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Friction Coefficient Displayed by the Scratch of Epoxy Composites Filled by Metallic Particles under the Influence of Magnetic Field

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Abstract

The wide use of epoxy composites as bearing materials in electronic appliances necessitates studying their frictional behaviour under the influence of magnetic field. Experiments were carried out to investigate the effect of magnetic field on the friction coefficient displayed by the scratch of epoxy composites filled by iron, copper and aluminium particles at different concentrations. It was observed that, for epoxy filled by the metallic fillers (iron, copper and aluminium), under the effect of the magnetic field, friction coefficient showed relative decrease then significantly increased with further increase of the intensity of the magnetic field. Besides, friction coefficient increased with increasing the content of the metallic fillers due to the decrease of the strength of the epoxy matrix. The values of friction coefficient displayed by epoxy filled by copper were lower than those observed for epoxy filled by iron. Filling epoxy by aluminium displayed lower friction coefficient than that observed for epoxy composites filled by iron and copper. This can be attributed to the charging of aluminium by positive charge when slid against steel. The resultant charge on the sliding surfaces was lower than that generated when epoxy was filled by iron and copper. In that condition, the adhesion of epoxy composites would be relatively weaker leading to the decrease of friction coefficient.

Keywords

Friction Coefficient, Epoxy Composites, Iron, Copper, Aluminium, Magnetic Field, Scratch

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1. Introduction

In many engineering applications, 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. The friction of polyamide sliding against steel in the presence of magnetic field was discussed [1]. Paraffin and vegetable oils such as almond, castor, corn, glycerine, jasmine, olive and sun flower oils were used as lubricants. It was found that application of magnetic field on the contact area affected friction coefficient displayed by 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. The friction decrease observed at dry sliding could 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.

Electric voltage was applied on the sliding steel surfaces' friction coefficient decreased with voltage increasing [2]. Addition of polymeric particles into oil caused significant friction increase in the presence of applied voltage. Influence of magnetic field on the friction of polyamide as bearing materials scratched by steel insert in the presence of different oils was discussed [3]. Paraffin, fenugreek, camphor, cress, olive, almonds, sesame, aniseed and El-Baraka seed oils were used as lubricants. The friction coefficient of the tested composites was 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, polytetrafluroethylene and polymethyl methacrylate, detergent additive (calcium sulphonate) was investigated [4]-[6]. Aluminium was used as friction counterface to reduce the magnetic force acting on the contact surfaces when the magnetic field was applied. It was found that, application of magnetic field decreased friction coefficient at dry sliding due to its influence to decrease the adherence of polyamide worn particles into the steel counterface. Besides, the magnetic field facilitated the formation of oxide film on the contact surface, where it played a protective role in dry friction, and modified the friction. It was noticed that for abrasion of steel, friction coefficient displayed the highest values at dry sliding [7] [8]. 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 [9]-[11]. The observed changes in the properties of polymers were attributed to the catalytic effect of the magnetic field on the molecules. Thus, the macromolecular compounds obtained in a magnetic field presented 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 [12] [13]. 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 physichemical transformations in polymers promote increases in the surface and bulk states density [14]. 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 rubbing process breaks up the polymer surface and liberates free radicals and ion radicals. 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. When a magnetic field is applied, the contact in ambient air progressively becomes black, covered by a brittle thick black layer of oxides, which leads to a low friction and a low wear mode.

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 [15]. The results indicate that, at dry sliding condition, the potential generated from friction increases rapidly with increasing both 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 changes 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.

In the present work, the effect of magnetic field on the friction coefficient displayed by steel indenter scratching epoxy composites filled by metallic particles under dry sliding condition is investigated.

