EGTRIB Journal

JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 12, NO. 1, January 2015, pp. 1 - 12 **ISSN 2090 – 5882**

FRICTION COEFFICIENT DISPLAYED BY RUBBER CYLINDRICAL PROTRUSIONS FITTED BY HOLES SLIDING AGAINST CERAMIC FLOORING

Mahmoud M. M.

Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT.

ABSTRACT
The present work aims to decrease friction coefficient of rubber soles sliding against ceramic floorings. Introducing holes of different diameters in the cylindrical protrusions in the rubber surfaces was proposed. Experiments were carried out to evaluate the performance of the proposed protrusions in increasing friction coefficient at dry and contaminated floorings.

It was found that, at dry sliding, friction coefficient significantly increased up to maximum then decreased with increasing number of holes. The highest friction values were observed for 1.5 mm diameter holes, while the lowest values were displayed by 3.0 mm diameter holes. In the presence of water on the flooring, it was shown that as the hole diameter increased, the volume of the water leaked out the contact area increased. The detergent layer formed on the contact area caused drastic friction decrease. The highest friction value did not exceed 0.13 which confirmed the severity of walking in the presence of detergent. When sand particles was covering sliding surfaces, the effect of hole diameter was much higher than number of holes. When oil contaminated the sliding surfaces, friction coefficient significantly increased at single hole protrusion. The single hole was more pronounced than the effect of hole diameter due to the strong adhesion of oil into the rubber and ceramic surfaces. Water/oil dilution contaminated ceramic flooring showed the highest friction coefficient (0.26) at single hole of 1.5 mm diameter. Further increase in the number of holes decreased friction values. Presence of sand in oil contaminated ceramic flooring did not increased friction coefficient, where the highest value did not exceed 0.2. Sliding against water/oil dilution and sand contaminated ceramic flooring represented relatively higher friction values. Protrusions perforated by three holes of 2.5 mm diameter showed the highest friction followed by single hole of 3.0 mm diameter and four holes of 1.5 mm diameter.

KEYWORDS
Friction coefficient, rubber cylindrical protrusions, holes, ceramic flooring.

INTRODUCTION
The presence of water and detergent drastically decreases the friction coefficient and consequently slip increases and accidents occur. The risks associated with slipping and falling is related mainly to the presence of fluid on the floorings. It is necessary to decrease the influence of the fluid by leaking it from the contact area between soles and

floorings. The effect of introducing holes as well as protrusions in the rubber surface on friction coefficient when sliding against ceramics was investigated, [1]. It was found that, for dry sliding, cylindrical protrusions are more sensitive to surface deformation than surface holes. Their influence on friction coefficient is more effective than holes at small contact area. Holes need 80 % contact area, while protrusions need 30 %. The presence of water and detergent as film covering the contact area decreases the adhesion between rubber and ceramic surfaces, where the difference between the values of friction coefficient is insignificant. Holes in rubber surface could store sand particles and consequently friction coefficient displayed relative increase. Water contaminated by sand particles showed significant friction increase for cylindrical protrusions. The friction difference increased as the contact area decreased.

The effect of grooves introduced in the rubber surface on the static friction coefficient when sliding against ceramic surface was investigated, [2 – 4]. It was found that at dry sliding test specimens of triple grooves showed the highest friction coefficient for soft rubber. In the presence of water friction coefficient of hard rubber of double grooves displayed significant friction increase. In presence of water contaminated by sand friction coefficient showed significant increase for soft rubber of triple and quadruple grooves. Friction coefficient of soft and hard rubber of quadruple grooves sliding against ceramic surfaces wetted by water and detergent showed relatively high friction. Introducing quadruple grooves in hard rubber increased friction coefficient generated from the sliding against oil lubricated ceramics. For surfaces lubricated by oil/water dilution friction coefficient showed remarkable increase.

The influence of rubber tread width and direction of motion on the friction coefficient displayed by the sliding of rubber against ceramic flooring was discussed, [5]. Based on the experimental findings, it was found that the effect of sliding direction on friction coefficient was significant due to the amount of rubber deflection. Besides, in the presence of water film, the ability of the groove to store the fluid was responsible for the variation of the values of friction coefficient. Sand particles strongly affected the contact, while water facilitates the motion of sand particles so that their effect was much pronounced. Oil decreased the adhesion between rubber and ceramic and consequently rubber deformation decreased.

The effect of rectangular and cross treads introduced in the rubber mats on friction coefficient when sliding against footwear was investigated, [6]. It was found that friction coefficient displayed slightly decreased with increasing tread groove at dry, detergent wetted and oily sliding due to the decreased contact area accompanied to the increased groove width of the rubber. At water wetted sliding friction coefficient remarkably increased with increasing the tread groove. Oily sliding displayed very low values of friction coefficient. As the tread width decreased, the friction values decreased due to the decrease of the contact area at dry, detergent wetted and oily sliding. At sliding against water wetted flooring, friction coefficient significantly increased with increasing both of the width of the tread and the groove due to the easier water escape from the contact area, where the groove volume was relatively higher. Friction coefficient displayed by cross tread rubber sliding against dry, detergent wetted and oily sliding showed drastic decrease with increasing tread groove. In general, rubber friction is divided into two parts; the bulk hysteresis and the contact adhesive term, [7]. These two contributions are regarded to be independent of each other, but this is only a simplified assumption.

