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# INCREASING SAFETY OF WALKING BY USING RUBBER FLOOR

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## ABSTRACT
**Rubber floors are used for indoor application such as gym, kid gardens and hospitals. They protect both the footwear and floor from being scratched. Rubber floors of thick mats offer durable and elastic behavior as well as shock absorption. They are less sensitive to chips, cracks, and fragmentation in the working area. Their thickness is one of the factors affecting their durability. As the thickness of the rubber mat increases, injuries are reduced by relieving stress on joints, legs, and feet and absorb physical impacts and vibration. The present work discusses the effect of the rubber floor thickness and hardness on the friction coefficient displayed by the walking of rubber footwear against dry and water wet rubber floor.**

**It was found that friction coefficient decreased with increasing rubber hardness due to decrease of deformation. Friction coefficient increased when normal load increased. Increasing thickness gave significant effect on increasing friction coefficient. Friction coefficient decreased with increasing normal load due to saturation of the rubber asperities and rubber filling the gaps between the contact asperities. At water wet sliding, friction coefficient increased up to maximum with increasing rubber floor thickness due to increase of the deformation. Rubber of the lowest hardness displayed relatively the highest values of friction coefficient although the rubber floor was covered by water film. Critical floor thickness displayed the highest friction. Further thickness increase showed slight friction decrease.**

## KEYWORDS
**Friction coefficient, footwear, rubber floor, thickness, hardness.**

## INTRODUCTION
**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.**

**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 that 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 – 7]. 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 conditions, was investigated, [8]. 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, [9]. 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, [10]. Three lubrication mechanisms identified as sliding, shearing and rolling have been observed depending on floor roughness, particle size and shape factor.**

**The effect, of treads width and depth of the shoe sole on the friction coefficient between the shoe and ceramic floor interface, was discussed, [11]. 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, [12 - 20]. 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 static friction coefficient, displayed by foot wearing socks of different textile materials under dry sliding, was investigated, [21]. Floor tiles of ceramics, flagstone, parquet, parquet ceramics, marble, porcelain and rubber were tested as floor materials. Rubber floor displayed the highest friction values, while marble showed the lowest ones.**

**Proper selection of socks textiles sliding against indoor floor materials can avoid slip accidents. The measurements of friction coefficient displayed by foot wearing socks slid against different types of floors under dry sliding condition was investigated, [22]. The floor materials are parquet, cement, marble and ceramic, while the socks textiles are wool, polyacrylonitrile, cotton, polyester, spandex, silk and polyamide. The experiments showed that careful selection of textiles used in fabrics of foot wearing socks should be considered. This selection depends mainly on the indoor floor materials. The results revealed that, socks sliding against cement floor experienced relatively higher friction coefficient than that observed for parquet. The highest friction values were displayed by polyacrylonitrile, spandex, wool, cotton and polyamide. Polyacrylonitrile displayed the highest values of friction coefficient when slid against parquet floor, while natural wool gave the lowest friction values. Polyamide showed the same trend observed for wool, while silk and spandex gave relatively higher friction. Sliding against marble floor showed relatively lower friction values than observed for parquet and cement floors. Polyacrylonitrile, wool and polyamide showed higher friction than that recorded for cotton, polyester spandex and silk. Ceramic floor showed relatively higher friction values than that observed for marble and lower than given by cement and parquet. The difference in the friction values increases the necessity to carefully select the materials of the socks textiles for use in indoor walking to avoid slip accidents.**

**Friction coefficient, displayed by sliding of rubber sole against dry recycled rubber floor tiles, drastically decreased with increasing the hardness of the tested flooring tiles, while increased with increasing normal load, [23]. At water and detergent wetted as well as oil lubricated sliding, soft tested rubber showed higher friction coefficient than the harder one. Besides, dry sliding showed significant increase of friction coefficient with increasing material thickness.**

**The effect, of reinforcing epoxy floor coatings by copper wires of different diameters on friction coefficient displayed by their sliding against rubber sole, was discussed, [24]. It was found that at dry, water and detergent sliding of the tested epoxy against rubber sheet, friction coefficient increased by increasing the number and diameter of wires reinforcing epoxy. When the wires were closer to the surface, they were strongly influenced by the electric field and consequently the intensity of the electric charge increased leading to an increase in friction coefficient.**

**The effect of thickness and hardness of the rubber floor on the friction coefficient displayed by rubber footwear is investigated in the present work.**

