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PREVENTION OF SLIP ACCIDENTS BY USING RUBBER FLOOR MAT

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ABSTRACT

There is an increasing demand to eliminate slip and fall in bathrooms. Wet ceramic surfaces usually promote slips and occasionally lead to indoor accidents. The present work aims to test the frictional behaviour of rubber mats made of recycled rubber and filled by polyurethane of different hardness to have specific information about their friction coefficient and evaluate their performance in increasing friction coefficient at dry, water, detergent wetted flooring. The presence of dust contaminating the floorings was tested.

It was found that at dry sliding, friction coefficient slightly decreased with increasing the hardness of the rubber mats. As the load increased friction coefficient decreased. Sliding against water as well as detergent wetted rubber mats showed the same trend observed for dry sliding. In the presence of sand particles, friction coefficient significantly decreased with increasing the hardness for lower loads. As the load increased friction coefficient showed slight increase with increasing hardness of the tested mats. At water wetted and sand contaminated rubber mats, the variation of friction coefficient with increasing the hardness of the tested rubber mats was significant. Compared to ceramic and polymeric tiles rubber mats showed the highest friction in all the sliding conditions tested in the present work. Besides, sliding against ceramic tiles showed very low friction values which resemble an increasing incidence of slip and falling. As accident prevention and slip resistance point of view, the values of friction coefficient displayed by the tested mats guarantee safe walking. In addition, wear significantly increased with increasing the hardness of the rubber mats. As the load increased wear increased. Based on the wear results it is recommended to use rubber of relatively lower hardness.

INTRODUCTION

The major factor in occupational walking accidents in bathrooms is the low static friction coefficient resulted from bare foot sliding on flooring tiles. The presence of water and detergent drastically decreases the friction coefficient between bare foot and flooring tiles. The probability of slip increases and consequently accidents occur. The risks associated with slipping and falling are related to the materials of floor, contamination condition, and geometric design of the sole. Floor slip-resistance may be quantified using the static coefficient of friction. In the USA, the static coefficient of friction of 0.5 has been recommended as the slip-resistant standard for unloaded, normal walking conditions [1]. Higher the static coefficient of friction values may be

required for safe walking when handling loads. In Europe, [2], it was suggested that a floor was ‘‘very slip-resistant’’ if the coefficient of friction was 0.3 or more. A floor with the coefficient of friction between 0.2 and 0.29 was ‘‘slip resistant’’. A floor was classified as ‘‘unsure’’ if its coefficient of friction was between 0.15 and 0.19. A floor was ‘‘slippery’’ and ‘‘very slippery’’ if the coefficient of friction was lower than 0.15 and 0.05, respectively. The subjective ranking of floor slipperiness was compared with the static coefficient of friction (μ) and found that the two measures were consistent, [3, 4]. It was concluded that human subjects could discriminate floor slipperiness reliably. Many state laws and building codes have established that a static $\mu \geq 0.50$ represents the minimum slip resistance threshold for safe floor surfaces. Furthermore, the Americans with Disabilities Act Accessibility Guidelines [5] contain advisory recommendations for static coefficient of friction of $\mu \geq 0.60$ for accessible routes (e.g. walkways and elevators) and $\mu \geq 0.80$ for ramps.

Soft material like rubber tends to a higher effective contact area and more pronounced microscopic deformations when mechanically interacting with the surface asperities of a rigid material, greater friction coefficients can be expected for rubber than for plastic, [6]. This was found in the friction measurements under wet conditions. In general, rubber friction is divided into two parts; the bulk hysteresis and the contact adhesive term. These two contributions are regarded to be independent of each other, but this is only a simplified assumption, [7].

Friction measurement is one of the major approaches to quantify floor slipperiness. Investigations on friction measurement have been focused on liquid-contaminated conditions. It was expected that wet surfaces had significant lower friction coefficient values than those of the dry surfaces, [8]. The friction coefficient difference between the dry and wet surfaces depended on the footwear material and floor combinations. Friction measurements under liquid-contaminated conditions were very common. The squeeze film theory explains the effects of the liquid on the measured friction.

Measurements of the static friction coefficient between rubber specimens and ceramic surfaces were carried out at dry, water lubricated, oil, oil diluted by water and sand contaminating the lubricating fluids, [9 - 12]. It was observed that, dry sliding of the rubber test specimens displayed the highest value of friction coefficient. For water lubricated ceramics, the value of the friction coefficient decreased compared to dry sliding. For oil lubricated ceramic, friction coefficient decreased with increasing height of the grooves introduced in the rubber specimens. 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.

The factors affecting friction coefficient measurement: the material and surface geometry of the footwear and floor, floor contamination conditions and even the slipmeter used, [13 - 15]. Investigators have concentrated the friction coefficient measurements on liquid contaminated floors because most slip/fall incidents occur on the surfaces of such floors, [16 - 19]. When stepping on a wet or lubricated floor, a shoe sole cannot touch the floor surface without squeezing the liquid out of the contact area. The liquid between the floor and the sole isolates the two contact surfaces, thus reducing the friction between them. The liquid drainage time between the two contact surfaces depends on the viscosity and pressure between the two surfaces. The higher the viscosity is, the longer the time is required for the film thickness to decrease, [20]. A longer

drainage time increases the risk of slipping due to the short time available to prevent a slip after the heel touches the floor.

