International Journal of Engineering

Journal Homepage: www.ije.ir

Study on the Friction of Bored Cylindrical Rubber Protrusions Sliding on Ceramic

Mahmoud M. M.*

Production Engineering and Mechanical Design Department, Faculty of Engineering, Minia University, El-Minia, Egypt

PAPER INFO

Paper history:
Received 10 August 2016
Received in revised form 12 February 2017
Accepted 10 March 2017

Keywords:
Friction Coefficient
Rubber Cylindrical Protrusions
Holes
Ceramic Flooring

ABSTRACT

The present work aims at reducing the friction of rubber soles sliding on ceramic floorings. Fitting bored cylindrical protrusions with different diameters on rubber soles 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 the 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 covered the sliding surfaces, the effect of hole diameter was much less than the number of holes. When oil contaminated the sliding surfaces, friction coefficient significantly increased at single hole protrusion. The effect of 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 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 increase the 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.

doi: *10.5829/idosi.ije.2017.30.05b.17*

1. 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 while 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 can store sand particles and consequently friction coefficient displays relative increase. Water contaminated by sand particles shows significant friction increase for cylindrical protrusions. The friction difference increases as the contact area decreases.

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

*Corresponding Author's Email: msharaief@gmail.com (Mahmoud M. M.)

increase. In the 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 the coefficient of friction due to the sliding versus oil lubricated ceramics. For surfaces lubricated by oil/water dilution friction coefficient showed remarkable increase.

Effect of tread width and direction of motion on the friction values shown by the sliding of rubber against ceramic floors was studied [5]. Based on the experimental results, it was remarked 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 influence of rectangular and cross treads fixed in the rubber mats on friction coefficient when sliding against footwear was investigated [6]. It was found that friction coefficient slightly decreased with increasing tread groove at dry, detergent wetted and oily sliding due to the decreased contact area along with 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 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 illustrated by cross tread rubber sliding against dry, detergent wetted and oily sliding showed drastic decrease with increasing tread groove. In general, rubber friction has been classified into two main parts which are the bulk hysteresis and the contact adhesive [7]. These two parts are separate, but this is only a simple hypothesis.

Measurement of friction is one of the main methods to determine floor slipperiness. Studies have been concentrated on wet contact conditions. It was predicted that liquid contaminated interfaces will display a clear lower coefficient of friction compared to dry conditions [8]. The coefficient of friction changes between the dry and liquid contaminated conditions according to the material of the footwear and floor together. Friction under wet conditions was usual. The squeeze film theory clarifies the effects of existence of the liquid at the contact surfaces on the friction. Static friction coefficient was measured between rubber samples and ceramic at different contact conditions [9-12]. It was noticed that, rubber samples showed the highest coefficient of friction at dry contact. For water wetted ceramics, the value of the friction reduced in comparison with the dry conditions. In case of oil wetted ceramics, friction values reduced with increase of the depth of the grooves bored in the rubber samples. In case of ceramic wetted by detergent mixed with sand, friction values grown obviously in contrast to ceramics wetted by soap and water.

Influence of the width and depth of the shoe sole treads sliding against ceramic floors was investigated [13]. It was clear that, the coefficient of friction is marginally grown with increase of the height of the tread. Perpendicular (according to the sliding direction) treads illustrated higher friction value compared to values obtained by parallel treads due to their increased deformation. Water existence on the contact surface decreased the friction in contrast to the dry sliding. In case of detergent lubricated ceramics, coefficient of friction extremely reduced to values lower than that showed by water wetted surfaces. Highest coefficient of friction was recorded by parallel treads comparing to the perpendicular treads due to the formation of the hydrodynamic wedge. The lowest friction coefficients was obtained by the oil wetted surfaces because of the presence of a squeezed oil film that attempts to separate rubber from the ceramic surface. Friction value is slightly increased in case of emulsion of water and oil compared to oil lubricated sliding. Friction increased as the height of the tread height increased because the lubricant escapes easily from the sliding surfaces. Tread groove patterns helped to assist contact between the shoe sole and floor on liquid wetted surface [14, 15]. The tread effectiveness was controlled by many factors such as footwear material, floor material and the kind of the contaminant. On the other hand, tread groove pattern could not maintain friction on a floor wetted by vegetable oil. Wider tread grooves are good to improve the capability of the drainage on wetted surfaces.

