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OIL LUBRICATED SLIDING OF POLYESTER COMPOSITES FILLED BY NANOPARTICLES AGAINST STEEL

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ABSTRACT

The present work investigates the friction coefficient and wear of polyester composites reinforced by different types of nanoparticles of iron, copper, aluminum, and aluminum oxide and sliding against steel aiming to develop new engineering materials with low friction coefficient and high wear resistance to be used as bearing materials. Experiments were carried out at oil lubricated sliding. Cylindrical test specimens of 10 mm diameter and 30 mm length of polyester resin impregnated by nanoparticles were tested. Pin on disc tribometer was used to perform friction and wear under the application of electric current of 0, ± 1.5, ± 3 and ± 4.5 volts.

It was found that, for oil lubricated sliding of negative charged test specimens, friction coefficient displayed by sliding of polyester filled by aluminium of negative voltage against steel slightly increased with increasing aluminium content. As the applied voltage increased friction coefficient significantly increased. At no electric voltage, wear slightly decreased with increasing copper content. Application of electric voltage increased wear. As for oil lubricated sliding of positive charged test specimens, friction coefficient showed no change with increasing aluminium content. As the applied voltage increased friction coefficient decreased. Wear increased with increasing both aluminium content and electric voltage. At no electric voltage, wear slightly decreased with increasing copper content. Application of electric voltage increased wear due to the increased adherence of the material removed from the the tested composites into steel. At no voltage wear increased with increasing aluminium oxide content. Application of electric voltage caused significant friction decrease.

INTRODUCTION

The field of nanotechnology is extended the applications of engineering and technology. The polymer–nanoparticles/nanocomposites are the fast growing field of research for developing the materials, [1]. There is an increasing demand to develop materials based on thermosetting polymers due to the relatively high thermal stability and environmental resistance as well as the good tribological performance. Thermosetting polymer composites are used as substrate, coating, and plastic bearings as well as in the automotive, railway and transport industries, [2]. The major drawback is their

relatively poor wear resistance. While many thermoplastic materials show self-lubricating behaviour, the lubricating properties of thermosetting polymers need to be modified by solid lubricants or by the addition of nanoparticles of selected materials in particular ZnO nanoparticles, [3]. Friction coefficient and wear of polyester composites reinforced by different types of nanoparticles of iron, copper, aluminum, and aluminum oxide and dry sliding against steel were measured to develop new engineering materials with low friction coefficient and high wear resistance which can be used as bearing materials, [4]. Experiments showed that when the test specimens were negative charged friction coefficient increased with increasing the electric voltage for composites filled by aluminium, while at no voltage, friction coefficient decreased with increasing aluminium content. As the electric voltage increased wear decreased. In condition of applying electric voltage friction coefficient increased with increasing copper content. As for positive charged test specimens, application of electric voltage showed significant wear decrease.

Silica nanoparticle filled polypropylene (PP) and PP blends were studied, [5 - 7]. Mechanical property improvement was the major. There are not as many reports on the non-isothermal crystallization behaviour of PP/silica nanocomposites as there are on the mechanical properties. $Si_3 N_4$ nanoparticles exhibit high potential for the reinforcement of polymers. In a recent report, high strength Nylon 6 composite fibers have been manufactured by adding $Si_3 N_4$ nanorods and spherical shaped nanoparticles.

New polycarbonate nanocomposites were being developed in order to improve the thermal, mechanical, electrical or optical properties of the base polymer, [8 - 10]. Clay nanocomposites were used as filler. The effect of silane treatment of Fe_3O_4 on the magnetic and wear properties of Fe_3O_4/epoxy nanocomposites was investigated, [11]. It was found that specific wear rate of surface-modified Fe_3O_4/epoxy nanocomposites was lower than that of unmodified Fe_3O_4/epoxy nanocomposites. Many authors became interested in magnetic nanopowder-reinforced polymer composites because magnetic nanoparticles have shown great potential for applications, including aircraft, spacecraft, magnetic hard disks, and the magnetic bars of credit card, [12]. These applications can take advantage of both the magnetic properties and wear properties of these compositions.

On the microscale of filling materials reinforcing polyester composites, several research work were carried out, [13]. Friction coefficients and wear rates of polyester composites reinforced by graphite fiber with different diameters and impregnated by vegetable oils (Corn, Olives, and Sunflower oil) were measured to develop new engineering materials with low friction coefficients and high wear resistance which can be used in industrial applications as bearing materials. Polyethylene and glass fibres were used to reinforce polyester in order to increase wear resistance. Paraffin, glycerin, almond, olives, cress, sesame and baraka oils were added to polyester during molding to produce self lubricated composites. The experimental results showed that unfilled polyester composites displayed relatively high friction values. When polyester matrix was filled by paraffin and glycerin oils significant reduction in friction coefficient and wear was observed. Besides, increasing oil content and polyethylene fibres decreased friction coefficient. Composites containing olive oil displayed higher friction and lower wear than that containing almond oil. The minimum wear was

displayed by composites filled by 20 wt. % oil content, [14 - 15]. The experimental results showed that increasing oil content and polyethylene fibres decreased friction content.
The influence of impregnating polyester–glass fibre composites by oil on their friction and wear was investigated, [16]. The test results showed that reinforcing polyester by glass fibres decreased friction coefficient and wear.

Four fabric composites were prepared in order to study the influence of fillers (nanoparticles and PTFE) on the tensile and tribological properties of polyester fabric composites, [17]. It was observed that the polyester fabric played a main role in the tensile-resistant and wear-resistant properties of the neat epoxy/polyester fabric composites. But once fillers were added, matrix played more and more important role.

