EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 13, No. 4, October 2016, pp. 28 – 40 ISSN 2090 - 5882

EFFECT OF COPPER WIRES REINFORCING POLYETHYLENE ON GENERATING ELECTROSTATIC CHARGE

Ali A. S.[1] and Khashaba M. I.[2]

[1]Petrojet Company, Cairo, EGYPT,
[2]Production Engineering and Mechanical Design Department, Faculty of Engineering, Minia University, Egypt.

ABSTRACT
The effect of reinforcing polyethylene (PE) by copper wires on the generation of the electrostatic charge (ESC) when slid against polytetrafluoroethylene (PTFE), polypropylene (PP), and polyamide (PA) is investigated. Tests have been carried out at dry sliding.

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.

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.

KEYWORDS
Triboelectrification, electrostatic charge, copper, carbon fibres, steel, polyethylene, polyamide, polypropylene, polytetrafluoroethylene.

INTRODUCTION
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, [1 - 4]. 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, [5]. 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, [6, 7]. 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, [8 - 10]. 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, [11]. 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. As the load increased, voltage increased. Based on this observation it can be suggested to select flooring materials according to their resistance to generate electric static charge. Voltage generated from sliding of footwear against parquet ceramic flooring was lower than marble and higher than that generated from smooth ceramic. It seems that surface topography of the parquet ceramic was responsible for that behaviour. Voltage presented significant increase when footwear slid against porcelain flooring, where the maximum value reached 5995 volts. This behaviour can be an obstacle in using porcelain as flooring material, while flagstone flooring showed the lowest generated voltage, especially at low loads. This observation can confirm the use of the flooring materials.

The addition of copper and brass particles into epoxy matrix displayed higher values of voltage than that observed for epoxy filled by iron particles, [12]. 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, [13]. 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,

[14]. 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, [15]. 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, [16]. 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 from the dry sliding of PE reinforced by copper wires as well as steel and carbon fibres against PA, PP and PTFE.

EXPERIMENTAL

The present work investigated the measurement of electrostatic charge generated by the dry sliding polyethylene (PE) against polyamide PA, polypropylene (PP) and polytetrafluoroethylene (PTFE). PE was reinforced by carbon fibres, steel wires of 0.3 mm diameter as well as copper wires of 0.1, 0.3 and 0.5 mm diameter. The electric static fields (voltage) measuring device (Ultra Stable Surface DC Voltmeter) was used to measure the electrostatic charge (electrostatic field) for test specimens.

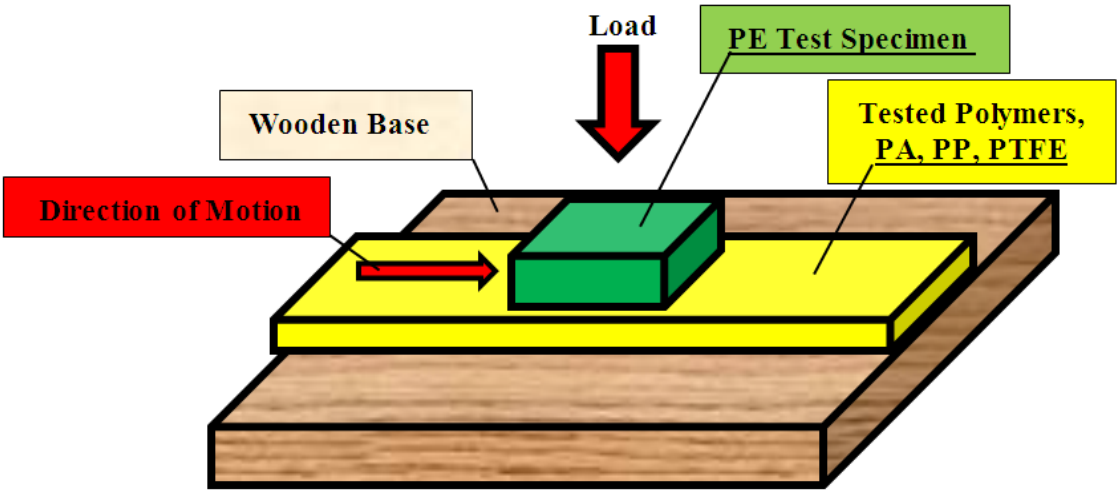

Fig. 1 Schematic drawing of the test procedure.

Tests were carried out at room temperature under varying normal loads. The test specimens were prepared from PE blocks of 50 × 50 mm^2 and 10 mm thickness adhered to wooden block of 50 mm height. The tested PE was pressed and slid against the polymeric materials (PA, PP and PTFE) in form of sheets of 100 × 300 × 5 mm^3. The applied force was 10 N. After sliding, the ESC generated on the two sliding surfaces was measured. The sliding distance was 0 (contact and separation), 50, 100, 150, 200 and 250 mm. The test rig used in the experiments is 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^o C and 50 ± 10 % humidity.

Table 1 Triboelectric series of the tested polymers.

Positive Charge		
	Polyamide	PA
	Polyethylene	PE
	Polypropylene	PP
	Polytetrafluoroethylene	PTFE
Negative Charge		

RESULTS AND DISCUSSION

ESC generated from PE sliding against PA recorded high voltage values up to -3200 volts for unreinforced PE. The voltage increased as PE reinforced by carbon fibres and metallic wires, where steel wires showed the highest values followed by carbon fibres while copper wires dsplayed the lower values. That behviour can be interpretted on the basis that the double layer of ESC generated on the sliding surfaces of PE and PA would generate an E-field inside the matrix of PE and PA. Presence of carbon fibres or metallic wires inside PE matrix would generate extra ESC on the sliding surfaces. As illustrated in Figs. 3 and 4, the ESC increased due to the presence of the carbon fibres and metallic wires inside PE due to the generation of electric field which affected the sliding surfaces by extra electric charge.