The effect of rectangular and cylindrical rubber treads was discussed [16]. It was remarked that both the tread height and coefficient of friction have a kind of direct proportional relationship with dry sliding. Perpendicular and parallel treads showed opposite manner because of the large occurred deformation by the perpendicular treads. Detergent wetted surfaces displayed extremely lower friction values in contrast to water wetted contact surfaces.

2. EXPERIMENTAL

A test rig was designed and manufactured to measure the coefficient of friction displayed due to sliding the tested rubber samples against ceramic flooring materials (tiles) through measuring both forces, friction and applied normal. The tested rubber materials were positioned in a base supported by two load cells, the first one to measure the friction force and the second one can measure the applied force. Friction coefficient is calculated by dividing the measured friction force on the applied measured force based on three repeated tests. The arrangement of the test rig is shown in Figure 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, as shown in Figure 2. Before and after any test, the tested flooring materials and rubber samples were cleaned using absorbent papers.

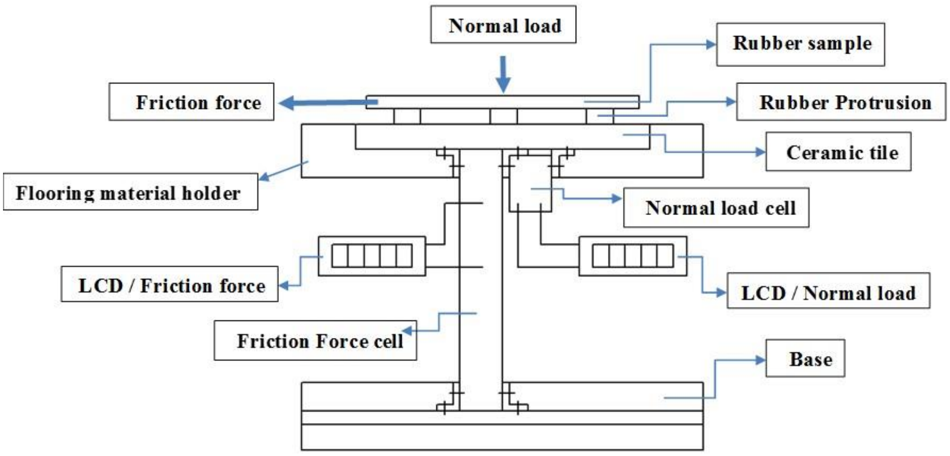
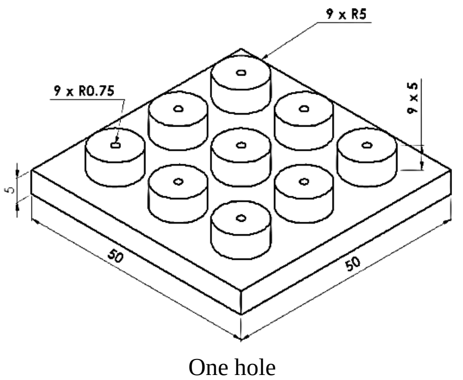
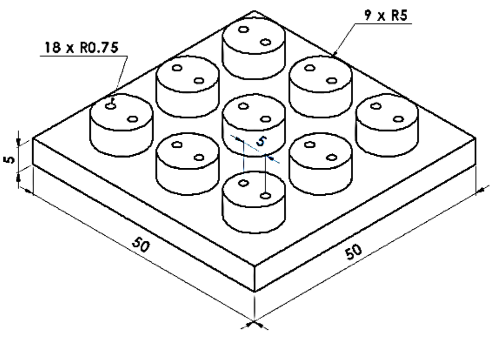


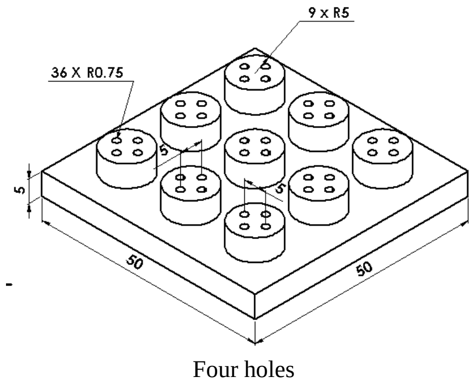
Figure 1. Test rig configuration



One hole



Two holes



Four holes

Figure 2. The rubber test specimen (50 x 50 x 5 mm^3) with various holes (ϕ 1.5, 2.5 & 3 mm) in different allocations

3. RESULTS AND DISCUSSION

At dry sliding, friction coefficient of rubber sliding against ceramic flooring is shown in Figure 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.

