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FRICTION BEHAVIOR OF INDOOR FLOOR MATERIALS

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ABSTRACT

The present work discusses the friction behavior of different floor materials when rubber sole slid against them under dry, water and detergent wet sliding conditions. In order to offer durable and elastic behavior as well as shock absorption for the tiles, polyurethane (PU) coating was applied on the surface of cement tiles. Then rubber, sand and glass granulates as well as steel wires were used as filling and reinforcing addition to PU.

It was found that at dry and wet sliding, friction coefficient displayed by tiles coated by PU filled by glass granulates showed the highest friction values. It seems that abrasive action of the glass granulates into the rubber surface was responsible for that behavior. Rubber coating displayed relatively lower value of friction coefficient followed by the unfilled PU coating. Cement tiles and tiles coated by PU and reinforced by steel wires offered the lowest values. Coating cement tiles by PU filled by sand particles showed higher values of friction coefficient at dry sliding. In contradiction to that, presence of water and detergent film caused drastic friction decrease due to the presence of multi tiny reservoirs that during sliding the fluid gets up to the sliding surface forming a film and consequently friction decreased.

KEYWORDS

Friction coefficient, indoor floor, polyurethane, rubber, hardness.

INTRODUCTION

Reducing slip and fall accidents can be achieved by selecting materials of relatively higher friction coefficient. It is well known that floors in work places are often made from hard materials for increased durability, while rubber mat has become a popular floor material due to the increased comfort, [1 – 7]. Recycled rubber is used in floors in gyms, fitness centers, community centers, health clubs, schools and universities, play areas as well as fire and police stations. 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 friction coefficient of different floor materials when rubber sole slid against them under dry, water and detergent wet sliding conditions is measured. Polyurethane coating is applied on the surface of cement tiles. Then rubber granulates, sand and glass as well as steel wires are used as filling and reinforcing addition to polyurethane.

EXPERIMENTAL

Experiments were carried out using test rig that consists of two load cells to measure both the normal force and the friction force. The upper base is covered by the tested tile surface, Fig. 1. The rubber surface that resembles the sole is 10 mm thickness adhered to wooden cube of 50 × 50 × 50 mm^3, Fig. 2. The hardness of the rubber footwear was 60 Shore A. Friction coefficient measurements were carried out at different load values ranged from 20 to 200 N. The rubber was loaded by hand at dry, water and detergent wet sliding. During test, horizontal and vertical load cells connected to the two monitors that detected normal and friction forces respectively. Friction coefficient is the ratio between friction and normal force. The tested coatings were unfilled PU and reinforced

PU by ductile steel wires of 1.0 mm diameter. Granulates of sand (20, 50 and 80 µm), rubber (250 – 1000 µm) and glass (150 – 300 µm) were used as filling material in the PU tested coating, Fig. 3.

Fig. 1 Details of the test rig.

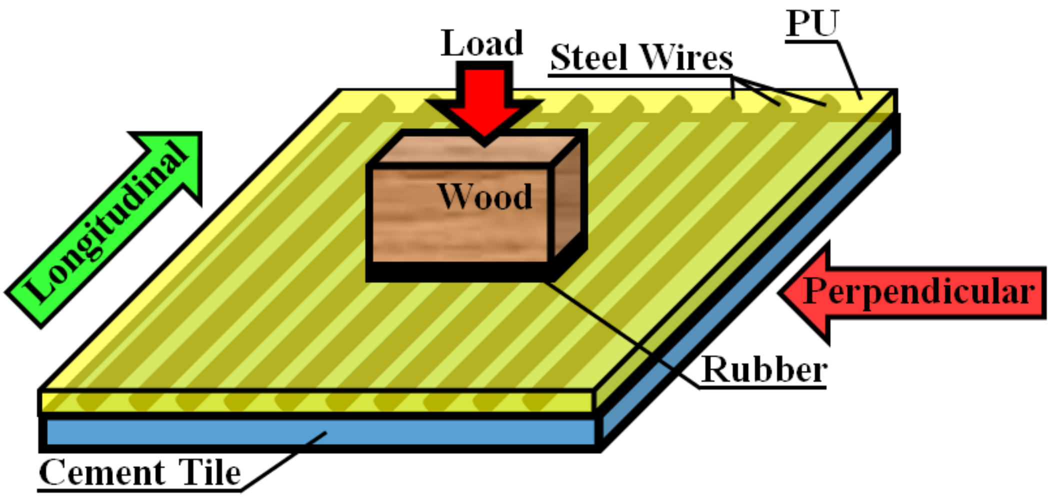
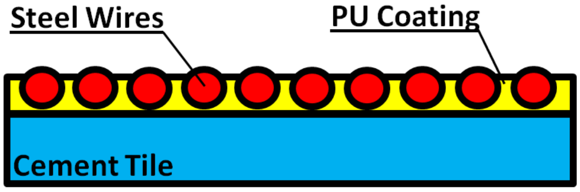
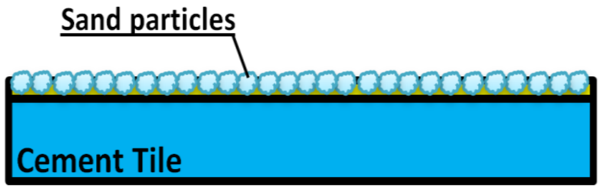


