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FRICTION COEFFICIENT OF EPOXY COMPOSITES FILLED BY METALLIC PARTICLES AND REINFORCED BY WIRES

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ABSTRACT
The present work investigates the effect of applying direct current electric voltage to the sliding surfaces on the friction coefficient displayed by epoxy composites sliding against dry and water wetted steel surface. Iron and copper particles and wires were used to fill and reinforce epoxy matrix.

It was found that, when no voltage was applying on the contact surfaces friction coefficient of the epoxy composites displayed the highest values. As the voltage was applied to the contact surfaces friction coefficient significantly decreased. Significant friction decrease was observed for epoxy composites filled by graphite. PTFE addition into epoxy composites displayed further friction decrease. As the voltage increased friction coefficient decreased, where the same trend was observed regardless the voltage charge. In the presence of water on the sliding surfaces the effect of graphite diminished, where water exchanged the electric static charge between the two sliding surfaces. As the voltage increased friction coefficient drastically decreased. Based on the low value of friction it is recommended to use this sliding condition in application.

Composites reinforced by iron wires displayed drastic decrease in friction coefficient, while slight friction increase was accompanied to the performance of composites filled by iron particles. Reinforcing epoxy by copper wires displayed relatively lower friction values than that observed for composites reinforced by iron wires. In the presence of water on the sliding surfaces, significant friction increase was observed for composites reinforced by iron wires and iron particles. As the voltage increased friction coefficient significantly increased. Based on these observations it can be recommended to avoid the application of those composites when water is the lubricating medium. Friction coefficient of the tested composites reinforced by copper wires showed lower values than that observed for iron wires.

KEYWORDS
Friction coefficient, epoxy, iron, copper, particles, wires, dry, water wetted sliding.

INTRODUCTION
In friction process, the presence of attractive force, generated from the electric static charges, can increase or decrease the normal applied load on the contact surface in a manner that influences the friction coefficient. The effect of applying external voltage on the sliding of copper, aluminium, and polyethylene (PE) against steel surface lubricated

by paraffin oil dispersed by polymeric particles such as PE, polyamide (PA), and polymethylmethacrylate (PMMA) was discussed, [1]. Friction coefficient and wear were significantly influenced by the generation of electric static charge on the contact surfaces, which caused an attractive force imposed to the normal load. The effect of the external voltage on generating electric static charge is higher than friction. Among the polymeric particles, crystalline polymers such as PE and PA perform more effectively than glassy polymers such as PMMA.

It has been observed that friction and wear behaviour of two components sliding against each other can be greatly influenced by an externally applied electrostatic field or electric current. It was observed that under boundary lubrication conditions in a ball-on-disc machine [2 - 5] during sliding of steel pairs in the presence of an additive-free mineral oil, the friction coefficient decreased but the ball wear increased when the disc was at a higher potential than the ball compared to the condition when no current passed. The decrease in friction coefficient was concluded to be because of the formation of a thin passivation layer on the disc surface. With continued sliding, damage to the passivation layer led to increased friction coefficient.

In the mixed lubrication regime, removal of the electric field decreased the friction coefficient compared to when no current passed through the contact. The effect of an applied electric field on the running in operation of a roller bearing was investigated [6]. In the mixed lubrication regime, when the bearing was the anode, the friction coefficient increased and also the bearing temperature increased and showed signs of seizure. The bearing surface was oxidized as would be expected, because of an anodic reaction. However, when the bearing was cathode, the friction coefficient rapidly decreased and so did the bearing temperature. The effect of additives in highly refined paraffinic base stocks on wear under the influence of an electric current was also investigated [7]. The addition of a sulphur compound decreased wear on the cathodic surface and increased wear on the anodic surface. However, addition of a phosphate compound (tricresylphosphate) decreased wear of both cathodic and anodic surfaces. These effects were explained by electrochemical reactions of additives on sliding surfaces.

The influence of electric field has also been observed to reduce friction and wear for sliding of two dissimilar materials, [8, 9]. The friction and wear behaviour of a steel pair when an electric current was passed through the contact in the presence of fully formulated engine oils was discussed [10]. The passage of electric current changed friction coefficient only to a small degree but the wear was impacted significantly. The wear changed by two to three orders of magnitude depending on the direction of current flow. The current level also played an important role in the magnitude of wear observed on surfaces.

Experimental results showed that the presence of electric current and magnetic field around the tribocontact modifies the mechanical properties of the surface and subsurface [11, 12]. The mean friction coefficient changes from 0.16 without electric current and magnetic field to 0.26 with them, and its variation reduces considerably. The worn surfaces were smoother with magnetic field application than that without it, and the modification of subsurface structure was observed. The magnetic field and the electric current modify the mechanical and chemical properties of this ferromagnetic material in the sliding contact by interaction with cyclic contact stresses and increasing the temperature on the contact surface. This interaction was characterized by an

increase in the microhardness, the activation of oxidation on the surfaces, the difference of contact noise level, and the changes induced in subsurface structure.

Magnetostriction or deformation of material took place during the application of the magnetic field [13]. An electric current crossing a sliding couple affects the surface temperature, the oxidation, and the contact behaviour. The magneto-tribological interaction of materials was investigated particularly for braking and cutting tools to increase their lifetime and to improve the surface quality after machining [14]. It has been observed that the friction behaviour of ferromagnetic and non-ferromagnetic metals was modified in the presence of a direct current (DC) magnetic field. The effects induced by a simultaneous application of a DC electric current and an alternating current (AC) magnetic field on the surface and subsurface modifications of the ferromagnetic contact couple steel/steel were presented. The application of the electric field induces an interfacial polarization on the particle owing to a mismatch of the dielectric constant between the particle and the liquid, and the polarization thus induced on the particle plays a role to form a chain-like structure along the electric field, leading to the increase in the viscosity of the suspension.

The effects of external electric fields on frictional behaviours of Al_2O_3/brass, Al_2O_3/stainless steel, and Al_2O_3/carbon steel couples under boundary lubricating conditions were studied on a self-made plate/plate-type tribotester, [15]. The experimental results showed that external electric fields affect the friction coefficient and its fluctuation of each rubbing couple substantially.

It was found that friction and wear were attributed to the migration of electrons across the interfaces of metals with different work functions. Indeed reduction in friction coefficient has been verified by canceling out the self-generated electric potential across a dry metallic contact with an external voltage. It was found that the difference in the orientations of function groups of polymers under different electric fields influences the intensity and the direction of interfacial forces between polymer and metal surfaces [16]. The apparent friction coefficient was changed by reversing the polarity of the external electric field because of the change in real normal pressure. The results showed that the change in friction coefficient can reach up to ±25 per cent. An extraordinary change in friction coefficient of graphite/graphite rubbing couples was discovered [17] under a large DC current at a critical sliding speed, jumping from a high value (about 0.7) to a low value (about 0.07) as rubbing slows down or from the low value to the high value as rubbing speeds up. It was found that for intentionally insulated metallic contacts lubricated with liquid crystals, the relative friction coefficient under boundary lubrication conditions can be reduced by up to 35 per cent by applying an external DC electric field [18]. 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 [19, 20]. It was reported that an AC voltage has effects on lubricating ability of synovia constituents [21]. It was observed that for Al_2O_3/brass couple lubricated with emulsion of zinc stearate, the change in friction coefficient because of an external DC voltage is not only remarkable, reaching 200 per cent, but also quick and reversible [22, 23]. Besides, friction coefficient of Al_2O_3/brass couple increased with increasing external electric field intensity.

