EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 12, NO. 2, April 2015, pp. 55 - 68 **ISSN 2090 - 5882**

ELECTROSTATIC CHARACTERISTICS OF COPPER WIRES REINFORCED EPOXY MATRIX COMPOSITES

Rehab I. A., Mahmoud M. M., Mohamed A. T. and Ali W. Y.

Production Engineering and Mechanical Design Department, Faculty of Engineering, Minia University, P.O. 61111 El-Minia, Egypt.

ABSTRACT

This study investigates the electrostatic characteristics of copper wires reinforced epoxy matrix composites through the measurement of the electrostatic charge generated from sliding of the copper wires reinforced epoxy matrix composites against rubber sheet. Experimental Testing program was designed to quantify the electrostatic charge generated under different conditions of sliding and different design of copper wires reinforcement to the composite matrix. The sliding conditions consider clamping force and dry; water and detergent wetted sliding. The copper wires design parameters include the number of wires, location and wires diameter. Based on the experimental measured results, it can be concluded the electrostatic charge built up on the contact surface during the sliding of copper wires reinforced epoxy matrix composites significantly affected by the sliding condition and copper wired reinforcement design. The measured electric potential; voltage is significantly increased with the increase of clamping load. Also the measured voltage increased as the copper wires location gets closer to the contact surface. However the electrostatic charge displayed slightly lower values in the case of wetted sliding conditions compared to that of dry contact, while a drastic decrease in the voltage for the sliding condition with detergent on the contact surfaces.

KEYWORDS

Electrostatic characteristics, epoxy composites, copper wire reinforcement, Sliding conditions, reinforcement design.

INTRODUCTION

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, [1]. 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, [2, 3]. 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, [4, 5]. 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, [6]. 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, [7]. Voltage was influenced by the load, where it increased with load increasing. Based on the present observations, it can be concluded that as the electrical conductivity of the metallic particles increased the metallic particles content to obtain the zero voltage decreased. Voltage generated from the sliding of the tested composites against rubber was much higher than that observed at contact and separation. Generally, values of metallic content that generated zero voltage at contact and separation were much lower than at sliding. 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, [8]. 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, [9]. 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. This behaviour can be explained on the basis that sliding of PMMA sphere on PTFE surface generated positive charge on the PMMA surface and negative charge on PTFE surface. The lower surface of PTFE sheet would be charged by positive charge which, in condition of connecting the steel sheet by the grounded steel pin, would move to the steel pin and increase the positive charge generated on its surface. In that

condition, the electric static charge would increase and consequently the attractive force would increase leading to an increase in friction coefficient. As for isolated test specimens, the electric static charge on the contact would be lower and consequently the attractive force would be lower causing slight decrease in friction coefficient. The same trend was observed for sliding of PE against PTFE and steel. Based on the experimental results, it is recommended to insulate the sliding surfaces in order to decrease friction coefficient.

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, [10]. 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. Significant friction coefficient increase was observed at water wetted surfaces. Epoxy free of iron showed relatively lower voltage than that observed for dry sliding. As iron content increased voltage drastically decreased. Friction coefficient and voltage slightly increased with increasing iron content at detergent wetted surfaces. Besides, at oil lubricated surfaces, friction coefficient slightly increased with increasing iron when sliding against rubber lubricated by oil. Voltage drastically decreased with increasing iron. At oil/water emulsion, voltage and friction coefficient significantly increased with increasing 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, [11]. 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. This behaviour is attributed to the fact that bare foot conducted the electric static charge generated in the contact surface. Voltage generated from sliding of bare foot against PVC floor significantly increased with increasing load. 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.

In the present work, electrostatic charge generated from contact and separation of epoxy composites reinforced by copper wires and rubber was investigated. An experimental testing program was designed to quantify the electrostatic charge generated under different conditions of sliding and different design of copper wires reinforcement to the composite matrix. The sliding conditions consider clamping force and dry; water and detergent wetted sliding. The cooper wires design parameters include the number of wires (*nW*), position from the contact surface (*s*) and wires diameter (*Di*).

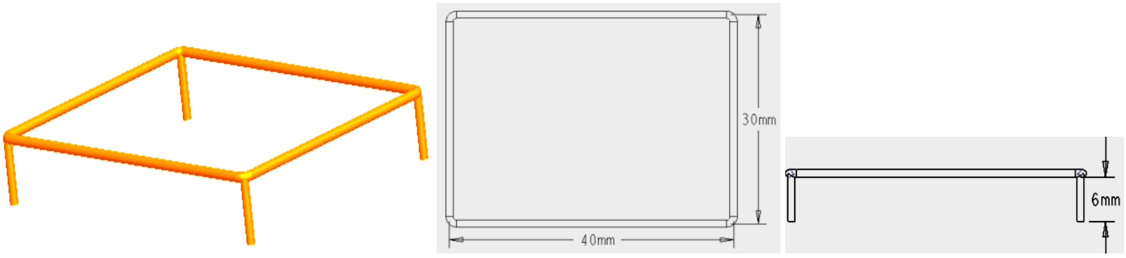
EXPERIMENTAL WORK

The (Ultra Stable Surface Voltmeter) was used to measure the electric static charge (electric static filed) after contacting the specimens with rubber for 10 second and separating to measure the generated charge under applied loads. The voltmeter, Fig. 1, has a chopper-stabilized (rotating) sensor with a remote sensor head at the end of a 100 cm long flexible cable. It measures down to 1/10 volt on a surface, and up to 20 000 volts