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, Figure 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 on the number of hole as well as hole diameter, Figure 5. This behavior can be explained as result of the electric properties of the detergent molecules which increase their adherence to 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 a reasonable 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 Figure 6, where friction coefficient showed higher values.

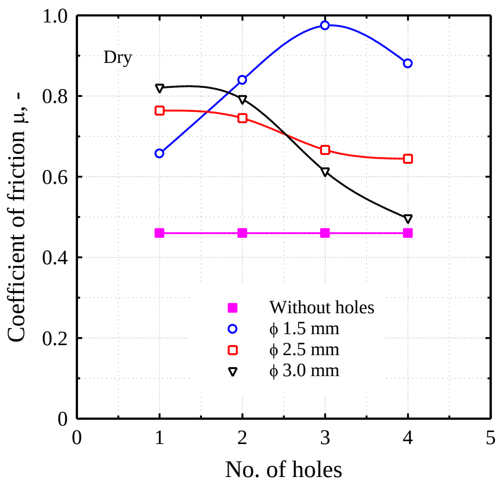


Figure 3. Friction coefficient of rubber sliding against dry ceramic flooring

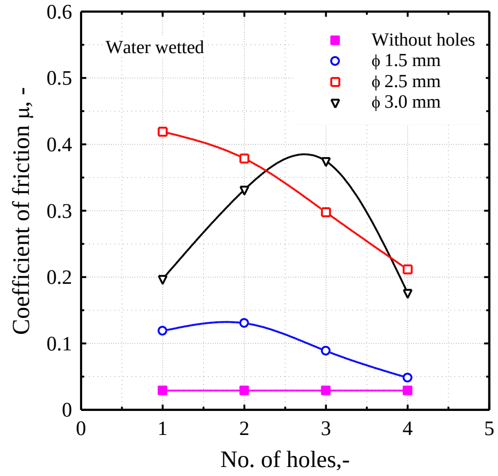


Figure 4. Friction coefficient of rubber sliding against water wetted ceramic flooring

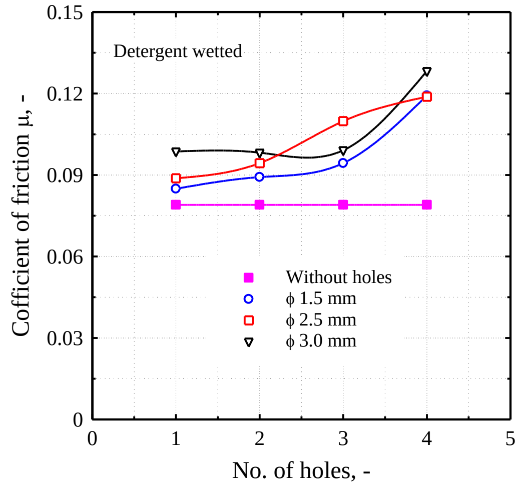


Figure 5. Friction coefficient of rubber sliding against detergent wetted ceramic flooring

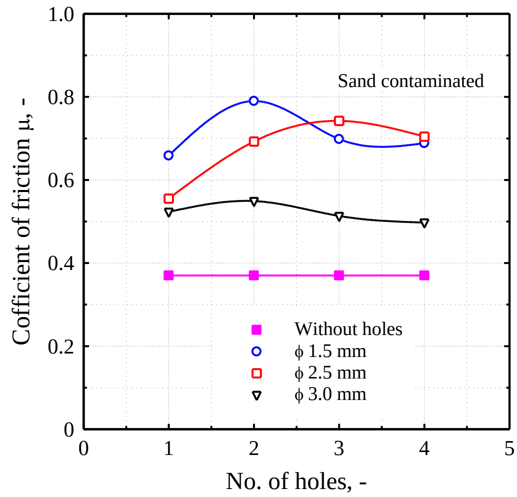


Figure 6. Friction coefficient of rubber sliding against sand contaminated ceramic flooring

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.

Friction coefficient of rubber sliding against water and sand contaminated ceramic flooring showed no much change in comparison with zero hole sample, Figure 7. This behavior 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, Figure 8.

