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FRICTION COEFFICIENT AND WEAR DISPLAYED BY THE SCRATCH OF EPOXY COMPOSITES FILLED BY METALLIC NANOPARTICLES UNDER THE INFLUENCE OF MAGNETIC FIELD

El-Zahraa F. I.[1], Abdel-Jaber G. T.[1], Khashaba M. I.[2], and Ali W. Y.[2]

[1]Faculty of Engineering, Qena, South Valley University, Qena, EGYPT.
[2]Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT.

ABSTRACT
There is increasing demand to develop the bearing materials of moving surfaces that perform under effect of magnetic field. Experiments have been carried out in the present work to study the effect of magnetic field on the friction coefficient and wear displayed by the scratch of epoxy composites filled by nanoparticles of metallic materials such as, iron (Fe), copper (Cu) and aluminium (Al).

It was observed that friction coefficient decreased with increasing nanoparticles content at no magnetic field. The highest values were displayed by unfilled composites. Filling epoxy by Al displayed lower friction coefficient than that observed for Fe and Cu filled epoxy composites, while wear of epoxy filled by Al nonoparticles showed higher values. Friction coefficient slightly increased with increasing the intensity of magnetic field, where iron filled composites displayed the highest values. Wear showed slight decrease with increasing the intensity of magnetic field.

KEYWORDS
Friction coefficient, wear, scratch, epoxy composites, iron, copper, aluminium, nanoparticles, magnetic field.

INTRODUCTION
In many engineering applications, the moving surfaces perform under the effect of magnetic field. It is necessary to investigate the tribological performance of sliding bearings which are probably made of polymers considering that effect. The friction of polyamide sliding against steel in the presence of magnetic field was discussed, [1, 2]. It was found that application of magnetic field on the contact area affected friction coefficient. Magnetic field decreased friction coefficient. The addition of nanoparticles to polymers has fulfilled the requirements needed from the advanced materials, [3 - 5].

Polymeric nanocomposites provide quite good tribological materials.

The lubricating properties of thermosetting polymers can be modified by the addition of ZnO nanoparticles into the lubricant, [6 - 8]. At no electric voltage, wear slightly decreased, while application of electric voltage increased wear. As the applied voltage increased friction coefficient significantly increased. It was found that the specific wear rate of surface modified Fe_3O_4/epoxy nanocomposites was lower than that of unmodified Fe_3O_4/epoxy nanocomposites.

Magnetic nanoparticles have wide applications that take advantage of both the magnetic properties and wear properties of their composites, [9 - 12], where superior properties can be exhibited. A number of studies have investigated the effect of a magnetic field on the tribological behaviour of materials, [13 - 15]. The observed experimental phenomena have not been discussed in detail and, in some cases, contradictory information has been obtained. The application of a magnetic field increases the microhardness of the sliding surfaces and modifies the mechanical properties, enhances and activates surface debris oxidation, [16, 17]. Besides, the potential difference generated by the friction of polymeric coatings against steel counterface has been measured.

The wear track was covered with very fine ferromagnetic particles in the presence of magnetic field, [18]. Because friction and wear are influenced by the presence of oxide, the oxide layer on the worn surface, make the contact oxide/oxide instead of metal/metal contact. The effect will be more significant on the ferromagnetic contact surface, [19]. Besides, dislocations in subsurface of the materials in contact are influenced by contact shear stress field, [20, 21], where the magnetic field accelerates the movement of dislocations due to mechanical stress so that increase of dislocations leads to the increase of surface hardness.