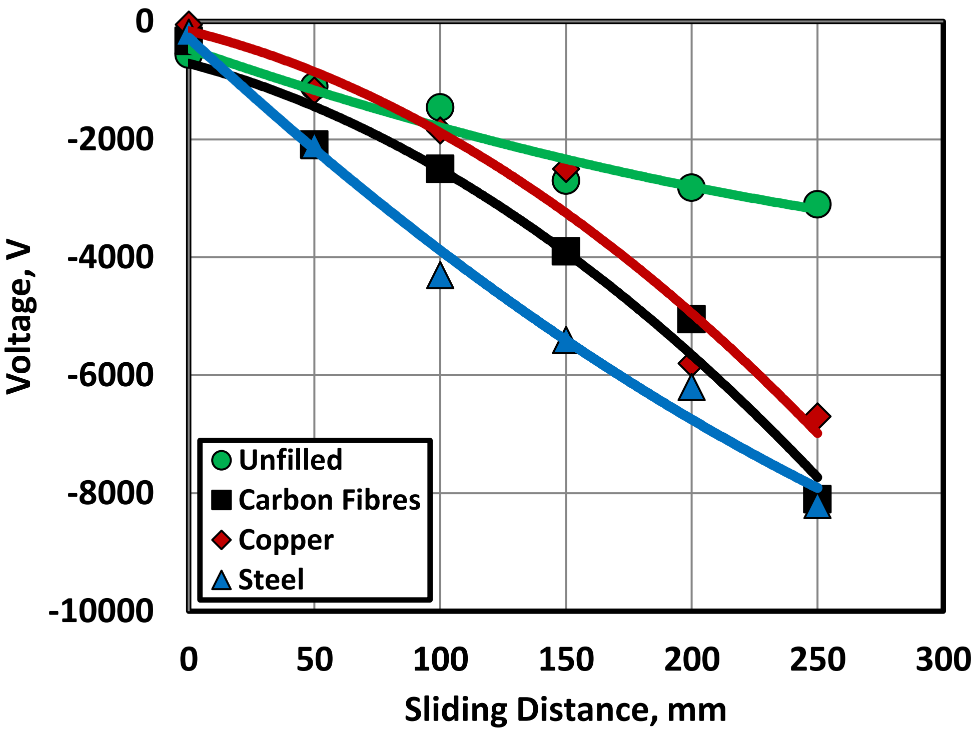

Fig. 2 ESC generated from PE sliding against PA.

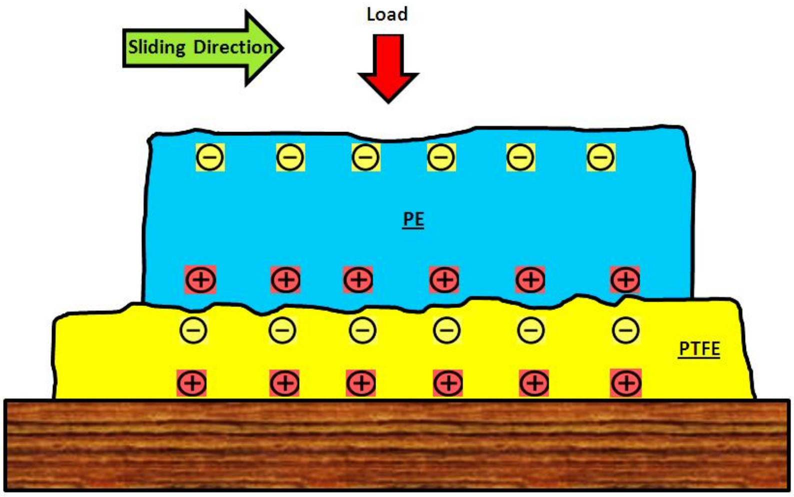

Fig. 3 Schematic drawings of generation of ESC when unreinforced PE slid against PTFE.

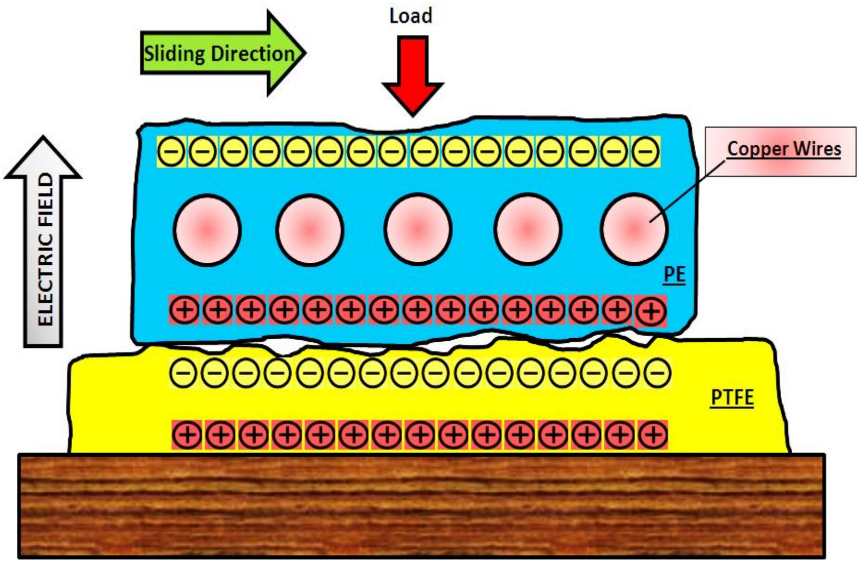

Fig. 4 Schematic drawings of generation of ESC when PE reinforced by copper wires slid against PTFE.

