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REDUCING THE SLIP OF RUBBER MATS ON CERAMIC FLOORINGS

Samy A. M.[1], El-Sherbiny Y. M.[2] and Hasouna A. T.[3]

[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.
[3]El-Minia High Institute of Technology, El-Minia, EGYPT.

ABSTRACT
Rubber mats are used to eliminate slip and fall. Liquid contaminated ceramic surfaces usually promote slips and occasionally lead to serious accidents indoor and in work places. In this particular case, rubber mats are recommended to adhere to the smooth surfaces of ceramics and polymeric flooring. The present work aims to reduce the slip of the rubber mats on ceramic flooring by introducing semispherical cavities into their sliding surface. The effect of semispherical cavities introduced in the rubber flooring mats on the static friction coefficient displayed by their sliding against ceramic flooring under dry, water, water + 5.0 vol. % detergent, oil and water + 5.0 vol. % oil lubricated sliding conditions is investigated. Rubber test specimens were prepared in the form of tiles of 58 x 58 mm square block. Semispherical cavities of 33, 36, 38, 42, 45 and 48 mm diameter were introduced in the rubber block. Two values of the height of the semispherical cavities 5 and 12 mm were tested.

Based on the experimental observation, it can be concluded that at dry sliding, smooth rubber displayed the lowest friction, while semispherical cavities showed an increased trend of friction. As the height of the cavity increased friction increased. Friction coefficient slightly increased up to maximum then decreased with increasing the diameter of the semispherical cavity. In the presence of water, water/detergent dilution, oil, oil/water dilution on the sliding surface, friction coefficient displayed the highest values at 12 mm cavity height. The semispherical cavity increased friction coefficient. The highest friction values where observed for cavity of 12 mm height and 38 mm diameter.

KEYWORDS
Friction coefficient, rubber mats, semispherical cavities, dry, water, detergent, and oil emulsion, ceramic flooring.

INTRODUCTION
Rubber floorings are commonly used in homes, gyms, fitness centers, community centers, health clubs, schools and universities, play areas as well as fire and police stations. Materials that increase floor friction forces under foot pressure could reduce the risk of slipping and enhance walking safety[1]. For reasons of technical design and economy, flooring and flooring systems in work places are often made from hard materials, which do not deform under the pressure of the foot. Rubber mat has become

a popular flooring materials due to the increased comfort, by adding a cushioning effect to the knees when walking, [2 – 7]. Recycled rubber is favoured over virgin rubber in flooring due to cost and the high quality and durability.

It was shown in a study of six different rubber walkway covers that the degree of compressibility of rubber walkway cover was well adapted for walkway evaluation [8]. The better traction for walking on rubber matting compared with concrete is due to a more effective transmission of forces from the foot to the elastomer, dissipating the energy into deformations within the material, and thus impeding the effect of force, with less displacement of body centre of gravity and less forward and backward slip. A deformation of 1.4 mm gave good slip resistance.

In bathrooms, contamination with water, detergents, and oily soap are evident, and these can change the tribological behaviour when walking on rubber floorings or moving on bathtub rubber mats.

The low friction of footwear on floor coverings is responsible of the occurrence of slips and falls. There is an increasing demand to develop the frictional behaviour of the footwear and flooring materials to reduce slip and fall accidents. The slip resistance is normally assessed on the basis of friction coefficient measured with footwear materials sliding against floorings. The effect of holes and leakage grooves introduced in cylindrical protrusion of the rubber flooring mats on the static friction coefficient of rubber footwear was investigated, [1]. It was found that, 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. At water and detergent lubricated sliding, friction coefficient drastically decreased with increasing normal load. In oily lubricated slidings, friction coefficient increased with increasing number of holes and grooves. At emulsion of water and oily lubricated sliding, smooth rubber surface displayed higher values of friction coefficient compared to surfaces lubricated by oil only.

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, [9]. It was found that, at dry sliding, friction coefficient slightly increased with increasing treads height. In the presence of water on the sliding surface significant decrease in friction coefficient was observed as compared to the dry sliding. For detergent wetted surfaces, friction coefficient drastically decreased to values lower than that displayed by water. Oily smooth surfaces gave the lowest friction value as a result of the presence of squeeze oil film separating rubber and ceramic. Emulsion of water and oil shows slight friction increase compared to oily lubricated sliding. Furthermore, friction coefficient significantly increased up to maximum then slightly decreased with increasing the treads height. At water, detergent and oil lubricated sliding conditions, friction coefficient decreased as the tread width increased due to the increased area of the fluid film. The friction decrease may be due to the increased ability of the tread to form hydrodynamic wedge as the tread width increased. Tread groove designs are helpful in facilitating contact between the shoe sole and floor on liquid contaminated surface, [10 - 13]. 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.

Explanation of rubber friction is based on several established theories. 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 [14]. In contrast, tests using a different geometry (flat on flat) did not show this effect.

The analysis of load dependence of the hysteresis friction coefficient of sliding rubbers over rough and self-affine surfaces was discussed, [15], to demonstrate the influence of height distributions of different road tracks within the corresponding friction model. Special attention is devoted to contact situations that correspond to slipping tires and tread deformations during ABS-braking. The V-shaped tread design, either perpendicular or parallel to the friction force direction, on the rubber soles provided no advantage in improving the slip resistance on wet and glycerol-contaminated conditions except for the flat glycerol contaminated floor surface, [16]. The floors with grooves perpendicular to friction force direction had the highest friction coefficients among all the flooring conditions on both the wet and glycerol-contaminated cases except for the wet/flat sole/10° case.