## EXPERIMENTAL

**Experiments were carried out using test rig shown in Fig. 1. It consists, mainly, of two load cells one installed in horizontal position and other in vertical one, where the horizontal load cell measured the normal force while the vertical one measured the friction force. Also it consists of upper base that will be covered by the flooring surface, and lower base used to make the test rig fixed on floor and not move during test. The effect of the tested parameters on friction coefficient of rubber footwear sliding against the tested rubber floor tiles such as rubber thickness and rubber hardness at different sliding conditions will be investigated. The tested rubber floor tiles in form of quadratic tiles of 0.2 m × 0.2 m, while the thickness ranged between 1 and 8 mm. The hardness of the rubber footwear was 80 Shore A, while the hardness of the rubber floor tiles was 30, 40, 50 and 60 Shore A.**

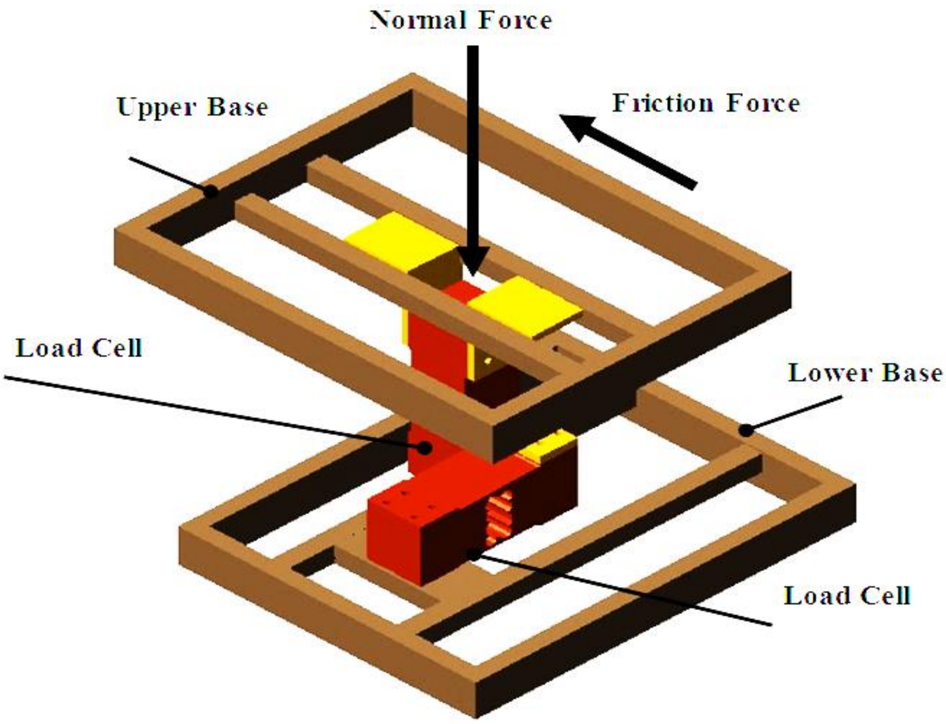


**Fig. 1 Arrangement of test rig.**

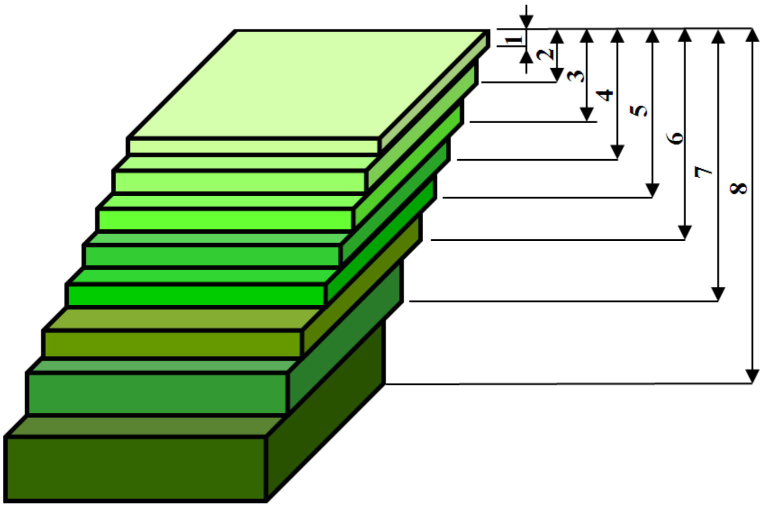


**Fig. 2 The tested rubber tiles.**

**Friction coefficient measurements were carried out at different load values. In the present work, the results of the selected values of load of 240, 480, 720 and 960 N will be considered. First, the tested rubber tiles were adhered on the upper base of the test rig then they and the footwear were cleaned with soap water to eliminate any dirt and dust and carefully dried before the test. The rubber floor tiles were loaded by footwear at dry and water wet sliding. During test, horizontal and vertical load cells connected to the two monitors detected normal and friction forces respectively. Friction coefficient is the ratio between friction and normal force. By taking five values for each test the values of friction coefficient could be calculated.