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INCREASING THE SAFETY OF WALKING ON RUBBER FLOOR MAT

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ABSTRACT
The present research investigates friction coefficient of bare foot sliding against four types of rubber floor mats to simulate the sliding conditions in bathrooms. Tests were carried out at dry and detergent wetted mats. Friction tests were carried out at different values of normal load. The rubber flooring mats were coated by an adhesive to investigate its effect on increasing friction coefficient.

Based on the experimental results, it was found that, the tested coated mats significantly increased friction coefficient at dry and detergent wetted sliding. Mat (A) displayed the highest friction coefficient due to the presence of rubber protrusions at dry and detergent wetted sliding, while mat (D) displayed the lowest values of friction coefficient. It was noted that the presence of protrusions in the surface of mat (B) was responsible for increasing friction coefficient. At detergent wetted sliding, a drastic friction decrease for uncoated mat (B) was observed. At dry sliding, mat (D), of smooth surface, showed consistent trend with increasing load, while at detergent wetted sliding, it showed relatively lower friction than the mats (A), (B) and (C) due to the absence of protrusions. The effect of adhesive on the surface of the rubber mat (D) was significant in increasing friction coefficient.

KEYWORDS
Friction coefficient, bare foot, rubber floor mats, adhesive coated mat.

INTRODUCTION
The slip and fall accidents in bathrooms are caused by the low static friction coefficient resulted from bare foot sliding on detergent wetted flooring tiles. The presence of water and detergent drastically decreases the friction coefficient. The risks associated with slip and fall 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. The frictional behaviour of rubber mats made of recycled rubber and filled by polyurethane of different hardness was tested 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, [1]. It was found that at dry sliding, friction coefficient slightly decreased

with increasing the hardness of the rubber mats. 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.

It was aimed to test the frictional behavior of rubber semi-spherical balls of different diameter and hardness to have specific information about their friction coefficient and evaluate their performance in increasing friction coefficient at dry, water, detergent wetted and oil lubricated floorings, [2]. The tested semi-spherical rubber protrusions were aimed to be used as protrusions in the rubber mat. It was found that friction coefficient drastically decreased with increasing hardness when sliding against water, detergent and oil lubricated rubber. Significant increase with increasing the diameter of the semi-spherical protrusions was observed. This behavior depended on the ability of the semi-spherical protrusion to allow the water to escape from the contact area, where the contact was between rubber against rubber interfaces.

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, [3]. The friction coefficient difference between the dry and wet surfaces depended on the footwear material and floor combinations. Friction measurements under liquid-contaminated conditions are 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 tested mats surfaces were carried out at dry, water lubricated, oil, oil diluted by water and sand contaminating the lubricating fluids, [4 - 7]. 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 include the material and surface geometry of the footwear and floor, floor contamination conditions and the slip meter used, [8 - 10]. Investigators have focused the friction coefficient measurements on liquid contaminated floors because most slip/fall incidents occur on the surfaces of such floors, [11 - 14]. When stepping on a wet or lubricated floor, a mat 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 leaking or 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, [15]. A longer leaking time increases the risk of slipping due to the short time available to prevent a slip after the heel touches the floor.

Tread groove designs are helpful in facilitating contact between the mat sole and floor on liquid contaminated surface, [16]. 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 with cylindrical treads on the friction coefficient was investigated, [17]. It was found that 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 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 mat sole, on the friction coefficient between the mat and ceramic floor interface, was discussed, [18]. 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.

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, [19]. 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 obtained during 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, [20]. 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, [21]. 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.

Recently, flooring tiles made of recycled rubber were tested, [22 - 24]. The effect of surface roughness on the frictional behavior of recycled rubber tiles was discussed. It was found that, for tiles made of recycled rubber, surface roughness had insignificant effect on the frictional behavior. Friction coefficient slightly increased with increasing the tile thickness. In the presence of water on the sliding surface, rough surface displayed higher friction values than the smooth one. Values of friction for detergent lubricated surfaces were lower than that observed for water lubricated surface. At dry sliding, friction coefficient slightly increased with increasing the content of the filling

materials. At water lubricated sliding, friction coefficient significantly decreased with increasing filling material content. Detergent decreased friction coefficient lower than water. The lowest friction values were observed for tiles filled by 70 wt. % polyurethane.

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, [25]. 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, [26]. 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.