The effect of surface roughness of ceramic on the friction coefficient, when rubber and leather are sliding against it, was investigated, [21]. 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.

Glazed ceramics tiles are extensively used as flooring materials. The increasing demand to enhance the degree of surface roughness of the tiles to facilitate for the consumer the cleaning process should be balanced by investigating the effect of surface roughness on the friction coefficient. Slips and falls are a serious problem due to the annual direct cost of occupational injuries, [22]. It was found that a higher friction could potentially improve slip resistance as discussed previously, [23 - 29]. It was observed that dynamic friction is more applicable to human walking than static friction. Surface roughness also plays a role in floor slipperiness even in hydrodynamic squeeze-film sliding, [30], where it was investigated that certain surface roughness is needed to improve slip resistance.

Tread groove designs are helpful in facilitating contact between the shoe sole and floor on liquid contaminated surface, [31]. The effectiveness of a tread groove design depends on the contaminant, footwear material and floor. Tread groove design was ineffective in maintaining friction on a floor covered by vegetable oil. Tread grooves should be wide enough to achieve better drainage capability on wet and water–detergent contaminated floors.

The effect of rubber flooring, provided by cylindrical treads on the friction coefficient, was investigated, [32]. 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, [33]. 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.

The friction coefficient of rubber sliding against different types of flooring materials of different surface roughness was investigated under different sliding conditions: dry, water, water/detergent dilution, oil, water/oil dilution, [34]. The flooring materials are parquet, polyvinyl chloride (PVC), epoxy, marble, cement and ceramic. It was found that sliding of rubber against water/detergent wetted tiles caused drastic decrease of friction coefficient. Parquet displayed the highest friction values followed by cement and marble. PVC, epoxy and ceramic represented relatively lower friction values.

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 was investigated, [35]. 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.

The effect of holes and leakage grooves introduced in cylindrical protrusion of the rubber flooring mats on the static friction coefficient of rubber footwear under dry, water, water + 5.0 vol. % soap, oil and water + 5.0 vol. % oil lubricated sliding conditions was tested, [36]. At dry sliding, friction coefficient increased with increasing number of holes and grooves. 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 behavior related to the easy escape of water through the holes and grooves out of the contact area.

In the present work, rubber mats of different hardness were tested through sliding of bare foot against them to determine friction coefficient at dry, water, detergent and sandy sliding conditions.

EXPERIMENTAL

Experiments were carried out using a test rig designed and manufactured to measure the friction coefficient displayed by the sliding of the bare foot against the polymeric bathroom mat through measuring the friction force and applied normal force. The bathroom mat were placed in a base supported by two load cells, the first can measure the horizontal force (friction force) and the second can measure the vertical force (applied load). Friction coefficient was determined by the ratio between the friction force and the normal load. The arrangement of the test rig is shown in Fig. 1.

The tested rubber mats were made of recycled rubber filled by coloured polyurethane, Table 1. Their hardness ranged between 52 – 77 Shore A. The mats in form of 300 × 300 mm and 10 mm thickness tiles were adhered to the base of the test rig. Friction test was carried out using bare foot applying variable forces up to 800 N. The friction values were extracted from the figure indicating the friction coefficient at 200, 400, 600 and 800 N. The bare foot was loaded against dry, water and water + 1.0 vol. % detergent wetted mat. Water was replenished on the tested mat, where the amount of water for each replenishment was 300 ml to form consistent water film covering the mat surface. In the water–detergent condition, a 1.0 vol. % detergent solution was applied to the tiles. After

each measurement, all contaminants were removed from the tiles surface and bare foot using absorbent papers. Both the bare foot and tested tiles were then rinsed using water and dried by using hair dryer after the cleaning process.