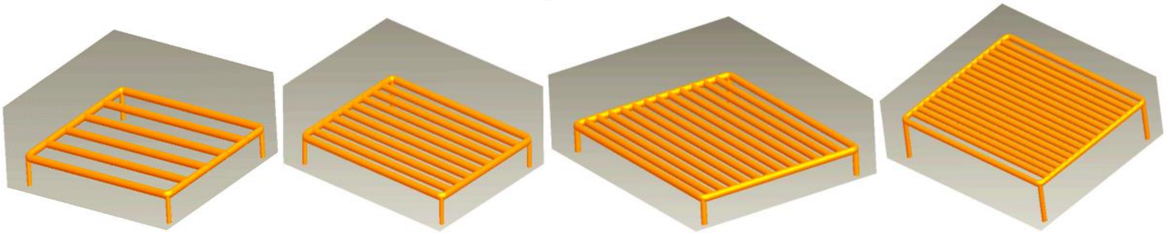
(20 kV). Readings are normally done with the sensor 1" (2.5 cm) from the surface being tested.

Fig. 1 Electric static charge (voltage) measuring device.

Test specimens were prepared from epoxy molded in boxes of 30 × 40 mm^2 and 11 mm height. Five sets of copper wires (0, 4, 8, 12 and 16 wires), of 0.1, 0.3, 0.5, 0.7 and 1.0 mm diameters were reinforcing the epoxy. The copper wires were placed at 4, 7 and 10 mm far from the surface, Fig. 2. Friction tests were carried out at room temperature under different values of applied normal loads ranging from 60 to 200 N. The test specimens were sliding against rubber sheet of 250 × 420 mm^2 area and 10 mm thickness. Tests were carried out at dry, water and detergent wetted surfaces.



(a) Test specimen frame



4 wires 8 wires 12 wires 16
wires

(b) Copper wires arrangement

Fig. 2 Copper wires reinforced epoxy matrix composites

RESULTS AND DISCUSSION

At dry contact and separation of the epoxy specimens with rubber, it was observed that the number of wires in epoxy specimen influenced the electric static charge generated on the contact surfaces, Fig. 3. In composites free of wires the electric static charge was 49 volts under applied normal load of 210 N, while the maximum charge was 142 volts for epoxy reinforced by 16 wires. Generally, voltage increased by increasing load. Similarly, the voltage increased by the increased of number of wires. This behavior was attributed to the ability of wires to conduct the electric static charge and enhance the conductivity of epoxy composites. Fig. 4 shows that the increase of number of wires in the composites up to 16 wires, increased the electric static charge to 210 volts at 200 N applied normal

load in epoxy reinforced by 16 wires, whiles in epoxy free of wires the voltage was 105 volts.

At water wetted epoxy, the maximum value of electric static charge decreased down to 30 volts, Fig. 5. This value was lower than that observed at dry contact condition, in Fig. 3. It seems that water, as good conductor, leaked the generated charge out the contact area. The same trend of results is shown in Fig. 6, where the electric static charge increased by increasing the number of wires, due to the increased conductivity of the tested composite.

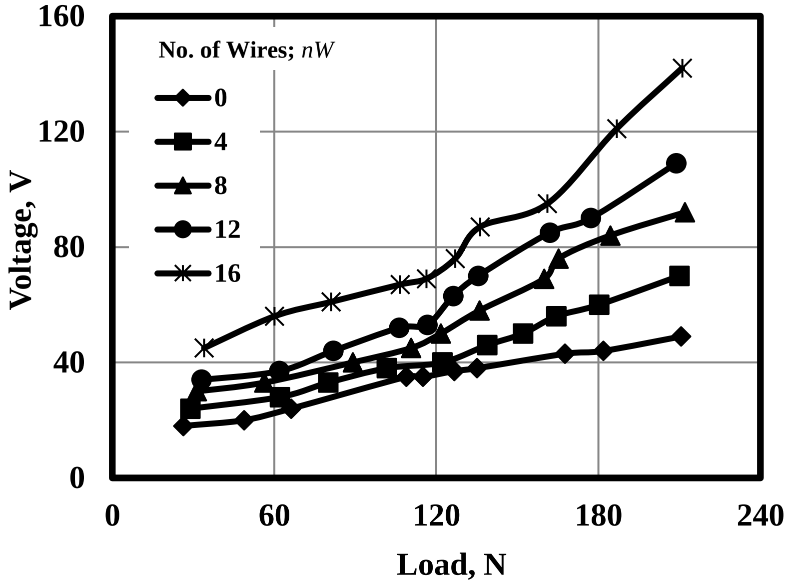


Fig. 3 Variation of the measured electrostatic charge with the number of wires and clamping force with dry sliding condition (*Di* = 0.3 mm, *S* = 7 mm).

