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Frictional behaviour of epoxy reinforced copper wires composites

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Abstract. Friction coefficient of epoxy metal matrix composites were investigated. The main objective was to increase the friction coefficient through rubber sole sliding against the epoxy floor coating providing appropriate level of resistance. This was to avoid the excessive movement and slip accidents. Epoxy metal matrix composites were reinforced by different copper wire diameters. The epoxy metal matrix composites were experimentally conducted at different conditions namely dry, water and detergent wetted sliding, were the friction coefficient increased as the number of wires increased. When the wires were closer to the sliding surface, the friction coefficient was found to increase. The friction coefficient was found to increase with the increase of the copper wire diameter in epoxy metal matrix composites. This behavior was attributed to the fact that as the diameter and the number of wires increased, the intensity of the electric field, generated from electric static charge increased causing an adhesion increase between the two sliding surfaces. At water wetted sliding conditions, the effect of changing number of wires on friction coefficient was less than the effect of wire diameter. The presence of water and detergent on the sliding surfaces decreased friction coefficient compared to the dry sliding. When the surfaces were detergent wetted, the friction coefficient values were found to be lower than that observed when sliding in water or dry condition.

Keywords: friction coefficient; epoxy metal matrix composites; copper wires; flooring materials

1. Introduction

Slipping and falling are a common phenomenon in both workplaces and daily activities. The risks associated with slipping and falling were related to the materials of footwear/floor, and contamination condition. Also, geometric design of the sole (Gabriel *et al*. 2010) is a key factor, it can increase the frictional force significantly above that expected from a consideration of the interfacial coefficient of friction alone. It was also reported by Heinrich and Kluppel (2008) that the hysteresis and adhesion friction of particle filled contributes to the improvement of the physical

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understanding of the dynamic frictional contact of the composites. Shoe soles of various tread design were very common (Kai *et al*. 2006, El-Sherbiny *et al*. 2010, Liu *et al*. 2010, Mohamed *et al*. 2010, El-Sherbiny *et al*. 2011). Slip resistance of flooring materials is one of the major environmental factors affecting walking and materials handling behavior (Li *et al*. 2007). 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 (Miller 1983, Grönqvist 1995). 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 (Li *et al*. 2008). 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, (Derler *et al*. 2008). This was reported in the friction measurements under wet conditions (Derler *et al*. 2008). In addition, mechanical abrasions and floor surface inhomogeneities had a stronger influence for rubber. In general, rubber friction could be divided into two parts, as the bulk hysteresis and the contact adhesive term (Maeda *et al*. 2007). These two contributions were regarded to be independent of each other, but this was only a simplified assumption.

Wear of composites reinforced by copper wires slightly decreased down to minimum then significantly increased with increasing wire diameter (Mohamed *et al*. 2014). 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 (Patnaik *et al*. 2010). 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. % aluminum.

Wear of epoxy reinforced by polyamide fibers showed the minimum wear values. Orientation of fibers much affected wear (Mohamed *et al.* 2014). Parallel fibers 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 0.3mm polyamide fiber diameters. This observation confirmed the application of the polyamide fibers as reinforcement in epoxy coatings.

In the present work, the effect of different diameters of copper wires reinforced epoxy specimens on the friction coefficient by sliding against rubber were investigated. The proposed composites are tested as flooring materials. Measurements of the friction coefficient were experimentally evaluated three different conditions namely, Dry Sliding, Water Wetted Sliding, and Detergent Wetted Sliding. The friction coefficient were measured for the three different conditions under three variables namely, the effect of number of copper wires, the effect of copper wires location, and effect of copper wire diameter.

