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INCREASING THE SAFETY OF WALKING AGAINST EPOXY FLOORINGS REINFORCED BY METALLIC WIRES

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ABSTRACT

In the present work, the main objective is to investigate the effect of reinforcing epoxy floor coatings by copper wires of different diameters on friction coefficient displayed by their sliding against rubber sole. Experiments were carried out to measure friction coefficient to guarantee appropriate level of motion resistance to avoid excessive movement and slip accidents. Epoxy was reinforced by copper wires of different diameters.

Based on the experiments carried out in the present work, it was found that at dry, water and detergent sliding of the tested epoxy against rubber sheet, friction coefficient increased by increasing the number and diameter of wires reinforcing epoxy. 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 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 mating surfaces, where the water film facilitated the distribution of electric static charge on the sliding surface. Besides, detergent wetted sliding displayed values of friction much lower than that observed at water wetted sliding.

Triboelectrification is the generation of 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 positive charged, while the other becomes negative charged. The intensity of the generated charge depends on the pressure and velocity of rubbing. Once charged, the two surfaces attract each other. In the present work, epoxy reinforced by copper wires and sheet of rubber are sliding against each other. The distribution of charges on the sliding surfaces generates electric field. Epoxy as insulator contains a distribution of charges which are conserved. The double layer of the electric static charge generated on the sliding surfaces would generate an E-field inside the matrix of epoxy. Presence of copper wire inside epoxy matrix would generate extra electric static charge on the sliding surfaces leading to further increase in the adhesion force acting on the two sliding surfaces leading to significant increase in friction coefficient.

KEYWORDS

Slip accident prevention, friction coefficient, walking, rubber sole, epoxy composites, copper wires, flooring materials.

INTRODUCTION

Slipping and falling are common phenomena in both workplaces and daily activities. The risk associated with slipping and falling is related to the materials of footwear/floor, contamination condition, and geometric design of the sole. Shoe soles of various tread design are very common, [1 - 8]. Slip resistance of flooring materials is one of the major environmental factors affecting walking and materials handling behavior. Floor slipperiness may be quantified using the static and dynamic friction coefficient. Certain values of friction coefficient were recommended as the slip-resistant standard for unloaded, normal walking conditions, [9, 10]. Relatively higher static and dynamic friction coefficient values may be required for safe walking when handling loads. There were two types of slips involved in pallet truck pulling. The slip distances of both of these slips interacted significantly with the weights of the load and the floor surface conditions, [11]. Soft material like rubber tends to a higher effective contact area and more pronounced microscopic deformations when mechanically interacting with the surface asperities of a rigid material, greater friction coefficients can be expected for rubber than for plastic, [12]. This was found in the friction measurements under wet conditions. In addition, mechanical abrasions and floor surface inhomogeneities had a stronger influence for rubber. In general, rubber friction is divided into two parts; the bulk hysteresis and the contact adhesive term, [13]. These two contributions are regarded to be independent of each other, but this is only a simplified assumption.

Wear of composites reinforced by copper wires slightly decreased down to minimum then significantly increased with increasing wire diameter, [14]. Perpendicular orientation represented the lowest wear followed by 45° cross plied, cross plied and parallel wire orientations. It seems that reinforcing epoxy coating by copper wires increased the tensile strength of the coating in the direction of the wires. Epoxy composites reinforced by steel wires showed relatively higher wear than that reinforced by copper wires. The minimum wear was observed for epoxy reinforced by wire diameter ranged from 0.2 to 0.4 mm for all the tested wire orientations. The influence of tin/copper addition to polyamide on friction and wear was much enhanced by presence of oil in polyamide matrix, [15]. Friction coefficient displayed by copper/zinc filled polyamide coatings increased with increasing zinc content. The best wear resistance was noticed for coatings of 10 wt. % copper and 10 wt. % oil. Coatings containing 20 wt. % oil represented minimum values of friction. The lowest wear values were observed for coatings containing 6 wt. % zinc and 4 wt. % aluminium.

Wear of epoxy reinforced by polyamide fibres showed the minimum wear values. Orientation of fibres much affected wear, [16]. Parallel fibres represented higher wear than perpendicular ones. The minimum wear was observed for cross plied coatings where shorter wear tracks and higher tensile strength in both perpendicular and parallel directions were existed. The minimum wear values which were lower than that displayed by uncoated steel test specimens were displayed by 0.1 and 0.3 mm polyamide fibre diameters. This observation confirmed the application of the polyamide fibres as reinforcement in epoxy coatings.

In a recent work, the effects of reinforcing epoxy by copper wires of different diameters on the electric static charge generated from sliding against rubber sheet were investigated, [17]. Tests were carried out at dry, water and detergent wetted sliding. The

effect of number of wires, location and wires diameter was studied. It was found that at dry, water and detergent wetted contact, the number of wires as well as the wire diameter in epoxy composites influenced the electric static charge generated on the sliding surfaces of rubber and epoxy. Generally, voltage increased by increasing load. The wires location in composites affected the values of electric static charge. When the wires were closer to the sliding surface, the measured voltage increased. At water wetted epoxy, electric static charge decreased compared to the dry contact. In the presence of detergent on the contact surfaces, drastic decrease in the electric static charge was observed.

In the present work, it is aimed to investigate the friction coefficient of epoxy composites reinforced by copper wires when sliding against rubber. The proposed composites are tested as flooring materials.

EXPERIMENTAL

Experiments were carried out using a test rig to measure the friction coefficient displayed by the tested epoxy composites reinforced by copper wires when sliding against rubber sheet of 10 mm thickness and 60 Shore A hardness. Friction coefficient was evaluated through measuring the friction force and applied normal force, Fig. 1.