DC voltages were found to be able to promote the generation of chemisorbed and chemical reaction films of ZDTP additives in mineral lubricating oils on metal surfaces, leading to a reduction in friction, [22, 23]. The experimental evidence showed that the oxide layer growth and the transferred graphite films on the steel track are enhanced by a magnetic field. That behaviour decreases wear and friction coefficient, [24 - 26]. Experiments showed that a magnetic field applied through the sliding contact leads to decrease the wear rate. The effect of magnetic field on the friction coefficient displayed by sliding surfaces lubricated by paraffin oil and dispersed by different lubricants additives such as zinc dialkyldithiophosphates (ZDDP), molybdenum disulphide (MoS_2), heteropolar organic based additive (CMOC), graphite (C), detergent additive (calcium sulphonate) (DA), polytetrafluroethylene (PTFE) and polymethyl methacrylate (PMMA) was discussed. It was observed that magnetic field much affected the performance of oil dispersed by additives of electrical properties such as CMOC, DA, C and PTFE.

The present work studies effect of magnetic field on friction coefficient and wear scar width displayed by the scratch of epoxy composites filled by nanoparticles of metallic materials such as Fe, Cu and Al.

EXPERIMENTAL

The test rig used in the experiments was top scratch tester. It is consisted of a rigid stylus mount to produce a scratch on a flat surface with a single pass, a diamond stylus of apex angle 90° and hemispherical tip as shown in Figure 1. The loading lever mounted to the stylus through three-jaw chuck. A counter weight is used to balance the loading lever before process of loading. Weights of 2, 4, 6, 8 and 10 N are vertically applied. 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 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. The flux intensities of the magnetic field were 0.2, 0.4 and 0.6 mG.

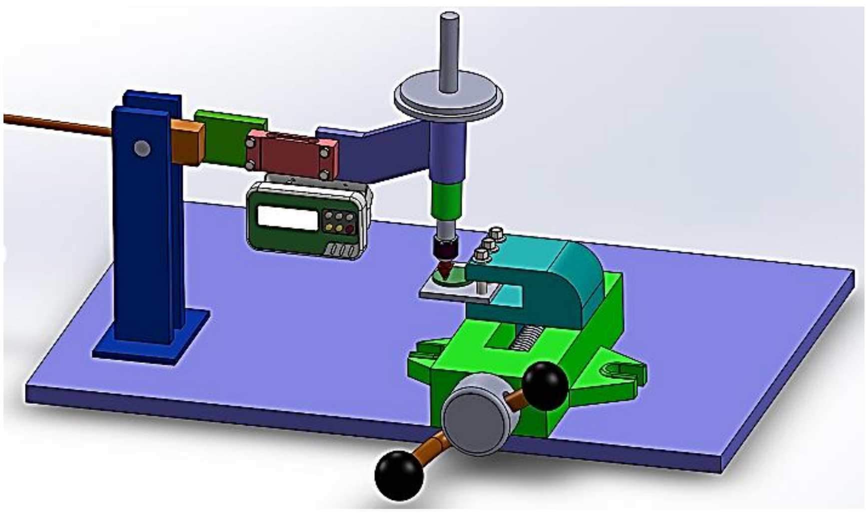

Fig. 1 Arrangement of scratch test rig.

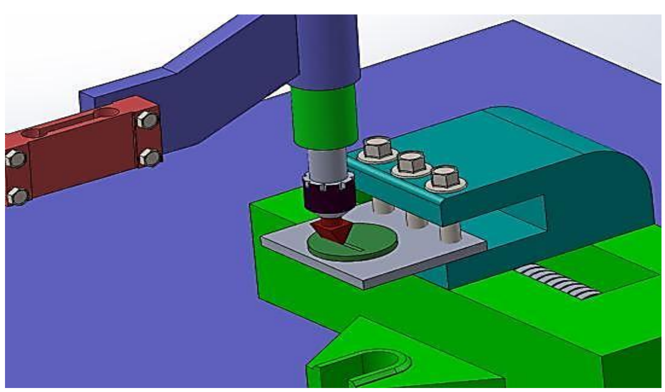

Fig. 2 Details of scratch.

