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ELECTROSTATIC CHARGE GENERATED FROM SLIDING OF POLYETHYLENE AGAINST POLYTETRAFLUOROETHYLENE

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ABSTRACT
Electrostatic charge (ESC) generated from sliding of polyethylene (PE) on polytetrafluoroethylene (PTFE) is investigated. 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 copper wires. It seems that the intensity of the E-field increased in the presence of iron wires.

KEYWORDS
Electrostatic charge, copper, polyethylene, polytetrafluoroethylene.

INTRODUCTION
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, [1]. 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, [2 - 5]. 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, [6]. 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, [7, 8]. 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, [9 - 11]. 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, [12]. 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, [13]. 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, [14]. 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,

[15]. 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, [16]. 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, [17]. 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 aim of the present study is to measure ESC generated on the surface of hollow box coated by PTFE when polyamide (PA) and PE reinforced by copper and iron wires are sliding against it.

EXPERIMENTAL

Two sets of tests have been performed. The first aimed to investigate the effect of introducing iron wires coils inside the hollow box on ESC generation, where the distance between the sliding surface and the iron wires was 15, 30 and 45 mm identified in the text as upper, medium and lower level respectively. 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 the polymeric materials PTFE of 5 mm thickness wrapped on paper hollow box. The applied force was 10 N for ESC measurements, while it was 2, 4 and 6 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), 100, 200, 300, 400 and 500 mm. The details of the test specimens used in the experiments are shown in Fig. 1. 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 28 ± 2° C and 50 ± 10 % humidity.

The second set aimed to measure ESC generated on the sliding surfaces of PE reinforced by copper wires of 0.1, 0.3, 0.5 mm diameter as well as iron wires of 0.3 mm diameter. The sliding distance was 0 (contact and separation), 50, 100, 150, 200 and 250 mm. The test specimens were prepared from PE hollow cylinders of 40 mm diameter and 50 mm height, Fig. 2, while the hollow box had different values of depth (gap thickness). The gap thickness was 2, 12, 20, 30, 42 and 66 mm. The electric static fields (voltage) measuring device (Ultra Stable Surface DC Voltmeter) was used to measure the electrostatic charge (electrostatic field) for test specimens.

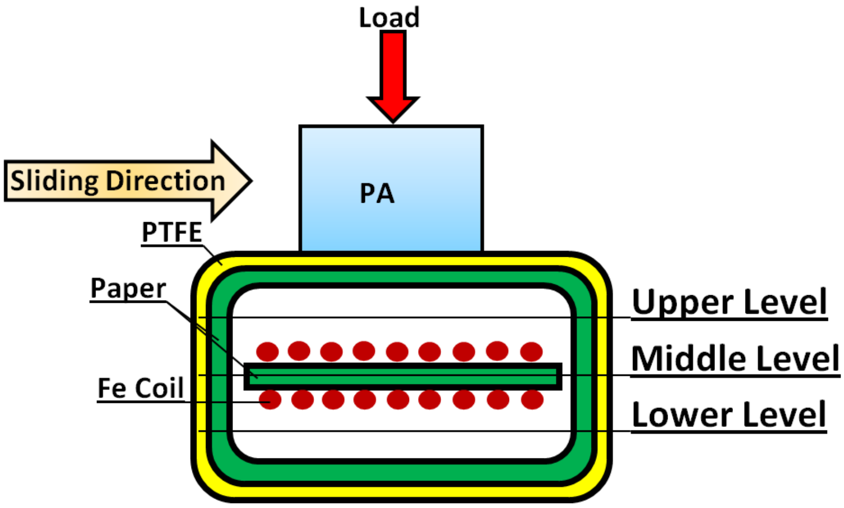

Fig. 1 Schematic drawing of the test procedure.

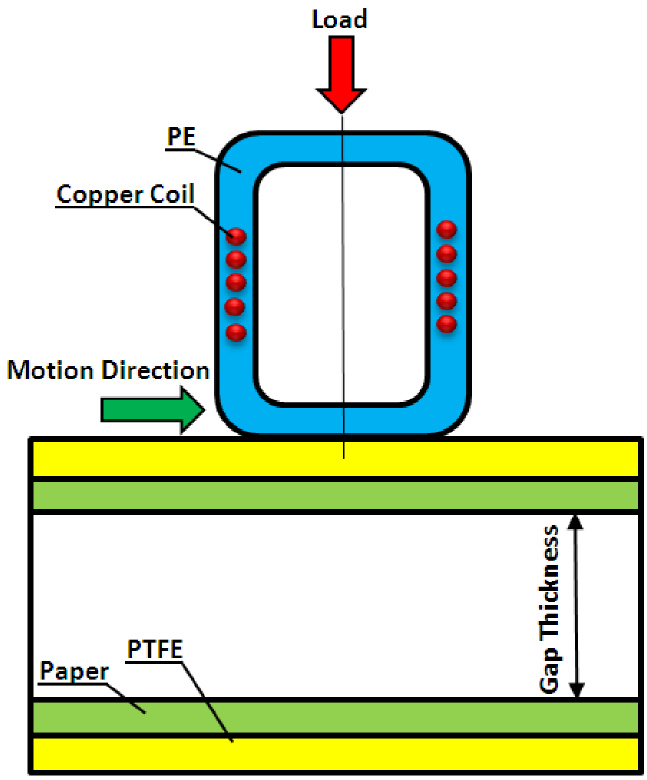

Fig. 2 Details of the tested specimen.