Polystyrene nanocomposites were filled by nanoparticles of tungsten disulfide (WS_2) and molybednum disulfide (MoS_2), [19 - 20]. Polymer nanocomposites impregnated with these nanoparticles showed increased wear resistance.

Friction of polymers is accompanied by electrification, [21 - 29]. 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. Ionization and relaxation of those states lead to electric fields of the surface and bulk charges. Electrification in friction is a common feature, it can be observed with any mode of friction, and with any combination of contacting surfaces.

Voltage generated as a result of the friction caused by the sliding of the tested polymers such as polyamide (PA6), polytetrafluoroethylene (PTFE), polyethylene terephthalate (PET), and polymethylmethacrylate (PMMA) against each other as well as steel surface was measured, [30]. The test results showed that friction coefficient displayed by the sliding in salt water represented maximum values due to the relatively high value of voltage generated as a result of friction. Triboelectrification of metallic and polymeric surfaces was investigated at dry and lubricated sliding conditions. The effect of sodium chloride (NaCl), gasoline, diesel fuel, and hydrochloric acid (HCl) as contaminants in the lubricant on voltage and friction was discussed, [31]. The test results show that relatively high voltage generated due to sliding of metallic surfaces against each other in salt water and oil dispersed by ethylene glycol while sliding of PA6 against steel surface produced highest values of voltage at oil lubricated condition. In the presence of NaCl in water, relatively high value of voltage due to friction was observed accompanied by high value of friction coefficient.

It was found that a correlation between friction coefficient and voltage generated was found for polymers sliding against PE terephthalate and against steel in water and salt water lubricated conditions, [32]. Wear of the tested polymers decreased with increase of sand particle size down to minimum because of the sand embedment in the polymeric surface. Further increase in sand particle size increased wear due to the removal of sand from the polymeric surface. Sliding of polymer against polymer decreased both friction coefficient and voltage generated, while wear increased due to the decrease of sand embedment in the polymeric surface.

The aim of the present work is to investigate the influence of the addition of nanoparticles to polyester composites on the friction and wear. Positive and negative direct current voltages are applied by connecting the terminals of the D. C. battery to the test specimen and the counterface at oil lubricated sliding. Two sets for experimental work were used, oil lubricated sliding of negative and positive charged test specimens. Friction coefficient and wear are measured.

EXPERIMENTAL

Experiments were carried out using pin on disc tribometer. It consists of a rotary horizontal steel disc driven by a variable speed motor. The details of the pin on disc are shown in Fig. 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 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. Its surface was a smooth surface. Test specimens were prepared in the form of cylindrical shape with cross section of 10 mm diameter and 30 mm length. The test specimens were loaded against counterface of the carbon steel disc.

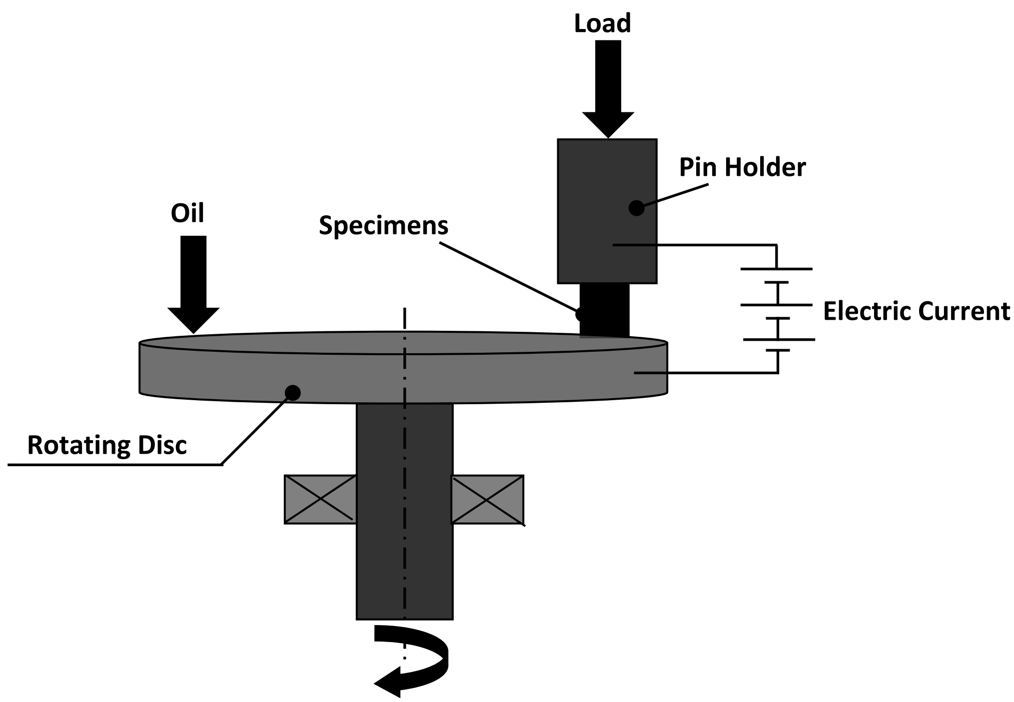

Fig. 1 Arrangement of the test rig.

Test specimens were prepared by filling the polyester by nanoparticles of aluminium, copper, aluminium oxide and iron of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 wt. % content. Electric current of 0, 1.5, 3 and 4.5 volt was applied. Two sets were carried out the first when the test specimens were negative charged, and the second when the test specimens were positive charged. Friction coefficient was determined through the friction force measured from the deflection of the load cell divided on the normal load, while wear was

measured by the difference between the weight of specimen before and after test using a digital balance of ± 1.0 mg accuracy.