Friction measurement is one of the major approaches to quantify floor slipperiness. Investigations on friction measurement have been focused on liquid contaminated conditions. It was expected that wet surfaces had significant lower friction coefficient values than those of the dry surfaces, [8]. The friction coefficient difference between the dry and wet surfaces depended on the footwear material and floor combinations. Friction measurements under liquid contaminated conditions were very common. The squeeze film theory explains the effects of the liquid on the measured friction. Measurements of the static friction coefficient between rubber specimens and ceramic surfaces were carried out at dry, water lubricated, oil, oil diluted by water and sand contaminating the lubricating fluids, [9 - 12]. It was observed that, dry sliding of the rubber test specimens displayed the highest value of friction coefficient. For water lubricated ceramics, the value of the friction coefficient decreased compared to dry sliding. For oil lubricated ceramic, friction coefficient decreased with increasing the height of the grooves introduced in the rubber specimens. As for ceramic lubricated by detergent and contaminated by sand, friction coefficient increased significantly compared to the sliding on ceramics lubricated by water and soap.

The effect of the treads width and depth, of the shoe sole on the friction coefficient between the sole and ceramic floor interface, was discussed, [13]. It was found that, at dry sliding, friction coefficient slightly increased with increasing tread height. Perpendicular (relative to the motion direction) treads displayed the highest friction coefficient due to their increased deformation, while parallel treads showed the lowest values. In the presence of water on the sliding surface, significant decrease in friction coefficient was observed compared to the dry sliding. For detergent wetted surfaces, friction coefficient drastically decreased to values lower than that displayed by water. Parallel treads showed the highest friction coefficient, while perpendicular treads displayed the lowest friction values as result of the formation of the hydrodynamic wedge.Oily smooth surfaces gave the lowest friction values as result of the presence of squeeze oil film separating rubber and ceramic. Emulsion of water and oil shows slight friction increase compared to oil lubricated sliding. As the tread height increased, friction increased due to the easy escape of the lubricant from the contact area. Tread groove designs are helpful in facilitating contact between the shoe sole and floor on liquid contaminated surface, [14, 15]. The effectiveness of a tread groove design depends on the contaminant, footwear material and floor. Tread groove design was ineffective in maintaining friction on a floor covered by vegetable oil. Tread grooves should be wide enough to achieve better drainage capability on wet and water detergent contaminated floors.

The effect of rubber flooring provided by rectangular and cylindrical treads on the friction coefficient was investigated, [16, 17]. It was found that, at dry sliding, friction coefficient slightly increased with increasing treads height. Perpendicular treads displayed the highest friction coefficient due to their increased deformation, while parallel treads showed the lowest values. In the presence of water on the sliding surface significant decrease in friction coefficient was observed. For detergent wetted surfaces, friction coefficient drastically decreased to values lower than that displayed by water.

EXPERIMENTAL

Experiments were carried out using a test rig designed and manufactured to measure the friction coefficient displayed by the sliding of the tested rubber specimens against

ceramic flooring materials through measuring the friction force and applied normal force. The tested materials were placed in a base supported by two load cells, the first can measure the horizontal force (friction force) and the second can measure the vertical force (applied load). Friction coefficient is determined by the ratio between the friction force and the applied load. The arrangement of the test rig is shown in Fig. 1. The tested flooring materials of ceramic were in form of a quadratic tiles of 400 × 400 mm^2 and 5 mm thickness. The surface roughness was 6.3 µm Ra, (the center line average of surface heights, CLA). Rubber test specimens were prepared in the form of square sheets of 50 × 50 mm^2 and 5 mm thickness. Nine rubber cylindrical protrusions of 5 mm height and 10 mm diameter were adhered to the rubber sheet. The cylindrical protrusions were perforated by one, two, three and four holes of 1.5 , 2.5 and 3.0 mm diameter, Fig. 2. After each measurement, all contaminants were removed from the flooring materials and the rubber specimens using absorbent papers. Both the flooring materials and tested rubber specimens were then rinsed using water.

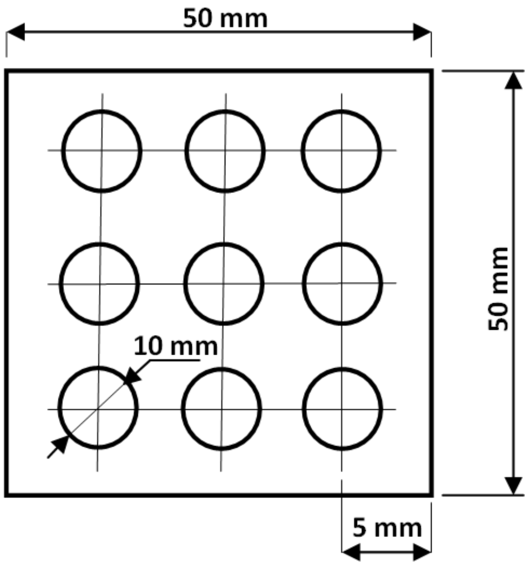

Fig. The rubber test specimens.

