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INFLUENCE OF INDUCTION MAGNETIC FIELD ON FRICTION COEFFICIENT OF STEEL SLIDING AGAINST OIL LUBRICATED POLYMERS

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ABSTRACT
The aim of the study is to investigate the influence of induction magnetic field on friction coefficient displayed by steel sliding against oil lubricated polymers. Induction magnetic field was applied with different fluxes of 0.1, 0.2, 0.3 and 0.4 mG intensity. Experiments were carried out using steel pin sliding on PMMA and PTFE sheets at dry sliding. Then paraffin and glycerin oils were dispersed by aluminium, copper, iron and graphite particles of 10 wt. % content.

The experiments showed that, sliding of steel against PMMA displayed the highest value of friction coefficient at dry sliding, while oil lubricated sliding showed relatively lower values. Slight friction decrease was observed as the intensity of the magnetic field increased. Paraffin oil showed the lowest friction values. The friction decrease might be attributed to the effect of the magnetic field which increased the viscous effect of the oil. Besides, polar molecules of the oil could significantly improve friction due to their adsorption on the sliding surfaces, where they 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.

Sliding against PTFE showed relatively low values at dry sliding. Application of magnetic field caused further friction decrease with increasing flux intensity. Magnetic field caused slight friction decrease in the presence of aluminium particles. Friction coefficient displayed by copper and iron particles showed slight increase with increasing flux intensity. When oil was dispersed by iron particles, magnetic field caused slight friction increase.

KEYWORDS
Induction, magnetic field, friction coefficient, iron, copper, aluminium, graphite, polymethyl methacrylate (PMMA), polytetrafluoroethylene (PTFE), paraffin, glycerin.

INTRODUCTION
There is an increasing demand to investigate the friction and wear of the mechanical drives that performed under the effect of magnetic field. Ferromagnetic materials have attracted much attention in both scientific and technical area, when they are under the influence of external magnetic field. The effect of magnetic field on the friction and wear

of steel scratched by TiC insert was tested, [1]. The steel was lubricated by oil and dispersed by iron, copper and aluminium powders as well as polymeric powders such as high density polyethylene (PE), polymethyl methacrylate (PMMA) and polyamide (PA6). Molybdenum disulphide (MoS_2) and graphite (C) were added to the oil as dispersant. It was found that application of induction magnetic field decreased friction coefficient. The decrease was significant for oil dispersed by aluminium, copper, PMMA and PA6 + 10 wt. % C, while addition of iron, PE and MoS_2 particles showed slight friction decrease. Magnetic field caused significant wear increase for oil lubricated steel, where aluminium, copper and PA6 + C particles displayed relatively higher wear, while addition of iron, PE, PMMA and MoS_2 particles showed slight wear increase. Magnetic field showed no significant change on wear of the steel surface.

It was observed that sliding between two steel cylinders under external magnetic field showed that the attractive force induced by external magnetic field increased normal force on the contact area. The friction coefficient decreased in the presence of magnetic field, [2]. External magnetic field could change the properties of ferromagnetic materials to improve the performance of cutting tool during metal manufacturing, [3]. It was found that the rate of the ferromagnetic materials and the friction coefficient can be changed by external magnetic field [4, 5]. Oil dispersed by suspensions of magnetic particles is used in many applications such as automotive brakes and vibration dampers, where their rheological properties can be dramatically altered by applying a magnetic field, [6 – 10]. When the magnetic field is applied magnetic particles orient themselves towards the magnetic flux line. This orientation of magnetic particles causes additional resistance to the flow and results in an increase in viscosity.

Influence of magnetic field on the friction and wear of polyethylene as bearing materials scratched by steel insert in the presence of different oil was discussed, [11]. 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. 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 (CMOC), graphite, polytetrafluroethylene and polymethyl methacrylate, detergent additive (calcium sulphonate), was investigated, [12, 13]. Aluminium was used as friction counterface to reduce the magnetic force acting on the contact surfaces when the magnetic field was applying.

The tribological performance of polyethylene, as bearing materials sliding against steel considering that effect, was discussed, [14]. 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. Based on the experimental observations, [15 - 17], 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.

The presence of a magnetic field around the ferromagnetic steel couple in sliding contact modifies considerably their tribological behaviour with an important decrease in the wear rate [18 - 24]. Applied magnetic field around the rotating sliding ferromagnetic steel/steel modifies the friction and the wear behaviour of the contact, [25]. 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, [26]. 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.

In the present work, the effect of induced magnetic field on the friction coefficient displayed by the oil lubricated sliding of steel against PMMA and PTFE is investigated.

