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DEPENDENCY OF FRICTION ON ELECTROSTATIC CHARGE GENERATED ON POLYMERIC SURFACES

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ABSTRACT
The dependency of friction coefficient on electrostatic charge (ESC) generated from sliding of polyethylene (PA) on polytetrafluoroethylene (PTFE) is investigated. The effect of reinforcing PTFE by carbon fibres (CF), copper and iron wires is tested. Besides, PTFE has been filled by layers of carbon black, copper and iron particles and tested. Tests have been carried out at dry sliding.

It was found that ESC generated on PA and PTFE reinforced by CF and friction coefficient increase as CF content increases. This observation strengthens the dependency of friction coefficient on ESC. Therefore, specific information about the value of ESC can be useful in controlling friction coefficient. This behavior can be explained on the bases that increasing ESC can increase the adhesion between the two contact surface and consequently friction coefficient increases. Besides, ESC can be controlled by applying magnetic or electric field. This behavior can be used in controlling friction coefficient of polymeric material when they are contacting each other. Finally, ESC generated on PA surface for composites containing iron particles showed the highest values followed by copper particles and carbon black. Generally, filling materials in form of particles generated higher ESC than that in form of wires. Friction coefficient displayed the same order observed for ESC, where iron showed higher values than copper and carbon black. That observation may recommend the application of layers of iron or copper particles to control ESC and friction coefficient.

KEYWORDS
Electrostatic charge, friction coefficient, carbon fibres, copper, iron, polyamide, polytetrafluoroethylene.

INTRODUCTION
Electrostatic charge (ESC) generated from sliding of polyethylene (PE) on polytetrafluoroethylene (PTFE) is investigated, [1]. The effect of reinforcing polyethylene by copper and iron wires is tested. Tests have been carried out at dry sliding. It was found that as the gap thickness of the hollow box coated by PTFE increased ESC decreased. ESC generated during contact and separation as well as sliding controls friction coefficient. The strength of the electric field crossing the sliding

surface is proportional to how much ESC is generated. That behviour can be interpretted on the basis that the double layer of ESC generated on the sliding surfaces of PE and PTFE would generate an E-field inside the gap. Presence of copper wires inside PE matrix would generate extra ESC on the sliding surfaces due to the generation of electric field which affected the sliding surfaces by extra electric charge. Reinforcing PE by iron wires generated higher ESC than the other tested composites. It seems that the intensity of the E-field increased in the presence of iron wires.

The effect of reinforcing PE by copper wires on the generation of ESC when slid against PTFE, polypropylene (PP), and polyamide (PA) has been investigated, [2]. It was found that, reinforcing PE by carbon fibres and metallic wires sliding against PA recorded relatively higher values of ESC than that observed for unreinforced PE. Steel wires showed the highest values followed by carbon fibres while the lowest values were displayed by copper wires. That behviour can be interpretted on the basis that the double layer of the electrostatic charge (ESC) generated on the sliding surfaces of PE and PA would generate an E-field inside the matrix of PE. Presence of carbon fibres or metallic wires inside PE matrix would generate extra electrostatic charge on the sliding surfaces. Besides, ESC generated from PE reinforced by copper wires sliding against PA increased with increasing wire diameter. It seems that the intensity of the E-field increased with increasing the copper diameter due to the increase of electric current flowing through the wire leading to the increase of the E-field.

The effect of reinforcing epoxy by copper wires of different diameters on the generation of the electric static charge and friction coefficient when rubber sole slides against epoxy floor was investigated, [3 - 6]. Tests have been carried out at dry sliding. The effect of number of wires, location and wires diameter inside the matrix of the epoxy was studied. It has been found that at the electrostatic charge measured in volts significantly increased with increasing the number of wires. As the sliding distance increased voltage increased. Voltage decreased with increasing the distance of wire location from the sliding surface. When the wires were closer to the surface, the generated voltage increased. Besides, the increase in the wire diameter caused significant voltage increase. At water wetted sliding, voltage decreased due to the good water conductivity. As the sliding distance increased, the generated voltage decreased.

Safe walking on the floor was evaluated by the static friction coefficient. Few researches paid attention to the electric static charge generated during walking on the floor. It is well known that walking and creeping on flooring can generate electric static charge of intensity depends on the material of flooring. The materials of the floors as well as footwear can affect the generated charge. The electric static charge and friction coefficient of bare foot and foot wearing socks sliding against different types of flooring materials were investigated under dry sliding condition, [7]. The tested flooring materials were ceramic, marble, parquet, moquette and rubber. It was found that rubber flooring showed the highest generated voltage among the tested floorings. The highest voltage values were displayed by polyester socks, while cotton socks showed the lowest one. This observation can confirm the necessity of careful selection of the flooring materials. Parquet flooring showed the lowest voltage among the all tested flooring. Charge generated from rubbing between shoes and carpet were discussed, [8, 9]. The effect of humidity was explained on the basis that water molecules on the surfaces convey charges in the form of ions to enhance charge relaxation, [10 - 12]. The effect of

the static charge generation on the environment is influenced by electrical conductivity of the sliding surfaces.

The effect of the type of flooring materials on the generation of electric static charge and friction coefficient was discussed, [13]. It was observed that voltage generated from sliding against ceramic flooring slightly. The measured voltage values showed significant scatter as well known for the generated electric static charge, where the maximum and minimum values reached 850 and 360 volts respectively. It is expected that electrical field will be formed due the electric charge formed on the footwear and floor surfaces. Marble flooring displayed higher values than that observed for ceramic flooring.

The addition of copper and brass particles into epoxy matrix displayed higher values of voltage than that observed for epoxy filled by iron particles, [14]. Voltage was influenced by the load, where it increased with load increasing. It was observed that the maximum level of the voltage generated from the friction of materials is dependent on their position in the triboelectric series relative to the counterface, [15]. The triboelectric series can be used to determine the charge polarity of the materials. This series can be used to evaluate the relative charging capacity of many polymeric materials.

The influence of triboelectrification of the contact surfaces on friction coefficient displayed by polymethyl methacrylate (PMMA), and high density polyethylene (HDPE) spheres sliding against polytetrafluoroethylene (PTFE) and steel sheets was discussed, [156]. The effect of insulating the sliding surfaces on the friction coefficient is discussed at dry and water as well as salt water wetted sliding conditions. It was found that insolated test specimens showed relatively lower friction coefficient than that observed for the connected ones.