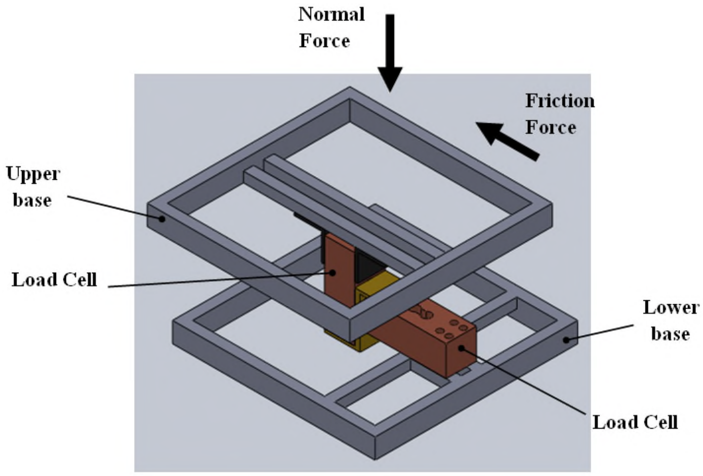
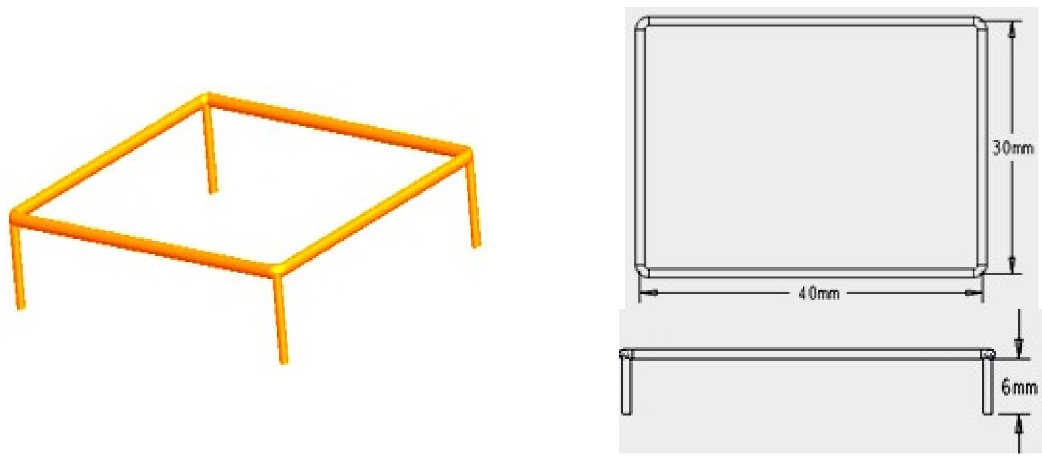


Fig. 1 Arrangement of the test rig

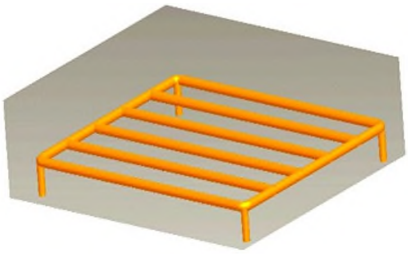
2. Materials preparation and experiments

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 hardness equals to 60 on Shore hardness scale. Friction coefficient was evaluated through measuring the friction force and applied normal force, Fig. 1. The tested specimens were prepared from epoxy molded in boxes of 30×40 mm 2 and 11 mm height. Five different meshes of the copper wires were used namely (nW= 0, 4, 8, 12 and 16 wires). Also, different copper wire diameters namely (diW=0.1, 0.3, 0.5, 0.7 and 1.0 mm) were used to reinforcing the epoxy metal composites. The copper wires were placed at distances namely (dsW= 4, 7 and 10 mm) measured from the surface, Fig. 2.

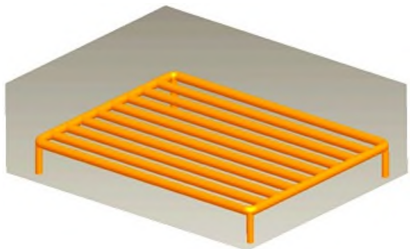


(a) Frame free of wires at 4mm far from the contact surface

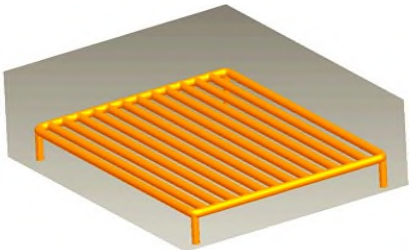
Fig. 2 Arrangement of the copper wire reinforcement



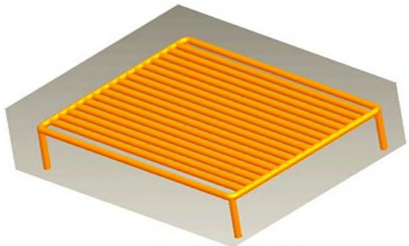
(b) 4 wires.



(c) 8 wires.



(d) 12 wires.



(e) 16 wires.

Fig. 2 Continued

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 counter face (rubber) of 250×420 mm^2 area and 10mm thickness. Tests were carried out at dry, water and detergent wetted surfaces conditions.

3. Results and discussion

3.1 Sliding measurements for dry surface condition

3.1.1 Effect of number of copper wires

It was observed that friction coefficient significantly increased up to maximum then slightly decreased with increasing the normal load, Fig. 3. As the number of wires increased, friction coefficient increased. This behavior may be attributed to the increased adhesion between epoxy and rubber caused by the increase of the number of the wires. It seems that electric static charge generated on the sliding surfaces was responsible for that increase by imposing electric force from the magnetic field on the normal load. The friction coefficient increased up to 0.99 in epoxy reinforced by 16 wires, while epoxy free of wires displayed lower friction value of 0.81.

The effect of number of wires on friction coefficient at 0.5 mm wire diameter and 7 mm distance from the surface as shown in Fig. 4, where the maximum friction coefficient was 0.86 in epoxy reinforced by 16 wires. This behavior can be attributed to the increase of the electric static charge that caused an increase in the electric attractive force which was imposed to the normal load so that the friction coefficient increased.