RESULTS AND DISCUSSION

The effect of application of negative voltage on polyester composite test specimens sliding against oil lubricated steel on friction and wear is shown in Figs. 2 - 9. Friction coefficient displayed by oil lubricated sliding of polyester filled by aluminum of negative voltage against steel slightly increased with increasing aluminum content, Fig. 2, where aluminum particles increased the adherence ability of polyester to the steel surface. As the applied voltage increased friction coefficient increased. The friction increase might be attributed to the increased composites particles adhered to the steel surface. Values of friction coefficient were relatively low due to the presence of oil film on the sliding surface which decreased the adherence of polyester composites into the steel surface.

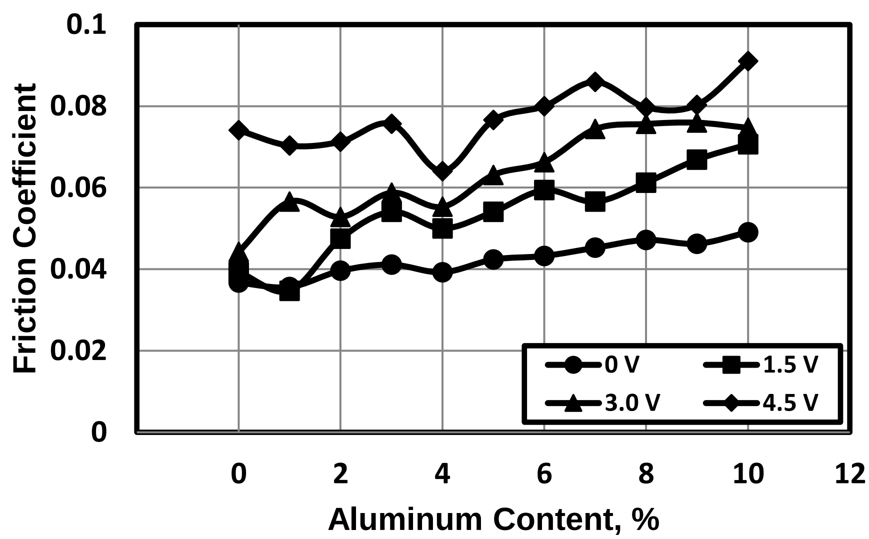

Fig. 2 Friction coefficient displayed by oil lubricated sliding of polyester filled by aluminum of negative voltage against steel.

Wear displayed by oil lubricated sliding of polyester filled by aluminum of negative voltage against steel is shown in Fig. 3. Presence of oil on the contact surface disturbed the process of composites adherence into the steel surface. As both the aluminum content and electric voltage increased wear increased. Wear increase was due to the removal of material from the composites surface and absence of material transfer back. The wear increase with increasing electric voltage might be from the ability of aluminum to balance the negative charge of polyester, where aluminum gained positive charge during sliding against steel.

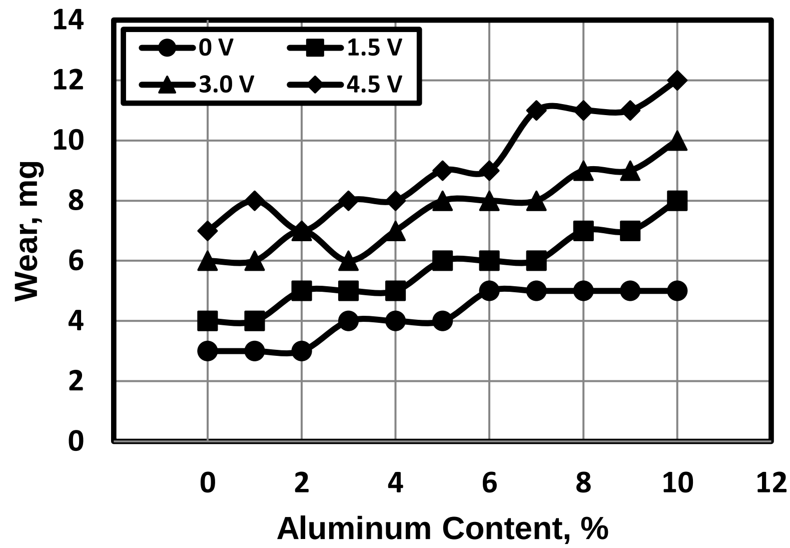

Fig. 3 Wear displayed by oil lubricated sliding of polyester filled by aluminum of negative voltage against steel.

Composites containing nanoparticles of copper showed the same trend observed for aluminium filled composites. Generally, friction coefficient increased with increasing copper content. Fig. 4. Friction coefficient displayed at no voltage showed no variance with increasing copper content. It seems that oil film prevented the adherence of copper as well as polyester into the steel surface. As the electric voltage increased friction coefficient increased as a result of the relatively stronger adhesion of composites particles into the steel surface caused by the negative charge gained by copper and polyester from both the electric voltage and friction.