It was suggested that the charge transfer is electronic charge and ionic charge. The gain or loss of the charge of both types is essential triboelectrification. It was demonstrated that the electron is the charge carrier that is transferred from one insulator to another during contact electrification of polymeric materials. ESC generated on the counterface (PA) is represented in Fig. 5, where reinforcing PE by steel wires generated the highest values followed by copper and carbon fibres. The reinforcement increased ESC by 136, 227 and 277 % for carbon fibres, copper wires and steel wires respectively. It is clear from the results that steel wires were able to generate relatively higher electric field than copper wires and carbon fibres.

ESC generated from PE sliding against PP is illustrated in Fig. 6, where steel wires generated voltage of value up to 9500 volts. The counterface (PP) gained relatively high

voltage ranked in the same trend observed for PE surfece, Fig. 7. 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.

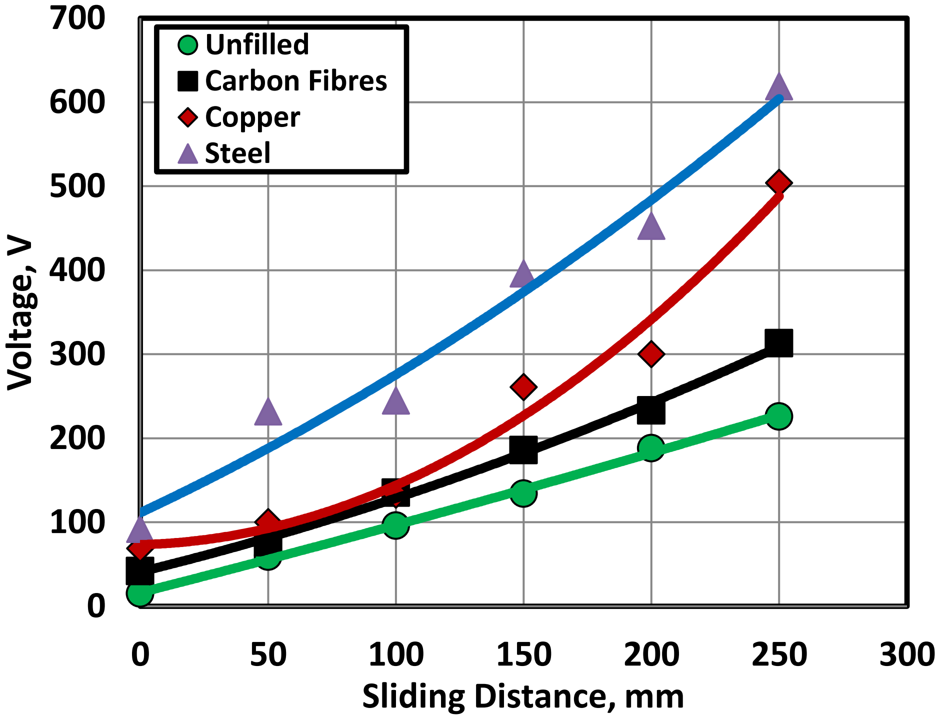

Fig. 5 ESC generated from PA sliding against PE.

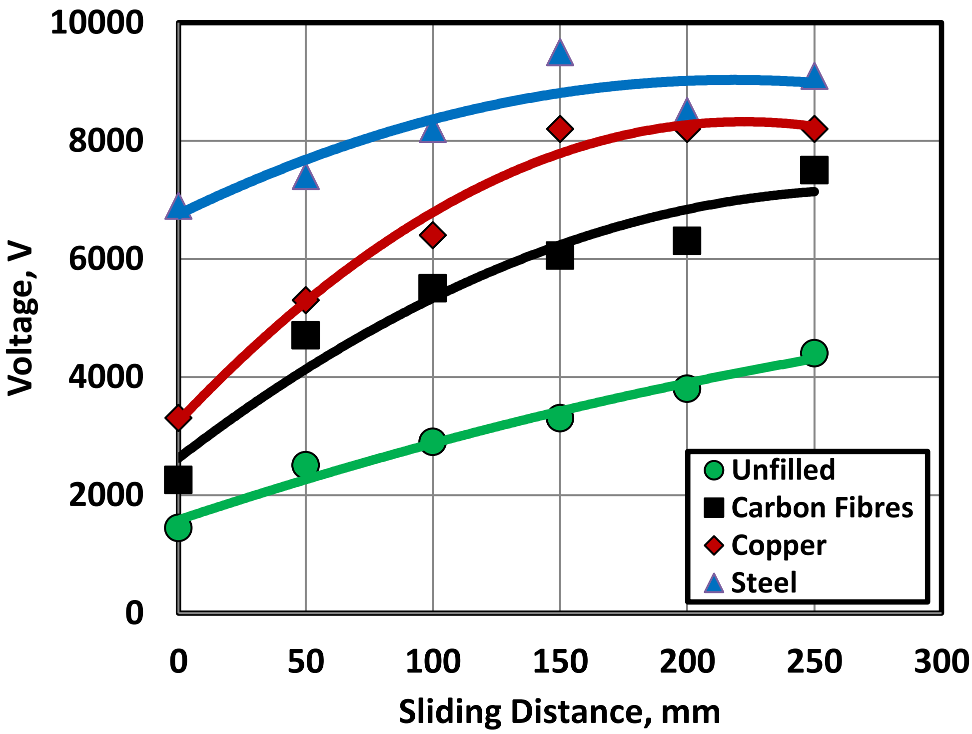

Fig. 6 ESC generated from PE sliding against PP.