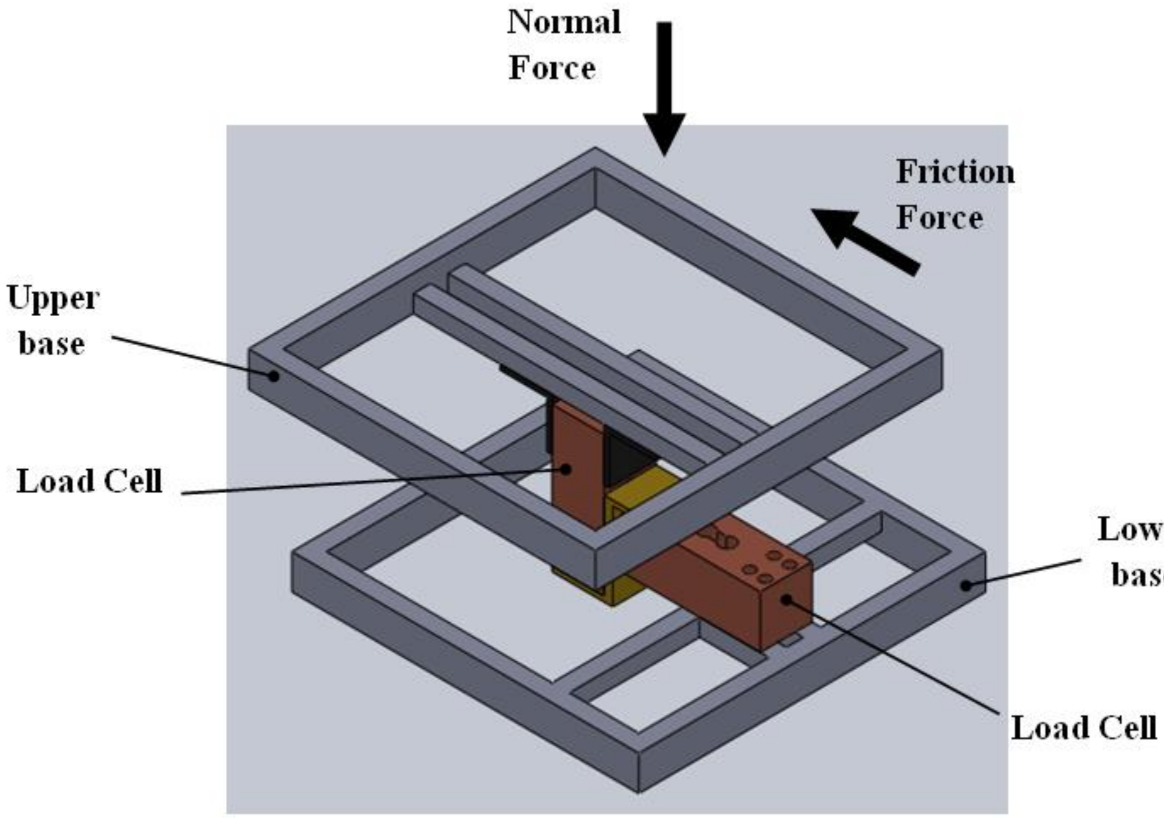

Fig. 1 Arrangement of the test rig.

Test specimens were prepared from epoxy molded in boxes of 35 $\times$ 45 mm^2 and 11 mm height. Five sets of epoxy matrix were reinforced by 0, 4, 8, 12 and 16 copper wires, of 0.1, 0.3, 0.5, 0.7 and 1.0 mm diameters. 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 load values were selected to provide the same pressure on the rubber exerted by walking of kids and adaults. The epoxy composites were sliding against counter face (smooth rubber) of 250 × 420 mm² area, 10 mm thickness and 50 Shore A hardness. Tests were carried out at dry, water and detergent wetted surfaces for 200 mm sliding distance. Detergent was added to water in concentration of 2.0 wt. %.

Table 1 Copper wire reinforcement.

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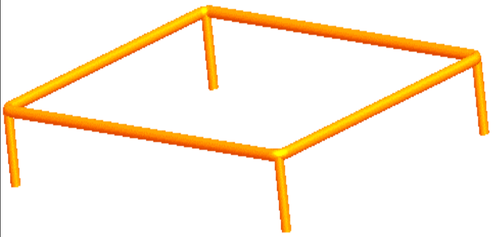
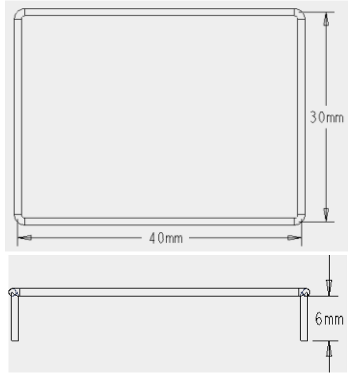
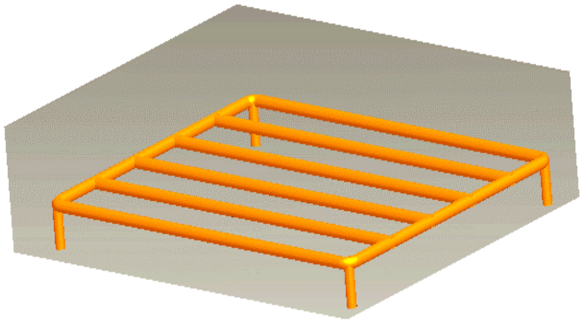
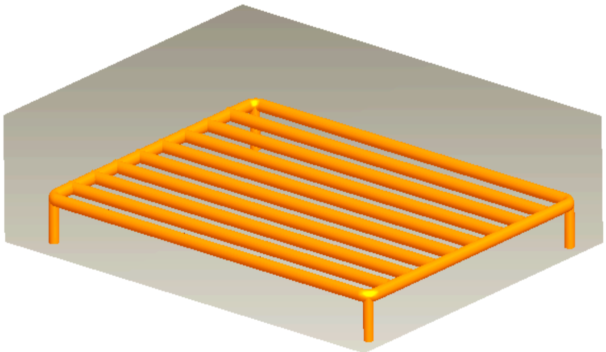
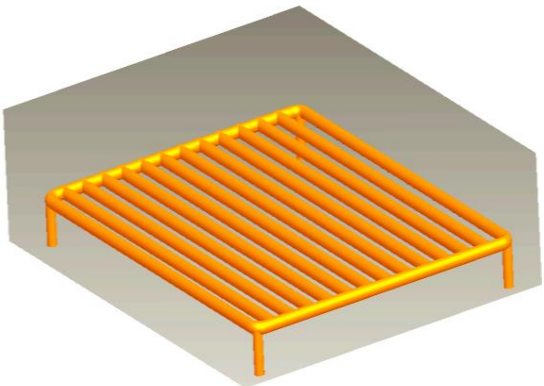
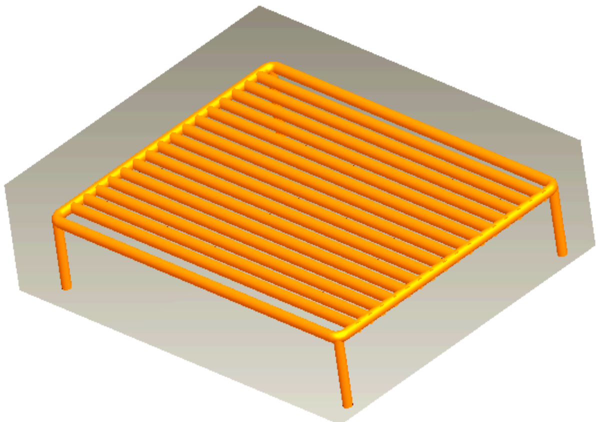
<tr><td></td><td></td></tr>
<tr><td colspan="2">Frame free of wires at 4 mm far from the contact surface.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>4 wires.</td><td>8 wires.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>12 wires.</td><td>16 wires.</td></tr>
</table>