Fig. 2 Details of test procedure.

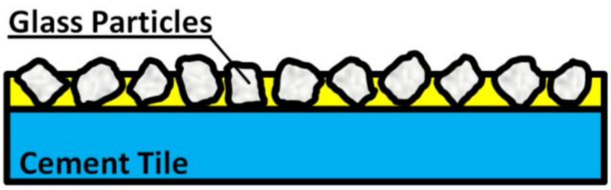
Polyurethane coating.



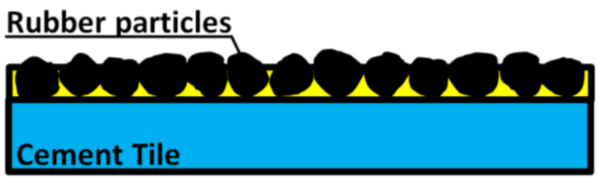
Polyurethane coating reinforced by steel wires.



Polyurethane coating filled by sand particles.



Polyurethane coating filled by glass granulates.



Polyurethane coating filled by rubber granulates.

Fig. 3 The tested coating materials.

RESULTS AND DISCUSSION

Friction coefficient displayed by dry sliding of rubber against the tested materials of floor tiles, Fig. 3, decreased with increasing normal load. The tested tile coated by glass granulates showed the highest friction values. This behavior can be attributed to the abrasive action of the glass granulates into the rubber surface. Rubber coating displayed relatively lower value of friction coefficient followed by the neat PU coating. Cement tiles and tiles coated by PU and reinforced by steel wires offered the lowest values.

Friction coefficient displayed by water wet sliding of rubber against the tested tiles is shown in Fig. 4. Tiles coated tiles by PU filled by glass granulates showed promising friction values in the presence of water on the sliding surfaces. It seems that the sharp edges of the glass inserted in the rubber surface were responsible for the remarkable friction increase. On the other side neat PU coatings displayed the lowest friction values. The other tested surfaces showed moderate friction values. In the presence of detergent, Fig. 6, friction coefficient decreased, where the lowest values were detected for cement and PU coating. Glass granulates filled PU coating displayed the highest friction values. As the applied load increased friction slightly decreased.

