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FRICTION COEFFICINET OF RUBBER FLOORING FITTED WITH HOLES AND LEAKAGE GROOVES

Samy A. M.[1], El-Sherbiny Y. M.[2] and Khashaba M. I.[1]

[1]Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT.
[2]Dept. of Civil and Architectural Engineering, National Research Center, Dokki, Giza, EGYPT.

ABSTRACT
The present study investigates the effect of holes and leakage grooves introduced in cylindrical protrusion of the rubber flooring on the static friction coefficient displayed by rubber footwear under dry, water, water + 5.0 vol. % soap, oil and water + 5.0 vol. % oil lubricated sliding conditions. Rubber test specimens were prepared in the form of cylindrical protrusion of 28 mm diameter and 10 mm thickness. Holes with different diameter and numbers (0, 1, 2, 3 and 4) were introduced in rubber protrusions. The holes were punched to produce holes of 1.5, 3, 4 and 4.5 mm diameter. Then the rubber protrusions were adhered to flat rubber of 6 mm thickness fitted with leakage grooves then the arrangement were adhered to the wood blocks.

At dry sliding, friction coefficient increased with increasing number of holes and grooves. Besides, friction coefficient decreased with increasing applied load. At water lubricated sliding, increasing diameter of holes was insignificant on friction coefficient. As the number of holes and grooves increased friction coefficient increased. This behaviour related to the easy escape of water through the holes and grooves out of the contact area. Maximum friction value (0.65) was observed for four holes of 1.5 mm diameter. At water and detergent lubricated sliding, friction coefficient drastically decreased with increasing normal load. At oil lubricated sliding, friction coefficient increased with increasing number of holes and grooves. The maximum friction values were noticed at four holes of 3 mm diameter. At emulsion of water and oil lubricated sliding, smooth rubber surface displayed higher values of friction coefficient compared to surfaces lubricated by oil only. As the applied normal load increased friction coefficient decreased.

KEYWORDS
Rubber, cylindrical protrusions, holes, grooves, rubber footwear, friction coefficient, dry, water, detergent and oil.

INTRODUCTION
In daily use of bathrooms there exist a number of lubricated conditions. Using fatty soaps, shampoo, body lotions, and detergents while washing and bathing is a common practice. Oily shampoo and lotions contaminate the bath water and may cause serious slippery conditions. People get used to cover the bathtub bottom and bathroom flooring with perforated rubber

mats. Quite often, these are designed with leaking grooves to allow contaminated water to escape from the sliding surface to the drain.
Several theories are widely established for the explanation of rubber friction. For the case of dry friction without wear, the friction is typically attributed to both adhesion forces that are related to the intermolecular process taking place on the interface surface and hysteresis, being the viscoelastic energy lost in a certain volume of deformed rubber. An entirely elastic FEA model of the mechanics of rubber friction has been considered which confirms the experimental observations and which suggests that an additional geometrical factor also exists. This contribution is dependent on the depth of penetration of the rigid surface into the elastomer, changing the angle of contact between both surfaces [1]. In contrast, tests using a different geometry (flat on flat) did not show this effect. The entirely geometric contribution considerably increases the actual coefficient of friction in comparison to the input value and is anticipated to make a significant contribution to many every-day frictional sliding applications. In real applications, such as at the tyre–road interface, it is not just a single asperity but a wide range of neighbouring asperities, whose geometries change with time, that are in contact with the tyre. Also, we have concentrated on using soft rubber samples to make an easily measurable effect. Future investigations will repeat this work using more typical asperity clusters that can represent real road surface as well as more typical rubber compounds.

The analysis of load dependence of the hysteresis friction coefficient of sliding rubbers over rough and self-affine surfaces was discussed, [2], to demonstrate how the influence of height distributions of different road tracks can be considered within the corresponding friction model. Special attention is devoted to contact situations that correspond to slipping tires and tread deformations during ABS-braking. From a point of view of fundamental research, the relationship between the area of real contact, the external applied load and the surface morphology is still a question of intensive research.

The V-shaped tread design, either perpendicular or parallel to the friction measurement direction, on the rubber soles provided no advantage in improving the slip resistance on our wet and glycerol-contaminated conditions except the flat glycerol contaminated floor surface. The floors with grooves perpendicular to friction measurement direction had the highest friction coefficients among all the floor conditions on both the wet and glycerol-contaminated conditions except the wet/flat sole/10° condition [3].

The coefficient of fiction, of three floors commonly used on a college campus under dry, wet, and sand-covered conditions, was investigated, [4]. It was found that there were significant friction reductions when the floors were covered by sand as compared with both dry and wet conditions. The grains of sand on the floor resulted in a friction loss ranging from 71% to 92% as compared with the dry non-contaminated surface. The results indicated that effects of sand particles on the friction at footwear–floor interface were more significant than that of the wet conditions for most of the footwear material–floor combinations tested. The changes in the surface properties and frictional characteristics of flooring materials can be expected in practical use because they are subject to mechanical wear, ageing, soiling and maintenance, [5]. In the sport halls the flooring surfaces are probably changed mainly through mechanical wear, periodic cleaning processes and material transfer from shoe soles (elastomer abrasions and dirt particles). Coefficients of friction were measured periodically over a period of 30 months on the surface of five types of floor coverings in a new sport complex, [6]. Surface changes through mechanical wear range from smoothing to roughening, [7, 8], depending on flooring material and surface characteristics. Surface roughness is known to be a key factor in determining the slip resistance of floors.

