

Effect of Magnetic Field on the Friction and Wear of Polyamide Sliding against Steel

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Received November 23rd, 2013; revised December 22nd, 2013; accepted January 7th, 2014

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ABSTRACT

The present work discusses the friction and wear of polyamide sliding against steel in the presence of magnetic field. Tests were carried out at dry and oil lubricated steel surfaces. Paraffin and vegetable oils such as almond, castor, corn, glycerine, jasmine, olive and sun flower oils were used as lubricants. The friction coefficient and wear were investigated using pin on disc wear tester. Based on the experimental results, it was found that application of magnetic field on the contact area affected both friction coefficient and wear of polyamide sliding against steel at dry and oil lubricated conditions. Magnetic field decreased friction coefficient. Lubricating the sliding surface by paraffin oil as well as almond, castor, corn, glycerine, jasmine, olive and sun flower oils significantly decreased friction coefficient. Generally, friction coefficient increased with increasing applied load. Dry sliding of polyamide against steel surface showed increased wear with increasing load. The lowest wear values at no magnetic field were displayed by jasmine oil followed by sun flower, almond, olive, castor, corn, glycerine and paraffin oils. Under the application of magnetic field, the lowest wear values were displayed by sun flower oil followed by jasmine, castor, glycerine, olive, paraffin, almond and corn oils. It can be concluded that friction and wear decrease observed at dry sliding can be explained on the basis that presence of magnetic field around the contact area decreased the adherence and transfer of polyamide into the steel surface. For oil lubricated sliding, the polar molecules of the tested lubricating oils were much affected by the magnetic field, where they oriented themselves to the polar end directed towards the sliding surface making a close packed multi-molecular layered surface film that could protect the sliding surfaces from excessive wear.

KEYWORDS

Friction; Wear; Magnetic Field; Polyamide; Steel; Paraffin Oil; Vegetables Oils

1. Introduction

In electronic appliances, the mechanical drives perform under the effect of magnetic field. It is necessary to investigate the tribological performance of sliding bearings which are probably made of polyamide considering that effect. It was found that when electric voltage was applied on the sliding steel surfaces friction coefficient and wear decreased with voltage increasing [1]. Addition of polymeric particles into oil caused significant friction increase in the presence of applied voltage, while wear significantly decreased. Influence of magnetic field on

the friction and wear of polyamide as bearing materials scratched by steel insert in the presence of different oil was discussed [2]. Tests were carried out at oil lubricated surfaces. Paraffin, fenugreek, camphor, cress, olive, almonds, sesame, aniseed and El-Baraka Seed 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. Besides, the influence of magnetic field on the friction coefficient displayed by the sliding of steel pin on aluminium, polyamide and steel discs lubricated by paraffin oil and dispersed by different lubricant additives such as zinc

dialkyldithiophosphates, molybdenum disulphide, heteropolar organic based additive, graphite, polytetrafluoroethylene and polymethyl methacrylate, detergent additive (calcium sulphonate), was investigated [3,4]. Aluminium was used as friction counterface to reduce the magnetic force acting on the contact surfaces when the magnetic field was applied. The tribological performance of polyamide, 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 polyamide 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. Based on the experimental observations [6,7], 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 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 [8-10]. 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 in a 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 [11,12]. Friction of polymers is accompanied by electrification. The basic mechanism of solid triboelectrification implies processes, which can be described in terms of surface conditions. During frictional interaction, chemical and physicochemical transformations in polymers promote increases in the surface and bulk states density [13]. Ionization and relaxation of those states lead to electric fields of the surface and bulk charges. Electrification in friction is a common feature, which can be observed with any mode of friction, and with any combination of contacting surfaces.

The potential difference generated by the friction of polymeric coatings against steel counterface has been measured. The effect of sliding velocity and load on the generation of electric charge on the friction surface has been investigated [14]. The results indicate that, at dry sliding condition, the potential generated from friction increases rapidly with increasing both of sliding velocity and load at certain values then decreases due to the rise of temperature which causes molecular motion and reorientation of the dipole groups in the friction direction and

leads to the relaxation of space charges injected during friction. Presence of water or oil on the friction surface reduces the potential difference while filling the coatings by graphite increases that potential.