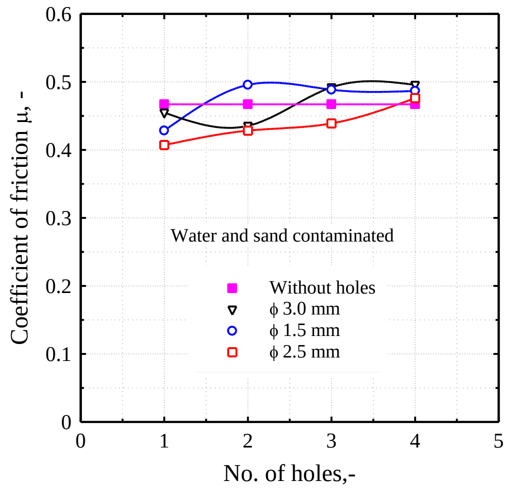


Figure 7. Friction coefficient of rubber sliding against water and sand contaminated ceramic flooring

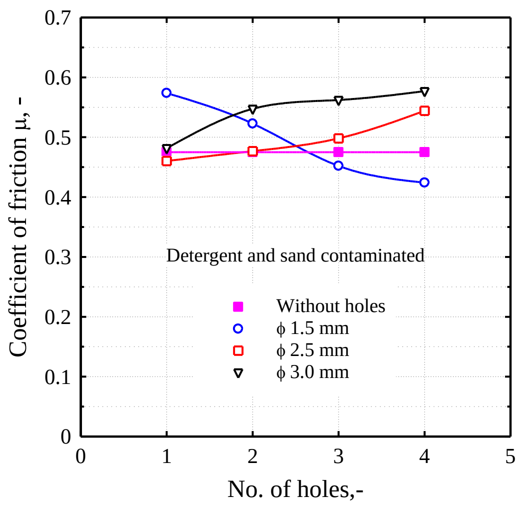


Figure 8. Friction coefficient of rubber sliding against detergent and sand contaminated ceramic flooring

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. When oil contaminated the sliding surfaces, Figure 9, friction coefficient significantly increased at single hole protrusion. The effect of 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 the number of holes to more than one showed slight change in friction coefficient. The highest friction value did not exceed 0.2 observed at 2.5 mm diameter. Water/oil dilution contaminated ceramic flooring showed the highest friction coefficient (0.26) at single hole protrusion of 1.5 mm diameter, Figure 10. Further increase in the number of holes decreased friction values.

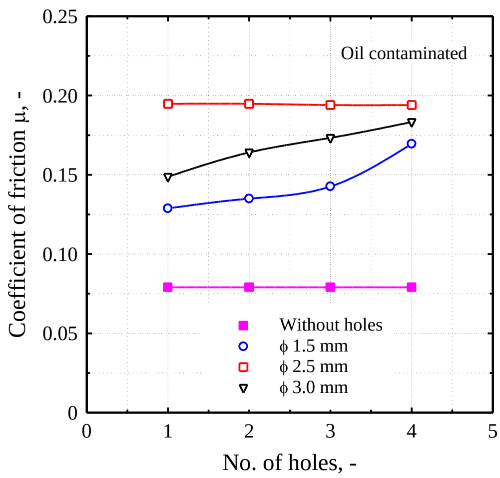


Figure 9. Friction coefficient of rubber sliding against oil contaminated ceramic flooring

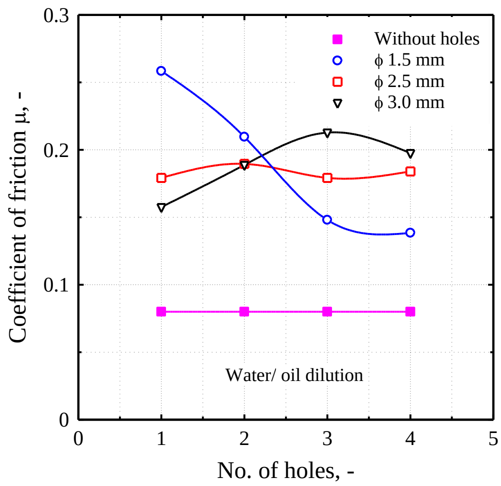


Figure 10. Friction coefficient of rubber sliding against water/oil dilution contaminated ceramic flooring

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 increase the friction coefficient, Figure 11, where the highest value did not exceed 0.2. Both the 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 Figure 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.