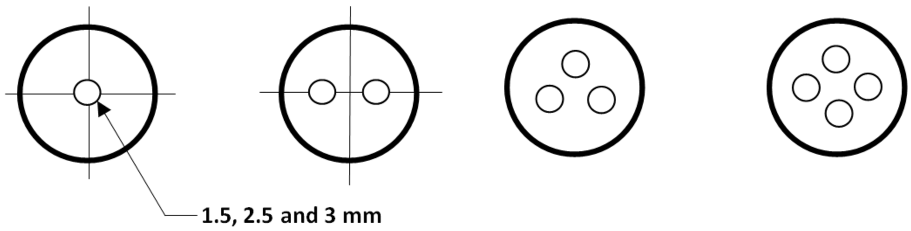

Fig. Distribution of the holes in the rubber protrusions.

RESULTS AND DISCUSSION

At dry sliding, friction coefficient of rubber sliding against ceramic flooring is shown in Fig. 3. It is clear that the main factor that controls the value of friction coefficient is the rubber deformation which increased with increasing number of holes accompanied by a decrease of area of contact. It is critical to make a balance between the number of holes and contact area in order to have the optimal value of friction coefficient. As illustrated, friction coefficient significantly increased up to maximum then decreased with

increasing number of holes. The friction increase was due to the increased rubber deformation, while the decrease was from the decrease of the contact area. The highest friction values were observed for protrusions perforated by 1.5 mm diameter holes, while the lowest values were displayed by 3.0 mm diameter holes.

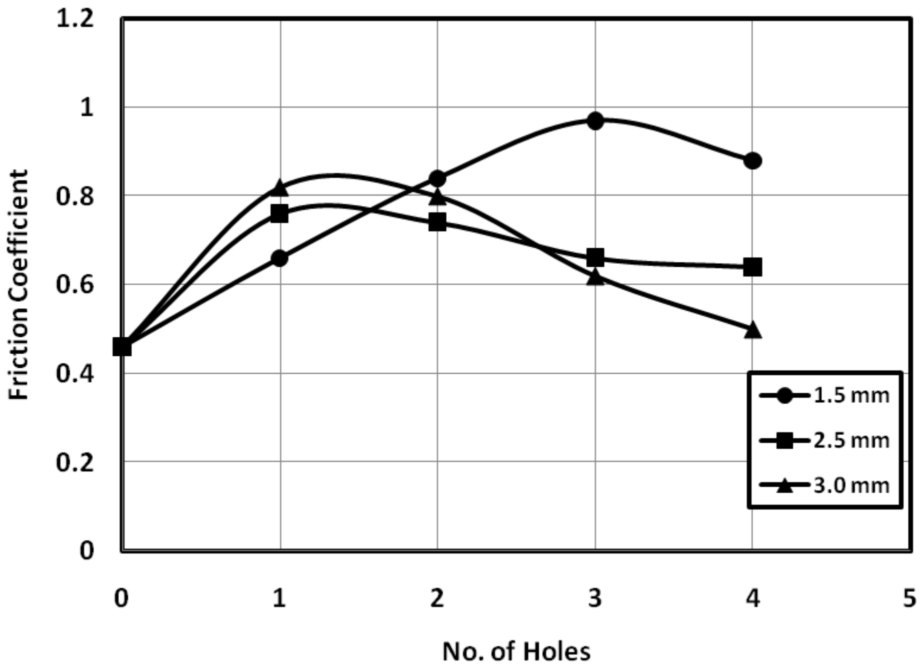

Fig. 3 Friction coefficient of rubber sliding against dry ceramic flooring.

In the presence of water on the flooring, it is important to scavenge the water out of the contact area. This function could be done through the holes of the protrusions. The highest friction values were shown for holes of 2.5 and 3.0 mm diameters, Fig. 4. It seems that as the diameter of the hole increased, the volume of the water leaked out the contact area increased. The difference in friction coefficient observed for 1.5, 2.5 and 3.0 mm holes was significant indicating that effect of hole diameter was much higher than the number of holes

Friction coefficient of rubber sliding against detergent wetted ceramic flooring showed no effect for the number of hole as well as hole diameter, Fig. 5. This behaviour can be explained as result of the electric properties of the detergent molecules which increase their adherence into the rubber and ceramic surfaces. In that condition, a detergent layer would be formed on the contact area leading to the decrease of the friction coefficient. The effect of the hole diameter was very low, while the number of holes showed relatively higher effect. The highest friction value did not exceed 0.13 which confirmed the severity of walking in the presence of detergent.

The effect of sand particles covering sliding surfaces is shown in Fig. 6, where friction coefficient showed relatively higher values. It is clearly shown that the effect of hole diameter was much higher than number of holes. It seems that increasing hole diameter accelerated the sand removal from the contact area. The optimal number of holes was ranging between two and three holes which produced higher friction coefficient.