In the present work, the effect of applying electric voltage on the friction coefficient displayed by epoxy composites filled by metallic particles and reinforced by metallic wires sliding against dry and water wetted steel is investigated.

EXPERIMENTAL

Experiments were carried out using a pin-on-disc wear tester. It consists of a rotary horizontal steel disc driven by a variable speed motor. The details of the wear tester are shown in Fig. 1. The test specimen is held in the specimen holder fastened to the loading lever through load cell, where friction force can be measured. Friction coefficient was determined through the friction force measured by the deflection of the cell. The load is applied by weights. The counterface in the form of a steel disc, of 100 mm outer diameter, was fastened to the rotating disc. Its surface roughness (Ra) was about 3.2 µm. Test specimens were prepared in the form of cylindrical pins of 8 mm diameter and 30 mm long. The test specimens were loaded against counterface of a carbon steel disc (1.16 wt. % C, 0.91 wt. % Si, 1.65 wt. % Mn, 0.52 wt. % Cr, and 95.5 wt. % 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 for 300 s.

The material of the matrix of test specimens was epoxy. The reinforcing materials were rods of graphite, wires of iron and copper as well as fibres of PTFE. The epoxy matrix was filled by particles of iron and copper of 30 – 50 µm particle size. The content of the filling and reinforcing materials were 0, 5, 10, 15, 20 and 25 wt. %. The two ends of the tested composites were polished before the test by cotton textile. The surface roughness (Ra) of contact surfaces of the tested pins was approximately 3.2µm. DC electric voltage of 0, 1.5, 3, 4.5, 6 and 7.5 volts was connected to the test specimens through the specimen holder and the steel disc through the bearing (Fig. 2). The polarity of the current was changed to allow the test specimens to be anode and cathode. Distilled water was used as lubricant.

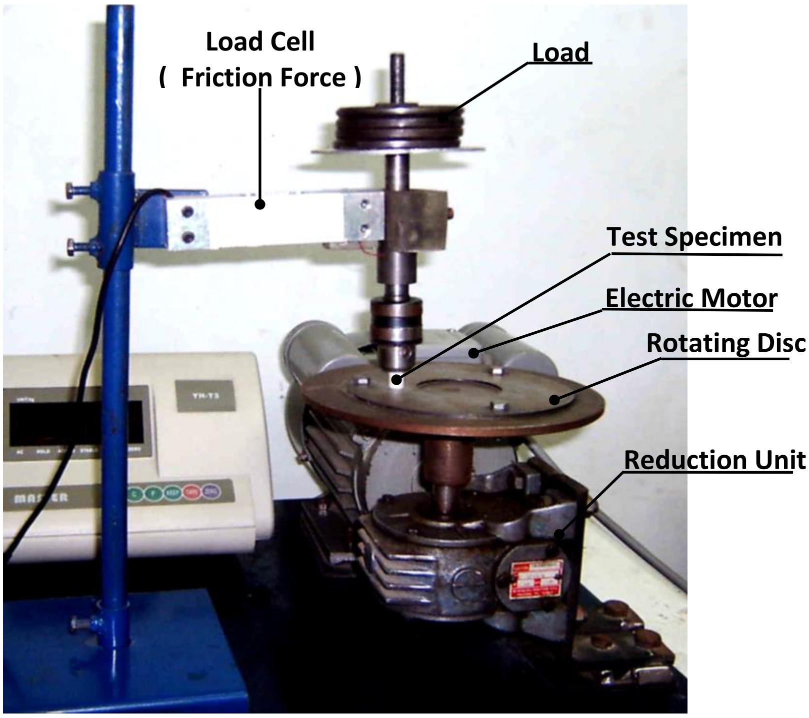

Fig. 1 Arrangement of the test rig.

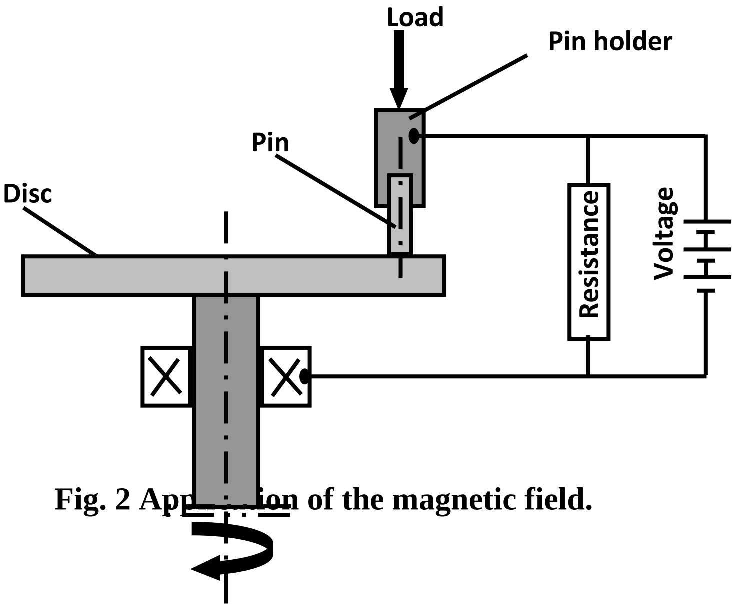

Fig. 2 Application of the magnetic field.

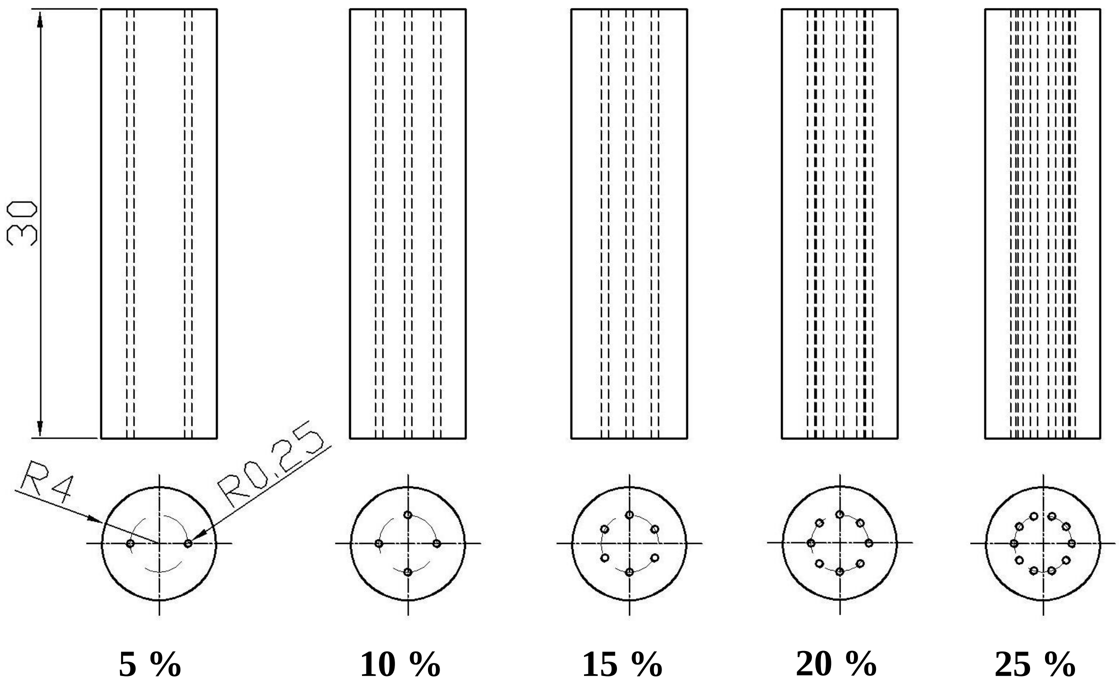

Fig. 3 Distribution of the metallic wires in the matrix of the tested composites.

