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INFLUENCE OF MAGNETIC FIELD ON THE FRICTION AND WEAR CAUSED BY THE SCRATCH OF OIL LUBRICATED HIGH DENSITY POLYETHYLENE

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ABSTRACT
The present work discusses the influence of magnetic field on the friction and wear of polyethylene as bearing materials scratched by steel insert in the presence of different oil. Tests were carried out at oil lubricated surfaces. Paraffin, Fenugreek, Camphor, Cress, Olive, Almonds, Sesame, Aniseed and Habet El-Baraka oils were used as lubricants. The friction coefficient and wear of the tested composites were investigated using a tribometer designed and manufactured for that purpose.

It was found that, at no magnetic field, friction coefficient increased with increasing applied load. The maximum value of friction coefficient was displayed in the presence of paraffinic oil, while the minimum values were displayed by olive and Habet El Baraka oils. As the magnetic field of 0.2 mG flux intensity was applied on the sliding surface significant friction decrease was observed. The rank of the tested oils as friction reducer was Olive, Camphor, Aniseed, Habet El Baraka, Fenugreek, Cress, Sesame, Almond and Paraffin. Camphor oil was much influenced by the application of the magnetic field. Increasing the flux intensity of magnetic field to 0.3 mG was accompanied by further decrease of friction coefficient.

Wear of the polyethylene lubricated by the tested oil increased with increasing applied load. In the presence of Almonds oil on the sliding surfaces wear displayed the lowest values, while Olive oil displayed the highest wear. Application of the magnetic field significantly decreased wear. The best wear resistance was displayed by Aniseed and Fenugreek oils, while Paraffin and Almonds oils displayed the highest wear values.

KEYWORDS
Magnetic field, scratch, friction coefficient, wear, polyethylene, vegetables oils, paraffin oil.

INTRODUCTION
There is an increasing demand to investigate the friction and wear of the mechanical drives that performed under the effect of magnetic field. It was observed that, for sliding of steel pin against oil lubricated brass discs, magnetic field decreased friction coefficient

for all the tested oils, [1 - 3]. Dispersing oil by polyethylene (PE) particles significantly increased friction coefficient. A drastic reduction of friction coefficient was observed for olive, castor and almonds oils, when dispersing the tested oils by polyamide (PA) particles. Sliding of steel pin on oil lubricated aluminium disc caused significant friction increase for all the tested oils. Drastic friction reduction was observed for castor, almonds, jasmine and camomile oils when dispersed by PE particles. Dispersing vegetables oils by PA particles showed relatively lower friction coefficient for olive and castor oils, while corn, almonds, camomile and jasmine oils showed relatively higher friction values. Sliding of steel pin on oil lubricated steel disc showed the highest values of friction coefficient. Dispersing the tested oils by PE particles did not decrease friction coefficient. Jasmine oil displayed relatively lower friction than the other tested oils.

The effect of magnetic field on the friction coefficient displayed by sliding of steel pin against steel disc lubricated by paraffin oil and dispersed by different lubricants additives was investigated, [4]. The experiments showed that, friction coefficient increased as the magnetic field increased due to the increase of the normal load caused by the magnetic force. The performance of ZDDP and MoS_2 additives was not affected by the application of magnetic field. Besides, it was observed that magnetic field much affected the performance of oil dispersed by additives of electrical properties such as CMOC, DA and PTFE particles. The same trend of friction decrease was observed for PMMA particles dispersed in oil.

The tribological performance of polyethylene, as bearing materials sliding against steel considering that effect, was discussed, [5]. It was found that, application of magnetic field decreases friction coefficient at dry sliding due to its influence to decrease the adherence of polyethylene worn particles into the steel counter face. Besides, the magnetic field favors the formation of oxide film on the contact surface, where it plays a protective role in dry friction, modifies the friction and changes wear from severe wear to mild. Lubricating the steel surface by oils caused significant reduction in friction coefficient, where the maximum reduction was displayed by paraffin followed by glycerin, almond, jasmine, corn, castor, olive and sun flower oils. Besides, wear of polyethylene test specimens shows relative decrease in the presence of magnetic field. Castor, sun flower, corn and olive oils showed the highest wear resistance, while glycerin, jasmine, almond and paraffin oils showed the lowest wear resistance.