RESULTS AND DISCUSSION

Experiments carried out without the application of magnetic field showed that friction coefficient displayed by the scratch of the tested nanocomposites decreased with increasing nanoparticles content at 10 N applied load, Fig. 3. The highest values were displayed by unfilled composites. Epoxy gained negative ESC, while steel indenter gained positive ESC. Therefore, material transfer from epoxy into steel surface and transfer back from steel to epoxy surface would be influenced by the resultant ESC. The suggestion of distribution of ESC on the contact surfaces is illustrated in Figs. 4, 5, 6 and 7 for unfilled epoxy, epoxy filled by Al nanoparticles, epoxy filled by Fe nanoparticles and epoxy filled by Cu nanoparticles respectively. The suggestion is based on the triboelectric series, Fig. 8. It is clearly shown that filling epoxy by aluminium displayed lower friction coefficient than observed for iron and copper filled epoxy composites. This can be attributed to the charging of aluminium by positive charge when slid against steel. Then 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. Scratch of epoxy filled by copper showed that 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. Although ESC generated during scratch of epoxy filled by Fe nanoparticles was low, friction coefficient displayed the relatively higher values.

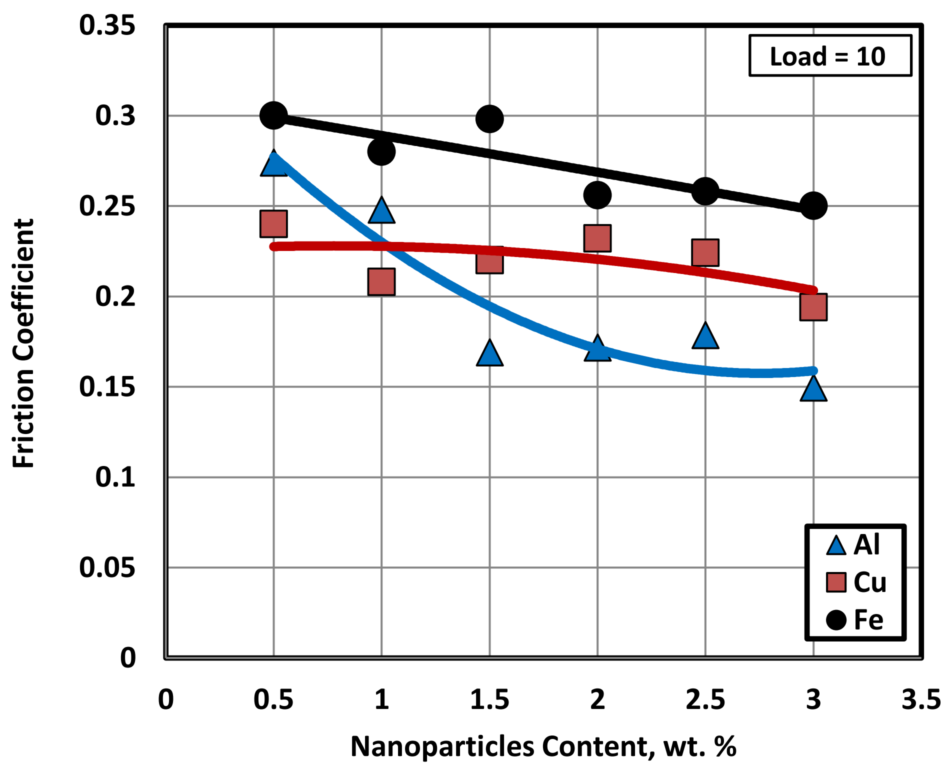

Fig. 3 Friction coefficient displayed by the scratch of tested nanocomposites.

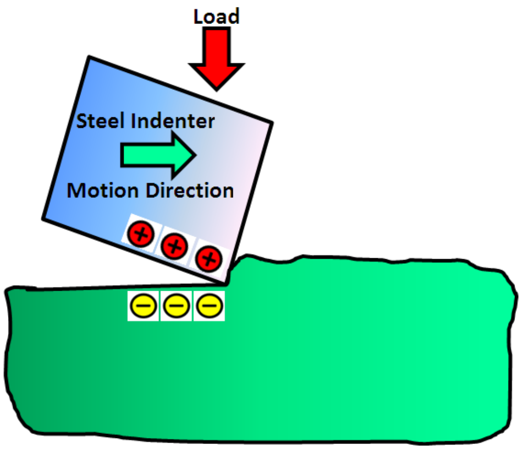

Fig. 4 ESC generated from the scratch of unfilled epoxy.