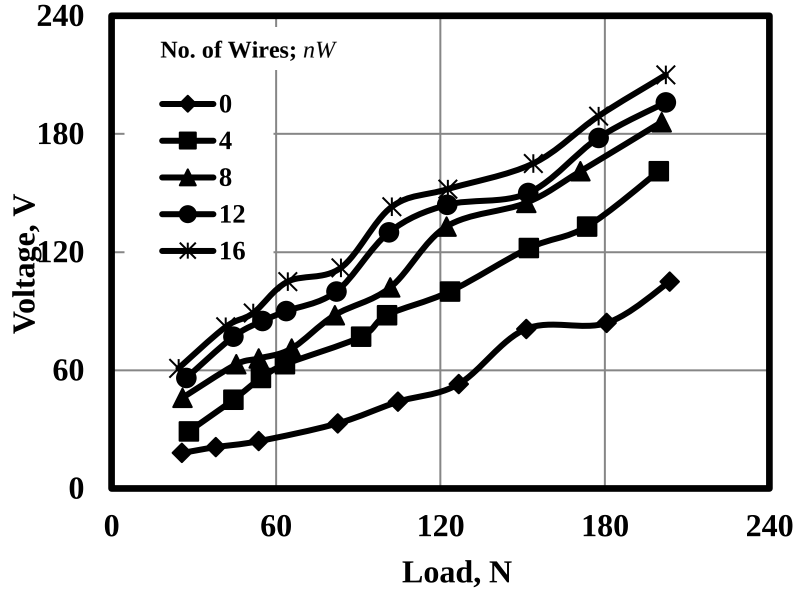


Fig. 4 Variation of the measured electrostatic charge with the number of wires and clamping force with dry sliding condition (*Di* = 0.7 mm, *S* = 4 mm).

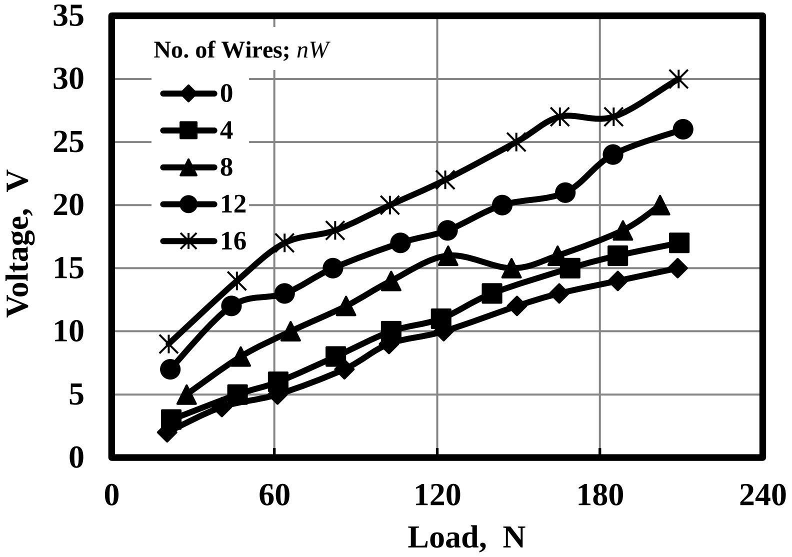


Fig. 5 Variation of the measured electrostatic charge with the number of wires and clamping force with water wet sliding condition (*Di* = 0.7 mm, *S* = 4 mm).

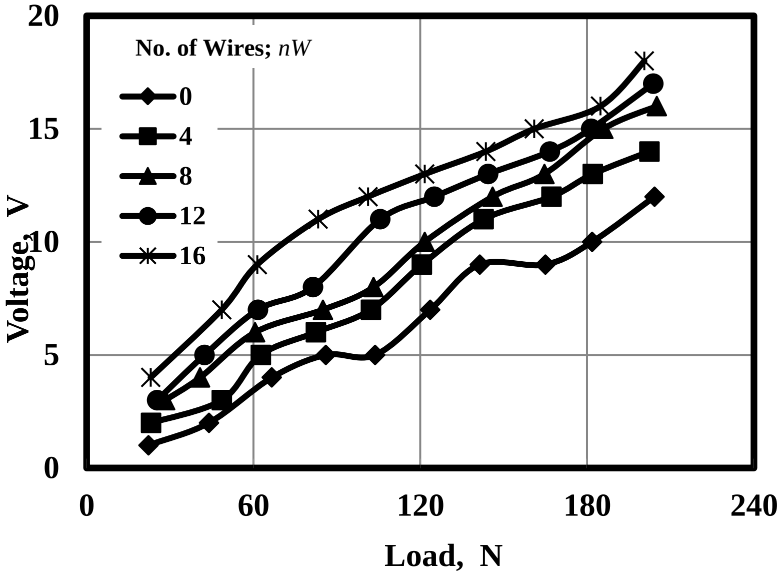


Fig. 6 Variation of the measured electrostatic charge with the number of wires and clamping force with water wet sliding condition (*Di* = 0.3 mm, *S* = 7 mm).

The wires location in composites affected the measurement of electric static charge, where the wires conducted the charge, so that when the wires were closer to the surface they facilitated the measurement of the generated voltage, but when the wires location was far from the surface, the measured voltage decreased, Fig. 7. The maximum voltage was 109 volts in epoxy reinforced by wires at 4 mm far from the surface, while that reinforced by wires at 10 mm far from the surface showed 70 volts. The same trend of results is shown in Fig. 8, the measured voltage was 93 and 34volts in epoxy reinforced by wires at 4 and 10 mm far from the surface respectively, less than 200 N applied load.

By increasing the wires diameter their ability to conduct the electric static charge increased, Fig. 9. It seems that the voltage increased as the wire diameter increased up to 120 volts and the minimum voltage was 40 volts in epoxy reinforced by 0.1 mm wire

diameter due to the decrease of the cross area of wires. The same trend of results is shown in Fig. 10, where the electric static charge increased up to 128 for 1.0 mm wire diameter and decreased down to 35 volts for 0.1 mm wire diameter under the same applied load.

