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ELECTRIC STATIC CHARGE GENERATED FROM SLIDING OF EPOXY COMPOSITES REINFORCED BY COPPER WIRES AGAINST RUBBER

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ABSTRACT
The present paper discusses the effects of reinforcing epoxy by copper wires of different diameters on the electric static charge generated from sliding against rubber sheet. Tests were carried out at dry, water and detergent wetted sliding. The effect of number of wires, location and wires diameter was studied.

Based on the experimental observations, it was found that at dry sliding, the voltage significantly increased with increasing the number of wires. As the sliding distance increased voltage increased. It is clearly noted that sliding generated higher voltage than that observed for contact and separation. Voltage decreased with increasing the distance of wire location from the surface. When the wires were closer to the surface, the ability of the surface to generate higher amount of charge increased. The increase in the wire diameter caused significant voltage increase. The influence of wire diameter was more pronounced than the number of wires as well as the location of wires relative to the surface.

At water wetted sliding, the presence of water decreased the electric static charge. It is well known that the water leaks the generated charge due to its good conductivity. In contradiction to what was observed at dry sliding, as the sliding distance increased the generated voltage decreased. It seems that sliding facilitated the water to be well distributed on the sliding surface so that the charge relaxation was easier.

KEYWORDS
Electric static charge, epoxy, wire coppers, sliding.

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 - 6]. 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, [7]. 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, [8]. 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, [9]. 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, [10]. 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, [11]. 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, [12]. 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.

In the present work, electric static charge generated from the sliding of epoxy composites reinforced by copper wires against rubber was investigated under dry, water and detergent wetted sliding conditions.

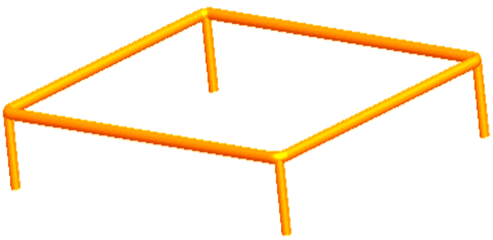
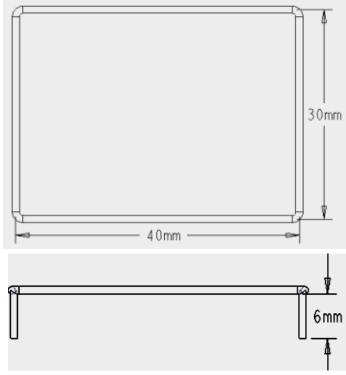
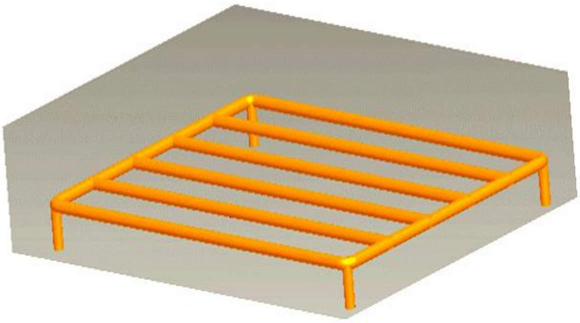
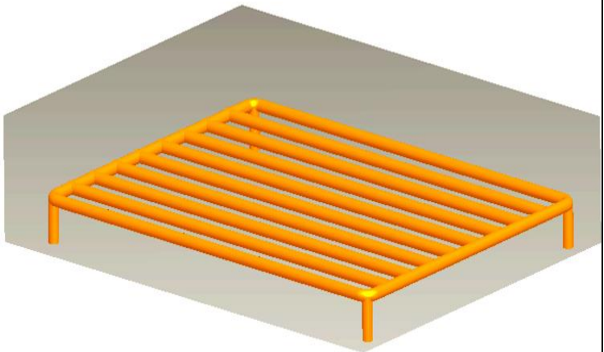
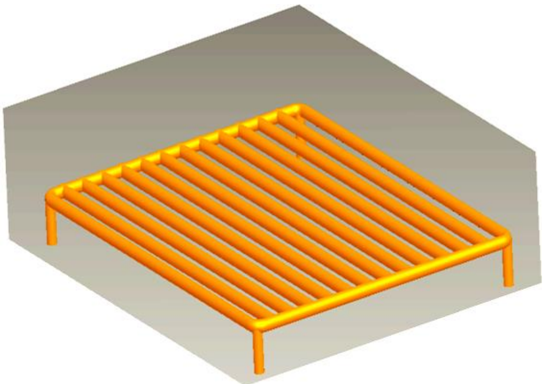
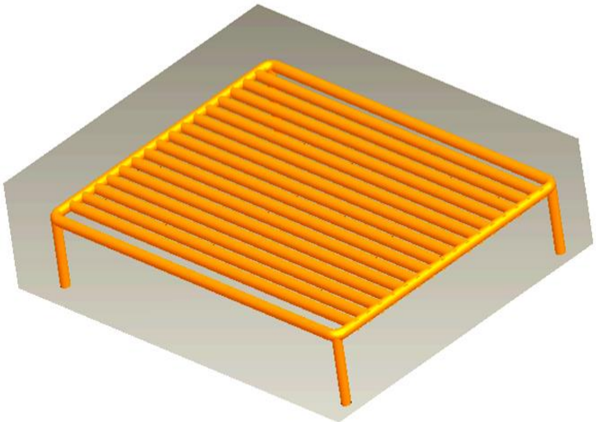
EXPERIMENTAL