3.1.2 Effect of copper wires location

It was noticed that when the wires were closer to the surface the electric static charge increased

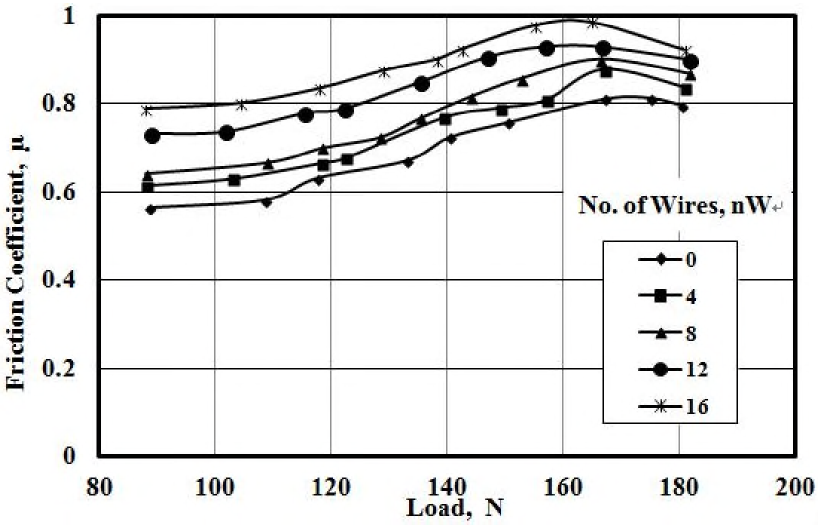


Fig. 3 Effect of number of wires on friction coefficient, diW= 0.3mm and dsW=7mm

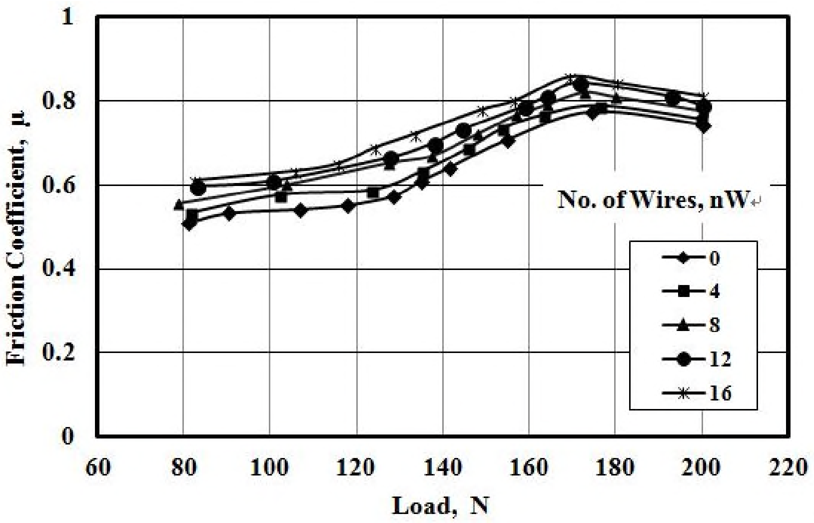


Fig. 4 Effect of number of wires on friction coefficient, diW=0.5 mm and dsW=7 mm

and consequently the friction coefficient increased, Fig. 5. The maximum friction coefficient was 0.95 in epoxy reinforced by wires at 4 mm from the surface, whereas the friction coefficient was 0.79 in epoxy reinforced by wires at 10 mm from the surface. Friction coefficient significantly increased up and attained its maximum peak value at applied load equal to 150 N then decreased with further load increase.

The effect of the location of the wires of 1.0 mm diameter and 8 wires as shown in Fig. 6. As the diameter of the wires increased to 1.0 mm, friction coefficient increased to 0.98. When the wires were close to the surface friction coefficient represented the highest values. This behavior may be attributed to the electric field generated from electric static charge and copper wires. The electric field intensity increased with decreasing the location distance from the sliding surface.

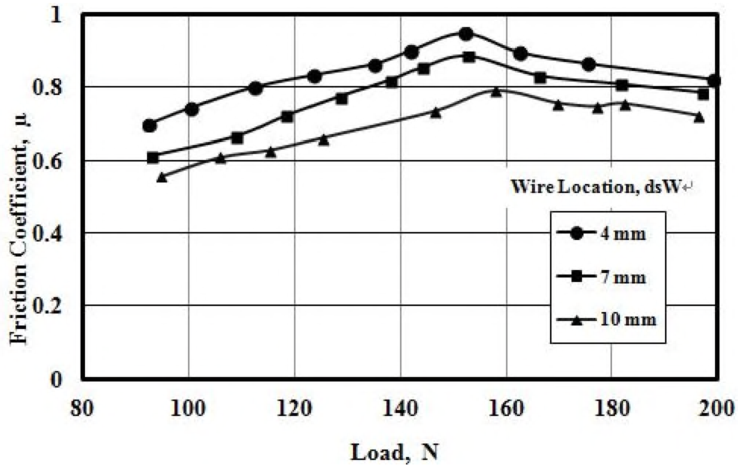


Fig. 5 Effect of wire location on friction coefficient, diW= 0.3mm and nW= 8 wires