The coefficient of fiction, of three floors commonly used on college campus under dry, wet, and sand-covered conditions, was investigated, [17]. 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 reduction in friction 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 tested footwear material–floor combinations. The effect of rubber flooring, provided by cylindrical treads on the friction coefficient, was investigated, [18]. 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 to 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 showed a decreasing trend of friction with increasing tread diameter as a result of the presence of squeeze oil film separating footwear and rubber flooring.

In the present work, the friction coefficient displayed by rubber mats fitted with semispherical cavity sliding on ceramic flooring at dry, water, water/detergent dilution,

oil and oil/water dilution is investigated. The semispherical cavity is introduced to prevent the slip of the rubber mats on ceramic flooring.

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.

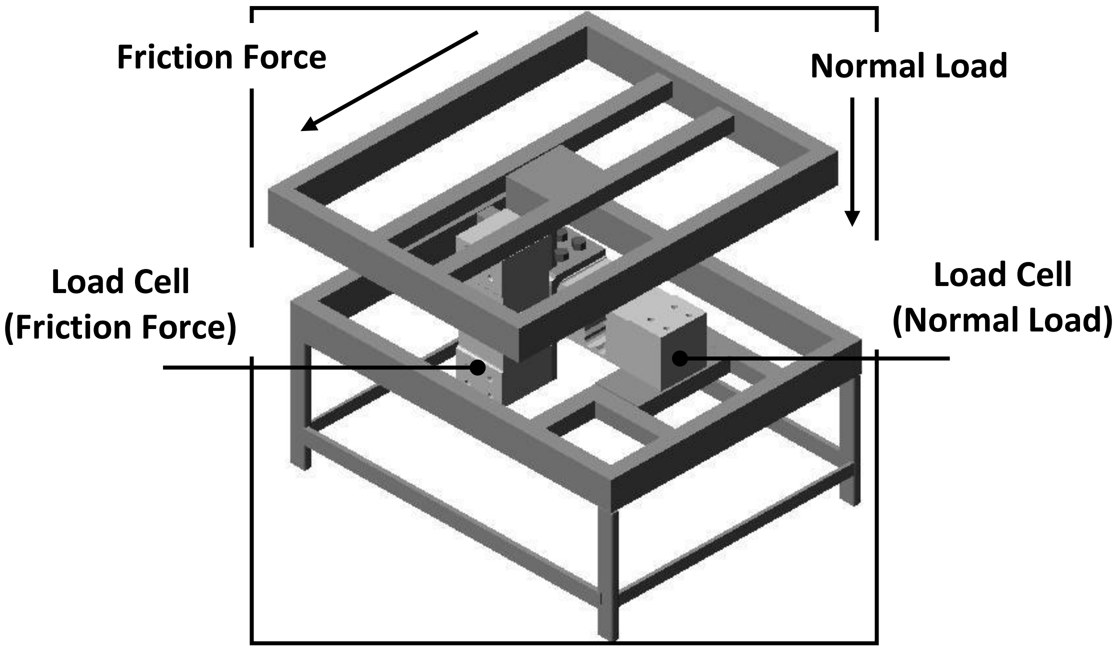

Fig. 1 Arrangement of the friction tester.

Rubber test specimens were prepared in the form of 58 × 58 mm square sheet and 15 mm thickness. Semispherical cavities of 33, 36, 38, 42, 45 and 48 mm diameter were introduced in the rubber sheet, Fig. 2. The heights of the semispherical cavities were 5 and 12 mm. The rubber test specimens were adhered to wooden blocks of 60 × 60 × 10 mm, Fig. 3. The hardness of the rubber specimens was 45 Shore A. Friction test was carried out using foot applying variable loads up to 300 N. The friction values were extracted from the figure indicating the friction coefficient at 50, 100, 150 and 200 N. The rubber test specimens were loaded against dry, water, water + 5.0 vol. % soap, oil (paraffin), water + 5.0 vol. % oil lubricated ceramic surface of 1.33 µm R_a surface roughness.