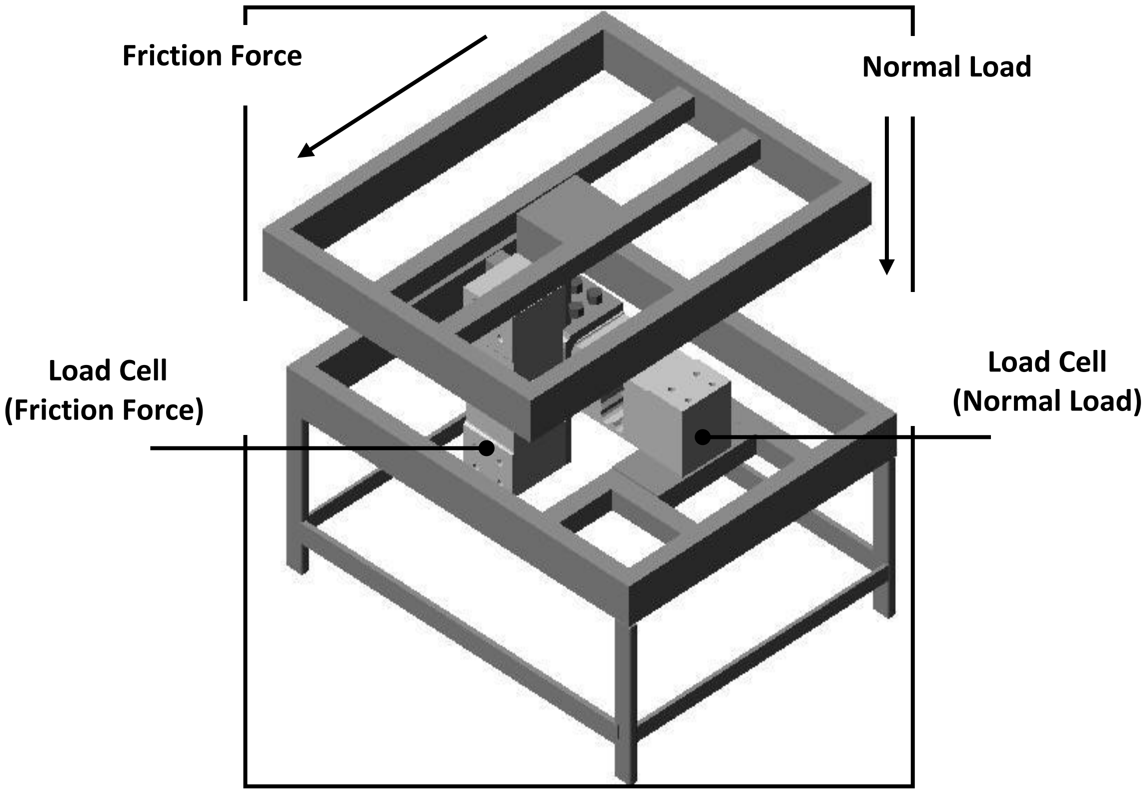


Fig. 1 Arrangement of the test rig.

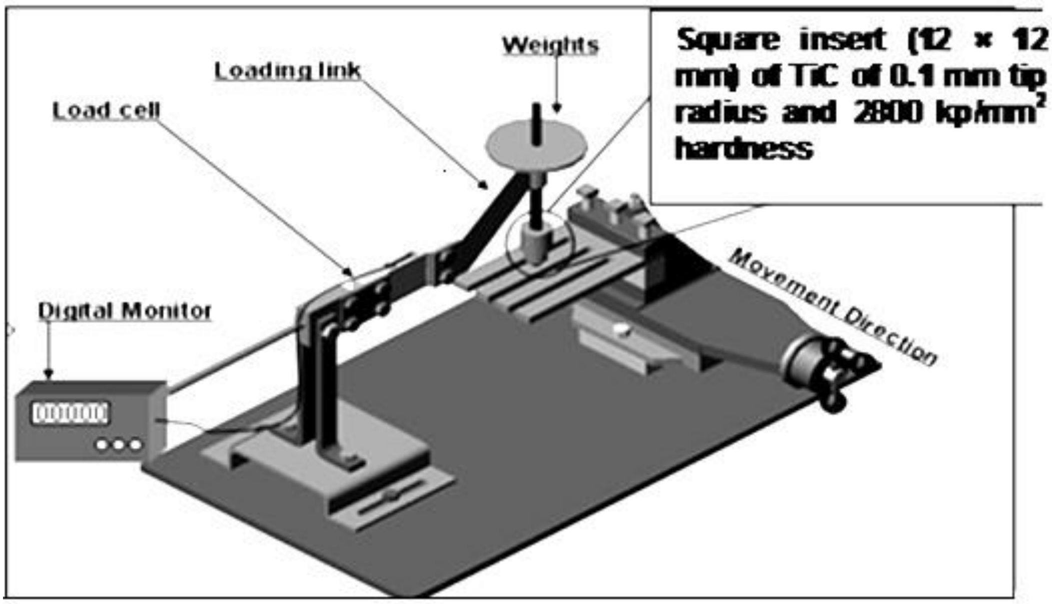
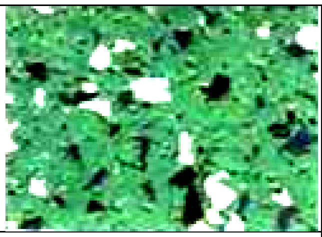
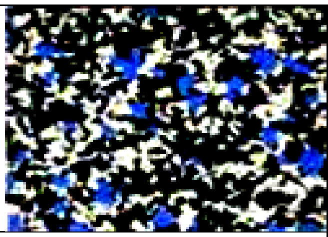
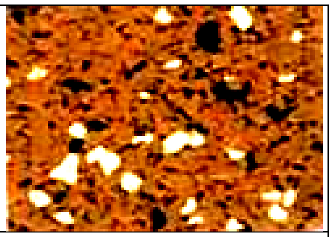


Fig. 2. Scratch test rig.