Based on the experimental observations, [6], it can be noticed that for abrasion of steel friction coefficient displayed the highest values at dry sliding. Olive oil displayed the lowest values of friction coefficient followed by castor oil, almonds, maize, chamomile and jasmine oil. It seems that 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. Application of magnetic field on the sliding surface caused significant friction reduction at dry sliding. This behaviour may be from the magnetization of the steel which is known to be accompanied by reduction of plasticity and increasing the brittleness. Besides, magnetic field enhanced

the ability of the oil molecules to orient themselves in relatively long chain adhered to the steel surface.

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, [7]. It was observed that wear resistance of lubricated surfaces can be significantly improved by the formation of a stable tribochemical film, [8, 9]. 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.

It is well known that a magnetic field affects polar molecules, which contain ionisable groups, by augmentation of the distance interactions and modification of the angles between bonds [10 - 12]. The observed changes in the properties of polymers are attributed to the catalytic effect of the magnetic field on the molecules. Thus, the macromolecular compounds obtained by magnetic field present higher molecular weights as compared to their homologues synthesized in the absence of the field. Thus, the utilization of continuous external magnetic fields during the reaction can lead to an improvement in some properties of the synthesized macromolecular compounds [13, 14]. These include very low conductivity, transparency and low elastic modulus. These, added to the basic importance of the magnetic molecular materials, justify the interest in their potential usefulness, and consequently they have received much attention in recent years. Modifications in the relaxation phenomena of the macromolecular compounds synthesized in the magnetic field, owing to the changes in the orientation and the mobility of the polar polymers, have also been shown. The displacements in the peaks of relaxation of dielectric losses, characteristic of weak polar polymers obtained in a magnetic field, appear especially at high temperature. Some studies mentioned the magnetic field action on the modification of the dielectric and mechanical properties of polymers as well as on the conductivity of polymers with included paramagnetic centers.

The presence of a magnetic field around the ferromagnetic steel couple in sliding contact modifies considerably its tribological behaviour with an important decrease in the wear rate [15 - 22]. Applied magnetic field around the rotating sliding ferromagnetic steel/steel modifies the friction and the wear behaviour of the contact, [23]. When a magnetic field is applied, the contact in ambient air progressively became black, covered by a brittle thick black layer of oxides which leads to a low friction and a low wear mode. The application of a magnetic field can induce many effects on mechanical, physical and chemical phenomena of ferromagnetic materials, such as the magnetostriction (interaction between the stress field and the magnetic field), the chemical catalysis of the surface oxidation by applied magnetic field. The friction and wear behaviour of a nickel/steel couple was studied and analyzed in the presence and absence of a direct current magnetic field, [24]. A magnetic field was applied to the nickel pin and remained constant during each test. It was found that the application of a magnetic field increased the friction coefficient and microhardness of the sliding surface and decreased the wear rate. The sliding surface was filled with thin, black particles.

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, [25]. 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, [26]. 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.

In the present work, the effect of magnetic field on the friction coefficient caused by the scratch of polyethylene under dry and lubricated working conditions is investigated.

EXPERIMENTAL

The test rig, 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 is shown in Fig. 1. The stylus, used in experiments, was a square insert (12 × 12 mm) of TiC of tip radius of 0.1 mm and hardness of 2800 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 tested surface was ground by an emery paper (500 grade) before testing.

