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EXPERIMENTAL STUDY OF ABRASIVE WEAR RESISTANT POLYESTER COMPOSITES

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ABSTRACT

The environment of Arab countries suffers from the relatively high concentration of dust in air, due to the lack of rain and the vast area of desert, which causes significant increase in wear rate of moving surfaces. To overcome those severe environmental impacts, it is necessary to develop the materials which can resist the abrasion action of sand.

The present work aims to develop polyester composites to be used as self lubricated bearing material in different engineering applications. Polyethylene and glass fibres were used to reinforce polyester in order to increase wear resistance of the tested composites. Paraffin, glycerine, almond, olives, cress, sesame and baraka oils were added to polyester during moulding to produce self lubricated composites. The friction coefficient and wear of the tested composites were investigated. The scratch resistance of the proposed composites was tested.

The experimental results showed that unfilled polyester composites displayed relatively high friction values as a result of polyester transfer to the steel counterface as well as the increase of the attractive force caused by the electric static charge formed on the two friction surfaces. When polyester matrix was filled by paraffin and glycerine oils significant reduction in friction coefficient and wear was observed. Besides, increasing oil content and polyethylene fibres decreased friction coefficient. 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 was displayed by composites filled by 20 wt. % oil content.

KEYWORDS

Friction, abrasive wear, sand, polyester composites, paraffin, vegetables oils, polyethylene fibres.

INTRODUCTION

Polyester composites are extensively used in many of tribological applications such as automotive and agricultural machinery as well as chemical industries. 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 [1 - 7] were more widely used compared to epoxy [8 - 10]. 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, [11, 12]. 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, [13], 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, [14 – 19]. 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, [20]. 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, [21]. 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, [22]. 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, [23]. It was observed that wear resistance of lubricated surfaces can be significantly improved by the formation of a stable tribochemical film, [24]. 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.

Polyethylene fibres were used to reinforce polyester in order to increase adhesive wear resistance of the tested composites, [25]. Vegetable oils such as almond, olives, cress, sesame and baraka oils were added to polyester during moulding to decrease friction coefficient. It was found that increasing oil content and polyethylene fibres decreased friction content. The highest friction and wear were displayed by composites free of oil. 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.

The agricultural fibres were investigated as reinforcing material for polyester composites to replace glass fibres, [26]. The agricultural fibres have some advantages over traditional reinforcement materials such as glass fibres in terms of cost, density, renewability, recyclability, abrasiveness and biodegradability. The experimental results revealed that reinforcing polyester by agricultural fibres decreased friction coefficient, where the minimum friction coefficient was displayed by composites reinforced by banana core fibres and the maximum friction values were displayed by straw reinforcing polyester composites. Besides, abrasive wear resistance of the tested composites was developed by the application of natural fibres as reinforcement, where the best wear resistance was achieved by reinforcing the polyester by coconut as well as banana core fibres of length ranged between 3 – 8 mm and 50 wt. % content.

In the present work, the abrasive wear resistance of polyester composites filled by oils and reinforced by polyethylene fibres on their friction and wear when dry sliding on steel surface. In addition of paraffin and glycerine oils, five types of vegetable oils, i.e., almond, olive, sesame, cress and baraka oils that possess different polar characteristics were used.

EXPERIMENTAL

Experiments were carried out using an abrasive wear tester under controlled testing conditions. The wear tester, used in the experiments, was top scratching tester equipped with a stylus to produce a scratch on a flat surface with a single pass. The details of the test rig are shown in Fig. 1. The stylus, used in experiments, was a square insert (12 × 12 mm) of hardened steel of tip radius of 0.1 mm and hardness of 600 kp/mm^2. The scratch force was measured by the deflection of the load cell. The ratio of the scratch force to the normal load was considered as friction coefficient. Wear was considered as the wear scar width of the scratch. The width was measured by optical microscope with an accuracy of ± 1.0 μm. The load was applied by weights. The test speed was nearly controlled by turning the power screw feeding the stylus in the scratch direction perpendicular to the orientation of the fibres inside the polyester matrix. The scratch velocity was 2 mm/s. The normal load was 20 N. All measurements were performed at 30 ± 2 º C and 50 ± 10 % humidity.