The rubbing process breaks up the polymer surface and liberates free radicals and ion radicals [15]. These are highly reactive and react with oxygen dissolved in the lubricant. They are immediately transformed to peroxide and these react with the metal surface to form oxide films. 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 [16-23]. Applied magnetic field around the rotating sliding ferromagnetic steel/steel modifies the friction and the wear behaviour of the contact [24]. 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 friction and wear behaviour of a nickel/steel couple was studied and analyzed in the presence and absence of a direct current magnetic field [25]. 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 [26]. 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 consist of a considerable amount of fatty acids with unsaturated bonds [27]. Vegetable oils are renewable resources, environmentally friendly non-toxic fluids, biodegradable and have no health hazards. The triacylglycerol structure of vegetable oil makes it an excellent candidate for potential use as a base stock for lubricants and functional fluids [28]. It was observed that wear resistance of lubricated surfaces can be significantly improved by the formation of a stable tribochemical film [29]. 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 magnetic field is on the friction and wear of polyamide sliding which is against steel counterface under dry and lubricated working conditions. Paraffin and vegetable oils such as corn, sun flower, glycerine, olive, jasmine, almond and castor

oils were used as lubricant.

2. Experimental

Experiments were carried out under laboratory conditions ($25^{\circ}\text{C} \pm 5^{\circ}\text{C}$ and $30\% \pm 10\%$ humidity) 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 **Figure 1**. The test specimen is held in the specimen holder that fastened to the loading lever. Through load cell, where strain gauges are adhered, friction force can be measured. Friction coefficient was determined through the friction force measured by the load cell. The load is applied by weights. The counterface in form of a steel disc, of 100 mm outer diameter, was fastened to the rotating disc. The radius of the contact track on the rotating disc was 75 mm. Its surface roughness was about $3.2 \mu\text{m}$, R_a . Test specimens of polyamide (PA 6) were prepared in the form of cylindrical pins of 6 mm diameter and 30 mm long. The two ends of the test specimens were polished before the test by cotton textile. The test specimens were loaded against counterface of carbon steel disc (1.16% C, 0.91% Si, 1.65% Mn, 0.52% Cr and 95.5% Fe) of 2720 N/mm^2 hardness. Friction and wear tests were carried out under constant sliding velocity of 2.0 m/s and 10 N applied load. Every experiment lasted 300 seconds. Wear was measured by the difference between the weights of test specimens before and after test using an electronic balance of $\pm 0.1 \text{ mg}$ accuracy.

A magnetic field was applied using an alternative cur-

rent applied to a coil located above the test specimens and delivered a field intensity of 10 kA/m. In the present work, experiments carried out with and without magnetic field will be referred in this text as MF and M0 respectively.

3. Results and Discussion

The results of the friction coefficient are discussed in **Figures 2-9**. Friction coefficient displayed by dry sliding of polyamide against steel is shown in **Figure 2**. Presence of magnetic field decreased the friction coefficient relative to the condition without magnetic field. It seems that the magnetic field reduced the possibility of polyamide worn particles to adhere into the steel surface, so that friction coefficient decreased.

Lubricating the sliding surface by paraffin oil significantly decreased friction coefficient, **Figure 3**. Generally, friction coefficient increases with increasing applied load. The paraffinic molecules are approximately linear and consequently they are more effective than other hydrocarbons in preventing solid contact. This allows for the formation and persistence of a relatively thicker film. Since the molecules are polar the opposite ends are attracted to form pairs of molecules which are subsequently incorporated into the viscous surface layer. Influence of magnetic field on the friction displayed by sliding surfaces lubricated by corn oil was lower than that shown for paraffin oil, **Figure 4**. It seems that the possibility of formation of multi-layers of corn oil on the sliding surface is not much affected by the magnetic field.

