayed by composites filled by 3.0 – 6.0 wt. % oil content. It seems that oil content higher than 6.0 wt. % weakened the strength of polyester composites. Generally, wear resistance of sesame oil is much lower than that displayed by composites containing almond and olive oils.

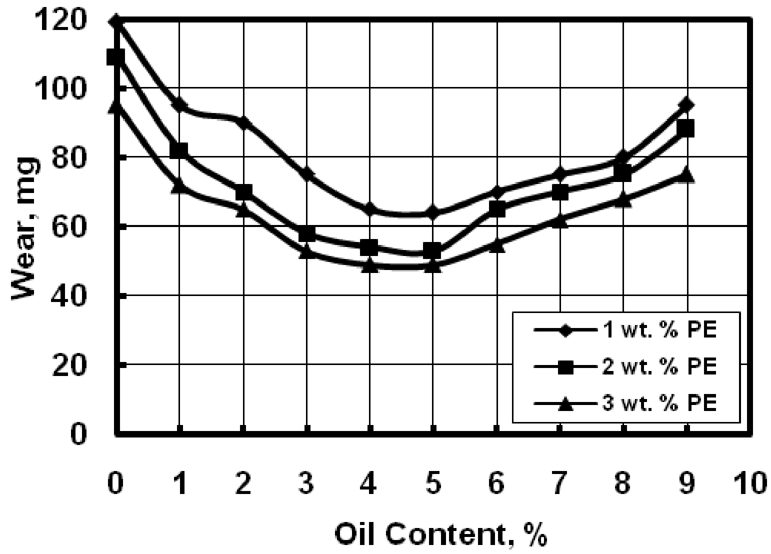

Fig. 8 Wear of polyester composites filled by sesame oil and sliding against rough steel surface.

Wear of polyester composites filled by cress oil and sliding against steel surface is shown in Fig. 9. Wear decreased down to minimum at 6.0 wt. % oil content. Further increase in oil content caused slight increase in wear. The wear reduction may be attributed to the fact that the shear strength of the adsorbed oil molecules on the steel surfaces was relatively high, resulting in relatively stronger wear protection.

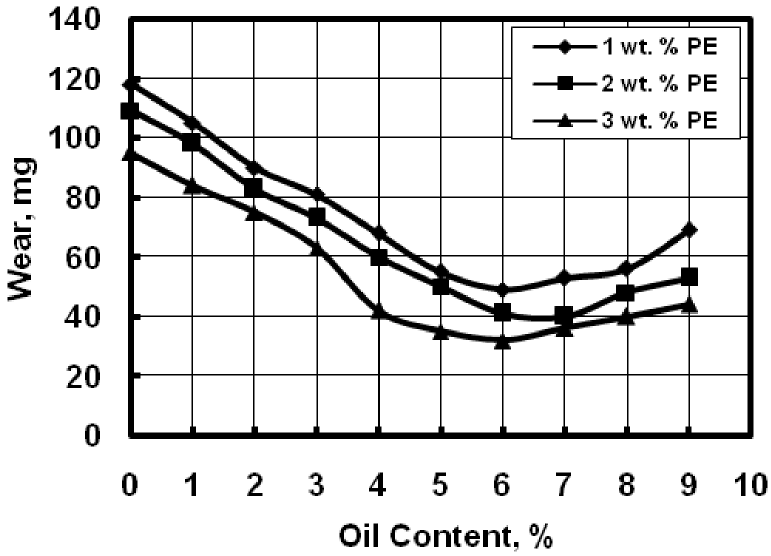

Fig. 9 Wear of polyester composites filled by cress oil and sliding against rough steel surface.

Wear of polyester composites, filled by baraka oil and sliding against steel surface, experienced relatively higher wear values than the other tested composites, Fig. 10, indicating that the shear strength of the adsorbed oil molecules on the composite and steel surfaces was lower than the other tested oils resulting in relatively poorer wear protection. This behaviour depends on the evidence of adhesion and the formation of transfer films. The wear of the oil filled composites was lower up to 100% lower than that of the oil free composites, which indicates that the amount of polar molecules that are readily available in the baraka oil could interact with the surfaces and consequently decreased wear.

The results confirm good tribological performance of the vegetable oils as filling materials in the polyester matrix, especially in terms of the low coefficient of friction. This effect is proportional to the amount of polar groups and double bonds in their fatty acids, related to increased adsorption and shear strength at the interface. On the contrary, the coefficient of friction for all the composites filled by vegetable oils was up to 50% lower than the oil free composites.

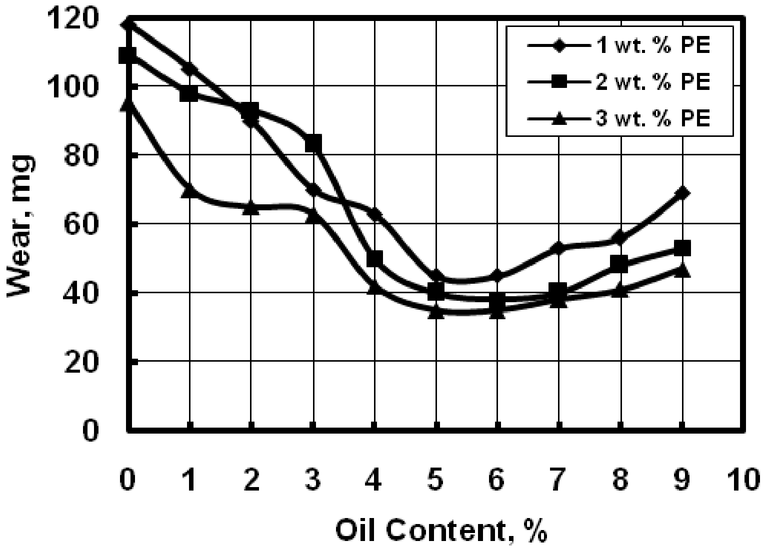

Fig. 10 Wear of polyester composites filled by baraka oil and sliding against rough steel surface.

CONCLUSIONS

1. Friction coefficient of polyester composites filled by almond oil and sliding against steel surface decreased with increasing oil content, where minimum friction values were displayed by composites containing 9.0 wt. % oil content. Increasing polyethylene fibres decreased friction content. The highest friction was displayed by composites free of oil. Friction decreased with increasing olive and sesame oils content. The friction values were relatively higher than that observed for composites filled by almond oil and lower that that observed for olive oil, while friction coefficient displayed by cress oil represented relatively higher values than that observed for the almond, olive and sesame oils. Baraka oil showed a decreasing trend with increasing oil content.

2. As the PE fibres content increased friction decreased due to strengthening effect of the PE fibres which were responsible for the retarding epoxy transfer into steel surface.

3. Wear of polyester composites filled by the tested oils decreased down to minimum then increased with increasing oil content. Reinforcing the tested composites by PE fibres significantly decreased wear. The lowest wear was displayed by composites filled by 6.0 wt. % almond oil and reinforced by 3.0 wt. % PE. Wear displayed by polyester composites filled by olive oil and reinforced by polyethylene fibres recorded relatively the lowest values for composites reinforced by 3.0 wt. % PE.

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