RESULTS AND DISCUSSION

Friction coefficient of epoxy composites sliding against dry steel disc is shown in Fig. 4. It is clearly seen that at no voltage applying on the contact surfaces, friction coefficient displayed the highest values. Epoxy free of filling materials displayed the highest friction coefficient. As the voltage was applied to the contact surfaces, friction coefficient significantly decreased. To explain the frictional behavior, three conditions would be considered. The first when there was no voltage applying on the contact surface. In this condition, steel disc gained positive charge, while epoxy composite surface gained negative charge. The worn layer of epoxy composite was strongly adhered to the steel

disc so that the contact was epoxy/epoxy and consequently friction coefficient displayed relatively higher values.
The second condition when positive voltage was applying to steel surface. The positive charge gained by steel surface increased as a result of friction against epoxy. Epoxy gained negative charge from friction against steel and at the same time gained positive charge from the contact with steel surface. The resultant of the charge gained by epoxy surface would be minimum. Based on that assumption epoxy transfer into steel surface would be minimum and the contact would be epoxy/steel.

The third condition was when steel surface was connected to negative voltage. In that condition the negative charge will be neutralized by the positive charge gained from friction of steel against epoxy. Like the second condition, epoxy transfer into steel surface would be weak and the contact was epoxy/steel.

Filling epoxy composites by 10 wt. % graphite caused significant friction decrease. This behavior might be attributed to the common good electrical conductivity of graphite which decreased the charge generated on the contact surfaces by conducting the charge from one surface to another. Presence of graphite would decrease epoxy transfer into steel surface so that the value of friction coefficient decreased. This performance might be from the electrical conductivity of graphite which exchanged the negative and positive charges formed on the two rubbing surfaces. The voltage increase could accumulate the graphite particles to be adhered to the rubbing surfaces decreasing the ability of epoxy to transfer to the steel surface. This explanation could interpret the friction decrease with voltage increase.

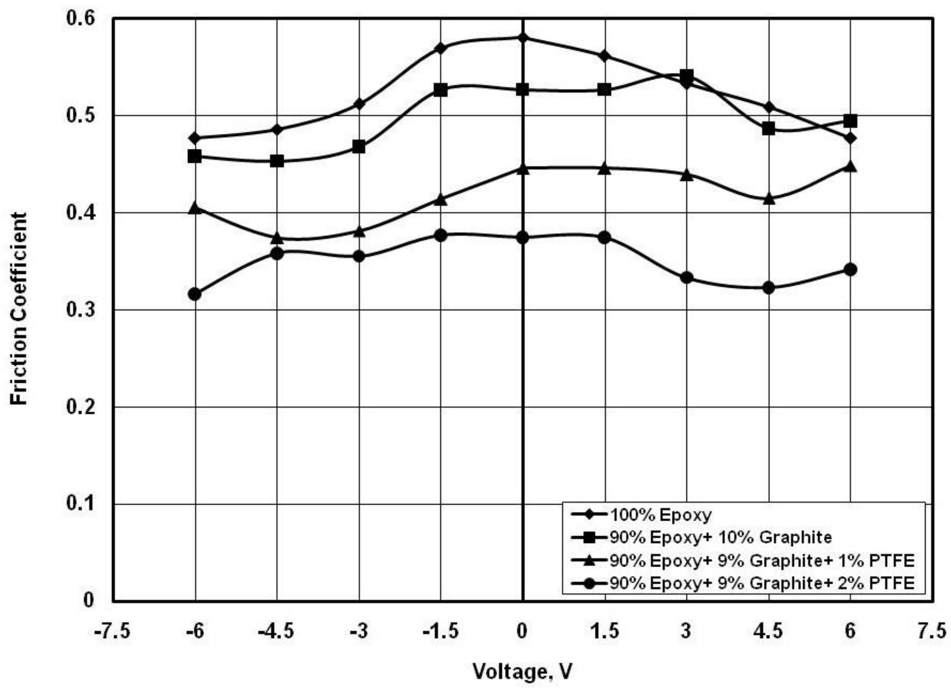

Fig. 4 Friction coefficient of the tested composites sliding against dry steel.

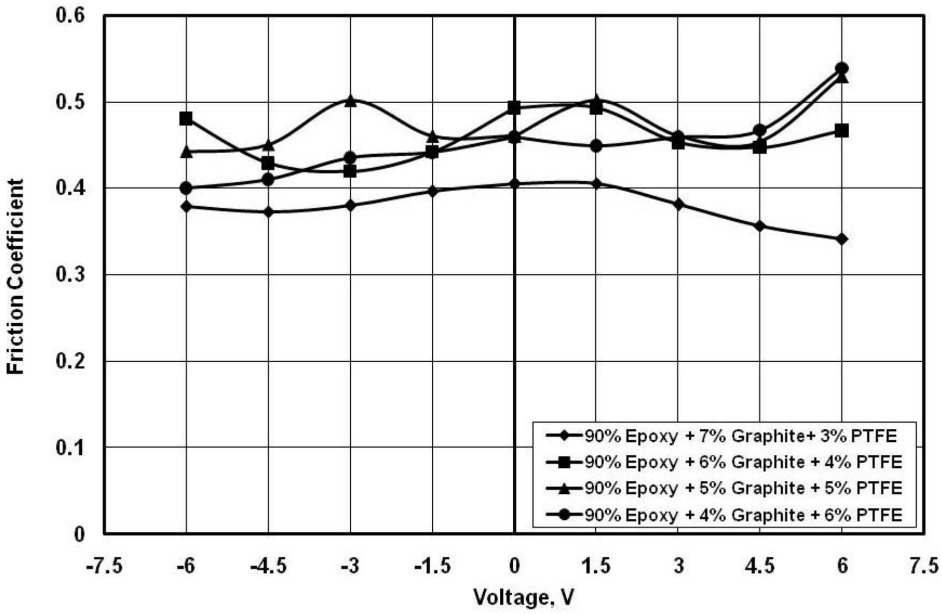

Fig. 5 Friction coefficient of the tested composites sliding against dry steel.