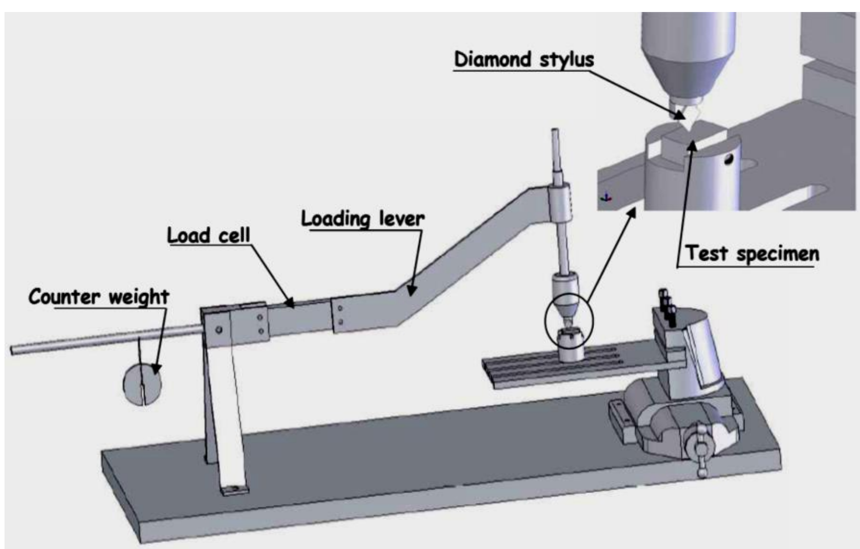

Fig. 1 Arrangement of the test rig.

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 2, 4, 6, 8 and 10 N. All measurements were performed at 28 ± 2 º C and 50 ± 10 % humidity.

Scratch testing is a method of mechanically testing a specimen surface. In this method, a hard scratching element (steel insert) is used to generate a groove in the specimen surface. The scratching action may, or may not, be accompanied by the formation of a chip or particles. The general objectives of performing scratch tests in materials research and testing are to clarify the mechanisms of deformation and/or material removal, evaluate or rank materials relative to abrasion resistance, measure scratch hardness and evaluate the adhesion of a surface coating to a substrate.

At first the experiment was carried out without any oils (dry). Then the oils were applied under the effect of two values of magnetic flux intensity (0.2, 0.3 mG). They will be referred in the text as M1 and M2 respectively. The condition of no magnetic field will be referred as M0. At the end of experiment the wear scar width was measured using room tool microscope.

INTRODUCTION

Abrasive wear without magnetic fields was transformed, in the presence of magnetic field, to fracture due to the shift of shear stress to the subsurface region. Also, a decrease in wear, a lower friction coefficient, increase in hardness of magnetised steel surface and a rise in temperature of rubbing surfaces were observed. In magnetic fields, strongly oxidised wear particles will pose a serious problem for the contact due to the paramagnetism of oxygen. Accelerated oxidation does affect not only wear particles but also contacting surfaces. More specifically, highly oxidised wear particles, affected by magnetic force operating between contacting surfaces, act both as abrasive and as lubricating agents depending on their conditions.

It was observed that, for sliding of steel pin against oil lubricated brass discs, magnetic field decreased friction coefficient for all the tested oils, [7]. Dispersing oil by polyethylene (PE) particles significantly increased friction coefficient. A drastic reduction of friction coefficient was observed for olive, castor and almonds oils, when dispersing the tested oils by polyamide (PA) particles. Sliding of steel pin on oil lubricated aluminium disc caused significant friction increase for all the tested oils. Drastic friction reduction was observed for castor, almonds, jasmine and camomile oils when dispersed by PE particles. Dispersing vegetables oils by PA particles showed relatively lower friction coefficient for olive and castor oils, while corn, almonds, camomile and jasmine oils showed relatively higher friction values. Sliding of steel pin on oil lubricated steel disc showed the highest values of friction coefficient. Dispersing the tested oils by PE particles did not decrease friction coefficient. Jasmine oil displayed relatively lower friction than the other tested oils.

The effect of magnetic field on the friction coefficient displayed by sliding of steel pin against steel disc lubricated by paraffin oil and dispersed by different lubricants additives was investigated, [8]. The experiments showed that, friction coefficient increased as the magnetic field increased due to the increase of the normal load caused by the magnetic force. The performance of ZDDP and Mo S_2 additives was not affected by the application of magnetic field. Besides, it was observed that magnetic field much affected the performance of oil dispersed by additives of electrical properties such as CMOC, DA and PTFE particles. The same trend of friction decrease was observed for PMMA particles dispersed in oil.