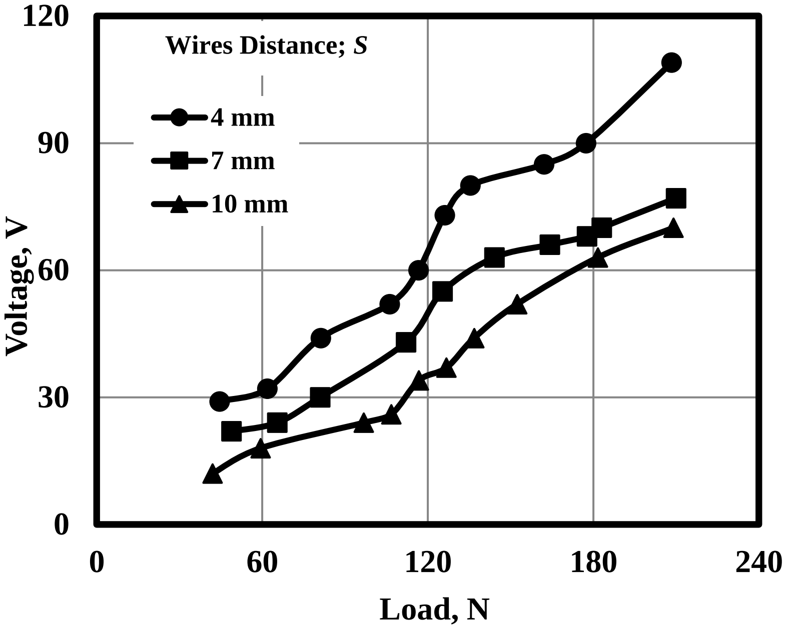


Fig. 7 Variation of the electrostatic charge with copper wires embedded depth form the contact surface (*Di* = 0.7 mm; *nW* = 12).

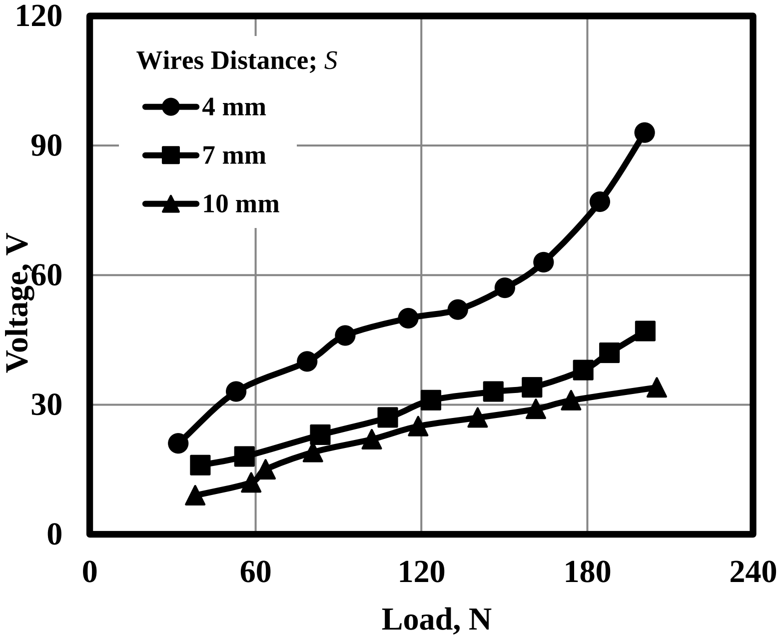


Fig. 8 Variation of the electrostatic charge with copper wires embedded depth form the contact surface (*Di* = 1.0 mm; *nW* = 4)

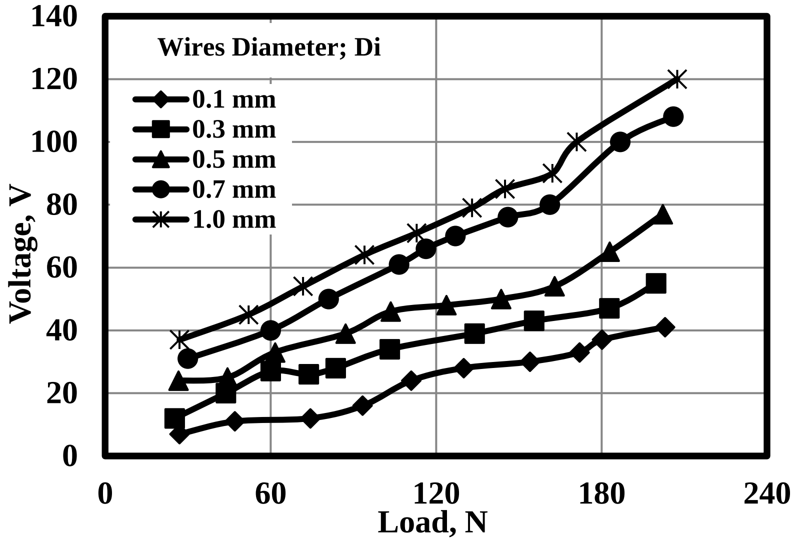


Fig. 9 Effect of wire diameter on electric static charge at 4 mm from the surface and 16 wires in the wires.