Triboelectric static charges built up on human skin and or clothes in direct contact with human body are very harmful and can create serious health problems, [17]. Based on the experiments carried out, it was found that, at dry sliding, iron nanoparticles addition into epoxy matrix increased friction coefficient with increasing iron content. Voltage drastically decreased with increasing iron content. Voltage showed the maximum values for epoxy free of iron.

Voltage generated from the sliding of rubber footwear against epoxy floor slightly increased with increasing load, while that generated from PVC floor displayed higher values, [18]. The highest value reached 2400 volts. Bare foot sliding against epoxy floor showed relatively lower voltage than that displayed by rubber footwear, where the maximum value reached 280 volts. It is clearly noted that PVC floor generated lowest voltage than that displayed by epoxy floor, where the maximum voltage did not exceed 520 volts. This observation can confirm the suitability of PVC floor to be applied as indoor floor where bare foot walking is dominating.

The electrical charges have been taken into account on friction between the two insulating materials. The change, in friction and electric charge of alumina sliding against polytetrafluoroethylene (PTFE) under boundary lubrication conditions, was measured, [19]. Specific information about the value of the electrical charge can be useful in controlling friction coefficient. In a study carried out by atomic force microscopy to measure forces and adhesion energy between tungsten and oxide surfaces,

[20], it was concluded that the coulombic forces were not dominant but they could have influenced the adhesion forces.

Electrostatic charges generated during contact and separation as well as sliding of insulating materials indicated their ability to trap charges, where the interaction energy during friction depends markedly on these trapped charges. To explain that, it is known that charges occur easily during simple contact or friction on the surface and the bulk by charge trapping. Then charges can play a major role in adhesion energy and alter friction by the effect of the trapped charges and, consequently on the presence of surface defects introduced during friction. During sliding, time-dependent deformation of the lattice is observed, leading to possible ionic polarization and to local variations of the atomic polarizability, [21 - 23]. This behavior is due to the friction process, leading to an electric field. Besides, the charges in movement can be trapped on defects (traps) and the surface becomes charged. The trapping event involves impurity, dislocation and grain boundary, [24, 25], so that the trapping energy depends on the material properties such as elastic constant and electrification. Friction induces movement of charged particles by triboelectrification, [26], where these charges can be trapped during friction. Then the polarisation energy is can be relaxed inducing electric field. It is expected that dislocations are formed during friction, [27]. Consequently, the existence of an internal electric field acting on all the lattice sites is confirmed.

The friction and triboelectrification between two adhering SAM-coated molecularly smooth dissimilar metal surfaces were measured using a modified surface forces apparatus, [28]. As the pressure is increased, triboelectrification increases significantly with large fluctuations about the mean. When the surfaces are in static contact, none of these effects is observed. Triboelectrification strongly depends on the friction type and force, sliding distance, contact area and sliding history. The charge transferred during shearing significantly depended on the normal pressure applied. At low pressures, the average current density was zero before, during, and after shearing, but the fluctuations drastically increased during shearing. The magnitude of these fluctuations depended on friction observed where stick-slip motion generated the largest fluctuations.

When two surfaces are in contact, only the summits of the asperities will be in contact and large areas of the surfaces will be separated. It may be expected that the area of true contact will even for highly polished surfaces be considerably less than the apparent area of contact. For higher loads or rougher surfaces the pressure on the asperities reaches the local plastic yield pressure, which is very nearly constant and is comparable to the indentation hardness. For repeated sliding, during the time between the two runs, electrons may have diffused from traps near the surface into deeper-lying ones, thus leaving empty ones at the surface which can readily be filled again, [29 – 31]. Besides, the applied pressure varies because the two surfaces are in contact with fresh areas within the charged track of the sliding surface as well as the possibility of introducing new traps during the first run. Those factors can lead to extra amount of charge on the sliding surfaces.

The aim of the present study is to investigate the dependency of friction coefficient on ESC generated on the surfaces of polymeric materials reinforced by CF, copper and iron wires due to their sliding against each other.

EXPERIMENTAL

The present work discusses the dependency of friction and ESC generated from the contact and separation as well as sliding of polymeric materials. Besides, friction coefficient was determined. The test specimens were prepared from PA block of 50 × 50 mm^2 and 10 mm thickness adhered to wooden block of 50 mm height. The tested PA was pressed and slid against three PTFE composites of 3.0 mm thickness, the first were reinforced by 2.0 and 4.0 wt. % carbon fibres (CF), Fig. 1. The second composites, Fig. 2, were reinforced by copper wires of 0.15 mm diameter of 50 and 100 turns (2500 and 5000 mm) as well as copper wires of 0.4 mm diameter of 50 and 75 turns (2500 and 3750 mm). While the third composites, Fig. 3, contained carbon black, copper particles of 30 – 50 µm particle size and 50 – 80 µm iron particles in form of layers.

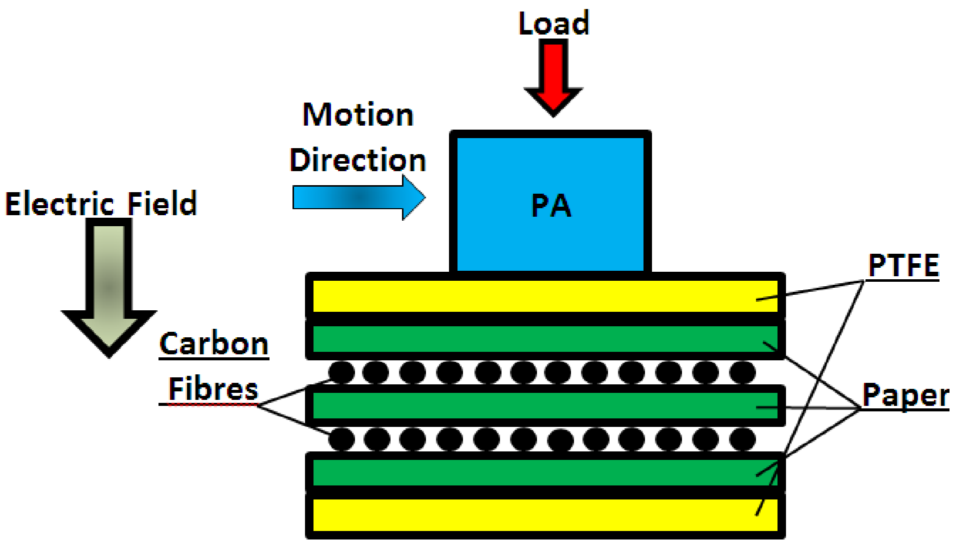

Fig. 1 Carbon fibres reinforced test specimens.

