Friction of Perforated Cylindrical Rubber Protrusions Sliding on Ceramic

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***Abstract*—The present work aims to discuss the effect of holes on the friction of rubber cylindrical protrusions fitted in the rubber surfaces sliding against ceramic. An apparatus was constructed and fabricated to measure the coefficient of friction during sliding of the rubber samples at ten different flooring contact conditions. Nine cylindrical protrusions (ϕ10 mm, 5 mm) were perforated by one, two, three and four holes of 1.5, 2.5 and 3.0 mm diameter then were adhered to a squared rubber sheet (50x50x5 mm^3).**

At dry sliding, friction coefficient notably increased up to maximum then dropped with increasing number of holes. The highest and lowest friction values were observed for hole diameters of ϕ1.5 mm and ϕ 3.0 mm respectively. 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. 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 showed higher values of friction in case of presence of water, detergent and oil in contrast the other contamination conditions.

Keywords—Friction coefficient, rubber cylindrical protrusions, holes, ceramic flooring.

I. 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 splitted into two types; the bulk hysteresis and the contact adhesive term, [7]. These two types are considered to be independent of each other, but this is only a simple assumption.

Friction measurement is one of the important methods to determine floor slipperiness. Studies on friction assessment have been concentrated on fluid contaminated conditions. It was predicted that wet surfaces had lower values of friction coefficient than those values obtained by dry surfaces, [8]. This difference between the friction values at dry and wetted surfaces relied on the material of footwear and floor itself. Friction at lubricated contaminated conditions is very widespread. The squeeze film theory describes the influences of the liquid on the friction coefficient. Tests were carried out at several wet conditions to determine the static friction coefficient between rubber specimens and ceramic, [9 - 12]. It was noticed that, dry slipping of the rubber test specimens showed the highest Coefficients of friction. For water lubricated surfaces, the friction coefficient reduced in comparison with that vales at dry sliding. For oily ceramic, friction coefficient reduced with enlarging the groove's height that inserted in the rubber samples. As for detergent lubricated ceramic with sand contaminated, coefficient of friction increased critically compared to the sliding on water and soap lubricated ceramics.

Effect of the size treads of shoe sole on the friction between the sole and floor interface, was studied, [13]. It was remarked that, at dry sliding, friction coefficient slightly raised with enlarging the tread height. The one relative to the motion direction (Perpendicular) treads illustrated the highest friction value due to their raised deformation, while parallel treads displayed the lowest friction coefficients. In existence of water on the contact surface, noticeable decrease in friction coefficient was displayed against to the dry running. For detergent wetted ceramics, friction coefficient extremely dropped to values lower than that obtained by water. Parallel treads exhibited the highest friction value, while perpendicular treads exhibited the lowest friction values due to formation of the hydrodynamic wedge. Oily smooth surfaces caused the lowest friction values because of presence of squeeze oil film isolated rubber and ceramic. Emulsion of water and oil displayed minor friction rise compared with oily sliding. As the tread height increased, friction increased due to the easy escape of the lubricant from the contact area. Designs of tread groove are useful in the ease of contact between the shoe sole and floor on wetly contaminated surface, [14, 15]. The effective tread groove design relies on the footwear material, floor, and contaminant. The ineffective tread groove design was in keeping up friction on a vegetable oily floor. Tread grooves have to be wide adequate to obtain improved drainage capability liquid lubricated contaminated ceramic surfaces.

The effect of rubber flooring provided by rectangular and cylindrical treads on the friction coefficient was investigated, [16]. It was resulted that, at dry sliding, friction coefficient lightly increased with increasing treads height. Normal treads showed the highest friction value owing to their high deformation, while parallel treads displayed the lowest friction coefficients. In existence of water on the sliding surface important drop in friction values was noticed. For detergent wetted surfaces, friction coefficient dramatically dropped to friction coefficients lower than that obtained by water.

The objective of this study was to determine the effect of holes (numbers and diameters) on the measured coefficient of friction of rubber cylindrical protrusions fitted in the rubber sheet sliding against ceramic under ten different contamination conditions.

II. EXPERIMENTAL

An apparatus had been constructed to measure the static friction coefficient of the tested rubber soles made of recycled rubber and sliding against ceramic tiles. The friction and normal forces had been measured. The tested soles were pressed and slid against the surface of the ceramic tile placed in a base supported by two load cells. One cell measures the tangential force (friction force) and the second can measure the applied normal load. Coefficient of friction was calculated by the dividing the value of friction force by the normal load. Friction coefficient is determined by the ratio between the friction force and the applied load. The configuration of the apparatus is shown in Fig. 1. The tested ceramic flooring materials were in form of a quadratic tiles of 400 × 400 mm^2 and 5 mm thickness. The surface roughness was 6.3 µm Ra. 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 Fig. 2. After every test, all impurities were cleaned from both contact surfaces by alcoholic wetted textile and then washed using water.

