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FRICTION COEFFICIENT DISPLAYED BY FOOTWEAR WALKING AGAINST RUBBER FLOORING FITTED BY CYLINDRICAL TREADS

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ABSTRACT

There is an increasing demand to investigate proper solutions for reducing slip and fall accidents. The friction of footwear on floor coverings is responsible of the occurrence of slips and falls. The slip resistance is normally assessed on the basis of friction coefficient measured with footwear materials sliding against floorings. In the present work, the effect of rubber flooring provided by cylindrical treads on the friction coefficient is investigated.

It was found that at dry sliding, friction coefficient significantly increased with increasing treads diameter, where (90°) and (45°) tread directions displayed the highest 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. Values of friction coefficient were 0.10, 0.085 and 0.06 for 90°, 0° and 45° tread directions respectively. Furthermore, emulsion of water and oil showed slight friction increase compared to oil lubricated sliding.

KEYWORDS

Friction coefficient, footwear, rubber flooring, cylindrical treads.

INTRODUCTION

Materials that increase floor friction forces under foot pressure could reduce the risk of slipping and enhance walking safety. 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, [1 – 6]. Recycled rubber is used over virgin rubber in flooring due to the high quality and durability. Rubber floorings are commonly used in home gyms, fitness centers, community centers, health clubs, schools and universities, play areas as well as fire and police stations. 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 forces into deformation energy within the material, and thus impeding the effect of force, with less displacement of body centre of gravity and less forward and backward slip. Recent studies of rubber walkways in cubicle barns have confirmed the benefits for cow locomotion. It was showed in a study of six different rubber walkway covers that the degree of compressibility of rubber walkway cover was well adapted for walkway evaluation. A deformation of 1.4 mm gave good slip resistance.The effect of sand particles, on the friction coefficient displayed by rubber sliding against ceramic tiles at different sliding conditions, was investigated, [7]. Experiments were carried out under dry, water, detergent, oil, soap, and water oil emulsion. It was found that, at dry sliding, dust particles caused drastic decrease in friction coefficient. In this case, it is recommended to use circular protrusion in the rubber surface. In the presence of water, dust 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 and soap, flat rubber embedded by dust particles gave higher friction compared with protruded surfaces, while dust particles embedded in rubber lubricated by oil showed higher friction values.

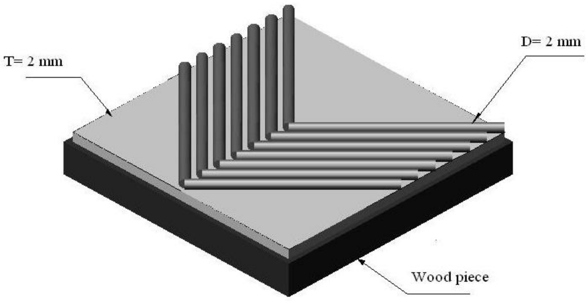
Circular protrusions gave higher friction than flat and square protrusions. Flat rubber surfaces, lubricated by water oil emulsion and contaminated by dust particles, displayed the highest friction coefficient. Dust particles on the floor prevent direct contact between the footwear pad and floor, [8]. The number of sand particles on the floor may affect the friction. However, the largest particles dominate the effects because they will be the first ones to contact the footwear pad. The rigidity, strength, and geometric characteristics of these critical particles will determine the type of interactions between the footwear pad and the particles and between the particles and the floor. The footwear pad contacts the solid particles first before it contacts the floor. For a solid with less rigidity, deformation occurs when a shoe sole presses it. For a more rigid particle, it may be broken into smaller pieces when the stress exceeds its crushing strength. At the moment of the contact of the two surfaces, rolling and sliding, of either the footwear pad on the particle, or the particle on the floor, or both, could occur for a rigid particle with high strength especially when both surfaces are hard and smooth. It was suggested that the adhesive friction is significantly affected by particulate contaminants, while the hysteretic component is not, [9]. Three lubrication mechanisms identified as sliding, shearing and rolling have been observed depending on floor roughness, particle size and shape factor.

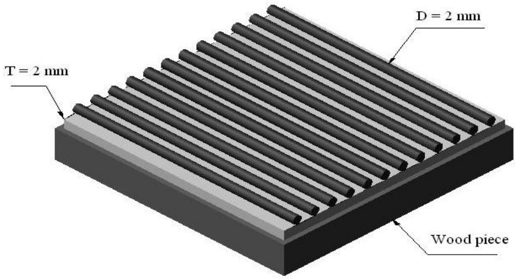
The effect of the treads width and depth of the shoe sole on the friction coefficient between the shoe and ceramic floor interface was discussed, [10]. It was found that, at dry sliding, friction coefficient slightly increased with increasing treads height. In the presence of water on the sliding surface 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 oil 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, [11 - 14]. 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 displayed by footwear is investigated in the present work.