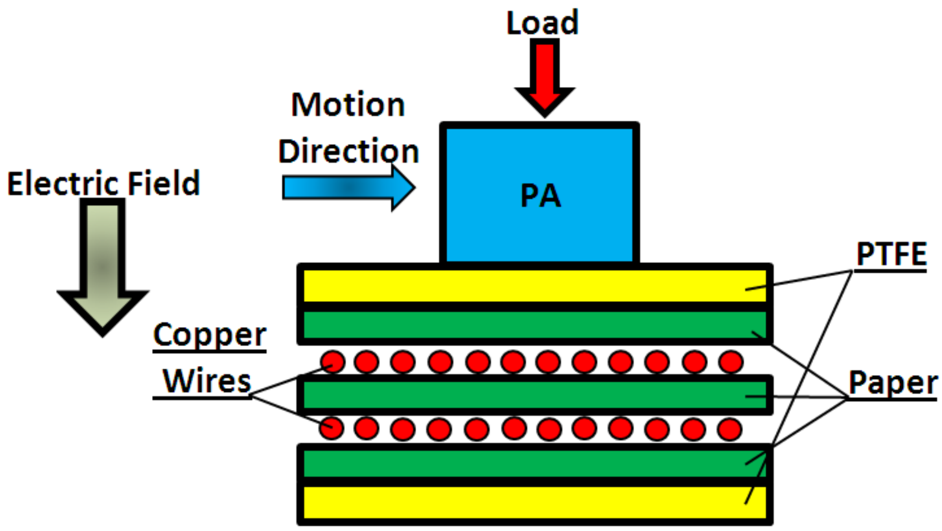

Fig. 2 Copper wires reinforced test specimens.

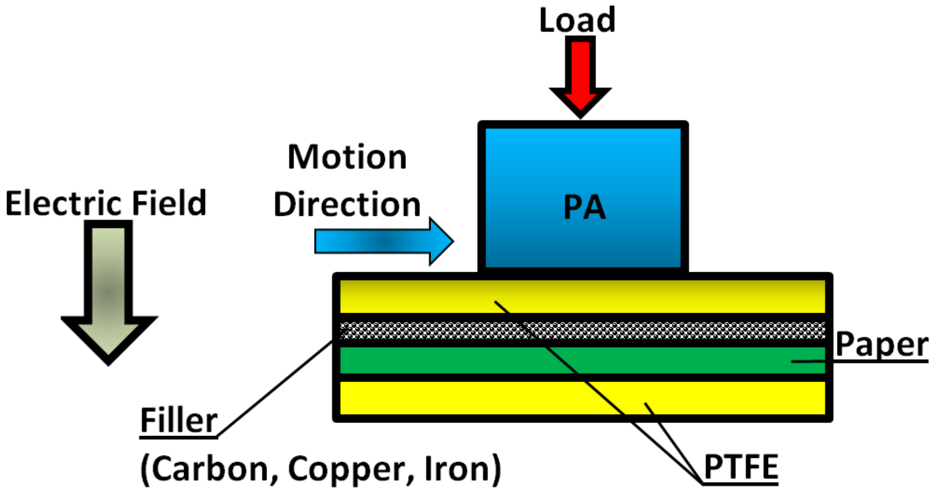

Fig. 3 the third tested composites.

The applied force was 10 N for ESC measurements, while it was ranging from 0.1 to 1.0 N in increment of 0.1 N for measuring friction force. After sliding, the ESC generated on the two sliding surfaces was measured. The sliding distance was 0 (contact and separation), 50, 100, 150 and 200 mm. The friction force was measured by the deflection of the load cell. The ratio of the friction force to the normal load was considered as friction coefficient. The load was applied by weights. The test speed was nearly controlled to be 2 mm/s. All measurements were performed at 30 ± 2^{o} C and 50 ± 10 % humidity. The electric static fields (voltage) measuring device (Ultra Stable Surface DC Voltmeter) was used to measure the electrostatic charge (electrostatic field) for test specimens.

RESULTS AND DISCUSSION

ESC generated on PA surface sliding against the first composites, Fig. 4, recorded higher values for composites reinforced by 4.0 wt. % CF, while unreinforced showed the lowest ESC. Besides, ESC increased with increasing sliding distance. The counterface (PTFE) of 4.0 wt. % CF gained higher ESC values reached -2200 volts at 200 mm sliding distance, Fig. 5. Friction coefficient displayed by PA sliding against the first composites, Fig. 6, decreased with increasing normal load. Composites reinforced by 4.0 wt. % CF gave the highest value of friction coefficient. This observation strengthens the dependency of friction coefficient on ESC. Therefore, specific information about the value of ESC can be useful in controlling friction coefficient. This behavior can be explained on the bases that increasing ESC can increase the adhesion between the two contact surface and consequently adhesion increases.