RESULTS AND DISCUSSION

Dry sliding of the tested composites against rubber sheet caused significant increase in friction coefficient up to maximum then slightly decreased with increasing the normal load, Fig. 2. Friction increase was related to the increase of the contact area, while the decrease was due to softening of epoxy caused by the heating during sliding. It is clearly seen that, as the number of copper wires increased, friction coefficient increased. It seems that there was high adhesion between epoxy and rubber, which increased with increasing number of wires. The friction coefficient increased up to 0.92 and 0.83 in epoxy reinforced by 16 and that was free of wires respectively. This behavior can be explained on the basis that triboelectrification is the generation of 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. In the present work, epoxy reinforced by copper wires and sheet of rubber are sliding against each other. The distribution of charges on the sliding surfaces generates electric field, Fig. 3. Epoxy as insulator contains a distribution of charges which are conserved. The double layer of the electric static charge generated on the sliding surfaces would generate an E-field inside the matrix of epoxy. Presence of copper wire inside epoxy matrix would generate extra electric static charge on the sliding surfaces leading to further increase in the adhesion force acting between the two sliding surfaces and causing significant increase in friction coefficient.

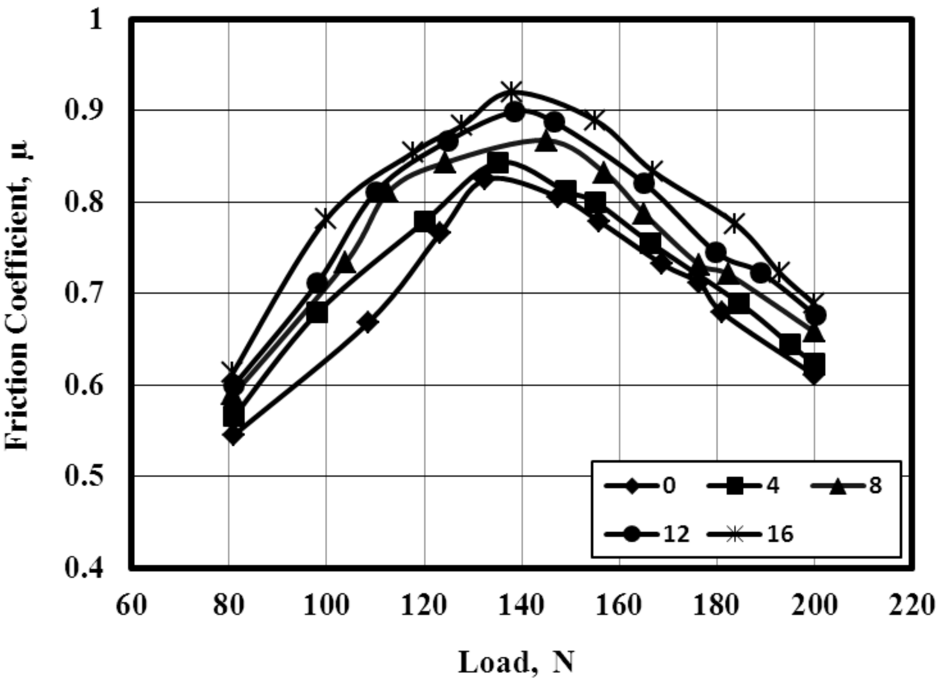


Fig. 2 Effect of number of wires on friction coefficient for epoxy reinforced by 0.5 mm diameter located at 7 mm distance from the surface.

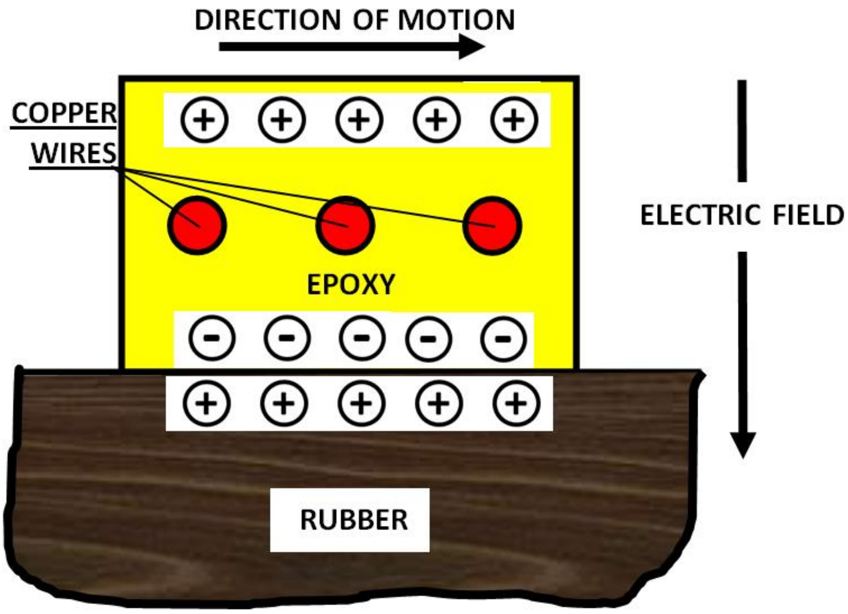


Fig. 3 Schematic illustration of electric static charge generation from friction between epoxy composites and epoxy.