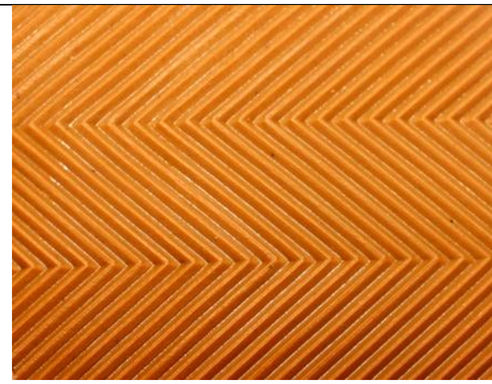
In the present work, the effect of coating the tested rubber mats by an adhesive on friction coefficient at dry, and detergent sliding conditions was investigated.

EXPERIMENTAL

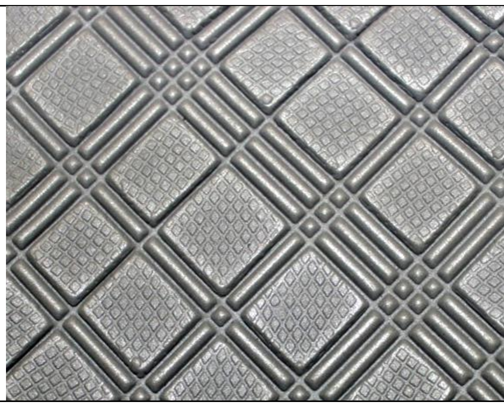
The test rig, used in the present work, was designed and manufactured to measure the friction coefficient displayed by the sliding of bare foot against the tested mats through measuring the friction and normal forces, [1]. The tested mats in form of a tile of 400 × 400 mm and 6 mm thickness were placed in a base supported by two load cells to measure the horizontal force (friction force) and the vertical force (applied load). Two digital screens were attached to the load cells to detect the friction and vertical forces. Friction coefficient was determined by the ratio between the friction force and the normal load.

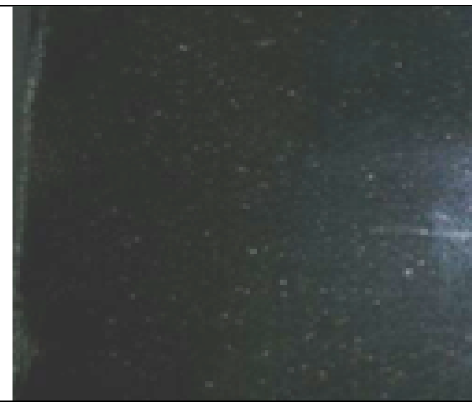
The test specimens were four types of indoor rubber mats (A, B, C and D), Table 1. Bare foot was loaded against dry and detergent wetted mats surfaces. The concentration of the detergent was 5.0 vol. % in water. The tested rubber mats were coated by an adhesive to increase friction coefficient. The proposed adhesive used to coat the sliding surfaces mainly contains alcohol denat dimethyl ether and hydroxyisohexyl 3-cuclohexene carboxaldehyde.

Table 1 Surfaces of the tested rubber mats.



Mat (A).	Mat (B).





Mat (C).	Mat (D).

RESULTS AND DISCUSSION

The results of experiments carried out to measure friction coefficient displayed by bare foot sliding against dry and detergent wetted mats are illustrated in Figs. 1 – 10. At dry sliding, mat (A) displayed the highest friction coefficient due to the presence of the rubber protrusions, Fig. 1. Mat (D) displayed the lowest values of friction coefficient. It seems that presence of protrusions increased the rubber deformation and consequently friction coefficient increased. Generally, friction coefficient decreased as the load increased.

At detergent wetted sliding, mat (A) displayed the highest friction coefficient due to the squeeze action exerted by the pockets introduced in the sliding surface, Fig. 2. Mats (D) displayed the lowest values of friction coefficient as a result of presence of the detergent film. The presence of the treads in the rubber surface of mats (A), (B) and (C) allowed the fluid to escape out of contact area and made the contact between foot skin and rubber effective. As the contact area of the groove increased friction coefficient increased.