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 35 × 45 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, Table 1. 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 smooth rubber sheet of 250 × 420 mm^2 area and 10 mm thickness. The hardness of the rubber was 50 Shore A. Tests were carried out at dry, water and detergent wetted surfaces.

Table 1 The copper wire reinforcement.

	
Frame free of wires at 4 mm far from the contact surface.	
	
4 wires.	**8 wires.**
	
12 wires.	**16 wires.**

RESULTS AND DISCUSSION

At dry sliding, the effect of number of wires on electric static charge at 1.0 mm wire diameter and 7 mm distance from the surface is shown in Fig. 2. The voltage significantly increased with increasing number of wires. As the sliding distance increased, voltage increased. The maximum voltage was displayed by epoxy reinforced by 16 wires after 200 mm sliding distance. It is clearly noted that sliding generated higher voltage than that observed for contact and separation (0 mm sliding distance).

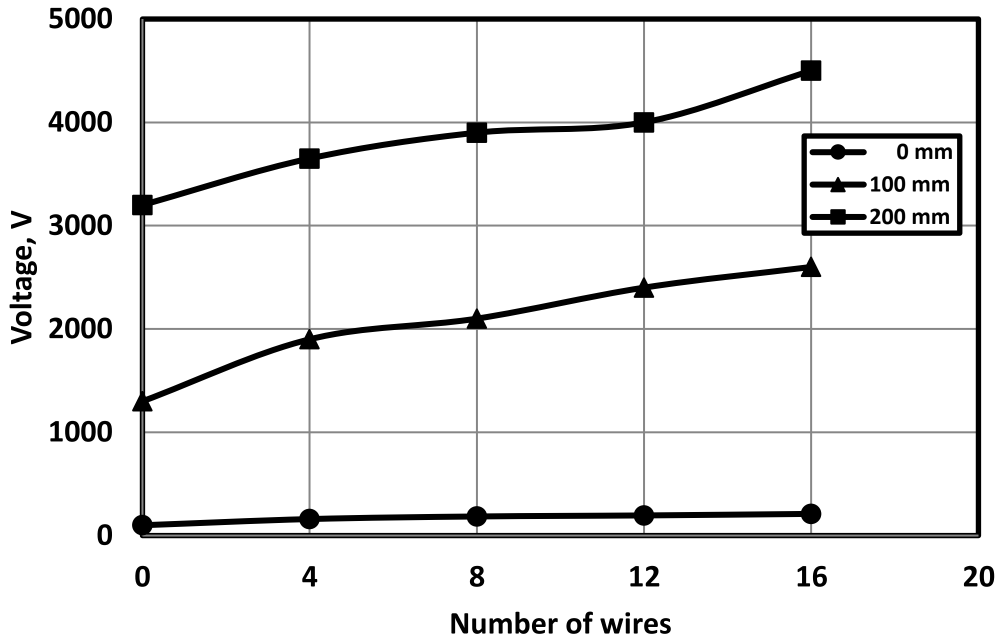


Fig. 2 Effect of number of wires on electric static charge at 1.0 mm wire diameter located at 7 mm distance from the surface.

When the diameter of the wires decreased down to 0.5 mm, the generated voltage decreased, Fig. 3. It seems that presence of copper wires inside epoxy matrix as well as the electric static charge on the contact surfaces influenced the voltage through the generated electric field. Sliding showed higher voltage than contact and separation.