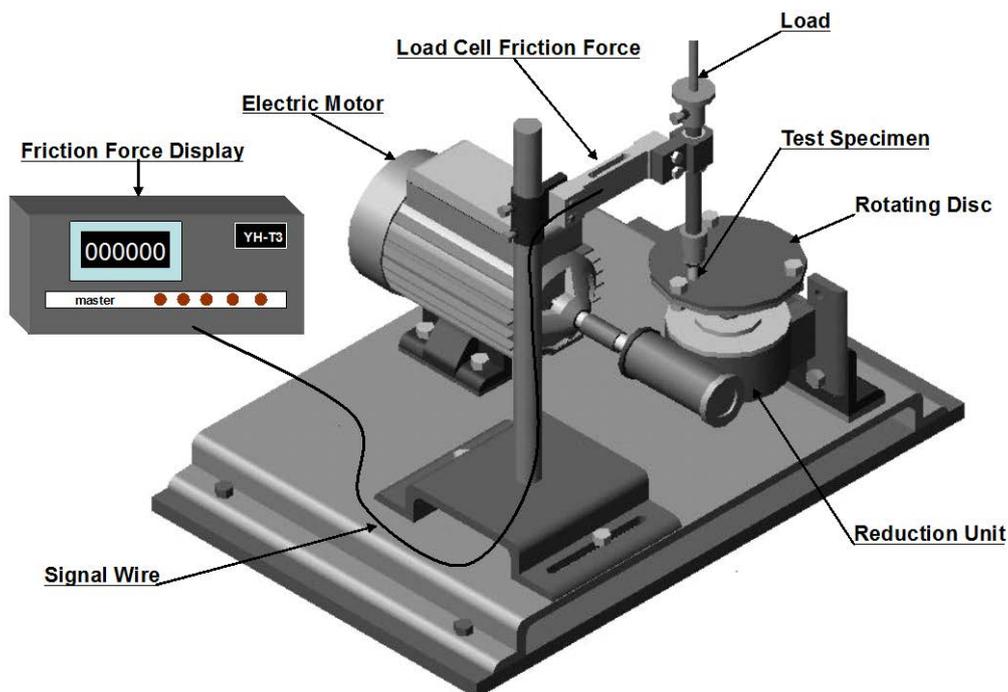


Figure 1. Arrangement of the test rig.

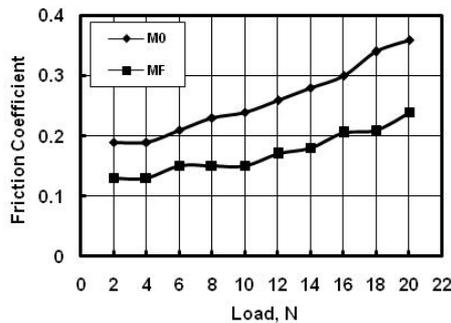


Figure 2. Friction coefficient displayed by dry sliding of polyamide against steel.

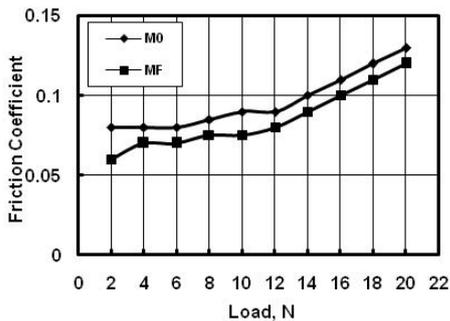


Figure 3. Friction coefficient displayed by sliding of polyamide against paraffin oil lubricated steel.

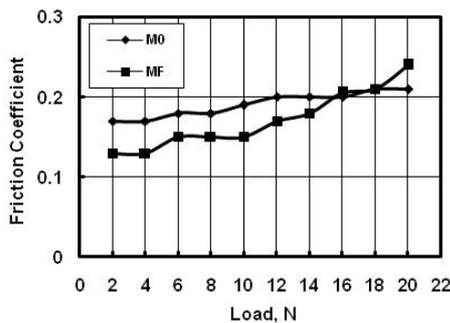


Figure 4. Friction coefficient displayed by sliding of polyamide against corn oil lubricated steel.