Table 1 The tested rubber mats.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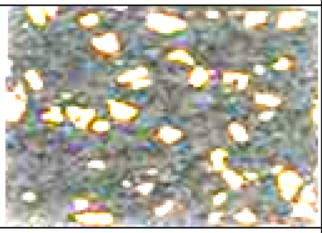	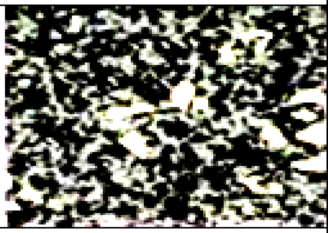	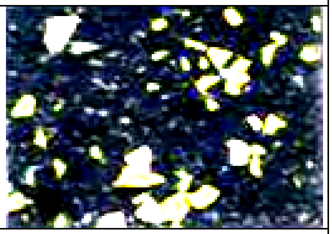
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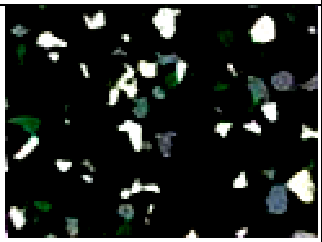	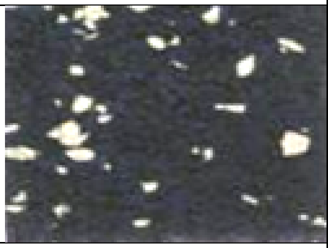	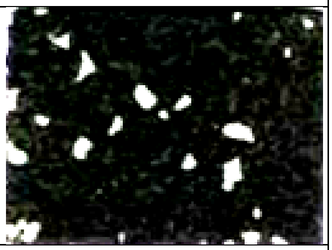
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	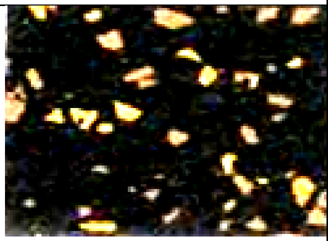	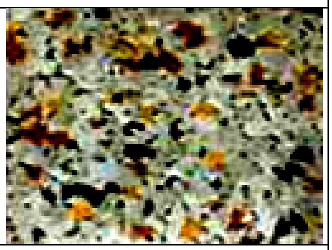
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	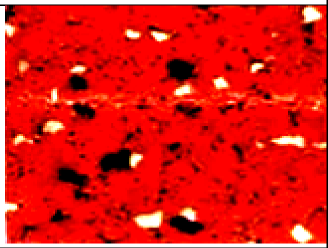	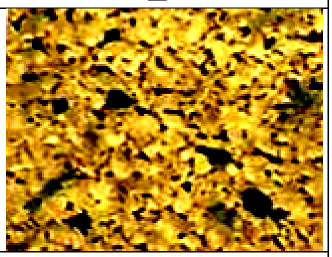
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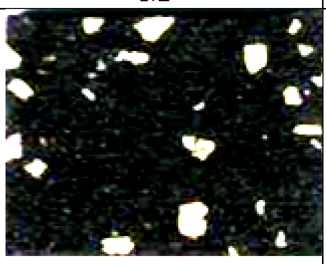	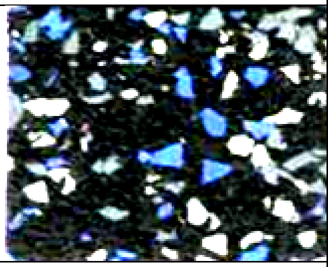	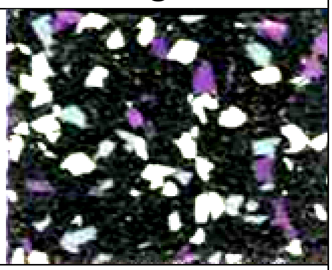
P	**Q**	**R**

The test rig, used in the wear experiments was top scratching tester equipped with an indenter to produce a scratch on a flat surface with 20 strokes 20 mm each. The details of the test rig are shown in Fig. 2. The indenter, used in experiments, was a square insert

(12 × 12 mm) of Ti C of 0.1 mm tip radius and 2800 kp/mm^2 hardness. The scratch force was measured by the deflection of load cell. The ratio of the scratch force to the normal force was considered as friction coefficient. Wear was determined by the weight loss after the test. The weight loss was measured by digital balance with an accuracy of ± 1.0 mg. The load was applied by weights. The test speed was nearly controlled by turning the power screw feeding the insert into the scratch direction. The applied load values were 2, 4, 6, 8 and 10 N.

RESULTS AND DISCUSSION

The results of the experiments to determine friction coefficient displayed by the sliding of bare foot against the tested rubber mats are shown in Fig. 2. Friction coefficient slightly decreased with increasing the hardness of the rubber mats. As the load increased friction coefficient decreased. At load of 600 N friction coefficient displayed the lowest value of 0.26 at 77 Shore A hardness of the rubber mat.

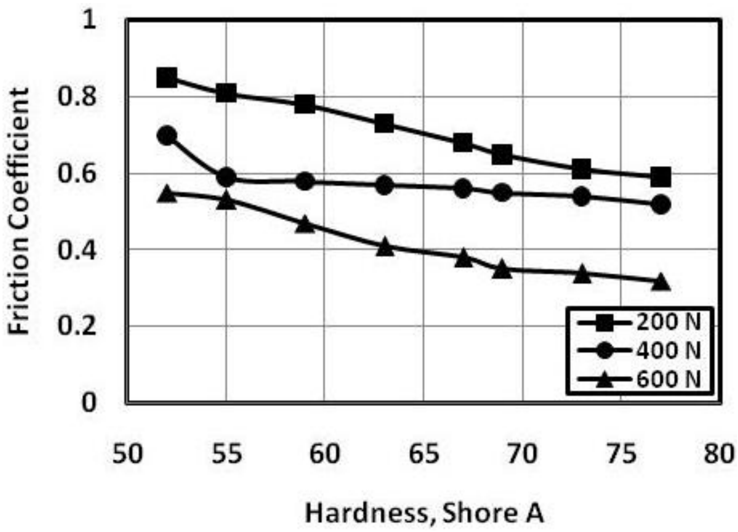

Fig. 2 Friction coefficient of bare foot sliding against dry rubber mat.