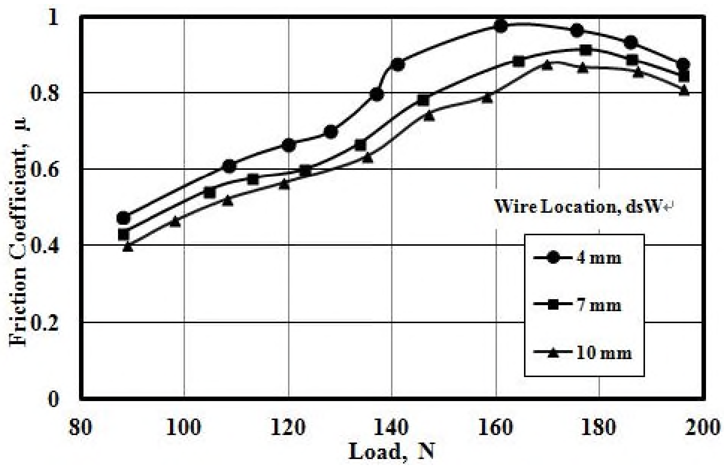


Fig. 6 Effect of wire location on friction coefficient, diW= 1.0 mm and nW= 8 wires

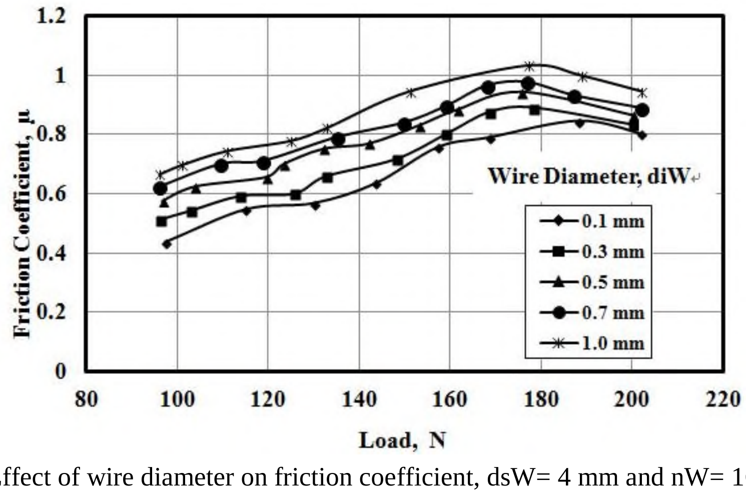


Fig. 7 Effect of wire diameter on friction coefficient, dsW= 4 mm and nW= 16 wires

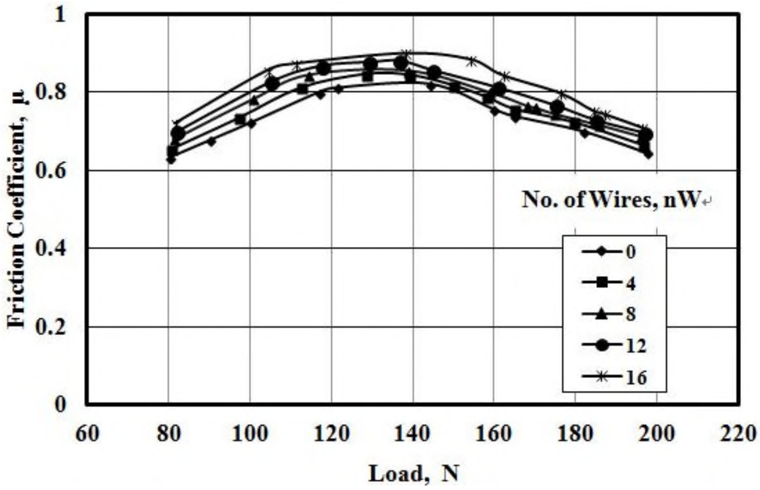


Fig. 8 Effect of number of wires on friction coefficient, diW= 0.5mm and dsW= 7mm