Friction coefficient displayed by the sliding of polyamide against sun flower oil lubricated steel is shown in **Figure 5**. Friction coefficient represented relatively lower values than paraffin and corn oils when magnetic field was applied. Friction decrease caused by the influence of the magnetic field was 30%. Glycerine oil lubricating the sliding surfaces showed the lowest friction coefficient under the influence of the magnetic field, **Figure 6**, where the friction decrease approximated 8%. The values of friction coefficient were 0.06 and 0.12 at loads of 2 and 20 N respectively. It seems that the electrolyte properties of glycerine oil are responsible for that behaviour. The polar molecules orient themselves with the polar end directed towards the sliding surface making a close packed multi-molecular layered structure resulting in a surface

film believed to inhibit metal-to-metal contact and progression of pits and asperities on the sliding surfaces.

Friction coefficient displayed by sliding of polyamide against olive oil lubricated steel is shown in **Figure 7**. The maximum friction decrease caused by magnetic field was 33%. Jasmine oil lubricating steel surface showed the lowest friction values with and without magnetic field, **Figure 8**, where the relative friction decrease was 27%. The values of friction coefficient were 0.05 and 0.08 at loads of 2 and 20 N respectively. Almond oil was significantly influenced by the application of the magnetic field, **Figure 9**. The quite good friction decrease observed for the sun flower, olive and glycerine oils was shown for almond oil. Application of magnetic field de-

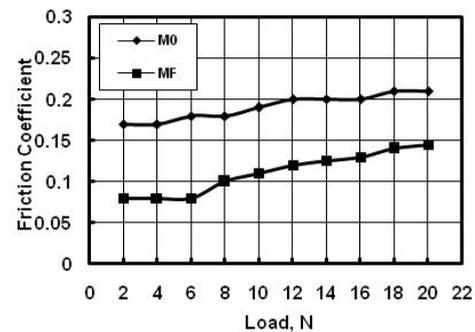


Figure 5. Friction coefficient displayed by sliding of polyamide against Sun Flower oil lubricated steel.

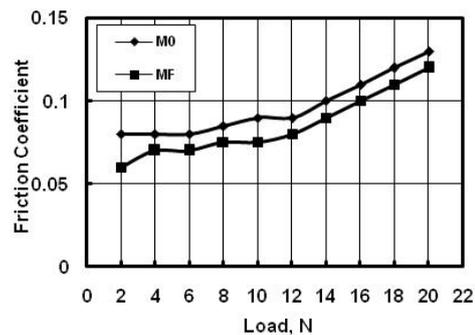


Figure 6. Friction coefficient displayed by sliding of polyamide against glycerine oil lubricated steel.

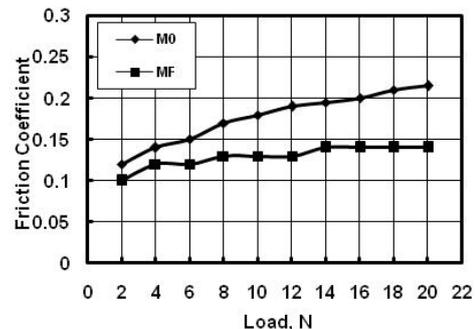


Figure 7. Friction coefficient displayed by sliding of polyamide against olive oil lubricated steel.

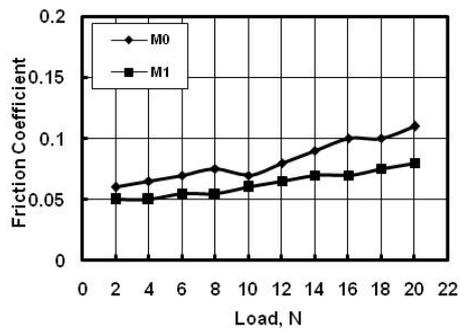


Figure 8. Friction coefficient displayed by sliding of polyamide against jasmine oil lubricated steel.

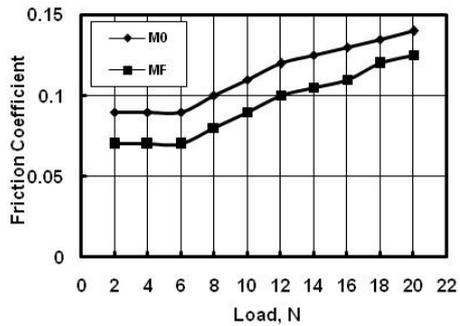


Figure 9. Friction coefficient displayed by sliding of polyamide against almond oil lubricated steel.

creased friction coefficient by about 11%. The long fatty acid chain and presence of polar groups in almond oil structure resulted in a surface film able to inhibit metal-to-metal contact.