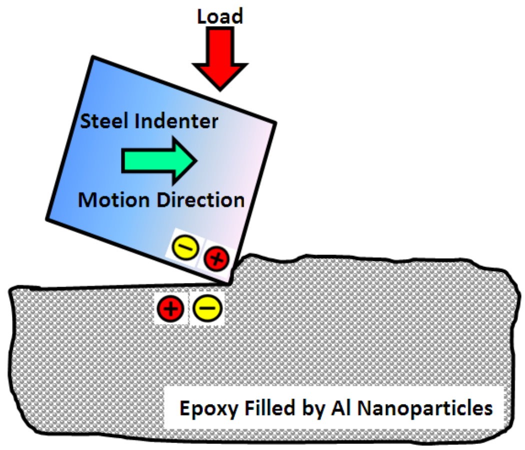

Fig. 5 ESC generated from the scratch of epoxy filled by Al nanoparticles.

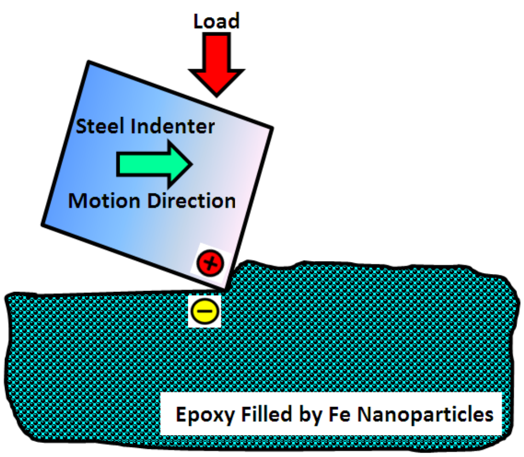

Fig. 6 ESC generated from the scratch of epoxy filled by Fe nanoparticles.

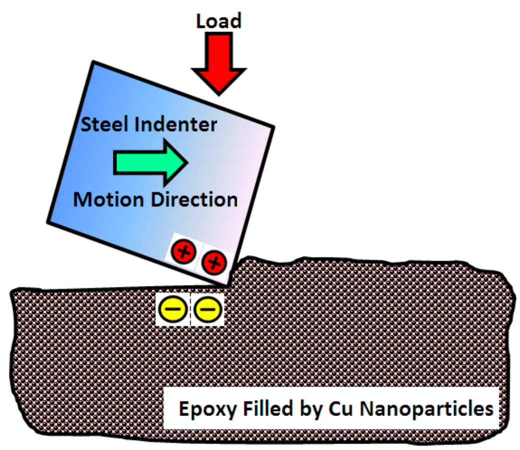

Fig. 7 ESC generated from the scratch of epoxy filled by Cu nanoparticles.

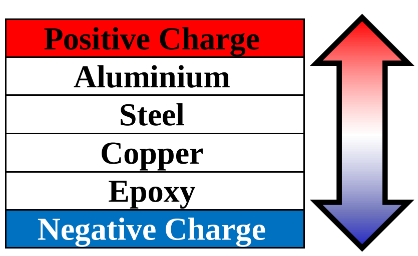

Fig. 8 Illustration of triboelectric series for tested materials.

Wear displayed by the scratch of epoxy filled by Al nonoparticles showed higher values than that observed for Fe and Cu filled epoxy. It seems that the adhesion of the worn composites into steel indenter was lower for Al filled composites, so that the cutting edge

of the steel indenter was able to abrade more epoxy from the tested composites. Besides, back transfer of worn epoxy would be retarded due to the weakness of the generated ESC during scratch. As the nanoparticles content increased wear decreased due to their effect generating ESC.