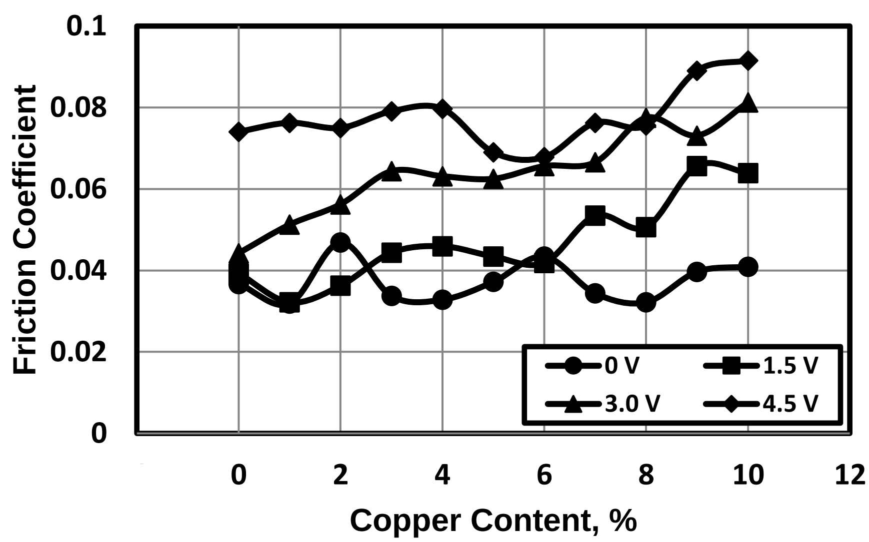

Fig. 4 Friction coefficient displayed by oil lubricated sliding of Polyester filled by copper of negative voltage against steel.

Wear displayed by oil lubricated sliding of polyester filled by copper of negative voltage against steel is shown in Fig. 5. At no electric voltage wear slightly decreased with increasing copper content. It seems that increasing copper content prevented polyester from adhering to the steel surface. Application of electric voltage increased wear due to the increased adherence of the material removed from the the tested composites into steel.

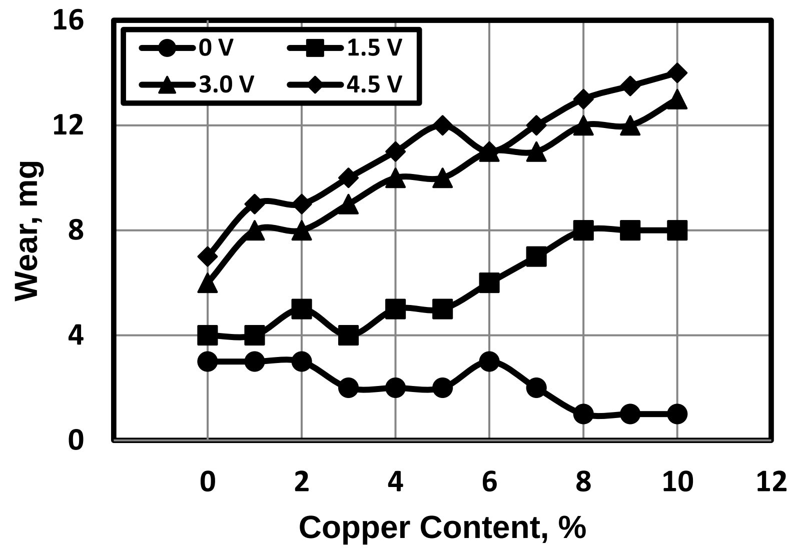

Fig. 5 Wear displayed by oil lubricated sliding of polyester filled by copper of negative voltage against steel.

Composites filled by aluminum oxide displayed friction increase with increasing aluminum oxide content, Fig. 6. The friction increase might be from the abrasion action of the aluminum oxide particles into the steel surface. As the voltage increased friction coefficient increased as a result of adherence of materials removed from the composites into the steel.

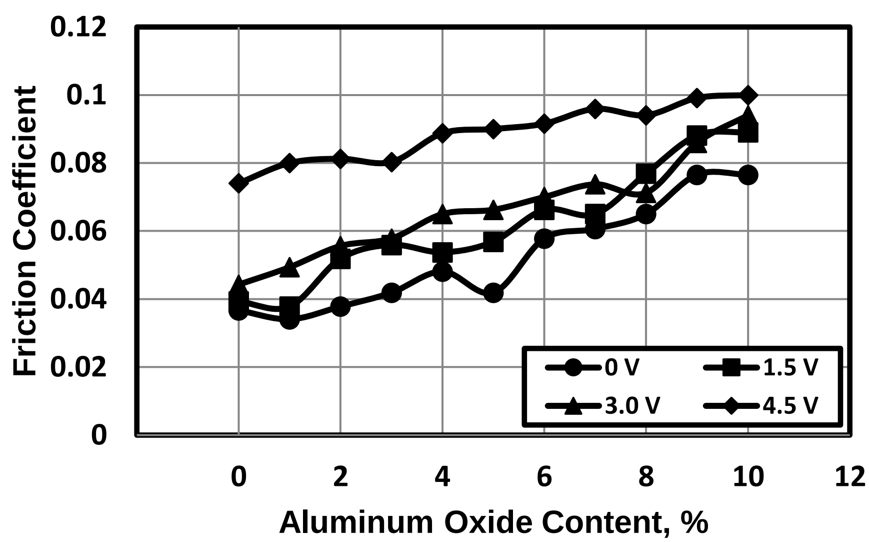

Fig. 6 Friction coefficient displayed by oil lubricated sliding of polyester filled by aluminum oxide of negative voltage against steel.