2. Experimental

Scratch tester shown in **Figure 1** was used. It consisted of a rigid indenter mount, a diamond indenter of apex angle 90˚ and hemispherical tip. The indenter was mounted to the loading lever through three jaw chuck. A counter weight was used to balance the loading lever before loading. Vertical load was applied by weights of 2, 4, 6, 8 and 10 N. Scratch resistance force was measured using a load cell mounted to the loading lever and connected to display digital monitor. The test specimen was held in the specimen holder which mounted in a horizontal base with a manual driving mechanism to move specimen in a straight direction. The scratch force was measured during the test and used to calculate friction coefficient. The test was conducted under dry conditions at room temperature. An optical microscope was used to measure scratch width with an accuracy of ±1.0 μm. Magnetic field was applied by a coil assembled under the steel base where the epoxy composites where fixed as shown in **Figure 2**. The flux intensities of the magnetic field were 0.2, 0.4 and 0.6 mG.

3. Results and Discussion

The effect of magnetic field on friction coefficient is discussed in **Figures 3-14**. It is clearly shown that friction coefficient increased with increasing iron content, **Figure 3**, due to the decrease of the cohesion of the epoxy matrix. Besides, friction coefficient increased with increasing applied load as a result of the increased depth of the indenter edge inside the epoxy matrix, where the amount of the removed material increased. In the presence of the magnetic field I, **Figure 4**, friction coefficient showed relative decrease. This behaviour might be from the increased matrix cohesion due to its filling by iron particles, where their attractive force increased with the application of the magnetic field. Besides, the removed material from epoxy composites strongly adhered into the

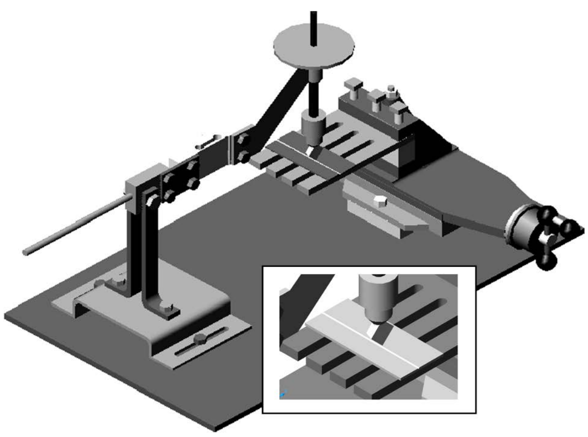

Figure 1. Details of the test rig.

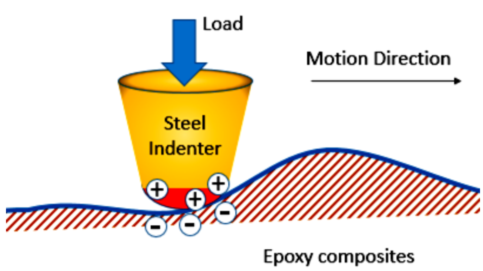

Figure 2. Formation of the electric static charge during scratch.

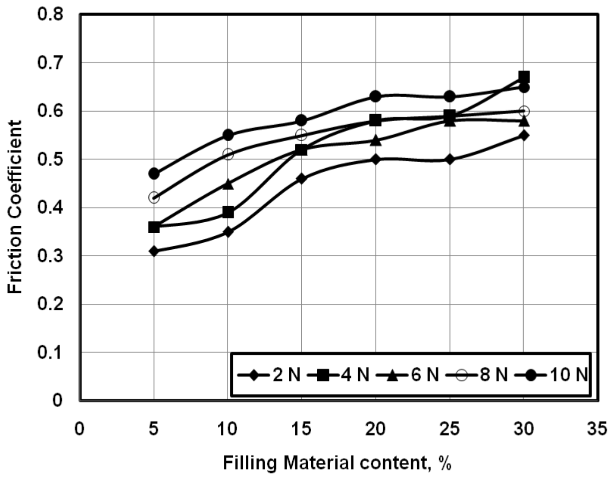

Figure 3. Friction coefficient displayed by the scratch of epoxy filled by iron.

