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EFFECT OF ELECTRIC STATIC CHARGE ON FRICTION COEFFICIENT DISPLAYED BY SLIDING OF RUBBER SOLE AGAINST EPOXY FLOOR REINFORCED BY COPPER WIRES

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ABSTRACT
Safe walking on the floor is evaluated by the static friction coefficient. Walking and creeping can generate electric static charge of intensity depends on the material of floor. Generation of electric static charge increases the adhesion between footwear and floor so that friction coefficient increases. The present paper discusses 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. Tests have been carried out at dry and water wet sliding. The effect of number of wires, location and wires diameter inside the matrix of the epoxy is studied.

Based on the experimental observations, it has been found that at dry sliding, the electric static 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.

Friction coefficient increased with increasing the number and diameter of copper wires. When the wires were closer to the surface, they were strongly influenced by the electric field and consequently the intensity of the electric charge increased leading to an increase in friction coefficient. At water wet sliding, the observed friction values were relatively higher due to the formation of the double layer of electric static charge on the two sliding surfaces causing an increase in the adhesion between the mating surfaces, where the water homogeneously distributed the electric static charge on the sliding surface.

KEYWORDS
Electric static charge, friction coefficient, epoxy, copper wires, rubber.

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, the effect of electric static charge on friction coefficient displayed by sliding of rubber sole against epoxy floor reinforced by copper wires is investigated under dry and water wet sliding conditions.

EXPERIMENTAL

The (Ultra Stable Surface Voltmeter) was used to measure the electric static charge (electric static filed) after contact and separation of the specimens against rubber to measure the generated charge under applied loads, Fig. 1. It measures down to 1/10 volt on a surface, and up to 20 000 volts (20 kV). Readings (Volts) are normally done with the sensor 25 mm from the surface being tested.

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

Friction tests were carried out using a test rig designed and manufactured to measure the friction force displayed by the tested epoxy composites when sliding against rubber sheet of 10 mm thickness and 60 Shore A hardness, Fig. 2. The rubber sole was placed in a base supported by two load cells, the first measures the horizontal force (friction force) and the second measures the vertical force (normal load). Friction coefficient was determined by the ratio between the friction force and the normal load. The test rig is supplied by two digital screens containing the electronic circuits of amplifier and balancing elements to indicate the values of those loads indicated by the two load cell.

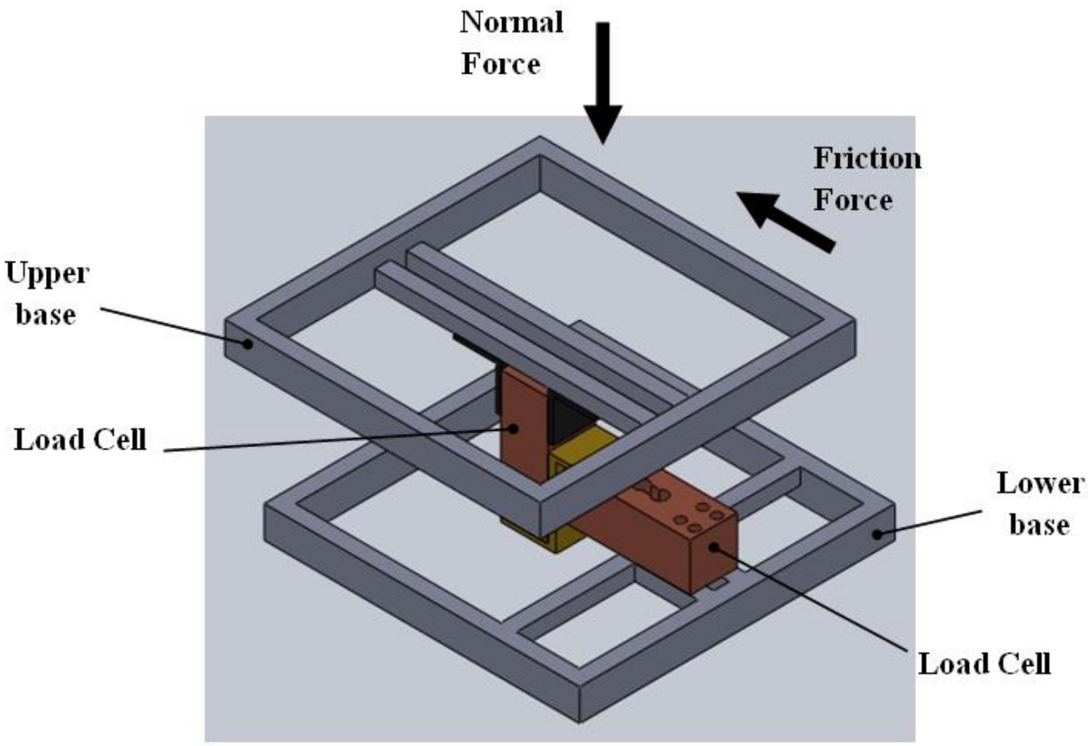

Fig. 2 Arrangement of the test rig.