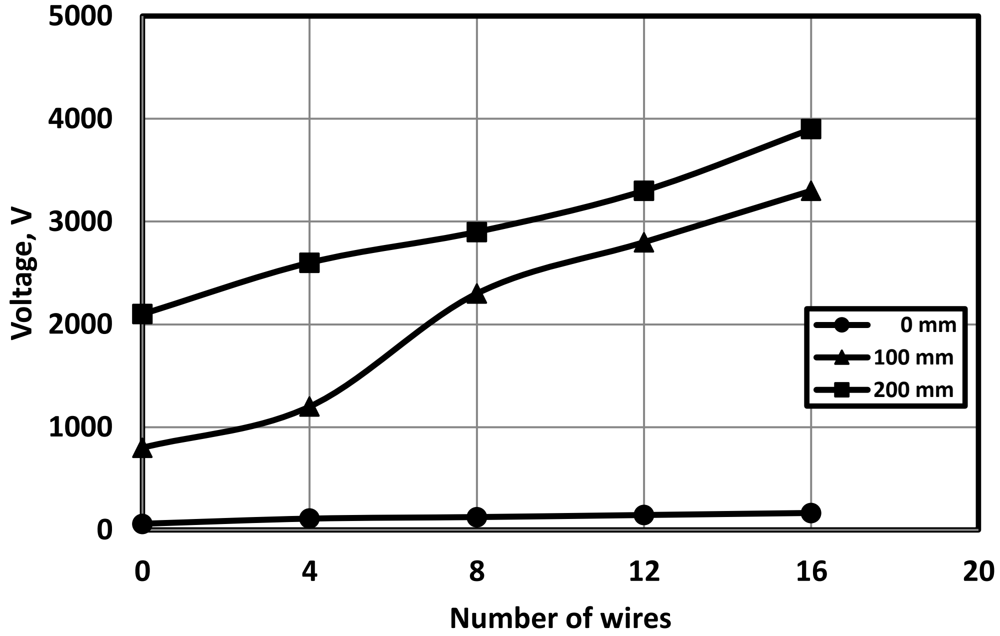


Fig. 3 Effect of number of wires on electric static charge at 0.5 mm wire diameter located 7 mm distance from the surface.

The effect of mesh location on electric static charge at 12 wires in the mesh of 0.1 mm diameter is shown in Fig. 4. Voltage decreased with increasing the distance of wire

location from the surface. As the sliding distance increased, voltage increased. The voltage was 2200 and 1850 volts in epoxy reinforced by wires at 4 and 10 mm far from the surface respectively after 200 mm sliding distance.

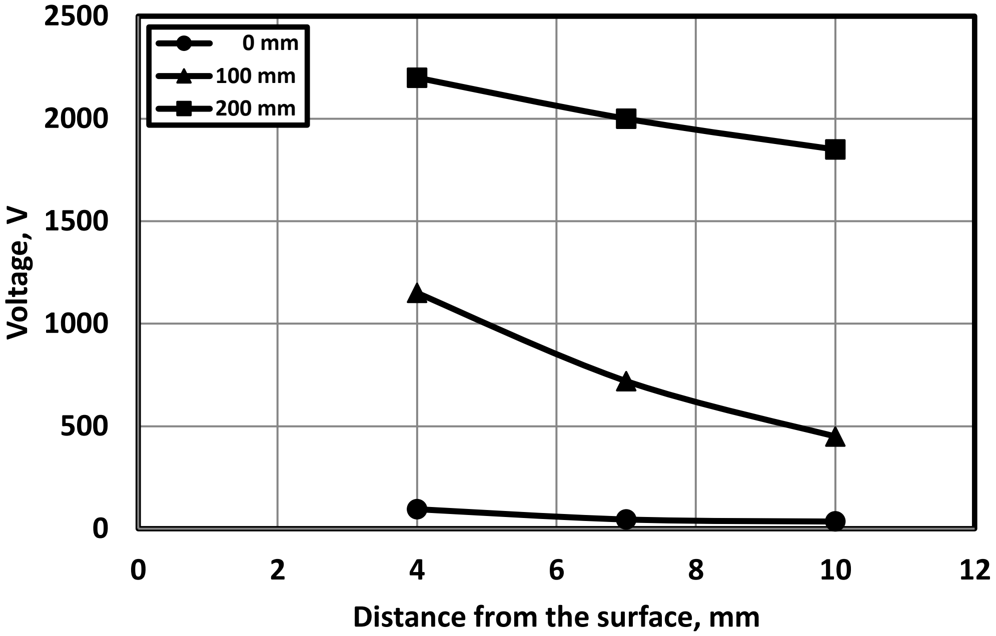


Fig. 4 Effect of mesh location on electric static charge at 12 wires in 0.1 mm diameter mesh.

When the wires were closer to the surface, the ability of the surface to generate the higher amount of charge increased, Fig. 5. The charge was 6250 and 2200 volts in epoxy reinforced by wires at 4 and 10 mm far from the surface respectively. The values of voltage were higher than that observed in the Fig. 4 due to the increase of the wire diameter to 0.7 mm.