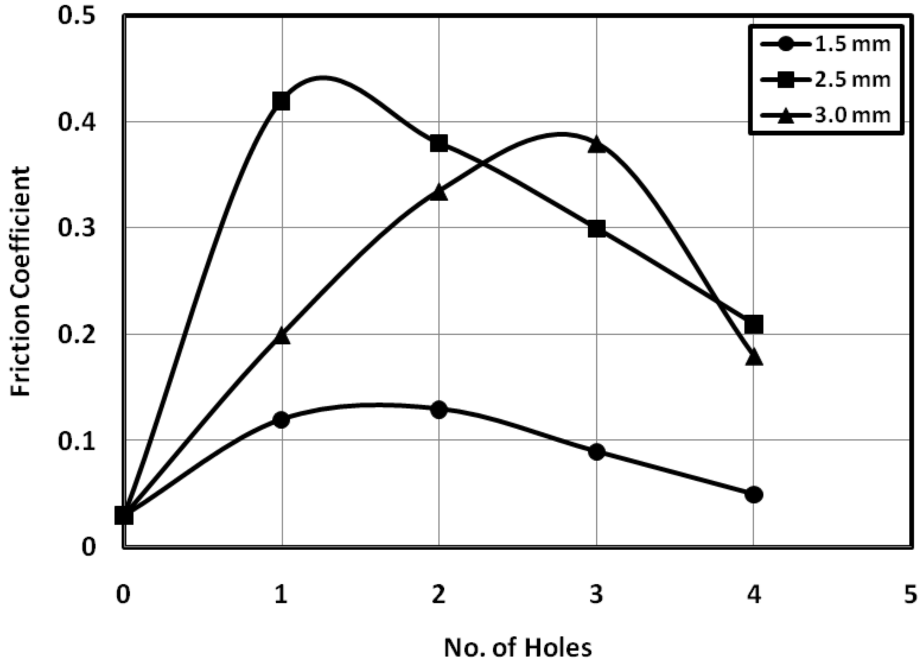

Fig. 4 Friction coefficient of rubber sliding against water wetted ceramic flooring.

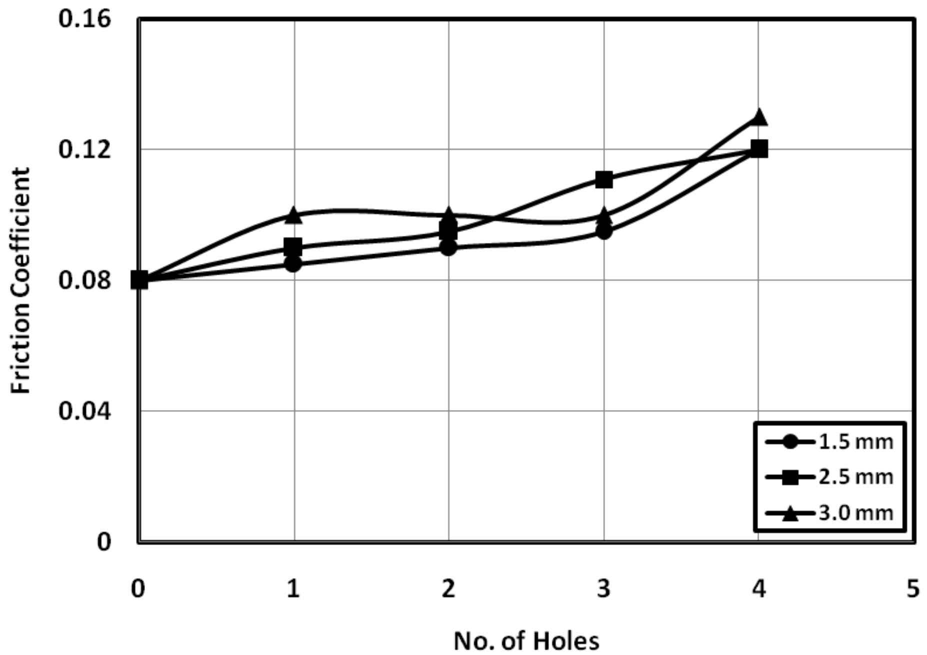

Fig. 5 Friction coefficient of rubber sliding against detergent wetted ceramic flooring.

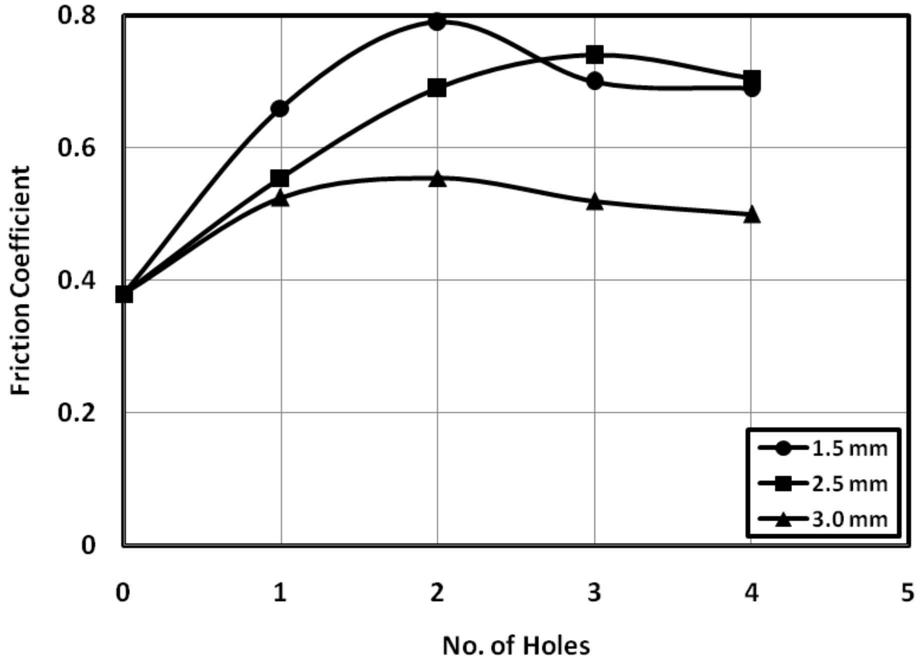

Fig. 6 Friction coefficient of rubber sliding against sand contaminated ceramic flooring.