EXPERIMENTAL

The details of the test rig are shown in Fig. 1. The steel pin (51200), used in experiments, was 8 mm diameter. The friction force was measured by the deflection of the load cell. The ratio of the fiction force to the normal load was considered as friction coefficient. The steel surface was ground by an emery paper (500 grade) before testing. The steel was lubricated by paraffin and glycerin oils dispersed by metallic particles such as aluminium, copper, iron, and graphite. The concentration was 10 wt. % and their particle size was ranging between 30 - 50 µm. The polymeric sheets of PMMA and PTFE were of 10 × 20 mm^2 and 4 mm thickness. The test track was 60 mm long.

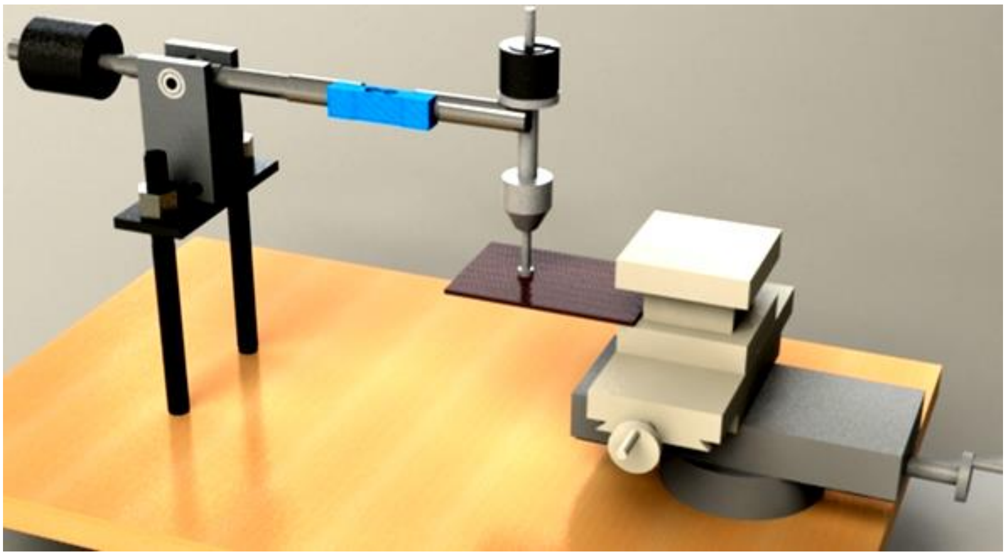

Fig. 1 Schematic layout of the test rig.

The load was applied by weights. The test speed was controlled by an electric motor connected to the power screw feeding the polymeric sheet in the friction direction. The test velocity was 2 mm/s. The normal load was 10 N. All measurements were performed at 25 ± 2 º C and 50 ± 10 % humidity. Experiments were carried out under the effect of magnetic flux intensity (0.1, 0.2, 0.3 and 0.4 mG). The value of induction magnetic field nearby the contact point was measured in the static condition before the beginning of tribological test.

RESULTS AND DISCUSSION

Friction coefficient displayed by steel sliding on oil lubricated PMMA is shown in Fig. 2. Dry sliding caused the highest value of friction coefficient, while oil lubricated sliding showed relatively lower values. Slight friction decrease was observed as the intensity of magnetic field increased. Paraffin oil showed the lowest friction values. The friction decrease might be attributed to the effect of the magnetic field which increased the viscous effect of the oil under the magnetic field. When the field is on, magnetorheological fluid behaves as a semi-solid with very high apparent viscosity. It is evident that the relatively high viscosity of magnetorheological fluid could decrease the friction accompanied to the abrasion process.