Castor oil was slightly influenced by magnetic field, **Figure 10**, where friction coefficient decreased as a result of application of magnetic field. The relative friction decrease was 5% at 20 N load. Based on the experimental observations it seems that magnetic field involved a greater reactivity of surfaces with the lubricant. In addition to the triboelectrification, the charged oil molecules can interact with each other, due to the direct effect of the magnetic field, and form multilayer film adhering to the sliding surface effectively, **Figure 11**. In addition to that, magnetic field induces an interfacial polarization on the particle owing to a mismatch of the dielectric constant between the particle and the oil, and the polarization thus induced on the particle plays a role to form a chainlike structure along the electric field, leading to an increase in the viscosity of the suspension.

Wear of polyamide is shown in **Figures 12-20**. Dry sliding of polyamide against steel surface showed increased wear with increasing load, **Figure 12**. Wear decreased in presence of magnetic field, where wear decrease was 25%. Wear decrease can be explained on the basis that presence of magnetic field around the contact area decreased the adherence and transfer of polyamide into the steel surface. Sliding of polyamide against steel

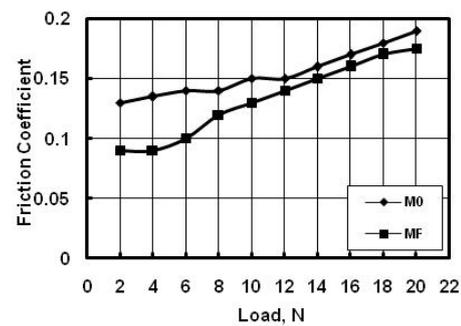


Figure 10. Friction coefficient displayed by sliding of polyamide against castor oil lubricated steel.

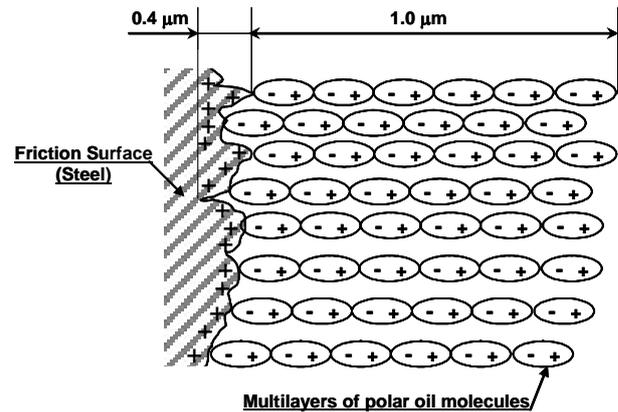


Figure 11. Multilayer oil molecules adhering to the sliding surface.

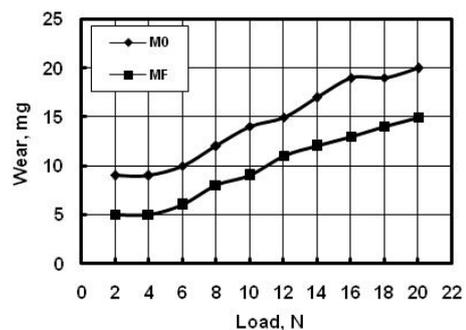


Figure 12. Wear displayed by dry sliding of polyamide against steel.

charged the contact surfaces so that they could interact with each other due to the direct electrostatic forces. Since these forces are strong and effective, they contribute a major part of the adhesion force. It is well known that the magnetic field affects polar molecules, which contain ionisable groups. The observed changes in the tribological properties of polyamide are attributed to the catalytic effect of the magnetic field on the molecules. The ability of polyamide to affect friction and wear depends on its adherence to the steel surface. The friction of polyamide against steel surface generates electric static charge on both the surfaces of polyamide and steel. The friction of

PA generate positive electric charge, while steel surface gains negative charge.