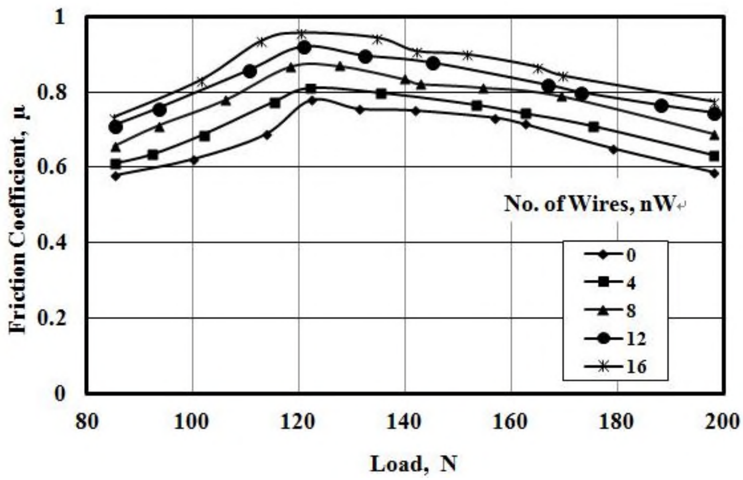


Fig. 9 Effect of number of wires on friction coefficient, diW= 0.7mm and dsW= 4mm

3.1.3 Effect of copper wire diameter

The voltage increased with increasing the wire diameter that was responsible for increasing the electric attractive force and consequently friction coefficient increased to 1.0 and 0.85 for epoxy reinforced by 1.0 and 0.1mm wire diameter respectively, Fig. 7. Increase of friction coefficient with load was due to the increase of the contact area, while the decrease was attributed to the yield shear strength of the epoxy composites.

3.2 Sliding measurements for water wetted surface condition

3.2.1 Effect of number of copper wires

At water wetted sliding the effect of number of wires at 0.5 mm wire diameter and 7 mm distance from the surface as shown in Fig. 8. The friction coefficient was 0.9 in epoxy reinforced by 16 wires, while it was 0.82 in epoxy free of wires. As the number of wires increased friction coefficient increased. The effect of changing number of wires was less than the effect of wire diameter.

Composites reinforced by 0.7 mm wire diameter located at 4mm from the surface displayed higher values of friction coefficient, Fig. 9, where the maximum friction coefficient was 0.94 under 120 N applied load for epoxy reinforced by 16 wires, while the minimum friction value was 0.78 for epoxy free of wires. As the number of wires increased friction coefficient increased. This behavior can be attributed to the fact that as the diameter and the number of wires increased the electric field increased causing an increase in the adhesion between the two sliding surfaces. Besides, water could facilitate the homogeneous charge distribution on the surfaces.

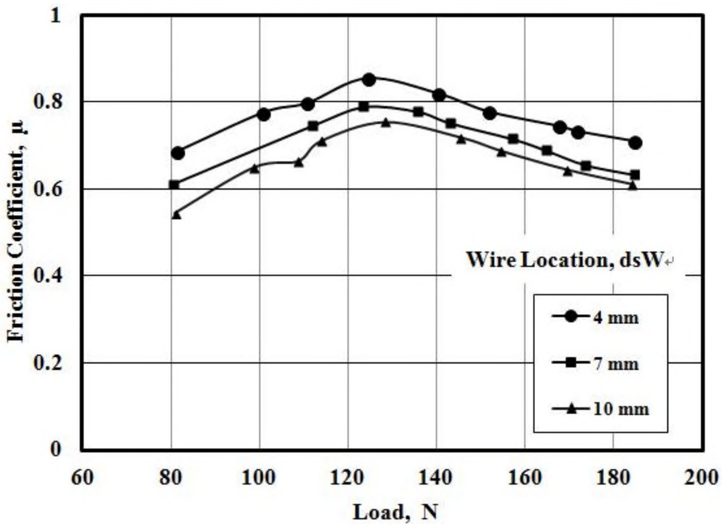


Fig. 10 Effect of wire location on friction coefficient, diW= 0.3 mm and nW= 16 wires

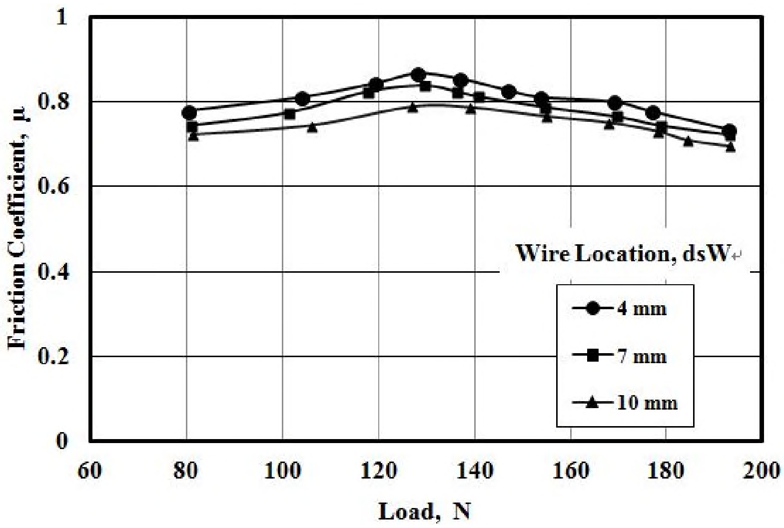


Fig. 11 Effect of wire location on friction coefficient, diW= 0.5 mm and nW= 12 wires