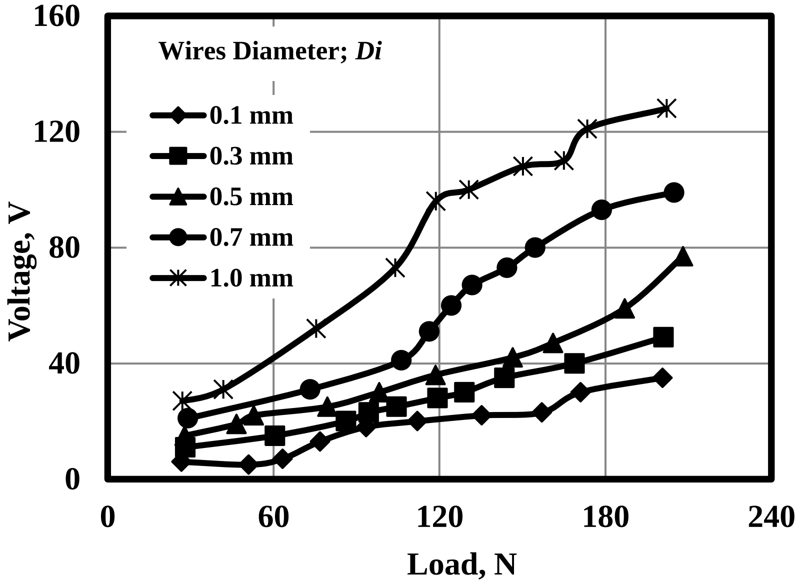


Fig. 10 Effect of wire diameter on electric static charge at 10 mm from the surface and 16 wires in the wires.

Fig. 11 illustrates that, when the wires were closer to the surface, they conducted the electric static charge and hence they facilitated the measurement of the generated voltage on the epoxy composites. The maximum voltage was 29volts, which was considered lower than that observed in Fig. 5. This reduction was caused by water electrical conductivity. The same trend of results is shown in Fig. 12, where the electric static charge increased because the wires reinforcing the tested composites were closer to the surface.

The wire diameter and wires location showed the same effect on the electric static charge because they increased the conductivity of the tested composites, Fig. 13. It is

shown that, the maximum voltage was 28 volts under 200 N applied load in epoxy reinforced by 1.0 mm wire diameter. The same trend of results is shown in Fig. 14, where the electric static charge increased by the increasing of the wire diameter, that caused the maximum voltage to be 28 volts under 216 N applied load.

At detergent wetted epoxy, the presence of detergent on the contact surfaces caused drastic decrease of the electric static charge, Fig. 15, which was more than the decrease caused by the presence of water. The maximum voltage was 18 volts in epoxy reinforced by 16 wires. Figure 16 shows that, the maximum voltage was 16 volts compared to the same composites in Fig. 11. Due to the relatively high electrical conductivity of the detergent, the electric static charge showed further decrease lower than observed for water. The same trend of results is shown in Fig. 17, where the maximum voltage was 24 volts higher than that observed in Fig. 16, due to the increase of the diameter of wires reinforcing the epoxy composites to 1.0 mm which facilitated the measurement of the voltage.

The maximum voltage was 14 volts in epoxy reinforced by 1.0 mm wire diameter, Fig. 18. The same trend of results is shown in Fig. 19, where the electric static charge increased by the increasing the wire diameter, that caused the maximum voltage to be 14 volts under 123 N applied load.

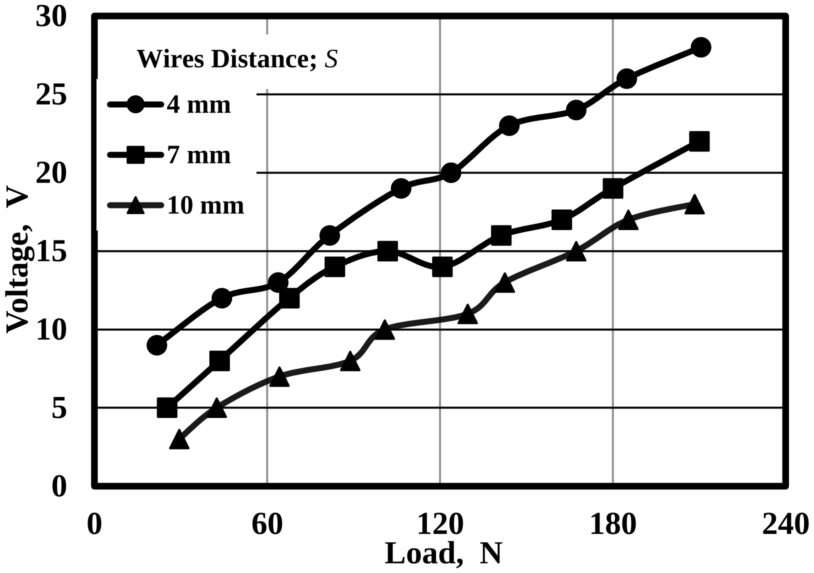


Fig. 11 Effect of wires location on electric static charge at 0.7 mm wire diameter and 12 wires in the wires.

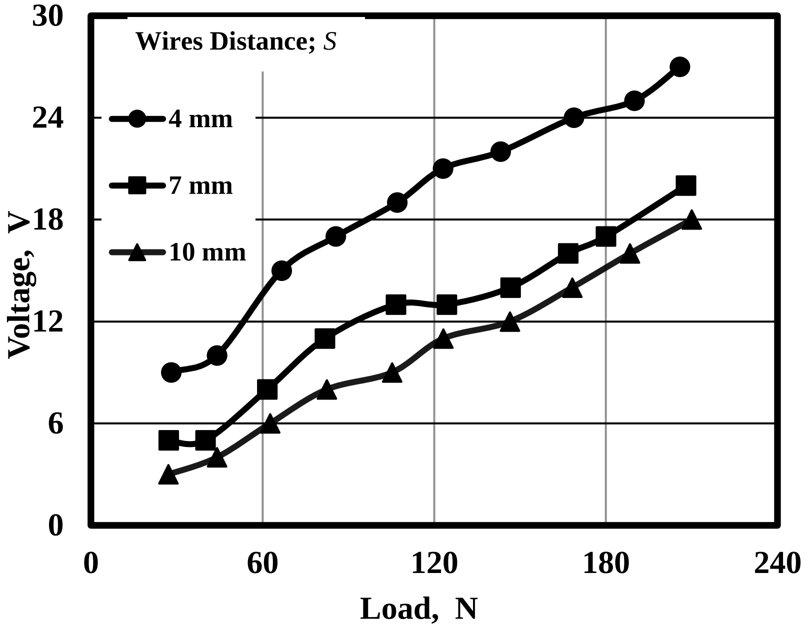


Fig. 12 Effect of wires location on electric static charge at 0.5 mm wire diameter and 4 wires in the wires.