The effect of number of wires on friction coefficient at 1.0 mm wire diameter located at 7 mm far from the surface is shown in Fig. 4. Friction coefficient increased by increasing the number of wires up to 1.073 in epoxy reinforced by 16 wires then slightly decreased with increasing applied load. The tested composites showed relatively higher values of friction coefficient than that observed in Fig. 2. It seems that increasing the copper diameter to 1.0 mm was responsible for that behavior due to the increase of the electric field generated from the electric static charge.

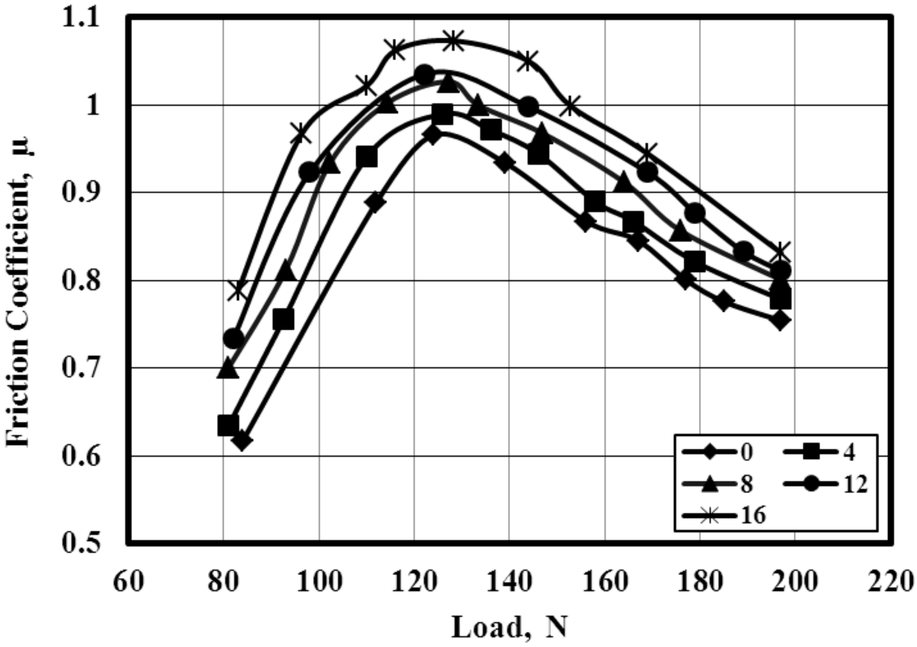


Fig. 4 Effect of number of wires on friction coefficient for epoxy reinforced by 1.0 mm diameter located at 7 mm distance from the surface.

The effect of wires location, relative to the sliding surface, on friction coefficient for composites reinforced by 8 wires of 1.0 mm diameter is shown in Fig. 5. It seems that if the wires were closer to the surface, they were strongly influenced by the electric field and consequently the intensity of the electric charge increased. 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.

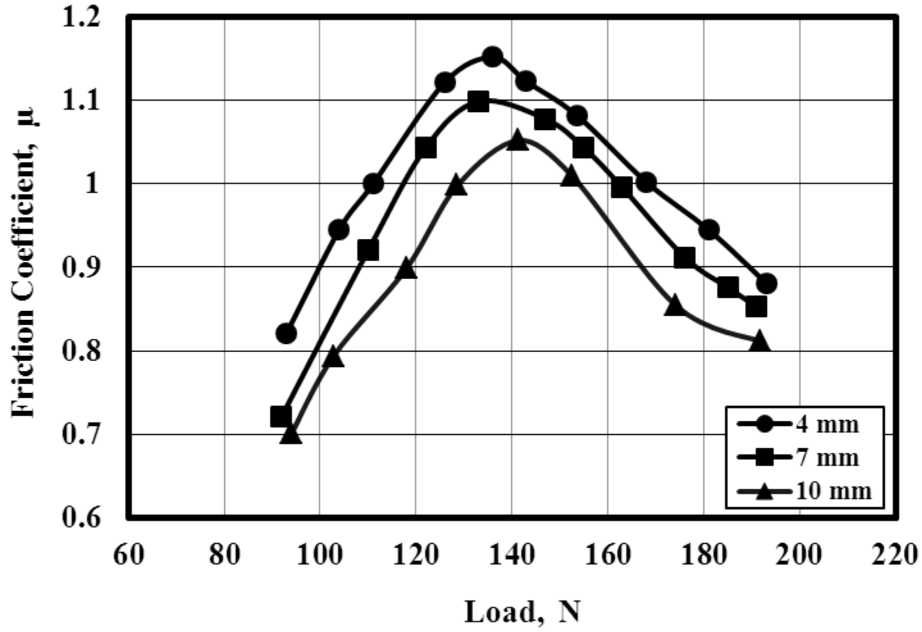


Fig. 5 Effect of wires location on friction coefficient for epoxy reinforced by 8 wires of 1.0 mm diameter.

The same effect of wires location on friction coefficient is illustrated in Fig. 6. The friction coefficient increased up to 0.98 and 0.88 in epoxy reinforced by wires located at 4 and 10 mm far from the surface respectively. 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. Besides, the friction values displayed by 0.7 mm wire diameter were lower than that observed for 1.0 mm diameter wires which focused the effect of the wire diameter on the generated electric static charge.