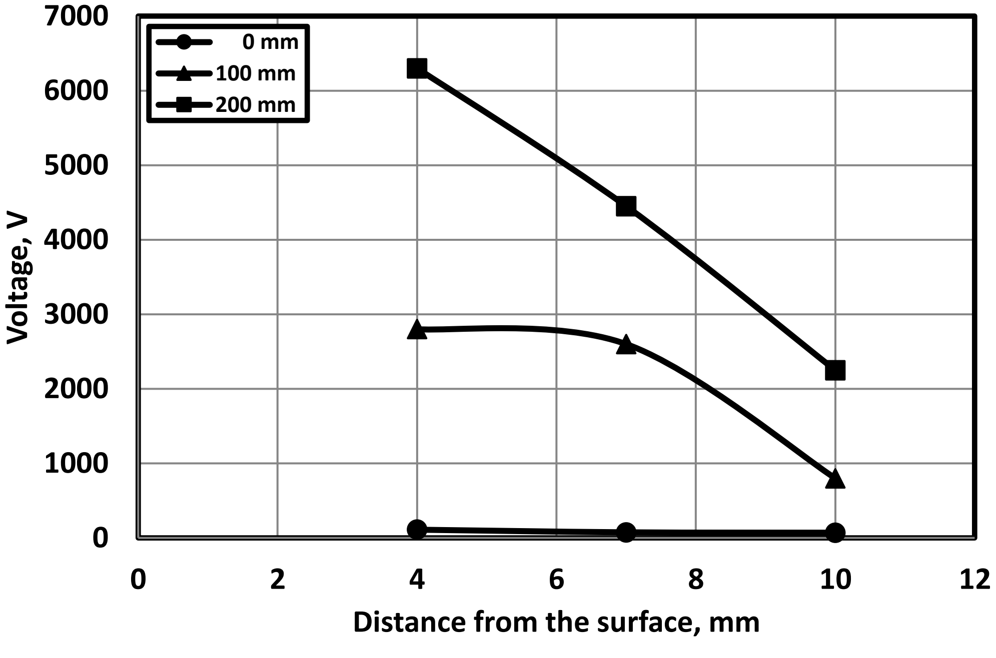


Fig. 5 Effect of mesh location on electric static charge at 12 wires in 0.7 mm diameter mesh.

The increase in the wire diameter will lead to the increase of the surface area of the conductor as well as the cross sectional area. The voltage increased up to 5400 and 4050 volts in epoxy reinforced by 1.0 mm wire diameter after 200 and 100 mm sliding distance respectively, Fig. 6. The influence of wire diameter was more pronounced than the number of wires as well as the location of wires relative to the surface. When the wires were 4 mm closer to the sliding surface, the maximum value of voltage increased up to 6200 volts, Fig. 7. This observation confirmed the effect of the distance of wires from the sliding surface on the generated voltage.