RESULTS AND DISCUSSION

At no magnetic field, it was noticed that lubricating sliding surfaces by the tested lubricating oils significantly decreased friction coefficient, Figs. 2 and 3. Generally, friction coefficient increased with increasing applied load. The maximum value of friction coefficient (1.35) was displayed in the presence of paraffinic oil, while the minimum values were displayed by olive and Habet El Baraka oils. It is supposed that an electric static charge would be formed on the contact surfaces where equal and opposite charges were always produced. The electric charge was responsible for the strong adhesion of polyethylene into the surface of the steel insert. The observed friction decrease could be caused by the response of the molecules of the tested oil to influence of the electric static charge and consequently altered the adhesion of polyethylene to the insert surface. The rank of the tested oils as friction modifier was Olive, Habet El Baraka, Aniseed, Camphor, Fenugreek, Sesame, Almonds, Cress and Paraffin oils.

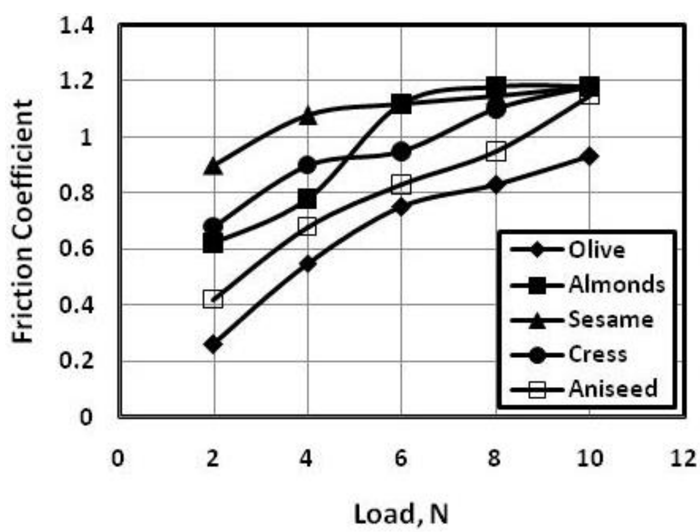

Fig. 2 Friction coefficient displayed by the tested oils lubricated polyethylene at no magnetic field.

Application of magnetic field of 0.2 mG flux intensity on the sliding surface caused significant friction decrease, Figs. 4 and 5. The maximum values of friction coefficient decreased from 1.35 at no magnetic field to 1.2 when magnetic field was applied. The rank of the tested oils as friction reducer was Olive, Camphor, Aniseed, Habet El Baraka, Fenugreek, Cress, Sesame, Almond and Paraffin. Camphor oil was much

influenced by the application of the magnetic field. The friction decrease might be attributed to the influence of the magnetic field which altered the electric static charge and consequently decreased the adhesion of polyethylene to the insert surface.

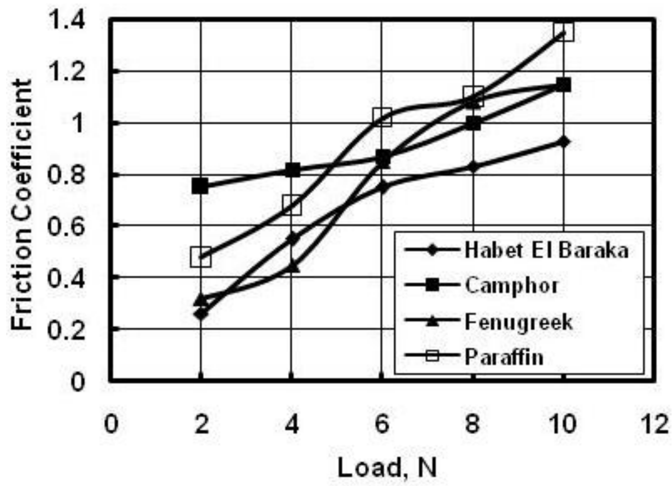

Fig. 3 Friction coefficient displayed by the tested oils lubricated polyethylene at no magnetic field.