EXPERIMENTAL

Experiments were carried out using a special test rig designed and manufactured to measure the friction coefficient between the rubber test specimens and the tested flooring tiles through measuring the friction and normal forces. The details of the test rig is illustrated elsewhere, [7].





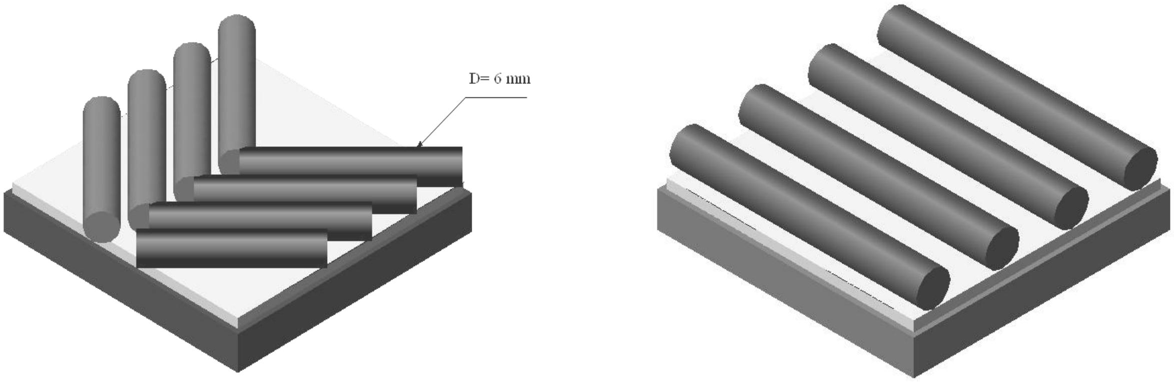


Fig. 1 Rubber test specimens of circular and square protrusions.

The tested flooring material was of rubber sheet of 50 × 50 mm and 2.0 mm thickness. The rubber test specimens were fitted by rubber cylindrical treads of 2, 3, 4, 5, 6, 7, 8, 9, and 10 mm diameter, Fig. 2. The rubber specimens were backed on wood plates. The hardness of the rubber was 63 ± 2 Shore A. Relative to the tread length, three directions of motion of the test specimens were investigated. The sliding directions were parallel, (0°), perpendicular, (90°) and (45°). The footwear sliding surface was flat leather of 87 ± 2 Shore A hardness and 6.3 µm R_a. The surfaces of footwear and rubber were thoroughly cleaned with soapy water to eliminate any dirt and dust and carefully dried before the tests. The working testing conditions were dry, water, water + 5.0 vol. % detergents, oil (Sunflower oil) and water + 5.0 vol. % oil. Tests were carried out at different values of load exerted by foot. In the present work, the results of the selected values of load of 300 and 800 N, which represent the average weights of the children and adults were considered.

RESULTS AND DISCUSSION

The results of the experiments carried out in the present work are shown in Figs. 2 – 11. The effect of the diameter of the treads on the friction coefficient at dry sliding is discussed in Figs. 2 and 3 at 300 and 800 N normal load. Friction coefficient significantly increased with increasing treads diameter. The increase might be from the increase of the contact area which increased with the increase of the treads diameter. The direction of the treads had a noticeable influence on the friction coefficient, where parallel (0°) treads to the motion direction showed the lowest values. Perpendicular (90°) and (45°) tread directions displayed the highest friction coefficient which reached a value of 0.92 for 10 mm tread diameter at 300 N normal load. This relatively high friction is attributed to the very low elastic modulus of rubber and its high internal friction. The friction force between rubber and ceramic has two components, adhesion and deformation. The deformation components results from the internal rubber friction, while adhesion will deform the rubber at the ceramic surface, where rubber follows the short-wavelength surface roughness profile. This gives an additional contribution to the friction force. As the load increased to 800 N, values of friction coefficient drastically decreased, Fig. 3. There was no influence for the tested directions on the values of

friction coefficient. The highest value was 0.57 displayed by (45°) and (90°) at 10 mm tread diameter, while (0°) direction gave relatively higher friction values (0.64).

Significant decrease in friction coefficient was observed, Fig. 4, in the presence of water on the sliding surface compared to the dry sliding. Generally, friction coefficient decreased with increasing the treads diameter. This behaviour can be attributed to the fact that the contact area increases with increasing the tread diameter, and hence the area of the water film trapped between rubber specimen and footwear increase. In this particular case, part of the contact area will be subjected to dry friction and the other will be water lubricated and consequently friction coefficient decreases. At tread diameter of 10 mm, the lowest friction values were 0.23, 0.16 and 0.14 for (45°), perpendicular (90°) and parallel (0°) tread direction respectively. Increasing the load up to 800 N, Fig. 5, caused drastic friction decrease due to the water film trapped between the rubber flooring and footwear. Tread direction of 45° displayed relatively higher friction than that observed for the other two directions. At 10 mm tread diameter the parallel treads showed friction value of 0.075 which represents very slippery flooring.