RESULTS AND DISCUSSION

ESC generated on the surface of PA after sliding against PTFE is shown in Fig. 3. As the sliding distance increased ESC increased. The highest value of charge is observed at 500 mm sliding distance. When the iron coil was closer to the sliding surface the highest ESC was measured (820 volts), while in the absence of the coil the lowest ESC value (320 volts) was observed. ESC gained by PTFE reached -5400 volts after 500 mm distance when the coil was closer to the sliding surface, Fig. 4, indicating the influence of the iron wires. ESC generated during contact and separation as well as sliding of the tested

materials 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, [18 - 22]. 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, [23, 24], so that the trapping energy depends on the material properties such as elastic constant and electrification. Friction induces movement of charged particles by triboelectrification, [25], where these charges can be trapped during friction. Then the polarization energy can be relaxed inducing electric field. It is expected that dislocations are formed during friction. Consequently, the existence of internal electric field acting on all the lattice sites is confirmed.

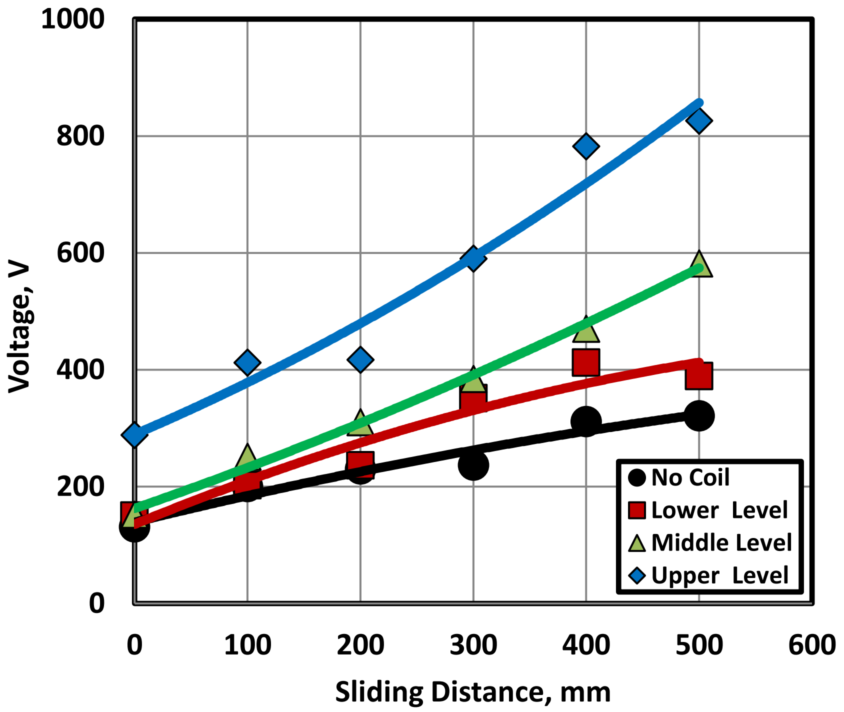

Fig. 3 ESC generated on the surface of PA after sliding against PTFE.

Friction coefficient displayed by the sliding of PA against PTFE increased as the iron coil got closer to sliding surface, Fig. 5. The strength of the electric field crossing the sliding surface is proportional to how much charge is generated. Faraday indicated that the change of the flux over time may induce a current in a conductor and thus create a source of EMF (voltage, potential difference). 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 when iron wires were close to the surface confirmed the presence of a magnetic field around the wires that is directly proportional to the current value and inversely proportional to the distance from the conductor.