Test specimens were prepared from epoxy molded in rectangular prisms of 35 × 45 mm^2 and 15 mm height. Copper wires of 0.1, 0.3, 0.5, 0.7 and 1.0 mm diameters were used as reinforcement in the epoxy matrix. The copper wires (4, 8, 12 and 16 wires) were placed at 4, 7 and 10 mm far from the surface. Figure 3 shows an illustration of the parameters studied in the present work. Those parameters are number and diameter of the copper wires as well as their location from the surface. 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 pressed to slide against smooth rubber sheet of 250 × 420 mm^2 area and 10 mm thickness representing the rubber sole of the footwear. The sliding distance was 100 and 200 mm. The hardness of the rubber was 50 Shore A. Tests were carried out at dry and water wet sliding.

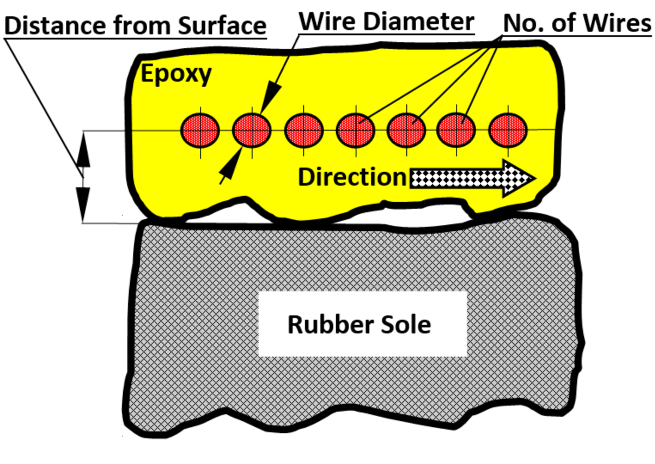

Fig. 3 Illustration of the studied parameters.

RESULTS AND DISCUSSION

At dry sliding, the effect of number of wires on the generation of the electric static charge at the surface of epoxy reinforced by 1.0 mm wire diameter and located at 7 mm distance from the surface is shown in Fig. 4. The measured voltage slightly increased with increasing number of wires. As the sliding distance increased, voltage significantly 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).

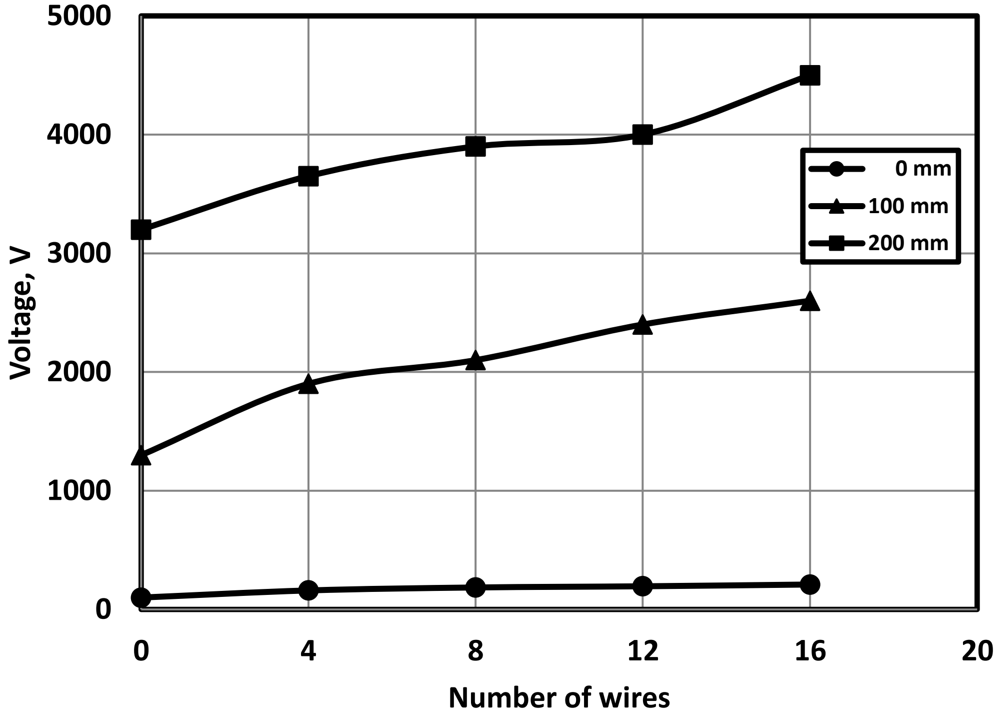

Fig. 4 Effect of number of wires on the generated voltage, (1.0 mm wire diameter, 7 mm far from the surface).

Friction coefficient increased up to maximum then slightly decreased with increasing normal load, Fig. 5. It is clearly seen that, as the number of copper wires increased, friction coefficient increased up to 1.073 for epoxy reinforced by 16 wires. It seems that adhesion between epoxy and rubber increased with increasing number of wires. This behavior can be explained on the basis of triboelectrification that generates double layer of electric static charge on the two sliding surfaces. When two dissimilar materials are pressed or rubbed together, the surface of one usually becomes positively charged, while the other becomes negatively charged. The intensity of the generated charge depends on the pressure and velocity of rubbing. Once charged, the two surfaces attract each other due to the generated electric force. In the present work, epoxy reinforced by copper wires slid against rubber sole, Fig. 6. The double layer of the electric static charge generated an electric field inside the matrix of epoxy due to the presence of copper wire, and consequently, an extra electric static charge is generated leading to further increase in the adhesion force acting between the two sliding surfaces and causing significant increase in friction coefficient.