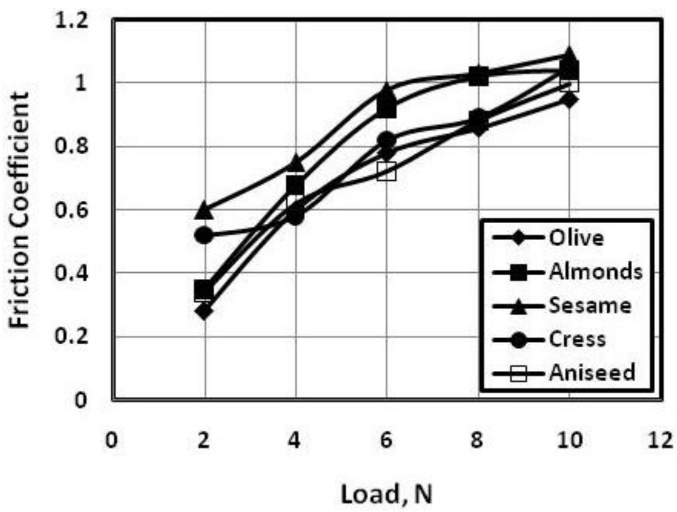

Fig. 4 Friction coefficient displayed by the tested oils lubricated polyethylene at magnetic field of 0.2 mG flux intensity.

As the flux intensity of magnetic field increased to 0.3 mG further decrease of friction coefficient was observed, Figs. 6 and 7. At 10 N normal load, the values of friction coefficient were 0.86, 0.92, 0.98, 0.99, 1.0, 1.01, 1.02, 1.03 and 1.04 displayed by Aniseed, Camphor, Fenugreek, Habet El Baraka, Almonds, Cress, Paraffin, Sesame and Olive respectively. It is clearly seen that the magnetic field accelerated the reorientation of the oil molecules to be strongly adhered to the surfaces of steel insert and polyethylene. It seems that as the thickness of the oil on the sliding surfaces increased friction decreased.

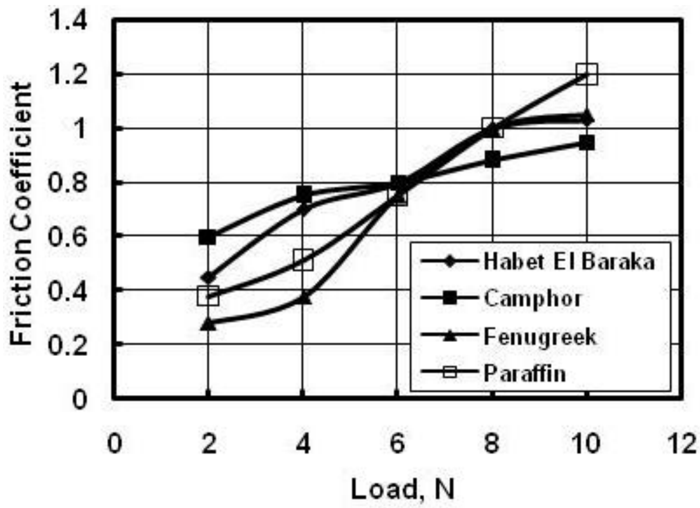

Fig. 5 Friction coefficient displayed by the tested oils lubricated polyethylene at magnetic field of 0.2 mG flux intensity.

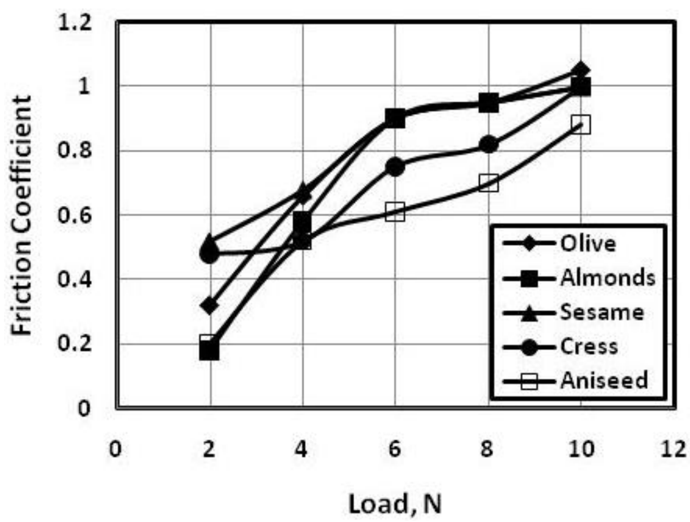

Fig. 6 Friction coefficient displayed by the tested oils lubricated polyethylene at magnetic field of 0.3 mG flux intensity.