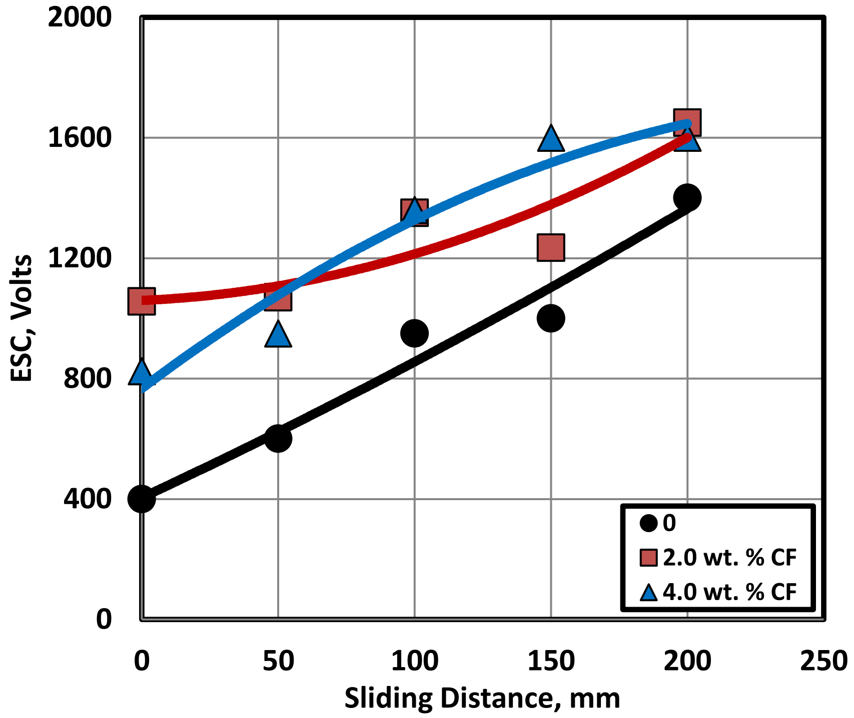

Fig. 4 ESC generated on PA surface sliding against the first composites.

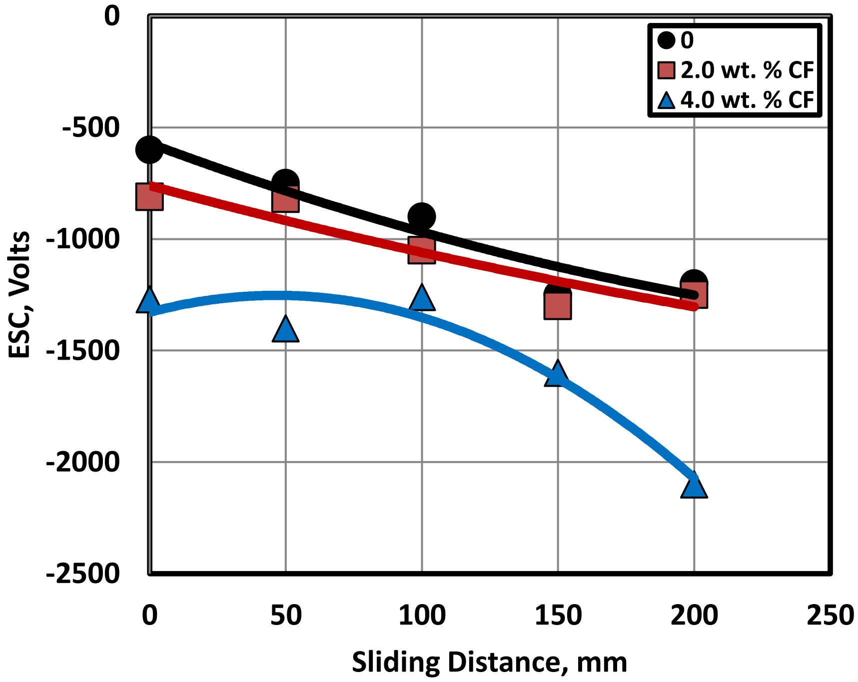

Fig. 5 ESC generated on PTFE surface sliding against the first composites.

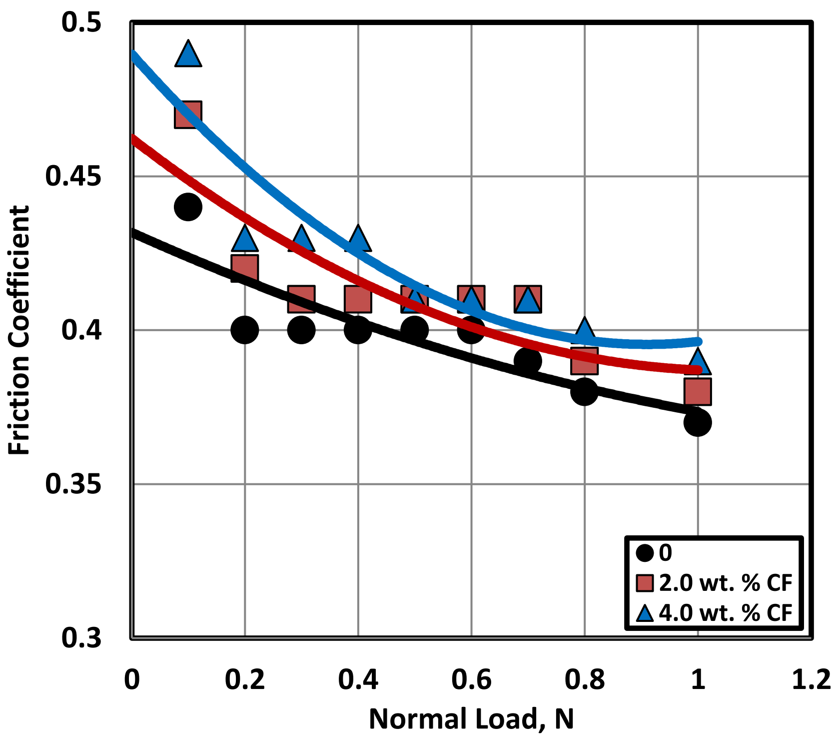

Fig. 6 Friction coefficient displayed by PA sliding against the first composites.