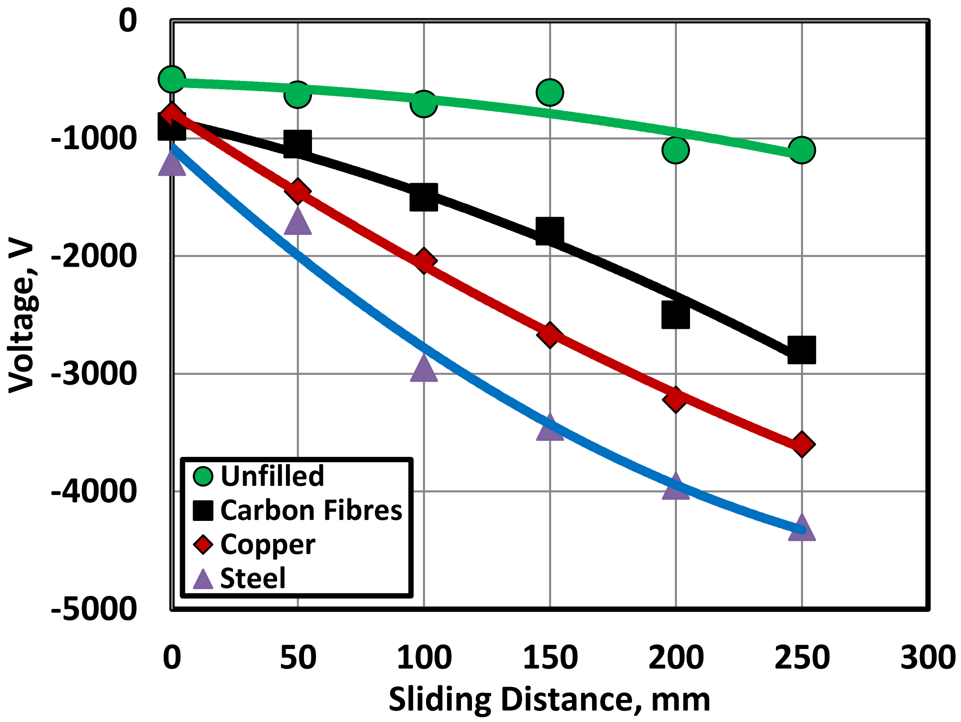

Fig. 7 ESC generated from PP sliding against PE.

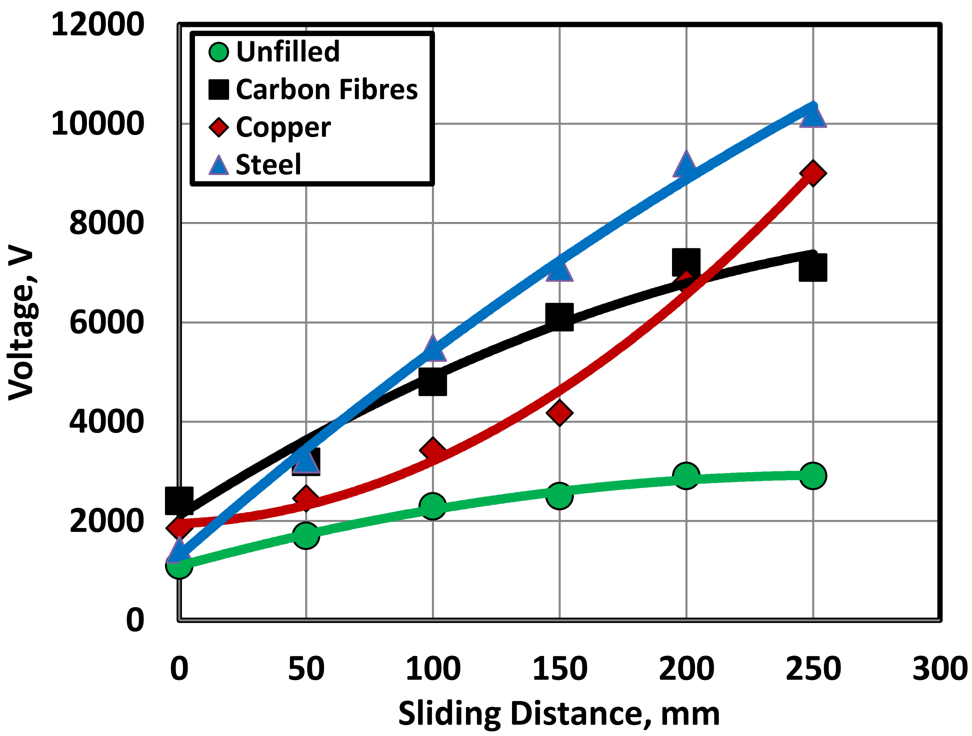

Fig. 8 ESC generated from PE sliding against PTFE.