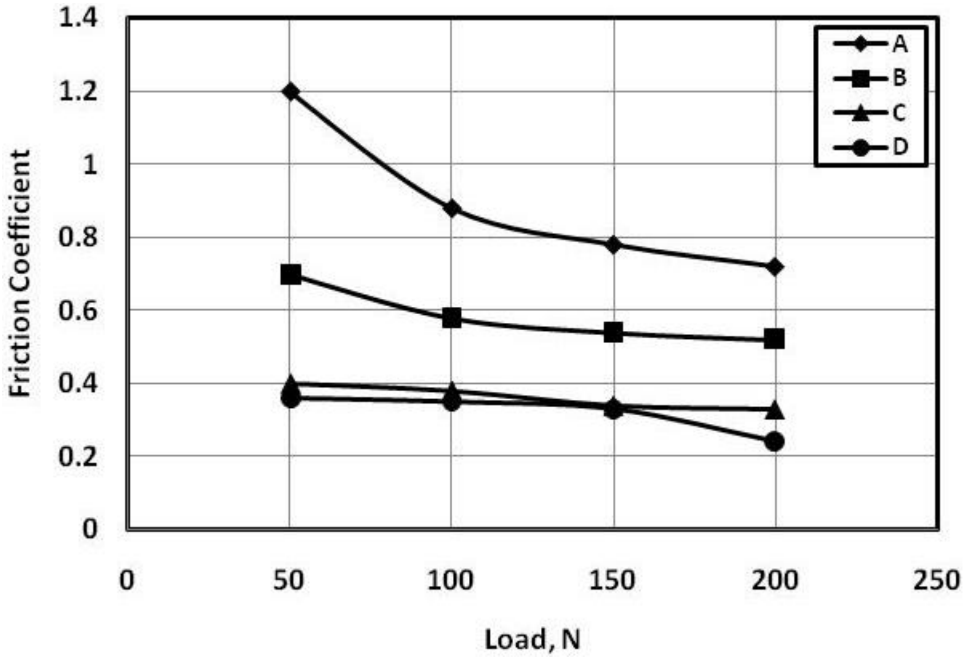


Fig. 1 Friction coefficient displayed by bare foot dry sliding against the tested mats.

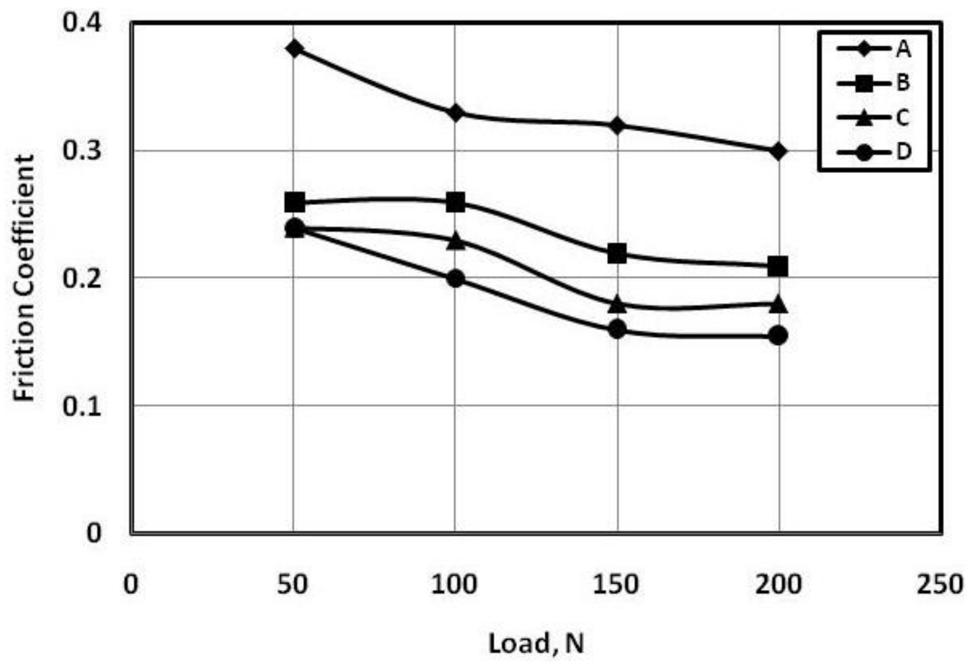


Fig. 2 Friction coefficient displayed by bare foot sliding against the detergent wetted tested mats.

At dry sliding, mat (A) when coated by adhesive displayed friction coefficient higher than that displayed by uncoated mat due to the increase of the adhesion of the two sliding surfaces and consequently friction coefficient increased, Fig. 3. Friction coefficient increased as a result of the coating from 0.86 to 1.06 and from 0.68 to 0.92 at 50 and 200 N load respectively.