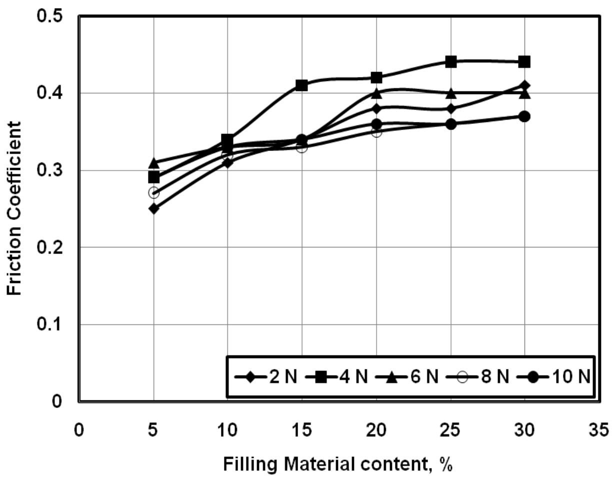

Figure 4. Friction coefficient displayed by the scratch of epoxy filled by iron under magnetic field I.

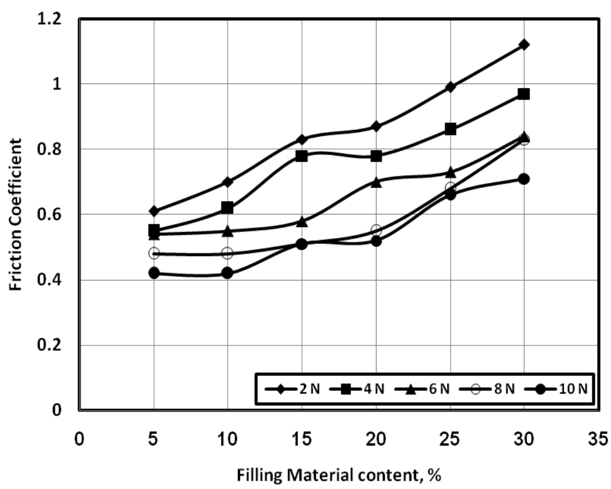

Figure 5. Friction coefficient displayed by the scratch of epoxy filled by iron under magnetic field II.

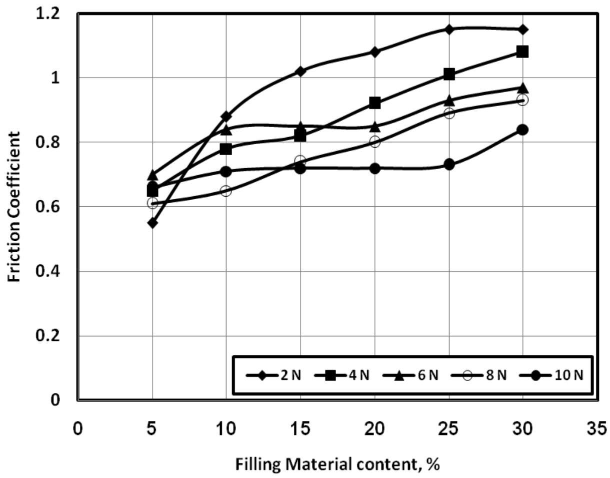

Figure 6. Friction coefficient displayed by the scratch of epoxy filled by iron under magnetic field III.

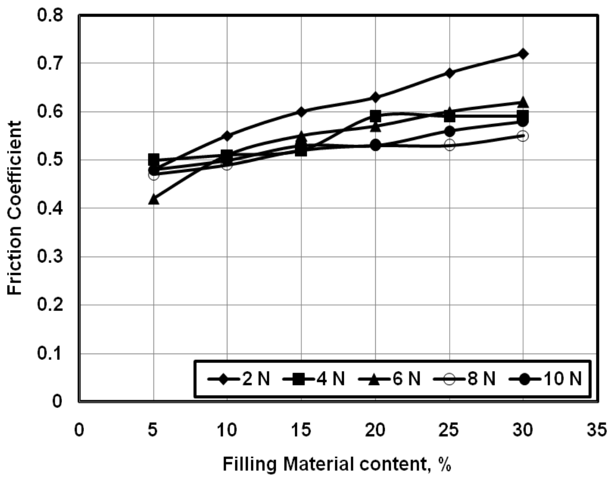

Figure 7. Friction coefficient displayed by the scratch of epoxy filled by copper.