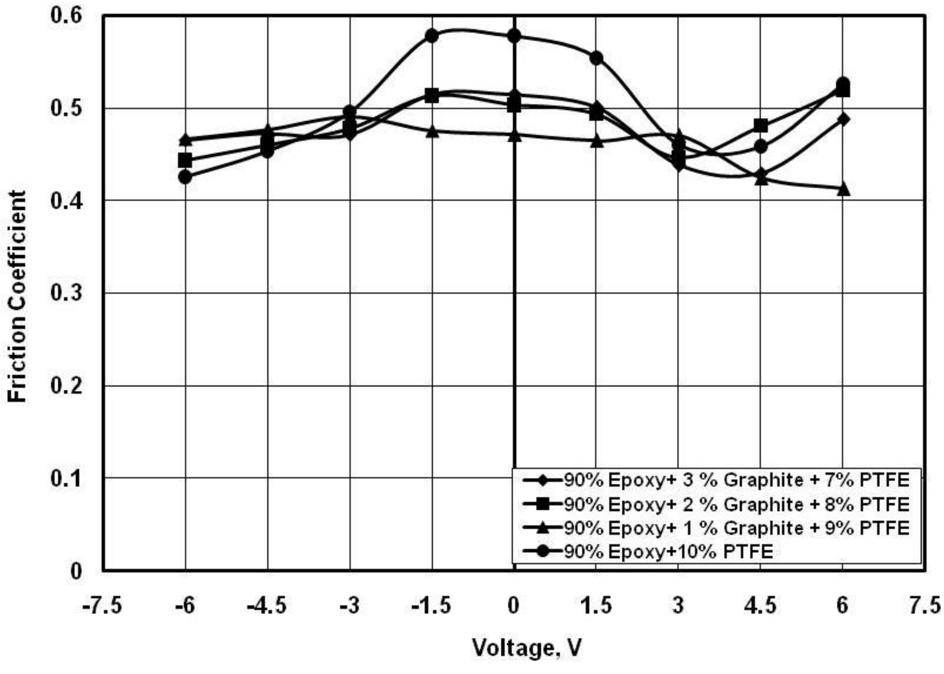

Fig. 6 Friction coefficient of the tested composites sliding against dry steel.

PTFE addition into epoxy composites displayed further friction decrease. The mechanism of action of PTFE depends on its relatively low friction coefficient and its ability to gain relatively high negative charge generated from friction. It was expected that the presence of PTFE would increase the negative charge gained by epoxy. Increasing PTFE content showed an increasing trend of friction coefficient due to the decrease of graphite content, Fig. 5. This behaviour could be attributed to increase of the negative static charge gained by PTFE which would be superimposed on the charge

gained by epoxy so that epoxy transfer to steel surface will be accelerated and the contact would be epoxy/epoxy leading to significant friction increase. Further increase of PTFE content in epoxy composites showed significant friction increase, Fig. 6. As the voltage increased friction coefficient decreased due to the drop in the adhesion force of the transfer layer into the steel surface. The same trend was observed for the positive and negative voltage.

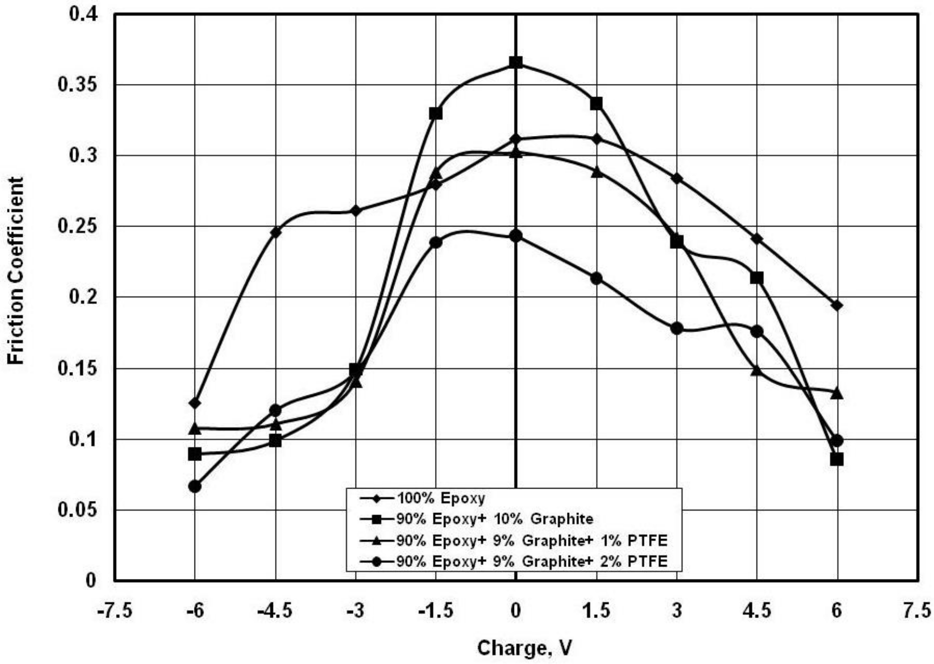

Fig. 7 Friction coefficient of the tested composites sliding against water lubricated steel.

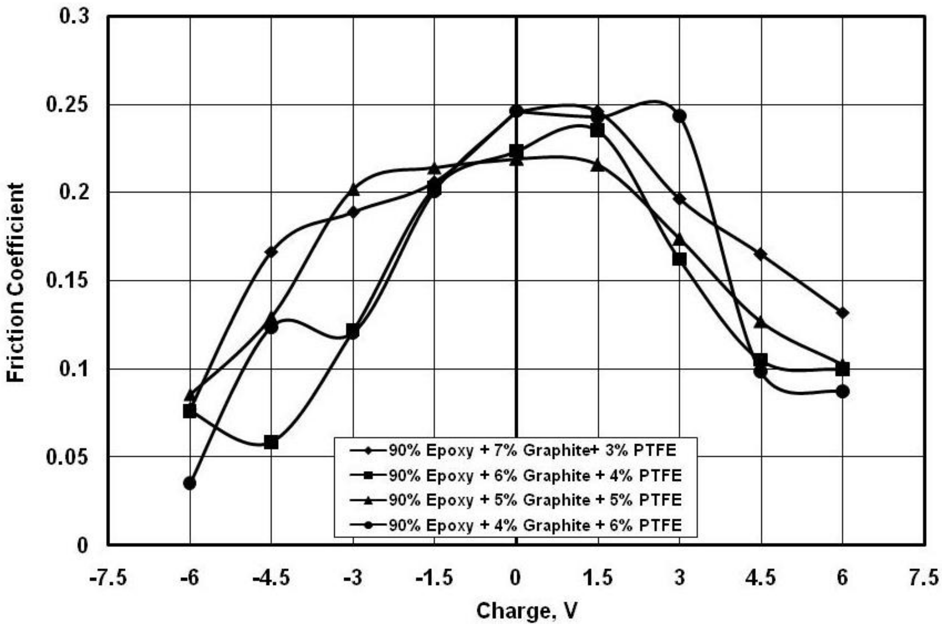

Fig. 8 Friction coefficient of the tested composites sliding against water lubricated steel.