Wear displayed by sliding of polyamide against paraffin oil lubricated steel is shown in **Figure 13**. Application of magnetic field decreased wear by about 43%. It seems that the bond between the oil film and the sliding surface was strong enough to resist asperities interaction and polyamide transfer into steel. The influence of magnetic field on corn oil lubricated steel is clearly shown in **Figure 14**, where the relative wear reduction was 33%. This behavior can be explained on the basis that polar molecules of paraffin and corn oil were much affected by the magnetic field, where they oriented themselves with the polar end directed towards the sliding surface making a close packed multi-molecular layered surface film that could protect the sliding surfaces from excessive wear.

Wear displayed by sliding of polyamide against sun flower oil lubricated steel is shown in **Figure 15**. Wear under application of the magnetic field showed slight increase with increasing applied load. In the presence of glycerine oil, polyamide surface showed good wear resistance, **Figure 16**. The relative wear decrease caused by the magnetic field was 57%. It seems that magnetic field modified the dielectric properties of polymers so that wear resistance increased.

Olive oil lubricating steel surface shows relatively lower wear under application of magnetic field, **Figure 17**. The strong adhesion of oil layers into the sliding sur-

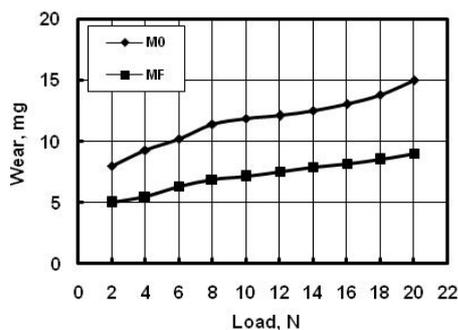


Figure 13. Wear displayed by sliding of polyamide against paraffin oil lubricated steel.

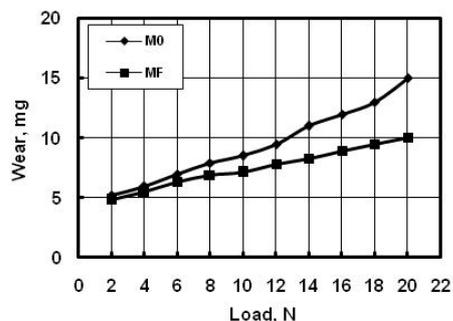


Figure 14. Wear displayed by sliding of polyamide against corn oil lubricated steel.

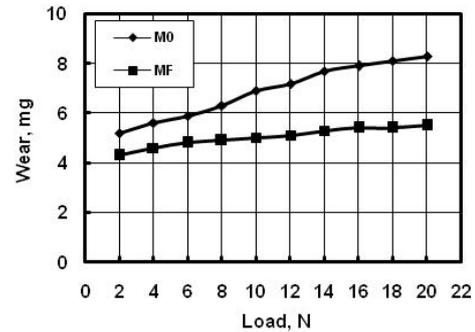


Figure 15. Wear displayed by sliding of polyamide against sun flower oil lubricated steel.

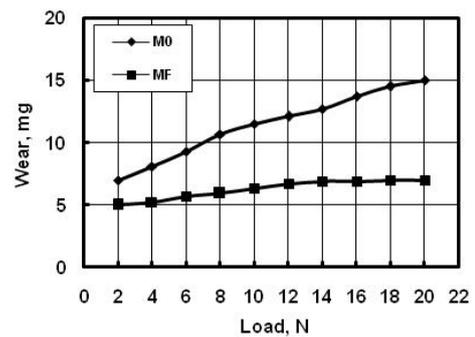


Figure 16. Wear displayed by sliding of polyamide against glycerine oil lubricated steel.

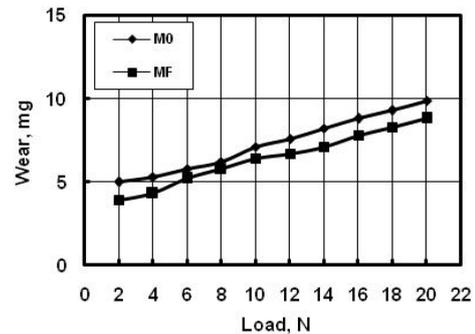


Figure 17. Wear displayed by sliding of polyamide against olive oil lubricated steel.

faces was accelerated by the magnetic field in a manner that wear of polyamide decreased. Wear displayed by sliding of polyamide against jasmine oil lubricated steel showed relative decrease of wear of 23%. The relative low wear values observed under application of magnetic field confirmed the surface protection provided by jasmine oil.