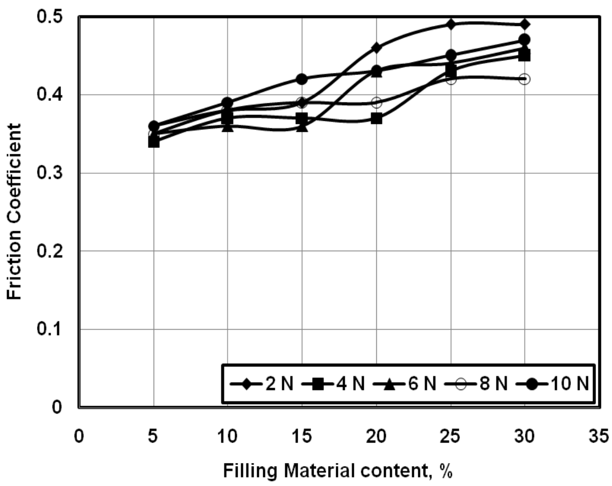

Figure 8. Friction coefficient displayed by the scratch of epoxy filled by copper under magnetic field I.

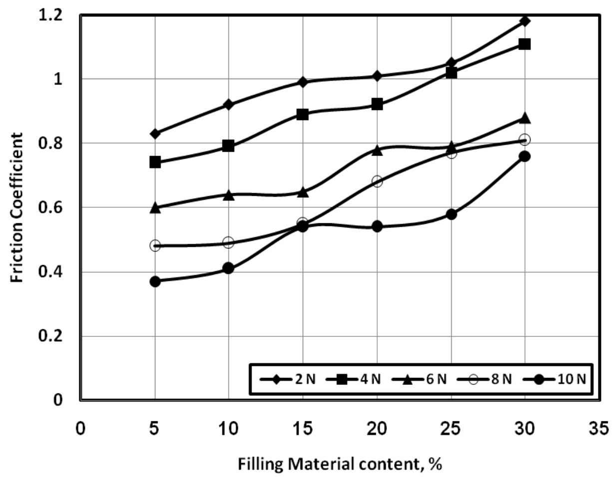

Figure 9. Friction coefficient displayed by the scratch of epoxy filled by copper under magnetic field II.

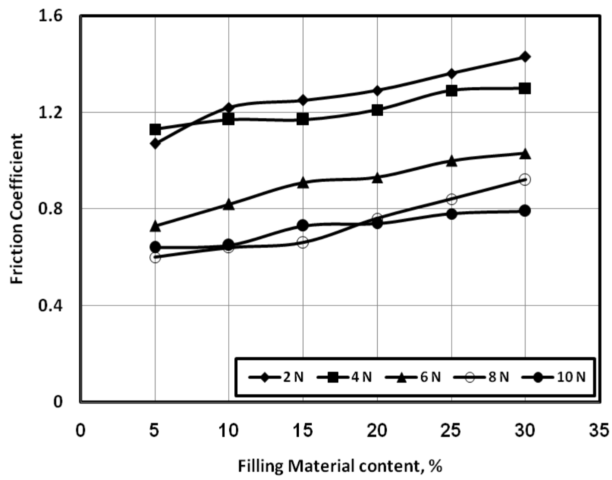

Figure 10. Friction coefficient displayed by the scratch of epoxy filled by copper under magnetic field III.

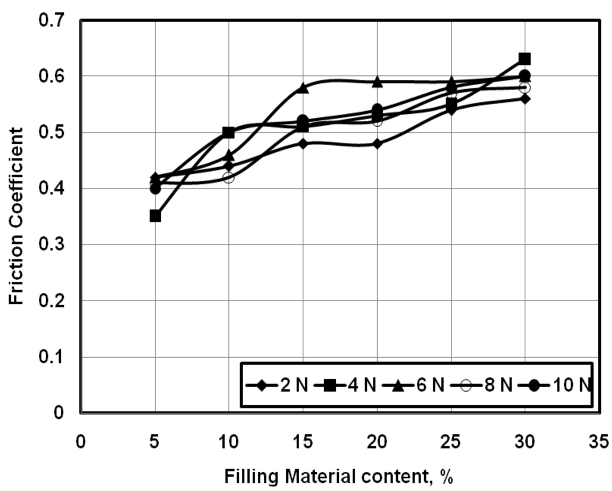

Figure 11. Friction coefficient displayed by the scratch of epoxy filled by aluminium.