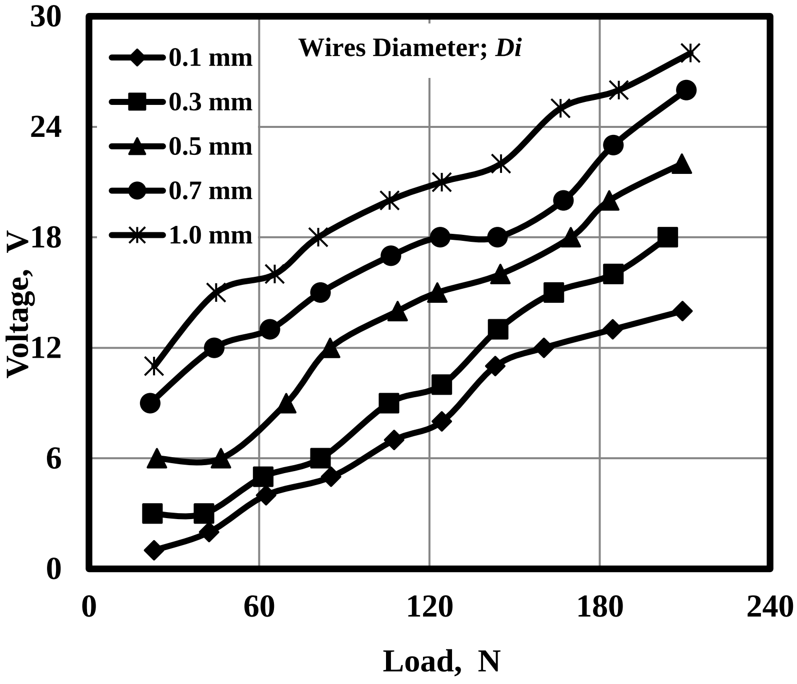


Fig. 13 Effect of wire diameter on electric static charge at 4 mm from the surface and 12 wires in the wires.

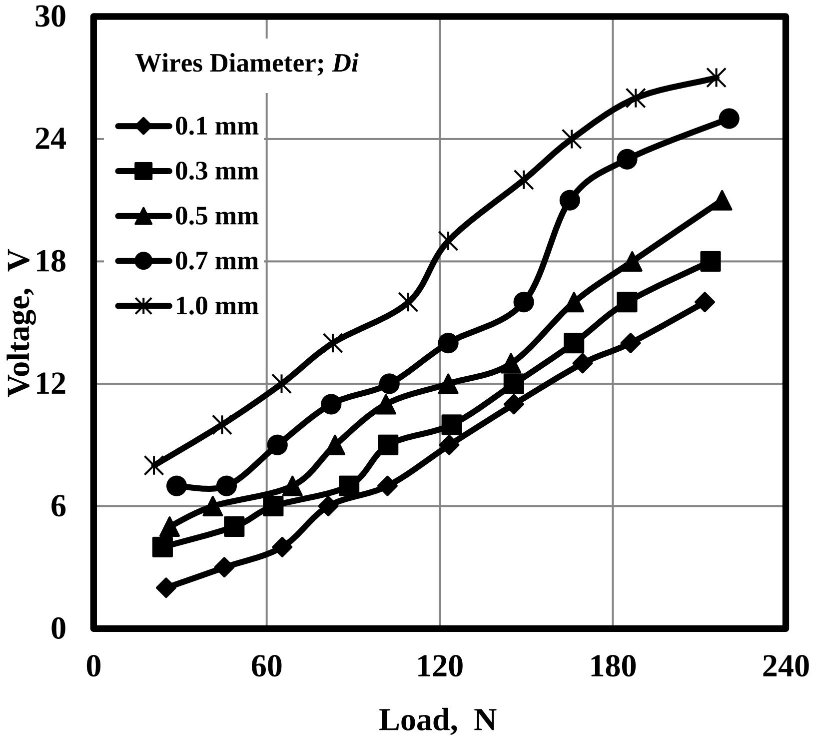


Fig. 14 Effect of wire diameter on electric static charge at 4 mm from the surface and 16 wires in the wires.