ESC generated on PA surface sliding against the second composites reinforced by copper wires, Fig. 7, represented lower values than that observed for composites reinforced by CF. As the diameter of copper wires decreased the number of turns increased ESC increased. The same trend was observed for ESC generated on PTFE surface, Fig. 8. Friction coefficient decreased with increasing normal load, Fig, 9. Reinforced composites showed higher friction coefficient than unreinforced ones. Based on the experimental results carried out in the present work, it was observed that ESC was influenced by the reinforcing the tested composites by CF as well as copper wires. To explain that behavior, it is demanded to understand the relationship between tribology and electrification, i. e., triboelectrification. Sliding of materials as well contact and separation cause the charge transfer to build up on the sliding surfaces. It is known that generation and formation of double layer of electrostatic charge on the sliding surfaces are responsible for generation of the electric field that induces electric current flowing in the conductor. The strength of the electric field inside the matrix is proportional to how much charge is generated on the friction surface. Due to the variation of the friction process as resulted from stick-slip, material transfer and surface distortion, ESC continues to increase, and sometimes it gradually decreases. The charge variations versus sliding distance suggest that, the charge does not always build up uniformly as sliding proceeds. These variations could be due to random contamination of the surface transfer of previously charged surface. The deformation which occurs during sliding must surely disturb the positions of the surface molecules by large amounts. Based on that fact, electric field may change over time and consequently may induce a current in the conductor and thus create a source of EMF (voltage, potential difference). The Faraday principle states that if an electric conductor is moved through a magnetic field, or a magnetic field moves through the conductor, electric current will be induced and flow into the conductor. The induced current creates an induced magnetic field. The Magnetic field around a straight conductor is directly proportional

to the current value and inversely proportional to the distance from the conductor. The significant ESC increase in the presence of CF and copper wires confirmed the presence of a magnetic field around them. It is well known that when an electric field and a wire move relative to each other, a voltage is induced. Besides, strong electric field produces high voltages. In the present work, CF and copper wires reinforcing PTFE represent the conductor, and the electric field is generated from ESC. It is expected that higher voltage will be generated on the sliding surface.

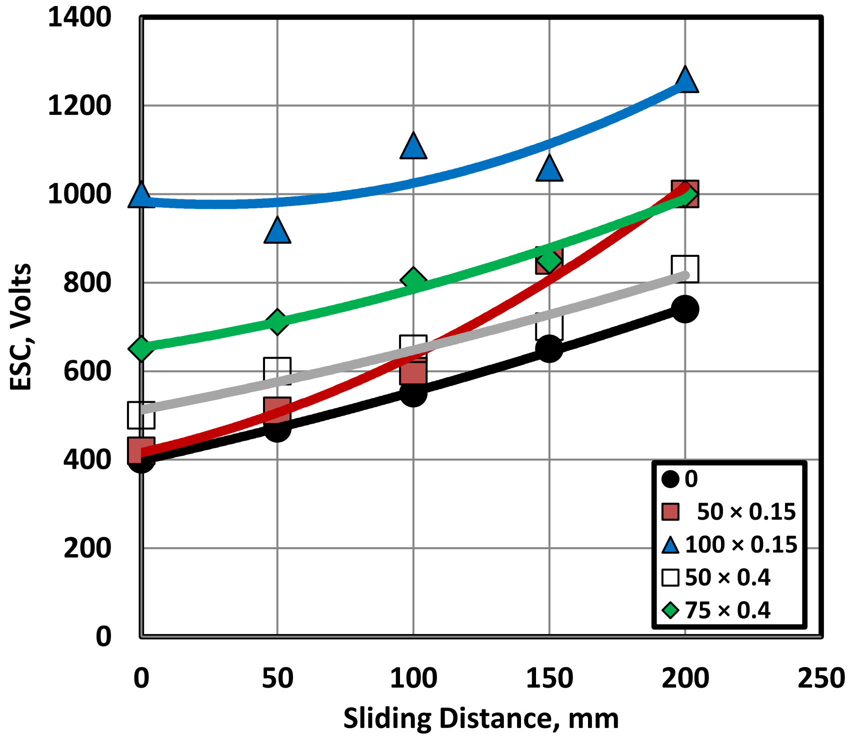

Fig. 7 ESC generated on PA surface sliding against the second composites.

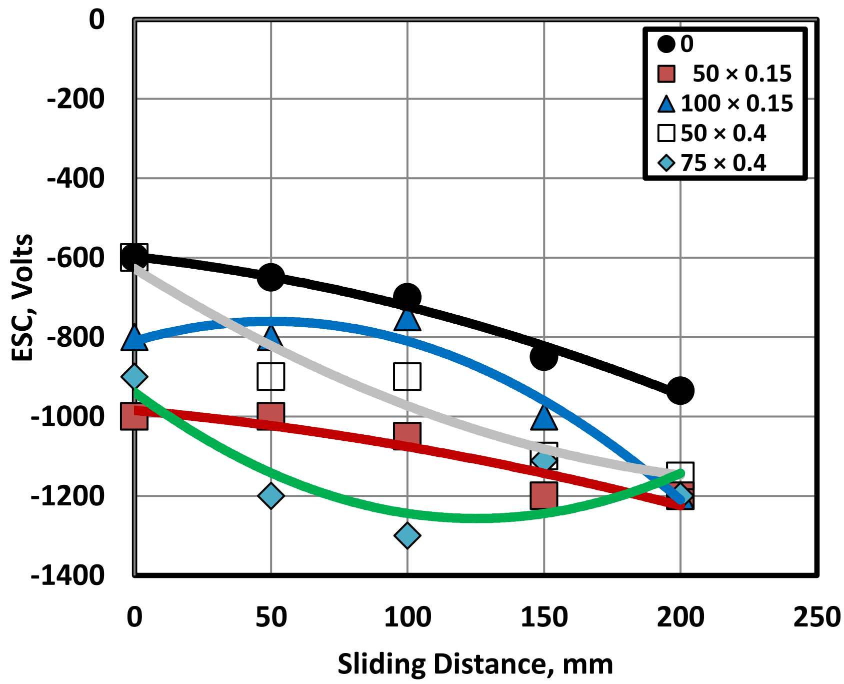

Fig. 8 ESC generated on PTFE surface sliding against the second composites.