Friction coefficient of bare foot sliding against water wetted rubber mat is shown in Fig. 3. At low hardness rubber, friction coefficient displayed relatively higher values then decreased with increasing the hardness. This relatively high friction is attributed to the very low elastic modulus of rubber and its high internal friction. It seems that soft rubber easily deformed and allowed the water to escape away from the contact area. This behaviour can be attributed to the fact that water film trapped between rubber footwear and the tested pads increased as the hardness of the surface material increased. In this condition, a part of the contact area performed under dry friction and the other was water lubricated. Both bare foot/pad and footwear/pad displayed the same values of friction coefficient. The relatively soft rubber easily deformed and consequently washed away water from the contact area.

In the presence of detergent on the sliding surface, friction coefficient drastically decreased, Fig. 4. At 600 N load sliding showed very low friction values. The friction values observed for ceramic tiles made the sliding as slipper and very slippery which resemble an increasing incidence of slip and falling, [9 - 12]. As accident prevention and slip resistance point of view, the values of friction coefficient displayed by the tested mat guarantee safe walking. It seems that the detergent which is a formulation comprising essential constituents such as surface active agents reacted with the fatty acids of foot. The mechanism of action may be explained on the basis that when the detergent is dissolved or dispersed in the water is preferentially absorbed at the sliding surfaces, giving rise to the growth of a film of detergent molecules which absorb fatty acids and perspiration from the skin of bare foot so that the contact remains between foot and flooring. The roughness in the surface of the tested mat were responsible of breaking the film covering the sliding surface and consequently increased the contact between the bare foot and the tested mat. Besides, it seems that the electrical properties of the polymeric materials increased the adhesion force between bare foot and the tested mat.

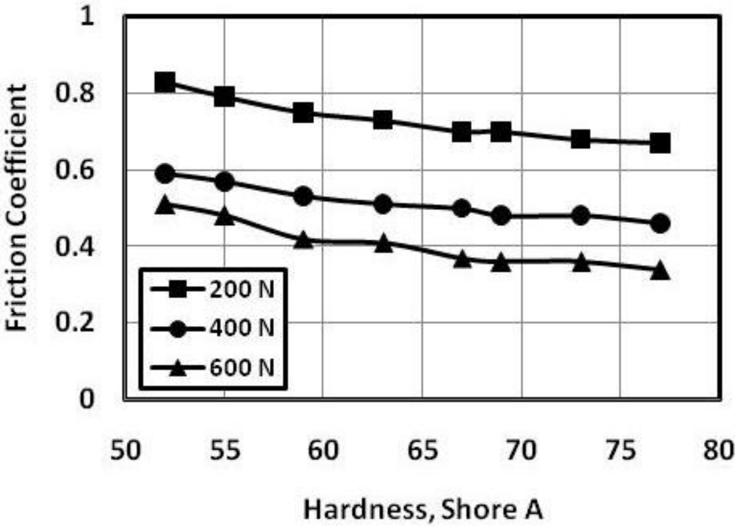

Fig. 3 Friction coefficient of bare foot sliding against water wetted rubber mat.

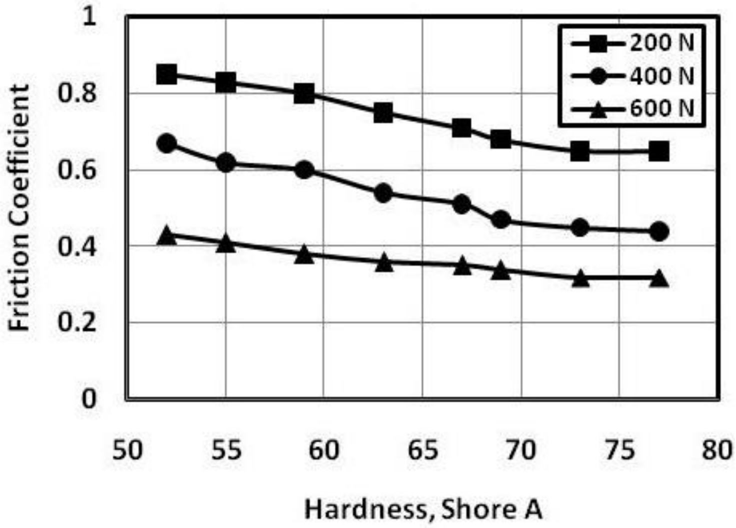

Fig. 4 Friction coefficient of bare foot sliding against detergent wetted rubber mats.

In the presence of sand particles between the foot and the tested pads, friction coefficient significantly decreased with increasing the hardness up to 67 Shore A, Fig. 5, for 200, 400 N load. As the load increased up to 600 N, friction coefficient showed slight increase with increasing hardness of the tested mats. The friction behaviour can be explained on the basis that sand particles trapped between the two rubber surfaces had two mechanisms of action; rolling and embedment. The action of sand depends on the relative hardness of the two contacting surfaces. When the hardness of the contact surfaces is the same, sand particles tend to roll. If one surface has higher hardness than the other sand particles tend to embed in the softer surface and abrade the other. When bare foot slid against the tested rubber pad, sand particles were embedded in the skin and decreased the contact area of bare foot/pad, while footwear/pad contact permitted the sand particles to roll and consequently friction coefficient decreased. At relatively lower hardness, embedment of sand particles was prevailing, so that friction coefficient increased. As the hardness of the tested pads increased, sand particles tended to roll on the rubber and embed in the skin of the bare foot and consequently the contact area of both rubber mats and skin of the bare foot decreased.