**

## RESULTS AND DISCUSSION

**Effect of rubber hardness on friction coefficient is shown in Figs. 3 - 6. Friction coefficient decreased with increasing rubber hardness due to decrease of deformation. Friction coefficient decreased when normal load decreased. Rubber of 30 shore A hardness displayed the highest value of friction coefficient, Fig. 2. The smooth rubber surface prevented escape of air from rubber surface gaps and made rubber with smooth surface leading to decrease in friction coefficient with increasing normal load.**

**Friction coefficient generated from sliding of smooth rubber surface of 40 Shore A hardness against dry flooring ceramic is shown in Fig. 5. It is clearly shown that, increasing rubber hardness caused slight decrease in friction coefficient due to decreasing deformation. Increasing normal load decreased friction coefficient. Increasing thickness gave significant effect on increasing friction coefficient which displayed a value of 0.85 for 5 mm rubber thickness, while the corresponding value was 0.6 for 3 mm rubber thickness due to the increase in deformation.**

**Figure 6 shows the effect of floor thickness on friction coefficient for smooth rubber surface of 60 Shore A hardness. Comparison of the values of friction coefficient showed a decrease with increasing rubber hardness. It is clearly shown that decreasing friction value with increasing normal load due to saturation of the rubber asperities and rubber filling the gaps between the contact asperities. For 5 mm thickness, friction coefficient represented higher values than the observed for 3 and 8 mm rubber thicknesses, where the maximum value of friction coefficient reached 0.64.**