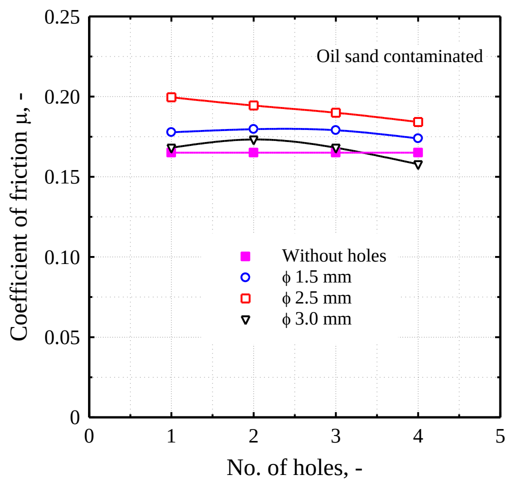


Figure 11. Friction coefficient of rubber sliding against oil and sand contaminated ceramic flooring

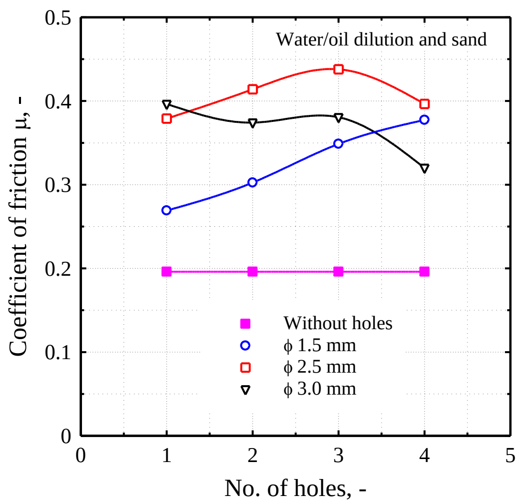


Figure 12. Friction coefficient of rubber sliding against water/oil dilution and sand contaminated ceramic flooring

4. CONCLUSIONS

All the three factors, number of holes, hole diameter and contamination condition affected friction coefficient between the rubber protrusions and ceramic floor. Both number of holes and contamination conditions control the friction values more than change of the hole diameter. Wider holes displayed higher values of friction in case of presence of water, detergent and oil in contrast to the other contamination conditions. The followings conclusions were drawn up:

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 in comparison with zero hole sample. 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 were 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 contaminated 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 increase the 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.

5. REFERENCES

1. Mohamed El-Minia, M., Mahmoud, M. and Ali, W., "Frictional behaviour of the cylind-rical protrusions and holes in rub-ber surfaces sliding on ceramics", ***KGK. Kautschuk, Gummi, Kunststoffe***, Vol. 65, No. 11-12, (2012), 37-40.

2. M., S.A., I., K.M. and Y., A.W., "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, (2014), 1 - 20.
3. M., S.A., I., K.M. and Y., A.W., "Friction coefficient of grooved rubber disc sliding against ceramics: Ii. Effect of load", ***Journal of the Egyptian Society of Tribology***, Vol. 11, No. 2, (2014), 21 - 38.
4. M., S.A., I., K.M. and Y., A.W., "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, (2014), 1 - 19.
5. T., H.A., "Influence of tread groove width of rubber on friction coefficient", ***Journal of the Egyptian Society of Tribology***, Vol. 11, No. 4, (2014), 46 - 57.
6. M., E.-S.Y., A., R.M. and Ali W. Y., "Frictional behaviour of rubber flooring mat fitted by rectangular treads", ***EGTRIB***, Vol. 11, No. 2, (2014), 39 - 52.
7. Maeda, K., Bismarck, A. and Briscoe, B., "Effect of bulk deformation on rubber adhesion", ***Wear***, Vol. 263, No. 7, (2007), 1016-1022.
8. Samy, A., Mahmoud, M., Khashaba, M. and Ali, W., "Friction of rubber sliding against ceramics part i dry and water lubricated conditions", ***KGK. Kautschuk, Gummi, Kunststoffe***, Vol. 60, No. 6, (2007), 322-327.
9. M., S.A., M., M.M., I., K.M. and Y., A.W., "Friction of rubber sliding against ceramics, ii. Oil and oil diluted by water lubricated conditions", ***KGK 60***, Vol. 693 - 696, (2007).
10. Samy, A., Mahmoud, M., Khashaba, M. and Ali, W., "Friction of rubber sliding against ceramics, iii. Sand contaminating the lubricating fluids", ***KGK Kautschuk Gummi Kunststoffe***, Vol. 61, (2006), 43-48.
11. Ezzat, F., Ali, W. and Hasouna, A., "Friction coefficient of rubber sliding against polymeric indoor flooring materials of different surface roughness", ***KGK. Kautschuk, Gummi, Kunststoffe***, Vol. 61, No. 12, (2008), 638-641.
12. Mohamed, M., Samy, A. and Ali, W., "Friction coefficient of rubber shoes sliding against ceramic flooring", ***KGK. Kautschuk, Gummi, Kunststoffe***, Vol. 65, No. 1-2, (2012), 52-57.
13. Li, K.W. and 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***, Vol. 35, No. 6, (2004), 499-507.
14. EI-SHERBINY, Y., Samy, A. and AII, W., "Friction coefficient of rubber sliding against dusty indoor flooring", ***KGK. Kautschuk, Gummi, Kunststoffe***, Vol. 65, No. 3, (2012), 37-42.
15. Li, K.W., Wu, H.H. and Lin, Y.-C., "The effect of shoe sole tread groove depth on the friction coefficient with different tread groove widths, floors and contaminants", ***Applied ergonomics***, Vol. 37, No. 6, (2006), 743-748.
16. El-Sherbiny, Y., Mohamed, M. and Ali, W., "Friction coefficient displayed by footwear walking against rubber floorings fitted by cylindrical treads", ***Journal of the Egyptian Society of Tribology***, Vol. 8, No. 1, (2011), 1-12.