Wear of polyethylene test specimens measured in scar width displayed by the steel insert at oil lubricated sliding at no magnetic field is shown in Figs. 8 and 9. Generally wear increased with increasing applied load. In the presence of Almonds oil on the sliding surfaces wear displayed the lowest values, while Olive oil displayed the highest wear. It seems that polar molecules of Almonds oriented themselves with the polar end directed towards the sliding surface making a close packed multimolecular layered surface film that could protect the sliding surfaces from the abrasion of the cutting edge of the insert into the surface of polyethylene.

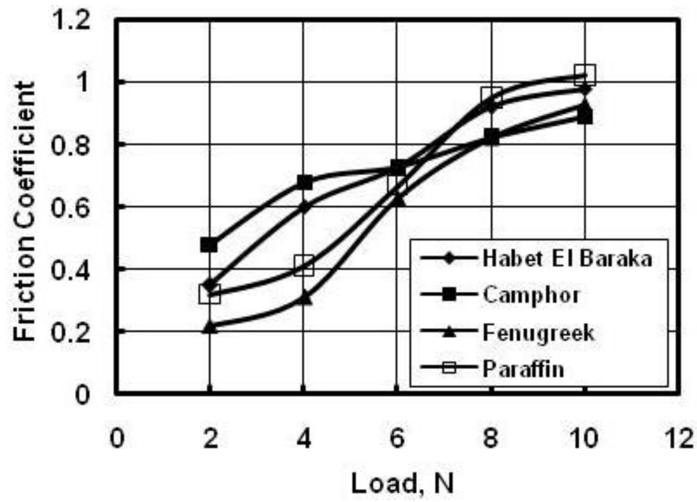

Fig. 7 Friction coefficient displayed by the tested oils lubricated polyethylene at magnetic field of 0.3 mG flux intensity.

Application of the magnetic field of 0.2 mG intensity, Figs. 10 and 11, decreased wear. The best wear resistance was displayed by Aniseed and Fenugreek oils, while Paraffin and Almonds oils displayed the highest wear values. At 10 N load, the maximum wear scar width at no field was 0.58 mm, while at magnetic field of 0.2 mG field intensity the highest wear was 0.49.

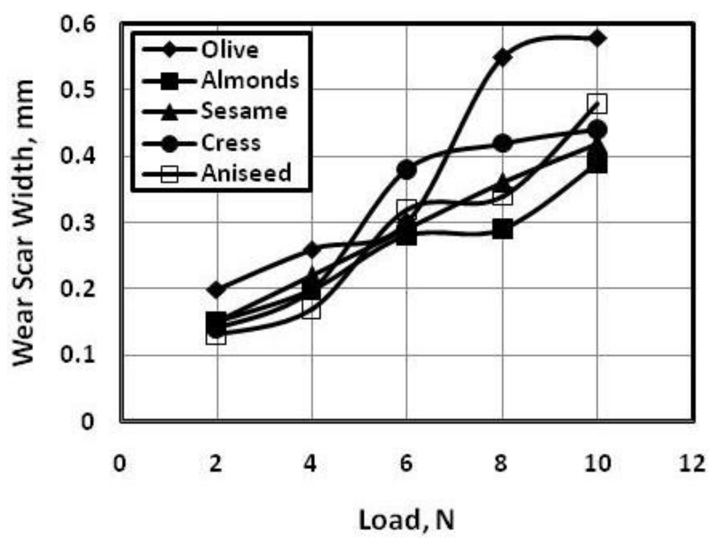

Fig. 8 Wear of oil lubricated polyethylene at no magnetic field.

Further wear decrease was observed as the flux intensity increased to 0.3 mG. The best performance was performed by Fenygreek oil, Fig. 12 and 13. It is clearly illustrated that wear significantly decreased compared to the condition of no magnetic field applied.