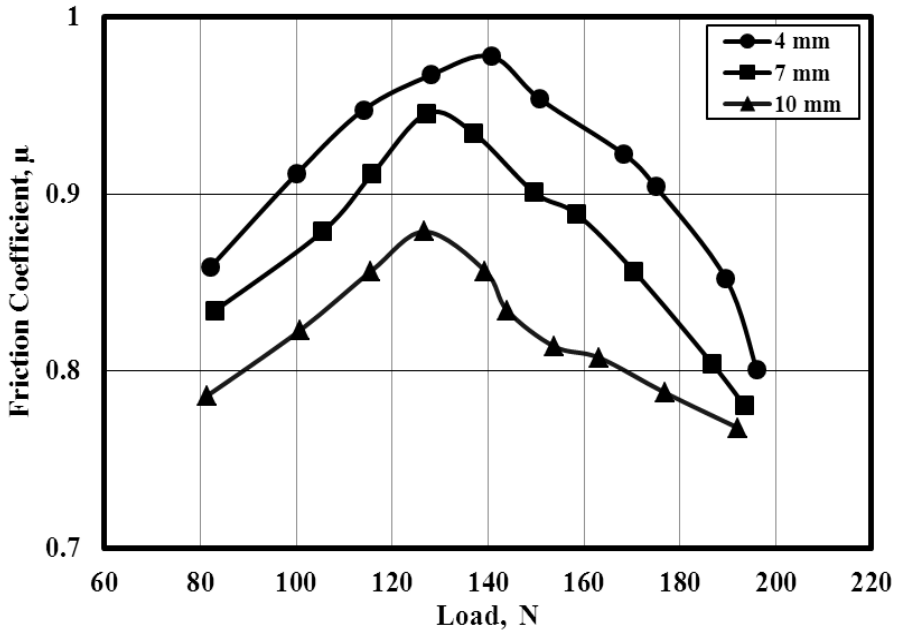


Fig. 6 Effect of wires location on friction coefficient for epoxy reinforced by 8 wires of 0.7 mm diameter.

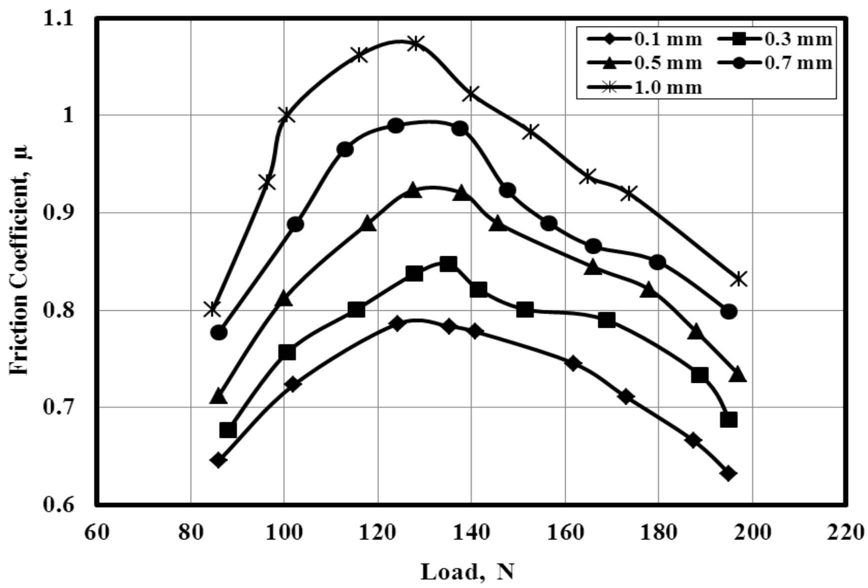


Fig. 7 Effect of wire diameter on friction coefficient for epoxy reinforced by 16 wires located at 7 mm from the surface.

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. 7. It is seen that 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.

At water wetted sliding, 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. 8, where the highest values of friction coefficient were 0.99 and 0.87 in epoxy reinforced by 16 wires and epoxy free of wires respectively. Generally, the observed values were relatively high for water wetted surfaces. This behavior can be explained on the basis that due to friction the double layer of electric static charge was formed on the two sliding surfaces causing an increase in the adhesion between the two mating surfaces.

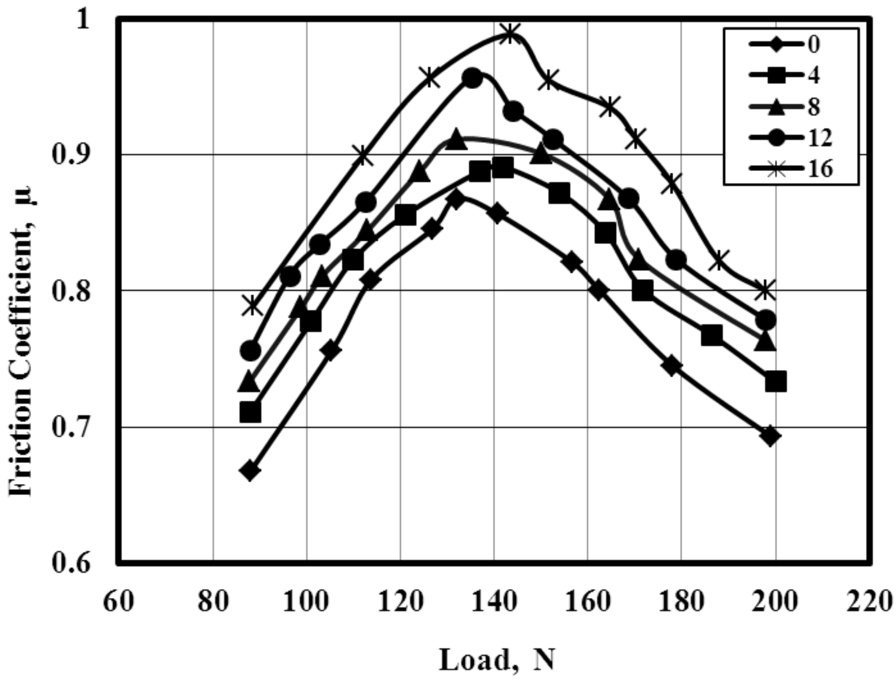


Fig. 8 Effect of number of wires on friction coefficient displayed by epoxy reinforced by wires of 1.0 mm diameter located at 4 mm far from the surface.

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.

The effect of wires location on friction coefficient at 0.7 mm wire diameter and 16 wires in the wires is shown in Fig. 10. The maximum friction coefficient was 0.88 in epoxy reinforced by wires at 4 mm from the surface. As the distance of wires from the sliding surface increased up to 10 mm, the maximum value of friction coefficient decreased to 0.83. When the diameter of the copper wires increased to 10 mm, Fig. 11, 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 indicated the effect of the electric field on friction coefficient.