The effect of surface roughness of ceramic on the friction coefficient, when rubber and leather are sliding against it, was investigated, [9]. Glazed floor tiles of different roughness ranging from 0.05 and 6.0 µm were tested. The test results showed that, friction coefficient decreased down to minimum then increased with increasing the surface roughness of the ceramic surface. The dynamic friction between porcelain tiles and a commonly used shoe sole material, vulcanized rubber, under six test conditions with four different mixtures of glycerol and water as contaminants at the interface was correlated with the surface parameters generated from the tile surfaces, [10]. The results showed that dynamic friction decreased as the glycerol content in the contaminant and the interface sliding speed were increased due to the lubrication effect.

There is an increasing demand to increase friction coefficient between shoes and flooring materials to eliminate slipping and prevent accidents. The necessity to develop and introduce new materials for shoes and floorings for relatively high friction coefficient is growing. The effect of cylindrical and square protrusions of rubber surface sliding on ceramics under dry, water, water-detergent, oil, water oil emulsion, sand and water contaminated by sand sliding is investigated, [11 and 12]. It was found that circular protrusions give higher friction than square ones for all the sliding conditions tested in the present work. The observation depends on the fact that the deformation of circular protrusions is relatively higher than that displayed by square ones. In the presence of oil on the sliding surfaces, smooth surfaces give the lowest friction values. Besides, sand particles prevent the contact between rubber and ceramic, where the contact becomes between sand particles and ceramic. The optimum contact areas are 30 and 50 % for circular and square protrusions respectively. In the presence of water on the sliding surface, circular protrusions give relatively higher friction than square ones due to the easy escape of water from the contact area. Circular protrusions displays maximum friction value of 0.66 at 10 % contact area.

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, [13 - 15]. 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 height of the grooves introduced in the rubber specimens. The decrease may be from the well adherence of oil on the rubber surface, where a film which is responsible for the friction decrease was formed. Besides, diluting oil by water displayed values of friction much lower than that observed for oil lubricated condition. As for ceramic lubricated by water and soap and contaminated by sand, friction coefficient increased significantly compared to the sliding conditions of water and soap only. In the presence of oil and sand on the sliding surface, the friction slightly increased. This behaviour may be caused by sand embedment in rubber surface and consequently the contact became between ceramic and sand. At lubricated sliding surface by oil and water contaminated by sand, the friction presented higher value than that of oil and sand sliding conditions.

The effect of sand particles, on the friction coefficient displayed by rubber sliding against ceramic tiles at different sliding conditions, was investigated, [16]. It was found that, at dry sliding, sand particles caused drastic decrease in friction coefficient. In this condition, it is recommended to use circular protrusion in the rubber surface. In the presence of water, sand particles embedded in rubber surface increased friction coefficient. Based on the experimental results, wet square protrusions are recommended to have relatively higher friction values. For surfaces lubricated by detergent, flat rubber embedded by sand particles gave higher friction than surfaces of protrusions, while sand particles embedded in rubber lubricated by oil showed higher friction values. Circular protrusions gave higher friction than flat and square protrusions. Flat rubber surfaces, lubricated by water oil emulsion and contaminated by sand particles, displayed the highest friction coefficient.

The effect of rubber flooring, provided by cylindrical treads on the friction coefficient, was investigated, [17]. It was found that at dry sliding, friction coefficient significantly increased with increasing treads diameter, where the tread directions displayed significant role in increasing the friction coefficient which reached a value of 0.92 at dry sliding. As for lubricated sliding surfaces, significant decrease in friction coefficient was observed in the presence of water on the sliding surface compared to dry sliding, where friction coefficient decreased with increasing treads diameter. In the presence of water/detergent dilution, 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. Presence of oil on the sliding surfaces displayed a decreasing trend of friction coefficient with increasing tread diameter as a result of the presence of squeeze oil film separating footwear and rubber flooring.

The effect of the treads width and depth of the shoe sole, on the friction coefficient between the shoe and ceramic floor interface, was discussed, [18]. Based on the experimental results, 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 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 a result of the formation of the hydrodynamic wedge. Oily smooth surfaces gave the lowest friction value as a result of the presence of squeeze oil film separating rubber and ceramic. Treads of 45° displayed the highest friction coefficient. 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.

In the present work, the friction coefficient displayed by rubber footwear sliding against rubber flooring fitted with cylindrical rubber protrusions and leakage grooves at dry, water, water-detergent, oil and oil-water is investigated.

EXPERIMENTAL WORK

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 the ceramics flooring materials through measuring the friction force and applied normal force. The tested materials are 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 normal load. The arrangement of the test rig is shown in Fig. 1.

Rubber test specimens were prepared in the form of cylindrical protrusion of 28 mm diameter and 10 mm thickness. Holes of 1.5, 3, 4 and 4.5 mm diameter were punched in the rubber protrusions, Fig. 2. The number of holes was 0, 1, 2, 3 and 4. To leak the liquid from the contact area grooves were introduced in the rubber layer to which the protrusions were adhered. Then the rubber arrangement was adhered to the wood blocks of 50 × 50 × 10 mm. The hardness of the rubber flooring and footwear were 45 and 62 Shore-A respectively. Friction test was carried out using footwear applying variable forces up to 300 N. The friction values were extracted from the figure indicating the friction coefficient at 50, 100 and 150 N. The rubber footwear was loaded against dry, water, water + 5.0 vol. % soap, oil (paraffin), water + 5.0 vol. % oil lubricated tested rubber surface.