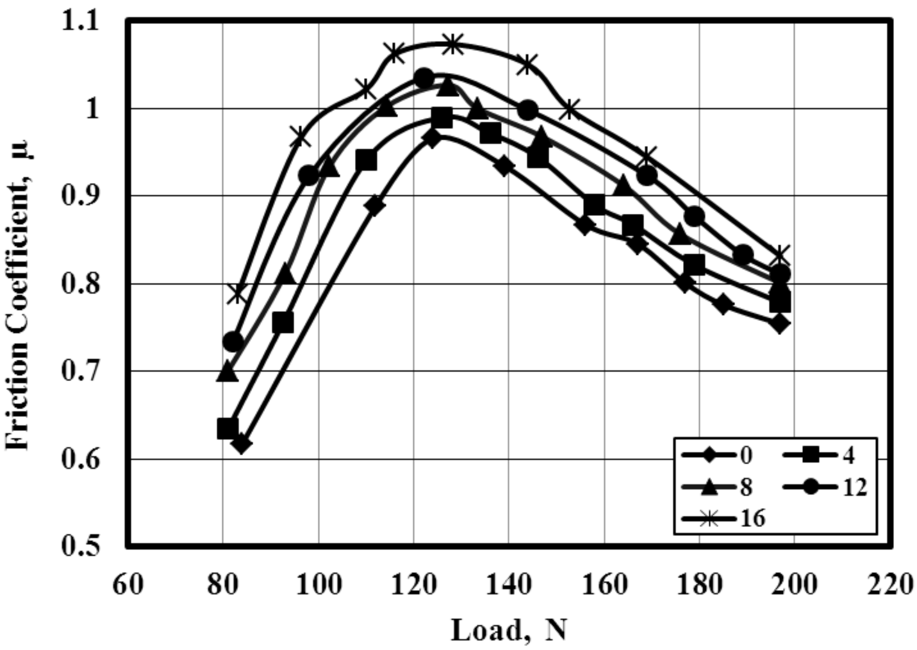

Fig. 5 Effect of number of wires on friction coefficient, (1.0 mm diameter and 7 mm far from the surface).

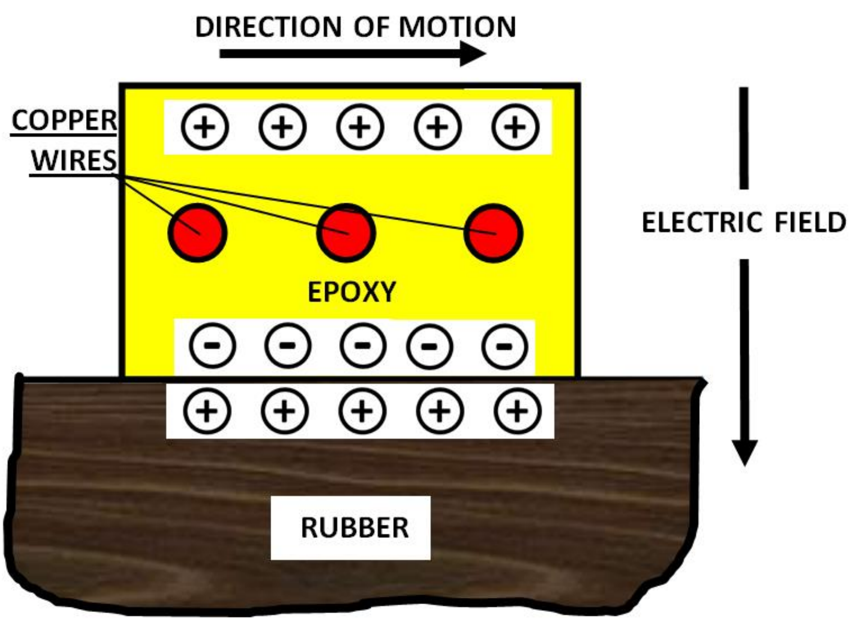

Fig. 6 Schematic illustration of electric static charge generation from friction between epoxy composites and epoxy.

The effect of wire location on voltage for test specimen reinforced by 12 wires of 0.7 mm diameter is shown in Fig. 7. When the wires were closer to the surface, the ability of the surface to generate relatively higher voltage increased. Voltage decreased with increasing the distance of wire location from the surface. Voltage was 6250 and 2200 volts in epoxy reinforced by wires at 4 and 10 mm far from the surface respectively after 200 mm sliding distance.