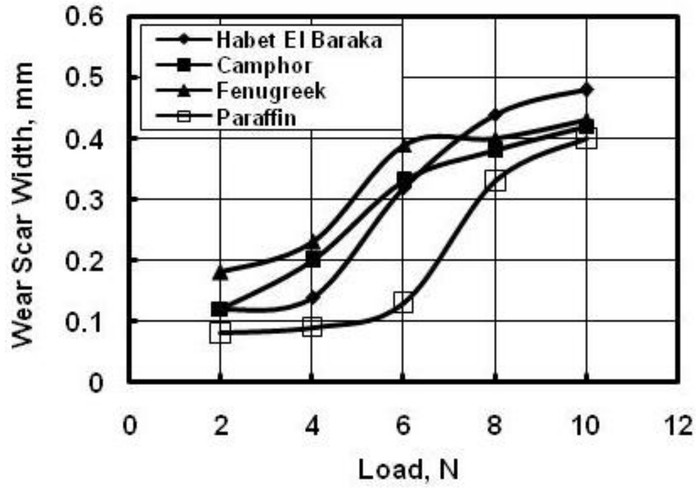

Fig. 9 Wear of oil lubricated polyethylene at no magnetic field.

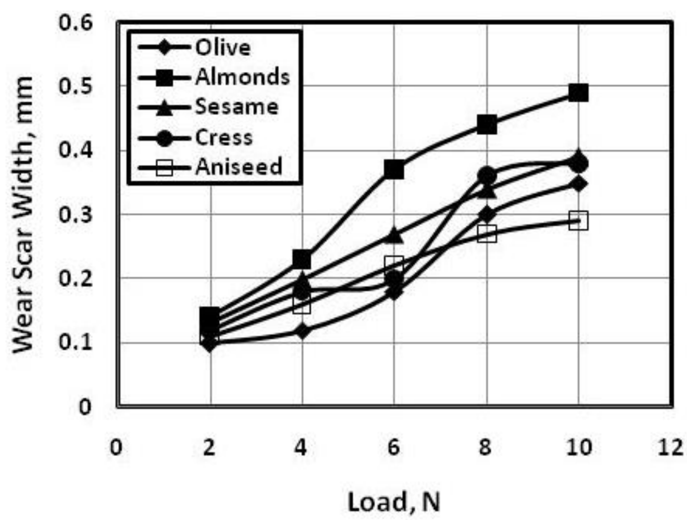

Fig. 10 Wear of oil lubricated polyethylene at magnetic field of 0.2 mG flux intensity.

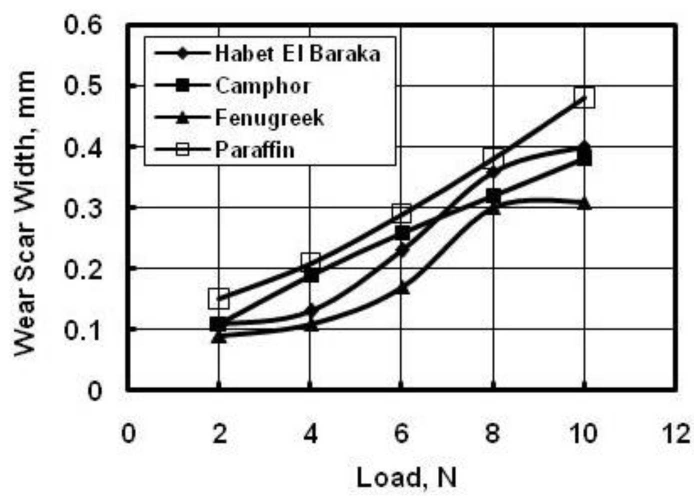

Fig. 11 Wear of oil lubricated polyethylene at magnetic field of 0.2 mG flux intensity.

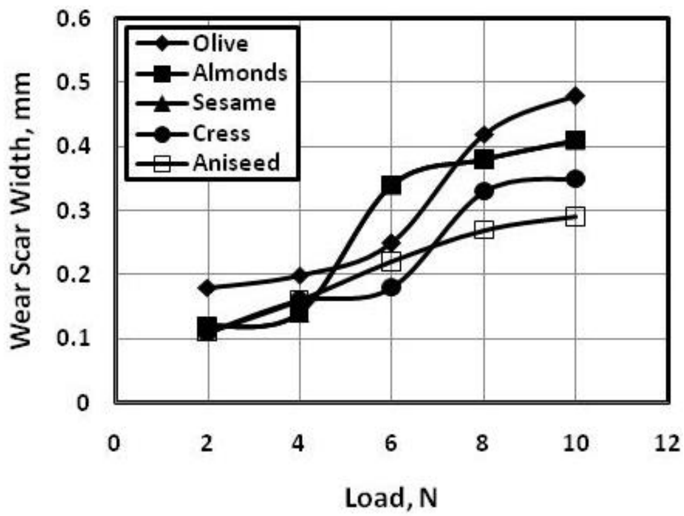

Fig. 12 Wear of oil lubricated polyethylene at magnetic field of 0.3 mG flux intensity.