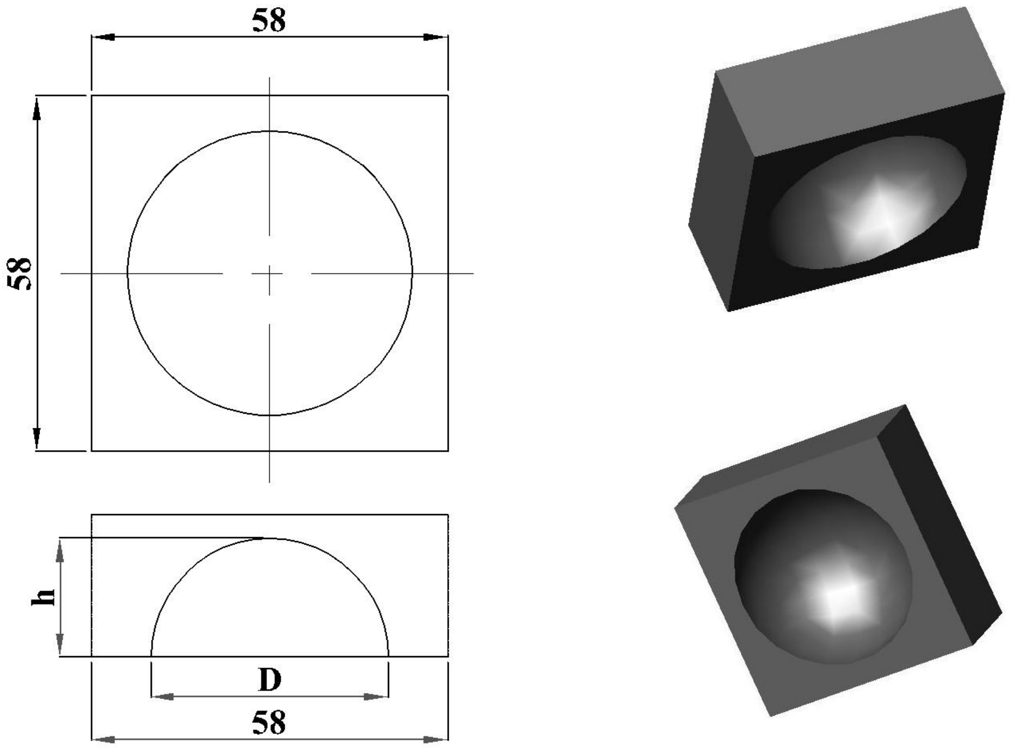

Fig. 2 Rubber test specimens.

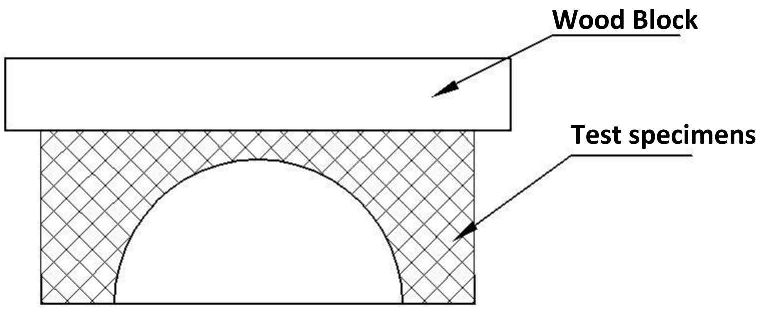

Fig. 3 Rubber test specimens adhered on wood block.

The sliding conditions tested in the experiment were dry, water, water/detergent dilution, oil and water/oil dilution. 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 dilution, 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.

RESULTS AND DISCUSSION

The results of the friction coefficient displayed by the tested rubber specimens sliding against ceramic surface at dry and different sliding conditions, (water, water/detergent

dilution, oil and oil/water dilution using four values of normal load of 50, 100, 150 and 200 N are shown in Figs. 4 - 13.

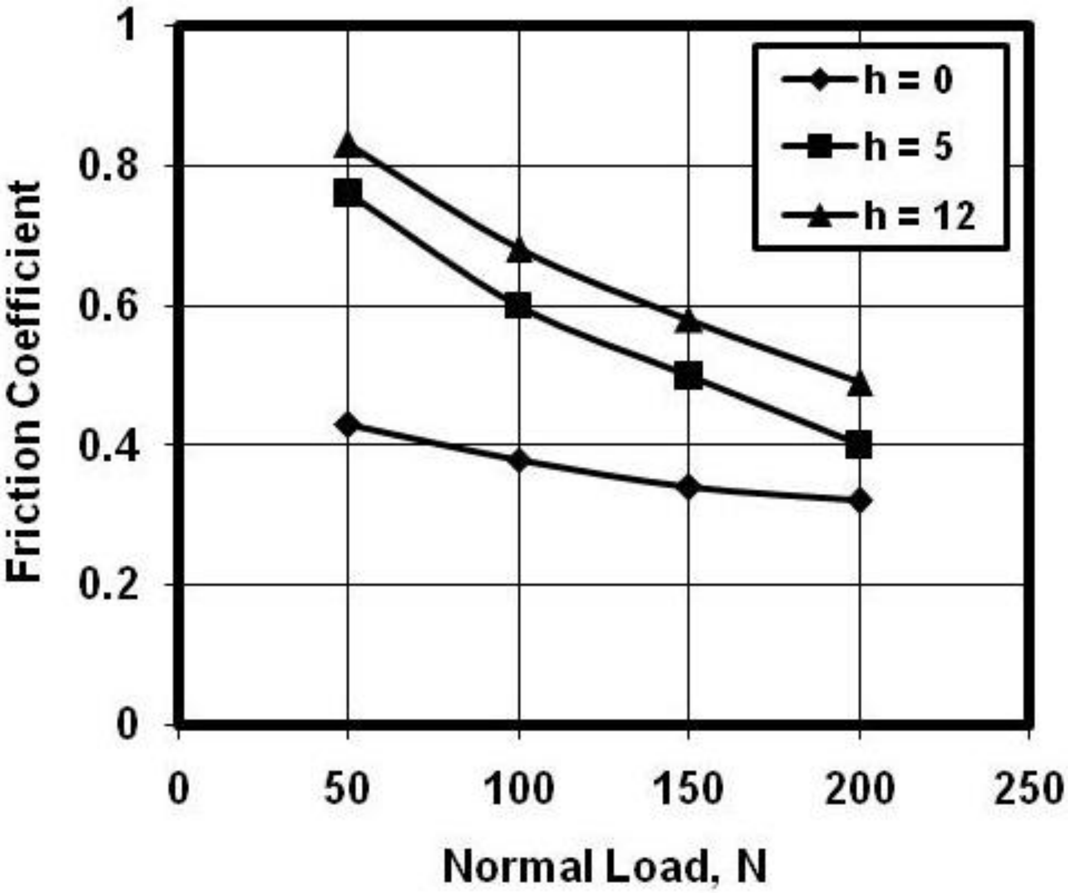

Fig. 4 Friction coefficient of dry sliding of the test specimens on ceramics.