The sliding conditions tested in the experiment were dry, water, water–detergent mixture, oil and water – oil mixture. Water was replenished on the tested flooring materials, where the amount of water for each replenishment was 10 ml to form consistent water film covering the sliding surface. In the water–detergent condition, a 5.0 vol. % detergent solution was applied to the flooring. In the oily condition, 2 ml of paraffin oil was spread on the flooring using a paintbrush. 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. In the oily condition, the sliding surfaces were cleaned using a detergent solution to remove the oil, rinsed using tap water and blown using hair dryer after the cleaning process.

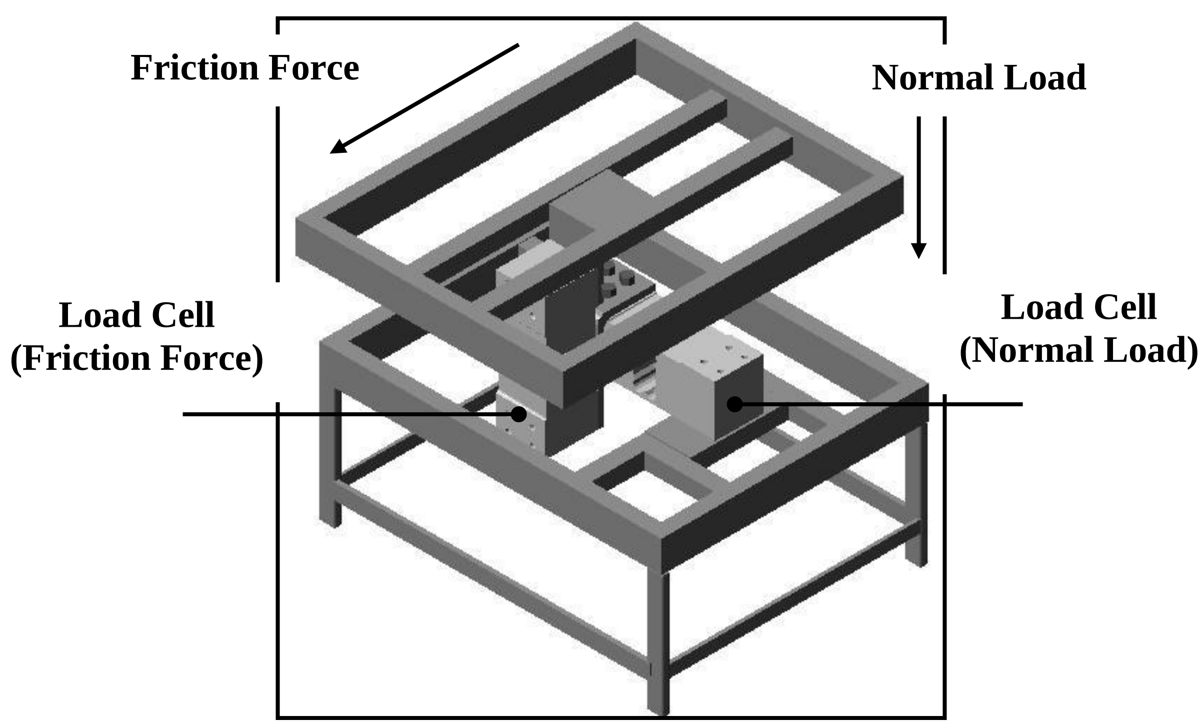
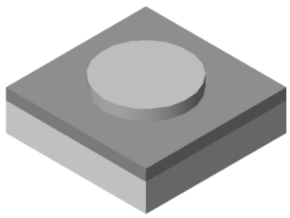
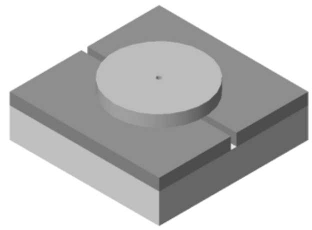


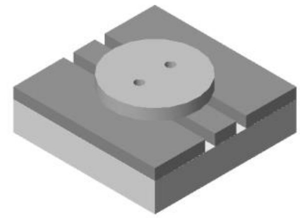
Fig. 1 Arrangement of the friction tester.



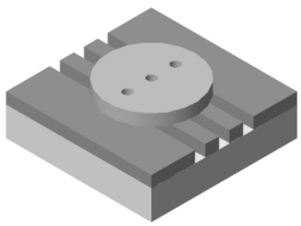
Flat rubber test specimen



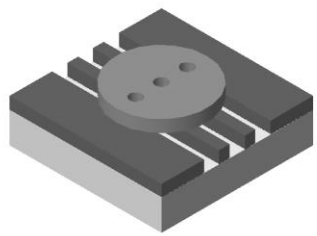
One hole, 1.5 mm diameter, one groove, 1.5 mm width.



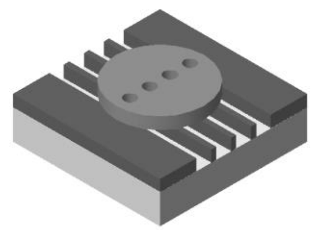
Two holes, 3 mm diameter, two grooves, 3 mm width.



Three holes, 3 mm diameter, three grooves, 3 mm width.



Three holes, 4.5 mm diameter, three grooves 4.5 mm width.



Four holes, 4 mm diameter, four grooves 4 mm width.

Fig. 2 Rubber test specimens.