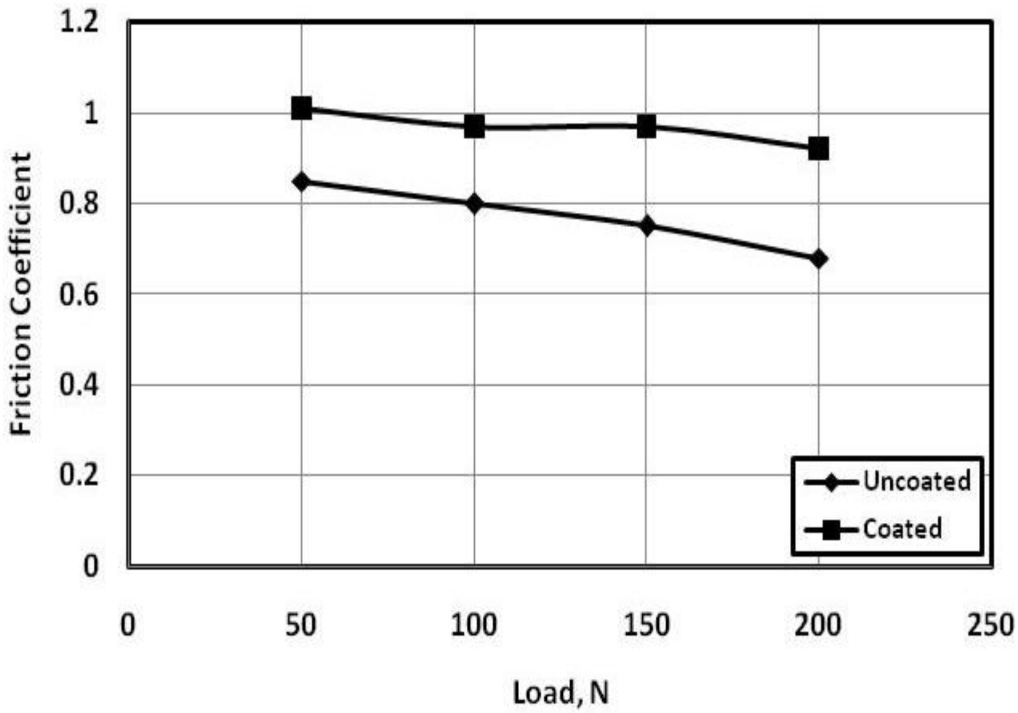


Fig. 3 Friction coefficient displayed by bare foot sliding against dry mat (A).

At detergent wetted sliding, significant friction increase was observed for coated mat (A) which displayed friction coefficient higher than uncoated mat because adhesive had increased the adhesion force between the two sliding surfaces, Fig. 4. Friction increased from 0.39 to 0.62 at 50 N load. It seems that the adhesive film prevented the detergent molecules to be adhered into the rubber surface. Based on the quantification of floor slip-resistance, the static friction coefficient of 0.5 has been recommended as the slip resistant standard for normal walking conditions. Besides, it was suggested that a floor was ''very slip-resistant'' if the friction coefficient was 0.3 or more. Besides, higher static friction coefficient values may be required for safe walking when handling loads.

At dry sliding, mat (B) when coated by adhesive displayed friction coefficient higher than that observed for uncoated mat due to the increase of rubber adhesion into foot skin surface, Fig. 5. The protrusions of the surface were responsible for the relatively high friction coefficient, where the value reached 1.25 at 50 N load. That performance suggests using this mat to reduce the risk of slip. based on the readings of mat (B), the safe walking for accessible routes (e.g. walkways and elevators) and ramps can be obtained.

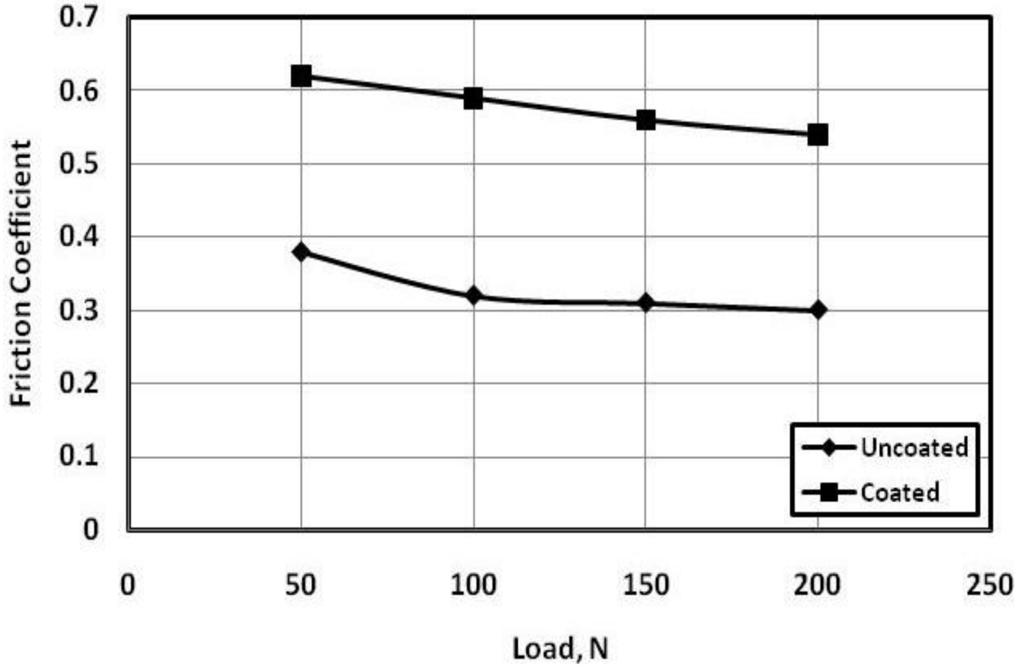


Fig. 4 Friction coefficient displayed by bare foot sliding against detergent wetted mat (A).