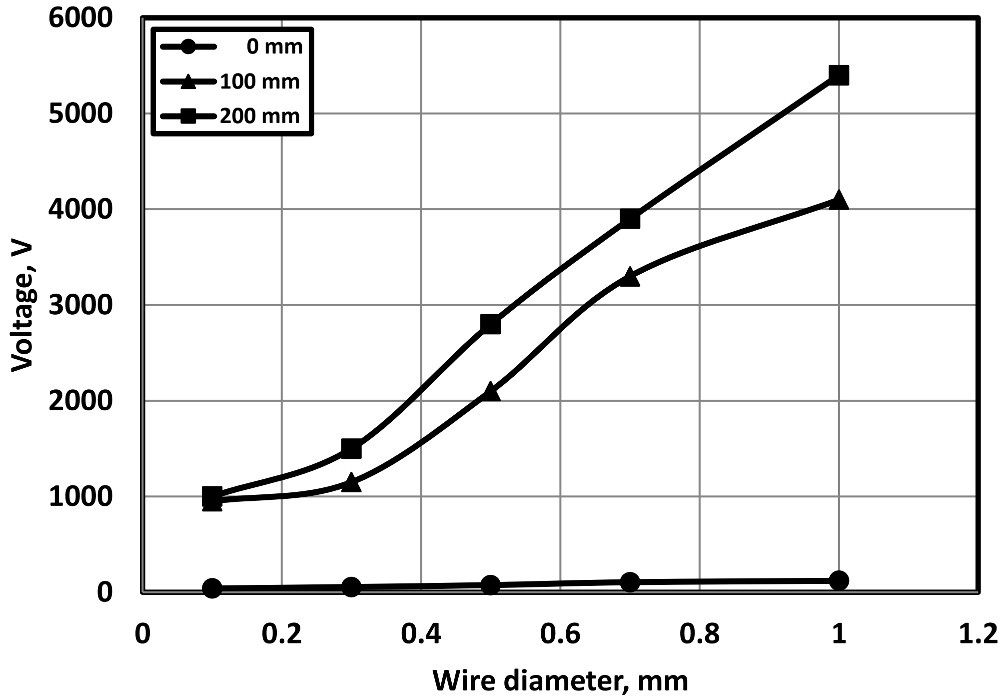


Fig. 6 Effect of wire diameter on electric static charge at 16 wires in the mesh of 7 mm from the surface.

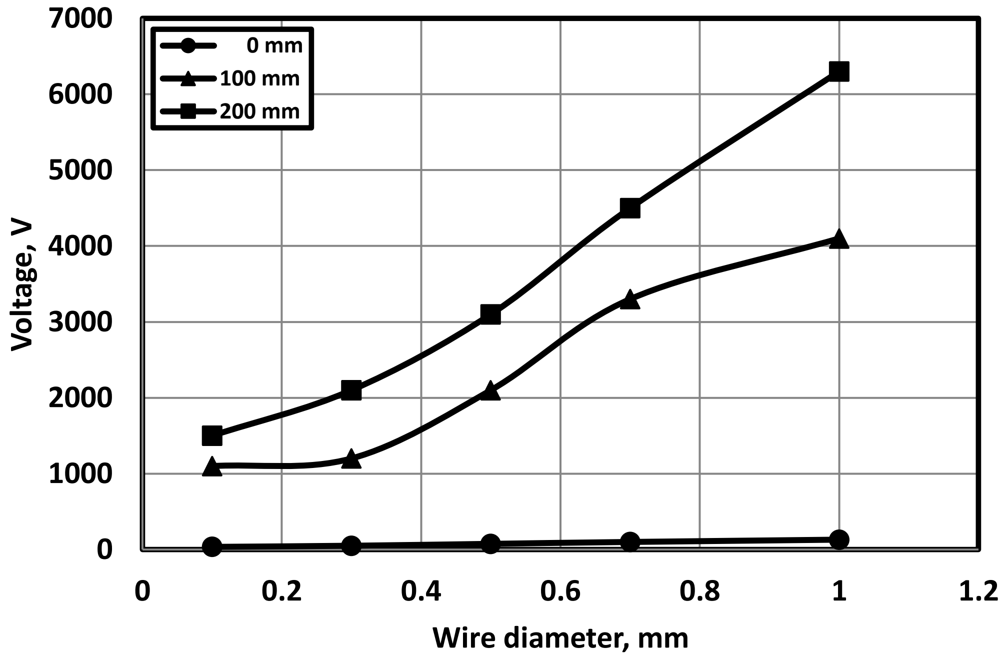


Fig. 7 Effect of wire diameter on electric static charge at 16 wires in the mesh of 4 mm from the surface.

The presence of water decreased the electric static charge down to 28 volts as a maximum value in epoxy reinforced by 12 wires of 0.7 and 0.3 mm wire diameter located at 4 mm far from the surface, Figs. 8 and 9 respectively. It is well known that the water leaks the generated charge due to its good conductivity. In contradiction to what was observed at dry sliding, as the sliding distance increased the generated voltage decreased. It seems that sliding facilitated the water to be well distributed on the sliding surface so that the charge relaxation was easier.