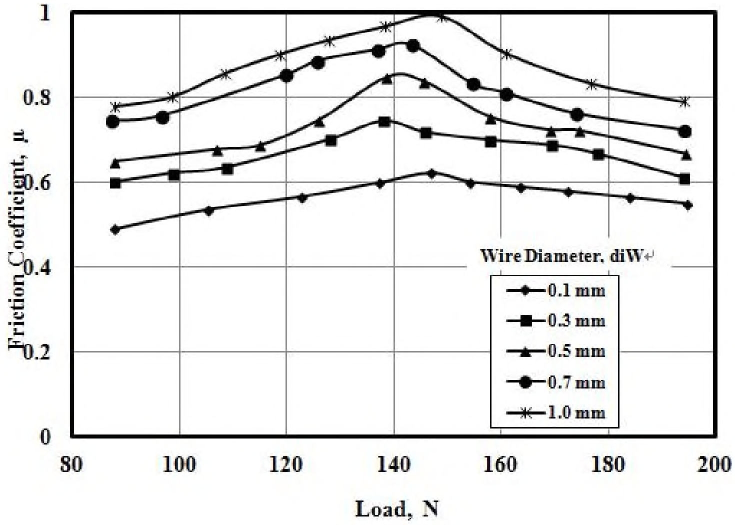


Fig. 12 Effect of wire diameter on friction coefficient, dsW= 4 mm and nW= 16 wires

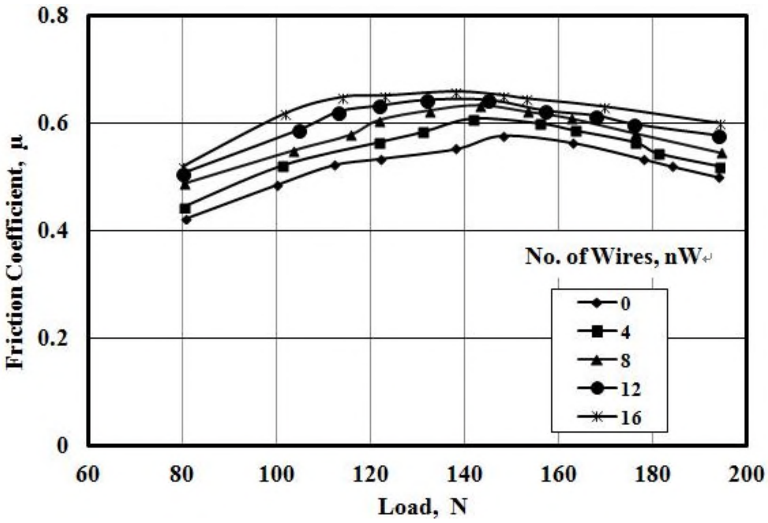


Fig. 13 Effect of number of wires on friction coefficient, diW= 0.7 mm and dsW= 4 mm

3.2.2 Effect of copper wires location

The presence of water on the sliding surfaces decreased friction coefficient down to 0.86, Fig. 10. This behavior can be attributed to the ability of water to leak the electric static charge outside the contact area. It was also clear that when the wires were closer to the surface the friction coefficient increased due to the increase of the electric field. Similarly as presented in Fig. 11, the highest and lowest friction coefficient values were 0.87 and 0.79 displayed by epoxy reinforced by wires located at 4 and 10 mm far from the surface respectively.

3.2.3 Effect of copper wire diameter

The presence of water conducted the generated electric charge out the contact area and consequently the attractive force caused by the electric force decreased so that the sliding motion became smoother and the friction coefficient decreased down to 0.99, Fig. 12. Epoxy reinforced by 0.1 mm wire diameter displayed the lowest friction value.

3.3 Sliding measurements for Detergent wetted surface condition

3.3.1 Effect of number of copper wires

When the surfaces were detergent wetted, the highest friction value decreased from 0.93 at water wetted sliding to 0.66, Fig. 13. It seems that the electrical conductivity of the detergent was higher so that the electric static charge decreased and consequently the attractive force decreased leading to friction decrease. The effect of number of wires on friction coefficient at 0.3 mm wire diameter located at 4 mm from the surface as shown in Fig. 14. It was shown that the highest friction value was 0.62 displayed by epoxy composites reinforced by 16 copper wires. This observation confirmed that as wire diameter increased the friction coefficient increased. Also it can be noticed that friction coefficient increased up to the maximum and then decreased by increasing the normal load.

3.3.2 Effect of copper wires location

The effect of mesh location on friction coefficient at 0.7 mm wire diameter and 16 wires as shown in Fig. 15. It seems that as the wires were closer to the surface, friction coefficient increased. Generally, the presence of detergent decreased the highest friction value down to 0.65 in epoxy reinforced by wires located at 4 mm from the surface. The friction coefficient was 0.64 and 0.57 for epoxy reinforced by wires at 4 and 10 mm from the surface respectively, Fig. 16. These values were lower than that observed when sliding in water or dry condition.