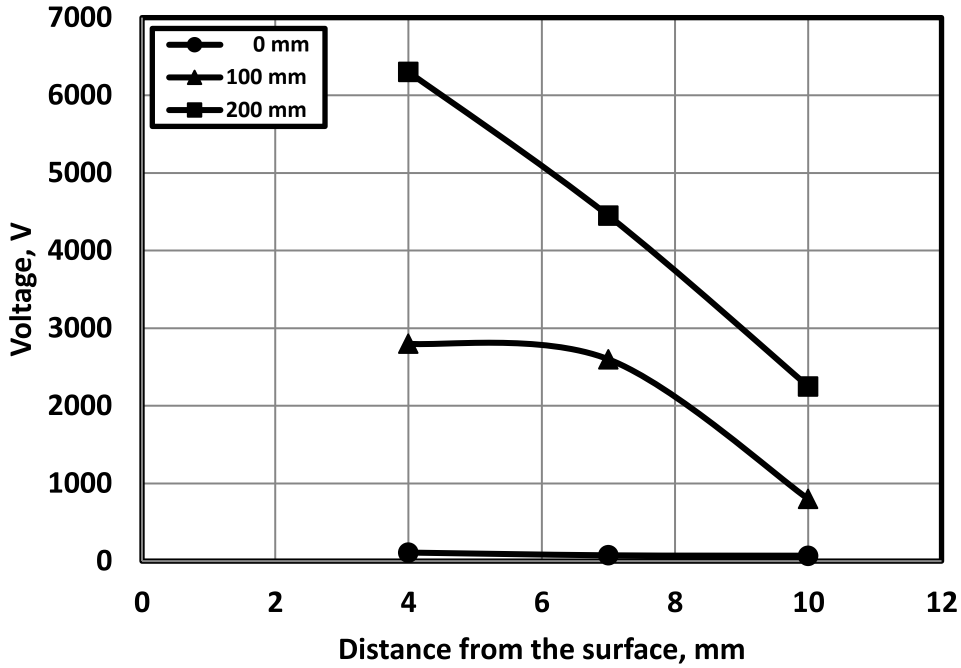

Fig. 7 Effect of wire location on the generated voltage, (12 wires and 0.7 mm wire diameter).

Figure 8 shows the effect of wires location, relative to the sliding surface, on friction coefficient for composites reinforced by 8 wires of 1.0 mm diameter. Friction coefficient increased up to 1.16 and 1.05 in epoxy reinforced by wires at 4 and 10 mm far from the surface respectively. It seems that when the wires were closer to the surface, they were strongly influenced by the electric static charge formed on the surface and consequently the adhesion of the sliding surfaces increased. This observation confirmed the influence of the electric field on friction coefficient, where the values of friction can be controlled by varying the distance of wires from the epoxy surface.

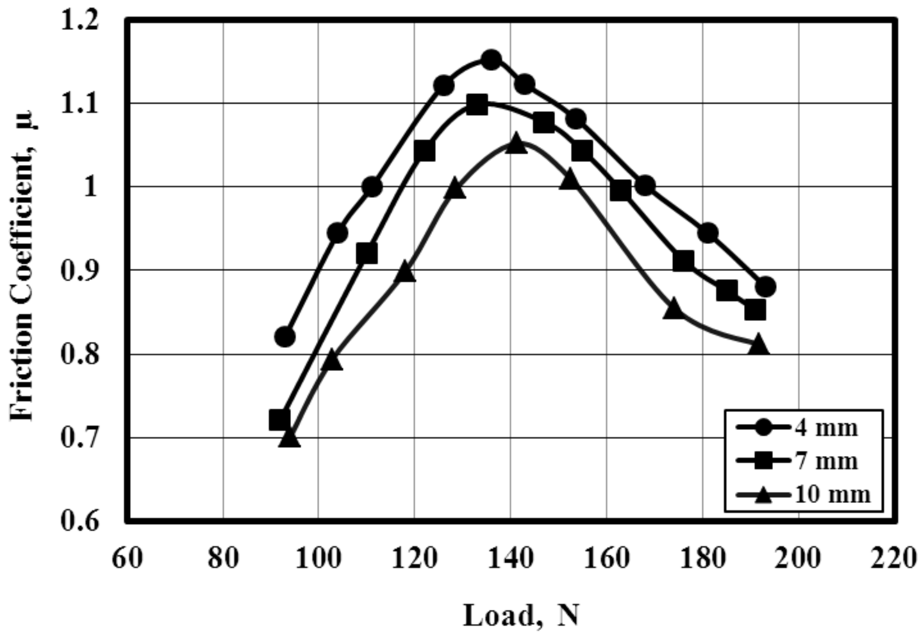

Fig. 8 Effect of wires location on friction coefficient, (8 wires and 1.0 mm diameter).

Figure 9 shows that voltage increased up to 6300 and 4050 volts in epoxy reinforced by 1.0 mm wire diameter after 200 and 100 mm sliding distance respectively. The influence of wire diameter was more pronounced than the number of wires and the location of wires relative to the surface.