At dry sliding, smooth rubber displayed the lowest friction, while semispherical cavities showed an increased trend of friction, Fig. 4. The diameter of semispherical cavity was 33 mm. As the height of the cavity increased friction increased. Value of friction coefficient recorded at 50 N load was 0.42 for smooth rubber, while rubber of 5 and 12 mm cavities height showed friction coefficient values of 0.77 and 0.88 respectively. The friction increase observed can be explained on the basis that friction of rubber 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. Besides, rubber deforms at the ceramic surface, where rubber follows the short-wavelength surface roughness profile. This gives an additional contribution to the friction force. Deformation is attributed to the ability of the rubber elements to elongate until the interface bonds are broken. It seems that presence of cavities increased the rubber deformation. As the load increased, values of friction coefficient decreased. The effect of the diameter of semispherical cavity on the friction coefficient of the sliding of the test specimens on dry ceramics is shown in Fig. 5. Friction coefficient slightly increased with increasing the diameter up to maximum then decreased. Maximum friction was observed at 38 mm diameter. Generally friction decreased with increasing the load. The mechanism of friction increase is based on the air release from the cavity when the load is applied. The pressure inside the cavity will be lower than the atmospheric one so that an extra adhesion of rubber into the ceramic surface will be expected. As observed from Fig. 4 that friction coefficient increased with increase the height of the cavity due to the increased air volume. As the diameter of the semispherical cavity increased the contact area decreased and consequently the sealing action decreased leading to a drop in the vacuum pressure inside the cavity and consequently the effect of the cavity decreased.

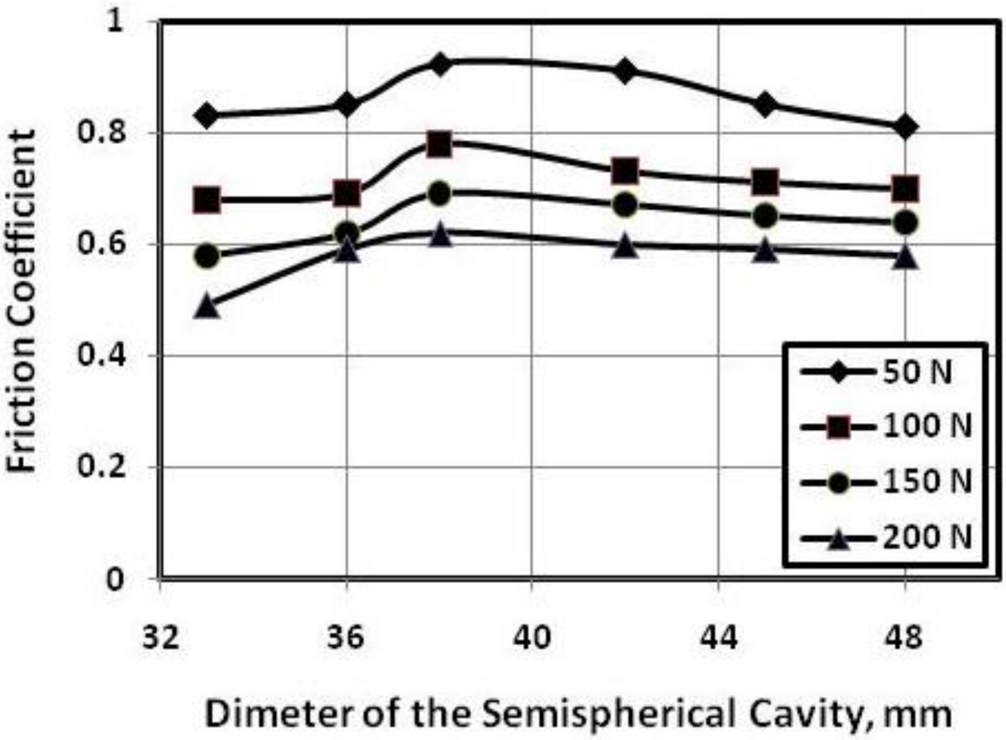

Fig. 5 Effect of the diameter of semispherical cavity on the friction coefficient of the sliding of the test specimens on dry ceramics.

In the presence of water on the sliding surface, the effect of the semispherical cavity on friction coefficient is shown in Fig. 6. Generally, it can be noticed that, the friction coefficient displayed the highest values at 12 mm cavity height. The increase of friction coefficient is attributed to the ability of the water to escape from the sliding surface through the cavity in the rubber surface, where the leakage of water changed the condition of surface from water lubricated to partially dry. The maximum value of friction coefficient (0.26) was observed at 50 N load, while smooth surface showed a value of 0.16. The effect of the diameter of semispherical cavity on the friction coefficient of the sliding of the test specimens on water wetted ceramics is shown in Fig. 7, where the semispherical cavity increased friction coefficient. The highest friction values where observed for cavity of 12 mm height and 38 mm diameter.

The values of friction coefficient of test specimens sliding against ceramics wetted by water/detergent are illustrated in Fig. 8. Values of friction coefficient showed significant reduction compared to water only due to the polarity of the molecules of the detergent. So, the adhesion between the detergent and the sliding surfaces are relatively strong. Generally, friction coefficient decreased as a result of the formation of the liquid film on the contact area. The maximum value of friction coefficient (0.026) was observed at 50 N load and cavity height of 12 mm, while the minimum values of friction coefficient were observed for smooth rubber specimens. The presence of semispherical cavity significantly increased friction coefficient displayed by sliding of the test specimens on water/detergent dilution wetted ceramics, Fig. 9. The maximum friction values were

observed ay cavity of 38 mm diameter. Further diameter increase remarkably decreased friction coefficient.