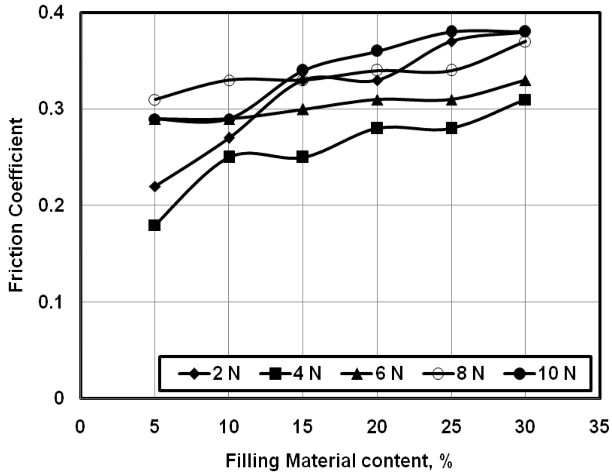

Figure 12. Friction coefficient displayed by the scratch of epoxy filled by aluminium under magnetic field I.

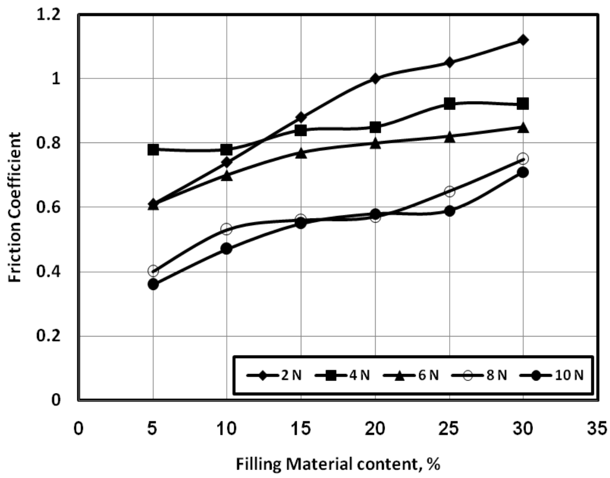

Figure 13. Friction coefficient displayed by the scratch of epoxy filled by aluminium under magnetic field II.

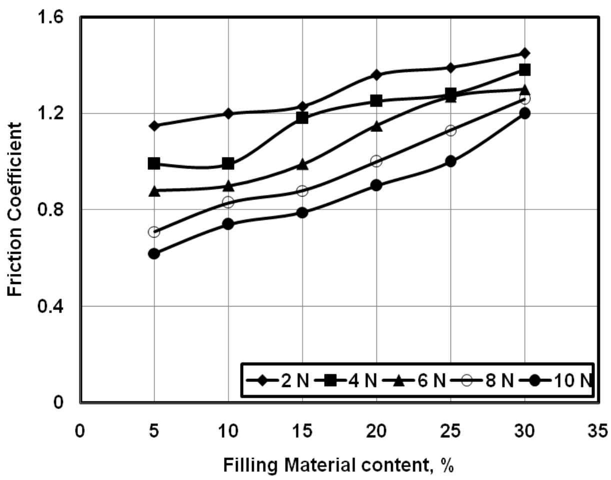

Figure 14. Friction coefficient displayed by the scratch of epoxy filled by aluminium under magnetic field III.

surface of the indenter. Increasing the intensity of the magnetic field showed significant friction increase, **Figure 5**. This behaviour might be attributed to the increase of the attractive force between the removed epoxy composites and the surface of the indenter. In this condition, the sliding would be between epoxy matrix and epoxy composites adhered to the indenter surface. The maximum value of friction coefficient observed was 1.13 at 2 N load and 30 wt% iron filled epoxy, while at no magnetic field the value did not exceed 0.44. Further significant friction increase was observed when the magnetic field increased, **Figure 6**. The indenter being as magnetic material strongly attracted the removed epoxy composites into its surface. Friction coefficient recorded relatively higher values. The friction increase was clearly observed at lower loads.