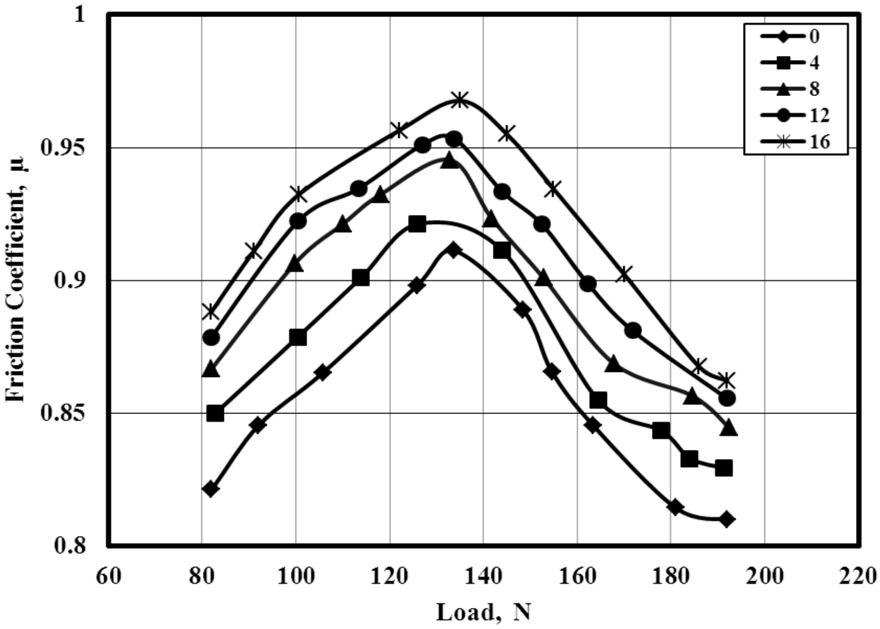


Fig. 9 Effect of number of wires on friction coefficient displayed by epoxy reinforced by wires of 0.7 mm diameter located at 4 mm far from the surface.

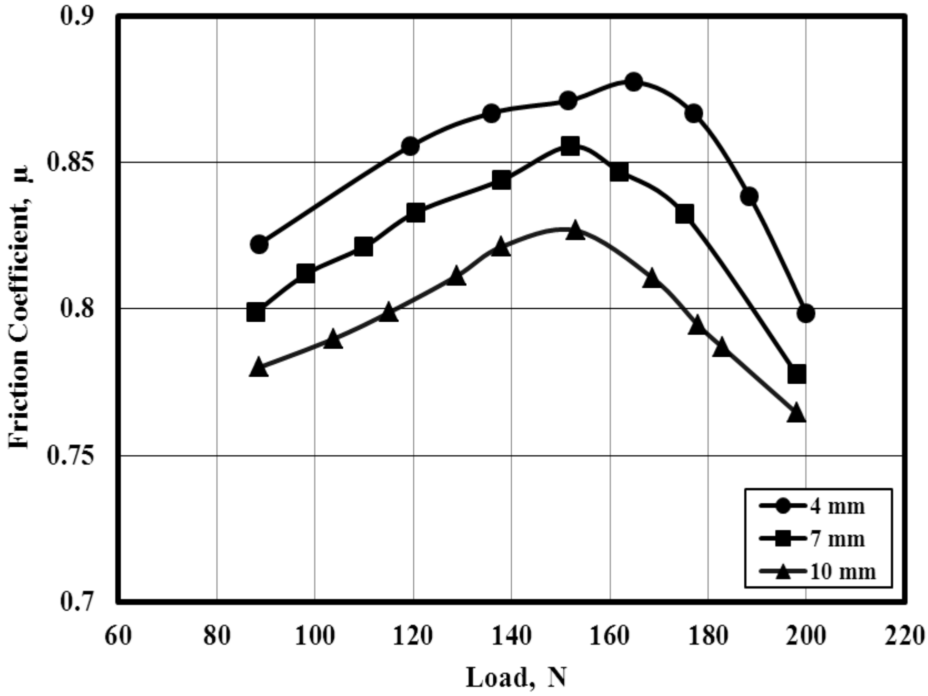


Fig. 10 Effect of wires location on friction coefficient displayed by epoxy reinforced by 16 copper wires of 0.7 mm diameter.

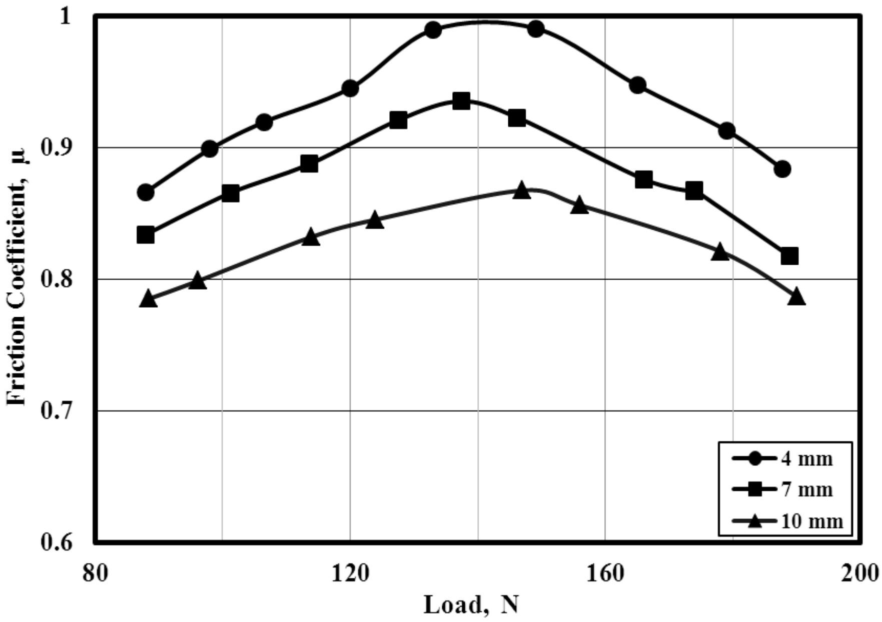


Fig. 11 Effect of wires location on friction coefficient displayed by epoxy reinforced by 16 copper wires of 1.0 mm diameter.