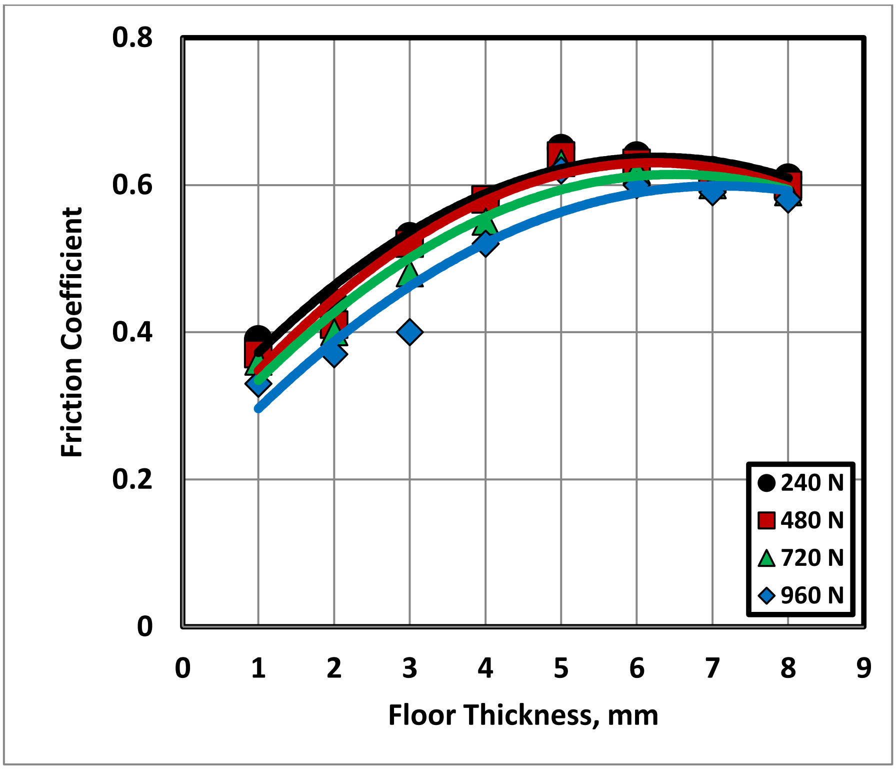


**Fig. 3 Friction coefficient displayed by the dry sliding of footwear against rubber floor of 30 Shore A hardness.**

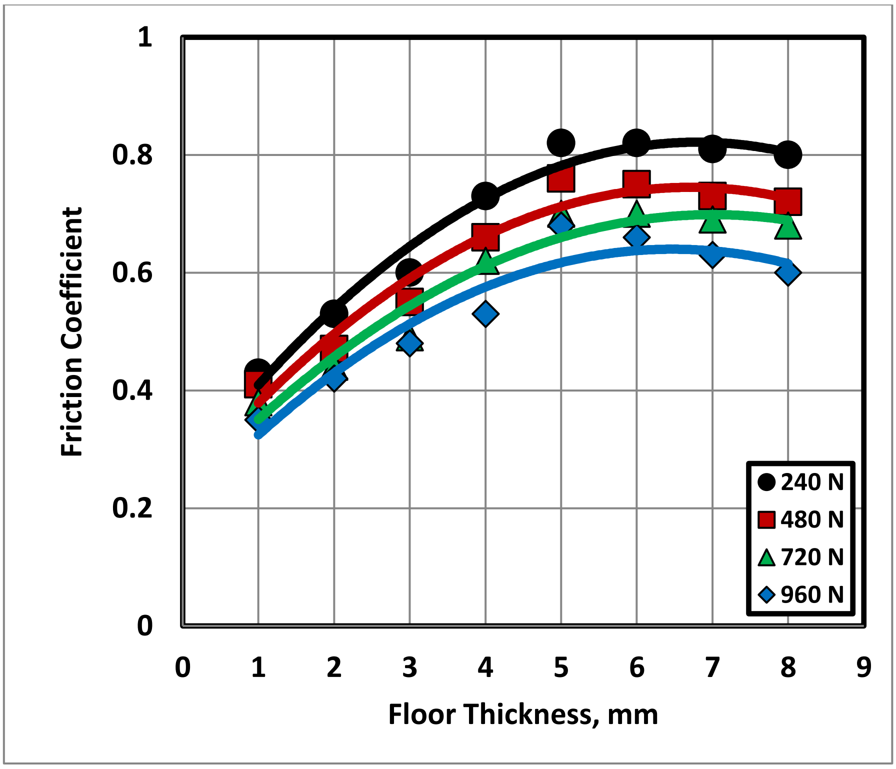


**Fig. 4 Friction coefficient displayed by the dry sliding of footwear against rubber floor of 40 Shore A hardness.**

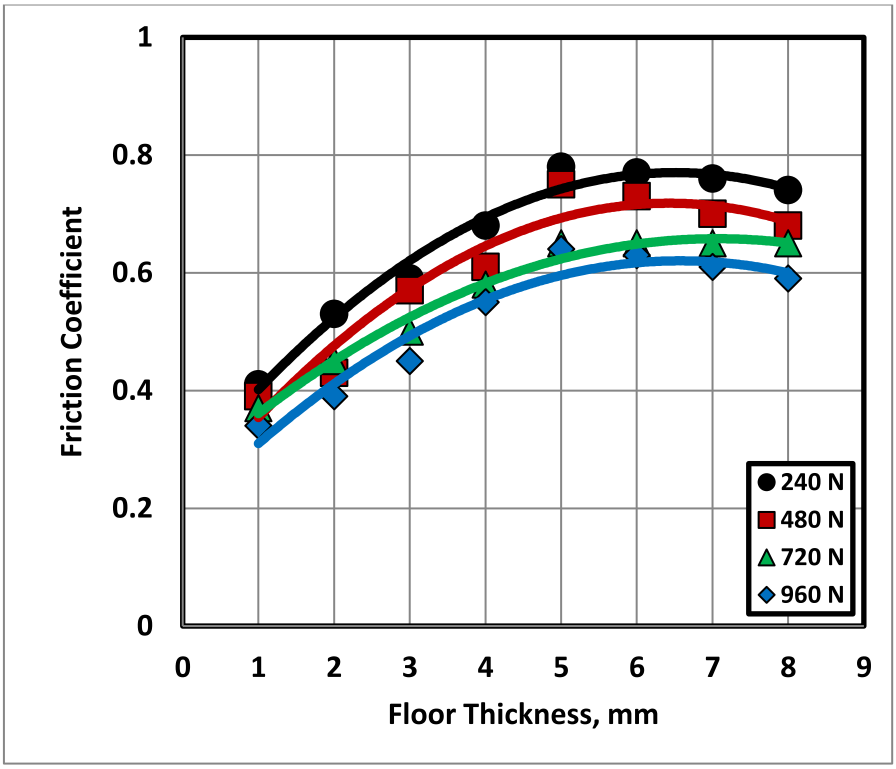


**Fig. 5 Friction coefficient displayed by the dry sliding of footwear against rubber floor of 50 Shore A hardness.**

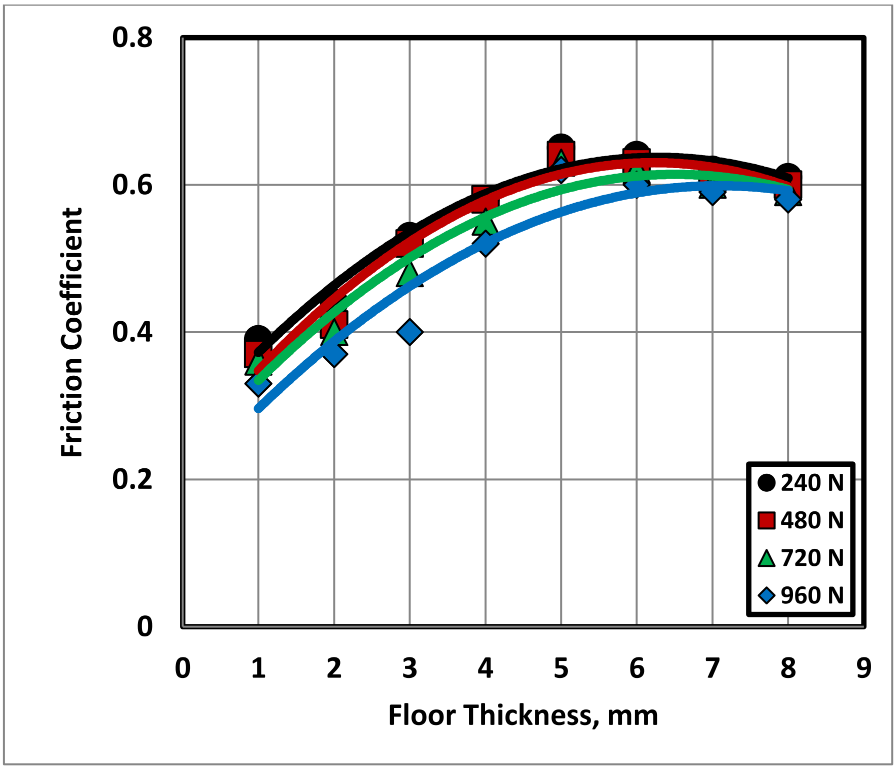


**Fig. 6 Friction coefficient displayed by the dry sliding of footwear against rubber floor of 60 Shore A hardness.**

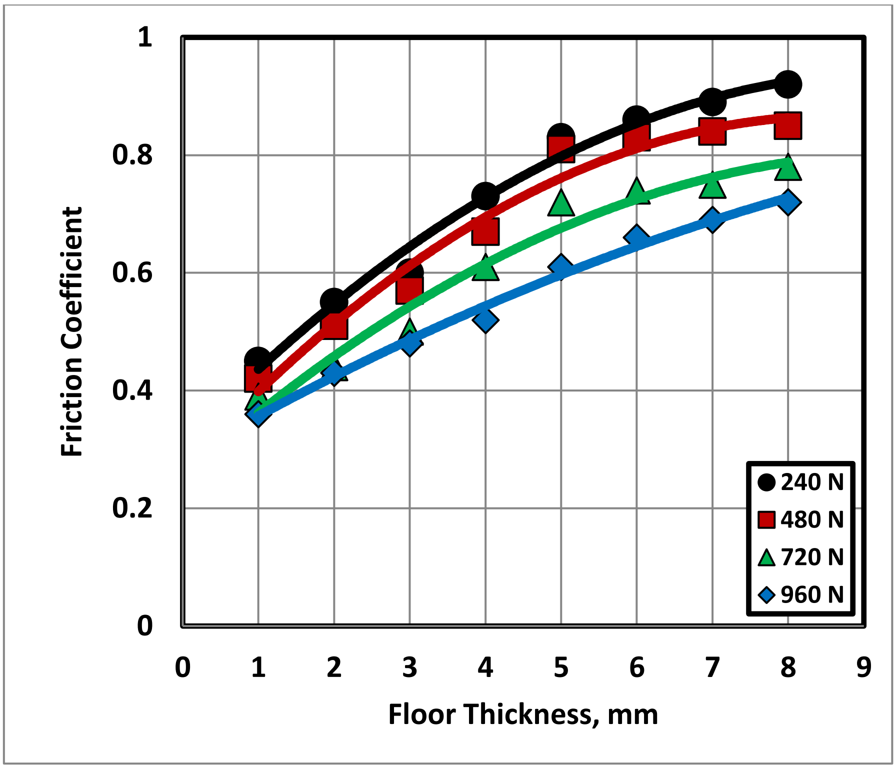