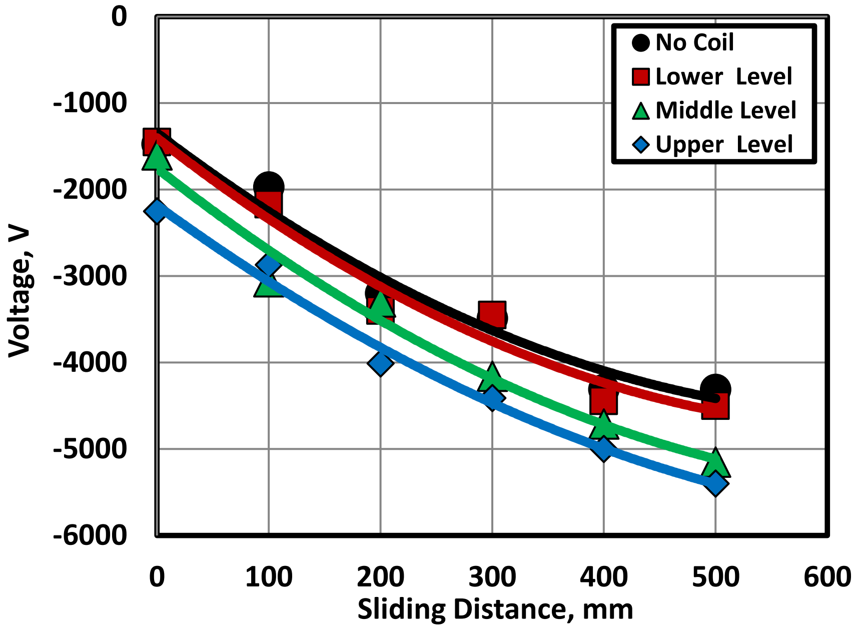

Fig. 4 ESC generated on the surface of PTFE after sliding against PA.

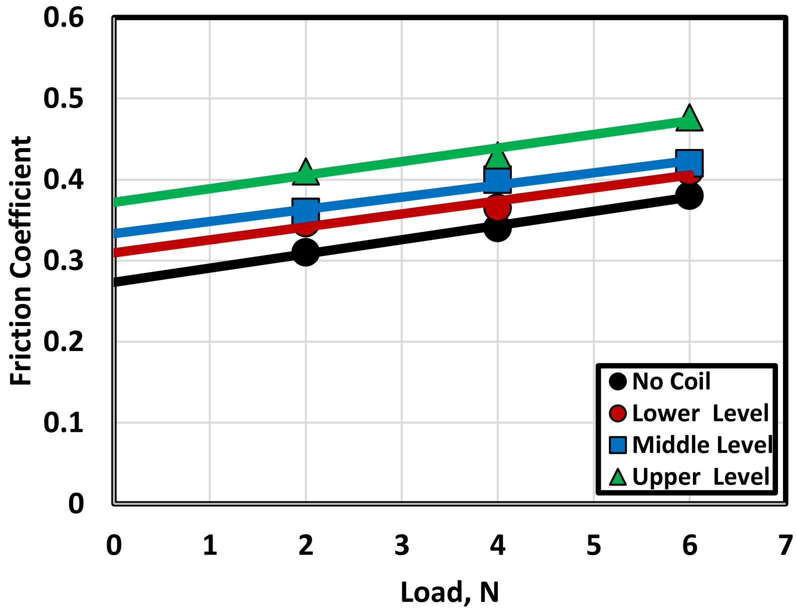

Fig. 5 Friction coefficient displayed by the sliding of PA against PTFE.

The influence of the gap thickness on ESC generated on the surface of hollow box is discussed in Figs. 6 – 15. It is clearly seen that as the gap thickness increases ESC decreases, while ESC increases with increasing sliding distance. The highest values of ESC were 3300 and -1300 on the surfaces of PE and PTFE respectively. PE slid against PTFE displayed positive charge, Figs. 6 and 7, while PTFE gained negative charge due to their relative position in the triboelectric series. ESC generated from PE reinforced by 0.1 mm copper wires and sliding against PTFE recorded high ESC values up to 6500 and -2000 volts for unreinforced PE and PTFE respectively, Figs. 8 and 9. ESC increased as the gap thickness decreased. Those composites showed the highest ESC values. 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.

It is known that the gain or loss of ESC due to friction is called triboelectrification. It was indicated that the electron is the charge carrier that is transferred from one surface to another during contact electrification of polymeric materials. ESC generated on the PE and PTFE is represented in Figs. 10 and 11, where reinforcing PE by copper wires of 0.3 mm diameter generated higher values than that observed for the unreinforced PE. It is clear from the results that copper wires were able to generate relatively higher electric field.