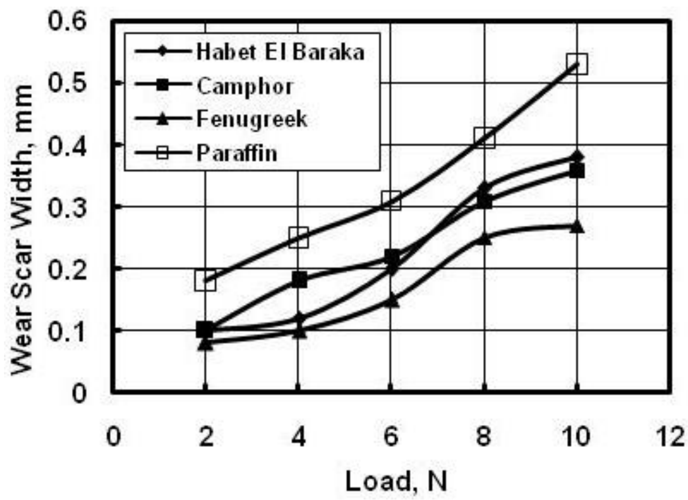

Fig. 13 Wear of oil lubricated polyethylene at magnetic field of 0.3 mG flux intensity.

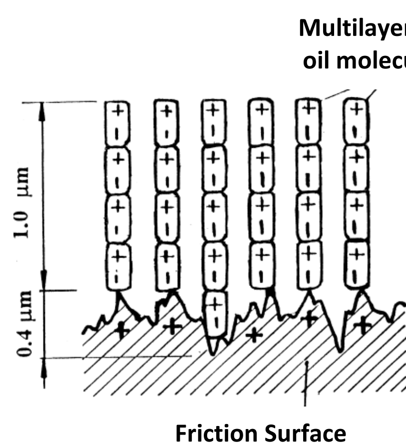

Fig. 14 The adherence of the molecules of the tested vegetable oils into the friction surface.

The enhancement in wear resistance may be from the action of the magnetic field which increased the adherence of polyethylene particles into the cutting edges of the steel insert. The mixed lubrication provided by the polar oils is primarily governed by the formation of a stable oil film on the sliding surfaces. Polar molecules of tested oils could significantly improve the wear resistance resulting from stronger adsorption on sliding surfaces. The long fatty acid chain and presence of polar groups in the oil structure recommended them to be used as boundary lubricants.

The variation of friction coefficient and wear might be attributed to the ability of the tested oils to form multilayer of the oil polar molecules on the steel surface. The mixed lubrication provided by the tested oil is primarily governed by the formation of a stable oil film on the sliding surfaces. Polar molecules of the tested oils can significantly improve the wear resistance resulting from their adsorption on the sliding surfaces. The long fatty acid chain and presence of polar groups in the tested oil structure recommend them to be used as boundary lubricants, Fig. 14. 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

1. At no magnetic field, friction coefficient increased with increasing applied load. The maximum value of friction coefficient was displayed in the presence of paraffinic oil, while the minimum values were displayed by olive and Habet El Baraka oils.
2. Application of magnetic field of 0.2 mG flux intensity on the sliding surface caused significant friction decrease. The rank of the tested oils as friction reducer was Olive, Camphor, Aniseed, Habet El Baraka, Fenugreek, Cress, Sesame, Almond and Paraffin. Camphor oil was much influenced by the application of the magnetic field. As the flux intensity of magnetic field increased to 0.3 mG further decrease of friction coefficient was observed.
3. Wear increased with increasing applied load. In the presence of Almonds oil on the sliding surfaces wear displayed the lowest values, while Olive oil displayed the highest wear.
4. Application of the magnetic field decreased wear. The best wear resistance was displayed by Aniseed and Fenugreek oils, while Paraffin and Almonds oils displayed the highest wear values.

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