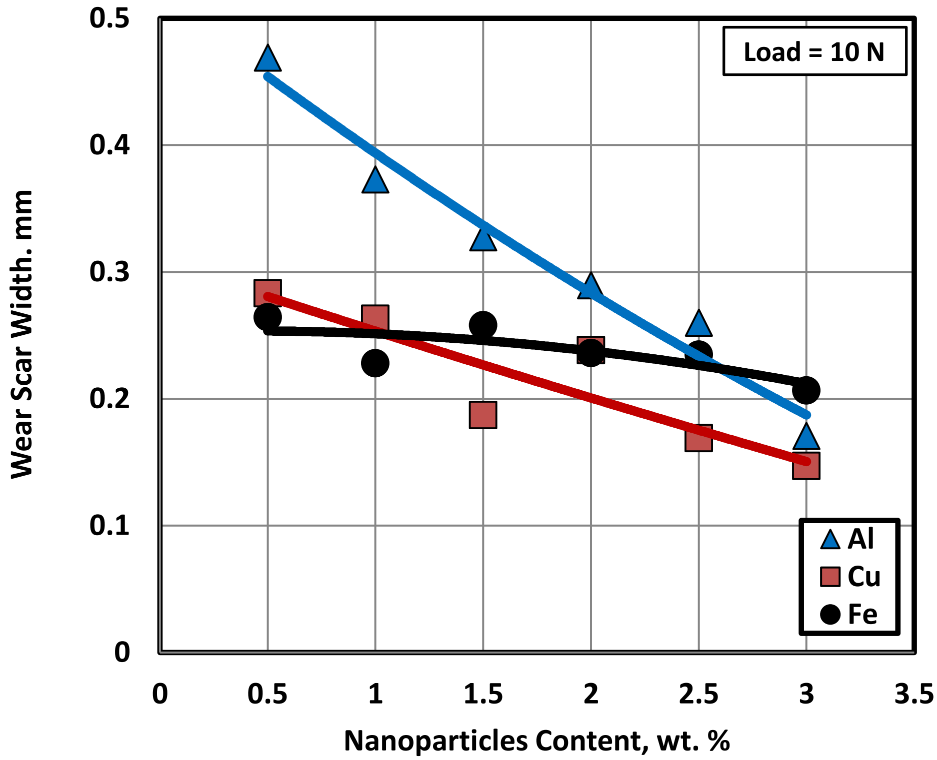

Fig. 9 Wear displayed by the scratch of the tested nanocomposites.

Friction coefficient and wear displayed by the scratch of the tested nanocomposites of 3.0 wt. % nanoparticles content under the influence of 0.6 mG magnetic field increased with increasing applied load, Figs. 10 and 11, as a result of the increased depth of the indenter edge inside the epoxy matrix, where the amount of the removed material increased. Wear displayed by the scratch of epoxy filled by Al showed lower values than that observed for epoxy composites filled by Cu and Fe. This performance could be attributed to the material transfer into the surface of the indenter from epoxy matrix. The friction decrease observed could be explained on the basis that presence of magnetic field around the contact area decreased the adherence and transfer of epoxy into the steel surface. Al and Cu are paramagnetic materials, while Fe is a magnetic one. It was found that, application of magnetic field decreased friction coefficient due to the ability of magnetic field to facilitate the formation of oxide film on the contact surface of the metallic nanoparticles, where it played a protective role and modified the friction and changes wear from severe wear to mild.