Wear displayed by sliding of polyamide against almond oil lubricated steel is shown in **Figure 19**. As the load increased wear increased indicating that wear resistance of surfaces lubricated by almond oil was influenced by the applied load. Wear displayed by sliding of polyamide against castor oil lubricated steel is shown in **Figure 20**. Under magnetic field, wear showed slight in-

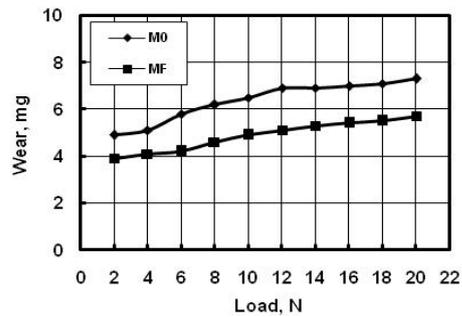


Figure 18. Wear displayed by sliding of polyamide against jasmine oil lubricated steel.

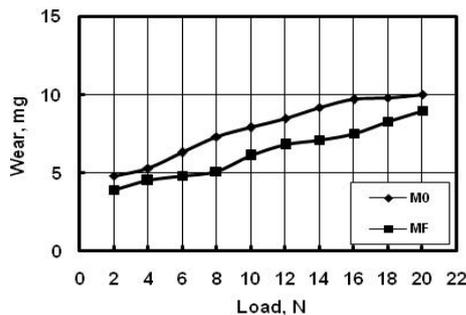


Figure 19. Wear displayed by sliding of polyamide against almond oil lubricated steel.

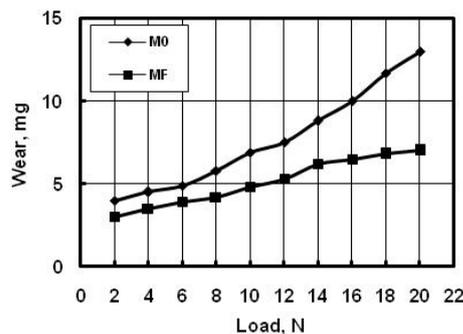


Figure 20. wear displayed by sliding of polyamide against castor oil lubricated steel.

crease with increasing applied load. The wear resistance offered by castor oil is the best among the tested oils in the present work. The mixed lubrication provided by the oil trapped in the valleys of surface roughness was primarily governed by the formation of a stable oil film on the sliding surfaces. Polar molecules of tested vegetable oils could significantly improve wear resistance due to the strong adsorption on the sliding surfaces. The long fatty acid chain and presence of polar groups in the vegetable oil structure recommend them to be used as efficient lubricants.

4. Conclusions

1) At dry sliding of polyamide against steel, magnetic field decreased the friction coefficient.

2) Lubricating the sliding steel surfaces by paraffin oil as well as almond, castor, corn, glycerine, jasmine, olive and sun flower oils significantly decreased friction coefficient. Generally, friction coefficient increased with increasing applied load.

3) The lowest friction values at no magnetic field were displayed by jasmine oil followed by glycerine, paraffin, almond, castor, corn, sun flower and olive oils.

4) Under application of magnetic field, the lowest wear values were displayed by jasmine oil followed by glycerine, paraffin, almond, olive, sun flower, castor and corn oils.

5) Dry sliding of polyamide against steel surface showed increased wear with increasing load. Wear decreased in the presence of the magnetic field, where relative wear decrease was 25%.

6) The lowest wear values at no magnetic field were displayed by jasmine oil followed by sun flower, almond, olive, castor, corn, glycerine and paraffin oils.

7) Under the application of magnetic field, the lowest wear values were displayed by sun flower oil followed by jasmine, castor, glycerine, olive, paraffin, almond and corn oils.

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