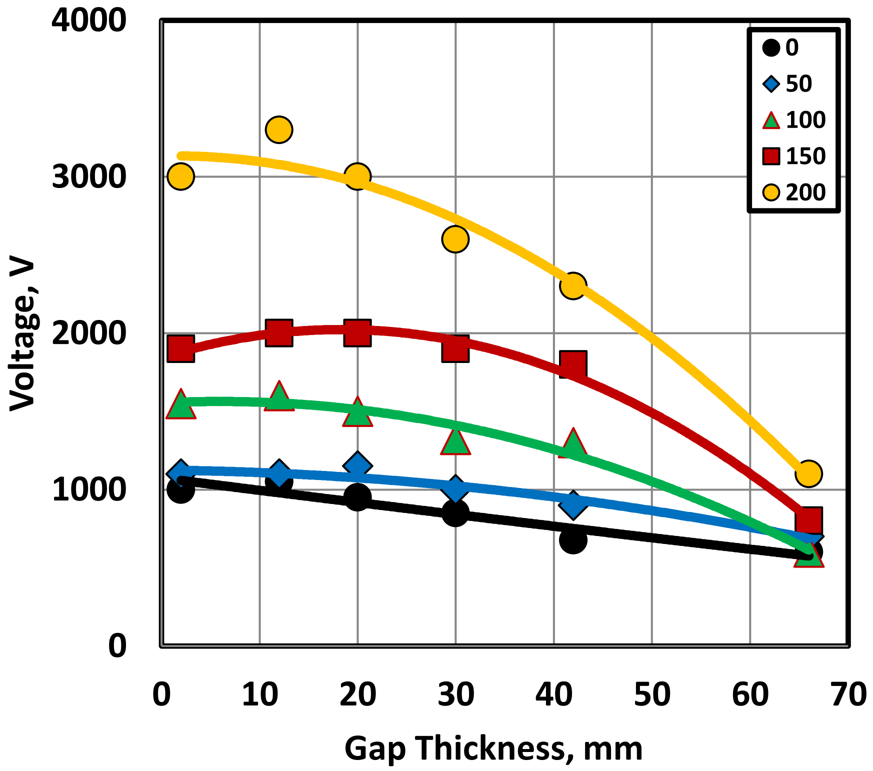

Fig. 6 ESC generated on the surface of PE after sliding against PTFE.

As the copper wire diameter increased to 0.5 mm, ESC generated increased for both PE and PTFE, Figs. 12 and 13. Generally, ESC increased proportionally with increasing the sliding distance. The generation of ESC is from the contact of the sliding surfaces which accelerates the electron exchange. ESC charge will be gained by each of the surfaces. Based on the rank of the two sliding materials in the triboelectric series, one surface would gain negative charge while the other would gain positive charge. The trend of increasing ESC with decreasing the gap thickness was observed for all the present experiments.

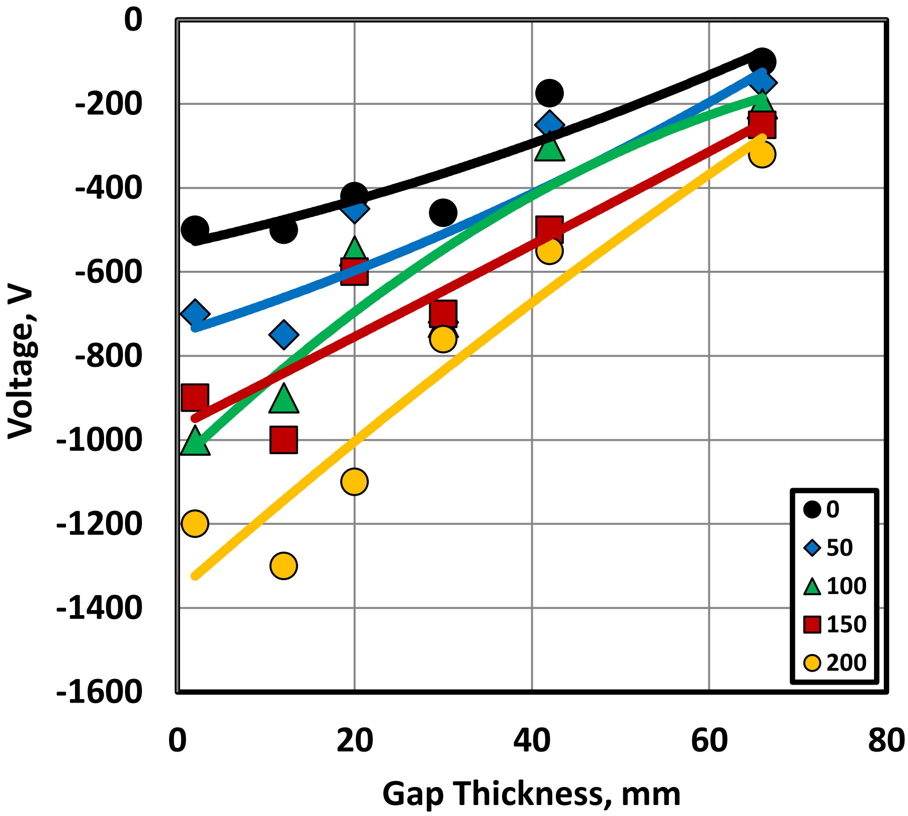

Fig. 7 ESC generated on the surface of PTFE after sliding against PE.