3.3.3 Effect of copper wire diameter

The effect of wire diameter on friction coefficient at 4 mm from the surface and 16 wires as

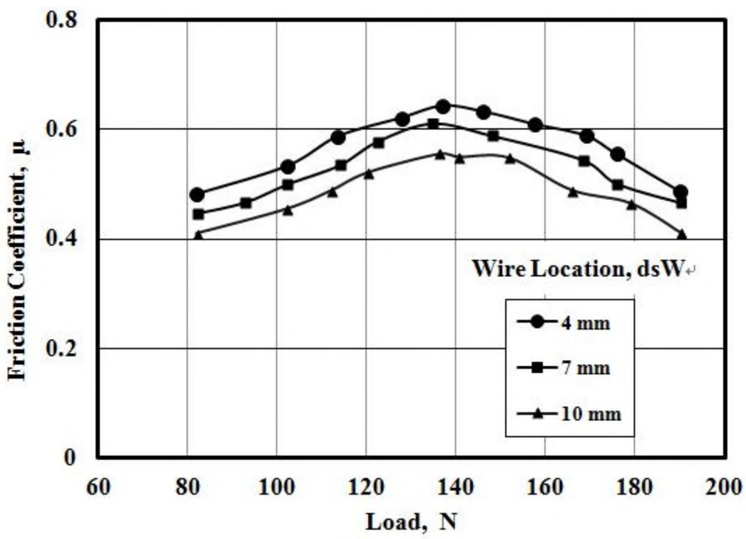


Fig. 14 Effect of number of wires on friction coefficient, diW= 0.3 mm and dsW= 4 mm

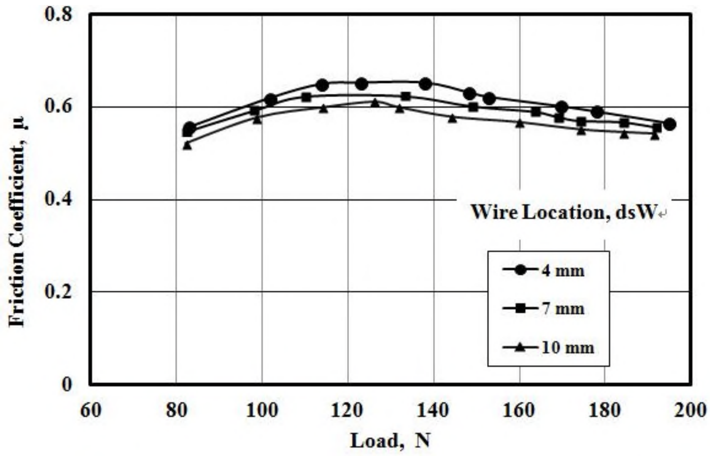


Fig. 15 Effect of wire location on friction coefficient, diW= 0.7 mm and nW= 16 wires

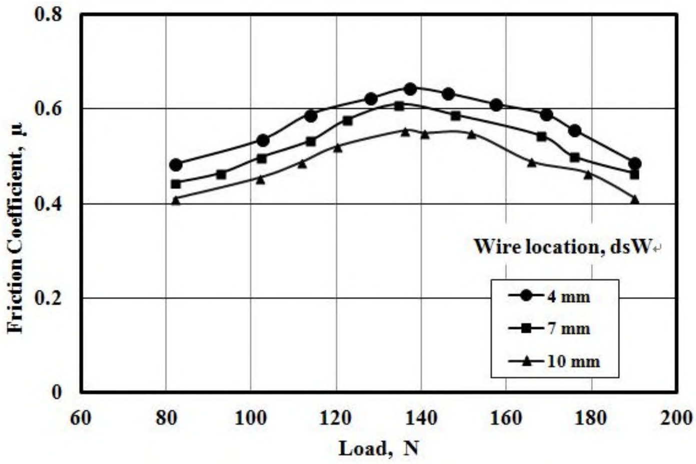


Fig. 16 Effect of wire location on friction coefficient, diW= 0.5 mm and nW= 8 wires