**Fig. 7 Friction coefficient displayed by the water wet sliding of footwear against rubber floor of 30 Shore A hardness.**

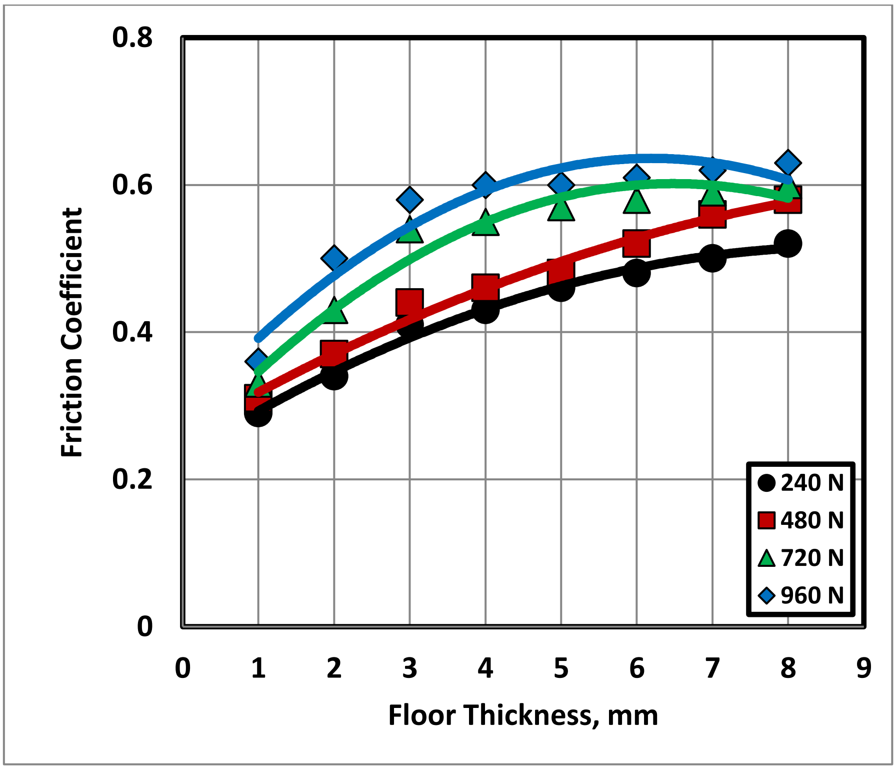


**Fig. 8 Friction coefficient displayed by the water wet sliding of footwear against rubber floor of40 Shore A hardness.**

**At water wet sliding, the effect of floor thickness on friction coefficient is shown in Figs. 7 – 10. Friction coefficient increased up to maximum with increasing rubber floor thickness due to increase of the deformation. Friction coefficient increased when normal load increased. Rubber of 30 Shore A hardness, Fig. 7, displayed relatively higher values of friction coefficient although the rubber floor was covered by water film. It seems that absence of groove allowed the escape of water from rubber surface at the contact area in a manner that friction coefficient increased.**

**Friction coefficient generated from sliding of smooth rubber surface of 40 Shore A hardness against The tested rubber floor is shown in Fig. 8. It is clearly shown that, increasing rubber thickness caused significant friction coefficient increase. Increasing normal load significantly increased friction coefficient. It can be observed that increasing thickness increased deformation that has significant effect on increasing friction coefficient which displayed a value of 0.63 at 8 mm thickness.**