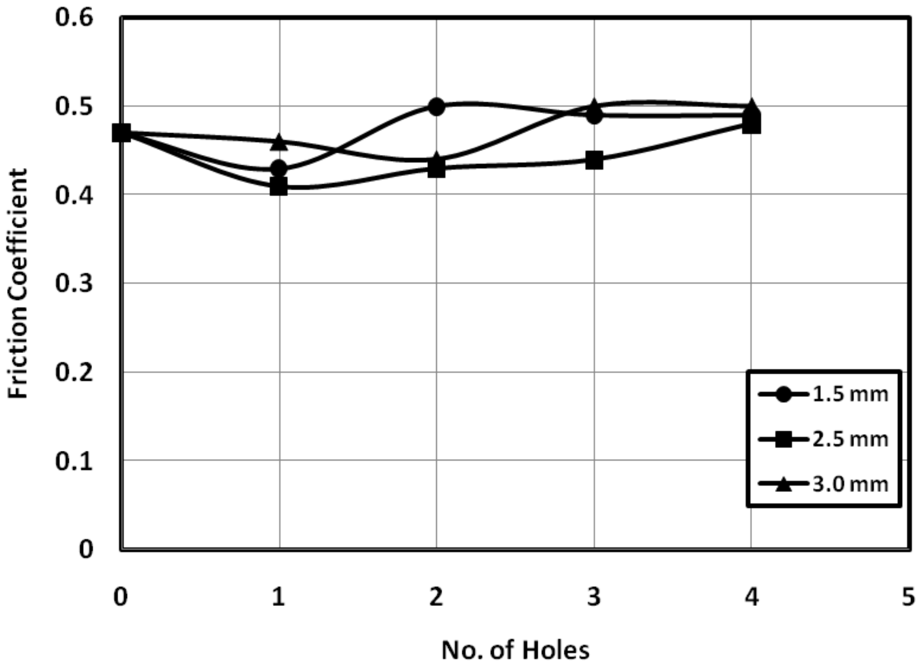

Fig. 7 Friction coefficient of rubber sliding against water and sand contaminated ceramic flooring.

Friction coefficient of rubber sliding against water and sand contaminated ceramic flooring showed insignificant change, Fig. 7. This behaviour might be from the function of water which facilitated the motion of sand particles.

The same trend observed in friction coefficient of rubber sliding against water and sand contaminated ceramic flooring is shown for rubber sliding against detergent and sand

contaminated ceramic flooring, Fig. 8. Values of friction coefficient were relatively higher than that observed for sliding against detergent wetted flooring due to the effect of sand particles which could disturb the action of the detergent film.

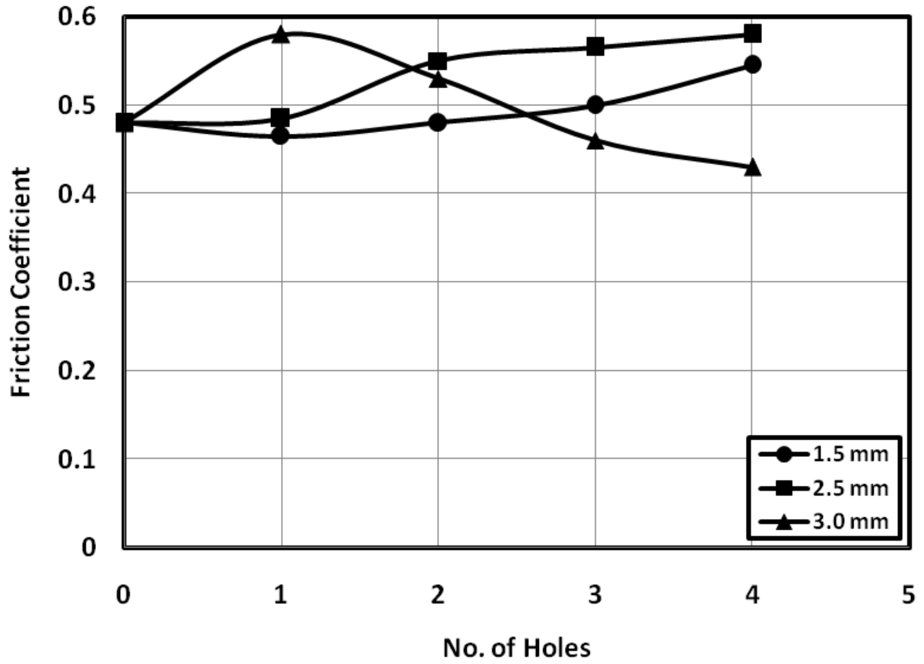

Fig. 8 Friction coefficient of rubber sliding against detergent and sand contaminated ceramic flooring.