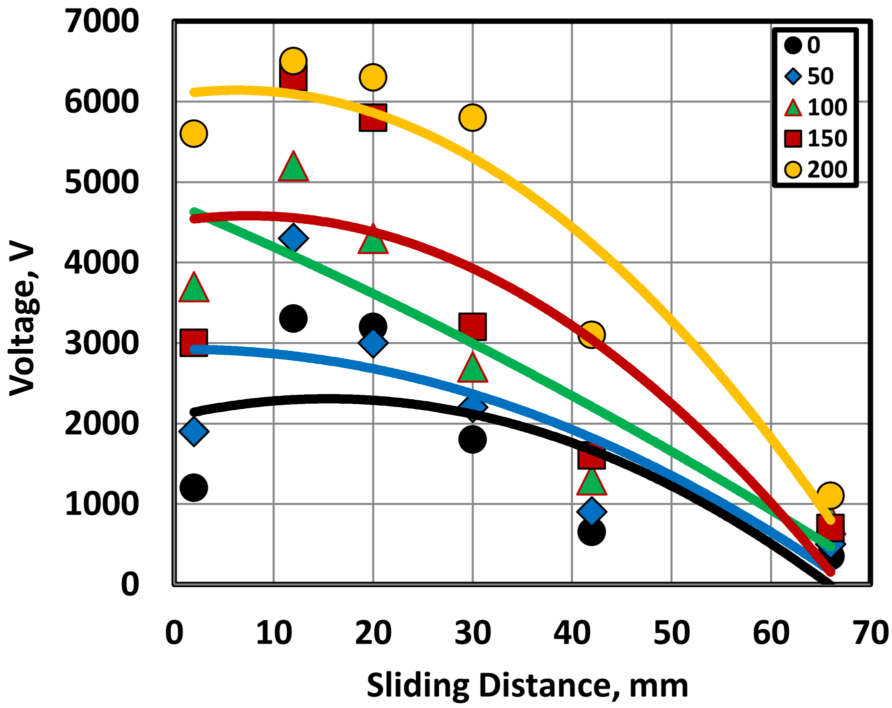

Fig. 8 ESC generated on the surface of PE reinforced by 0.1 mm copper wire diameter after sliding against PTFE.

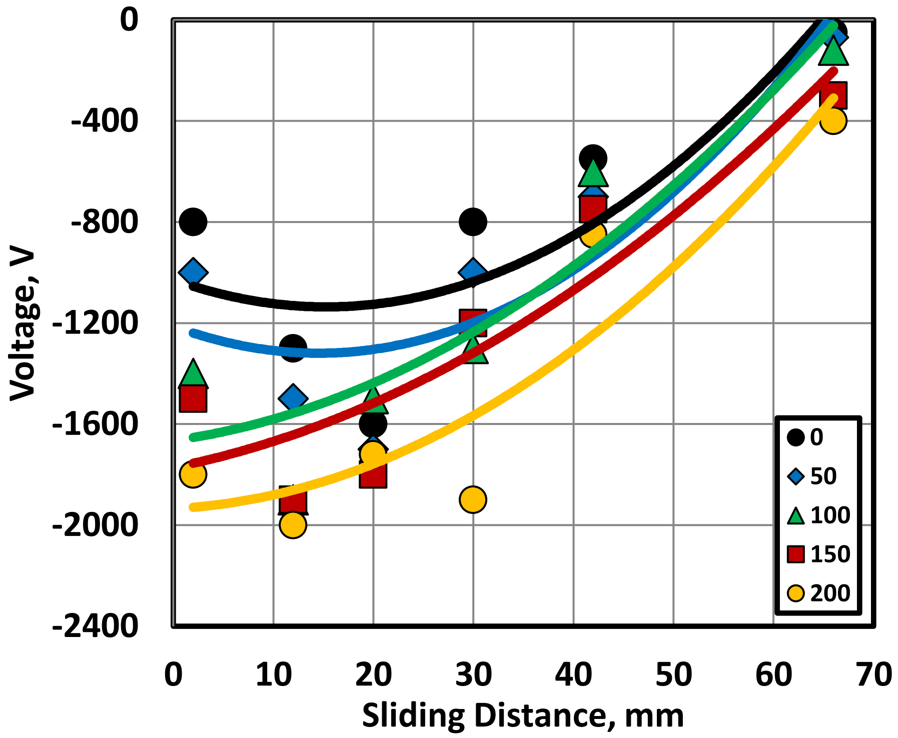

Fig. 9 ESC generated on the surface of PTFE after sliding against PE reinforced by 0.1 mm copper wire diameter.