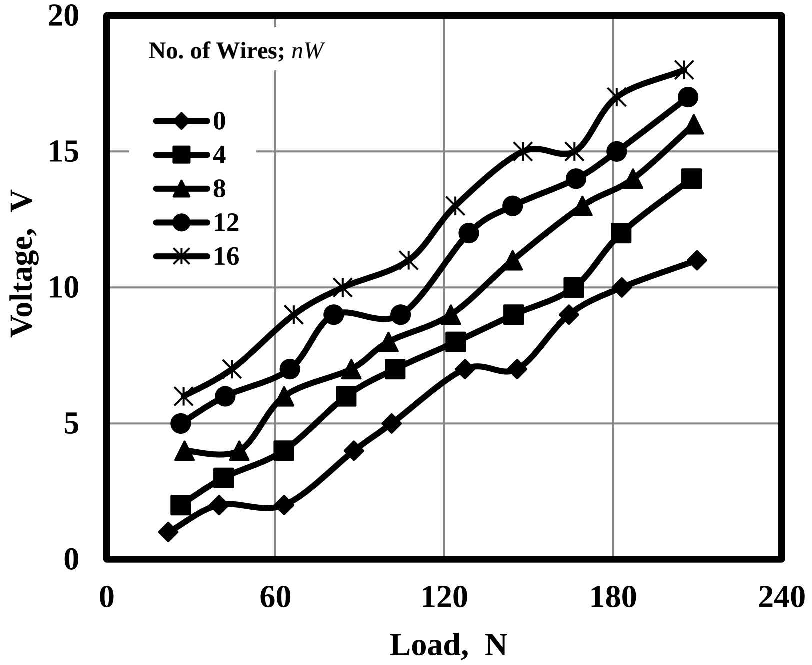


Fig. 15 Effect of number of wires on electric static charge at 0.7 mm wire diameter and 7 mm distance from the surface.

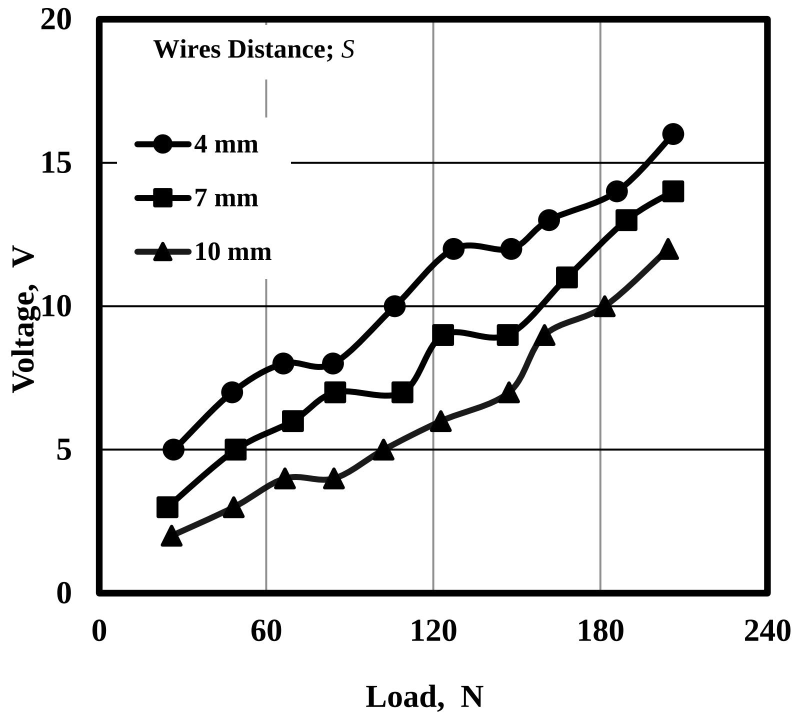


Fig. 16 Effect of wires location on electric static charge at 0.5 mm wire diameter and 4 wires in the wires.

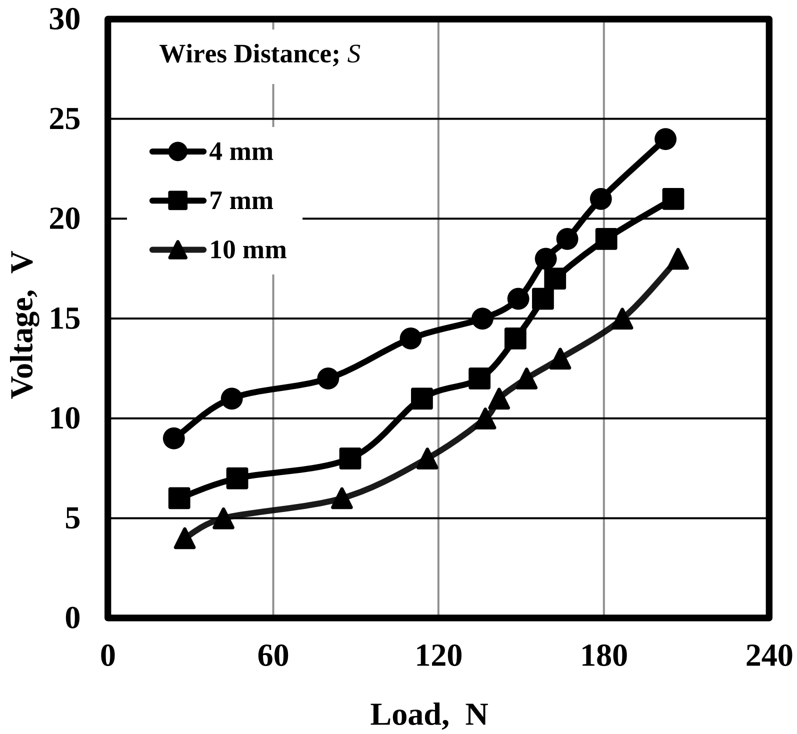


Fig. 17 Effect of wires location on electric static charge at 1.0 mm wire diameter and 4 wires in the wires.