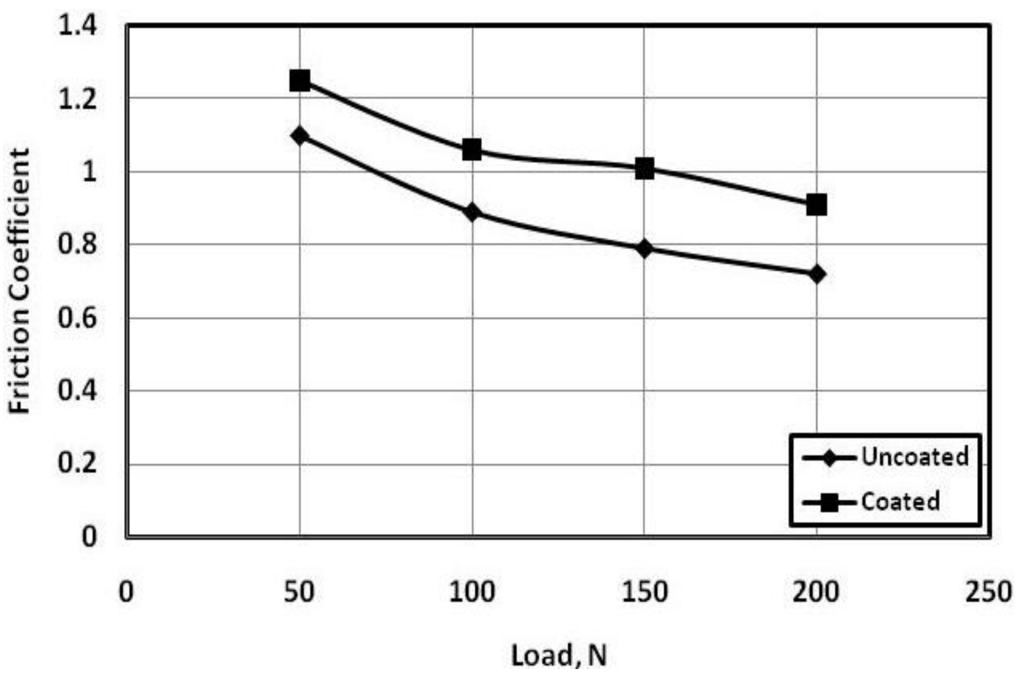


Fig. 5 Friction coefficient displayed by bare foot sliding against dry mat (B).

At detergent wetted sliding, friction coefficient displayed by mat (B) displayed lower friction values than that observed for dry sliding, where the mat coated by adhesive displayed friction coefficient higher than uncoated mat, Fig. 6. The difference in friction for coated and uncoated mats increased with increasing normal load. The drastic friction decrease for uncoated mat (B) was attributed to the formation of continuous detergent fluid film on mat surface, while the coated rubber surface showed consistent

friction coefficient with increasing load. Mat (B) showed lower friction values than that displayed by mat (A) at detergent wetted sliding due to the difference in the formality of the surface protrusions.