**Figure 9 shows the effect of floor thickness on friction coefficient for smooth rubber surface of 50 Shore A hardness. Testing smooth rubber surface generated decreasing friction coefficient with increasing rubber hardness. It is clearly shown that increasing friction value with increasing normal load due to squeeze effect. For 8 mm thickness, friction coefficient represented lower values than the observed for 5 mm rubber thickness, where the maximum value of friction coefficient was 0.6 at 960 N load. Friction coefficient displayed by the water wet sliding of footwear against rubber floor of 60 Shore A hardness showed the lowest values of friction coefficient, Fig. 10. Floor thickness of 5 mm displayed the highest friction. Further thickness increase showed slight friction decrease. As the load increased friction coefficient increased. It seems that water film was scavenged from the contact area as the load increased.**

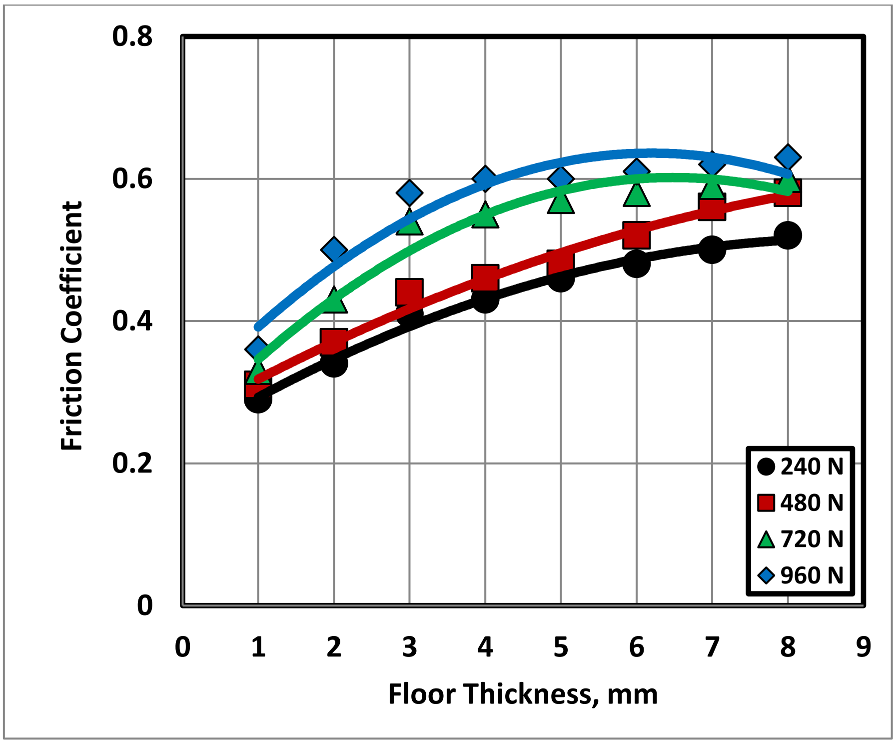


**Fig. 9 Friction coefficient displayed by the water wet sliding of footwear against rubber floor of 50 Shore A hardness.**