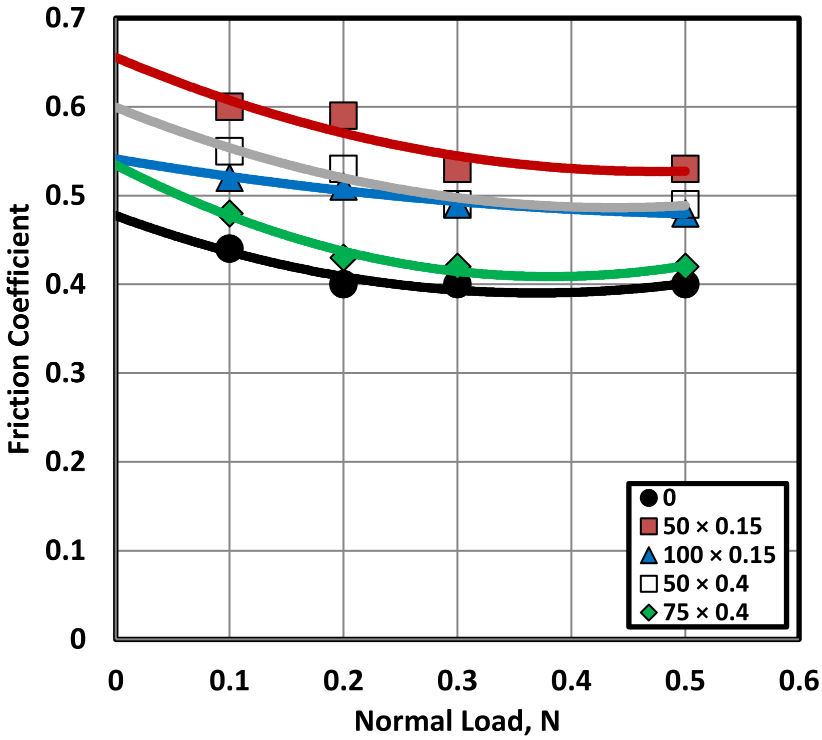

Fig. 9 Friction coefficient displayed by PA sliding against the second composites.

The first and the second composites were tested under presence of magnetic field, where ESC generated on PA surface showed values higher than that observed for experiments carried out without magnetic field. The highest value reached 1800 volts for PTFE reinforced by 4.0 wt. % CF, Fig. 10, while that recorded for composites in absence of magnetic field was 1650 volts. ESC generated on PTFE surface sliding against PTFE reinforced by CF in the presence of magnetic field, Fig. 11, displayed a value of -2400 volts which exceeded that observed in the absence of magnetic field. The same trend was observed for the composites reinforced by copper wires, Figs. 12 and 13. It can be concluded that ESC can be controlled by applying magnetic or electric field. This behavior can be used in controlling friction coefficient of polymeric material when they are contacting each other.

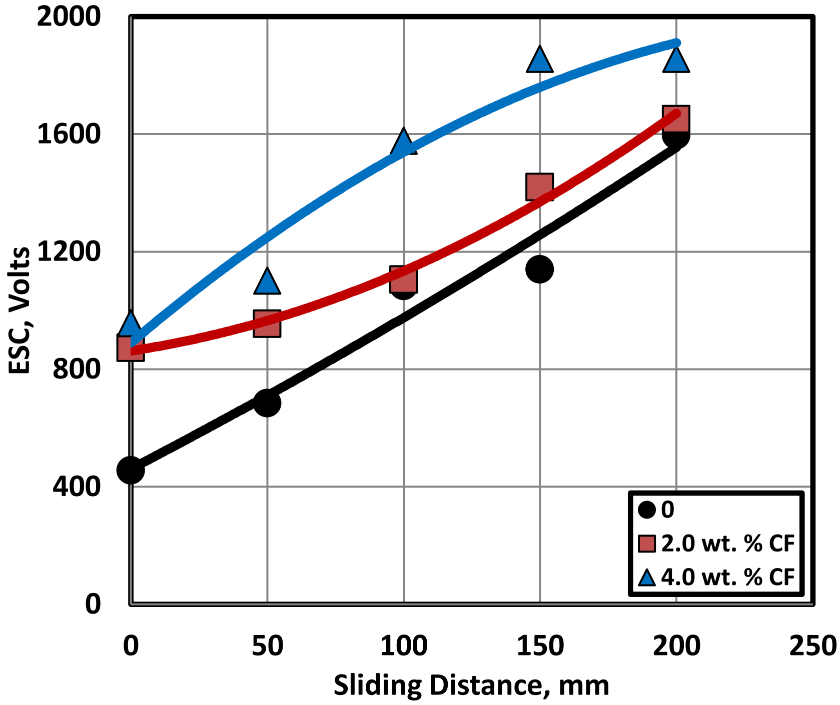

Fig. 10 ESC generated on PA surface sliding against the first composites in the presence of magnetic field.

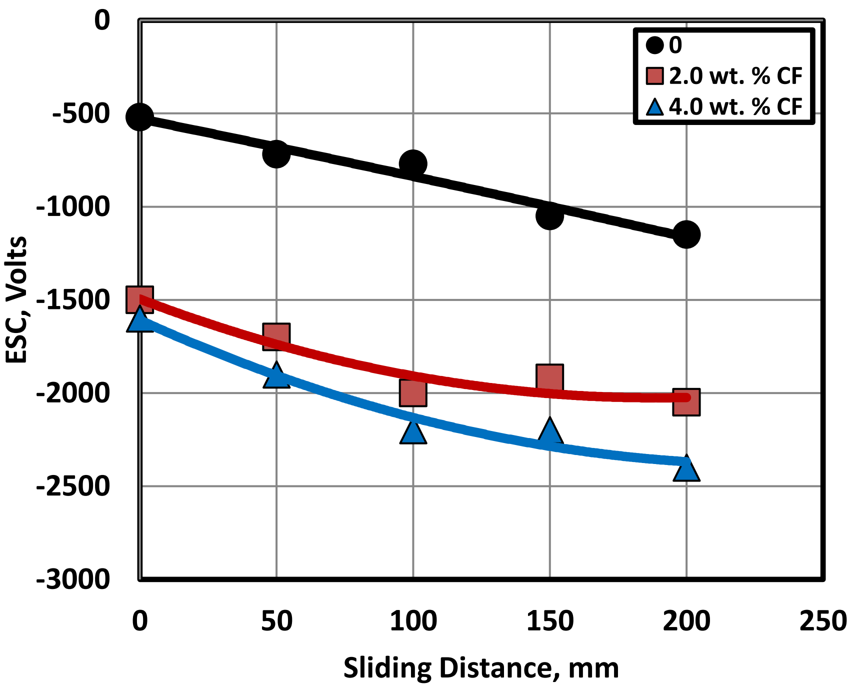

Fig. 11 ESC generated on PTFE surface sliding against the first composites in the presence of magnetic field.