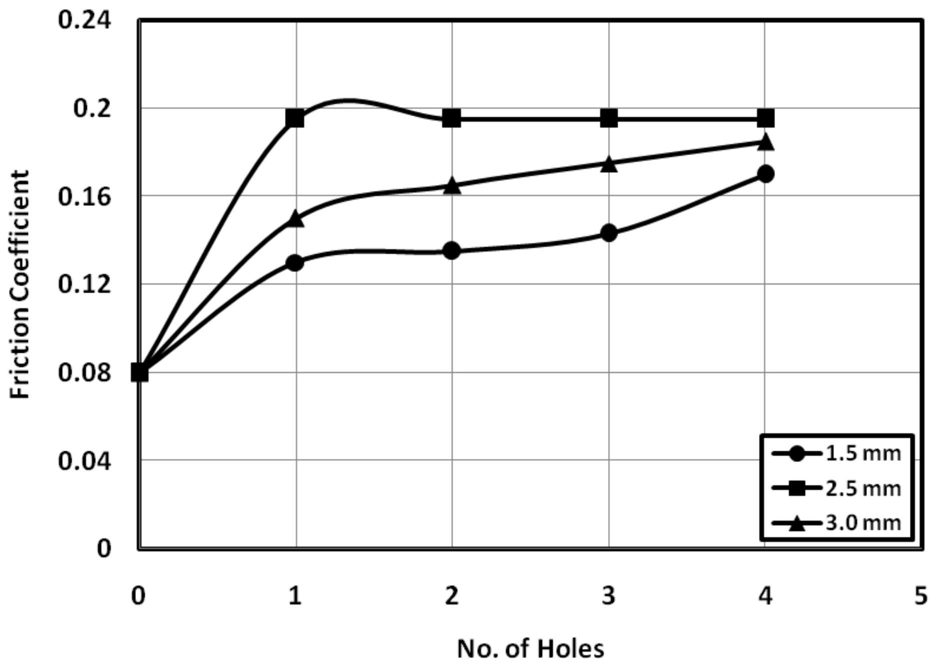

Fig. 9 Friction coefficient of rubber sliding against oil contaminated ceramic flooring.

When oil contaminated the sliding surfaces, Fig. 9, friction coefficient significantly increased at single hole protrusion. The single hole was more pronounced than the

effect of hole diameter due to the strong adhesion of oil into the rubber and ceramic surfaces. Increasing number of holes more than one showed slight change in friction coefficient. The highest friction value did not exceed 0.2 observed at 2.5 mm diameter.

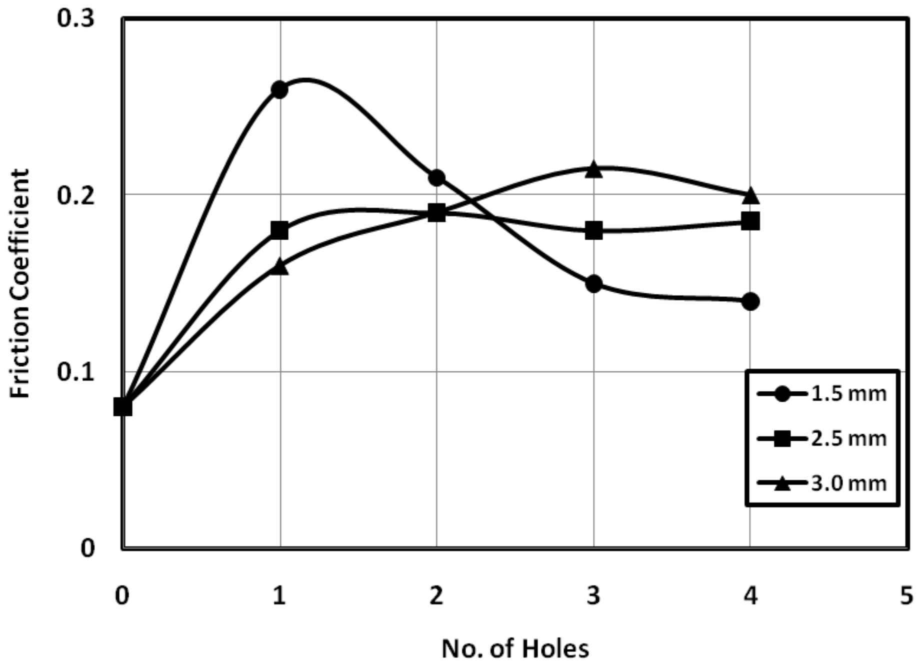

Fig. 10 Friction coefficient of rubber sliding against water/oil dilution contaminated ceramic flooring.