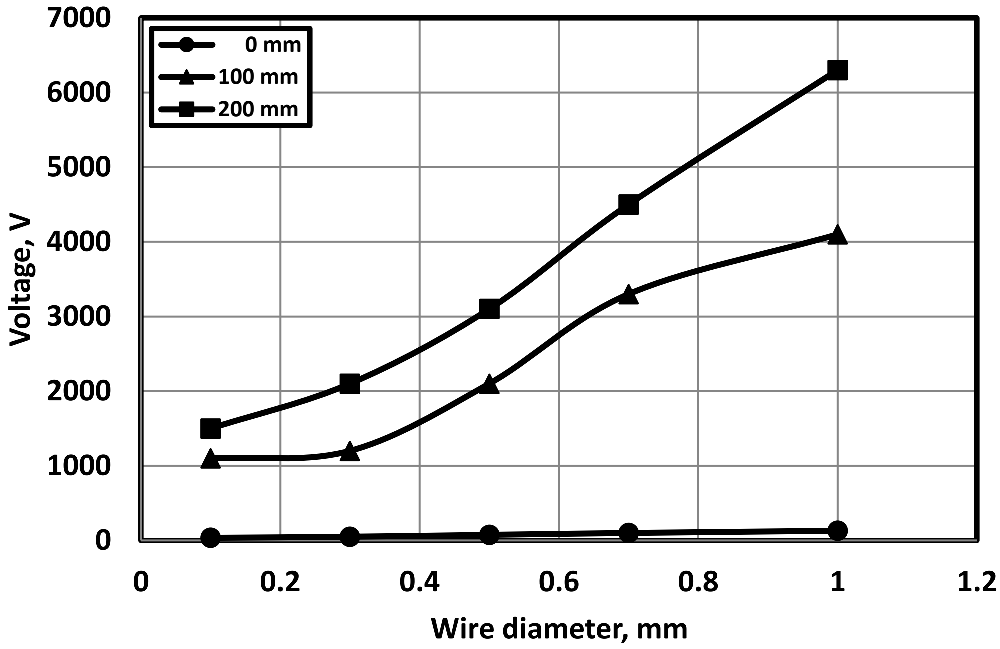

Fig. 9 Effect of wire diameter on the generated voltage, (16 wires and 4 mm far from the surface).

The effect of wire diameter on friction coefficient for epoxy reinforced by 16 wires located at 7 mm from the surface is shown in Fig. 10, where friction coefficient increased up to 1.073 and 0.783 in epoxy reinforced by 1.0 and 0.1 mm wire diameter respectively. This behavior can be attributed to the increase of the generated electric static charge which caused an increase in the adhesive force between the two sliding surfaces leading to friction increase.

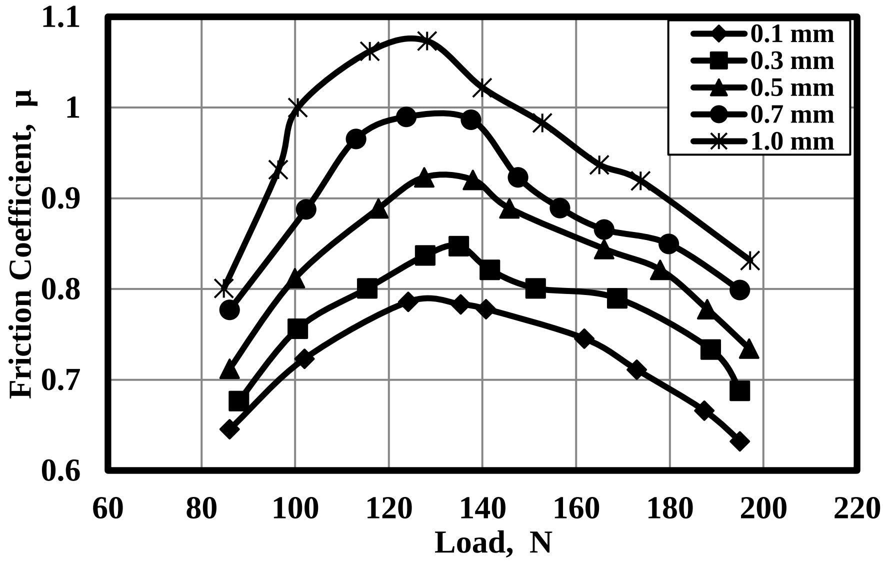

Fig. 10 Effect of wire diameter on friction coefficient, (16 wires and 7 mm far from the surface).

The presence of water on the sliding surface decreased the maximum voltage down to 28 volts in epoxy reinforced by 12 wires of 0.7 mm wire diameter located at 4 mm far from the surface, Fig. 11. The relatively low value of voltage is attributed to the ability of water to conduct the generated voltage out of the contact area 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 formation of water film on the sliding surface so that the charge relaxation was easier.