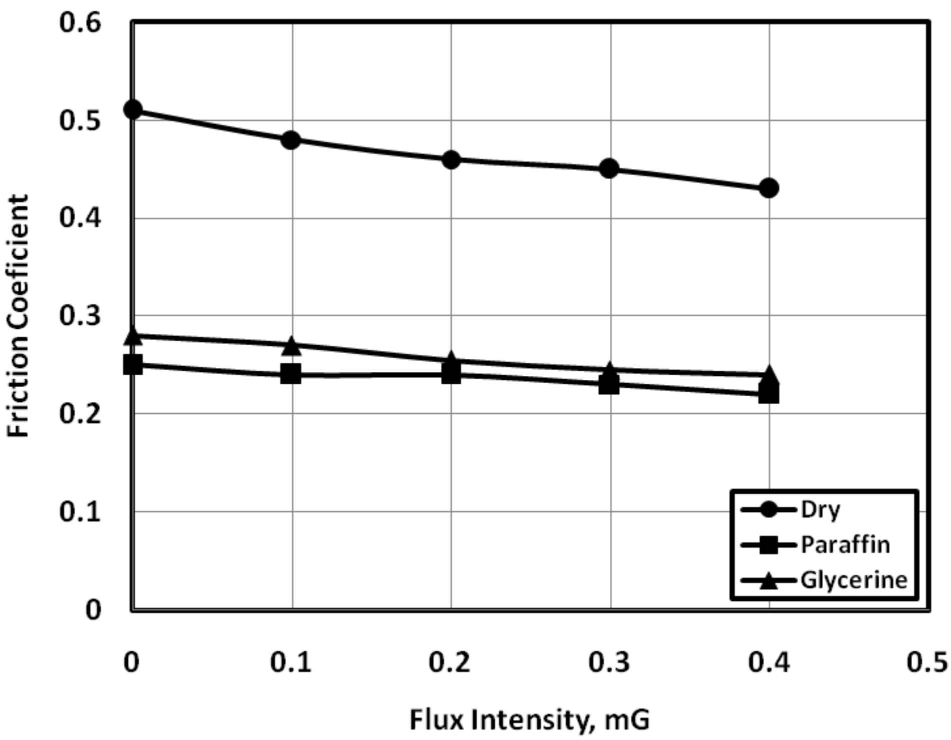

Fig. 2 Friction coefficient displayed by steel sliding on oil lubricated PMMA.

Although aluminium is paramagnetic material, significant friction decrease was observed when oil was dispersed by aluminium particles, Fig. 3. At no magnetic field, friction coefficient showed values lower than that observed for oil free of aluminium particles. Aluminium is relatively softer than steel and easily deformed at the contact area to give more protection friction. When magnetic field was applied friction coefficient slightly decreased.

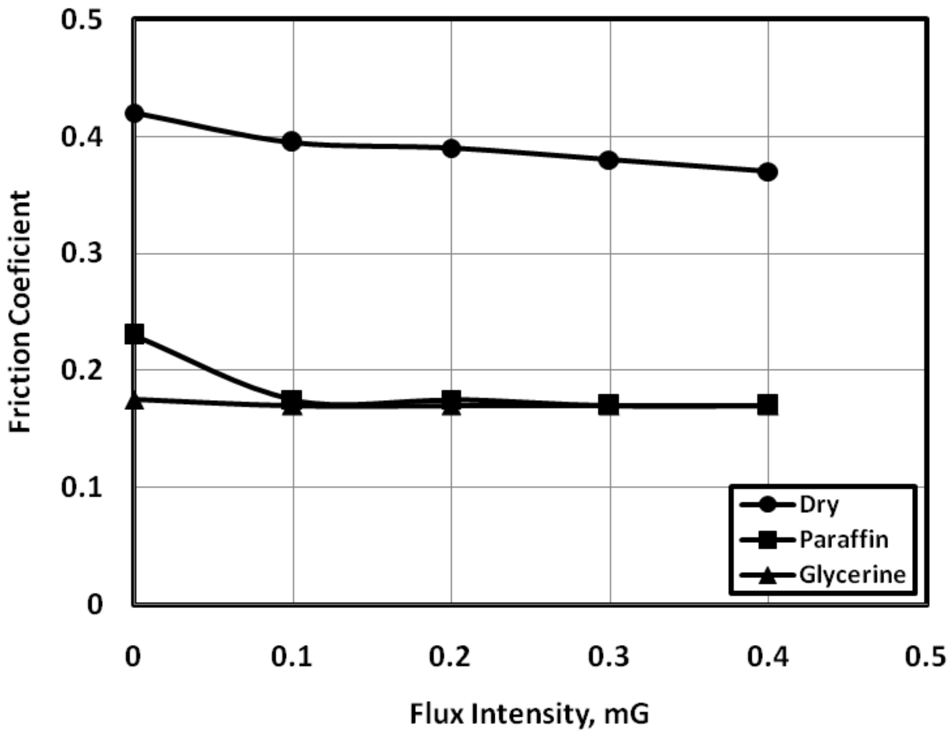

Fig. 3 Friction coefficient displayed by steel sliding on oil lubricated PMMA dispersed by aluminium particles.

Friction coefficient displayed by steel sliding on oil lubricated PMMA dispersed by graphite particles is shown in Fig. 4. Significant friction decrease was observed for dry sliding. At no magnetic field friction coefficient decreased due to the action of graphite. The good surface adherence of graphite is attributed to the low shear strength of graphite platelets, where they shear easily to give low friction.

When copper was dispersing oil, no enhancement was observed under the application of magnetic field, Fig. 5. Friction displayed values lower than that observed for oil free of dispersants. The highest friction values were 0.42 and 0.39 mm for 0 and 0.4 mG magnetic flux respectively at dry sliding. The low shear strength of copper particles enabled them to be deformed on the contact area to protect the steel surface from further wear.