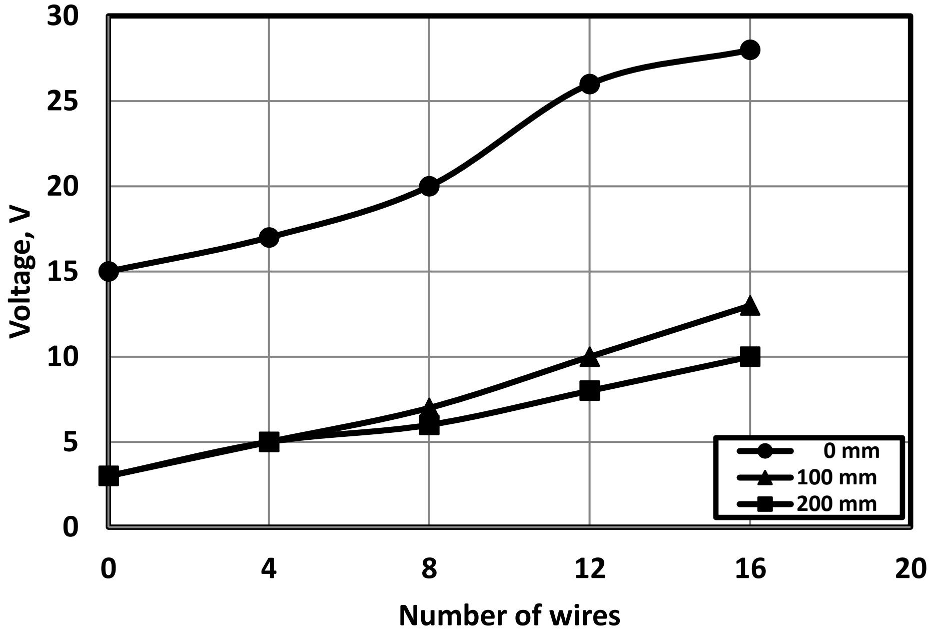


Fig. 8 Effect of number of wires on electric static charge at 0.7 mm wire diameter located at 4 mm far from the surface.

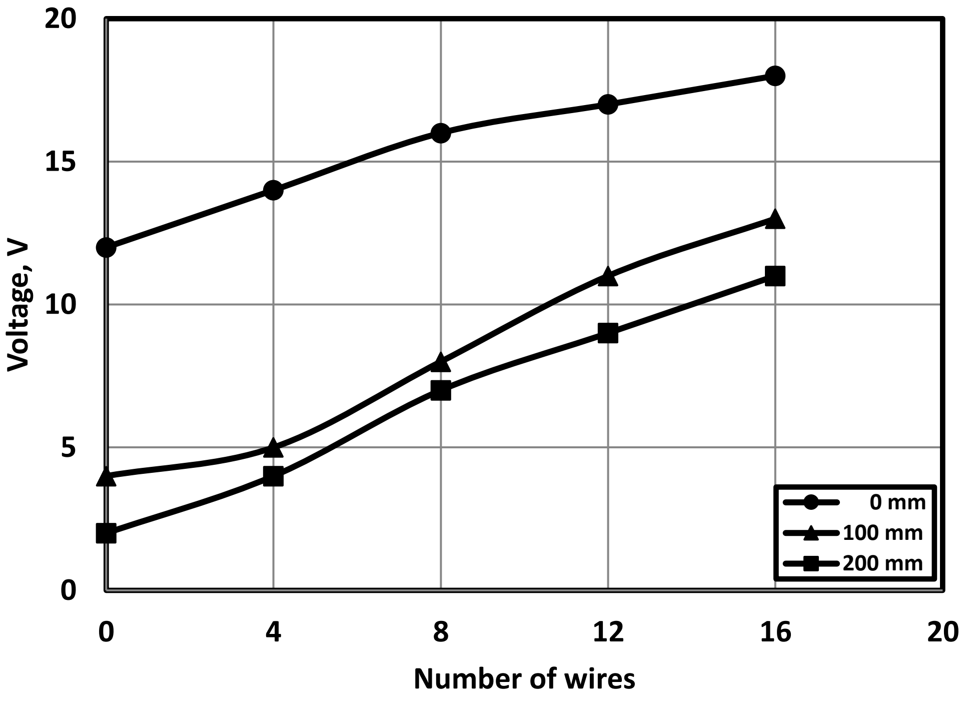


Fig. 9 Effect of number of wires on electric static charge at 0.3 mm wire diameter located at 7 mm far from the surface.

The effect of mesh location on electric static charge is shown in Figs. 10 and 11. It can be noticed that when the wires were closer to the surface the ability of wires to conduct electric static charge increased. While the presence of water decreased the electric static charge down to 18 and 27 volts in epoxy reinforced by wires at 4 and 10 mm far from the surface respectively, Fig. 10. When the wire diameter and the number of wires increased, the generated voltage from sliding decreased, Fig. 11. Increasing the sliding distance decreased the values of the generated voltage.