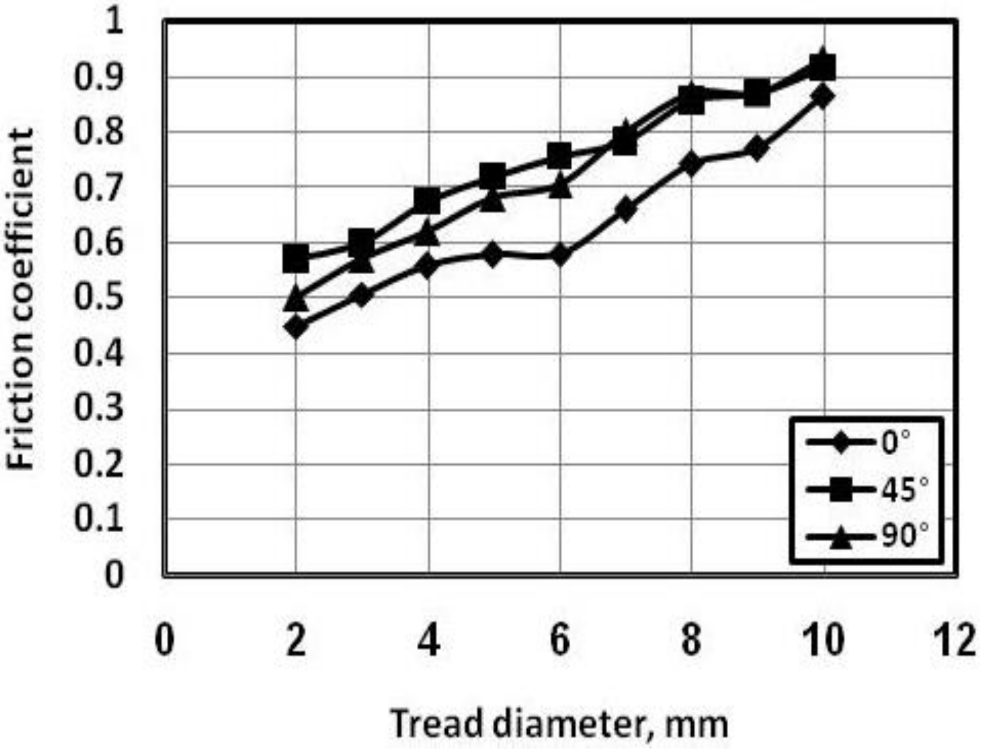


Fig. 2 Friction coefficient displayed by dry sliding at 300 N.

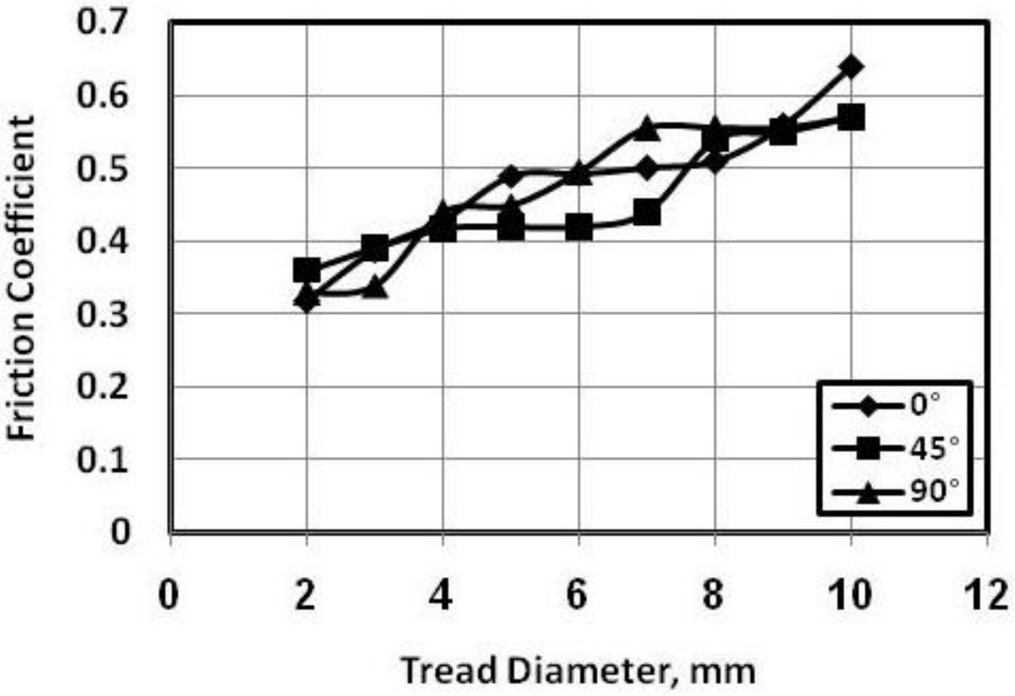


Fig. 3 Friction coefficient displayed by dry sliding at 800 N.