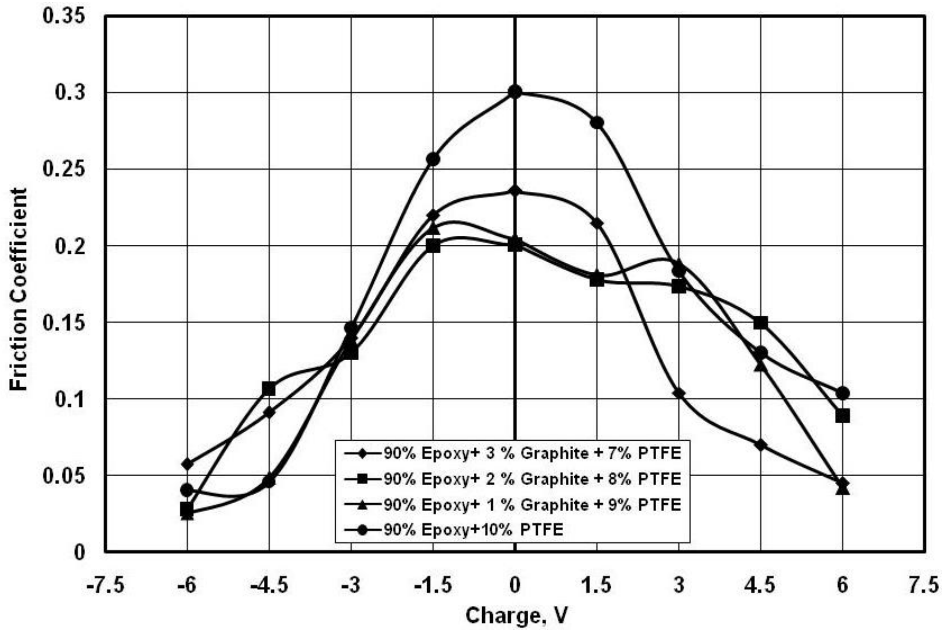

Fig. 9 Friction coefficient of the tested composites sliding against water lubricated steel.

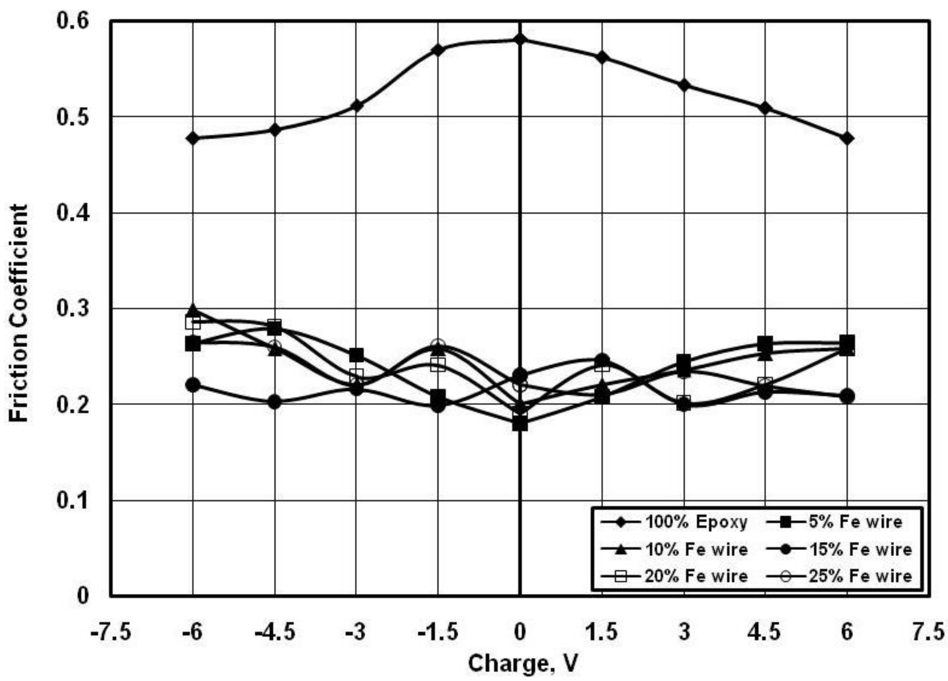

Fig. 10 Friction coefficient of the tested composites reinforced by iron wires dry sliding against steel.

In the presence of water on the sliding surfaces the effect of graphite was diminished, Figs. 7 – 9, where water exchanged the electric static charge between the two sliding surfaces. Composites containing 10 wt. % graphite displayed relatively higher friction coefficient than 100 wt. % epoxy. As the voltage was applied on the sliding surfaces, friction coefficient drastically decreased. Friction coefficient remarkably decreased with increasing PTFE content. As the voltage increased friction coefficient drastically

decreased, where the value was 0.06 at - 6 volts. Based on the low value of fiction it is recommended to use this sliding condition in application.

Composites reinforced by iron wires displayed drastic decrease in friction coefficient, Fig. 10, although that the friction of the wires against steel should gave relatively higher friction. It may be from the ability of iron wires to abrade the epoxy layer transferred and adhered into the steel surface. The other reason for the friction decrease might be from the electrical conductivity of the wires so that the electric static charges generated on the two sliding surfaces were neutralized. This behaviour effectively decreased the adherence of epoxy worn particles into the steel surface. The wire content showed insignificant effect on friction coefficient. As the voltage increased friction coefficient slightly increased. The behaviour might be from the electric forces generated from the electric static charge.

Slight friction increase was accompanied to the performance of composites filled by iron particles, Fig. 11. The friction increase might be from relatively lower electrical conductivity of iron particles compared to the wires. The same trend observed for iron wires is shown for iron particles. It seems that filling epoxy by iron particles decreased the adherence of epoxy in steel surface. Slight friction increased was noticed with increasing voltage. The increase is higher than that observed for iron wires.

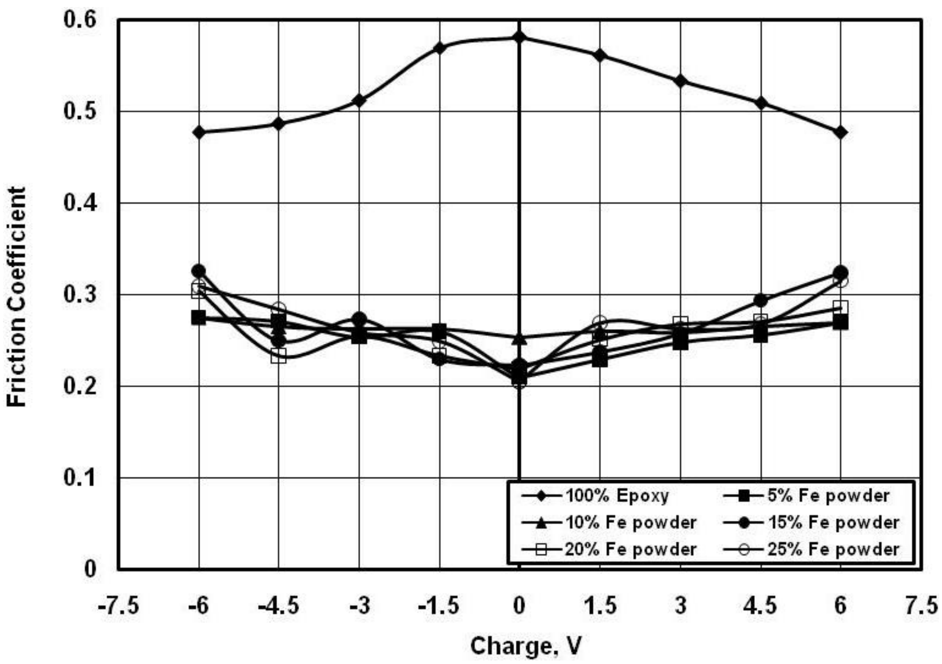

Fig. 11 Friction coefficient of the tested composites filled by iron particles dry sliding against steel.