The tested materials were unsaturated polyester resin G154TB. The polyethylene fibres of 0.5 mm diameter were used to reinforce the polyester matrix in concentrations ranging from 0 to 20 wt. %. The concentration of the constituents was considered relative to the gross weight of the test specimen. Glass fibres of 0.1 mm diameter were used to reinforce the polyester matrix. Test specimens of 50 × 50 × 5 mm were prepared by moulding. The tested oils were added to polyester composites before molding at concentration of 5 wt. %. After well mixing of polyester components A & B, oil was added to the mixture and remixing was achieved. Glycerine oil was selected due to its good electrical conductivity to give some information about the influence of electrical charge formed on the friction surface. After well mixing of the polyester and the hardener, the filling materials and the oil were added to the mixture and remixing was achieved for five minutes. Then the polyethylene and glass fibres were inserted in the mould of the specimen in the same direction. The friction surface of the test specimens was finished by steel mesh before test, where the surface roughness was approximately 3.0 μm. 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.

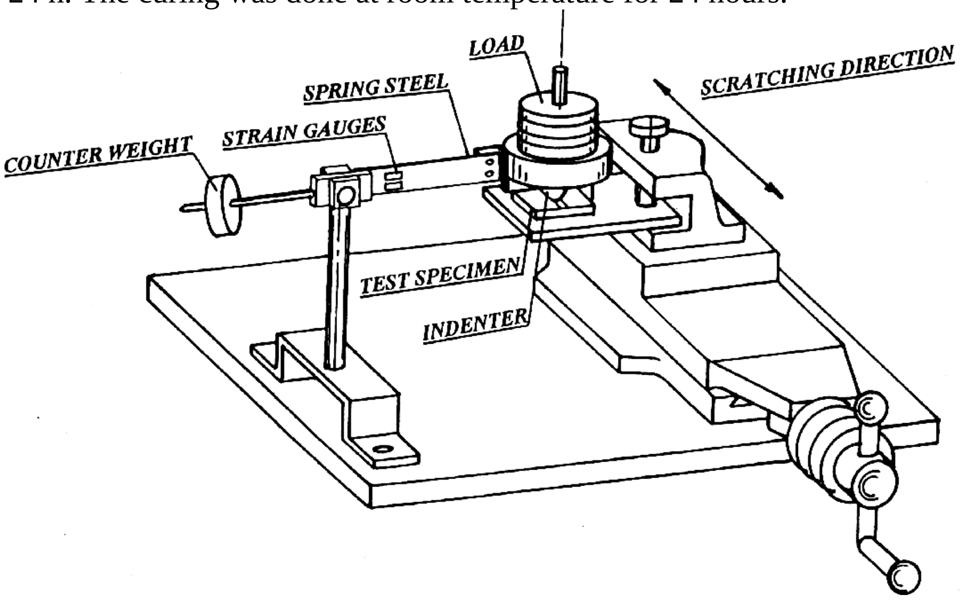

Fig. 1 Arrangement of the scratch tester.

RESULTS AND DISCUSSION

The effect of filling the tested composites by polyethylene on friction coefficient is shown in Fig. 2. For paraffin oil, glass fibres reinforced composites experienced lower values of friction coefficient than that observed for composites free of glass fibres, where friction coefficient slightly decreased with increasing polyethylene content. Glass fibres reinforced polyester composites displayed relatively lower friction values. This behavior might be from the ability of glass fibres to abrade the polyester transferred to the cutting edge of the steel insert. Wear slightly decreased with increasing polyethylene content, Fig. 3. The difference in wear values between unfilled and filled polyester composites is relatively high. This behavior might be attributed to the strong adhesion of glass fibres in the polyester matrix as well as their strengthening effect. Minimum wear scar width displayed by the glass fibres reinforced polyester was 0.96 mm, while it was 1.28 mm for unfilled composites.