Friction coefficient drastically decreased to values lower than that displayed by water, Fig. 6, in the presence of water/detergent dilution between the sliding surfaces. This observation could be attributed to the relatively strong adhesion of detergent molecules to the sliding surfaces. Parallel treads showed the highest friction coefficient, while perpendicular treads up to 8 mm tread diameter displayed the lowest friction values. This behaviour could be explained on the basis that perpendicular treads formed a hydrodynamic wedge easier than the parallel one, so that the friction coefficient experienced relatively lower values. As the diameter of the treads increased friction coefficient decreased due to the increased contact area of the sliding surfaces which enabled the formation of fluid film. At 800 N load, Fig. 7, it was observed that the lowest friction values displayed by (45°), (0°) and (90°) were 0.1, 0.06 and 0.055 respectively at 10 mm tread diameter. These very low friction values are very slippery. Many state laws and building codes have established that a static friction coefficient, $\mu \geq 0.50$ represents the minimum slip resistance threshold for safe floor surfaces, [15]. Furthermore, the Americans Disabilities Act Accessibility Guidelines, [16], 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.

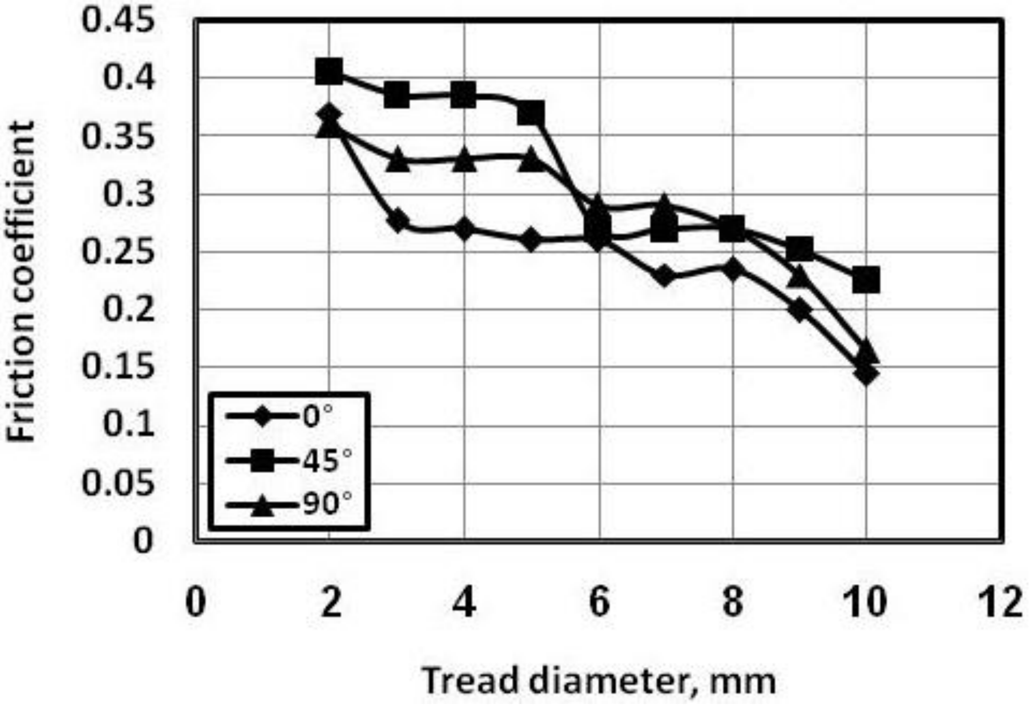


Fig. 4 Friction coefficient displayed by water lubricated sliding at 300 N.

Presence of oil on the sliding surfaces displayed decreasing trend of friction coefficient with increasing the tread diameter, Fig. 8, as a result of the presence of squeeze oil film separating footwear and rubber flooring. Values of friction coefficient were 0.10, 0.085 and 0.06 for (90°), (0°) and (45°) tread directions respectively. The significant difference among the values of friction coefficient indicates that the direction of the treads remarkably influenced the friction values. As the load increased up to 800 N, Fig. 9, further friction decrease was observed at 10 mm tread diameter, where friction values

were 0.05, 0.025 and 0.015 for (90°), (0°) and (45°) tread directions respectively. The friction values indicated that the sliding condition was in full film hydrodynamic lubrication regime. In practical application, this condition should be avoided by controlling the tread diameter.