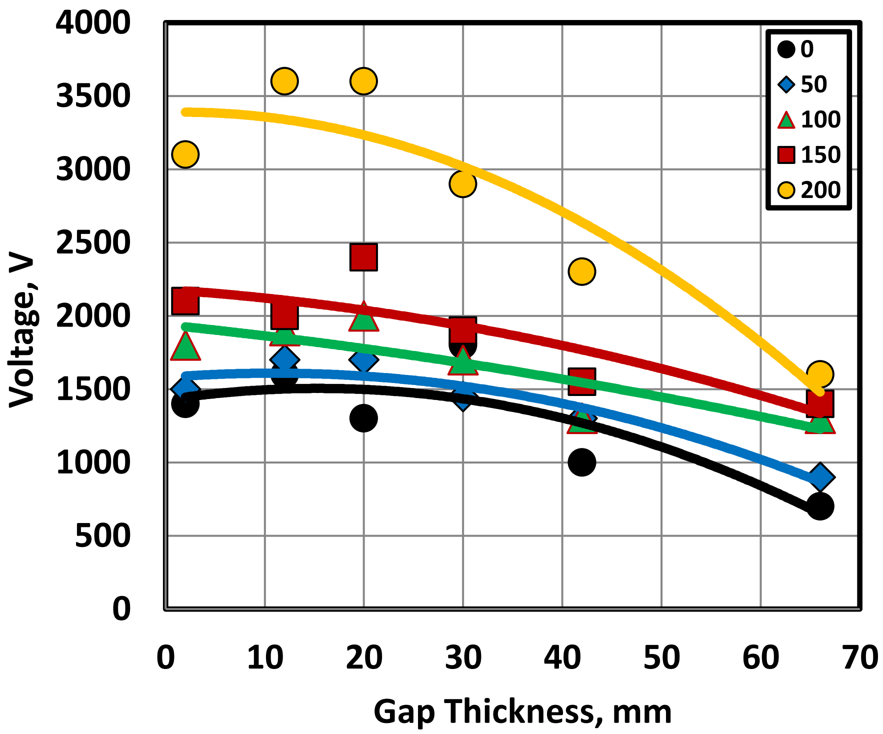

Fig. 10 ESC generated on the surface of PE reinforced by 0.3 mm copper wire diameter after sliding against PTFE.

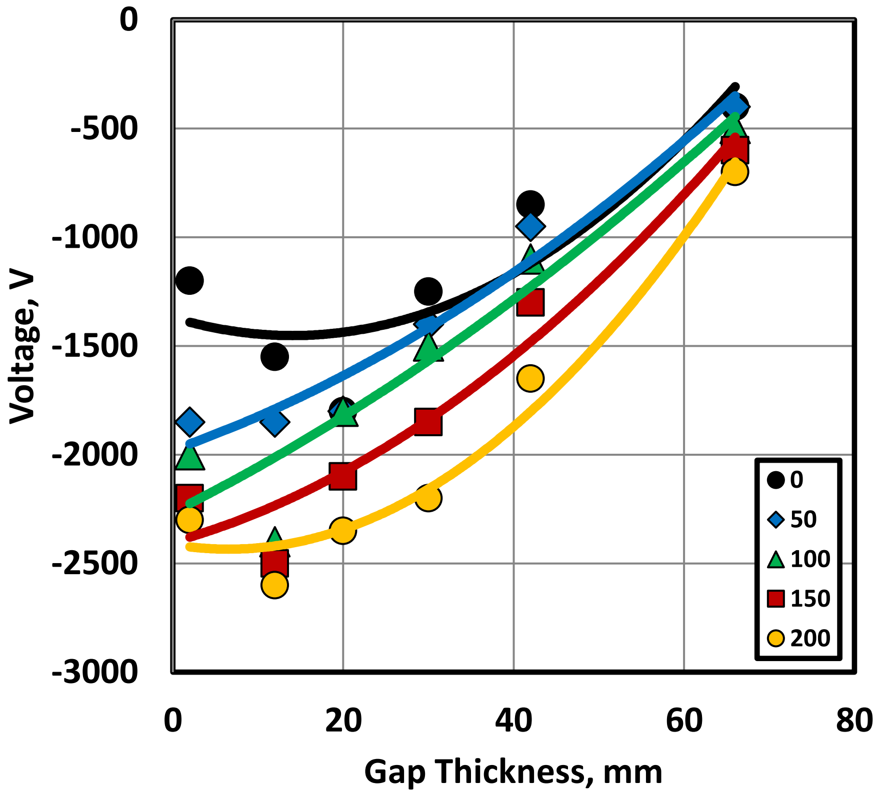

Fig. 11 ESC generated on the surface of PTFE after sliding against PE reinforced by 0.3 mm copper wire diameter.