Friction coefficient displayed by steel sliding on oil lubricated PMMA dispersed by iron particles is shown in Fig. 6. At dry sliding, friction coefficient slightly increased with increasing flux intensity. It seems that magnetic field increased the attractive force between the steel pin and the steel moving table. Therefore, friction coefficient decreased. For surfaces lubricated by paraffin oil friction coefficient slightly decreased due to the ability of the magnetic field to reorient the oil molecules to be strongly adhered to the surfaces of steel and PMMA sheet.

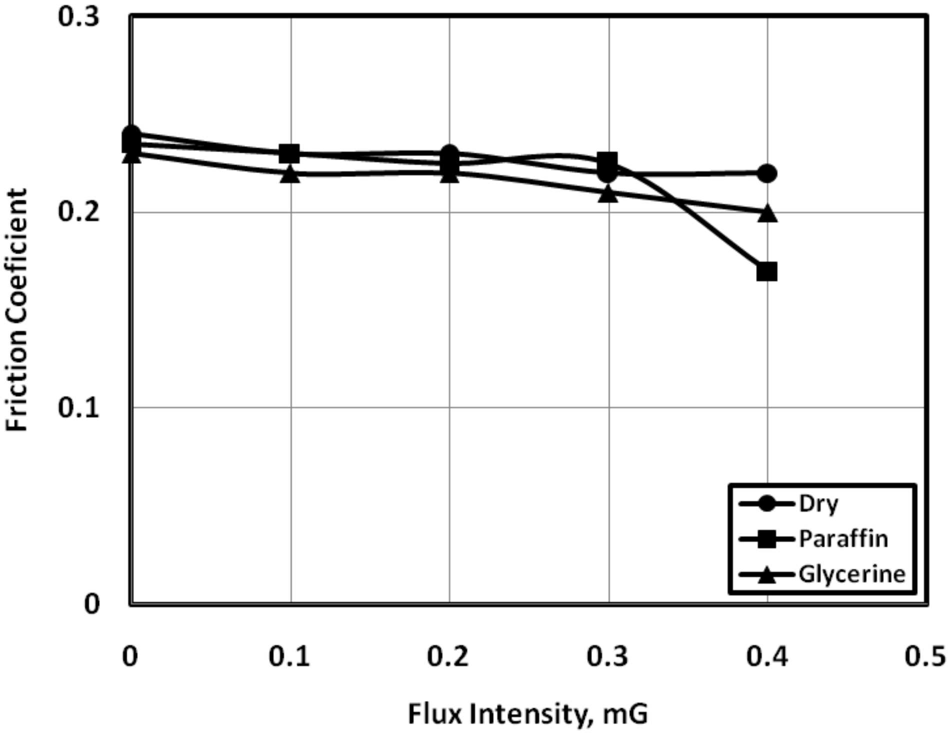

Fig. 4 Friction coefficient displayed by steel sliding on oil lubricated PMMA dispersed by graphite particles.