RESULTS AND DISCUSSION

The dry sliding of the rubber test specimens against rubber footwear is shown in Figs. 3 – 6. At dry sliding, rubber friction is composed of two mechanisms adhesion and deformation. Adhesion is attributed to the bonding of the exposed surface atoms between sliding surfaces and the breaking which requires work to be done. Deformation is attributed to the ability of the rubber elements to elongate until the interface bonds are broken. Friction coefficient decreased with increasing applied normal load. It is commonly known that as load increases the friction coefficient decrease for elastomer materials. The friction coefficient is seen to increase with load and fall after reaching a maximum. The reason for the rise in friction is attributed to the increase in the contact area when load increased. The fall in friction after the maximum is possibly due to extra heat which is generated during sliding at load higher than a critical value. If the temperature is high enough, a layer of low shear strength material will be expected to form at the interface which should provide low values of friction coefficient. It can be noticed that the friction coefficient increases with increasing number of holes. A maximum value of friction coefficient (0.95) was observed at 50 N normal load and four holes with 4 mm diameter, this behaviour was attributed to the increasing adhesion and deformation for surfaces of holes and grooves.

In the presence of water on the sliding surface, the effect of the holes and grooves on friction coefficient is illustrated in Figs. 7 - 10. Generally, it can be noticed that, the friction coefficient increased with increasing number and diameter of the holes, then decreased with increasing the holes diameter. The increase of friction coefficient might be attributed to the ability of the water to escape from the contact area through the holes and grooves in the rubber surface, where water leakage changed the condition of sliding from water lubricated to mixed lubricated. Increasing holes diameter up to 4 mm decreased contact area and consequently friction coefficient decreased. Besides, friction coefficient decreased with increasing applied load. This behaviour might be related to water trapped the in contact area. The maximum value of friction coefficient (0.65) was observed for surfaces of four holes of 1.5 mm diameter.

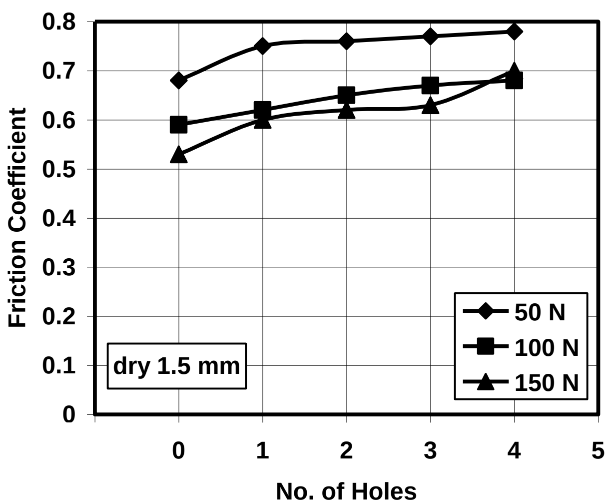


Fig. 3 Friction coefficient of rubber test specimens of 1.5 mm hole diameter.

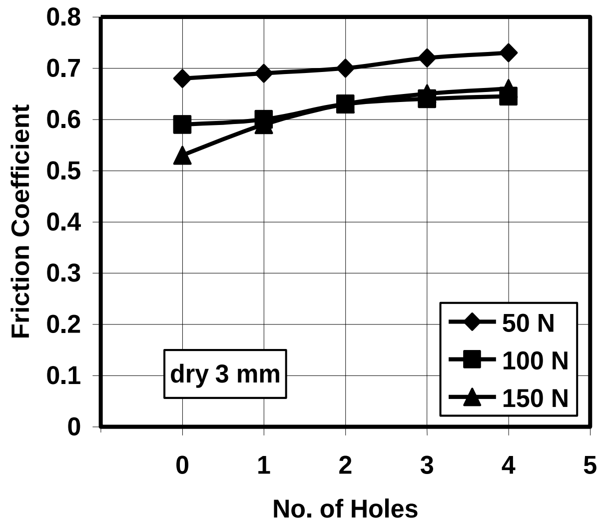


Fig. 4 Friction coefficient of rubber test specimens of 3 mm hole diameter.

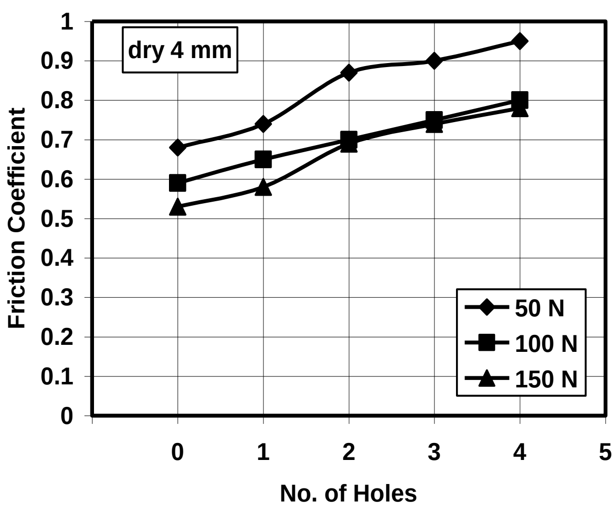


Fig. 5 Friction coefficient of rubber test specimens of 4 mm hole diameter.

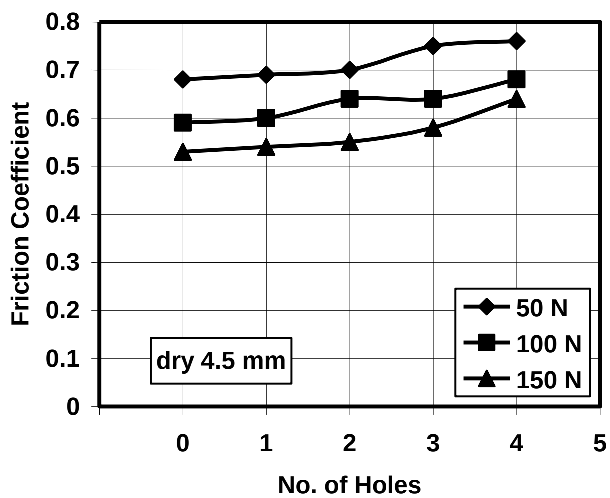


Fig. 6 Friction coefficient of rubber test specimens of 4.5 mm hole diameter.