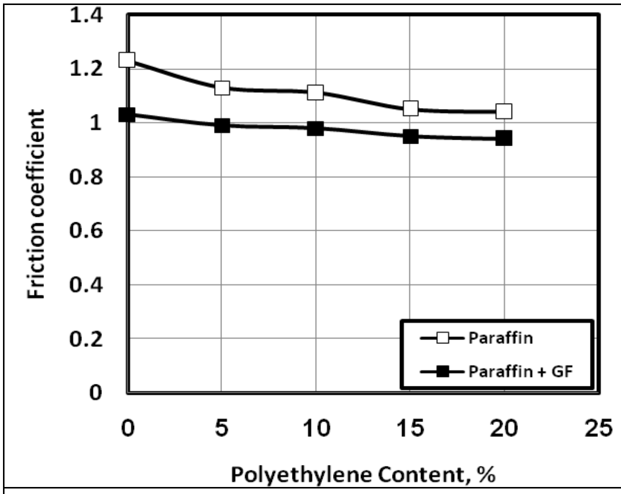

Fig. 2 Friction coefficient displayed by abrasion of polyester composites filled by paraffin oil.

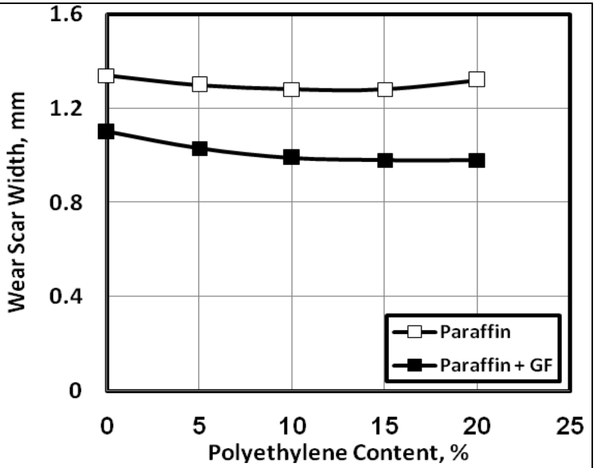

Fig. 3 Wear of polyester composites filled by paraffin oil.

Composites containing glycerine displayed relatively higher values of friction coefficient. It seems that the ability of glycerine to conduct electric current Friction coefficient decreased to minimum then increased with increasing polyethylene content. Minimum friction coefficient was observed at 5 wt. % polyethylene content, Fig. 4. As the content of polyethylene increased friction coefficient increased up to values higher than that observed for composites free of polyethylene.

Glycerine impregnated composites displayed lower wear than composites free of glass fibres, Fig. 5, where composites reinforced by glass fibres showed the lowest wear values at 10 wt. % polyethylene content. It seems that combination of polyethylene and glass fibres in a matrix of polyester impregnated by glycerine oil possesses good adhesion.

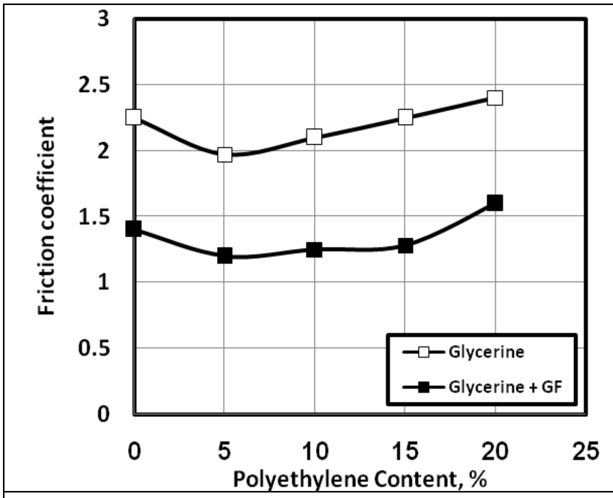

Fig. 4 Friction coefficient displayed by abrasion of polyester composites filled by glycerine oil.