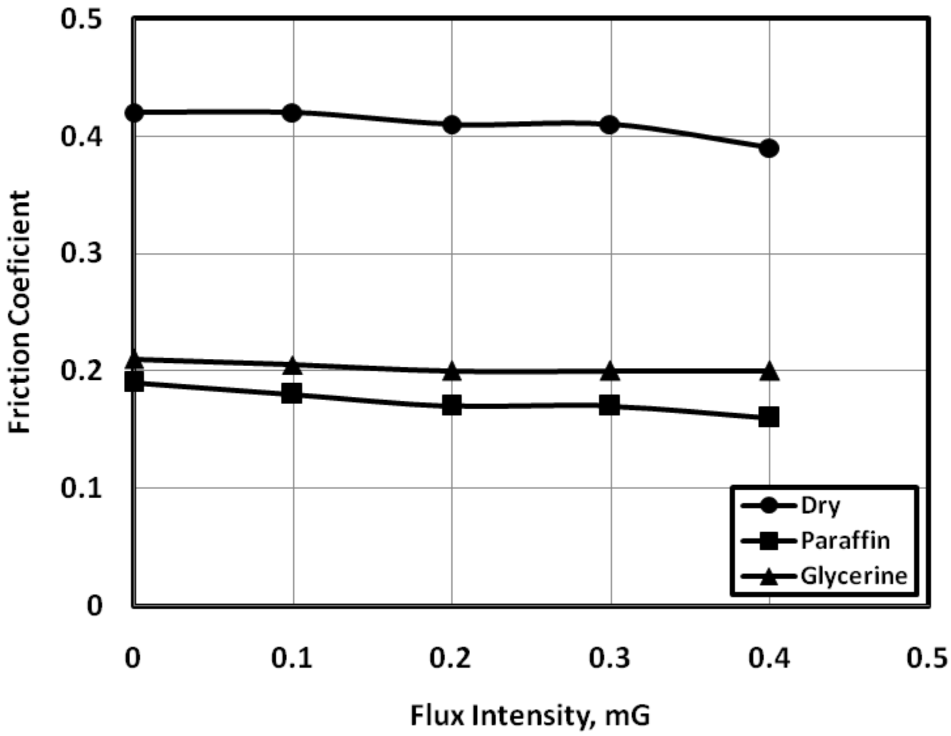

Fig. 5 Friction coefficient displayed by steel sliding on oil lubricated PMMA dispersed by copper particles.

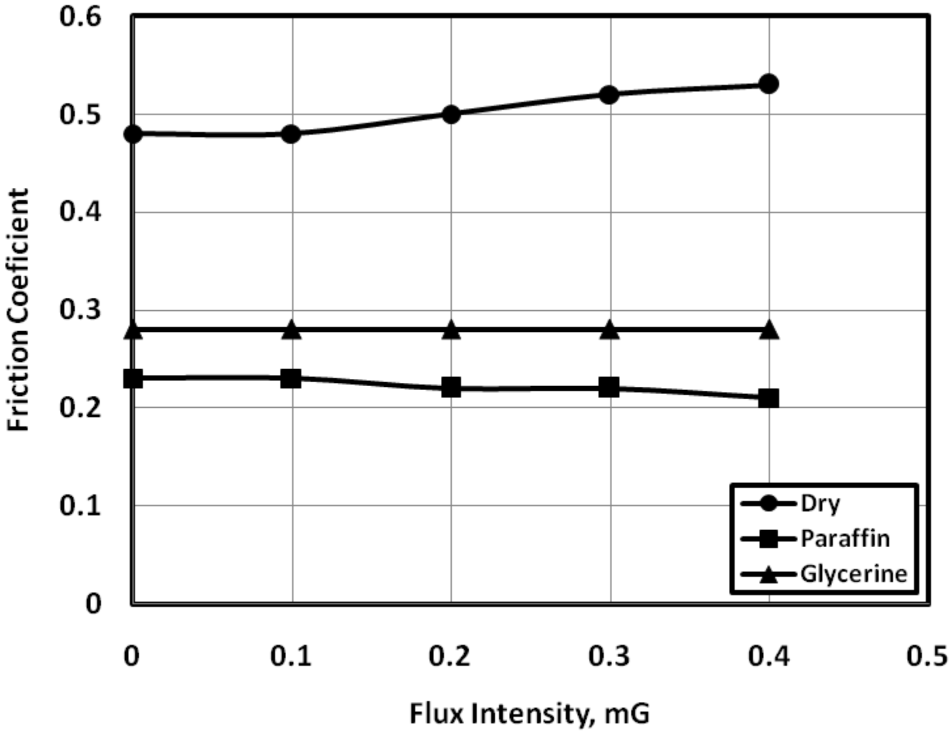

Fig. 6 Friction coefficient displayed by steel sliding on oil lubricated PMMA dispersed by iron particles.

Friction coefficient displayed by steel sliding on oil lubricated PTFE showed relatively low values at dry sliding, Fig. 7. Application of induction magnetic field caused further friction decrease with increasing flux intensity. Induction magnet behaves like a permanent magnet as long as there is power applied to it. It is a magnet that can be turned on and off 50 times a second (50 Hz), and its magnetic strength can be varied as the voltage to it is varied. The variation of the magnetic flux would decrease accumulation of the PTFE debris around contact asperities and make the steel surface clean for further abrasion.

Friction of oil lubricated steel dispersed by aluminium particles is shown in Fig. 8. Magnetic field caused slight friction decrease. At dry sliding, friction coefficient showed relatively high values due to the embedment of aluminium particles in the surface pf PTFE so that the contact was partially aluminium/steel which was the reason of increasing friction coefficient.

Friction coefficient displayed by steel sliding on oil lubricated PTFE dispersed by copper particles showed slight increase with increasing flux intensity, Fig. 10. During friction the contact area was covered by oil and copper particles. Significant friction increase was observed for all the sliding conditions due to the embedment of copper particles in PTFE surface. That behaviour was observed clearly in the oil lubricated conditions.