Mixing water by detergent caused significant decrease of friction coefficient, Figs. 11 - 14. It is noted that friction coefficient for lubricated surfaces by water and detergent represented lower values than that displayed by water only. The friction decrease might be attributed to the enhanced adhesion of water film to the sliding surfaces as a result of the presence of the detergent. As the number of holes increased the friction coefficient increased due to the leakage of lubricating fluid from the contact surface. Increasing holes diameter decreased the friction. This behaviour was attributed to that the holes could store more oil as the diameter increased due to the increased deformation, where the oil could go up to the sliding surface as the rubber footwear pressed the tested rubber surface. As the normal load increased the friction coefficient decreased. Increasing normal load increased the fluid film trapped inside the contact area. The maximum value of friction coefficient (0.34) was observed for test specimens of four holes of 1.5 mm diameter at 50 N normal load.

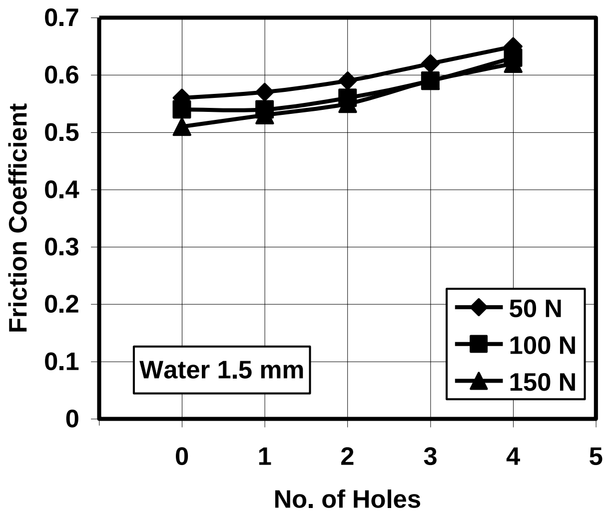


Fig. 7 Friction coefficient of rubber test specimens of 1.5 mm hole diameter.

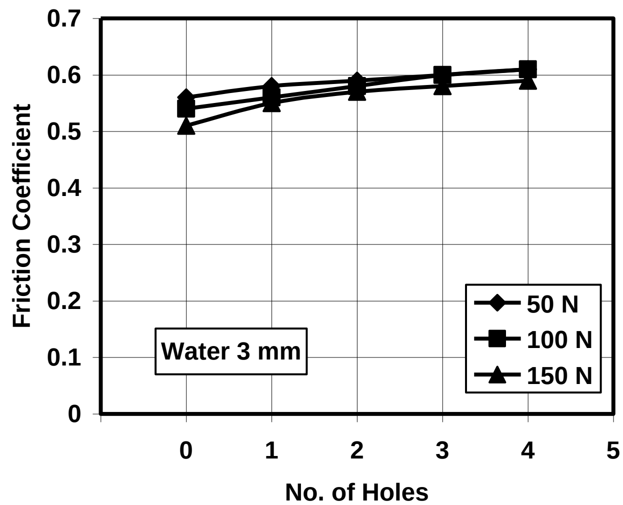


Fig. 8 Friction coefficient of rubber test specimens of 3 mm hole diameter.

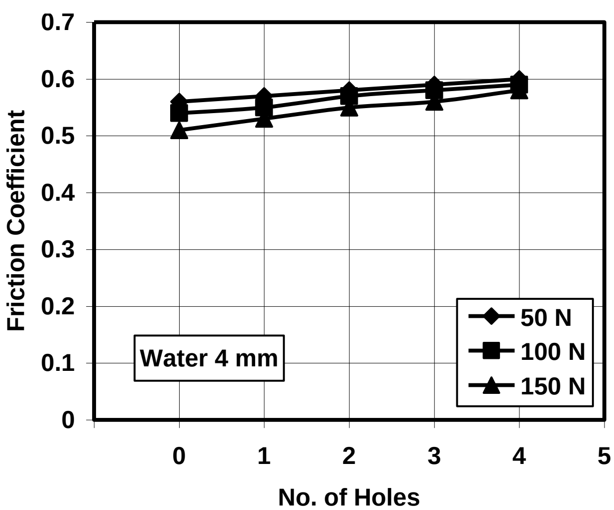


Fig. 9 Friction coefficient of rubber test specimens of 4 mm hole diameter.

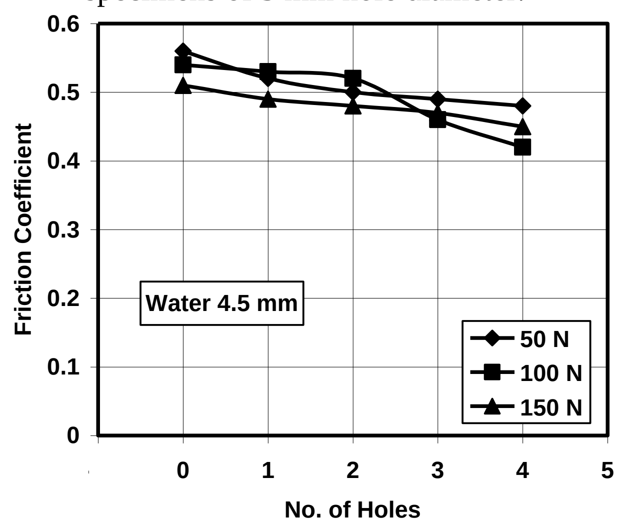


Fig. 10 Friction coefficient of rubber test specimens of 4.5 mm hole diameter.