Study on the Friction of Bored Cylindrical Rubber Protrusions Sliding on Ceramic

Mahmoud M. M.

Production Engineering and Mechanical Design Department, Faculty of Engineering, Minia University, El-Minia, Egypt

PAPER INFO

Paper history:
Received 10 August 2016
Received in revised form 12 February 2017
Accepted 10 March 2017

Keywords:
Friction Coefficient
Rubber Cylindrical Protrusions
Holes
Ceramic Flooring

چکیده

این کار با هدف کاهش اصطکاک تخت کفشهای لاستیکی سرخورنده روی زمین سرامیکی انجام شده است. استفاده از برآمدگی استوانه ای با قطر های مختلف در کف لاستیکی پیشنهاد شد. آزمایش به منظور بررسی عملکرد برآمدگی پیشنهاد شده در افزایش ضریب اصطکاک در کف خشک و آلوده انجام شد. مشخص شد که، در خشک کشویی، ضریب اصطکاک به طور قابل توجهی تا یک مقدار بیشینه افزایش یافته و پس از آن با افزایش تعداد حفره کاهش یافت. بالاترین ضریب اصطکاک برای سوراخهایی به قطر ۱/۵ میلی متر مشاهده شد، در حالی که کمترین مقدار در ۳ میلی متر قطر سوراخ حاصل شد. در حضور آب در کف پوش، نشان داده شد که با افزایش قطر سوراخ ، حجم آب به بیرون درز کرد افزایش یافت. لایه مواد شوینده تشکیل شده بر روی سطح تماس باعث کاهش شدید اصطکاک شد. بالاترین ضریب اصطکاک از ۰/۱۳ تجاوز نکرد که تایید کننده شدت راه رفتن در حضور مواد شوینده است. هنگامی که ذرات شن و ماسه سطوح لغزنده را پوشاند، اثر قطر سوراخ بسیار کمتر از تعداد حفره بود. هنگامی که سطوح لغزنده آلوده به روغن شد، ضریب اصطکاک به طور قابل توجهی در برآمدگی سوراخ افزایش یافت. اثر حفره تنها به علت چسبندگی قوی روغن به لاستیک و سطوح سرامیکی بیشتر از اثر قطر سوراخ بود. کف سرامیک آلوده به آب/روغن بالاترین ضریب اصطکاک (۰/۲۶) را در سوراخ با قطر ۱/۵ میلی متر نشان داد. افزایش بیشتر در تعداد سوراخ ضریب اصطکاک را کاهش داد. حضور شن و ماسه در کف سرامیک آلوده به روغن ضریب اصطکاک را افزایش نداد جایی که بالاترین ضریب ۰/۲ بود. لغزش در کف سرامیک آلوده آب/ روغن و شن و ماسه تقریبا بالاترین ضریب اصطکاک را نشان داد. برآمدگی ایجاد شده توسط سه سوراخ با قطر ۲/۵ میلی متر بالاترین اصطکاک را نشان داد و به دنبال آن سوراخ با قطر ۳ میلی متر و چهار سوراخ با قطر ۱/۵ میلی متر بودند.

doi*: 10.5829/idosi.ije.2017.30.05b.17*