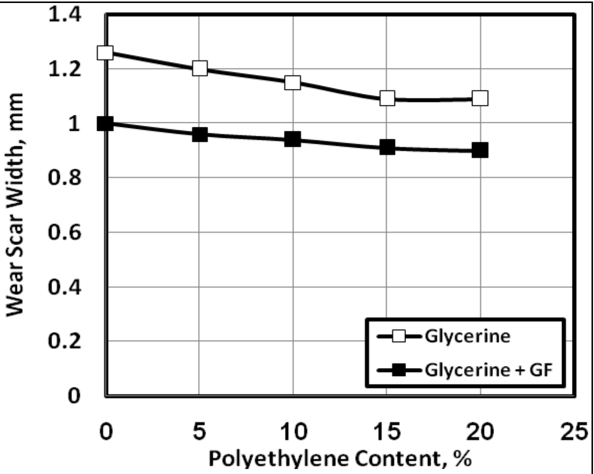

Fig. 5 Wear of polyester composites filled by glycerine oil.

Friction coefficient of polyester composites filled by almond oil and sliding against steel surface is shown in Fig. 6. 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.

Wear of polyester composites filled by almond oil and sliding against steel surface decreased with increasing oil content, Fig. 7. Reinforcing the tested composites by polyethylene fibres decreased wear. The lowest wear was displayed by composites filled by 9 wt. % and reinforced by 3.0 wt. % polyethylene. 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.

The effect of filling polyester by olive oil on the friction coefficient is shown in Fig. 8. Friction decreased with increasing oil content. The friction values are relatively higher than that displayed by composites filled by almond oil. Wear displayed by polyester composites filled by olive oil and reinforced by polyethylene fibres is shown in Fig. 9. Wear recorded relatively lower values for composites reinforced by 3.0 wt. % polyethylene fibres. The behaviour can be explained on the basis that the brittle mode of polyester composites can be reduced by the ductile mode of polyethylene fibres. On the other hand, for the olive oil used, the friction was higher while wear displayed relatively lower values, 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.

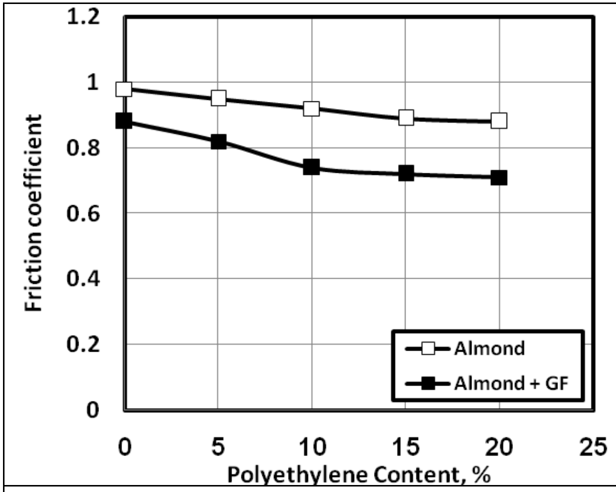

Fig. 6 Friction coefficient displayed by abrasion of polyester composites filled by almond oil.

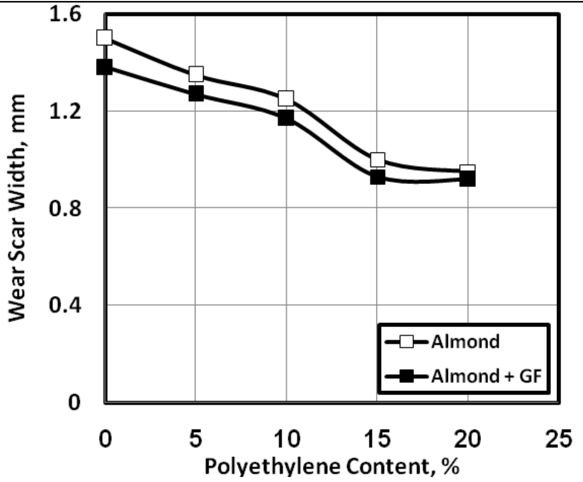

Fig. 7 Wear of polyester composites filled by almond oil.