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. 12. Friction coefficient increased by increasing wire diameter up to 1.02 and 0.86 in epoxy reinforced by 1.0 and 0.1 mm wire diameter respectively at 114 N normal load. It is also shown that the friction coefficient increased up to maximum then decreased with increasing load.

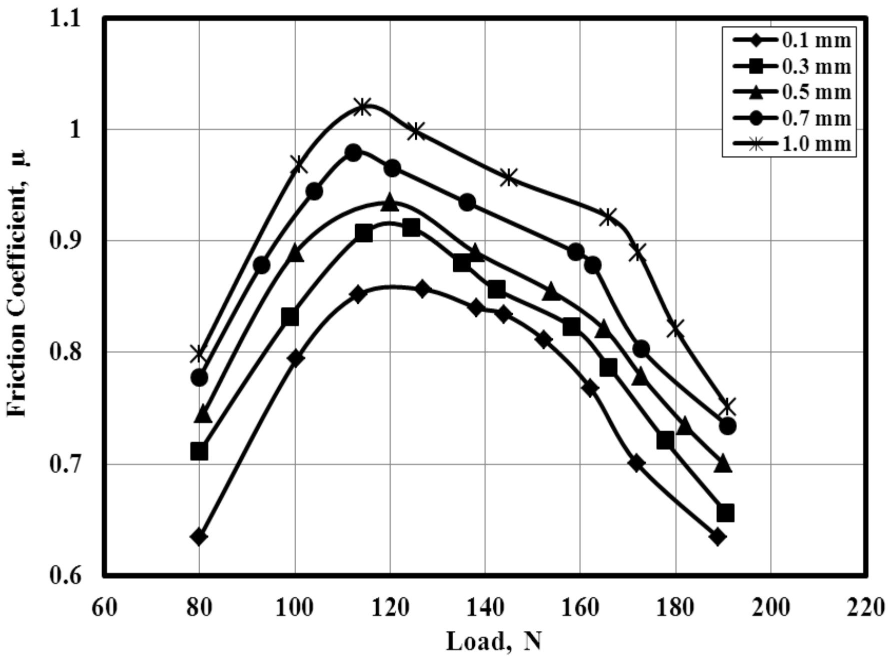


Fig. 12 Effect of wire diameter on friction coefficient for epoxy reinforced by 12 wires located at 7 mm from the surface.

At Detergent wetted sliding, the effect of number of wires of 0.7 mm diameter located at 7 mm far from the surface, on friction coefficient of epoxy composites is shown in Fig. 13. Friction coefficient increased up to 0.77 and 0.59 in epoxy reinforced by 16 and free of wires respectively. Besides, detergent wetted sliding displayed values of friction much lower than that observed for water wetted sliding. Figure 14 illustrates the effect of wires location relative to the surface on friction coefficient. The friction coefficient increased up to 0.77 and 0.69 in epoxy reinforced by wires located at 4 and 10 mm far from the surface respectively.

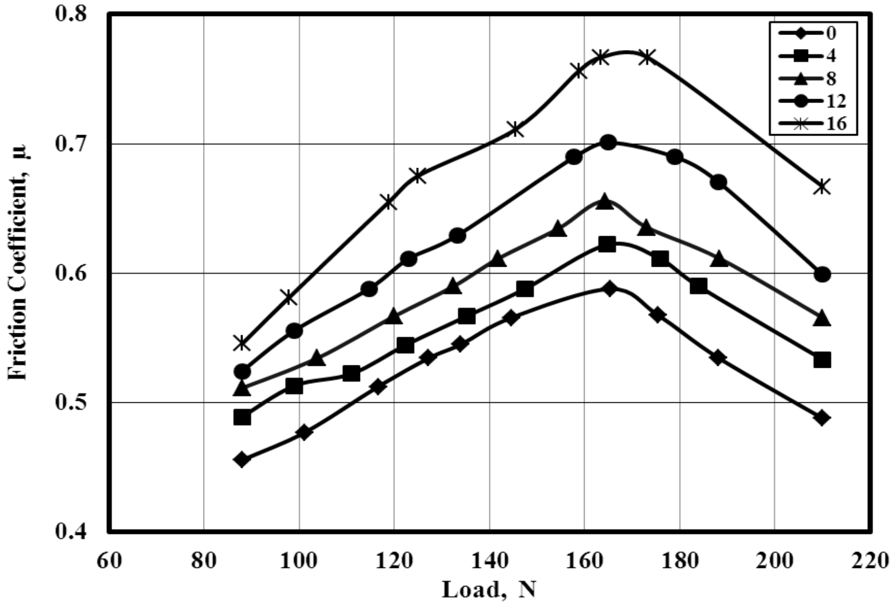


Fig. 13 Effect of number of wires on friction coefficient displayed by epoxy reinforced by wires of 0.7 mm diameter located at 7 mm far from the surface.

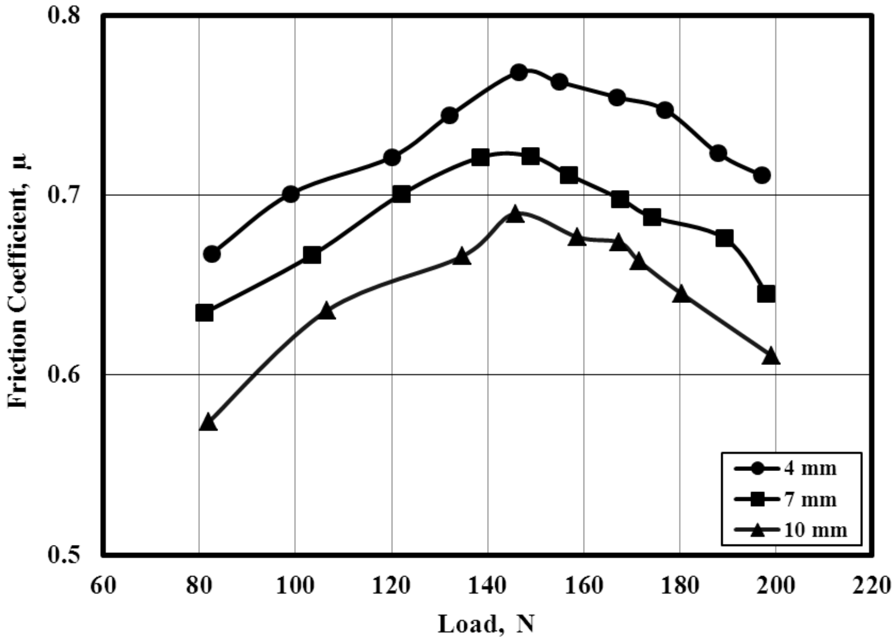


Fig. 14 Effect of wires location on friction coefficient displayed by epoxy reinforced by 8 copper wires of 0.7 mm diameter.