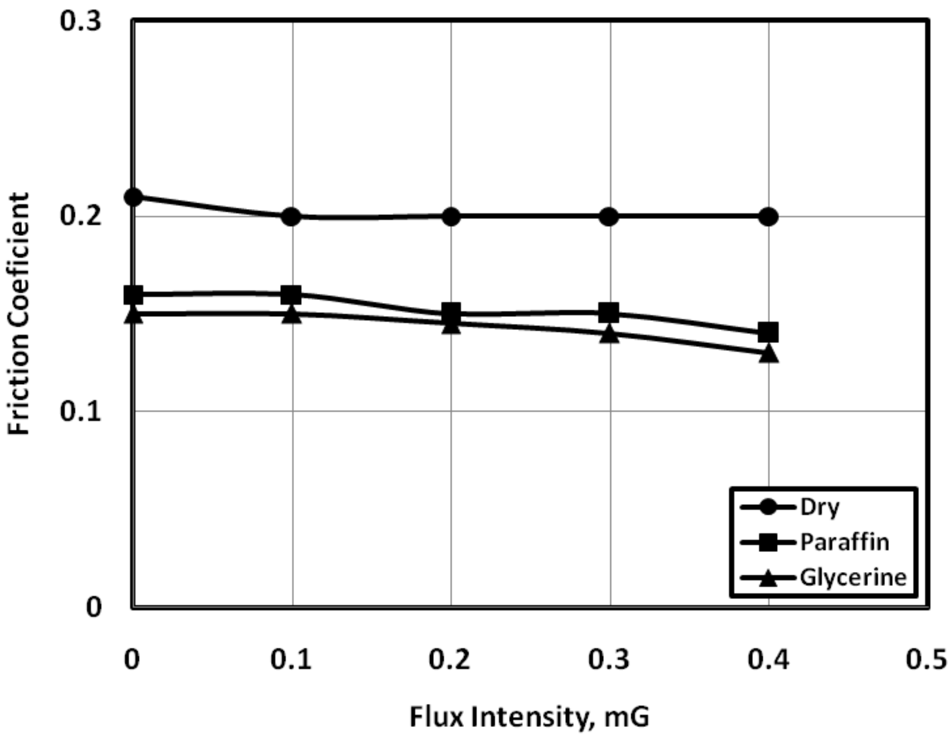

Fig. 7 Friction coefficient displayed by steel sliding on oil lubricated PTFE.

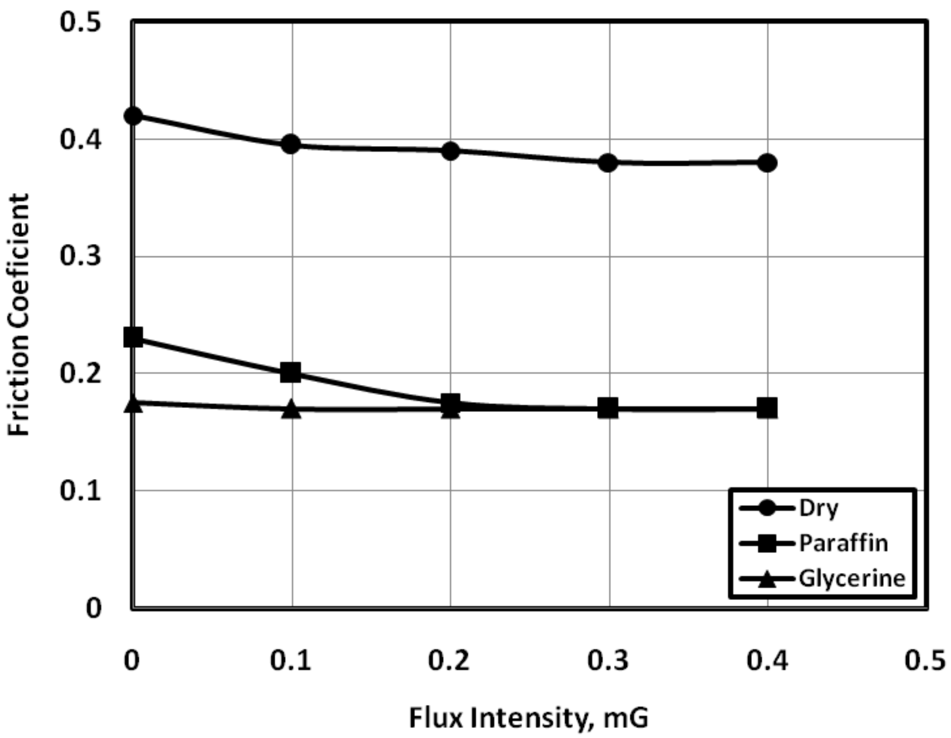

Fig. 8 Friction coefficient displayed by steel sliding on oil lubricated PTFE dispersed by aluminium particles.