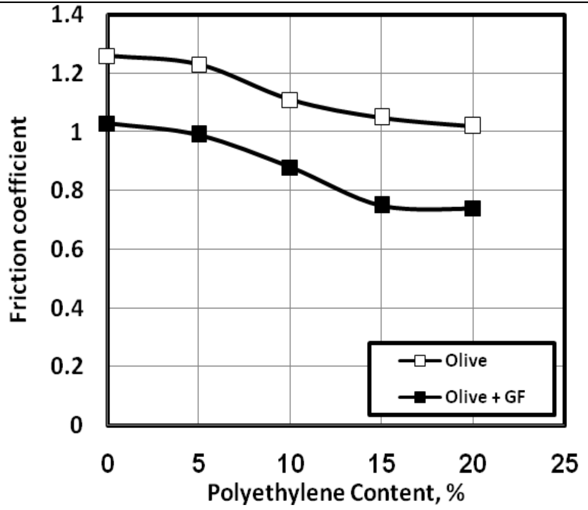

Fig. 8 Friction coefficient displayed by abrasion of polyester composites filled by olive oil.

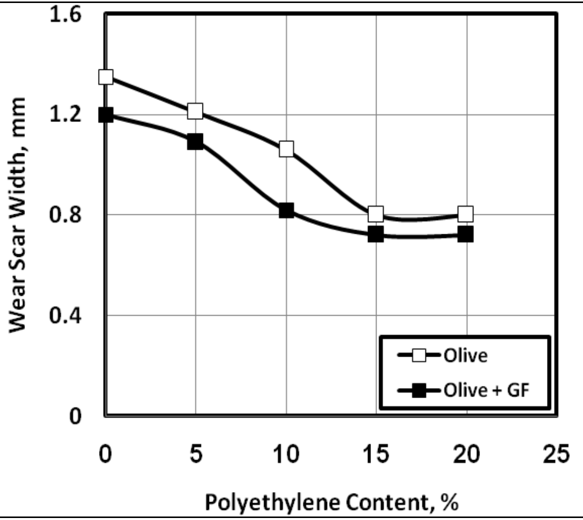

Fig. 9 Wear of polyester composites filled by olive oil.

The same trend of friction decrease was observed for composites filled by sesame oil, Fig. 10. The friction values are relatively higher than that observed for composites filled by almond oil. Wear of polyester composites filled by sesame oil and sliding against steel surface is shown in Fig. 11. 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.

The friction coefficient displayed by the tested composites illustrates the quite good lubricity of the cress oil, which resulted in a noticeably lower friction Fig. 12. As the polyethylene fibres content increased friction decreased. Wear of polyester composites filled by cress oil and sliding against steel surface is shown in Fig. 13. Wear decreased down to minimum at 5.0 – 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.

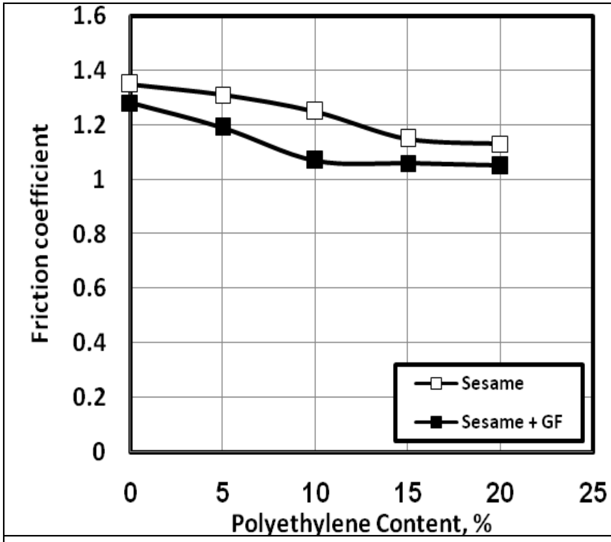	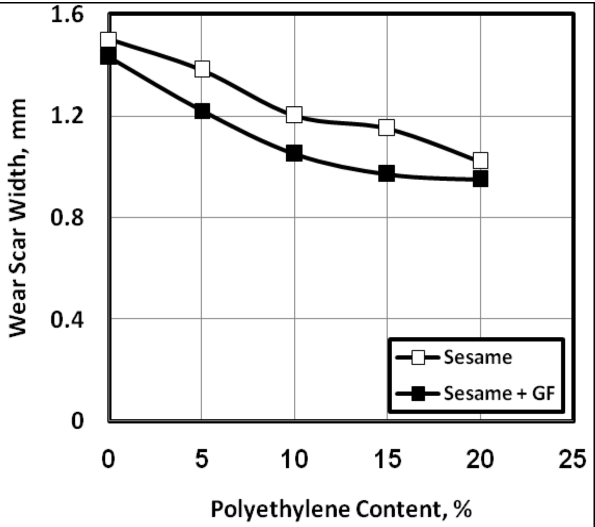
Fig. 10 Friction coefficient displayed by abrasion of polyester composites filled by sesame oil.	**Fig. 11 Wear of polyester composites filled by sesame oil.**