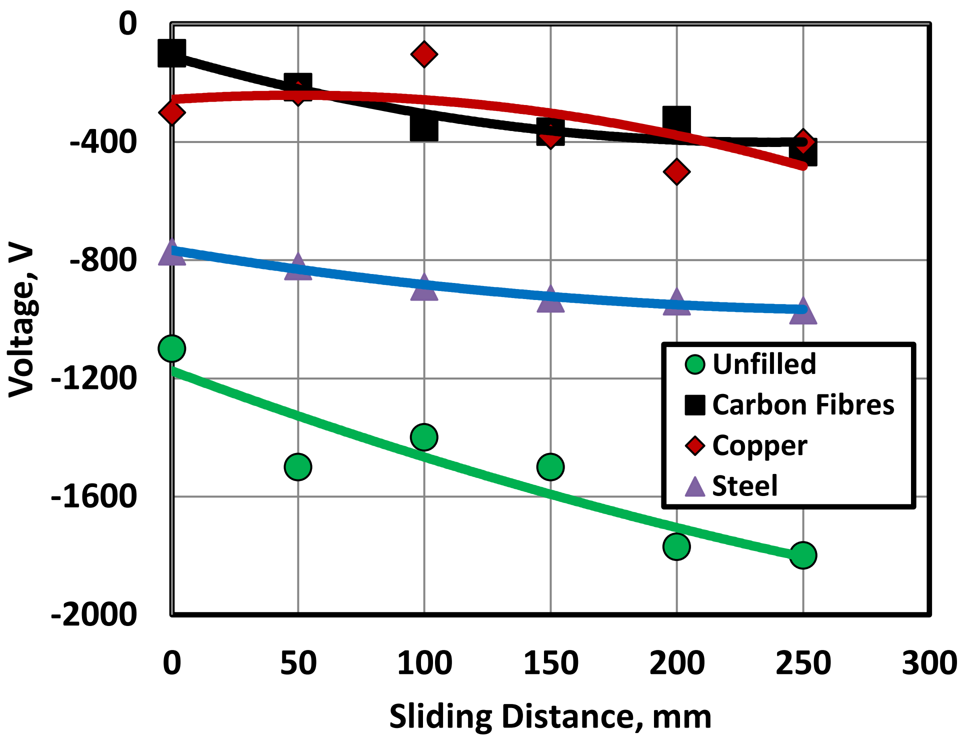

Fig. 9 ESC generated from PTFE sliding against PE.

When PE slid against PTFE, very high voltage values were generated on PE surface, Fig. 8. The values exceeded up to 10000 volts for PE reinforced by steel wires. On the counterface (PTFE), the voltage recorded lower values compared to PE, Fig. 9. The charge transfer depends on the topography, area of contact and the type of the sliding surface materials. It seems that only a fraction of electrons transfers into PTFE or due to the imperfection of PTFE charges that could leak outside its surface.

To investigate the effect of the diameter of copper wires on the amount of ESC generated on the sliding surfaces, further experiments were carried out using different diameters of copper wires, Figs. 10 – 15. ESC generated from PE reinforced by copper wires sliding against PA is shown in Fig. 10, where voltage increased with increasing wire diameter. It seems that the intensity of the E-field increased with increasing the copper diameter. 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 PA surface showed slight decrease in voltage value showing the same effect of the diameter of copper wires, Fig. 11. Reinforcing PE by copper wires and the generation of ESC on the space surrounding the wires generates a magnetic field whose intensity depends on the length and diameter of the wire. As the wire diameter increases, electric current flowing through the wire increases and consequently E-field increases. Sliding against PP showed the same trend of values, Figs. 12 - 13, that observed for PA. The diameter increase caused significant increase in voltage. The percentage voltage increase measured for 0.1, 0.3, and 0.5 mm wire diameter was 120, 230 and 350 % respectively at 250 mm sliding distance.

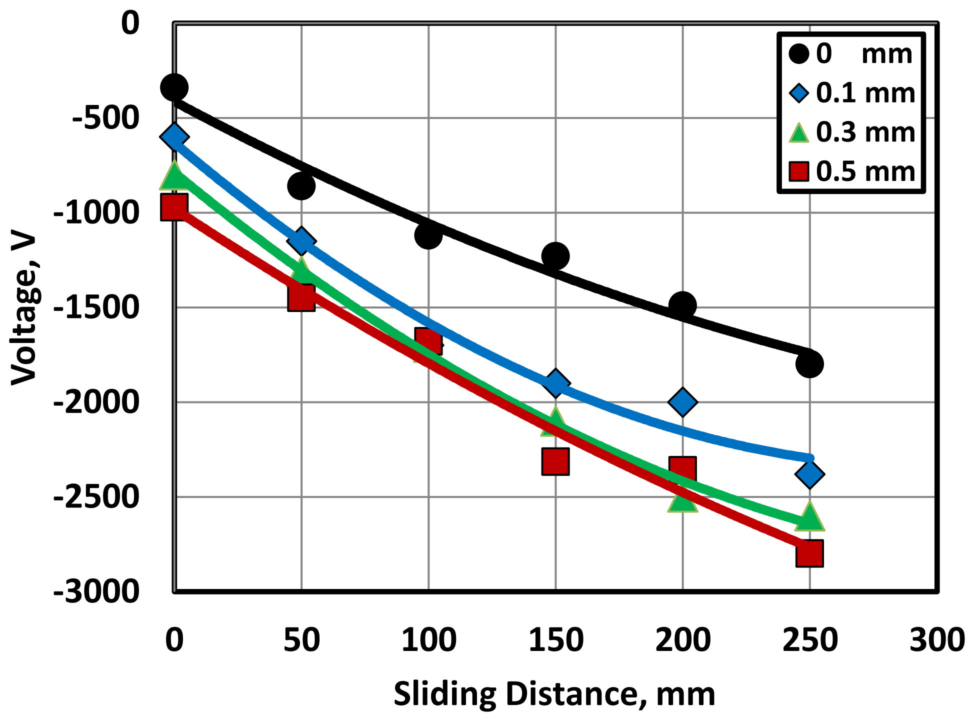

Fig. 10 ESC generated from PE reinforced by copper wires sliding against PA.