Friction coefficient generated from the sliding of rubber footwear against the tested rubber specimens lubricated by oil is shown in Figs. 15 - 18. It can be noticed that, for smooth surfaces, the oil film formed on the sliding surface was responsible for the friction decrease. Introducing holes and grooves in rubber surface helped the oil to escape from the contact area into this holes. This behaviour caused significant friction increase. Friction coefficient increased with increasing number of holes and grooves, this behaviour was attributed to the easy escape of the oil through the hole out of contact area to the leakage grooves. Friction coefficient decreased with increasing applied load due to the increase of the deformation of rubber and displacing the oil up to the contact surface. The maximum value of friction coefficient (0.23) was observed for four holes with 3 mm diameter at 50 N normal load.

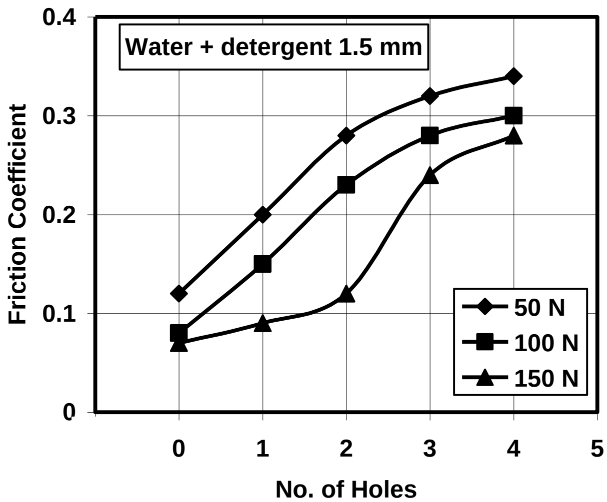


Fig. 11 Friction coefficient of rubber test specimens of 1.5 mm hole diameter.

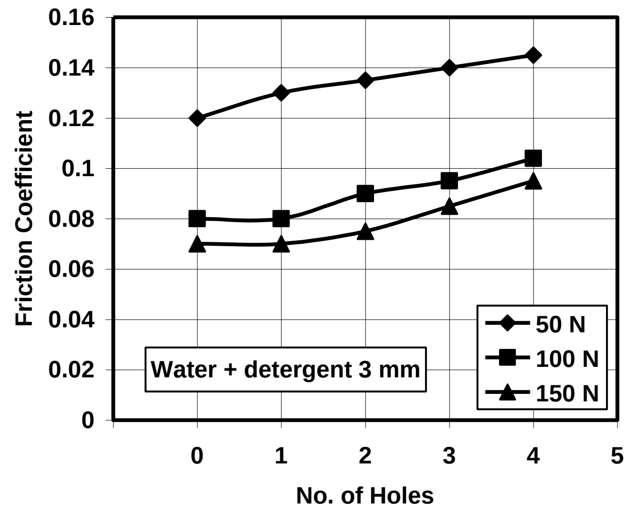


Fig. 12 Friction coefficient of rubber test specimens of 3 mm hole diameter.

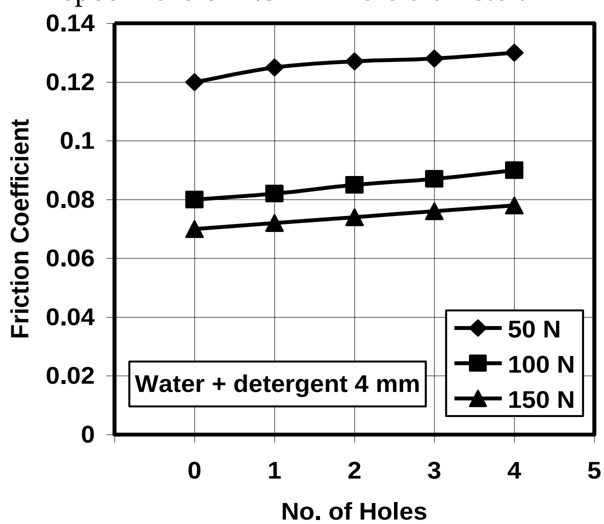


Fig. 13 Friction coefficient of rubber test specimens of 4 mm hole diameter.