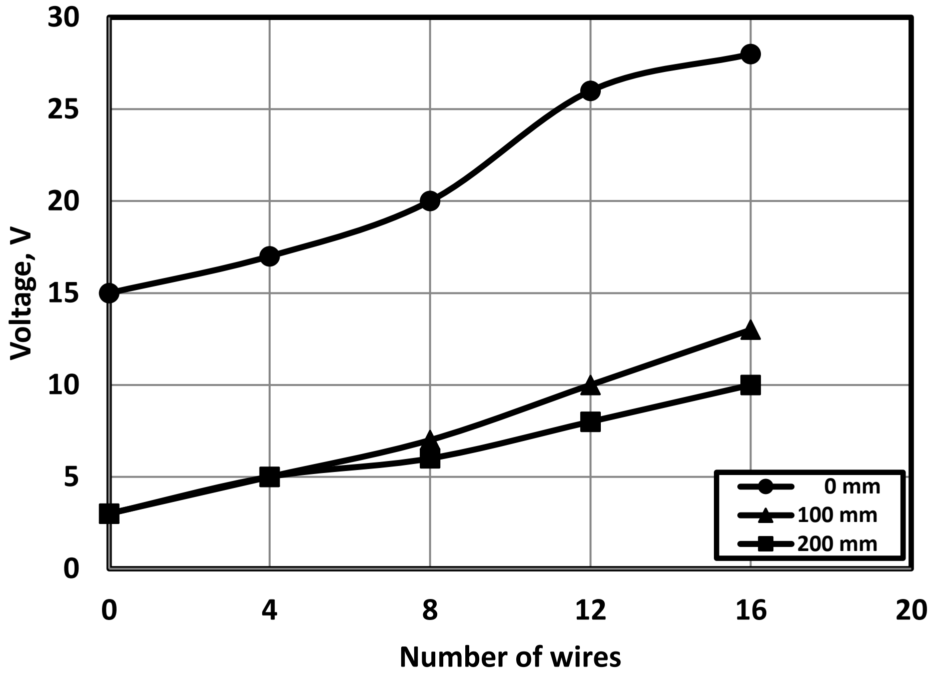

Fig. 11 Effect of number of wires on the generated voltage at water wetted sliding, (0.7 mm wire diameter and 4 mm far from the surface).

The effect of number of wires on friction coefficient displayed by epoxy reinforced by copper wires of 0.7 mm diameter located at 4 mm distance from the surface is shown in Fig. 12, where the highest values of friction coefficient were 0.97 and 0.91 in epoxy reinforced by 16 wires and epoxy free of wires respectively. Generally, the observed values were relatively high for water wet sliding. This behavior can be explained on the basis that due to friction a double layer of electric static charge was formed on the two sliding surfaces causing an increase in the adhesion between the two sliding surfaces.

The effect of wire location on voltage is shown in Fig. 13. It can be noticed that when the wires were closer to the surface, the ability of wires to be affected by the electric static charge increased. The presence of water decreased the voltage down to 27 volts in epoxy reinforced by wires located at 10 mm far from the surface. Besides, increasing the sliding distance decreased the values of the generated voltage.

The effect of wires location on the friction coefficient at 1.0 mm wire diameter and 16 wires in the matrix is shown in Fig. 14. The highest value of friction coefficient increased up to 0.998 at 142 N applied load, which resembled relatively higher value than that observed for composites reinforced by 0.7 mm wire diameter. This result confirmed the effect of the electric field on friction coefficient.

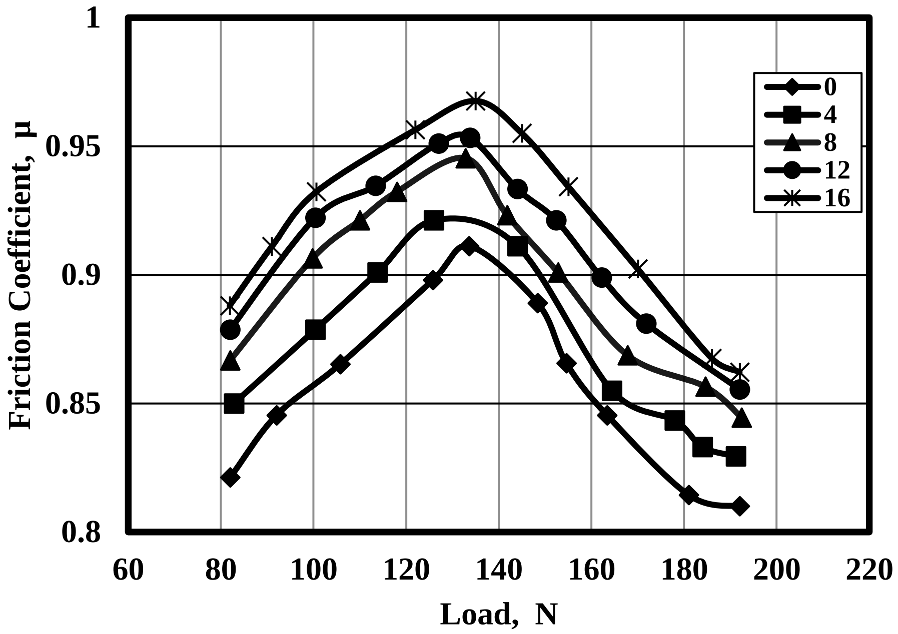

Fig. 12 Effect of number of wires on friction coefficient, (0.7 mm diameter and 4 mm far from the surface).