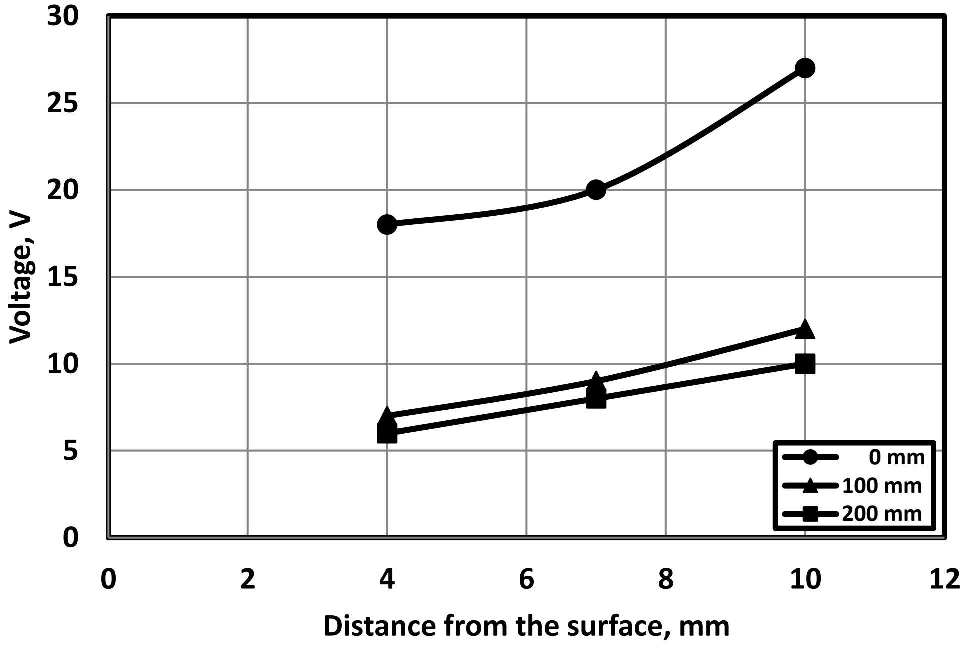


Fig. 10 Effect of mesh location on electric static charge at 4 wires in the mesh of 0.5 mm wire diameter.

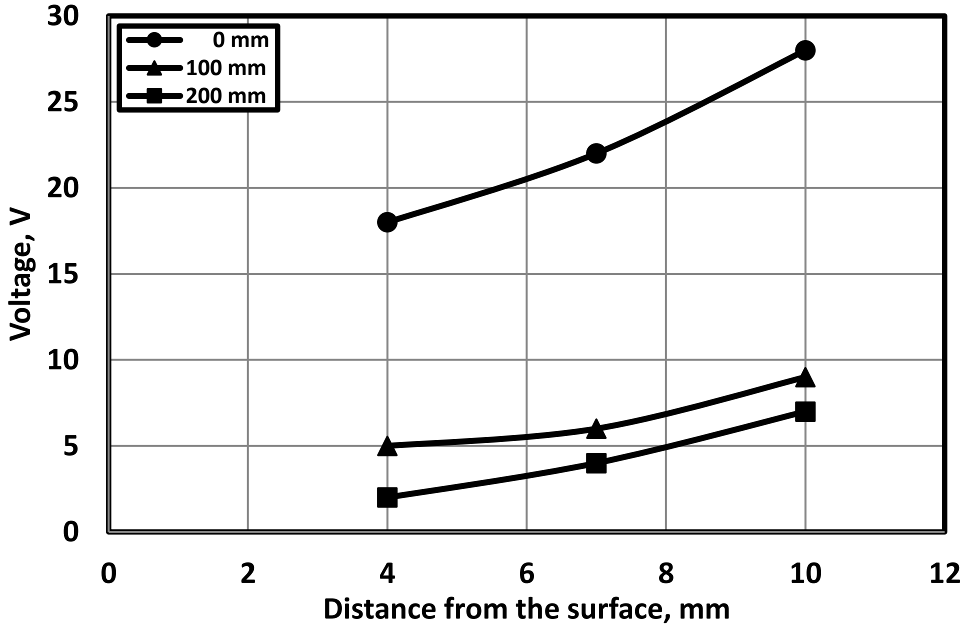


Fig. 11 Effect of mesh location on electric static charge at 12 wires in the mesh of 0.7 mm wire diameter.

The effect of wire diameter on electric static charge at 16 and 12 wires in the mesh located at 4 mm far from the surface is shown in Figs. 12 and 13 respectively. It can be noticed that the maximum electric static charge was 27 volts at 1.0 mm wire diameter for contact and separation. This result was much lower than that observed in at dry sliding. Voltage slightly increased with increasing wire diameter.