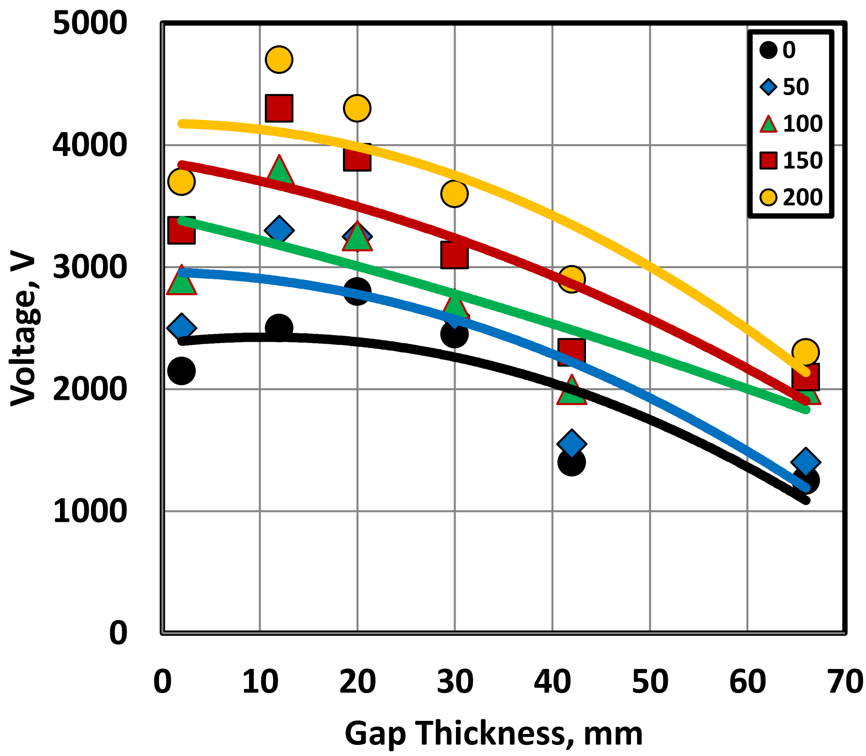

Fig. 12 ESC generated on the surface of PE reinforced by 0.5 mm copper wire diameter after sliding against PTFE.

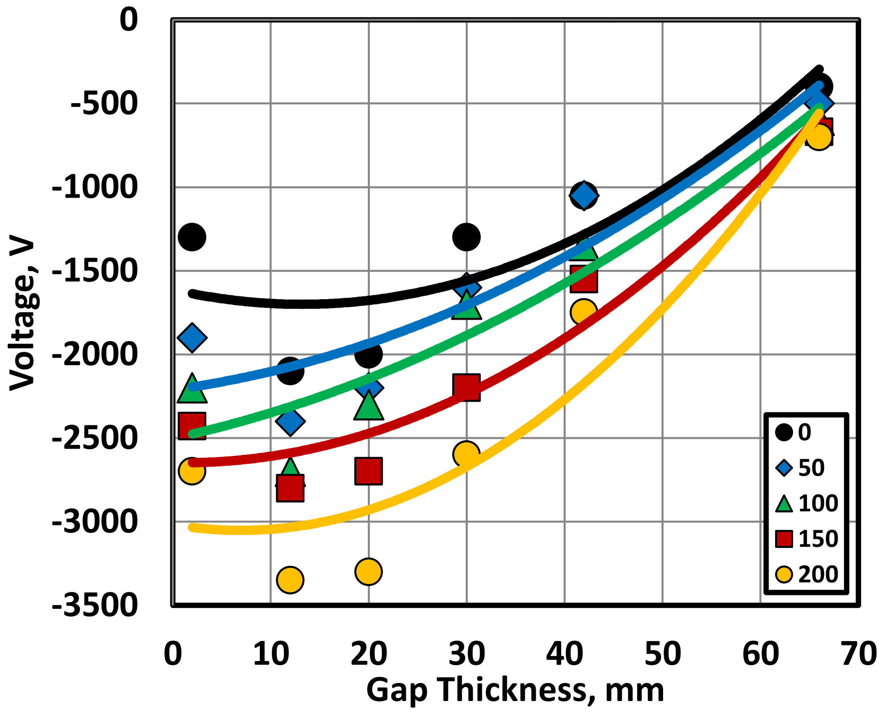

Fig. 13 ESC generated on the surface of PTFE after sliding against PE reinforced by 0.5 mm copper wire diameter.