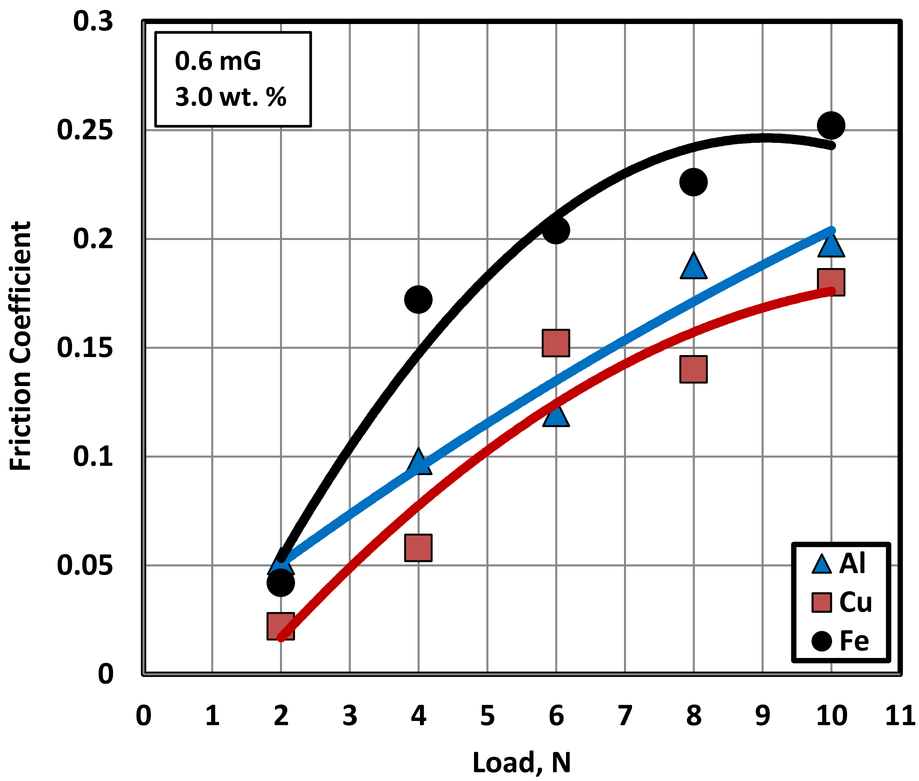

Fig. 10 Effect of load on friction coefficient displayed by the scratch of the tested nanocomposites.

Friction coefficient slightly increased with increasing the intensity of magnetic field, Fig. 12, where iron filled composites displayed the highest values. 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 surface of the indenter. Increasing the intensity of the magnetic field showed significant friction increase. 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. The maximum values of friction coefficient observed was 0.3 at intensity of magnetic field of 0.6 mG for iron filled epoxy, while at no magnetic field the value did not exceed 0.21. The indenter as magnetic material strongly attracted the removed epoxy composites into its surface. In addition to that, the relative motion of the indenter against the epoxy composites generated an electric current which affected the intensity of ESC on the contact area. Increasing the intensity of the magnetic field would increase the magnetic force that enabled the transferred epoxy to be strongly adhered into the steel indenter.