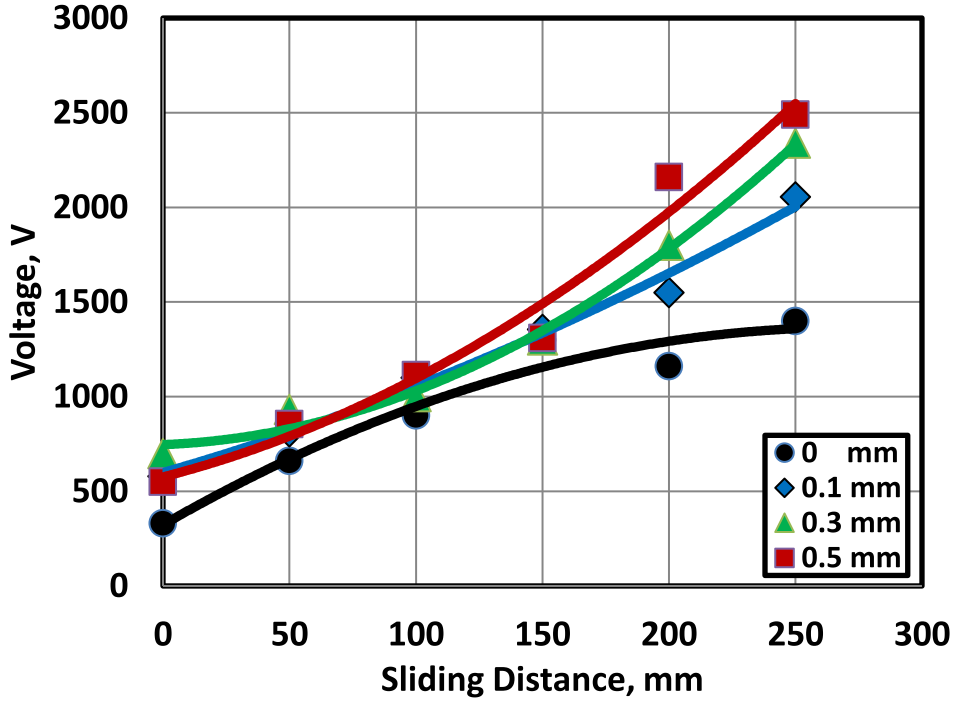

Fig. 11 ESC generated from PA sliding against PE reinforced by copper wires.

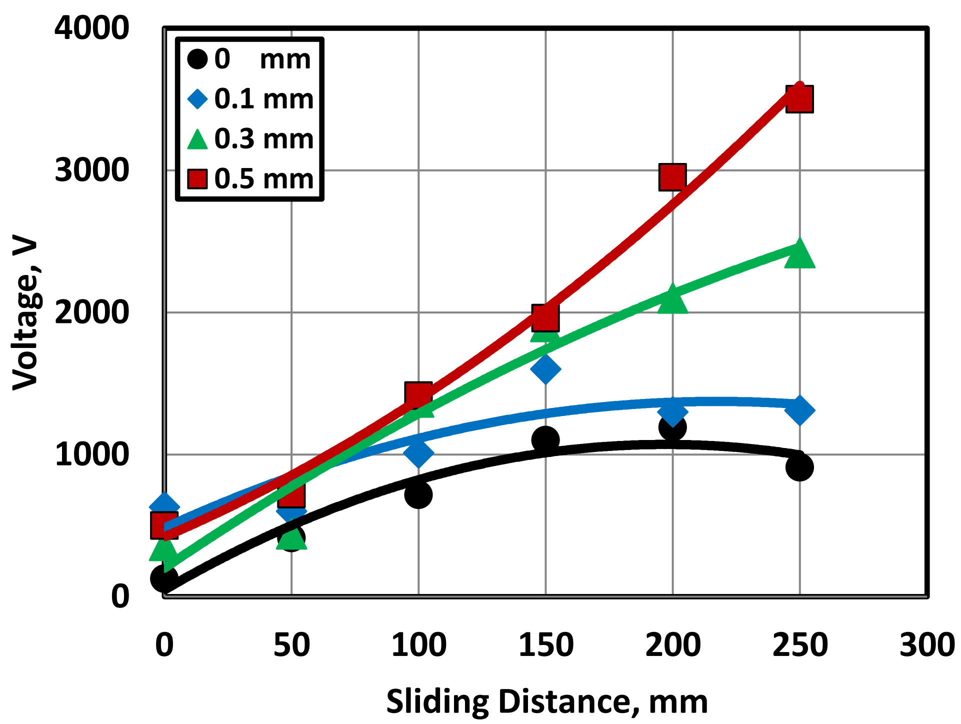

Fig. 12 ESC generated from PE reinforced by copper wires sliding against PP.

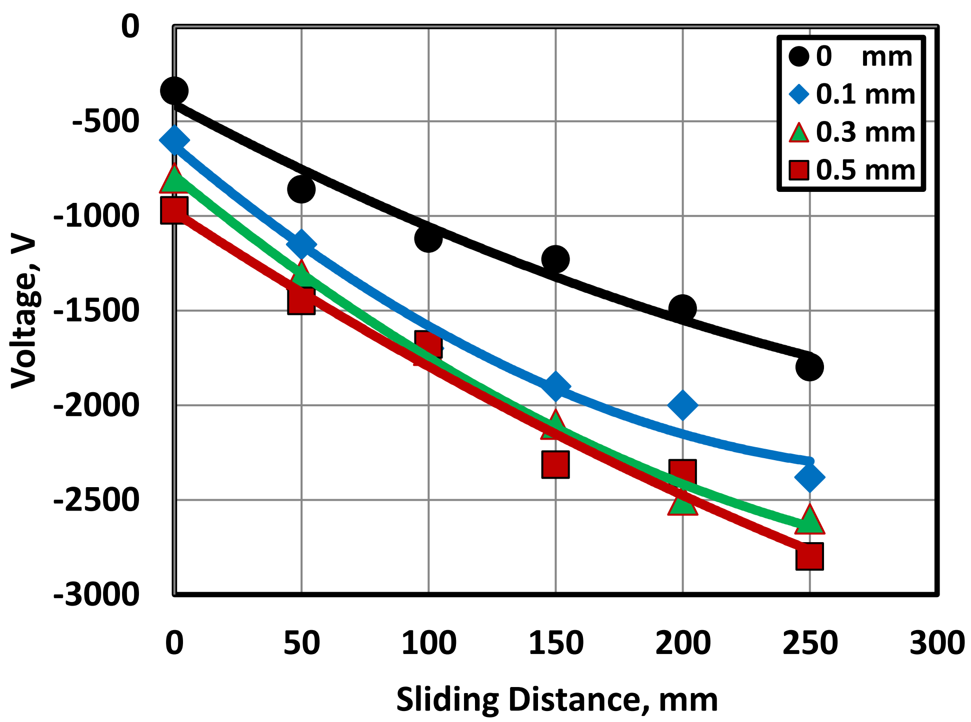

Fig. 13 ESC generated from PP sliding against PE reinforced by copper wires.