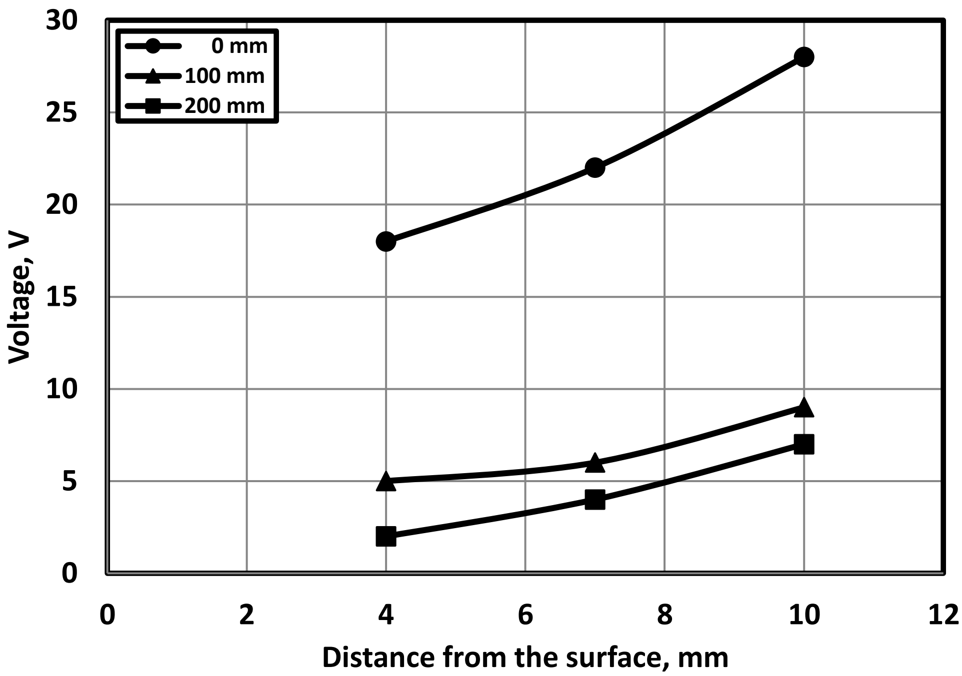

Fig. 13 Effect of wire location on the generated voltage, (12 wires and 0.7 mm wire diameter).

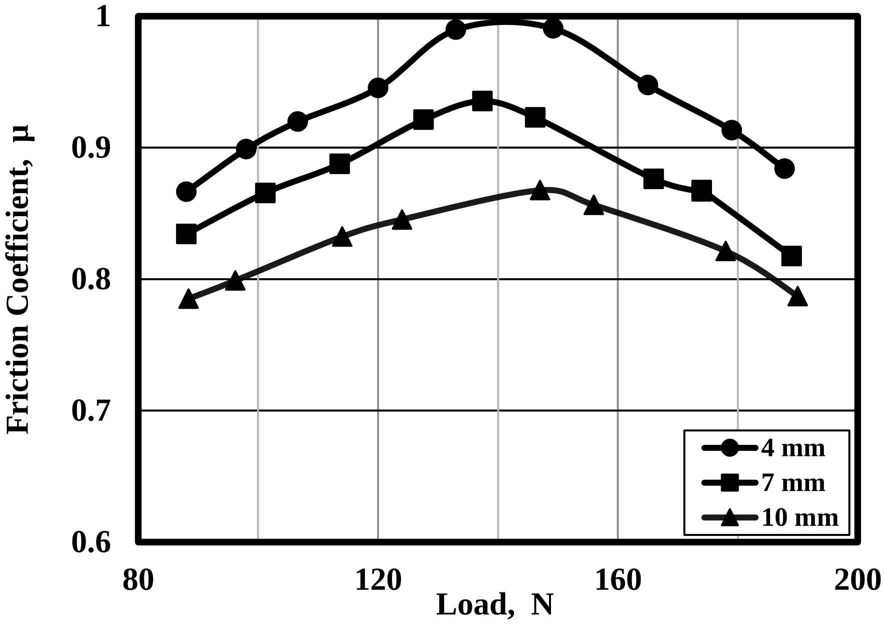

**Fig. 14 Effect of wires location on friction coefficient,
(16 wires and 1.0 mm diameter).**

The effect of wire diameter on voltage for epoxy reinforced by 16 wires located at 4 mm far from the surface is shown in Fig. 15. It is shown that the maximum voltage was 27 volts at 1.0 mm wire diameter for contact and separation. This value was much lower than that observed in dry sliding. Voltage significantly increased with increasing wire diameter.