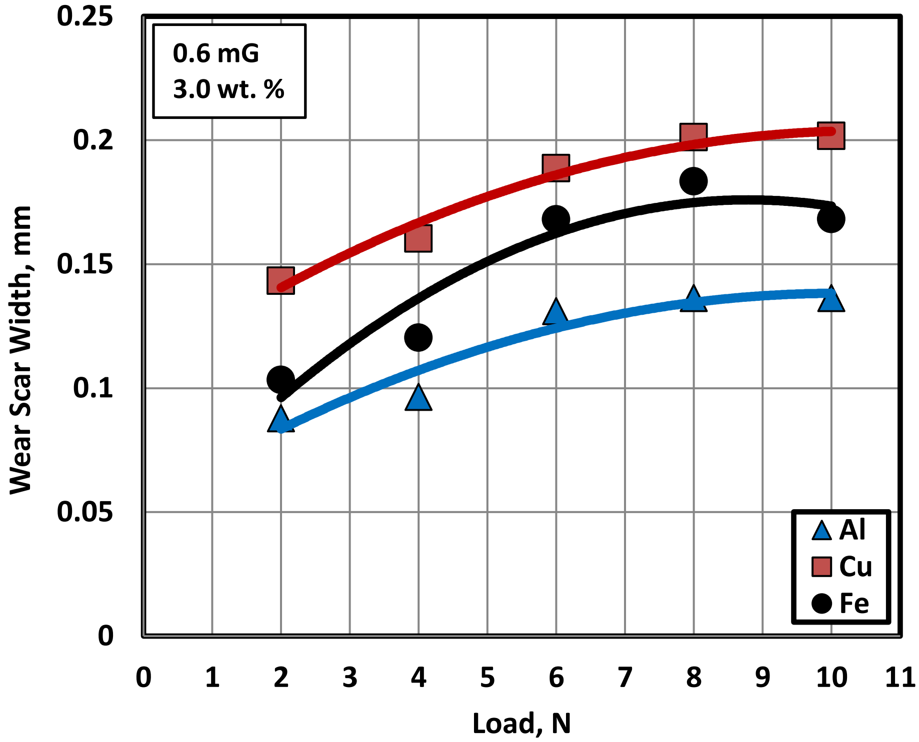

Fig. 11 Effect of load on wear displayed by scratch of tested nanocomposites.

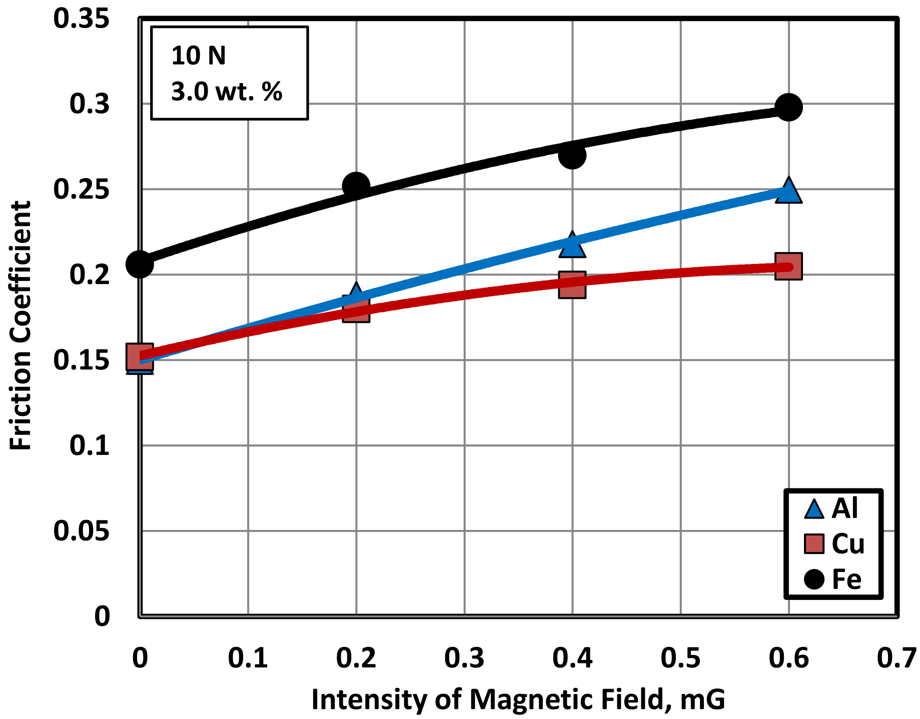

Fig. 12 Effect of magnetic field on friction coefficient displayed by the scratch of the tested nanocomposites.