When the oil was dispersed by graphite, magnetic field of 0.1 mG flux intensity showed significant friction decrease for paraffin lubricated PTFE, Fig. 9. Further flux increase

showed no change in friction coefficient. It seems that graphite particles were adhered into the steel and PTFE surfaces so that friction coefficient increased.

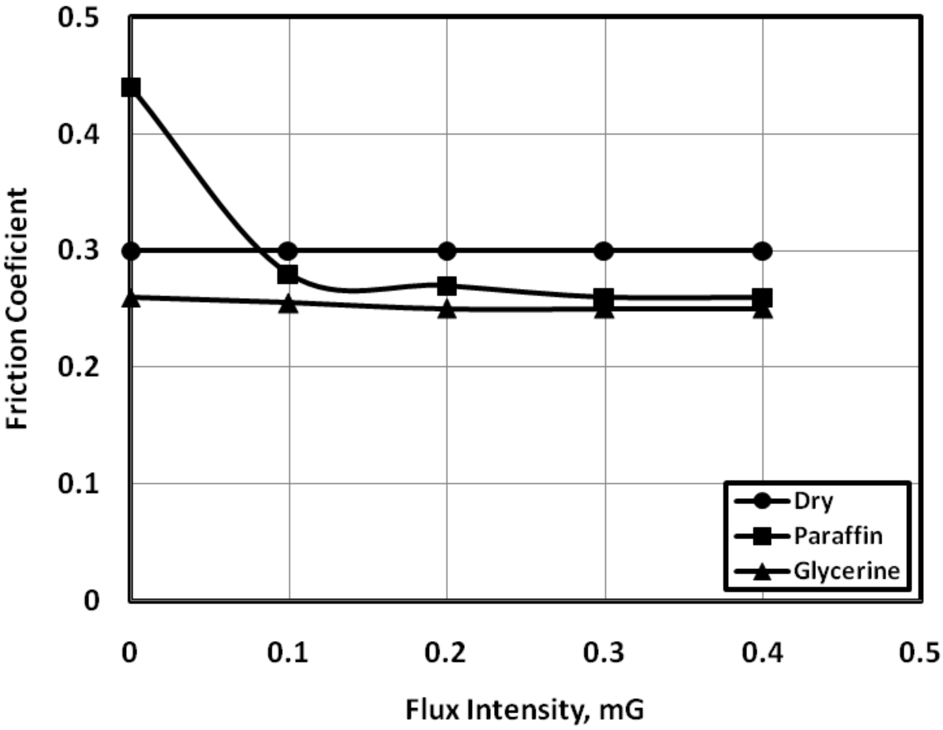

Fig. 9 Friction coefficient displayed by steel sliding on oil lubricated PTFE dispersed by graphite particles.

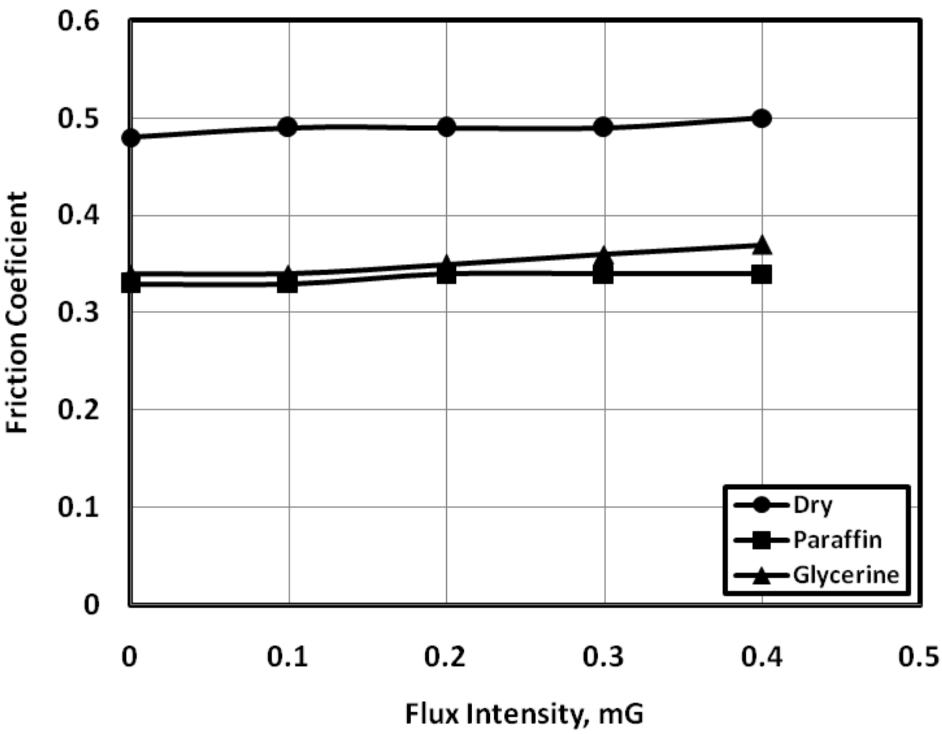

Fig. 10 Friction coefficient displayed by steel sliding on oil lubricated PTFE dispersed by copper particles.