Reinforcing epoxy by copper wires displayed relatively lower friction values than iron wires, Fig. 12. The minimum friction values were observed at zero voltage then slightly increased with increasing voltage. Generally the difference in friction caused by copper wire reinforcement was very high. This observation confirms the application of those composites. Friction increase was observed as voltage increased which could be attributed to the electric force that attracted the two sliding surfaces. It seems that

copper wires generated higher force than iron wires. The same trend was observed for the tested composites reinforced by copper particles, Fig. 13, where friction coefficient showed relatively low values.

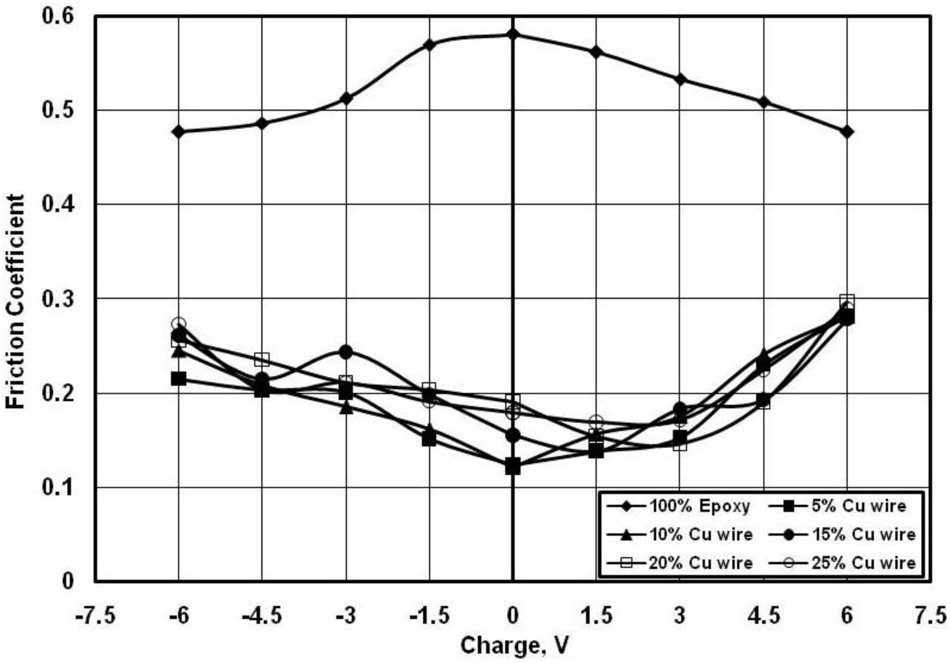

Fig. 12 Friction coefficient of the tested composites reinforced by copper wires dry sliding against steel.

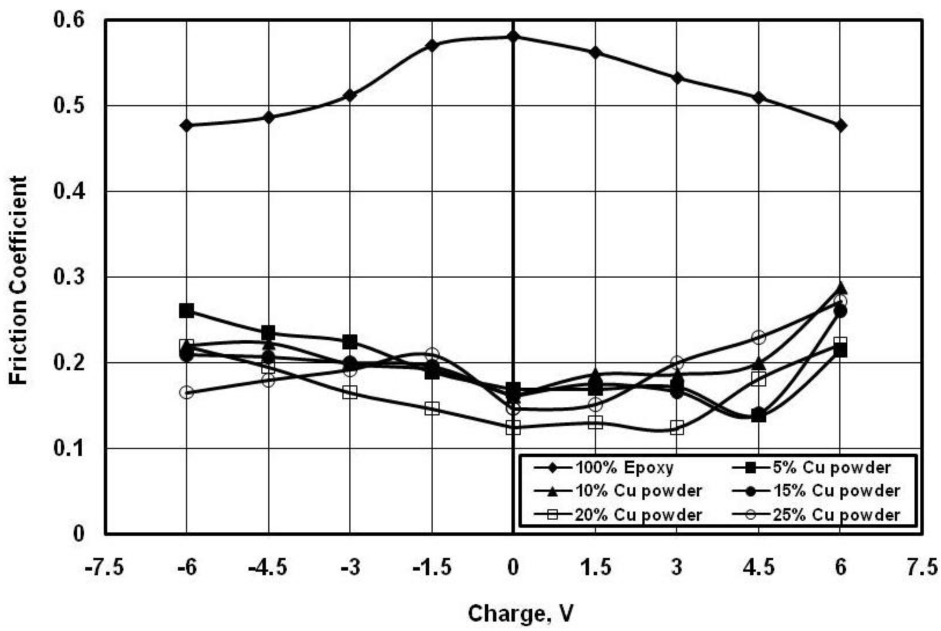

Fig. 13 Friction coefficient of the tested composites filled by copper particles dry sliding against steel.

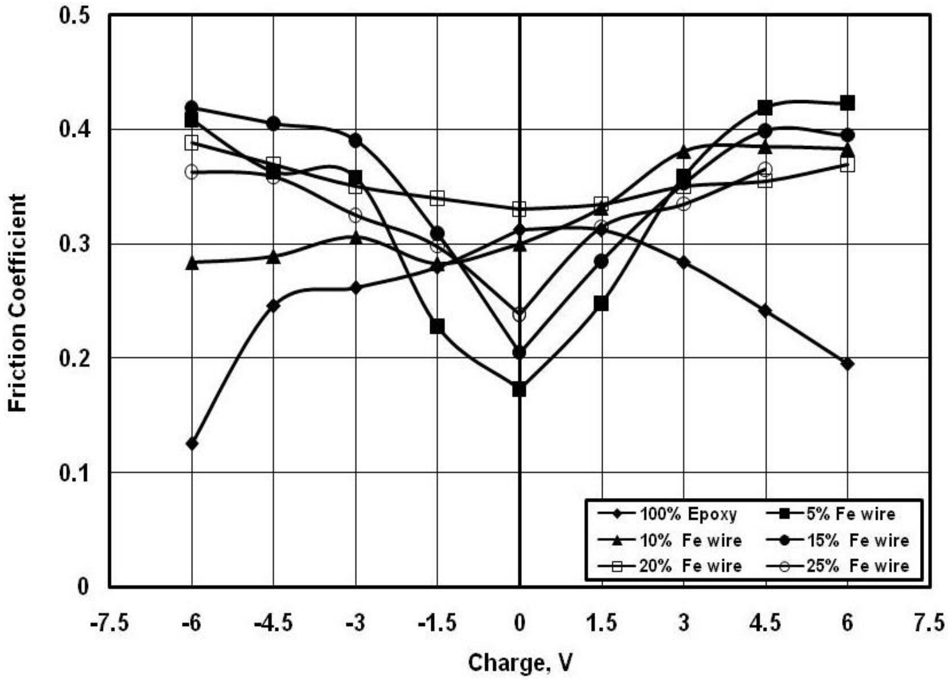

Fig. 14 Friction coefficient of the tested composites reinforced by iron wires sliding against water wetted steel.