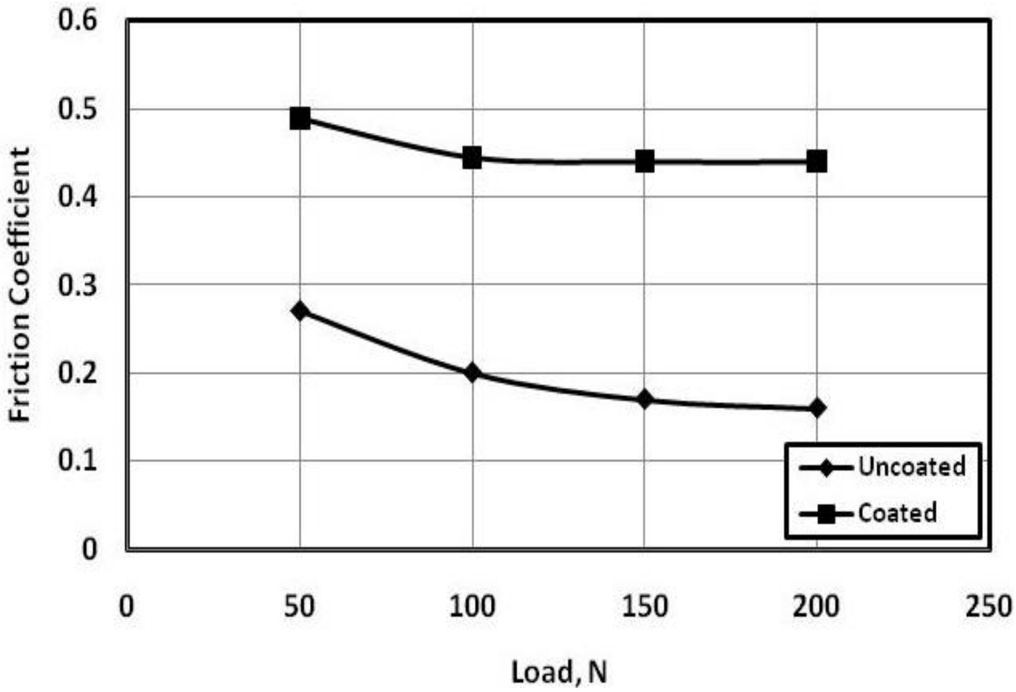


Fig. 6 Friction coefficient displayed by bare foot sliding against detergent wetted mat (B).

Mat (C) when coated by adhesive displayed friction coefficient higher than uncoated mat due to the increase of the adhesive force between the two contact surfaces, Fig. 7, at dry sliding. The values of friction coefficient were relatively lower than that displayed by mats (A) and (B). This behaviour can be explained on the fact that the flat area of rubber surface represented higher fraction than mats (A) and (B), so that the amount of surface deformation would be lower and consequently friction coefficient decreased.

At detergent wetted sliding, coated mat (C) by adhesive displayed friction coefficient more than uncoated mat due to the good interaction between adhesive and the foot skin, Fig. 8, where friction coefficient showed consistent trend with increasing load. It seems that presence of the flat area enabled the adhesive to perform efficiently.

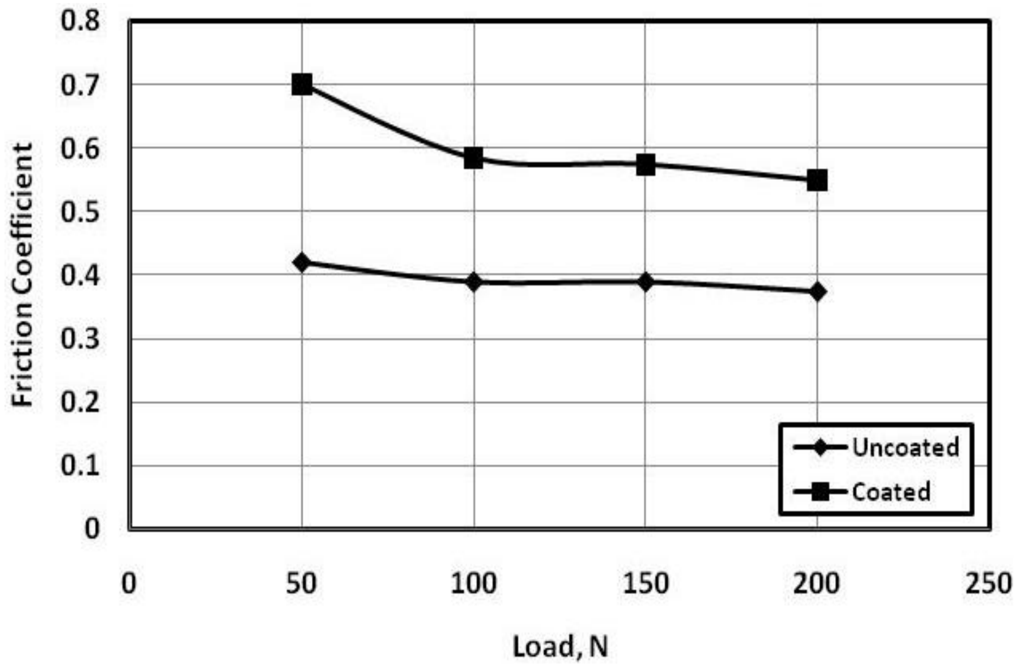


Fig. 7 Friction coefficient displayed by bare foot sliding against dry mat (C).