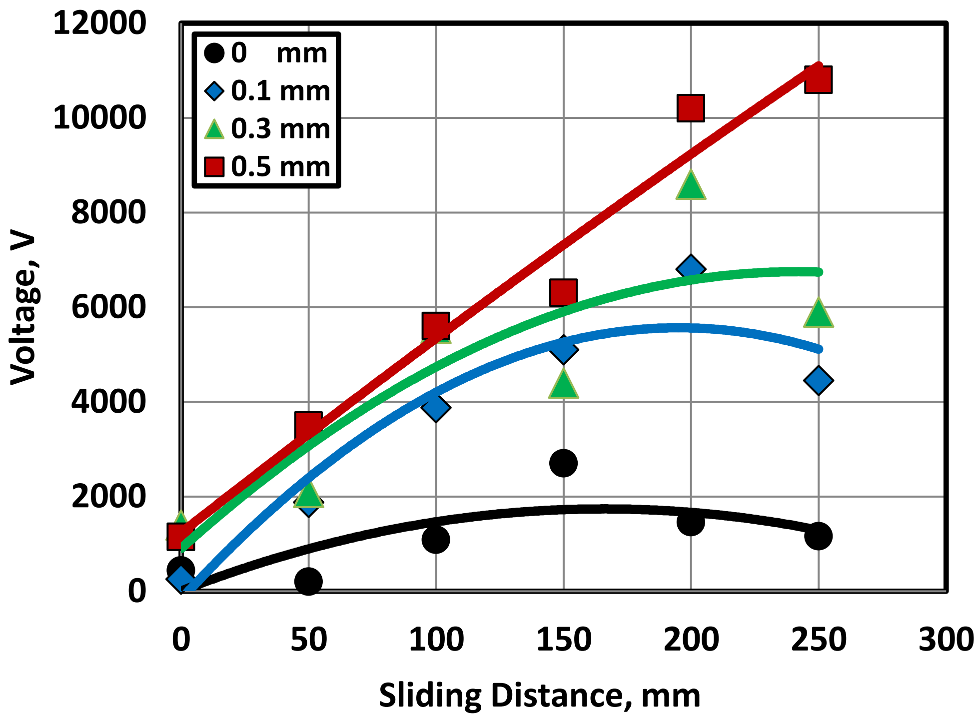

Fig. 14 ESC generated from PE reinforced by copper wires sliding against PTFE.

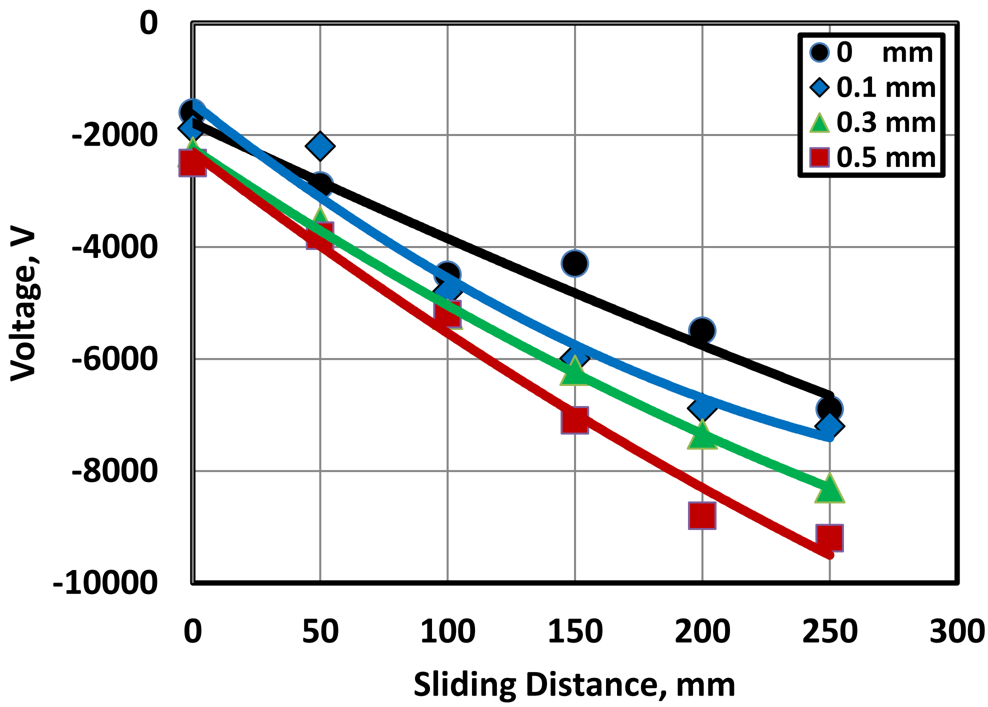

Fig. 15 ESC generated from PTFE sliding against PE reinforced by copper wires.