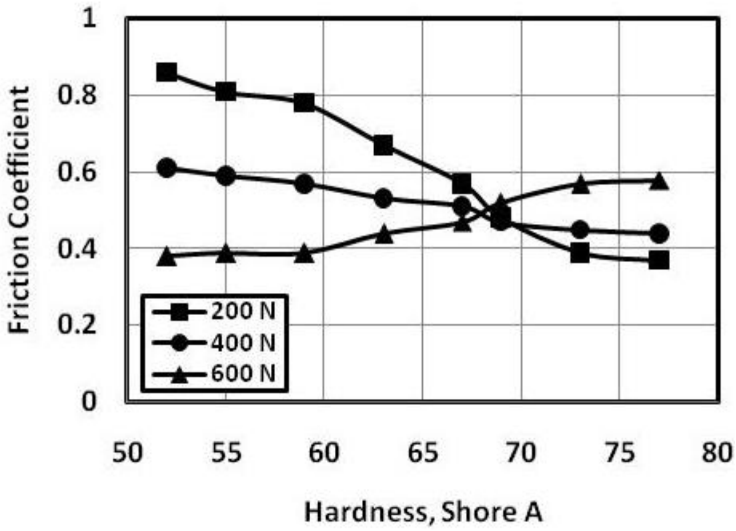

Fig. 5 Friction coefficient of bare foot sliding against sand contaminated rubber mats.

Friction coefficient of bare foot sliding against water wetted and sand contaminated rubber mat is illustrated in Fig. 6. Variation of friction coefficient with increasing the hardness of the tested rubber mats was significant. It seems that presence of water retarded the embedment of sand particles in the two sliding surfaces. The condition of the sliding was mixed lubrication in which the two sliding surfaces were partially separated by water film contaminated by sand particles. Friction coefficient slightly decreased with increasing load. It seems that as the sand particles deeply embedded in the rubber and foot skin the contact area between rubber and foot increased. The decreased embedment of sand particles may be from the relatively higher hardness of the tested flooring materials (77 Shore A).

Wear significantly increased with increasing the hardness of the rubber mats, Fig. 7. It seems that as the hardness of the tested materials increases the elastic deformation of the flooring decreases and consequently abrasive wear of the tested flooring materials increases. This behaviour can be explained on the basis of the elastic deformation in front and sides of the wear track accompanied to the scratch process. As the hardness of the scratched surface increased the deformation decreased and the material removed increased. As the load increased wear increased. Based on the wear results it is recommended to use rubber of relatively lower hardness.

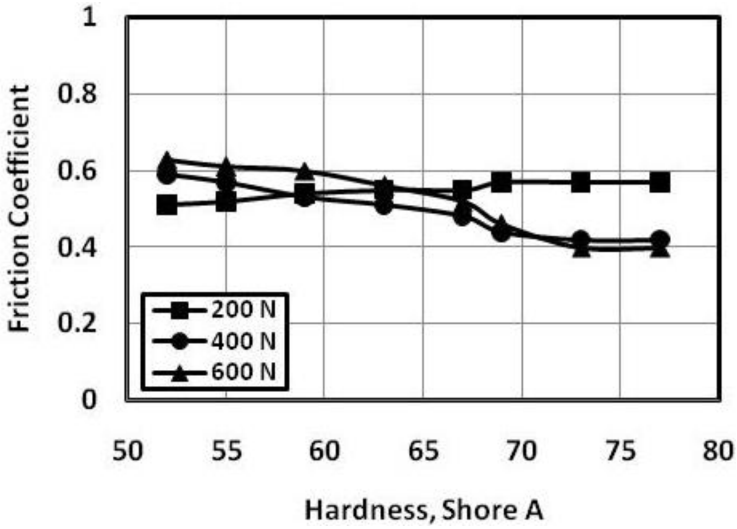

Fig. 6 Friction coefficient of bare foot sliding against water wetted and sand contaminated rubber mats.

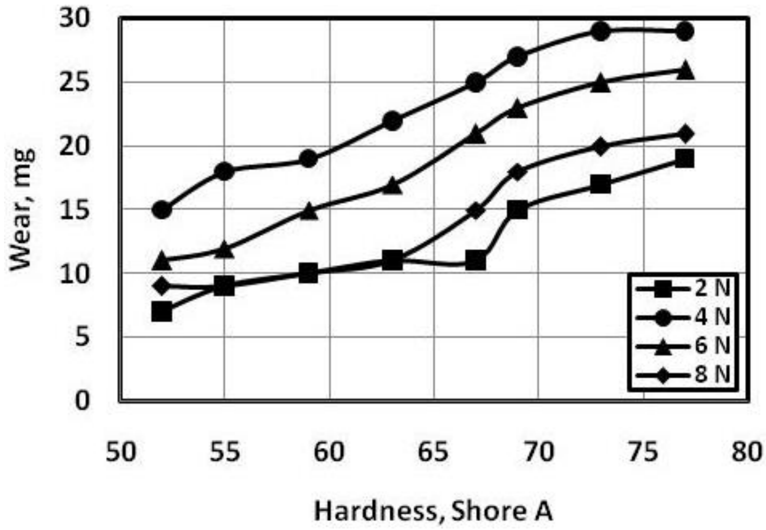

Fig. 7 Wear of the tested rubber mats.