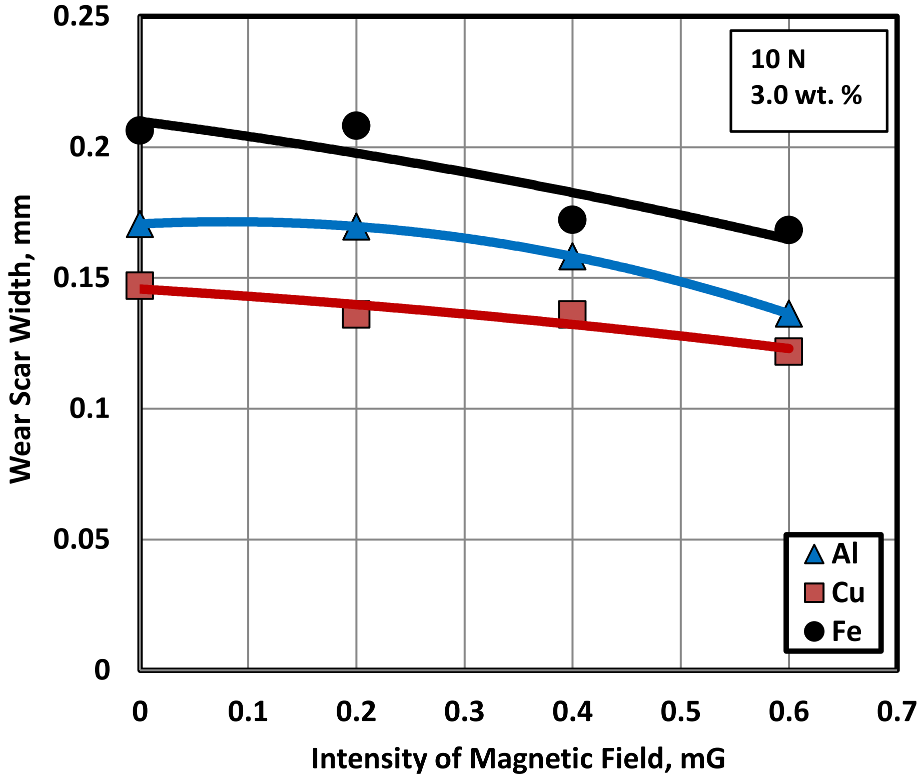

Fig. 13 Effect of magnetic field on wear displayed by scratch of the tested nanocomposites.

Presence of the magnetic field might generate electric current at the contact area leading to an increase in the intensity of ESC. The removed epoxy filled by copper adhered strongly into the steel surface and decrease the ability of the indenter to scratch the composites and consequently wear decreased, Fig. 13. It is supposed that presence of magnetic field followed by the movement of the indenter in the epoxy composites generated electric current which caused softening of the epoxy composites. In that condition removal of epoxy from the wear track and transfer back into the composites surface were easier and consequently wear decreased. Besides, the attractive force between the removed material and steel surface increased in a manner that the cutting of the steel indenter became less abrasive. Increasing the intensity of the magnetic field showed slight decrease in wear. Based on this observation, it could be supposed that as the magnetic field increased the rubbing process breaks up the polymer surface and liberates electrons and ions. They react with the metal nanoparticles to form oxide films that lead to low wear value. In a magnetized sliding contact, metallic nanoparticles are transferred from composites surface to indenter. The ferromagnetic character of the nanoparticles has significant influence on the wear of the surface. The decrease of wear rate under magnetic field was resulted from the adhesion of oxidized wear particles into the sliding surface and decreased wear.

CONCLUSIONS

1. Friction coefficient displayed by the scratch of the tested nanocomposites decreased with increasing nanoparticles content at no magnetic field. The highest values were displayed by unfilled composites. Filling epoxy by aluminium displayed lower friction coefficient than observed for iron and copper filled epoxy composites. Epoxy filled by Fe nanoparticles displayed the relatively higher values of friction coefficient, while wear showed higher values than that observed for Fe and Cu filled epoxy.

2. Friction coefficient and wear under the influence of magnetic field increased with increasing applied load.

3. Friction coefficient slightly increased with increasing the intensity of magnetic field, where Fe filled composites displayed the highest values. Wear showed slight decrease with increasing the intensity of magnetic field.

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