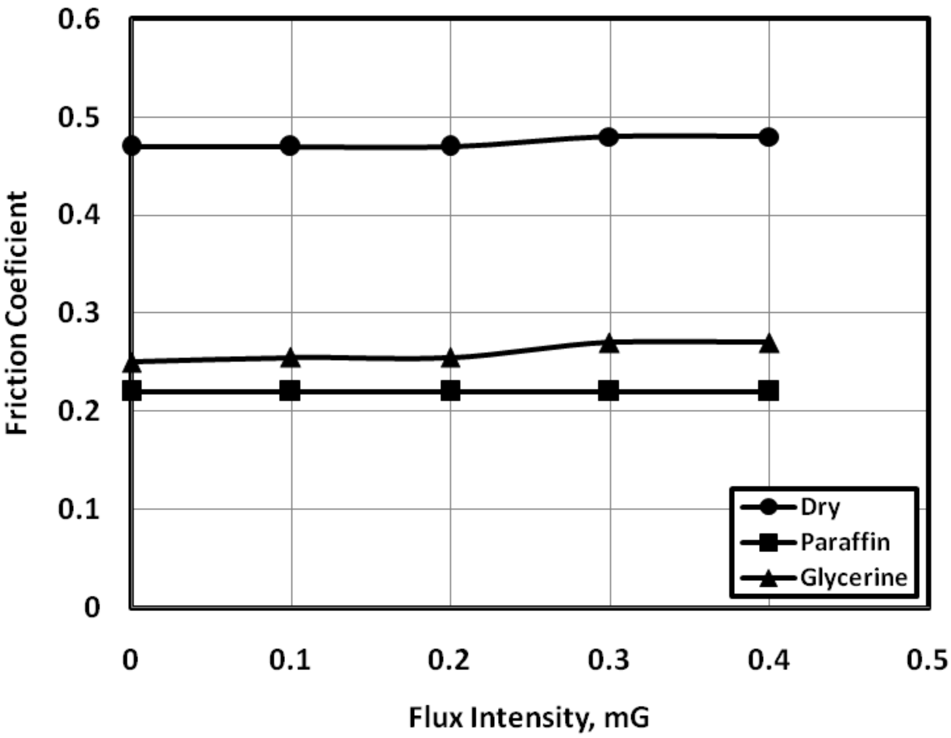

Fig. 11 Friction coefficient displayed by steel sliding on oil lubricated PMMA dispersed by iron particles.

When oil was dispersed by iron particles magnetic field caused slight friction increase, Fig. 11. Because iron particles are magnetic they were attracted to the steel surface and orient themselves towards the magnetic flux lines. This orientation of magnetic particles caused additional resistance to friction. At no magnetic field wear value was lower than that observed for oil lubricated steel.

CONCLUSIOSN

1. Sliding of steel against PMM showed that, a slight friction decrease was observed as the intensity of the magnetic field increased. Paraffin oil showed the lowest friction values. Friction decrease was observed when oil was dispersed by aluminium particles. At no magnetic field friction coefficient showed values lower than that observed for oil free of aluminium particles. When magnetic field was applied friction coefficient slightly decreased. Significant friction decrease was observed for steel sliding on oil lubricated PMMA dispersed by graphite particles as result of magnetic field. When copper was dispersing oil, no enhancement was observed under the application of magnetic field. Addition of iron particles into oil caused friction increase with increasing flux intensity at dry sliding. For surfaces lubricated by paraffin oil friction coefficient slightly decreased due to the ability of the magnetic field to reorient the oil molecules to be strongly adhered to the surfaces of steel and PMMA sheet.

2. Sliding against PTFE showed relatively low values at dry sliding. Application of magnetic field caused further friction decrease with increasing flux intensity. Magnetic field caused slight friction decrease in presence of aluminium particles. When the oil was dispersed by graphite, magnetic field of 0.1 mG flux intensity showed significant friction decrease. Further flux increase showed no change in friction coefficient. Friction

coefficient displayed by copper particles showed slight increase with increasing flux intensity. When oil was dispersed by iron particles, magnetic field caused slight friction increase.

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