The results of the comparative performance of rubber mats, ceramic and polymeric tiles are shown in Figs. 8 – 12. At dry sliding, friction coefficient decreased with increasing load, Fig. 8. Rubber mats showed the highest friction compared to ceramic and polymeric tiles. This behaviour might be from the rubber deformation which increased the adhesion between rubber and foot skin. The deformation of rubber was responsible for the increase of friction coefficient.

Friction coefficient of bare foot sliding against water wetted flooring materials is illustrated in Fig. 9. Sliding against water wetted flooring materials showed significant decrease in friction coefficient, Fig. 9. Generally, friction coefficient decreased with increasing load. This behavior can be attributed to the fact that as the hardness increases the deformation of the flooring materials increases and consequently the area of the water film trapped between foot and flooring increases. In this condition, a part of the contact area will be performed under dry friction and the other will be water lubricated. At 800 N values of friction coefficient were 0.47, 0.43 and 0.2 for rubber,

polymeric and ceramic tiles respectively. Concentrating in the value of friction coefficient at load of 800 N, it should be noted that it is lower than the minimum slip resistance threshold for safe floor surfaces when sliding against ceramic flooring.

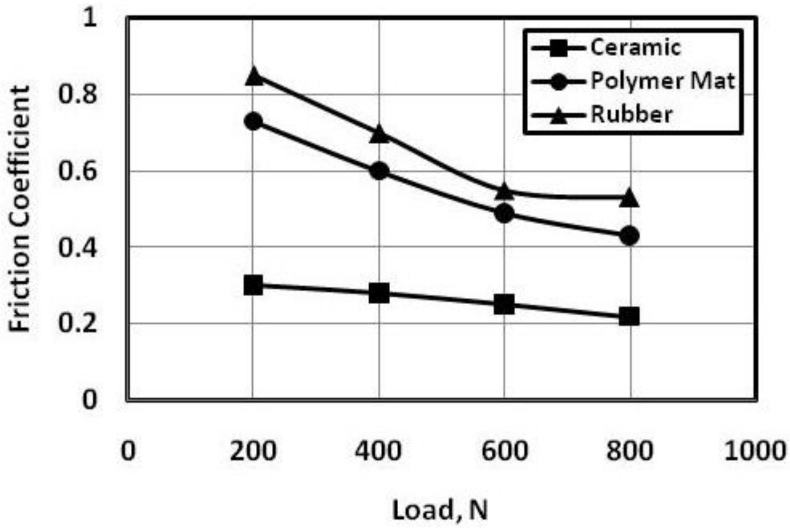

Fig. 8 Friction coefficient of bare foot sliding against dry flooring materials.

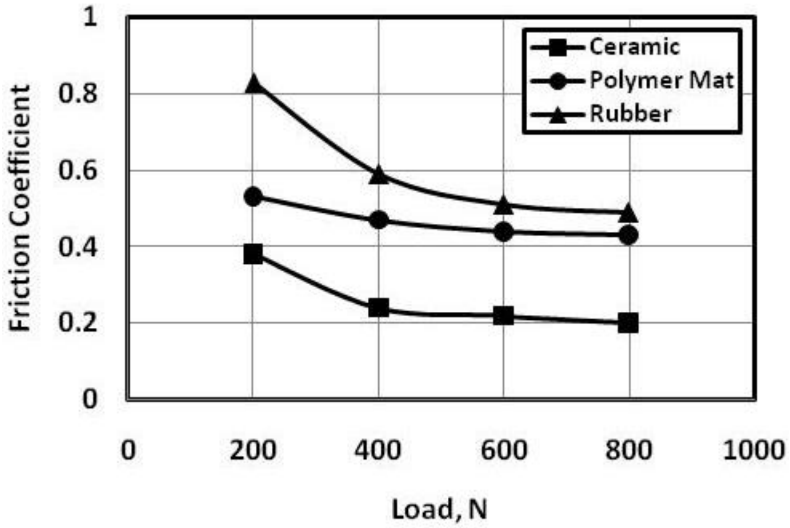

Fig. 9 Friction coefficient of bare foot sliding against water wetted flooring materials.

In the presence of detergent between the sliding surfaces, friction coefficient drastically decreased to values lower than that displayed by water, Fig. 10. At load of 800 N, friction coefficient value was 0.05 for ceramic tiles which represented very slippery sliding condition, while friction coefficient showed value of 0.4 for rubber tiles.

Presence of sand particles on the flooring friction coefficient decreased as the load increased. The performance may be from the increased embedment of sand particles with increasing the load so that foot/sand and rubber/sand contact increased, Fig. 11, at the expense of foot/rubber contact. The relatively high friction values observed for rubber mats especially at lower load confirmed their suitability to be used as flooring materials.