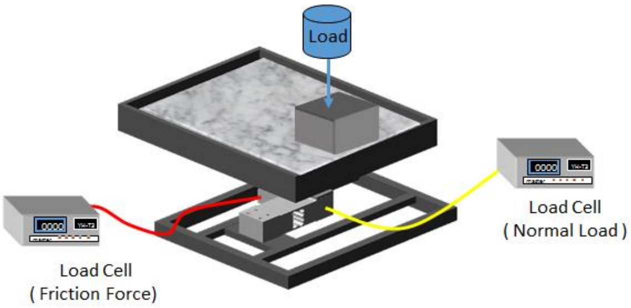
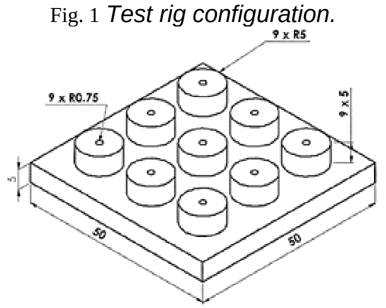
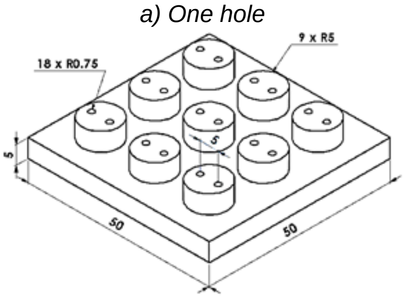


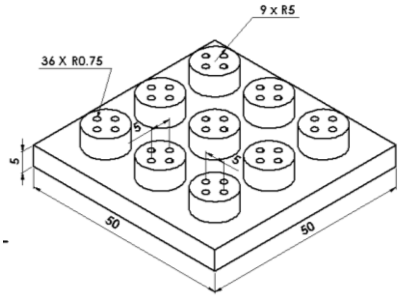
Fig. 1 *Test rig configuration.*



a) One hole



b) Two holes



c) Four holes

Fig. 2 (a, b and c) *The rubber test specimen (50 x 50 x 5 mm^3) with various holes (ϕ 1.5, 2.5 & 3 mm) in different allocations.*

III. 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.

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 behavior 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.

Friction coefficient of rubber sliding against water and sand contaminated ceramic flooring showed insignificant change, Fig. 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, 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.

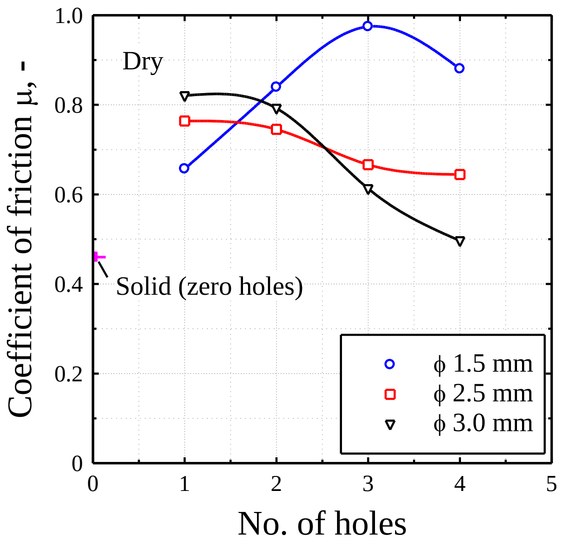


Fig. 3 *Friction coefficient of rubber sliding against dry ceramic flooring.*

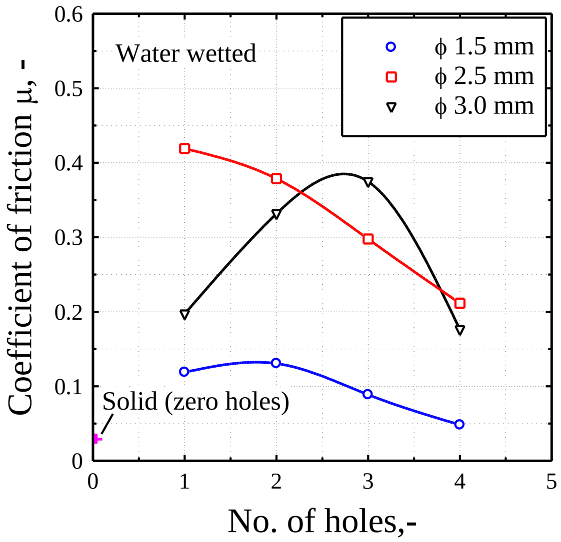


Fig. 4 *Friction coefficient of rubber sliding against water wetted ceramic flooring.*