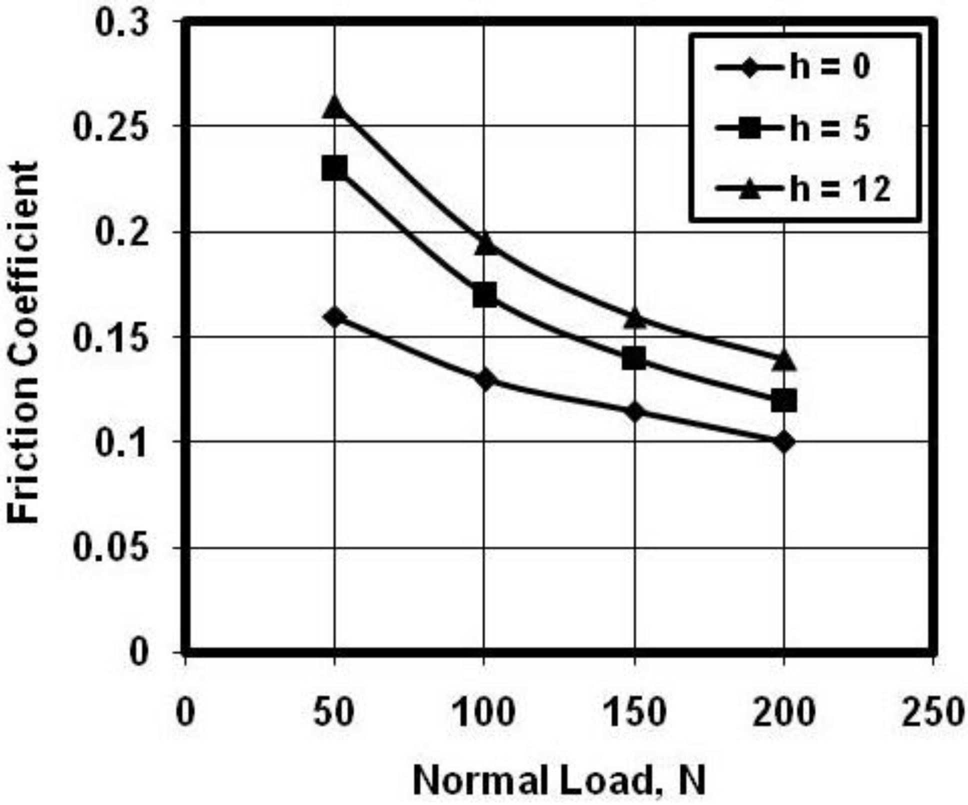

Fig. 6 Friction coefficient of the sliding of the test specimens on water wetted ceramics.

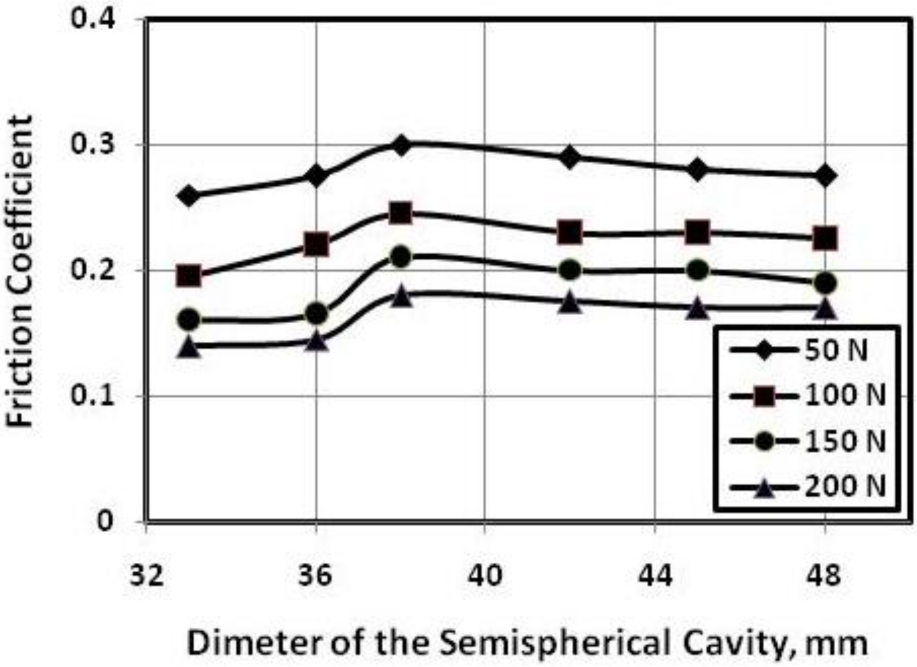

Fig. 7 Effect of the diameter of semispherical cavity on the friction coefficient of the sliding of the test specimens on water wetted ceramics.

In the presence of oil as lubricant on the ceramic surface, Fig. 10, smooth rubber test specimens displayed the lowest friction values, while presence of semispherical cavity significantly increased friction coefficient. Friction coefficient decreased as the applied load increased. The enhancement developed by cavity can be interpreted on the basis that cavity in rubber specimens would help the oil to escape from the contact area. The maximum value of friction coefficient (0.098) was observed for cavity of 12 mm height at 50 N. Significant friction increase was observed at 38 mm diameter of the semispherical cavity, Fig. 11. Friction increased from .04 for smooth surface to 0.18 for the surface provided by cavity of 38 mm diameter at 50 N load. This observation confirms the effective performance of the semispherical cavity when introduced on the rubber mats.