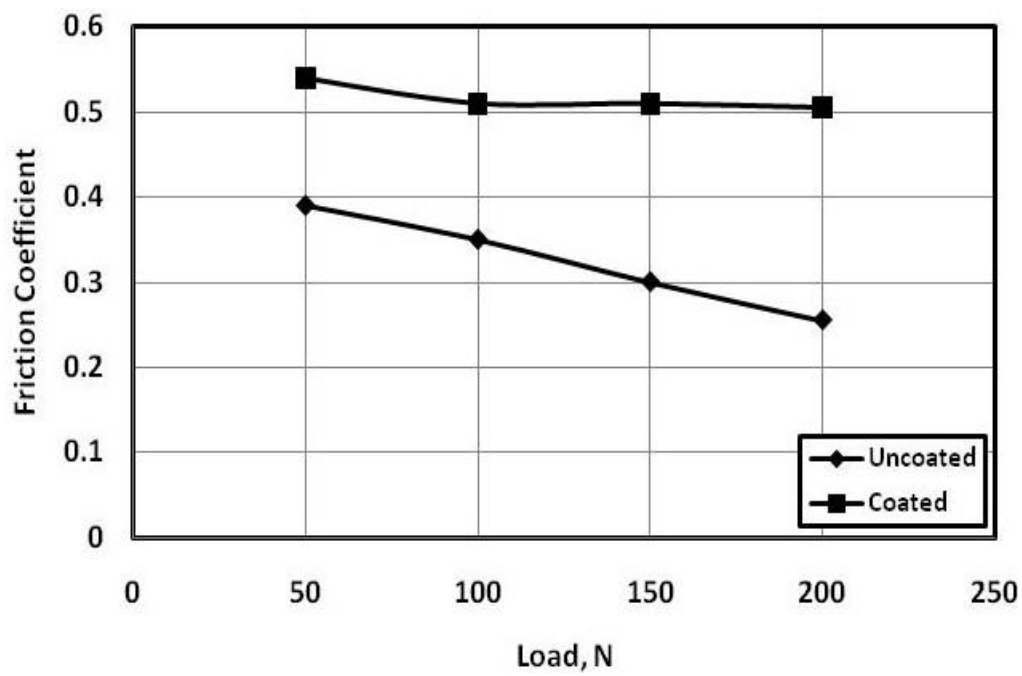


Fig. 8 Friction coefficient displayed by bare foot sliding against detergent wetted mat (C).

At dry sliding, mat (D) when coated by adhesive displayed friction coefficient higher than shown for uncoated mats, Fig. 9. Although the surface of mat (C) was smooth but friction values were quite higher due the relatively low value of hardness (53 Shore A). Besides, friction coefficient showed consistent trend with increasing load.

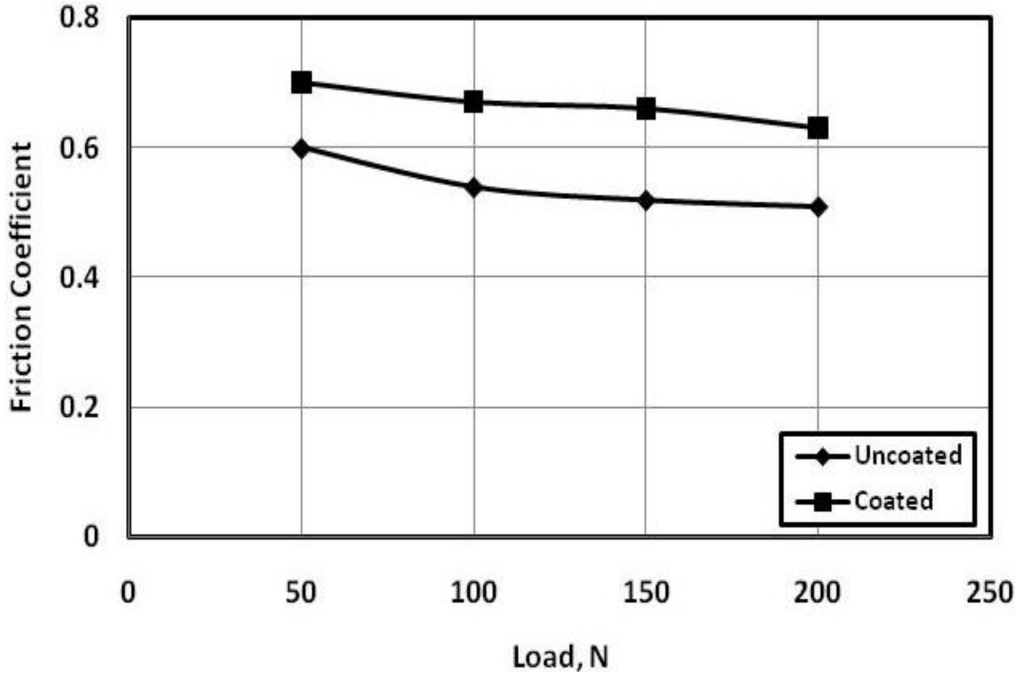


Fig. 9 Friction coefficient displayed by bare foot sliding against dry mat (D).