Friction coefficient displayed by the scratch of epoxy filled by copper is shown in **Figure 7**. Copper gained negative and positive charges when slid against steel and epoxy respectively. Therefore, material transfer from epoxy composites into steel surface and transfer back from steel to epoxy surface would influence the resultant electric static charge. At no magnetic field, friction coefficient slightly increased with increasing copper content. Generally, friction values were lower than that observed for epoxy filled by iron. It seems that copper particles were able to conduct some of the electric charge generated on the contact asperities and consequently the attractive force decreased.

Under the effect of the magnetic field I, friction coefficient showed significant decrease, **Figure 8**. It seems that the relative motion of the indenter against the epoxy composites generated an electric current which affected the intensity of the electric charge on the contact area. Besides, epoxy transfer into indenter surface was diminished by the presence of copper particles, where they abraded the epoxy layer attracted to the indenter surface. Friction coefficient displayed by the scratch of epoxy filled by copper under magnetic field II showed significant increase, **Figure 9**. The friction increase might be from the increase of the negative charge intensity generated from sliding of steel against epoxy filled by copper. Increasing the intensity of the magnetic field would increase the magnetic force which enables the transferred epoxy composite to be strongly adhered into the steel indenter, **Figure 10**. The highest value of friction coefficient was 1.43 detected at 2 N load and 30 wt. copper filled epoxy composites.

Filling epoxy by aluminium displayed lower friction coefficient than observed for iron and copper filled epoxy composites, **Figure 11**. This can be attributed to the charging of aluminium by positive charge when slid against steel. The resultant charge on the sliding surfaces was lower than that generated when epoxy was filled by iron and copper. In that condition the adhesion of epoxy composites would be relatively weaker leading to the decrease of friction coefficient.

Application of the magnetic field I, **Figure 12**, significantly decreased friction coefficient due to the increase of positive charge of aluminium particles so that the adhesive force of the epoxy composites into the steel decreased and made the removal of the abraded epoxy easier. Friction coefficient displayed by the scratch of epoxy filled by aluminium under magnetic field II is shown in **Figure 13**, significantly increased with increasing aluminium content. It seems that aluminium gained positive charge, while epoxy gained negative one so that the bond between aluminium and epoxy increased and consequently friction coefficient significantly increased. Further increase in magnetic field showed remarkable friction increase, **Figure 14**. Presence of magnetic field increased the intensity of the electric static charge formed on the contact surface. As a result of that the electrical force increased causing an increase in the adhesion of epoxy composites into the steel surfaces and the bond between aluminium particle and epoxy increased.

4. Conclusions

1) Friction coefficient increased with increasing both iron content and applied load. In the presence of the magnetic field, friction coefficient showed relative decrease. This behaviour might be from the increased matrix cohesion due to its filling by iron particles, where their bonding force increased with the application of the magnetic field. Besides, the removed material from epoxy composites strongly adhered into the surface of the indenter. Increasing the intensity of the magnetic field showed significant friction increase due to the increase of the attractive force between the removed epoxy composites and the surface of the indenter. In this condition, the sliding would be between epoxy matrix and epoxy composites adhered to the indenter surface.

2) Friction coefficient displayed by epoxy filled by copper showed lower values than that observed for epoxy filled by iron. Under the effect of the magnetic field, friction coefficient showed significant increase.

3) Filling epoxy by aluminium displayed lower friction coefficient than that observed for epoxy composites

filled by iron and copper. Application of the magnetic field significantly decreased friction coefficient then increased with further increase of the magnetic field. Friction coefficient displayed by the scratch of epoxy significantly increased with increasing aluminium content. It seems that presence of magnetic field increased the intensity of the electric static charge formed on the contact surface. As a result of that, the electrical force increased causing an increase in the adhesion of epoxy composites into the indenter surfaces and the bond between aluminium particle and epoxy increased.

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