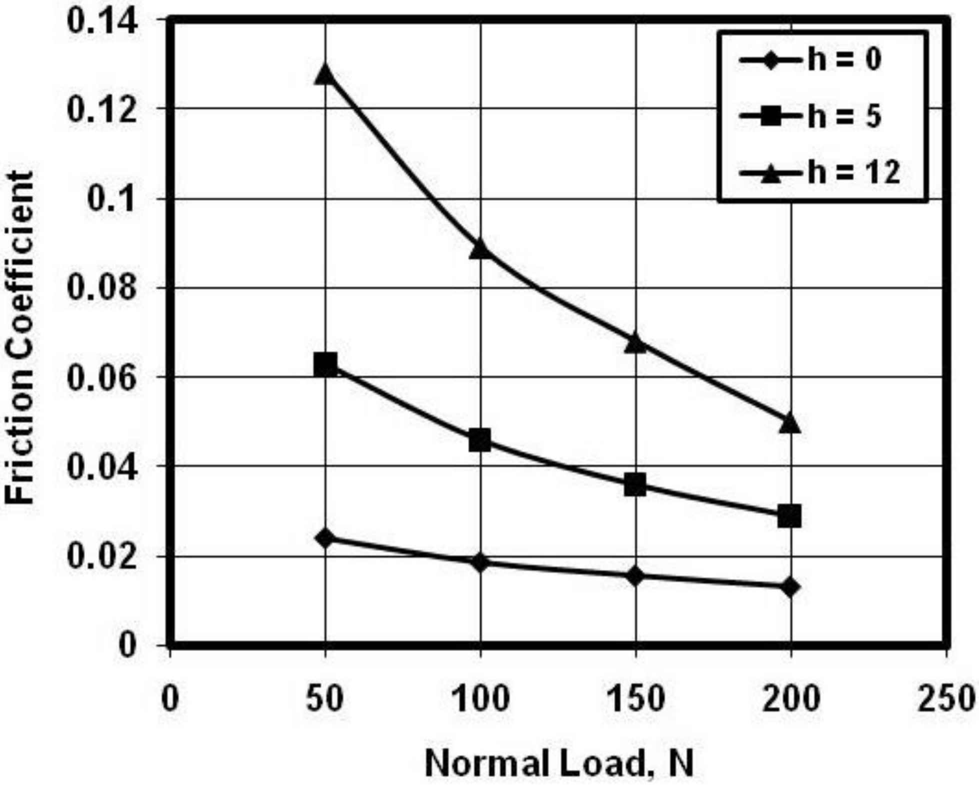

Fig. 8 Friction coefficient of the sliding of the test specimens on water/detergent dilution wetted ceramics.

Friction coefficient for rubber test specimens sliding on ceramics lubricated by water/oil dilution is shown in Fig. 12. Friction coefficient increased significantly compared to the condition of oil only. This behaviour is attributed to the effect of water which decreased the adhesion of oil on the sliding surfaces. As the height of the cavity increased the friction coefficient increased due to the increased volume of trapped oil and water out of the contact area. The maximum value of friction coefficient (0.13) was observed at 12 mm cavity height, while the minimum value (0.056) was observed at smooth rubber specimens.

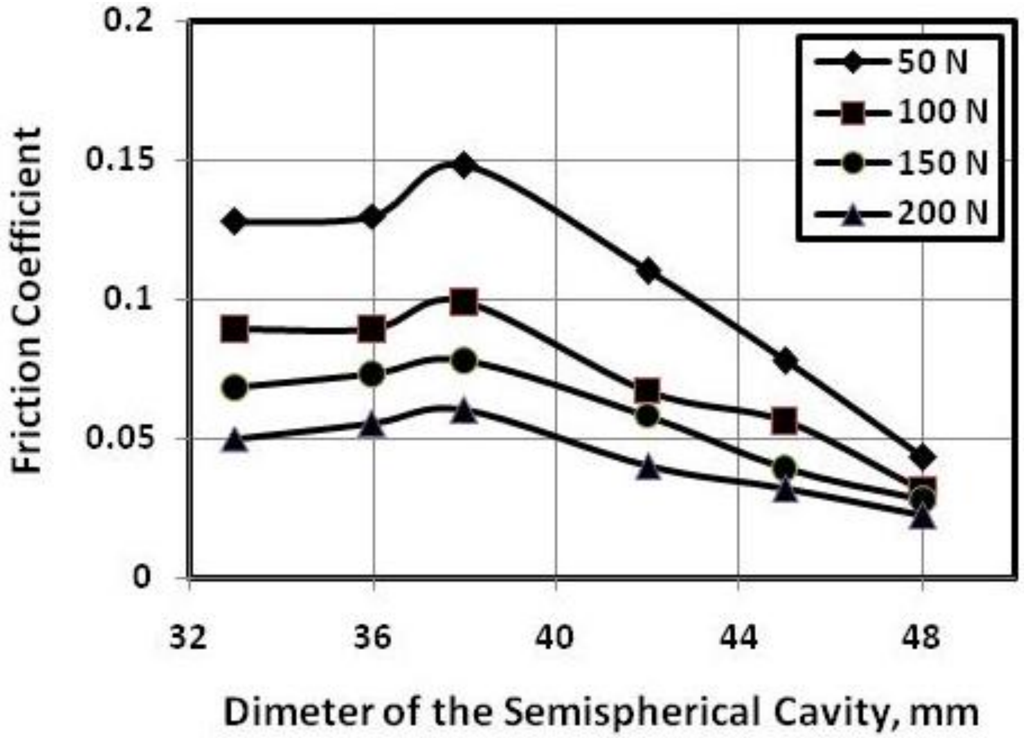

Fig. 9 Effect of the diameter of semispherical cavity on the friction coefficient of the sliding of the test specimens on water/detergent dilution wetted ceramics.