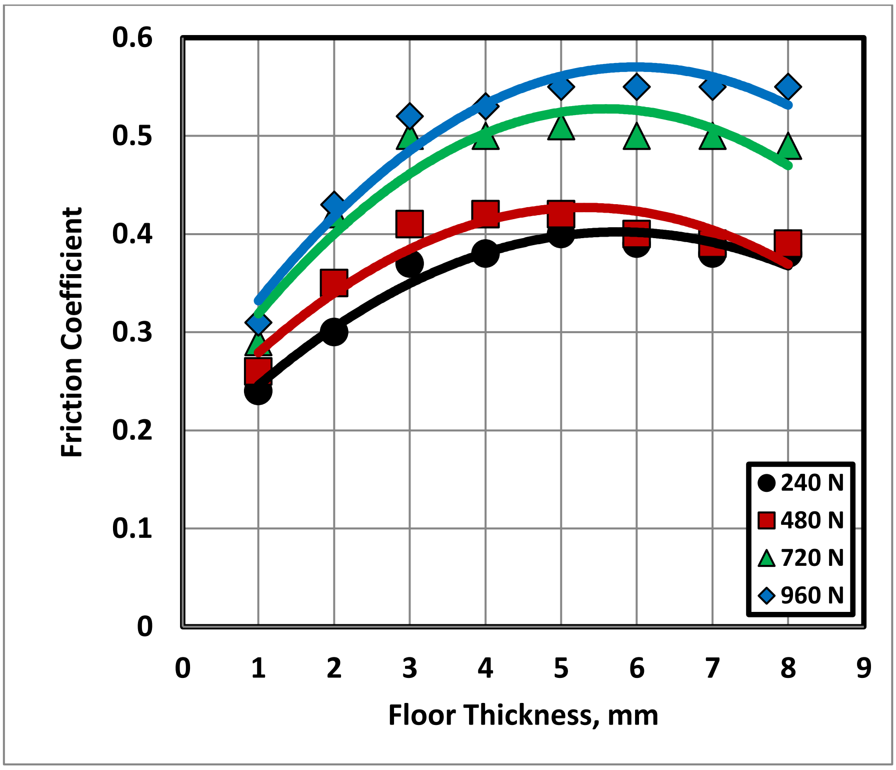


**Fig. 10 Friction coefficient displayed by the water wet sliding of footwear against rubber floor of 60 Shore A hardness.**

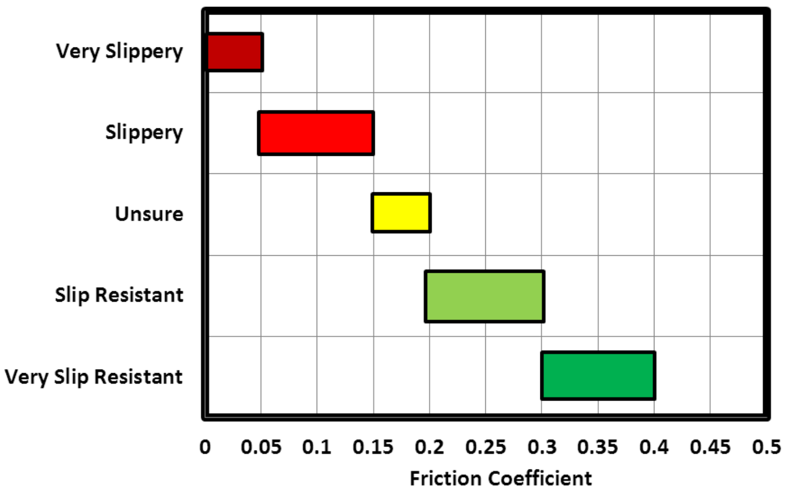


**Fig. 11 Dependency of friction coefficient on the safety of walking, [27].**

**It is well known that the relatively high friction is attributed to the very low elastic modulus of rubber and its high internal friction. The friction force has two components, adhesion and deformation. The deformation component results from the internal rubber friction, while adhesion deforms the rubber at the contact surface, where rubber follows the short-wavelength surface roughness profile. This gives an additional contribution to the friction force. Besides, significant decrease in friction coefficient was observed in the presence of water on the sliding surface compared to the dry sliding. This behaviour can be attributed to 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.**

**Many state laws and building codes have established that a static friction coefficient, μ ≥ 0.50 represents the minimum slip resistance threshold for safe floor surfaces, [25]. Furthermore, the Americans Disabilities Act Accessibility Guidelines, [26], contain advisory recommendations for static coefficient of friction of μ ≥ 0.60 for accessible routes (e.g. walkways and elevators) and μ ≥ 0.80 for ramps. In Europe, [27], 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, Fig. 11. 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. 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. At dry sliding, friction coefficient decreased with increasing rubber hardness due to decrease of deformation. Friction coefficient decreased when normal load decreased. Increasing normal load decreased friction coefficient. Increasing thickness gave significant effect on increasing friction coefficient. Friction coefficient decreased with increasing normal load due to saturation of the rubber asperities and rubber filling the gaps between the contact asperities.**

**2. At water wet sliding, friction coefficient increased up to maximum with increasing rubber floor thickness due to increase of the deformation. Friction coefficient increased with increasing normal load. Rubber of the lowest hardness displayed relatively the highest values of friction coefficient although the rubber floor was covered by water film. It seems that absence of groove allowed the escape of water from rubber surface at the contact area in a manner that friction coefficient increased. Floor thickness of 5 mm displayed the highest friction. Further thickness increase showed slight friction decrease. As the load increased friction coefficient increased. It seems that water film was scavenged from the contact area as the load increased.**

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