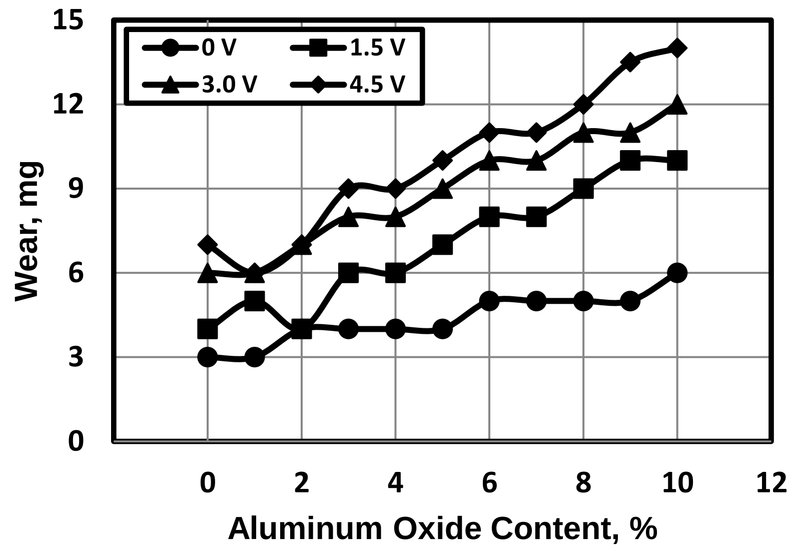

Fig. 7 Wear displayed by oil lubricated sliding of polyester filled by aluminum oxide of negative voltage against steel.

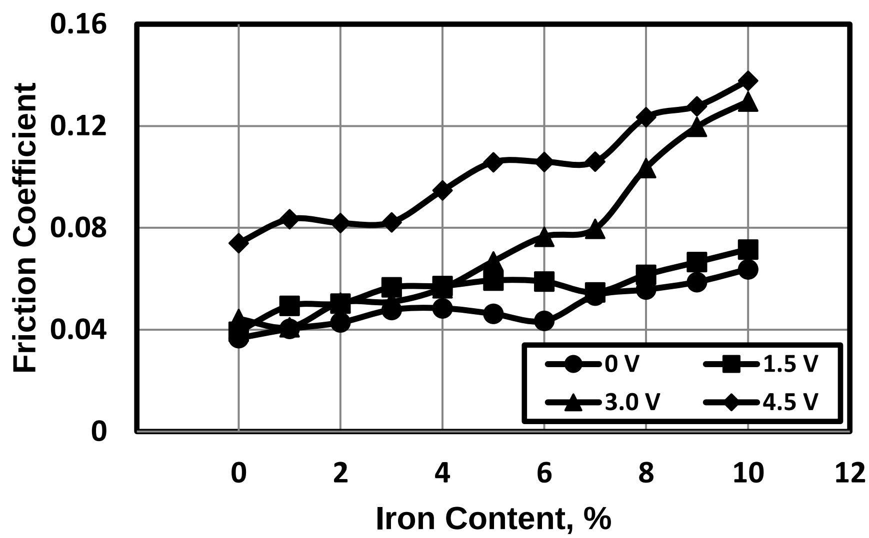

Fig. 8 Friction coefficient displayed by oil lubricated sliding of polyester filled by iron of negative voltage against steel.

Wear displayed by oil lubricated sliding of polyester filled by aluminum oxide of negative voltage against steel is shown in Fig. 7. Wear increased with increasing aluminum oxide content. Application of electric voltage caused significant friction increase due to the material transfer into steel surface. Composites filled by iron showed the same trend for friction and wear observed for composites filled by aluminum and copper. Friction coefficient increased with increasing iron content, Fig. 8. As the electric voltage increased friction coefficient increased. Wear displayed by oil lubricated sliding of polyester filled by iron of negative voltage against steel is shown in Fig. 9. At no

voltage wear decreased with increasing iron content, while in the presence of electric voltage wear significantly increased.

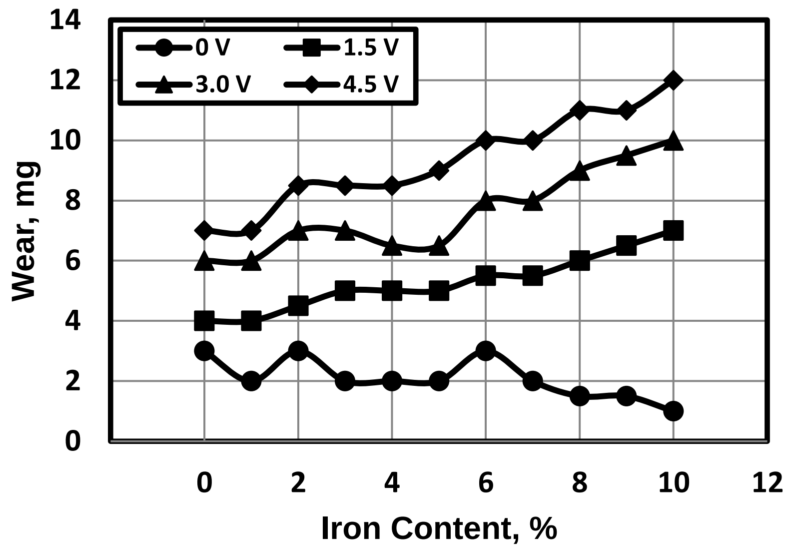

Fig. 9 Wear displayed by oil lubricated sliding of polyester filled by iron of negative voltage against steel.

The effect of application of positive voltage on polyester composites sliding against oil lubricated steel on friction and wear is shown in Figs. 10 - 17. Friction coefficient displayed by oil lubricated sliding of polyester filled by aluminum of positive voltage against steel showed no change with increasing aluminum content, Fig. 10, where aluminum particles gained positive charge from voltage imposed on the positive charge gained from friction, while polyester gained positive charge from the voltage imposed on the negative charge gained from friction so the resultant charge of material removed from polyester composites was not enough for adherence into the steel surface in the presence of oil film covering the contact area. As the applied voltage increased friction coefficient decreased. Values of friction coefficient were relatively low due to the presence of oil film on the sliding surface which decreased the adherence of composites into the steel surface.