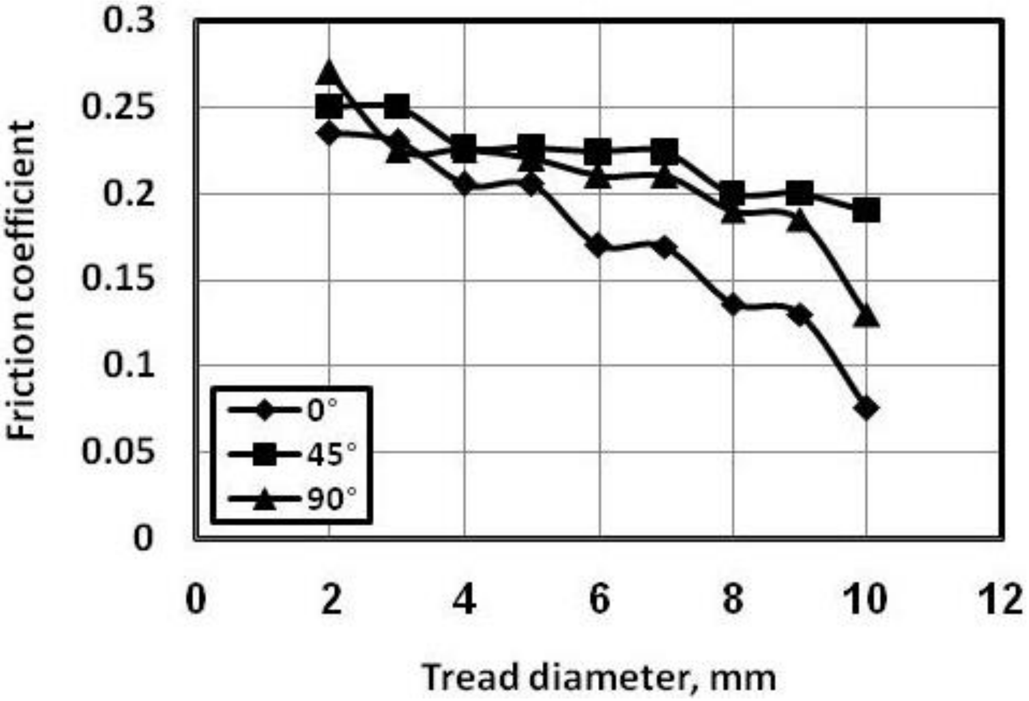


Fig. 5 Friction coefficient displayed by water lubricated sliding at 800 N.

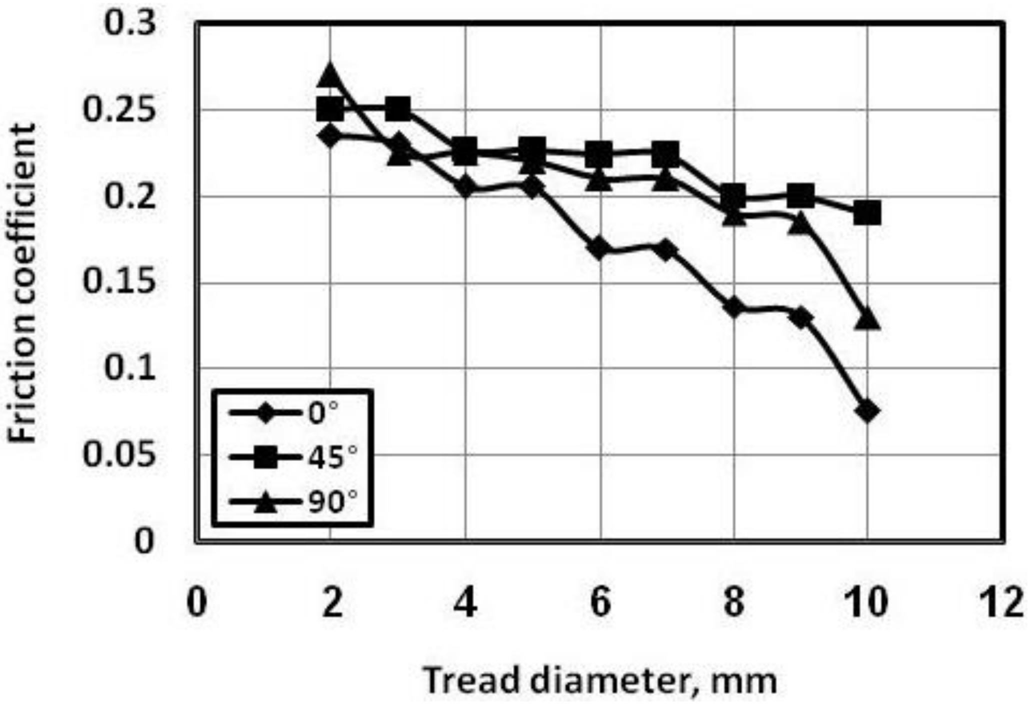


Fig. 6 Friction coefficient displayed by detergent lubricated sliding at 300 N.