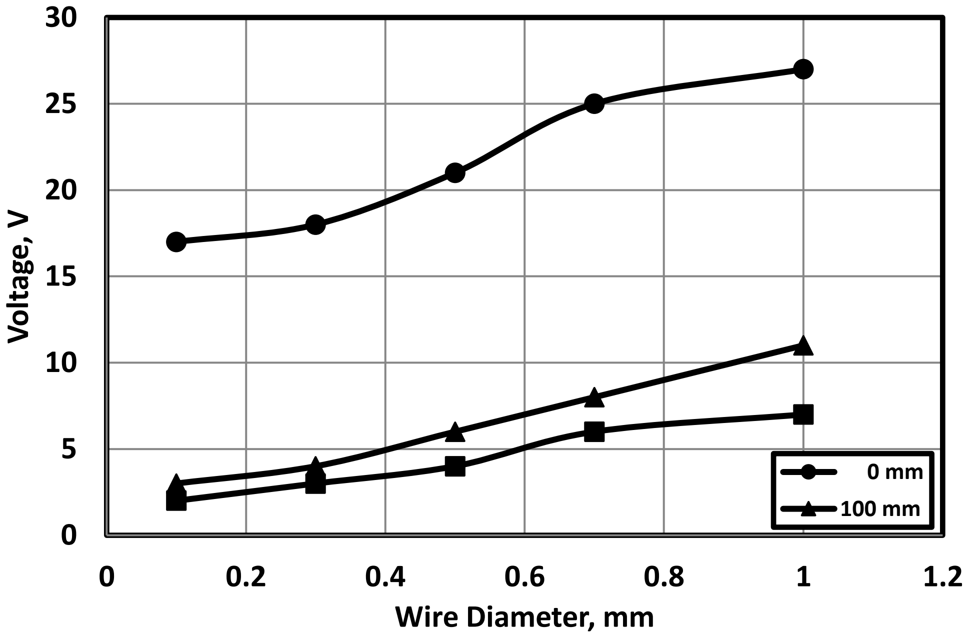

**Fig. 15 Effect of wire diameter on the generated voltage,
(16 wires and 4 mm distance from the surface).**

When the diameter of wires decreased to 0.7 mm, friction values slightly decreased, Fig. 9. Friction coefficient decreased from 0.97 for epoxy reinforced by 16 wires to 0.92 for epoxy free of wires at 130 N normal load. The friction values reflected that the effect of the electric static charge was much higher than the effect of water film. Besides, friction coefficient was influenced by the load due to increase of the contact area. The effect of the diameter of wires located at 7 mm far from the surface on friction coefficient, where the matrix was reinforced by 12 wires, is shown in Fig. 16. Values of friction coefficient were 1.02 and 0.86 in epoxy reinforced by 1.0 and 0.1 mm wire diameter respectively at 114 N normal load.

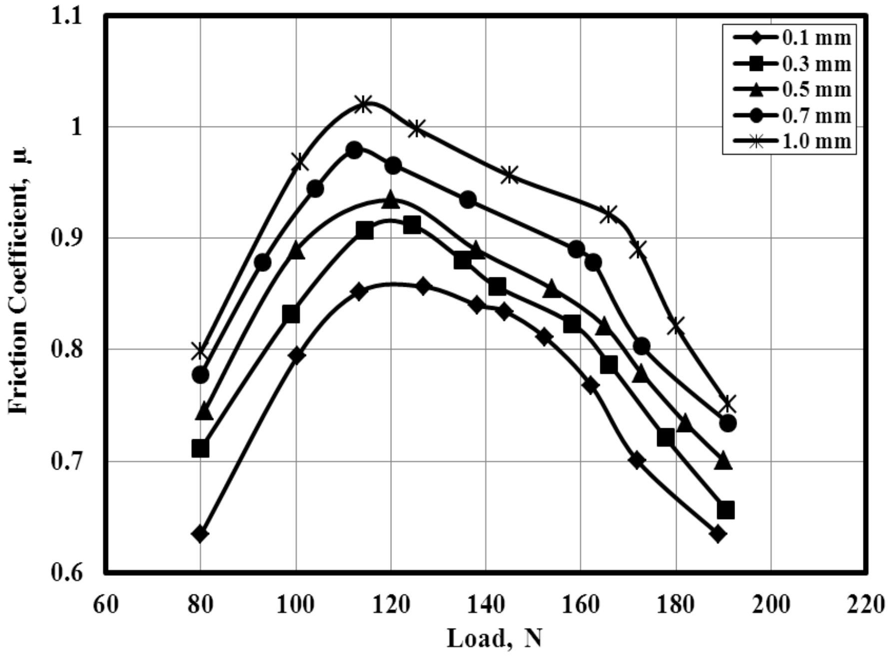

Fig. 16 Effect of wire diameter on friction coefficient,
(12 wires, 7 mm distance from the surface).

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. Voltage decreased with increasing the distance of wire location from the surface. The increase in the wire diameter caused significant voltage increase. Influence of wire diameter on generating electric static charge was more pronounced than the number of wires as well as the location of wires relative to the surface. At water wetted sliding, voltage drastically decreased. In contradiction to what observed at dry sliding, as the sliding distance increased the generated voltage decreased. When the wires were closer to the surface, the ability of wires to conduct charge increased. Voltage slightly increased with increasing wire diameter.

2. Friction coefficient significantly increased by increasing the number of wires at dry and water wet sliding. When the wires were closer to the surface, they were strongly influenced by the electric field and consequently the intensity of the electric charge increased leading to an increase in friction coefficient. As the diameter of copper wires reinforcing epoxy increased, friction coefficient significantly increased. At water wetted sliding, the observed friction values were relatively high due to the formation of the

double layer of electric static charge on the two sliding surfaces causing an increase in the adhesion between the two sliding surfaces.

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