ESC generated from PE reinforced by copper wires sliding against PTFE, Figs. 14 – 15, recorded relatively higher voltage values up to 10800 volts at 250 mm sliding distance. Because of the electric forces caused by the charges, the electrons try to move or redistribute themselves on the sliding surfaces leading to serious effects such as sparks. The charge intensity depends on the sliding velocity, normal load and the type of materials. As a result of charging, the excess charge can leak out causing serious

problems such walking on carpet, where the charge would transfer to the person. The accumulation of the charge during walking would be gained by the person.

CONCLUSIONS

1. When sliding against PA, ESC generated from PE reinforced by carbon fibres and metallic wires, steel wires showed higher values than that observed for unnreinforced one. Steel wires generated the highest voltage followed by carbon fibres and copper wires due to its ability to generate relatively higher E-field than copper wires and carbon fibres. The same trend was observed at sliding against PP.

2. When PE slid against PTFE, very high voltage values were generated on PE surface. The values exceeded up to 10000 volts for PE reinforced by steel wires. On the counterface (PTFE), the voltage recorded lower values compared to PE. It seems that only a fraction of electrons transfers into PTFE or due to the imperfection of PTFE, where charges could leak outside its surface.

3. ESC generated from PE reinforced by copper wires sliding against PA showed that voltage increased with increasing wire diameter. It seems that the intensity of the E-field increased with increasing the copper diameter. ESC generated from PE reinforced by copper wires sliding against PTFE recorded relatively higher voltage values up to 10800 volts at 250 mm sliding distance. As a result of charging, the excess charge can leak out causing serious problems such walking on carpet, where the charge would transfer to the person. The accumulation of the charge during walking would harm and cause serious health problems for the people.

REFRENCES

1. Rehab I. A., Mahmoud M. M., Mohamed A. T. and Ali W. Y., "Electric Static Charge Generated from Sliding of Epoxy Composites Reinforced by Copper Wires against Rubber", EGTRIB Journal, Vol. 12, No. 3, July 2015, pp. 28 – 39, (2015).

2. Rehab I. A., Mahmoud M. M., Mohamed A. T. and Ali W. Y., "Increasing the Safety of Walking against Epoxy Floorings Reinforced by Metallic Wires", KGK, 05 2016, pp. 54 – 59, (2016).

3. Rehab I. A., Mahmoud M. M., Mohamed A. T. and Ali W. Y., "Effect of Electric Static Charge on Friction Coefficient Displayed by Sliding of Rubber Sole Against Epoxy Floor Reinforced by Copper Wires", EGTRIB Journal, Vol. 12, No. 4, October 2015, pp. 40 – 52, (2015).

4. Rehab I. A., Mahmoud M. M., Mohamed A. T. and Ali W. Y., "Frictional Behaviour of Epoxy Reinforced Copper Wires Composites", Advances in Materials Research, Vol. 4, No. 3, pp.165 -177, (2015).

5. El-Sherbiny Y. M., Samy A. M. and Ali W. Y., "Electric Static Charge Generated from Bare Foot and Footwear Sliding Against Flooring Materials", Journal of the Egyptian Society of Tribology, Vol. 11, No. 1, January 2014, pp. 1 – 11, (2014).

6. Greason W. D., "Investigation of a Test Methodology for Triboelectrification", Journal of Electric statics, 49, pp. 245 - 56, (2000).

7. Nomura T., Satoh T., Masuda H., "The Environment Humidity Effect on the Tribocharge of Powder", Powder Technology (135 - 136), pp. 43 - 49, (2003).

8. Diaz AF, Felix-Navarro RM., "A Semi-Quantitative triboelectric Series for Polymeric Materials", Journal of Electric statics, 62, pp. 277 - 290, (2004).

9. Nemeth E, Albrecht V, Schubert G, Simon F, "Polymer Triboelectric Charging: Dependence on Thermodynamic Surface Properties and Relative Humidity", Journal of Electric statics, 58, pp. 3 - 16, (2003).

10. Al-Qaham Y., Mohamed M. K. and Ali W. Y., "Electric Static Charge Generated From the Friction of Textiles", Journal of the Egyptian Society of Tribology Vol. 10, No. 2, April 2013, pp. 45 – 56, (2013).
11. El-Sherbiny Y. M., Abdel-Jaber G. T. and Ali W. Y., "Friction Coefficient and Electric static Charge Generated From Rubber Footwear Sliding Against Flooring Materials", Journal of the Egyptian Society of Tribology, Vol. 11, No. 4, October 2014, pp. 13 - 24, (2014).
12. AlOtaiby A., Elhabib O. A. and Ali W. Y., "Reducing Electric Static Charge Generated From Epoxy Flooring Materials", Journal of the Egyptian Society of Tribology, Vol. 11, No. 4, October 2014, pp. 25 - 35, (2014).
13. Alahmadi A., "Triboelectrification of Engineering Materials", Journal of the Egyptian Society of Tribology, Vol. 11, No. 1, January 2014, pp. 12 – 23, (2014).
14. Alahmadi A., "Influence of Triboelectrification on Friction Coefficient", International Journal of Engineering & Technology IJET-IJENS Vol:14 No:05, pp. 22 – 29, (2014).
15. Shoush K. A., Elhabib O. A., Mohamed M. K., and Ali W. Y., "Triboelectrification of Epoxy Floorings", International Journal of Scientific & Engineering Research, Volume 5, Issue 6, June 2014, pp. 1306 - 1312, (2014).
16. Elhabib O. A., Mohamed M. K., AlKattan A. A. and Ali W. Y., "Triboelectrification of Flooring Polymeric Materials", International Journal of Scientific & Engineering Research, Volume 5, Issue 6, June 2014 , pp. 248 - 253, (2014).