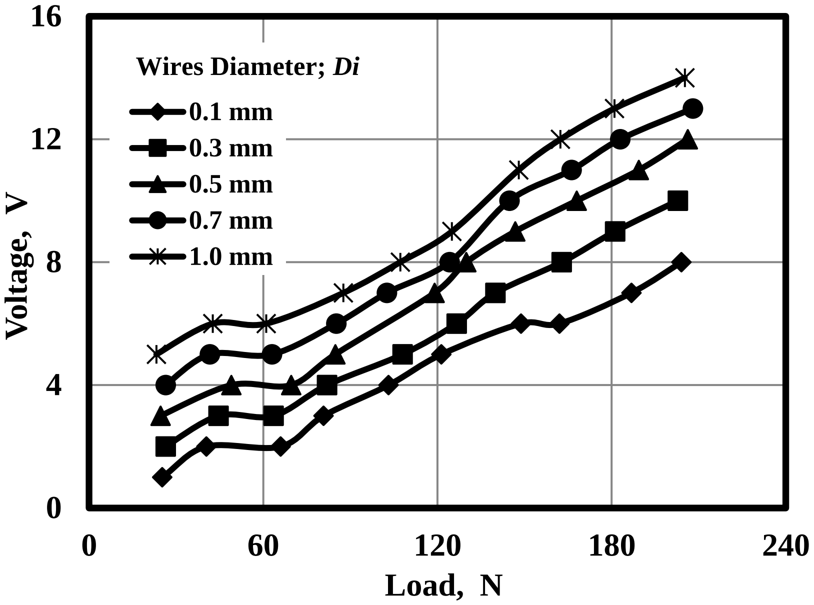


Fig. 18 Effect of wire diameter on electric static charge at 7 mm from the surface and 4 wires in the wires.

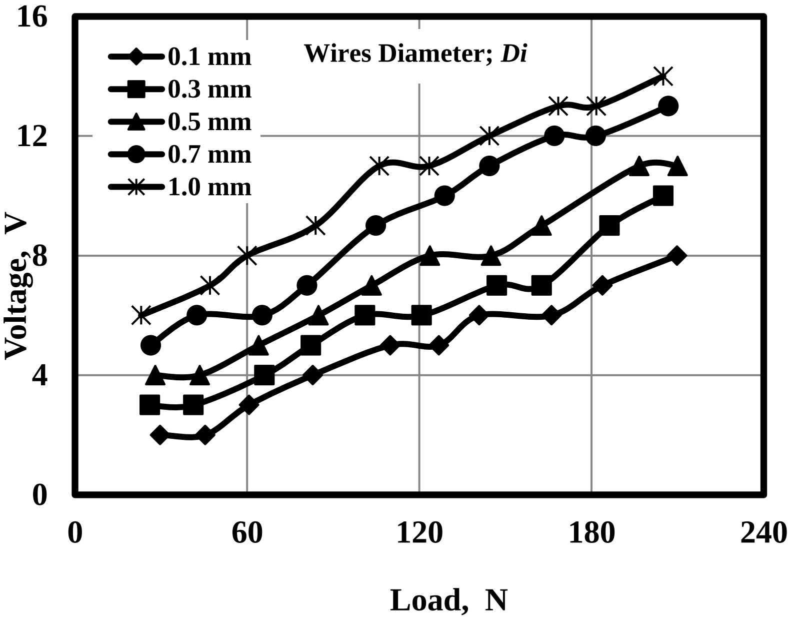


Fig. 19 Effect of wire diameter on electric static charge at 7 mm from the surface and 12 wires in the wires.

CONCLUSIONS

1. At dry contact, it was observed that the number of wires in epoxy specimen influenced the electric static charge generated on the surfaces of rubber and epoxy specimens. Generally, voltage increased by increasing load. The wires location in composites affected the measurement of electric static charge, whereas the wires

were closer to the contact surface, the measured voltage increased. Voltage increased as the wire diameter increased.

2. **At water wetted epoxy, electric static charge decreased compared to dry contact. The electric static charge increased by increasing the number of wires. The location of wires influenced the measured voltage. The wire diameter and wires location showed the same effect observed for dry contact on the electric static charge because they increased the conductivity of the tested composites.**
3. **At detergent wetted epoxy, the presence of detergent on the contact surfaces caused drastic decrease in the electric static charge, which was more than the decrease caused by the presence of water. Besides, wires location relative to the contact surfaces as well wires diameter showed significant effect on the generation of electric static charge**

REFERENCES

1. El-Sherbiny Y. M., Samy A. M. and Ali W. Y., "Electric static charge generated from bare foot and foot wear sliding against flooring materials", Journal of the Egyptian Society of Tribology, Vol. 11, No. 1, January 2014, pp. 1 – 11, (2014).

1. Greason W. D., "Investigation of a test methodology for triboelectrification", Journal of Electric statics, 49, pp. 245 - 56, (2000).

2. Nomura T., Satoh T., Masuda H., "The environment humidity effect on the tribocharge of powder", Powder Technology (135 - 136), pp. 43 - 49, (2003).

3. Diaz AF, Felix-Navarro RM., "A semi-quantitative triboelectric series for polymeric materials", Journal of Electric statics, 62, pp. 277 - 290, (2004).

4. 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).

5. 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).

6. 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).

7. 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).

8. Alahmadi A., "Triboelectrification of Engineering Materials", Journal of the Egyptian Society of Tribology, Vol. 11, No. 1, January 2014, pp. 12 – 23, (2014).

9. Alahmadi A., “Influence of Triboelectrification on Friction Coefficient", International Journal of Engineering & Technology IJET-IJENS Vol:14 No:05, pp. 22 – 29, (2014).

10. 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).

11. 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).