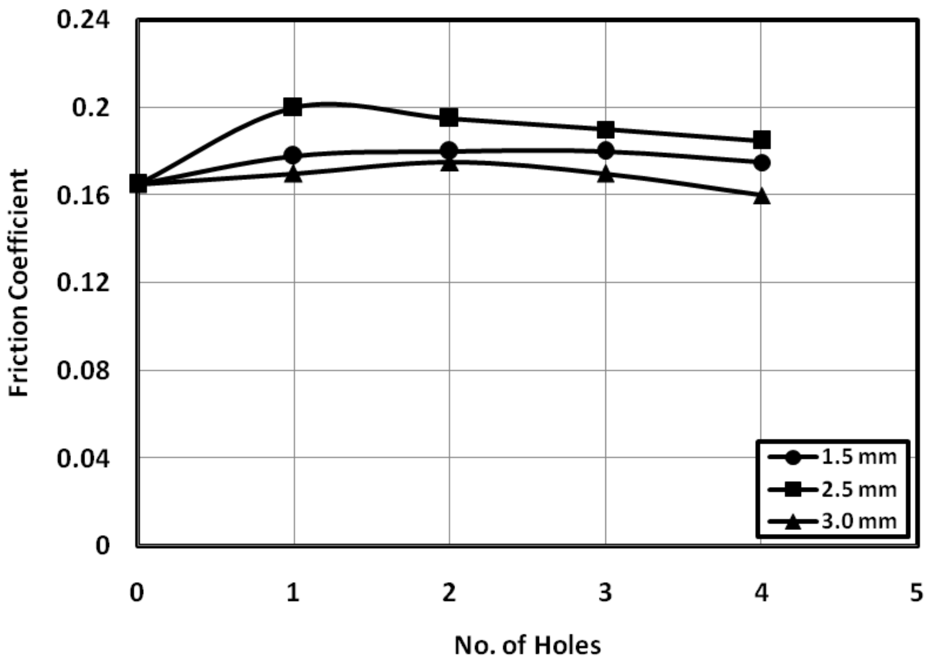

Fig. 11 Friction coefficient of rubber sliding against oil and sand contaminated ceramic flooring.

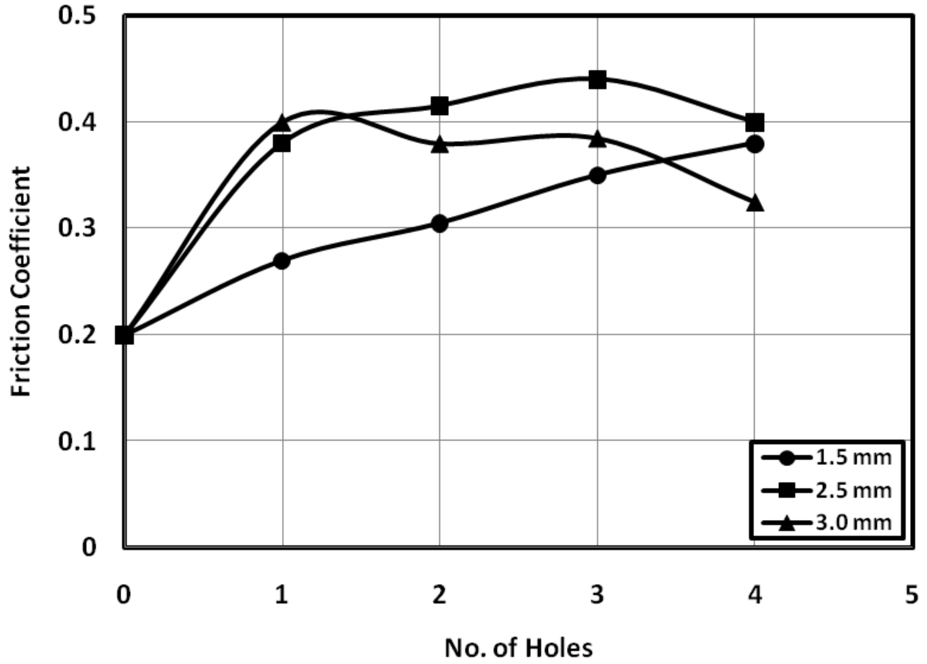

Fig. 12 Friction coefficient of rubber sliding against water/oil dilution and sand contaminated ceramic flooring.

Water/oil dilution contaminated ceramic flooring showed the highest friction coefficient (0.26) at single hole protrusion of 1.5 mm diameter, Fig. 10. Further increase in the number of holes decreased friction values. Protrusions of 2.5 mm diameter showed their highest friction at two holes, while at 3.0 mm diameter the highest friction was observed at three holes.

Presence of sand in oil contaminated ceramic flooring did not increased friction coefficient, Fig. 11, where the highest value did not exceed 0.2. Both of number of holes and hole diameter showed insignificant friction change. It seems that sand particles and oil obstructed the leakage of oil into the holes and oil prevented sand particles to embed into the rubber surface.

Friction coefficient of rubber sliding against water/oil dilution and sand contaminated ceramic flooring is shown in Fig. 12, where it represented relatively higher values. Protrusions of 2.5 mm diameter of three holes showed the highest friction followed by 3.0 mm diameter of single hole and 1.5 mm diameter of four holes.

CONCLUSIONS

1. At dry sliding, friction coefficient of rubber sliding against ceramic flooring significantly increased up to maximum then decreased with increasing number of holes. The highest friction values were observed for protrusions perforated by 1.5 mm diameter holes, while the lowest values were displayed by 3.0 mm diameter holes.
2. In the presence of water on the flooring, the highest friction values were shown for holes of 2.5 and 3.0 mm diameters. The difference in friction coefficient observed for 1.5, 2.5 and 3.0 mm holes was significant indicating that effect of hole diameter was much higher than the effect of the number of holes.
3. Friction coefficient of rubber sliding against detergent wetted ceramic flooring showed no effect for the number of hole as well as hole diameter. The effect of the hole diameter

was very low, while the number of holes showed relatively higher effect. The highest friction value did not exceed 0.13 which confirmed the severity of walking in the presence of detergent.

4. Friction coefficient showed relatively higher values when sand particles was covering the sliding surfaces. The effect of hole diameter was much higher than the number of holes.