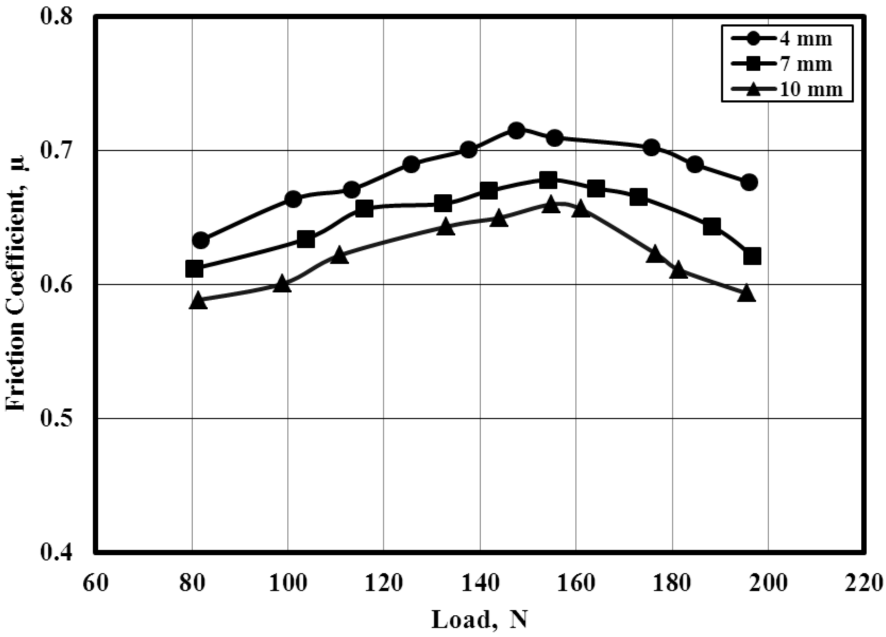


Fig. 15 Effect of wires location on friction coefficient displayed by epoxy reinforced by 8 copper wires of 0.5 mm diameter.

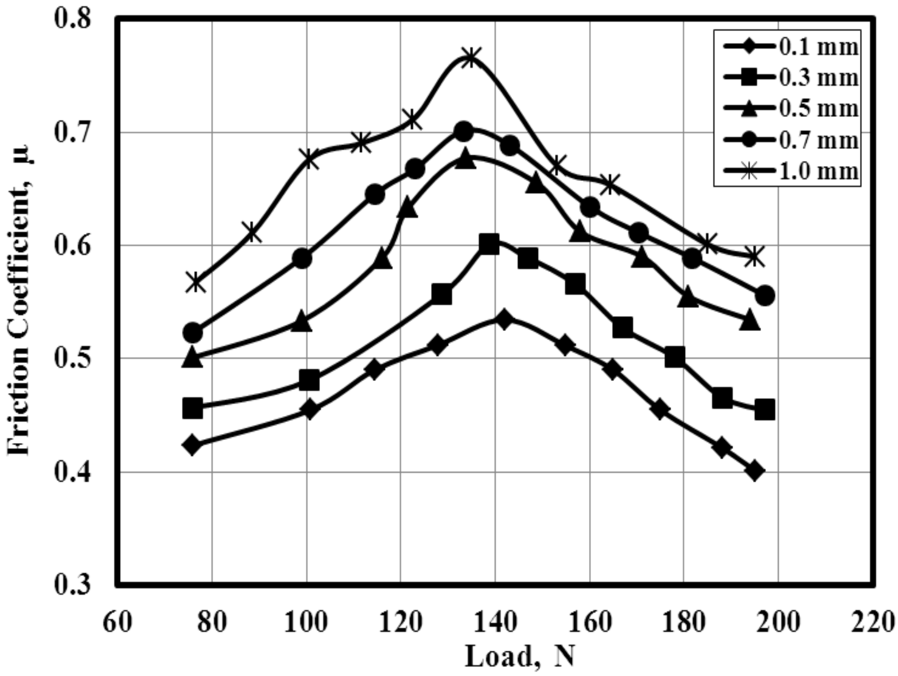


Fig. 16 Effect of wire diameter on friction coefficient for epoxy reinforced by 12 wires located at 7 mm from the surface.

The same effect of wire location on friction coefficient is observed, Fig. 15. The friction increased up to 0.72 and 0.66 in epoxy reinforced by wires at 4 and 10 mm far from the surface respectively. The values of friction coefficient were relatively lower than that observed in Fig. 14 due to the effect of wire diameter on the intensity of the electric static

charge generated on the sliding surface. Figure 16 shows that friction coefficient increased by increasing wire diameter, where the maximum value was 0.77. Values of friction coefficient in detergent wetted sliding were relatively lower than that observed for water wetted sliding.

CONCLUSIONS

1. At dry, water and detergent wetted sliding of the tested composites against rubber sheet caused significant increase in friction coefficient up to maximum then slightly decreased with increasing the normal load. Friction coefficient increased by increasing the number of 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. As the diameter of copper wires reinforcing epoxy increased, friction coefficient significantly increased.

2. 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 mating surfaces. Presence of water film facilitated the distribution of electric static charge on the sliding surface.

3. Detergent wetted sliding wetted sliding displayed values of friction much lower than that observed at water wetted sliding.

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