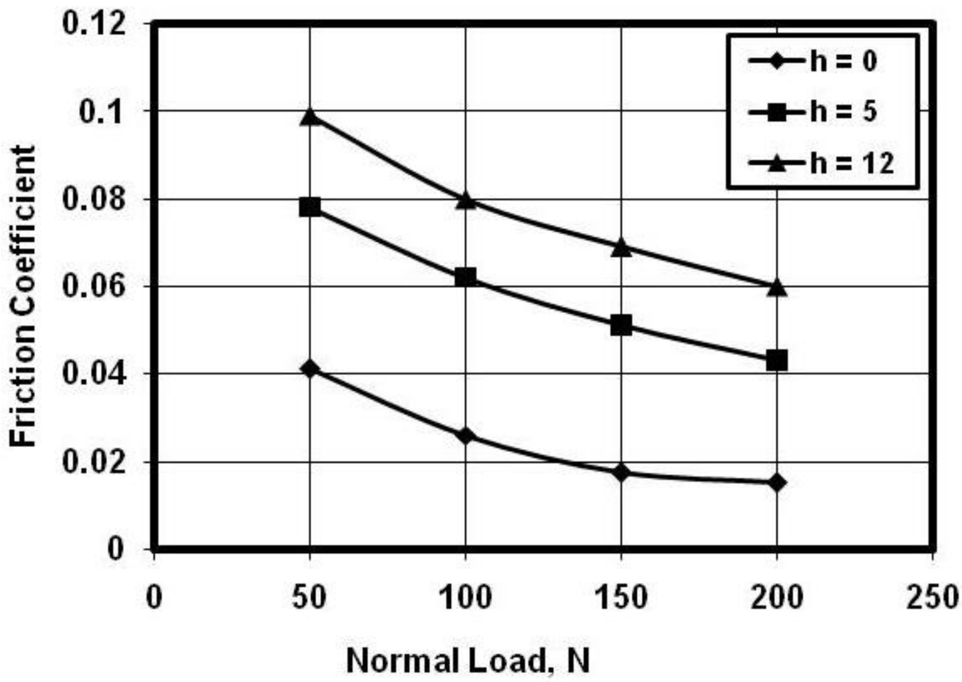

Fig. 10 Friction coefficient of the sliding of the test specimens on oil lubricated ceramics.

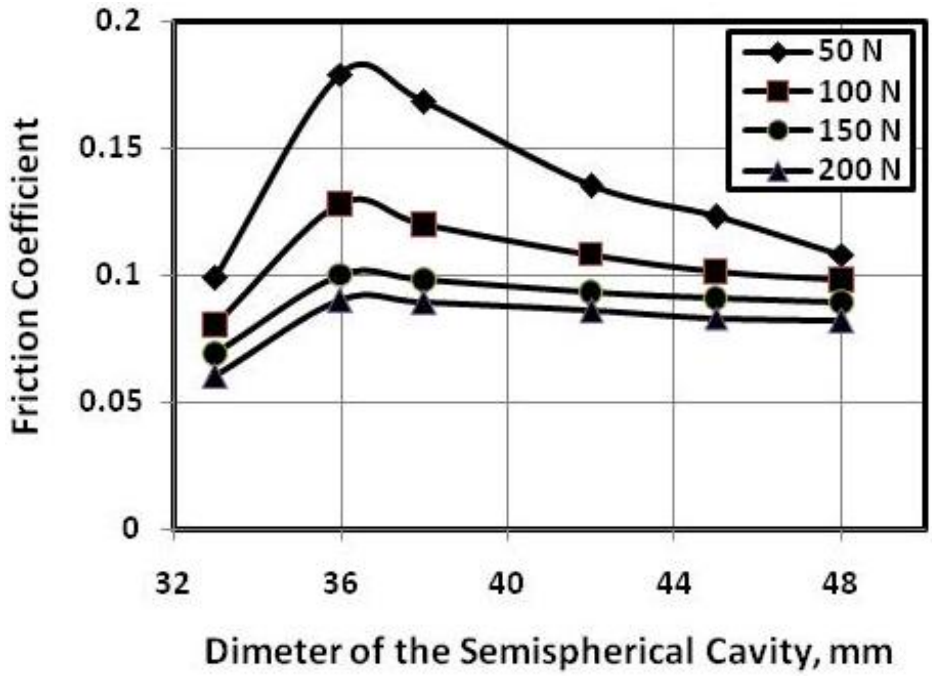

Fig. 11 Effect of the diameter of semispherical cavity on the friction coefficient of the sliding of the test specimens on oil lubricated ceramics.