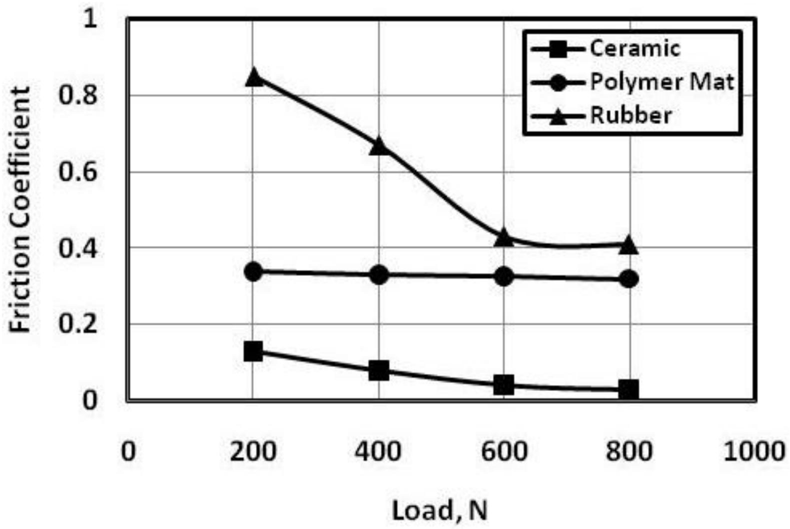

Fig. 10 Friction coefficient of bare foot sliding against detergent wetted flooring materials.

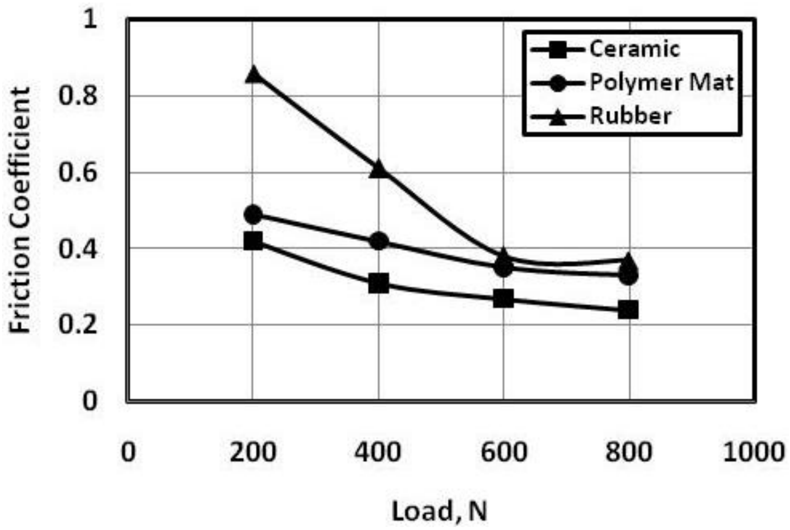

Fig. 11 Friction coefficient of bare foot sliding against sand contaminated flooring materials.

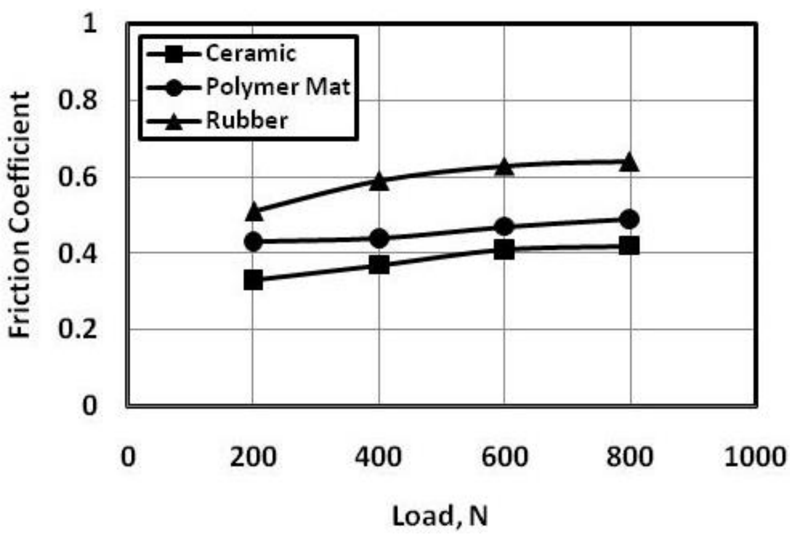

Fig. 12 Friction coefficient of bare foot sliding against water wetted and sand contaminated flooring materials.

When the sliding surfaces were wetted by water and contaminated by sand particles, friction coefficient showed an increasing trend with increasing load, Fig. 11. It seems that presence of sand particles broke water film formed on the sliding surface so that the contribution of hydrodynamic effect exerted by water decreased. In this condition, the contact can be classified as foot skin/rubber, foot skin/sand particles, rubber/sand particles, foot skin/water and rubber/water.

CONCLUSIONS

Based on the experimental observations the following conclusions can be withdrawn:

1. At dry sliding, friction coefficient slightly decreased with increasing the hardness of the rubber mats. As the load increased friction coefficient decreased.
2. Sliding against water wetted surface showed that at low hardness rubber, friction coefficient displayed relatively higher values then decreased with increasing the hardness.
3. In the presence of detergent on the sliding surface, friction coefficient drastically decreased with increasing rubber hardness.
4. In the presence of sand particles between the foot and the tested mats, friction coefficient significantly decreased with increasing the hardness for 200, 400 N load. As the load increased up to 600 N, friction coefficient showed slight increase with increasing hardness of the tested mats.
5. At water wetted and sand contaminated rubber mats, the variation of friction coefficient with increasing the hardness of the tested rubber mats was significant.
6. Rubber mats showed the highest friction compared to ceramic and polymeric tiles in all the sliding conditions used in the present work.
7. Wear significantly increased with increasing the hardness of the rubber mats. As the load increased wear increased. Based on the wear results it is recommended to use rubber of relatively lower hardness.

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