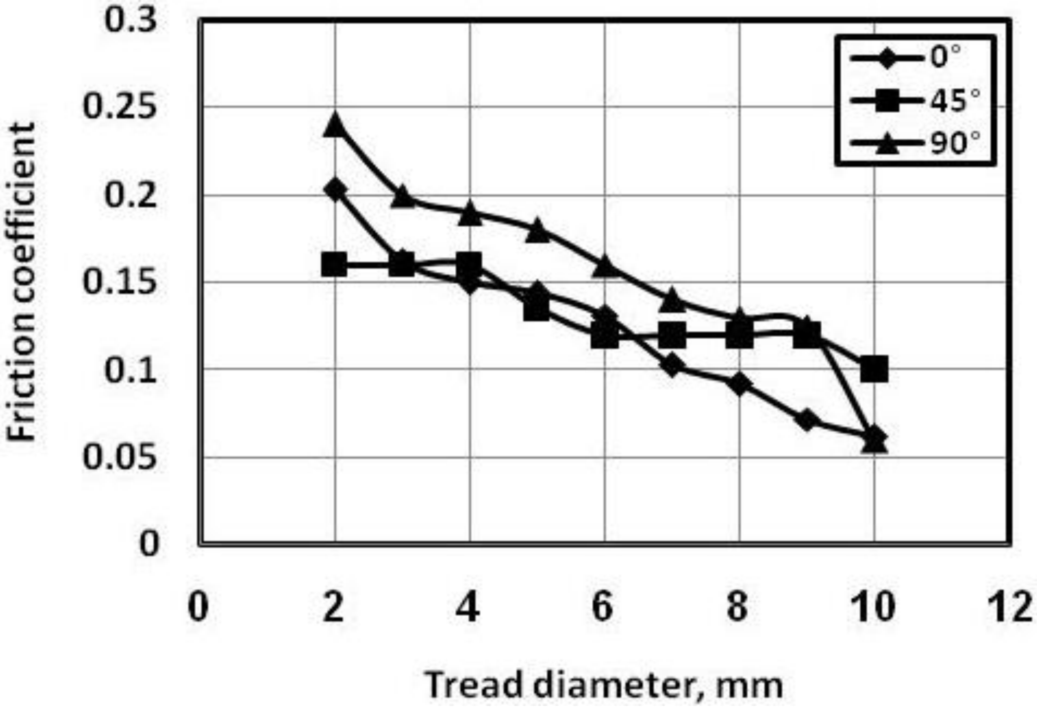


Fig. 7 Friction coefficient displayed by detergent lubricated sliding at 800 N.

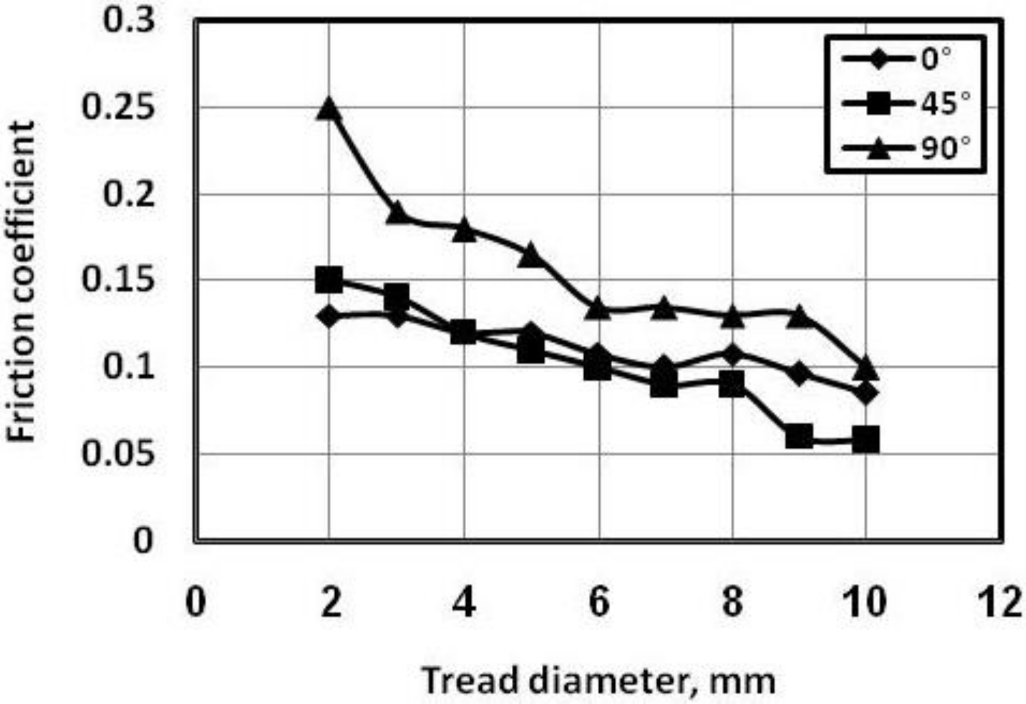


Fig. 8 Friction coefficient displayed by oil lubricated sliding at 300 N.