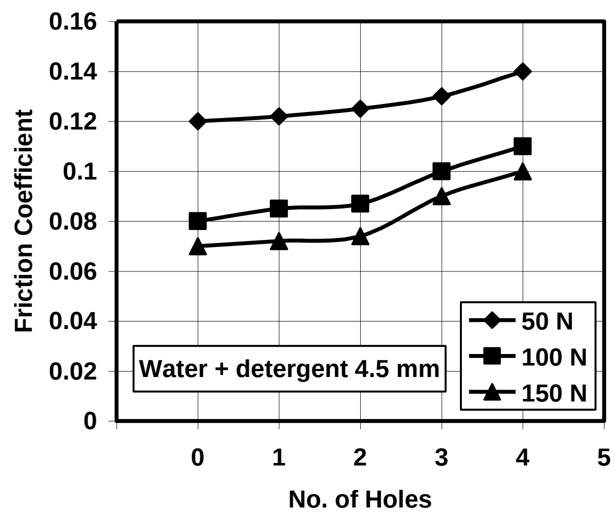
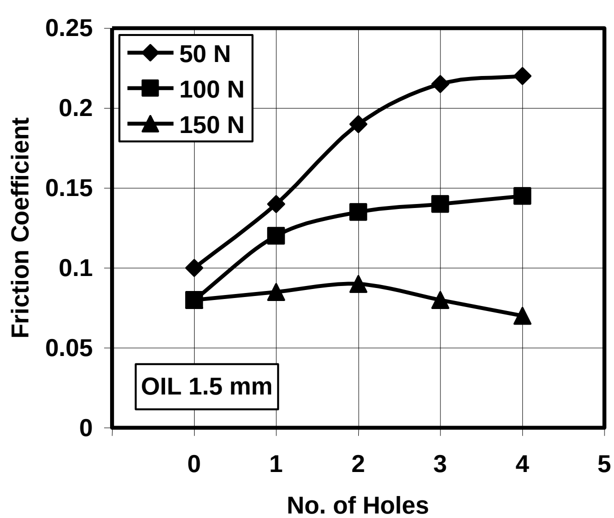


Fig. 14 Friction coefficient of rubber test specimens of 4.5 mm hole diameter.



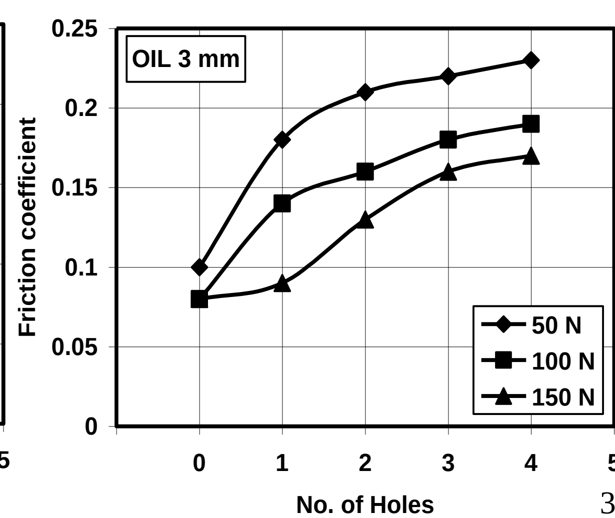


Fig. 15 Friction coefficient of rubber test specimens of 1.5 mm hole diameter.

Fig. 16 Friction coefficient of rubber test specimens of 3 mm hole diameter.

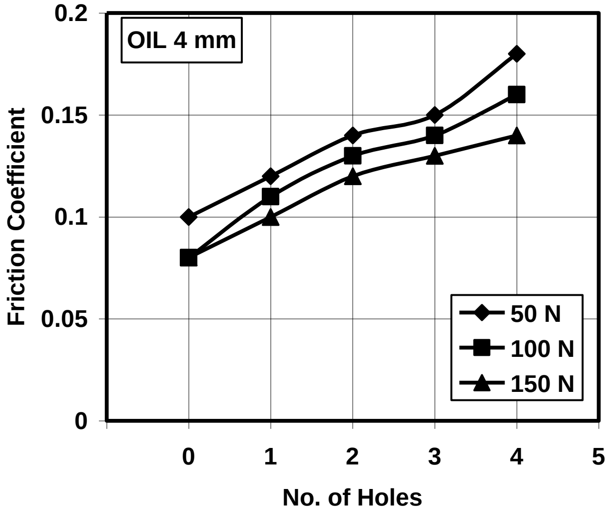


Fig. 17 Friction coefficient of rubber test specimens of 4 mm hole diameter.

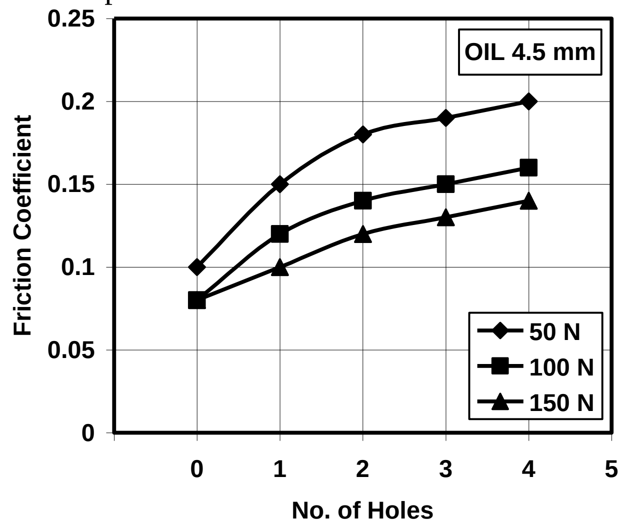
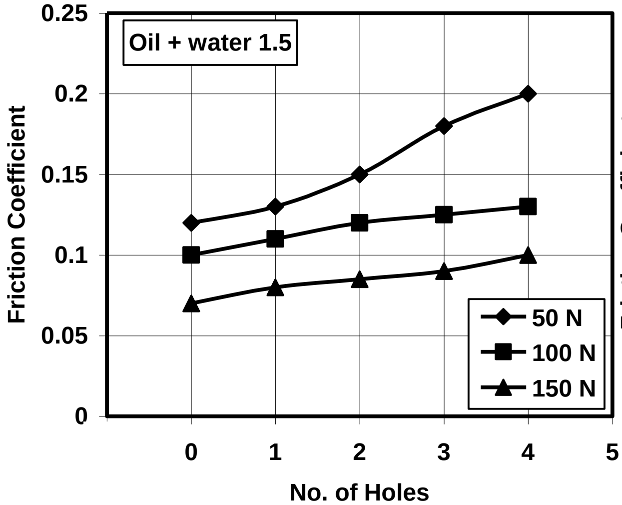


Fig. 18 Friction coefficient of rubber test specimens of 4.5 mm hole diameter.