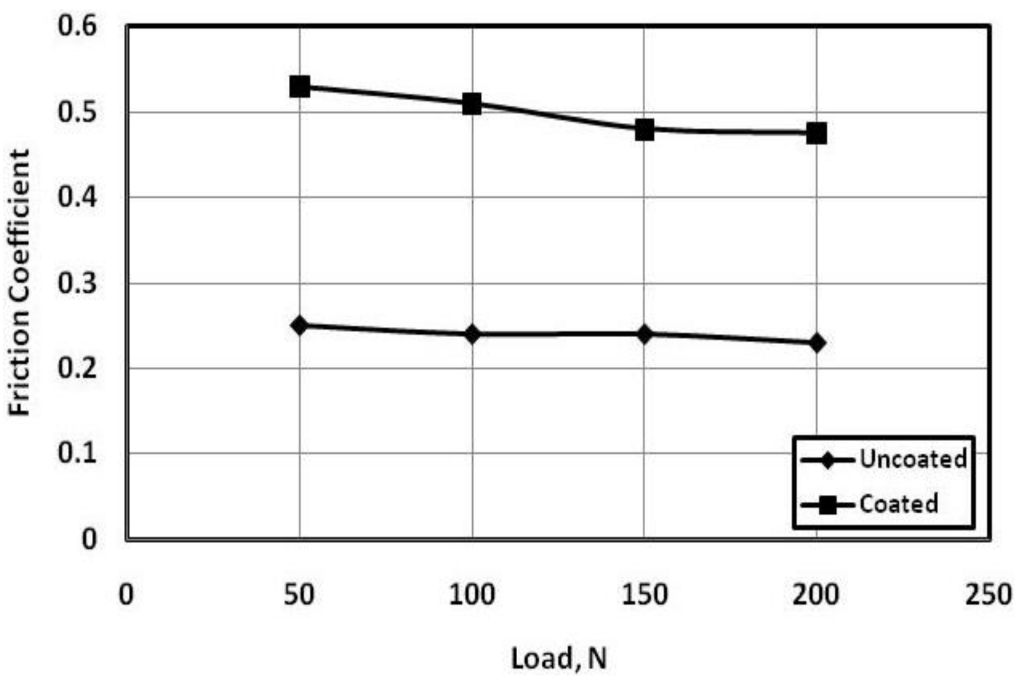


Fig. 10 Friction coefficient displayed by bare foot sliding against detergent wetted mat (D).

At detergent wetted sliding, mat (D) showed relatively lower friction than mats (A), (B) and (C) due to the absence of protrusions, Fig. 10. The effect of adhesive on the surface of the rubber mat (D) was significant in increasing friction coefficient, where friction coefficient increased from 0.25 to 0.53 at 50 N load. The effectiveness of the adhesive

increased due to the smoothness of the surface which increased the area of the contact of the two sliding surfaces.

CONCLUSIONS

1. At dry sliding, mat (A) displayed the highest friction coefficient due to the presence of the rubber protrusions, while mat (D) displayed the lowest values of friction coefficient. At detergent wetted sliding, mat (A) displayed the highest friction coefficient due to the squeeze action exerted by the pockets introduced in the sliding surface. Mats (D) displayed the lowest values of friction coefficient.

2. Mat (A) when coated by adhesive displayed friction coefficient higher than that displayed by uncoated mat at dry sliding. At detergent wetted sliding, significant friction increase was observed for coated mat (A) which displayed friction coefficient higher than uncoated mat.

3. Mat (B) when coated by adhesive displayed friction coefficient higher than that observed for uncoated mat at dry sliding. The protrusions of the surface were responsible for the relatively high friction coefficient. At detergent wetted sliding, a drastic friction decrease for uncoated mat (B) was observed.

4. Adhesive coated mat (C) displayed friction coefficient higher than uncoated mat due to the increase of the adhesive force between the two contact surfaces at dry sliding. At detergent wetted sliding, coated mat (C) by adhesive displayed friction coefficient more than uncoated mat due to the good interaction between adhesive and the surfaces of the mat.

5. At dry sliding, mat (D) showed consistent trend with increasing load, while at detergent wetted sliding, the tested mat (D) showed relatively lower friction than the mats (A), (B) and (C) due to the absence of protrusions. The effect of adhesive on the surface of the rubber mat (D) was significant in increasing friction coefficient.

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