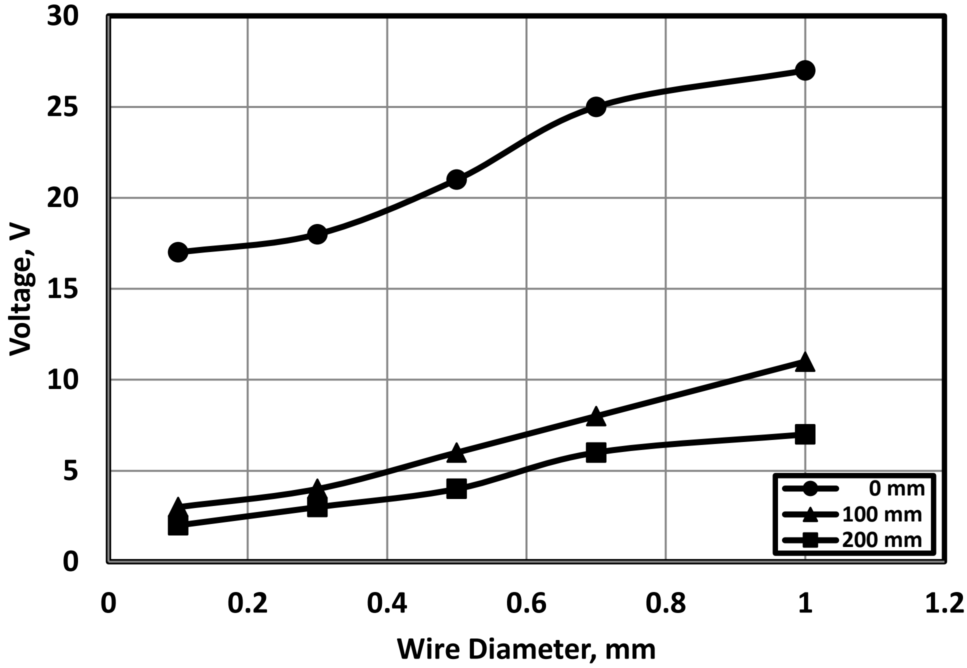


Fig. 12 Effect of wire diameter on electric static charge at 16 wires in the mesh of 4 mm from the surface.

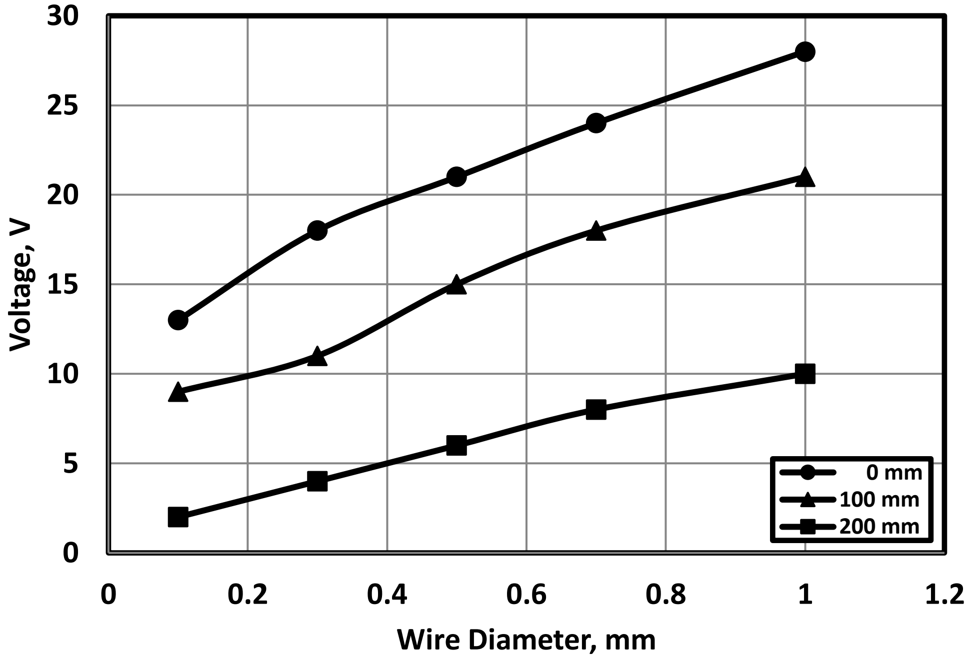


Fig. 13 Effect of wire diameter on electric static charge at 4 mm from the surface and 12 wires in the mesh.

CONCLUSIONS

1. At dry sliding, the voltage significantly increased with increasing the number of wires. As the sliding distance increased voltage increased. Sliding generated higher voltage than that observed for contact and separation.

2. Voltage decreased with increasing the distance of wire location from the surface.

3. The increase in the wire diameter caused significant voltage increase. Influence of wire diameter was more pronounced than the number of wires as well as the location of wires relative to the surface.

4. At water wetted sliding, the presence of water drastically decreased the electric static charge. In contradiction to what was observed at dry sliding, as the sliding distance increased the generated voltage decreased.

5. When the wires were closer to the surface, the ability of wires to conduct charge increased.

6. Voltage slightly increased with increasing wire diameter.

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