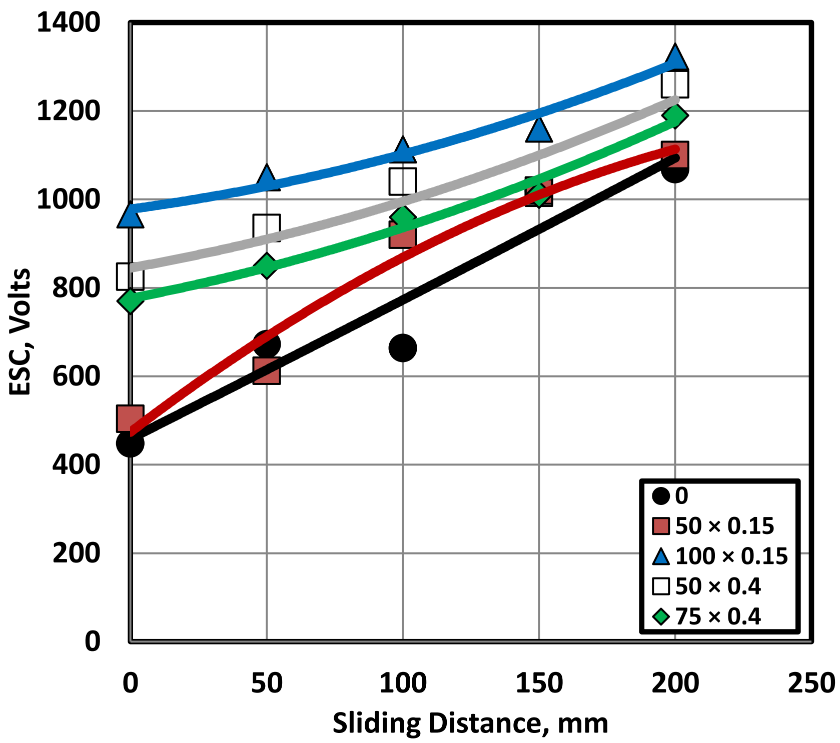

Fig. 12 ESC generated on PA surface sliding against the second composites in the presence of magnetic field.

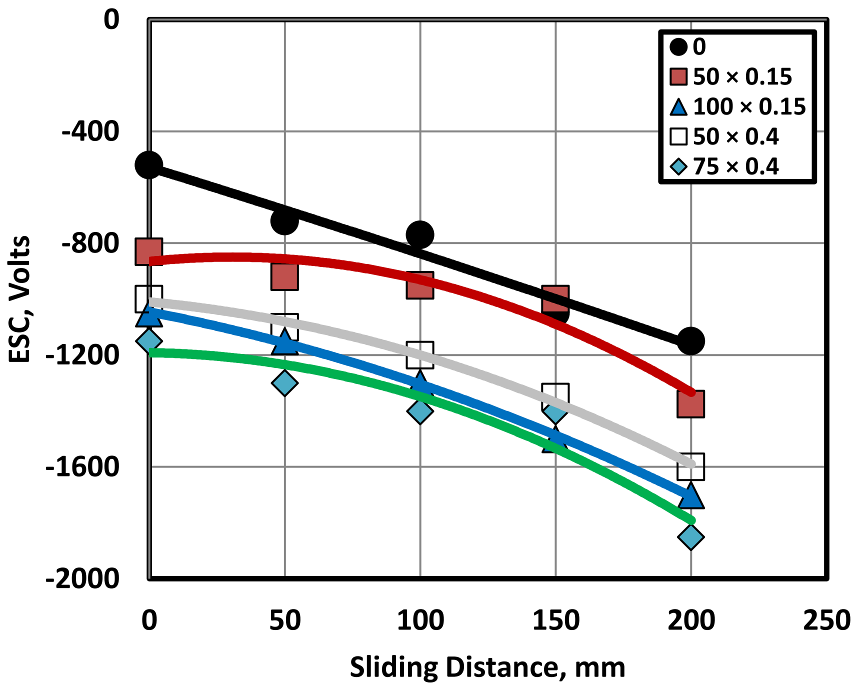

Fig. 13 ESC generated on PTFE surface sliding against the second composites in the presence of magnetic field.

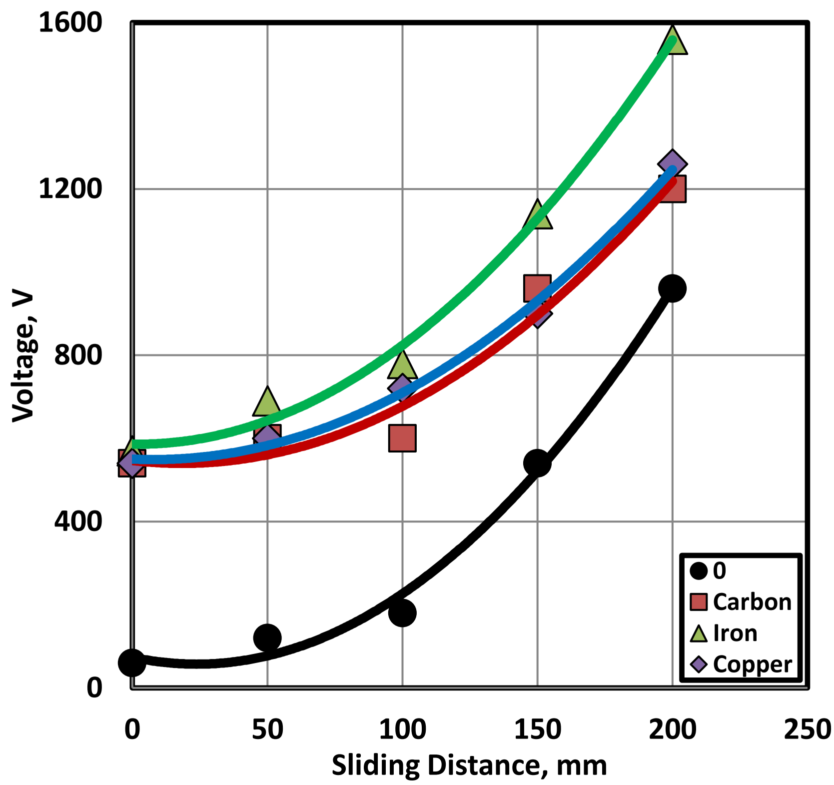

Fig. 14 ESC generated on PA surface sliding against the third composites.