Wear displayed by oil lubricated sliding of polyester filled by aluminum of positive voltage against steel is shown in Fig. 11. Presence of oil on the contact surface disturbed the process of composites adherence into the steel surface. As both the aluminum content and electric voltage increased wear increased. Wear increase was due to the removal of material from the composites surface and absence of material transfer back. The wear increase with increasing electric voltage might be from the ability of aluminum to balance the negative charge gained by polyester during friction which was more higher than that gained by the electric voltage, where aluminum gained positive charge during sliding against steel.

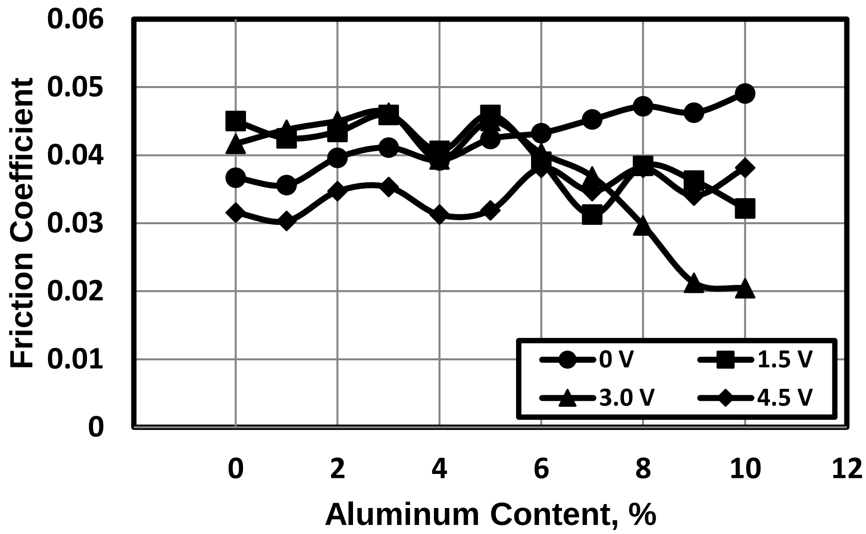

Fig. 10 Friction coefficient displayed by oil lubricated sliding of polyester filled by aluminum of positive voltage against steel.

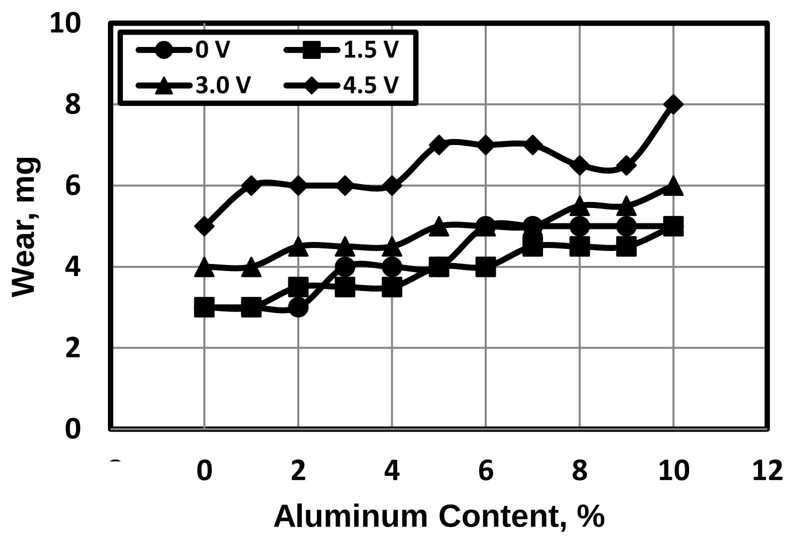

Fig. 11 Wear displayed by oil lubricated sliding of polyester filled by aluminum of positive voltage against steel.

Copper filled composites showed the same trend observed for aluminum filled composites. Generally, friction coefficient significantly increased with increasing copper content. Fig. 12. Friction coefficient displayed at no voltage showed no variance with increasing copper content. It seems that the oil film prevented the adherence of copper as well as polyester into the steel surface. As the electric voltage increased friction coefficient increased as a result of the relatively stronger adhesion of composites particles into the steel surface caused by the positive charge gained by copper and polyester from the electric voltage.

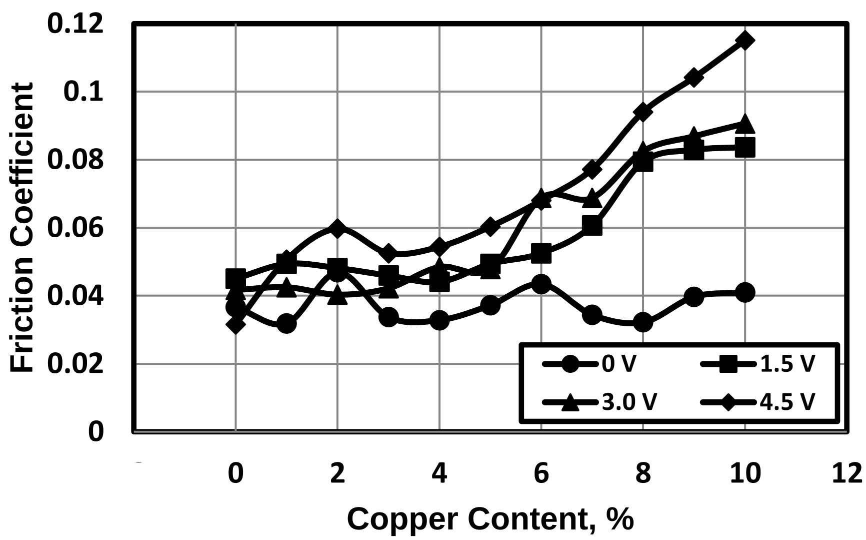

Fig. 12 Friction coefficient displayed by oil lubricated sliding of polyester filled by copper of positive voltage against steel.