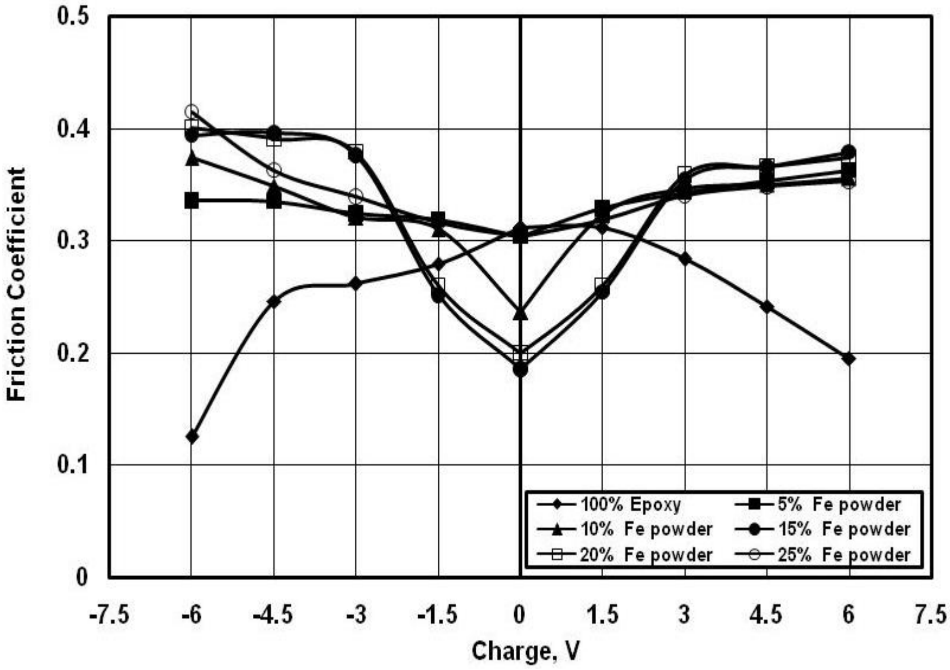

Fig. 15 Friction coefficient of the tested composites filled by iron particles sliding against water wetted steel.

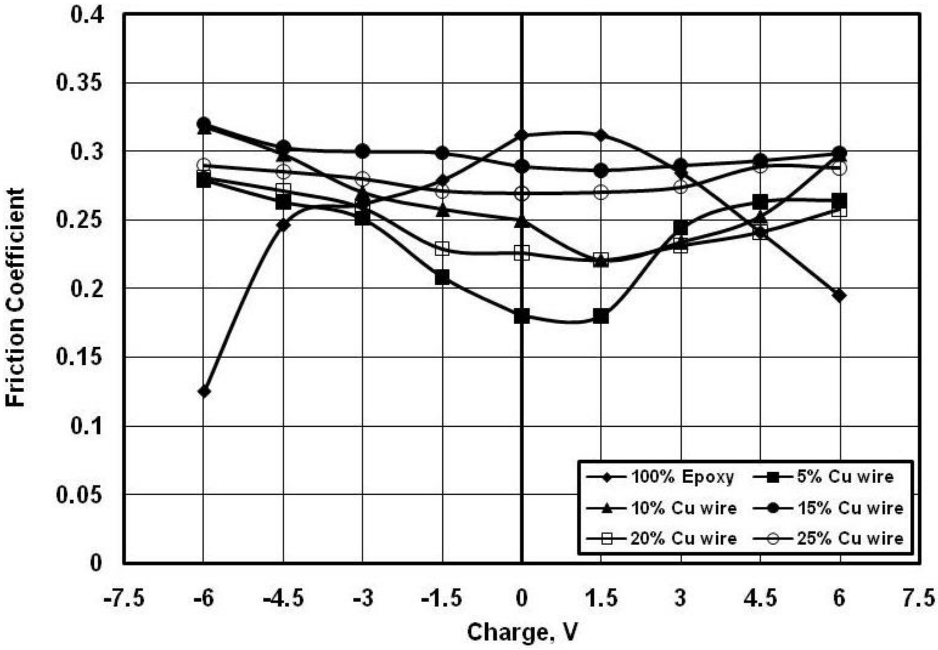

Fig. 16 Friction coefficient of the tested composites reinforced by copper wires sliding against water wetted steel.

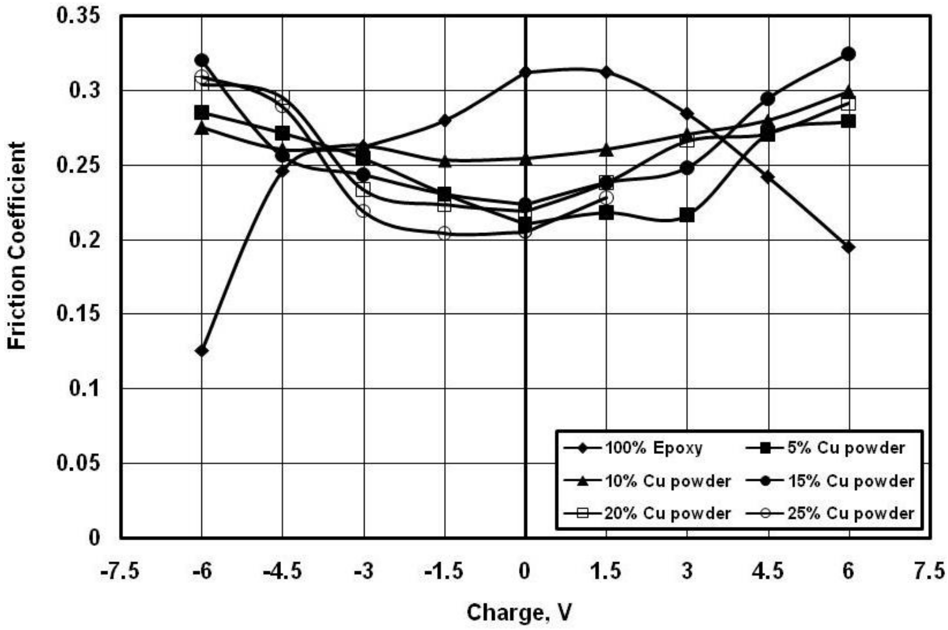

Fig. 17 Friction coefficient of the tested composites filled by copper particles sliding against water wetted steel.

In the presence of water on the sliding surfaces significant friction increase was observed, Fig. 14. It seems that the good electrical conductivity of water neutralized the electric static charge formed on the two sliding surfaces. The role of iron wires was to increase the strength of epoxy composites and to abrade the transferred epoxy layer to the steel surface. As the voltage increased friction coefficient significantly increased. The friction increase can be explained on the fact that the adherence of worn epoxy particles increased with increasing the voltage. The same trend was observed for composites filled

by iron particles with relatively lower friction values, Fig. 15. Based on these observations it can be recommended to avoid the application of those composites where water is the lubricating medium.