5. When oil contaminated the sliding surfaces, friction coefficient significantly increased at single hole protrusion. The single hole was more pronounced than the effect of hole diameter.

6. Water/oil dilution contaminating ceramic flooring showed the highest friction coefficient (0.26) at single hole protrusion of 1.5 mm diameter. Further increase in the number of holes decreased friction values.

7. Presence of sand in oil contaminated ceramic flooring did not increased friction coefficient, where the highest value did not exceed 0.2.

8. Friction coefficient of rubber sliding against water/oil dilution and sand contaminated ceramic flooring represented relatively higher values.

REFERENCES

1. Mohamed M. K., Mahmoud M. M. and Ali W. Y., “Frictional Behaviour of the Cylindrical Protrusions and Holes in Rubber Surfaces Sliding on Ceramics”, Bulletin of the Faculty of Engineering, Minia University, Vol. 20, No. 1., July 2008, (2008), KGK, December 2012, pp. 37 – 40, (2012).

2. Samy A. M., Khashaba M. I. and Ali W. Y., "Friction Coefficient of Grooved Rubber Disc Sliding Against Ceramics: I. Effect of Motion Direction", Journal of the Egyptian Society of Tribology, Vol. 11, No. 2, April 2014, pp. 1 – 20, (2014).

3. Samy A. M., Khashaba M. I. and Ali W. Y., "Friction Coefficient of Grooved Rubber Disc Sliding Against Ceramics: II. Effect of Load", Journal of the Egyptian Society of Tribology, Vol. 11, No. 2, April 2014, pp. 21 – 38, (2014).

4. Samy A. M., Khashaba M. I. and Ali W. Y., "Friction coefficient of grooved rubber disc sliding against ceramics: iii. effect of the grooves", Journal of the Egyptian Society of Tribology, Vol. 11, No. 3, July 2014, pp. 1 – 19, (2014).

5. Hasouna A. T., "Influence of Tread Groove Width of Rubber on Friction Coefficient", Journal of the Egyptian Society of Tribology, Vol. 11, No. 4, October 2014, pp. 46 - 57, (2014).

6. El-Sherbiny Y. M., Ramadan M. A. and Ali W. Y., “Frictional Behaviour of Rubber Flooring Mat Fitted by Rectangular Treads”, EGTRIB, Vol. 11, No. 2, pp. 39 – 52,(2014).

7. Maeda K., Bismarck A., Briscoe B., "Effect of bulk deformation on rubber adhesion", Wear 263, pp. 1016 - 1022, (2007).

8. Samy A. M., Mahmoud M. M., Khashaba M. I. and Ali W. Y., “Friction of Rubber Sliding Against Ceramics, I. Dry And Water Lubricated Conditions”, KGK 60. Jahrgang, Nr 607, Juni 2007, pp. 322 - 327, (2007).

9. Samy A. M., Mahmoud M. M., Khashaba M. I. and Ali W. Y., “Friction of Rubber Sliding Against Ceramics, II. Oil And Oil Diluted By Water Lubricated Conditions”, KGK 60. Jahrgang, Nr 607, December 2007, pp. 693 - 696, (2007).

10. Samy A. M., Mahmoud M. M., Khashaba M. I. and Ali W. Y., “Friction of Rubber Sliding Against Ceramics, III. Sand Contaminating The Lubricating Fluids”, KGK 60. Jahrgang, Nr 607, January/February 2008, pp. 43 - 48, (2008).

11. Ezzat F. H., Hasouna A. T., Ali W. Y., "Friction Coefficient of Rubber Sliding Against Polymeric Indoor Flooring Materials of Different Surface Roughness", Journal of the Egyptian Society of Tribology, Vol. 4, No. 4, JANUARY 2007, pp. 37 - 45, (2007).
12. Mohamed M. K., Samy A. M., Ali W. Y., "Friction Coefficient of Rubber Shoes Sliding Against Ceramic Flooring", September 27 - 29, 2010, Tribologie Fachtagung, Göttengen, Germany, (2010).
13. Li K. W., Chen C. J., "The effect of shoe soling tread groove width on the coefficient of friction with different sole materials, floors, and contaminants", Applied Ergonomics 35, pp. 499 - 507, (2004).
14. El-Sherbiny Y. M., Samy A. M. and Ali W. Y., "Friction Coefficient of Rubber Sliding Against Dusty Indoor Flooring", Journal of the Egyptian Society of Tribology, Vol. 7, No. 2, April 2010, pp. 11 - 25, (2010).
15. Li K. W., Wu H. H., Lin Y. C., "The effect of shoe sole tread groove depth on the friction coefficient with different tread groove widths, floors and contaminants", Appl. Ergon. 37, pp. 743 - 748, (2006).
16. Mohamed M. K., Samy A. M., Ali W. Y., "Friction Coefficient of Rubber Shoes Sliding Against Ceramic Flooring", September 27 – 29, 2010, Tribologie Fachtagung, Göttengen, Germany, (2010).
17. El-Sherbiny Y. M., Mohamed M. K., Ali W. Y., "Friction Coefficient Displayed by Footwear Walking Against Rubber Floorings Fitted by Cylindrical Treads", Journal of the Egyptian Society of Tribology, Vol. 8, No. 1, pp. 1 – 12, (2011).