Wear displayed by oil lubricated sliding of polyester filled by copper of positive voltage against steel is shown in Fig. 13. At no electric voltage, wear slightly decreased with increasing copper content. It seems that increasing copper content prevented polyester from adhering to the steel surface. Application of electric voltage increased wear due to the increased adherence of the material removed from the the tested composites into steel. Wear values were relatively lower than that observed when the the negative voltage was applied to the tested composites.

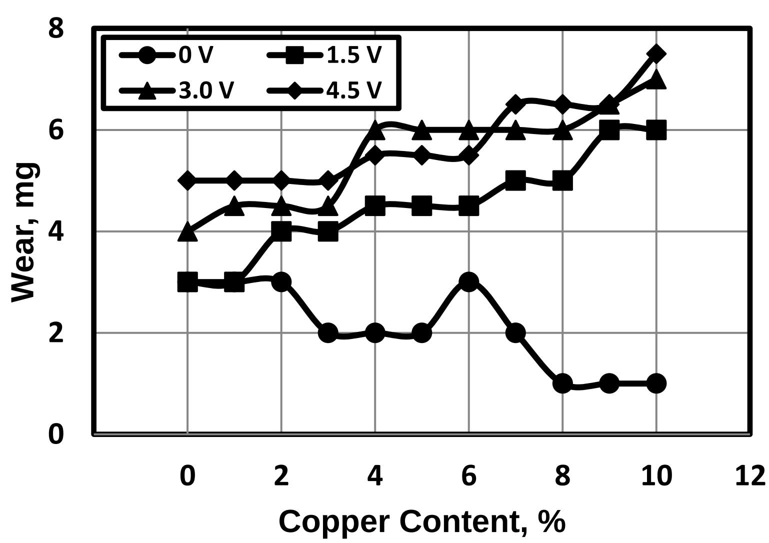

Fig. 13 Wear displayed by oil lubricated sliding of polyester filled by copper of positive voltage against steel.

The addition of nanoparticles of aluminum oxide into polyester displayed friction increase with increasing aluminum oxide content, Fig. 14. The friction increase might be from the abrasion action of the hard aluminum oxide particles into the steel surface. As the voltage increased friction coefficient increased as a result of adherence of the materials removed from the composites into the steel. The triboelectrification of aluminum oxide is lower than that observed for the metallic particles tested like aluminum, copper and iron due to the existence of the oxide layer on its surface.

Wear displayed by oil lubricated sliding of polyester filled by aluminum oxide of positive voltage against steel is shown in Fig. 15. At no voltage wear increased with increasing aluminum oxide content. This might be attributed to the decrease of the strength of polyester matrix as well as the continuous material removal from the test specimens. Application of electric voltage caused significant friction decrease due to ability of aluminum oxide particles to store the electric charge which could increase the adherence of the material transfer into steel surface.

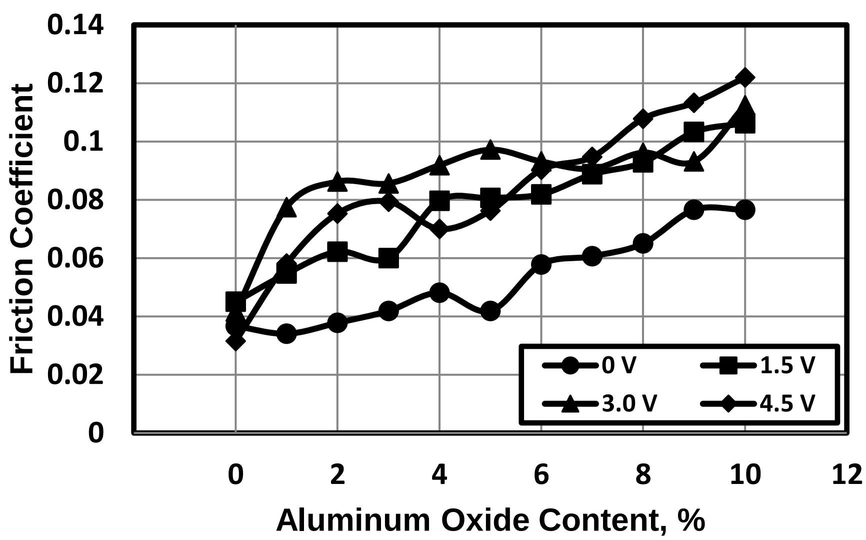

Fig. 14 Friction coefficient displayed by oil lubricated sliding of polyester filled by aluminum oxide of positive voltage against steel.

Iron filled composites showed the same trend for friction and wear observed for composites filled by aluminum and copper. Friction coefficient increased with increasing iron content, Fig. 16. As the electric voltage increased friction coefficient increased. This behaviour can be attributed to the friction of iron particles against steel surface. Values of friction coefficient were more higher than that observed for the other tested composites. That might be from the nature of friction between iron particles against steel surface which increased friction coefficient.