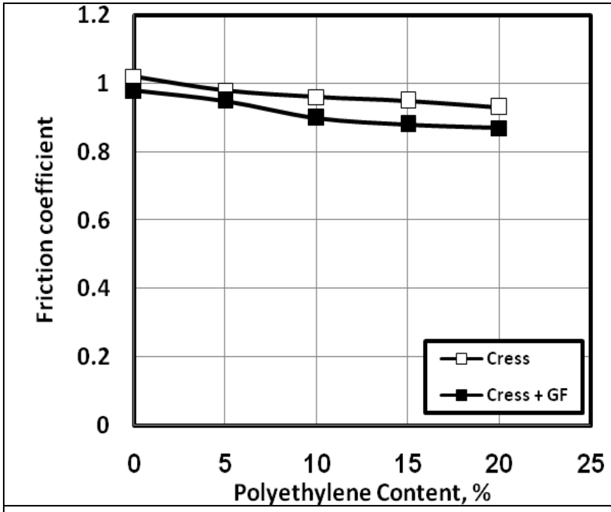	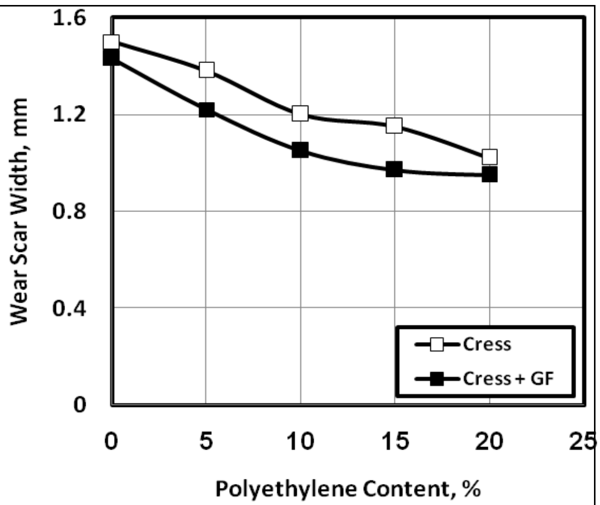
Fig. 12 Friction coefficient displayed by abrasion of polyester composites filled by cress oil.	**Fig. 13 Wear of polyester composites filled by cress oil.**

Based on the lubrication mechanisms of vegetable oils which depend on physical and chemical adsorption, where the baraka oil with its polar molecules, Fig. 14, showed a decreasing trend with increasing oil content. Wear of polyester composites, filled by baraka oil and sliding against steel surface, experienced relatively higher wear values than the other tested composites, Fig. 15, 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.