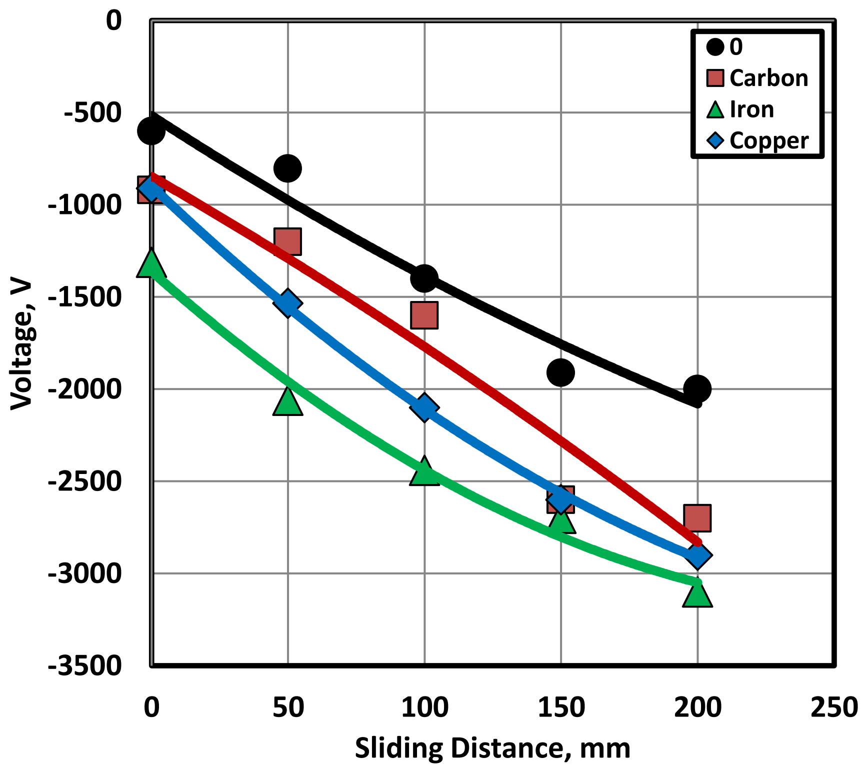

Fig. 15 ESC generated on PTFE surface sliding against the third composites.

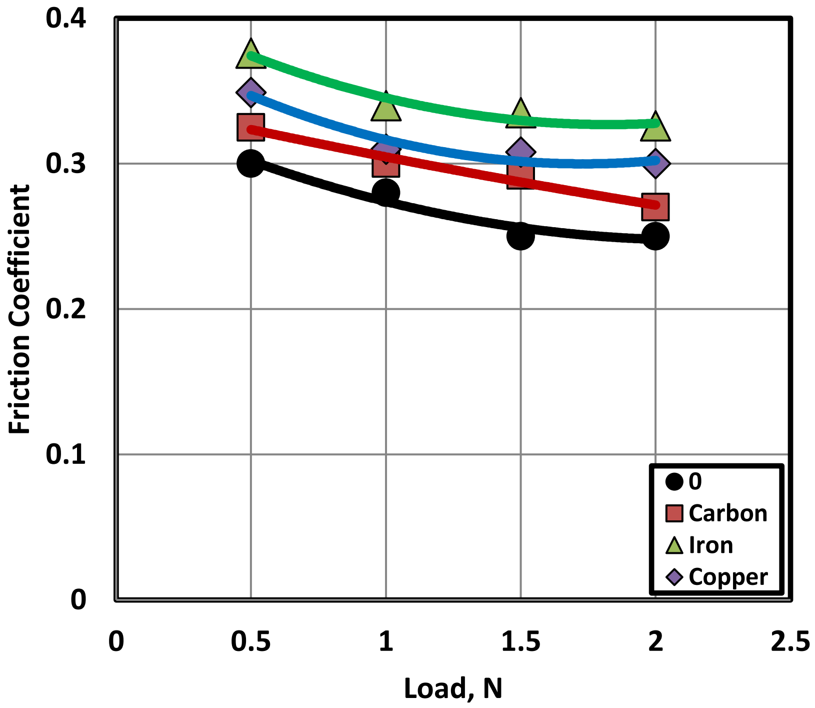

Fig. 16 Friction coefficient displayed by PA sliding against the third composites.

ESC and friction coefficient of the third composites sliding against PA are shown in Figs. 14 – 16. ESC generated on PA surface for composites containing iron particles showed the highest values followed by copper particles and carbon black, Fig. 14. Generally, filling materials in form of particles generated higher ESC than that in form of wires. It seems that the uniform distribution of the electric or magnetic is responsible for that behavior. ESC generated on PTFE surface showed the highest ESC among all the tested composites, Fig. 15. Friction coefficient displayed the same order observed for ESC, where iron showed the higher values than copper and carbon black, Fig. 16. That observation may recommend the application of layers of iron or copper to control ESC and friction coefficient.

CONCLUSIONS

1. ESC generated on PA surface sliding against PTFE reinforced by CF increases as CF content increases. Friction coefficient displayed by PA sliding against the first composites, Fig. 6, decreased with increasing normal load. Composites reinforced by 4.0 wt. % CF gave the highest value of friction coefficient. This observation strengthens the dependency of friction on ESC.

2. ESC generated on PA surface sliding against PTFE reinforced by copper wires represented lower values than that observed for composites reinforced by CF. As the diameter of copper wires decreased the number of turns increased ESC increased. Reinforced composites showed higher friction coefficient than unreinforced ones.

3. Under presence of magnetic field, ESC generated on PA and PTFE surfaces showed higher values than that observed for experiments carried out without magnetic field.

4. ESC generated on PA surface for composites containing iron particles showed the highest values followed by copper particles and carbon black. Generally, filling materials in form of particles generated higher ESC than that in form of wires. Friction coefficient displayed the same order observed for ESC, where iron showed the higher

values than copper and carbon black. That observation may recommend the application of layers of iron or copper to control ESC and friction coefficient.

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