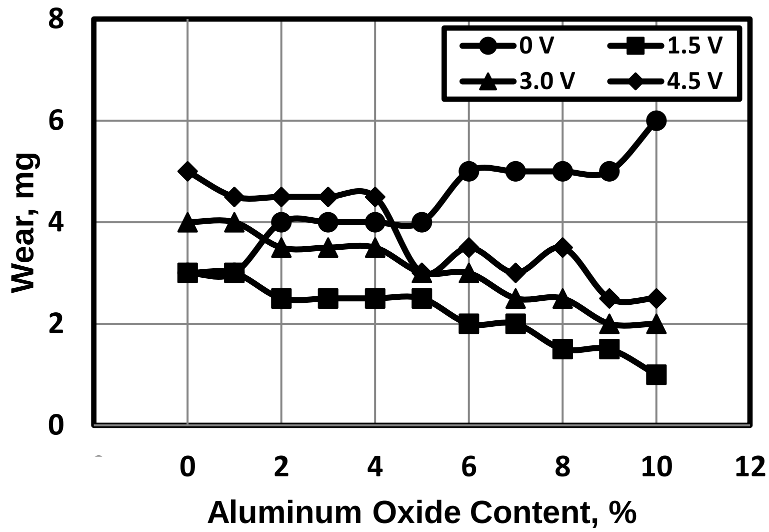

Fig. 15 Wear displayed by oil lubricated sliding of polyester filled by aluminum oxide of positive voltage against steel.

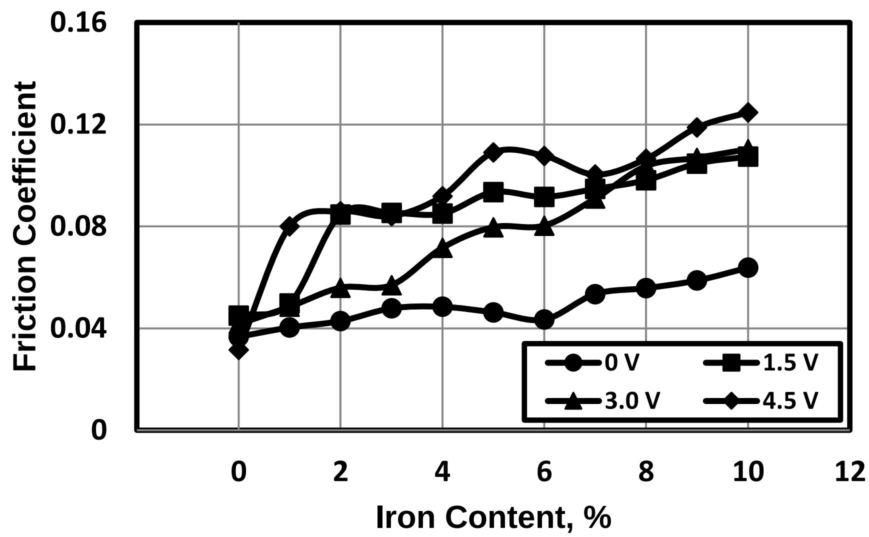

Fig. 16 Friction coefficient displayed by oil lubricated sliding of polyester filled by iron of positive voltage against steel.

Wear displayed by oil lubricated sliding of polyester filled by iron of positive voltage against steel is shown in Fig. 17. At no voltage wear decreased with increasing iron content, while in the presence of electric voltage wear significantly increased.

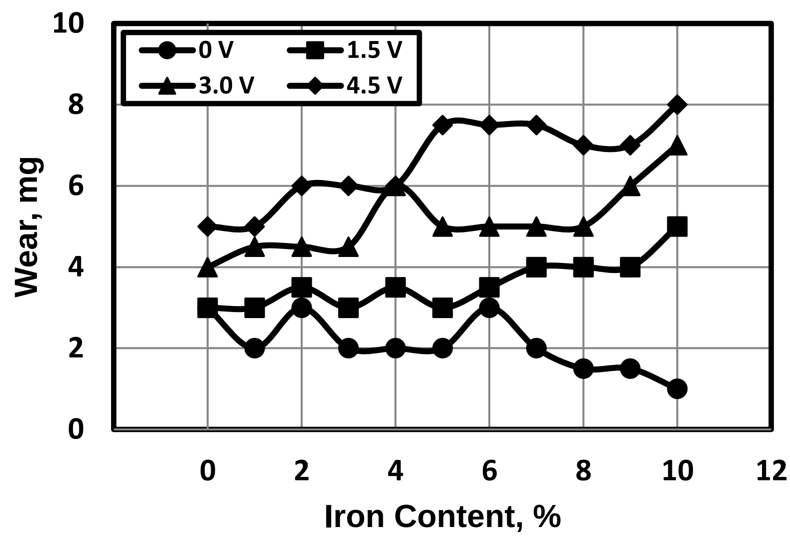

Fig. 17 Wear displayed by oil lubricated sliding of polyester filled by iron of positive voltage against steel.

CONCLUSIONS

I. Oil lubricated sliding of negative charged test specimens

1. Friction coefficient displayed by sliding of polyester filled by aluminium of negative voltage against steel slightly increased with increasing aluminium content. As the applied voltage increased friction coefficient increased.

2. At no electric voltage wear slightly decreased with increasing copper content. Application of electric voltage increased wear.

II. Oil lubricated sliding of positive charged test specimens

1. Friction coefficient showed no change with increasing aluminium content. As the applied voltage increased friction coefficient decreased.

2. Wear increased with increasing both aluminium content and electric voltage.

3. At no electric voltage wear slightly decreased with increasing copper content. Application of electric voltage increased wear due to the increased adherence of the material removed from the the tested composites into steel.

4. At no voltage wear increased with increasing aluminium oxide content. Application of electric voltage caused significant friction decrease.

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