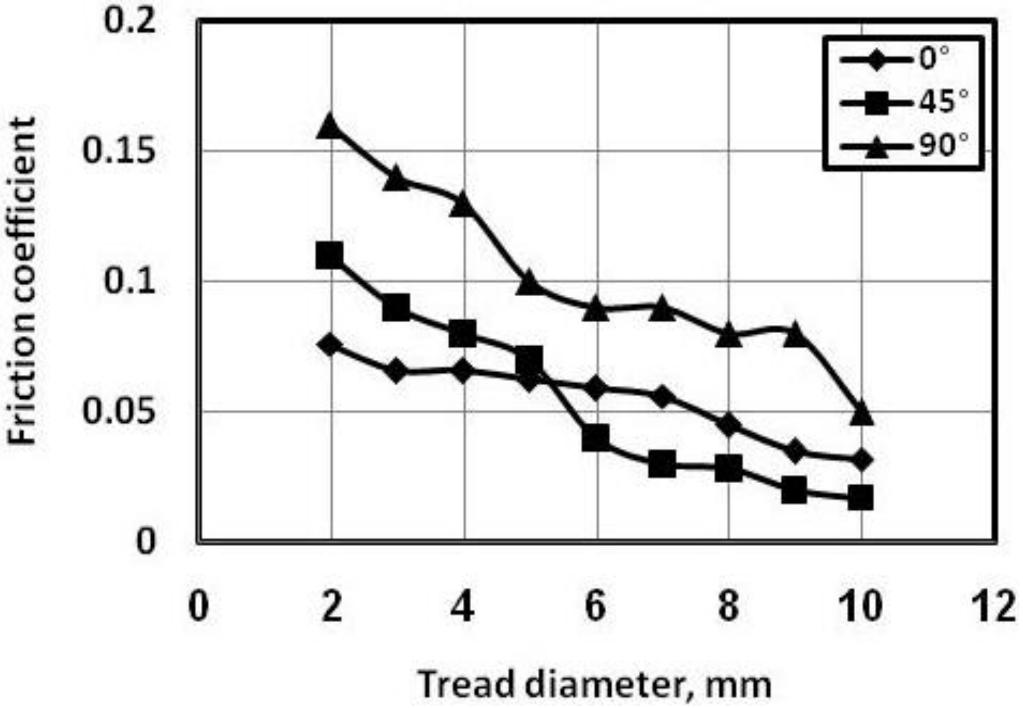


Fig. 9 Friction coefficient displayed by oil lubricated sliding at 800 N.

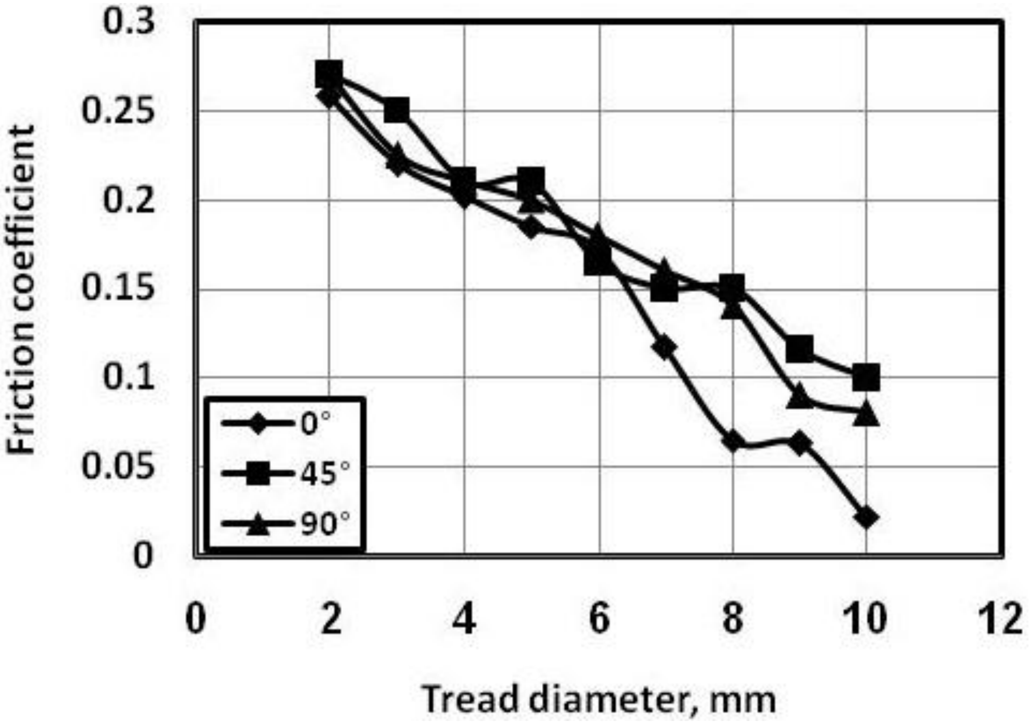


Fig. 10 Friction coefficient displayed by water + oil dilution lubricated sliding at 300 N.