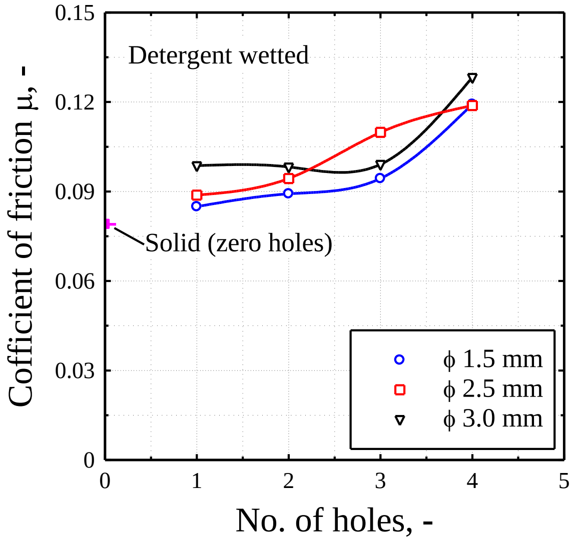


Fig. 5 *Friction coefficient of rubber sliding against detergent wetted ceramic flooring.*

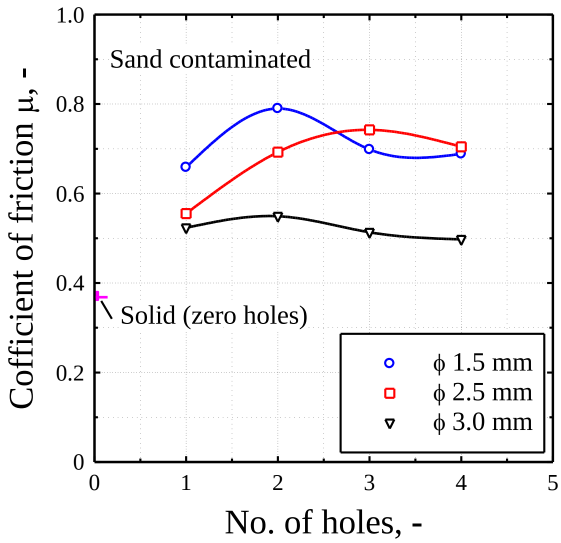


Fig. 6 *Friction coefficient of rubber sliding against sand contaminated ceramic flooring.*

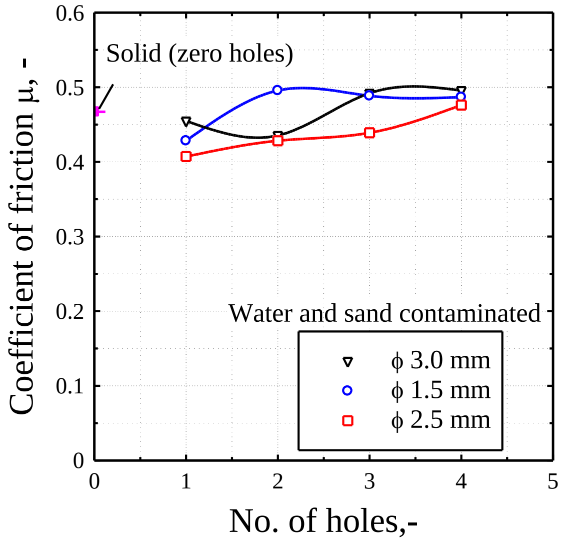


Fig. 7 *Friction coefficient of rubber sliding against water and sand contaminated ceramic flooring.*

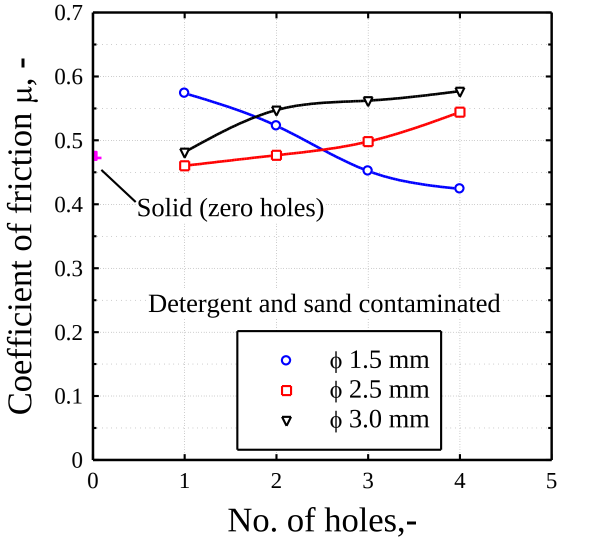


Fig. 8 *Friction coefficient of rubber sliding against detergent and sand contaminated ceramic flooring.*