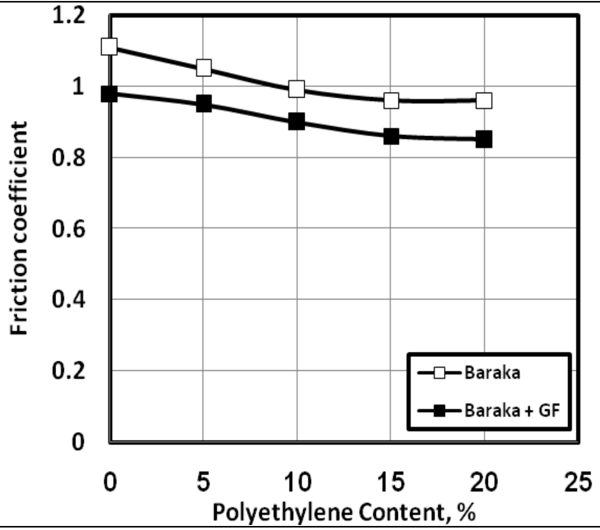

Fig. 14 Friction coefficient displayed by abrasion of polyester composites filled by baraka oil.

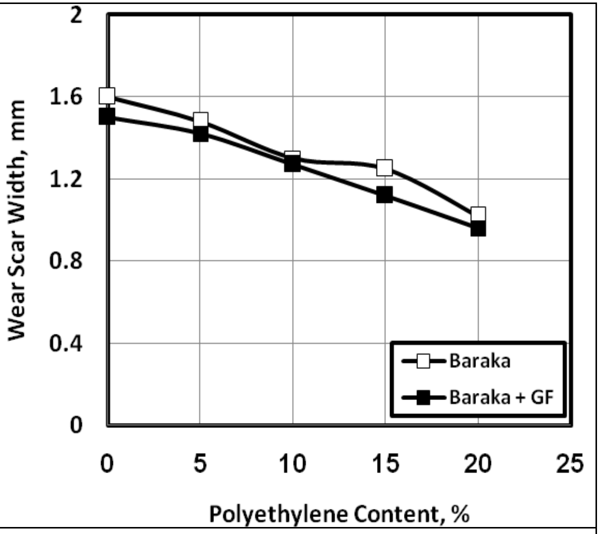

Fig. 15 Wear of polyester composites filled by baraka oil.

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.

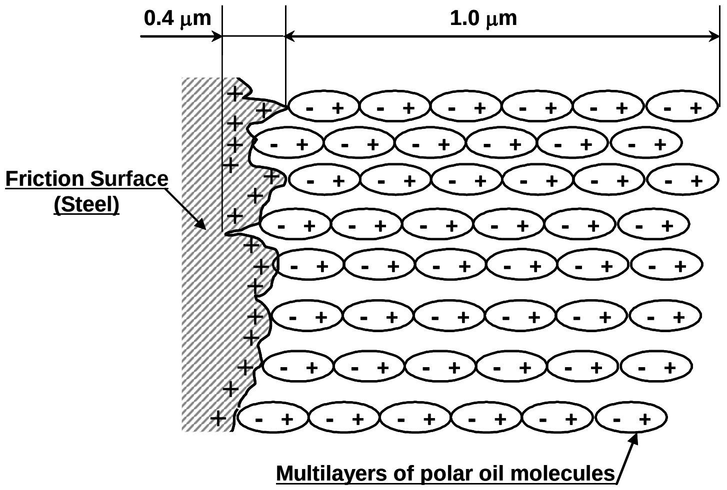

Fig. 16 The adherence of the molecules of the tested vegetable oils.

The mixed lubrication provided by the oil trapped inside the pores in the polyester matrix is primarily governed by the formation of a stable oil film on the sliding surfaces. Polar molecules of tested vegetable oils can significantly improve the wear resistance resulting from stronger adsorption on sliding surfaces. The long fatty acid chain and presence of polar groups in the vegetable oil structure recommends them to be used as boundary lubricants, Fig. 16. The polar molecules orient themselves with the polar end directed towards the metal surface making a close packed monomolecular or multimolecular layered structure resulting in a surface film believed to inhibit metal-to-metal contact and progression of pits and asperities on the sliding surfaces.

CONCLUSIONS

Within the limitations of the present work the followings can be concluded:

1. Increasing polyethylene fibres decreased friction and wear.
2. The highest friction and wear were displayed by composites free of oil.
3. Composites containing olive oil displayed higher friction and lower wear than that displayed by almond oil. This behaviour can confirm the higher wear protection due to the stronger surface interactions between the polar molecules and the sliding surfaces offered by olive oil.
4. 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.

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