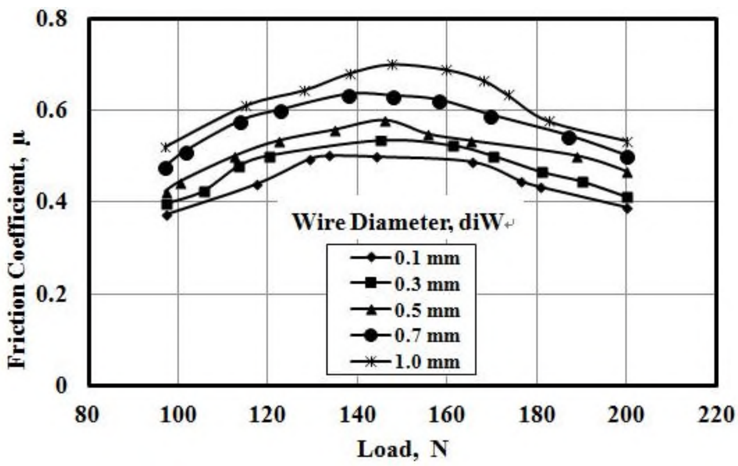


Fig. 17 Effect of wire diameter on friction coefficient, nW= 16 wires and dsW= 4 mm

shown in Fig. 17. The friction coefficient was 0.70 and 0.50 in epoxy reinforced by 1.0 and 0.1 mm wire diameter respectively. Generally, the increase of the wire diameter increased the friction coefficient and it seems that the detergent wetted sliding caused the lowest voltage which was observed by friction decrease.

4. Conclusions

In this work, frictional behavior of epoxy metal matrix composites were investigated and the following conclusions are drawn

- At dry, water and detergent wetted sliding conditions, it was noticed that increase both the number of wires and wire diameter raised the value of the friction coefficients particularly, when the wires were closer to the rubbing surface. This increase can be explained because of the generated electric field which affecting the adhesion between the contact surfaces. Moreover, existence of the water could ease the distribution of charges on the surfaces.
- At water wetted sliding surfaces, the effect of changing the number of wires on the friction was less than the effect of changing the wire diameters. The presence of water on the sliding surfaces decreased friction coefficients comparing with dry sliding.
- At detergent wetted sliding surfaces, friction coefficient showed relative lower friction values in contrast to the values observed in case of water or dry condition. As well as increase of wire diameter significantly increased friction coefficient.

References

Derler, S., Kausch, F. and Huber, R. (2008), “Analysis of factors influencing the friction coefficients of shoe sole materials”, *Safety Sci.*, **46**(5), 822-832.

El-Sherbiny, Y.M., Mohamed, M.K. and Ali, W.Y. (2011), “Friction coefficient displayed by footwear walking against rubber floorings fitted by cylindrical treads”, *J. Egyptian Soc. Tribol*., **8**(1), 1-12.

El-Sherbiny, Y.M., Samy, A.M. and Ali, W.Y. (2010), “Friction coefficient of rubber sliding against dusty indoor flooring”, *J. Egyptian Soc. Tribol.*, **7**(4), 11-25.

Gabriel, P., Thomas, A.G. and Busfield, J.J.C. (2010), “Influence of interface geometry on rubber friction", *Wear*, **268**(5-6), 747-750.

Grönqvist, R. (1995), "Mechanisms of friction and assessment of slip resistance of new and used footwear soles on contaminated floors", *Ergonomics* **38**, 224-241.

Heinrich, G. and Kluppel, M. (2008), "Rubber friction, tread deformation and tire traction", *Wear*, **265**(7-8), 1052-1060.

Kai, W.L., Horng, H.W. and Yu-Chang, L. (2006), “The effect of shoe sole tread groove depth on the friction coefficient with different tread groove widths, floors and contaminants”, *Appl. Ergon.*, **37**(6), 743-748.

Li, K.W., Yu, R. and Han, X.L. (2007), “Physiological and psychophysical responses in handling maximum acceptable weights under different footwear-floor friction conditions”, *Appl. Ergon.*, **38**(3), 259-265.

Li, K.W., Chang, C.C. and Chang, W.R. (2008), “Slipping of the foot on the floor when pulling a pallet truck”, *Appl. Ergon.*, **39**(6), 812-819.

Liu, L., Li, K.W., Lee, Y.H., Chen, C.C. and Chen, C.Y. (2010), “Friction measurements on “anti-slip” floors under shoe sole, contamination, and inclination conditions”, *Safety Sci*., **48**(10), 1321-1326.

Maeda, K., Bismarck, A. and Briscoe, B. (2007), “Effect of bulk deformation on rubber adhesion”, *Wear*,

263(7-12), 1016-1022.
Miller, J.M. (1983), "Slippery" work surface: toward a performance definition and quantitative coefficient of friction criteria", *J. Safety Res.*, **14**, 145-158.
Mohamed, M.K., Abdel-Jaber, G.T. and Ali, W.Y. (2014), "Abrasive wear of epoxy composites filled by abrasive particles and reinforced by polyamide fibres", *Materialwiss. Werkst.* **45**(2), 123-129.
Mohamed, M.K., Samy, A.M. and Ali, W.Y. (2010), "Friction coefficient of rubber shoes sliding against ceramic flooring", Tribologie Fachtagung, Göttengen, Germany, September.
Patnaik, A., Satapathy, A., Chand, N., Barkoula, N.M. and Biswas, S. (2010), "Solid particle erosion wear characteristics of fiber and particulate filled polymer composites: a review", *Wear*, **268**(5-6), 249-263.

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