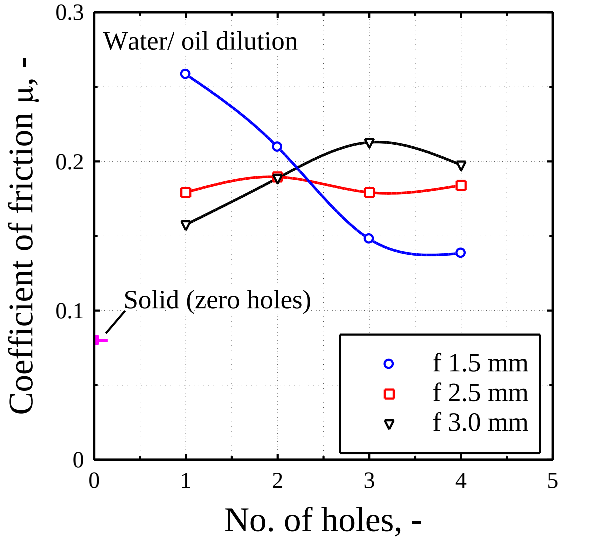


Fig. 10 *Friction coefficient of rubber sliding against water/oil dilution contaminated ceramic flooring.*

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. 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.

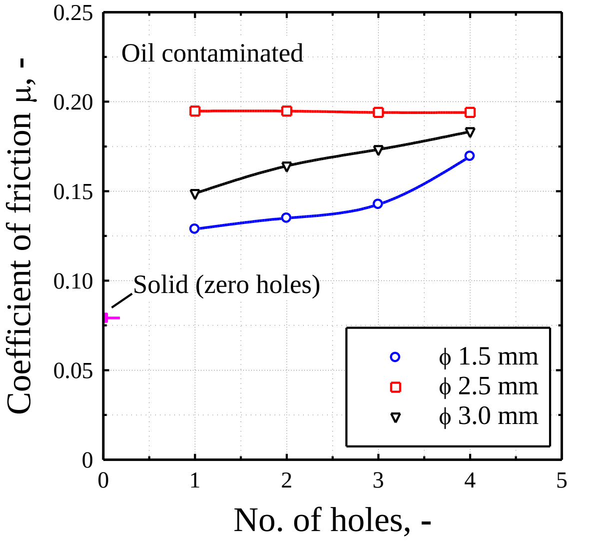


Fig. 9 *Friction coefficient of rubber sliding against oil contaminated ceramic flooring.*

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.

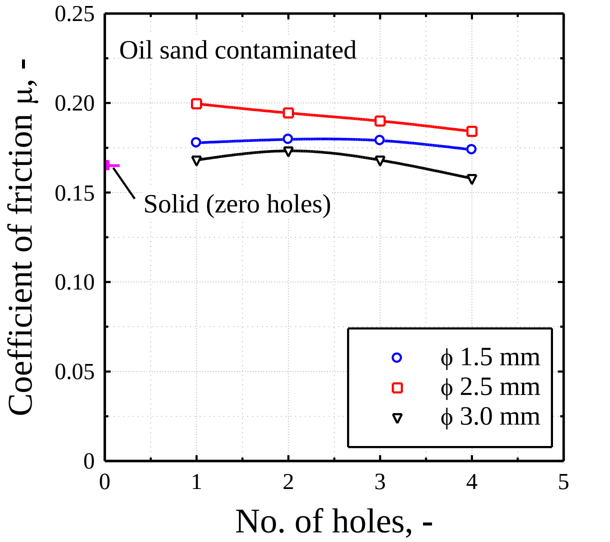


Fig. 11 *Friction coefficient of rubber sliding against oil and sand contaminated ceramic flooring.*

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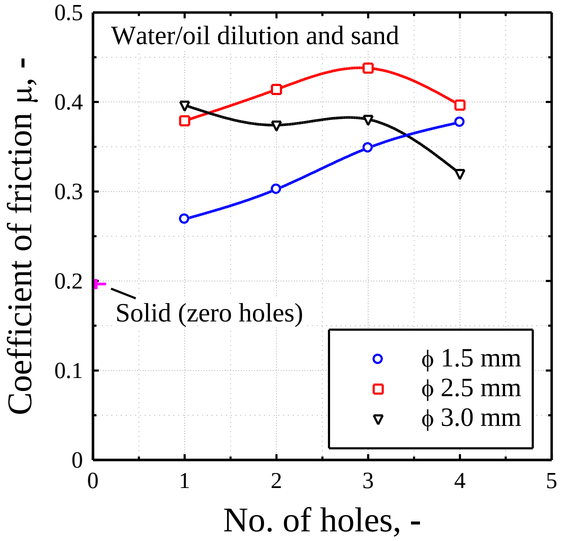

Fig. 12 *Friction coefficient of rubber sliding against water/oil dilution and sand contaminated ceramic flooring.*

IV. 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 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. 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.

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