Friction coefficient of the tested composites reinforced by copper wires sliding against water wetted steel, Fig. 16, showed lower values than that observed for iron wires. At low voltage, composites reinforced by copper wires showed friction lower than unreinforced composites. As voltage increased reinforced composites displayed higher friction. The same trend was shown for the tested composites filled by copper particles, Fig. 17, where the friction values were relatively higher.

CONCLUSIONS

1. Friction coefficient of epoxy composites sliding against dry steel disc displayed the highest values when no voltage was applying on the contact surfaces. Epoxy free of filling materials displayed the highest friction coefficient. As the voltage was applied to the contact surfaces friction coefficient significantly decreased.

2. Filling epoxy composites by graphite caused significant friction decrease. PTFE addition into epoxy composites displayed remarkable friction decrease. Increasing PTFE content showed an increasing trend of friction coefficient due to the decrease of graphite content. Further increase of PTFE content in epoxy composites showed significant friction increase. As the voltage increased friction coefficient decreased. The same trend was observed for the positive and negative voltage.

3. In the presence of water on the sliding surfaces the effect of graphite was diminished, where water conducted the electric static charge between the two sliding surfaces. Friction coefficient remarkably decreased with increasing PTFE content. As the voltage increased friction coefficient drastically decreased. Based on the low value of fiction it is recommended to use this sliding condition in application.

4. Composites reinforced by ion wires displayed drastic decrease in friction coefficient. The wire content showed insignificant effect on friction coefficient. As the voltage increased friction coefficient slightly increased. Slight friction increase was accompanied to the performance of composites filled by iron particles. Slight friction increase was noticed with increasing voltage. The increase is relatively higher than that observed for iron wires.

5. Reinforcing epoxy by copper wires displayed lower friction values than iron wires. The minimum friction values were observed at zero voltage then slightly increased with increasing voltage. The difference in friction caused by copper wire reinforcement was very high. This observation recommends the application of those composites.

6. In the presence of water on the sliding surfaces significant friction increase was observed for composites reinforced by iron wires and the others filled by iron particles. As the voltage increased friction coefficient significantly increased. Based on these observations it can be recommended to avoid the application of those composites where water is the lubricating medium. Friction coefficient of the tested composites reinforced by copper wires showed lower values than that observed for iron wires.

REFERENCES

1. Mahmoud M. M., Mohamed M. K. and Ali W. Y., "Tribological behaviour of the contact surface in the presence of electric current", IME, Journal of Engineering Tribology, Vol. 224 No J1 2010, pp. 73 – 79, (2010).

2. Gangopadhyay, A., Barber, G., and Zhao, H., "Tool wear reduction through an externally applied electric current", Wear, 2006, 260, pp. 549 – 553, (2006).

3. Magda S., Khashaba M. I. and Ali W. Y., "Dry Sliding of Polyester Composites Filled by Nanoparticles Against Steel", Journal of the Egyptian Society of Tribology Vol. 9, No. 2, April 2012, pp. 43 – 59, (2012).
4. Magda S., Khashaba M. I. and Ali W. Y., "Oil Lubricated Sliding of Polyester Composites Filled by Nanoparticles Against Steel", Journal of the Egyptian Society of Tribology Vol. 9, No. 2, April 2012, pp. 60 – 75, (2012).
5. Yamamoto, Y., Ono, B., and Ura, A., "Effect of applied voltage on friction and wear characteristics in mixed lubrication. Lubr. Sci., 1996, 8, pp. 199 – 207, (1996).
6. Takeuchi, A. Various tribological phenomena in current flow. Part 3: control of running-in by application of electric field. Jpn. J. Tribol., 1996, 41, pp. 735 – 744, (1996).
7. Katafuchi, T., "Effects of electric current on wear under lubricated conditions", JSLE, 1985, 30, pp. 887 – 893, (1985).
8. Wistuba, H., "The effect of an external electric field on the operation of an aluminum oxide-cast iron sliding contact joint", Wear, 1997, 208, pp. 113 – 117, (1997).
9. Endo, K., Fukuda, Y., and Takamiya, O., "Wear behaviors of metals under lubricated condition and the effect of small electric potential", Bull. JSME, 1971, 14, pp. 1281 – 1288, (1971).
10. Gangopadhyay, A., Peck, M., and Simko, S.,"Wear control in a lubricated contact through externally applied electric current", Tribol. Trans., 2002, 45, pp. 302 – 309, (2002).
11. El Mansori, M., Pierron, F., and Paulmier, D., "Reduction of tool wear in metal cutting using external electromotive sources", Surf. Coat. Technol., 2003, pp. 163 - 164, pp. 472 – 477, (2003).
12. Zaidi, H., Chin, K., and Frene, J., "Electrical contact steel/steel in magnetic field: analysis of surface and subsurface of sliding. Surf. Coat. Technol., 2001, 148, pp. 241 - 250, (2001).
13. Nabarro, F. Theory of dislocations, 1987, p. 658 (Dover Publications, Inc., Mineola, New York), (1987).
14. Negita, K., Itou, H., and Yakou, T., "Electrorheological effect in suspension composed of starch powder and silicone oil. J. Colloid Interface Sci., 1999, 209, pp. 251–254, (1999).
15. Hongjun, J., Yonggang, M., Shizhu, W., and Hong, J., "Effects of external electric fields on frictional behaviors of three kinds of ceramic/metal rubbing couples", Tribol. Int., 1999, 32, pp. 161 – 166, (1999).
16. Lavielle, L., "Electric field effect on the friction of a polythyleneter polymer film on a steel substrate", Wear, 1994, 176, pp. 89 – 93, (1994).
17. Csapo, E., Zaidi, H., and Paulmier, D., "Friction behavior of a graphite–graphite dynamic electric contact in the presence of argon", Wear, 1996, 192, pp. 151 – 156, (1996).
18. Kimura,Y., Nakano, K., Kato, T., and Morishita, S., "Control of friction coefficient by applying electric fields across liquid crystal boundary films. Wear, 1994, 175, pp. 143 – 149, (1994).
19. Tung, S. and Wang, S., "In-situ electro-charging for friction reduction and wear resistant film formation", Tribol. Trans., 1991, 34(4), pp. 479 – 488, (1991).
20. Tung, S. and Wang, S., "Friction reduction from electrochemically deposited films", Tribol. Trans., 1991, 34 (1), pp. 23 – 34, (1991).
21. Nakanishi, Y., Murakami, T., and Higaki, H., "Effects of electric field on lubricating ability of sodium hyaluronate solution", Nippon Kikai Gakai Ronbunshu (C Hen), 1996, 62 (598), pp. 2359 – 2366, (1996).

22. Hongjun, J., Yonggang, M., and Shizhu, W., "Effects of external DC electric fields on friction and wear behavior of alumina/brass sliding pairs", Sci. China E, 1998, 41 (6), pp. 617 - 25, (1998).
23. Hongjun, J., Yonggang, M., Shizhu, W., and Wong, P., "Active control of friction by applying electric fields across boundary films of stearate", In Proceedings of the ASIARTIB'98, Beijing, China, 1998, pp. 755 - 760, (1998).