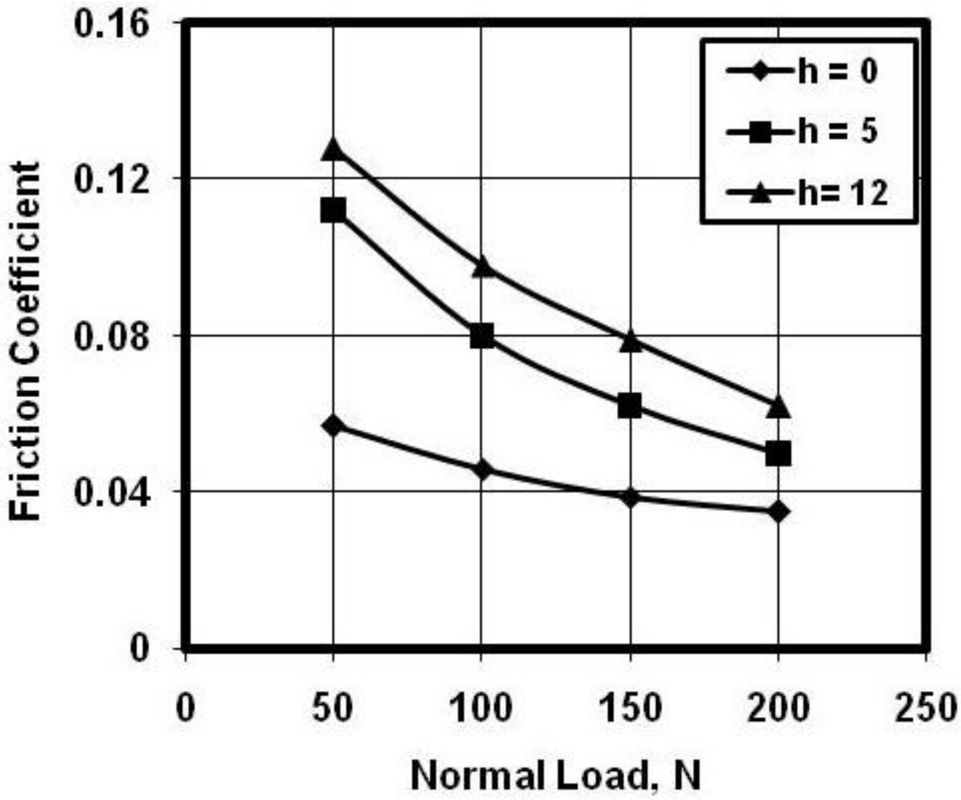

Fig. 12 Friction coefficient of the sliding of the test specimens on water/oil dilution wetted ceramics.

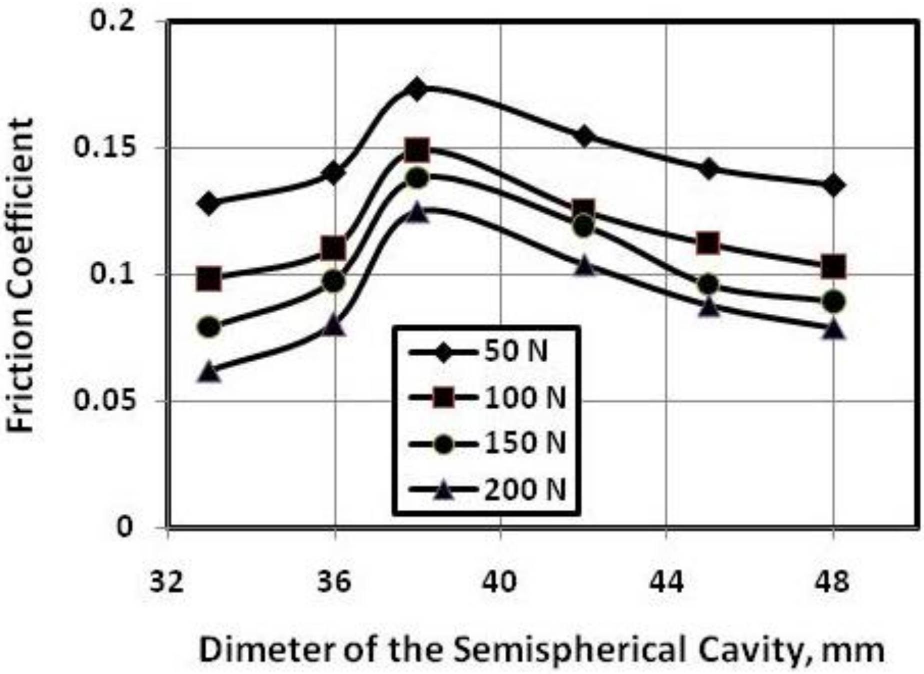

Fig. 13 Effect of the diameter of semispherical cavity on the friction coefficient of the sliding of the test specimens on water / oil dilution wetted ceramics.

The effect of the diameter of semispherical cavity on the friction coefficient of the sliding of the test specimens on water / oil dilution wetted ceramics is shown in Fig. 13. Friction coefficient significantly increased up to maximum then slightly decreased. The maximum friction values were observed at 38 mm cavity diameter.

CONCLUSIONS

1. For dry sliding, smooth rubber displayed the lowest friction, while semispherical cavities showed an increased trend of friction. As the height of the cavity increased friction increased. Friction coefficient slightly increased up to maximum then decreased with increasing the diameter of the semispherical cavity.

2. In the presence of water on the sliding surface, friction coefficient displayed the highest values at 12 mm cavity height. The semispherical cavity increased friction coefficient. The highest friction values were observed for cavity of 12 mm height and 38 mm diameter.

3. In the presence of water/detergent, values of friction coefficient showed significant reduction compared to water. The presence of semispherical cavity significantly increased friction coefficient. The maximum friction values were observed at cavity of 38 mm diameter. Further diameter increase remarkably decreased friction coefficient.

4. In the presence of oily emulsions as lubricant on the ceramic surface, smooth rubber test specimens displayed the lowest friction values, while presence of semispherical cavity significantly increased friction coefficient. This observation confirms the effective performance of the semispherical cavity when introduced on the rubber mats especially in kitchens, bathrooms and workplaces.

5. Friction coefficient for rubber test specimens sliding on ceramics lubricated by water/oil dilution increased significantly compared to the condition of oil. As the height of the cavity increased the friction coefficient increased due to the increased volume of trapped oil and water out of the contact area.

Finally, it is important to consider surface and geometrical surface textures of rubber flooring mates for appropriate walking friction for reducing slip and falls.

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