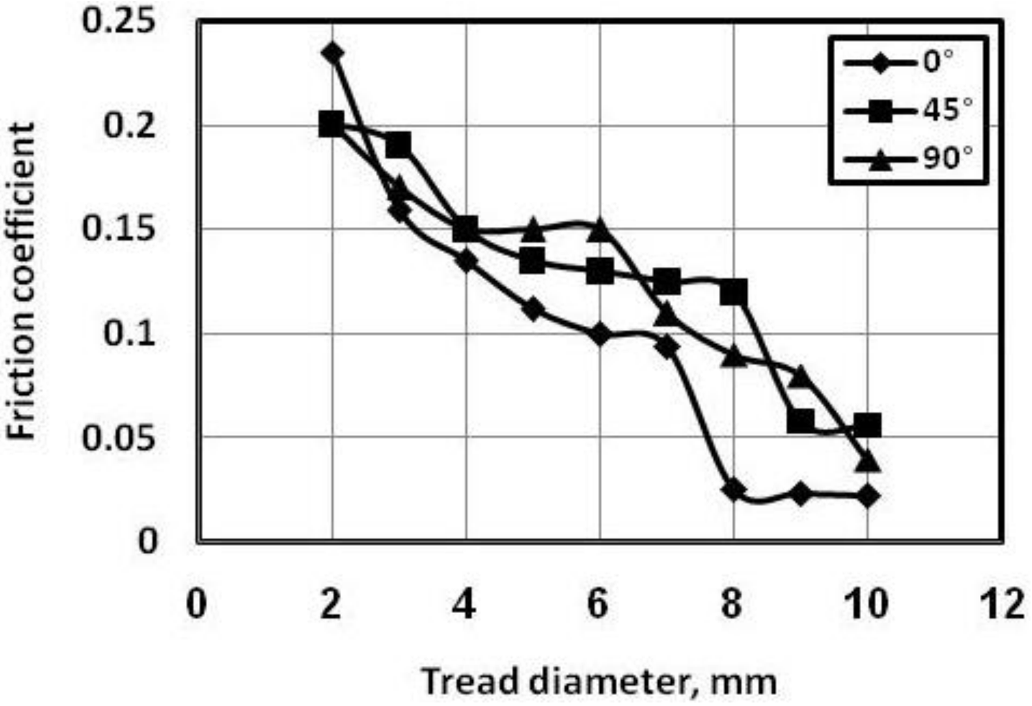


Fig. 11 Friction coefficient displayed by water + oil dilution lubricated sliding at 800 N.

Emulsion of water and oil showed slight friction increase compared to oil lubricated sliding, Fig. 10. Friction coefficient increased due to the increase of the contact area. Tread direction (45°) displayed relatively higher friction than the other two directions. Parallel treads (0°) showed the lowest friction values, where friction value was 0.02 at 10 mm tread diameter. Increasing the load up to 800 N caused further friction decrease. As the tread diameter decreased friction coefficient decreased. The lowest friction values were displayed by tread diameters ranging from 8 – 10 mm, where the values were 0.055, 0.03 and 0.02 for (45°), (90°) and (0°) respectively. It is well known that the static coefficient of friction of 0.5 was recommended as the slip-resistant standard for unloaded, normal walking conditions [17], while higher static coefficient of friction values may be required for safe walking when handling loads. In Europe, [18], 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. Rubber tends to provide 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, [19]. The above characteristic frictional behaviour of rubber was greatly disturbed when fluid film separating the two sliding surfaces.

CONCLUSIONS

Based on the experimental observations in the present work, the following conclusions can be drawn:

1. **Friction coefficient significantly increased with increasing treads diameter, wher(90°) and (45°) tread directions displayed the highest friction coefficient which reached a value of 0.92 at dry sliding.**
2. **Significant decrease in friction coefficient was observed in the presence of water on the sliding surface compared to the dry sliding, where friction coefficient decreased with increasing the treads diameter.**
3. **Friction coefficient drastically decreased to values lower than that displayed by water,in the presence of water/detergent dilution. Parallel treads showed the highest frictioncoefficient, while perpendicular treads displayed the lowest friction values.**
4. **Presence of oil on the sliding surfaces displayed a decreasing trend of friction coefficient with increasing the tread diameter as a result of the presence of squeeze oil film separating footwear and rubber flooring. Values of friction coefficient were 0.100, .085 and 0.06 for (90°), (0°) and (45°) treads directions respectively**.
5. **Emulsion of water and oil showed slight friction increase compared to oil lubricated sliding.**

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