Sliding of rubber footwear against the tested rubber specimens lubricated by water + 5.0 vol. % oil caused insignificant decrease in friction coefficient, Figs. 19 - 22. The values of friction coefficient for smooth rubber surface slightly increased compared to surfaces lubricated by oil only. This behaviour was attributed to the easy escape of the emulsion of water and oil from the contact area. Increasing the applied load caused relative friction decrease due to the increased rubber deformation which displaced the fluid up to the sliding surface, where the rubber was completely deformed and trapped the lubricating fluid inside the contact area. Increasing number of holes increased friction coefficient. The maximum value of friction coefficient (0.24) was observed for four holes of 3 mm diameter at 50 N normal load.



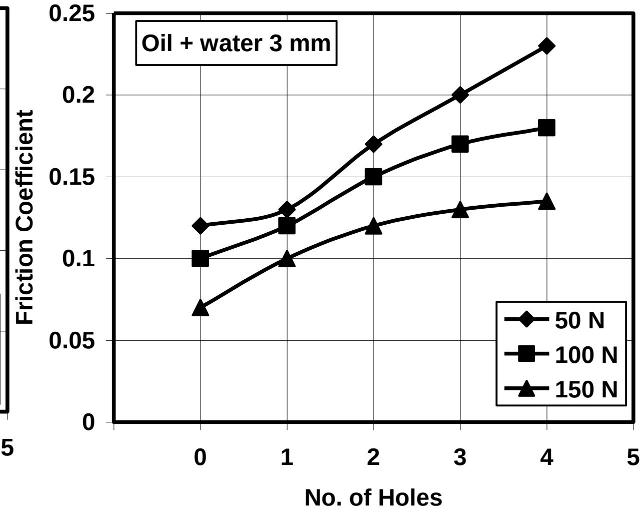
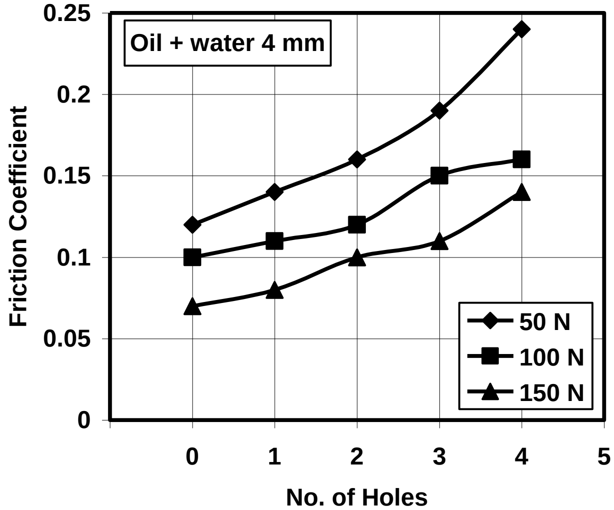


Fig. 19 Friction coefficient of rubber test specimens of 1.5 mm hole diameter.

Fig. 20 Friction coefficient of rubber test specimens of 3 mm hole diameter.



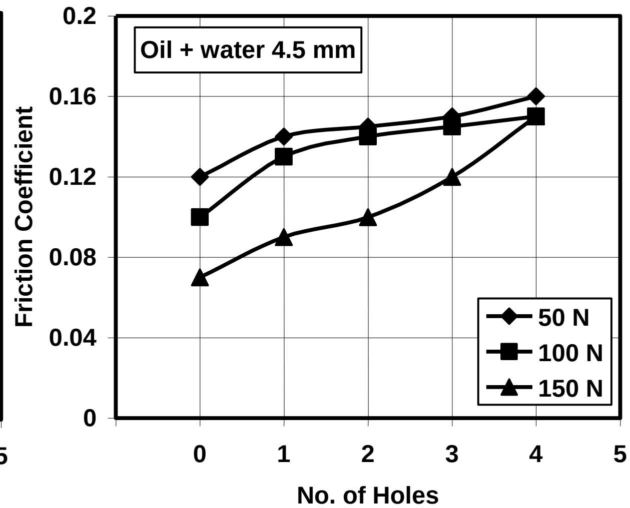


Fig. 21 Friction coefficient of rubber test specimens of 4 mm hole diameter.

Fig. 22 Friction coefficient of rubber test specimens of 4.5 mm hole diameter.

CONCLUSIONS

1. At dry sliding, friction coefficient increased with increasing number of holes. Besides, friction coefficient decreased with increasing applied load.
2. At water lubricated sliding, increasing diameter of holes was insignificant on friction coefficient, as the number of holes increased friction coefficient increased. Maximum friction value (0.65) was observed for surfaces of four holes of 1.5 mm diameter.
3. At water and detergent lubricated sliding, friction coefficient drastically decreased with increasing normal load.
4. At oil lubricated sliding, friction coefficient increased with increasing number of holes. The maximum friction values were noticed for four holes of 3 mm diameter.
5. At emulsion of water and oil lubricated sliding, smooth rubber surface displayed higher values of friction coefficient than that displayed by surfaces lubricated by oil.

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