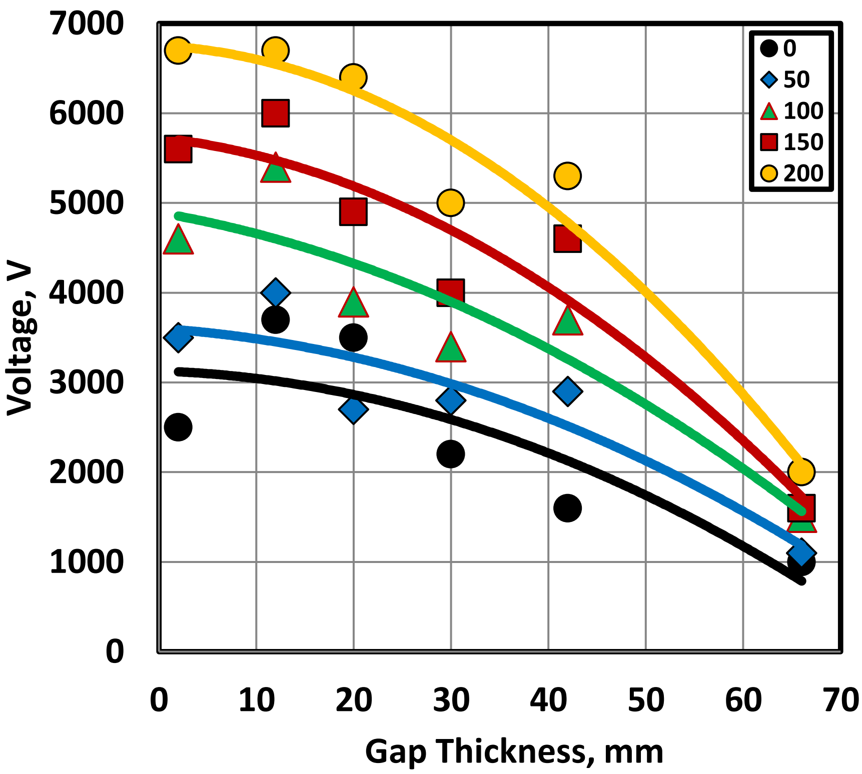

Fig. 14 ESC generated on the surface of PE reinforced by 0.3 mm iron wire diameter after sliding against PTFE.

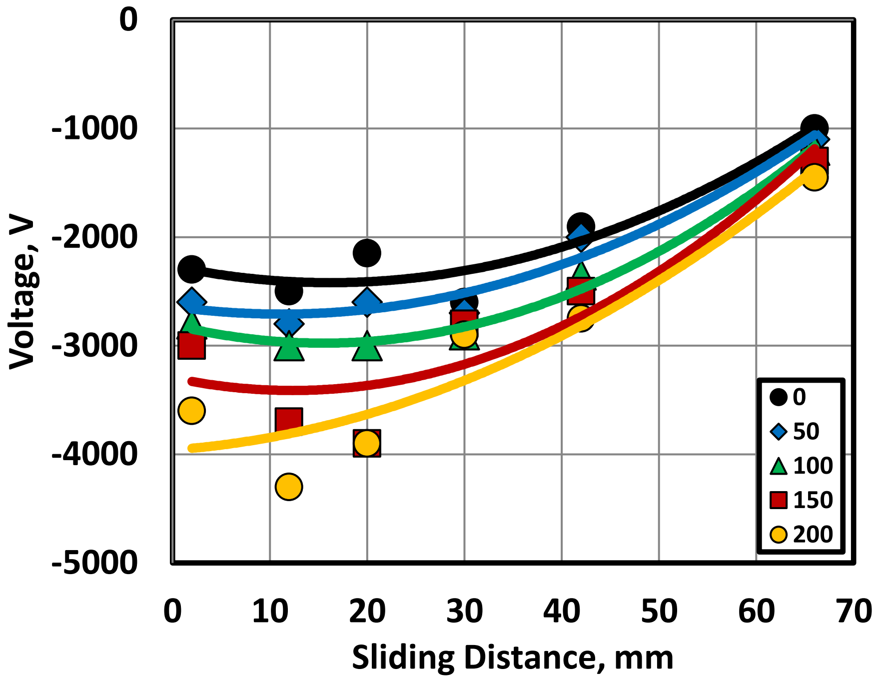

Fig. 15 ESC generated on the surface of PTFE after sliding against PE reinforced by 0.3 mm iron wire diameter.

Reinforcing PE by iron wires of 0.3 mm diameter generated higher ESC than the other tested composites, Figs. 14 and 15. It seems that the intensity of the E-field increased in the presence of iron wires. The E-field is considered as the total electric force resulted from the charge, where the distribution of charges controls the generation of electric field. ESC measured on the PE surface reached 6800 volts after 200 mm sliding distance at 2 – 12 mm gap thickness. Reinforcing PE by iron wires and the generation of ESC on the space surrounding the wires generates a magnetic field whose intensity was higher than that supposed for copper wires.

CONCLUSIONS

1. ESC generated on the surface of PA after sliding against PTFE increases as the sliding distance increases.
2. The highest value of ESC is observed when the iron coil was closer to the sliding surface.
3. ESC generated during contact and separation as well as sliding controlled friction coefficient, where it increased as the iron coil got closer to sliding surface.
4. As the gap thickness of the hollow box increased ESC decreased.
5. Reinforcing PE by copper wires generated higher values than that observed for the unreinforced PE. As the diameter of the copper wire increases, ESC increases due to the increased ability to generate relatively higher electric field.
6. 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.

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