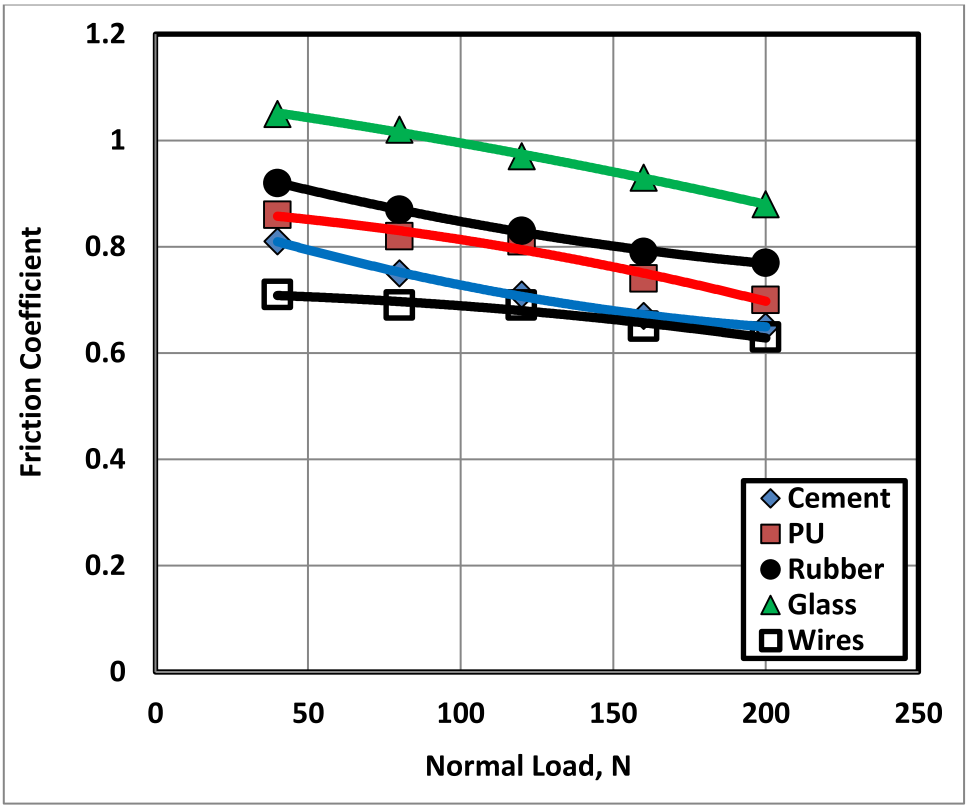


Fig. 4 Friction coefficient displayed by dry sliding of rubber against the tested tiles.

It is known that rubber friction coefficient is given by

$$\mu = \mu_A + \mu_C + \mu_H + \mu_V$$

where, μ_A is the adhesion component caused by the molecular interactions between rubber and counterface. μ_C is the cohesion component resulted on rough counterface. μ_H is the hysteresis component displayed by the deformation of the rubber by the action of the rough counterface. μ_V is the viscous component. When the counterface is rough with sharp corners such as glass granulates and sand particles the influence of abrasion is arising and significantly affects friction coefficient, [25 – 27]. It is expected that sliding of rubber against abrasive particles such as glass or sand causes an increase in the value of friction coefficient. This fact is confirmed in Figs. 5 - 7, where glass coated PU displayed the highest friction values. The deformation and hysteresis components of friction coefficient are responsible for the values displayed by rubber. Besides, the increase of actual contact area of rubber during sliding on PU coated by rubber granulates raises the values of friction coefficient, Fig. 7. At dry sliding, PU showed relatively higher friction than PU reinforced by steel wires, Fig. 4. It seems that deformation of unreinforced PU is higher than reinforced PU, so that the actual contact area increases and consequently friction coefficient increases.

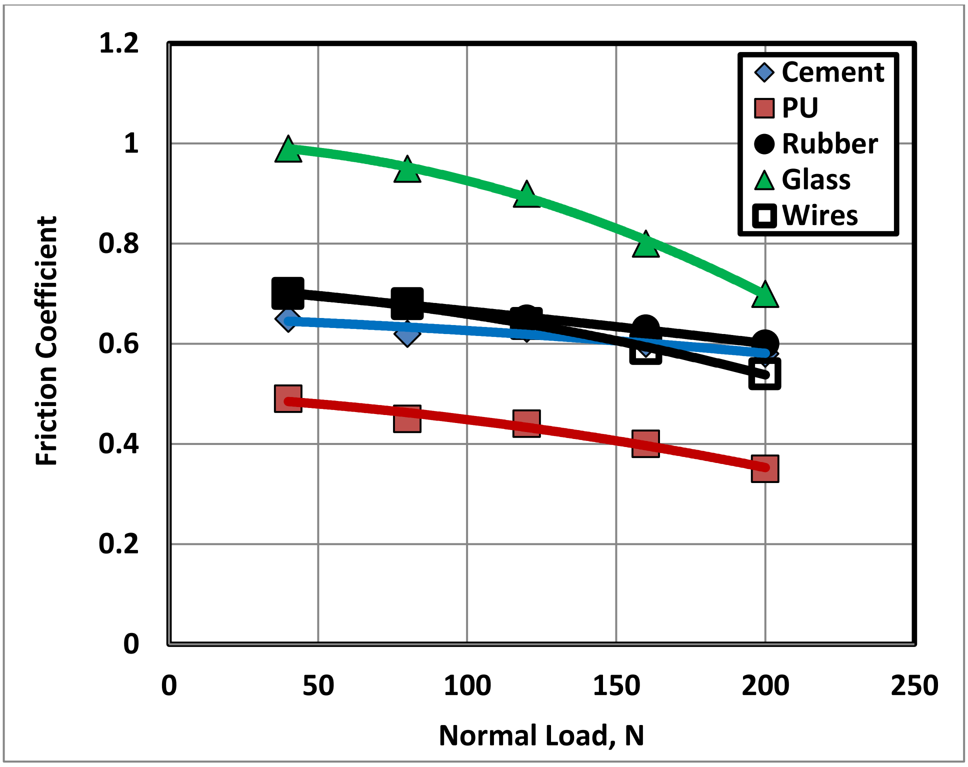


Fig. 5 Friction coefficient displayed by water wet sliding of rubber against the tested tiles.

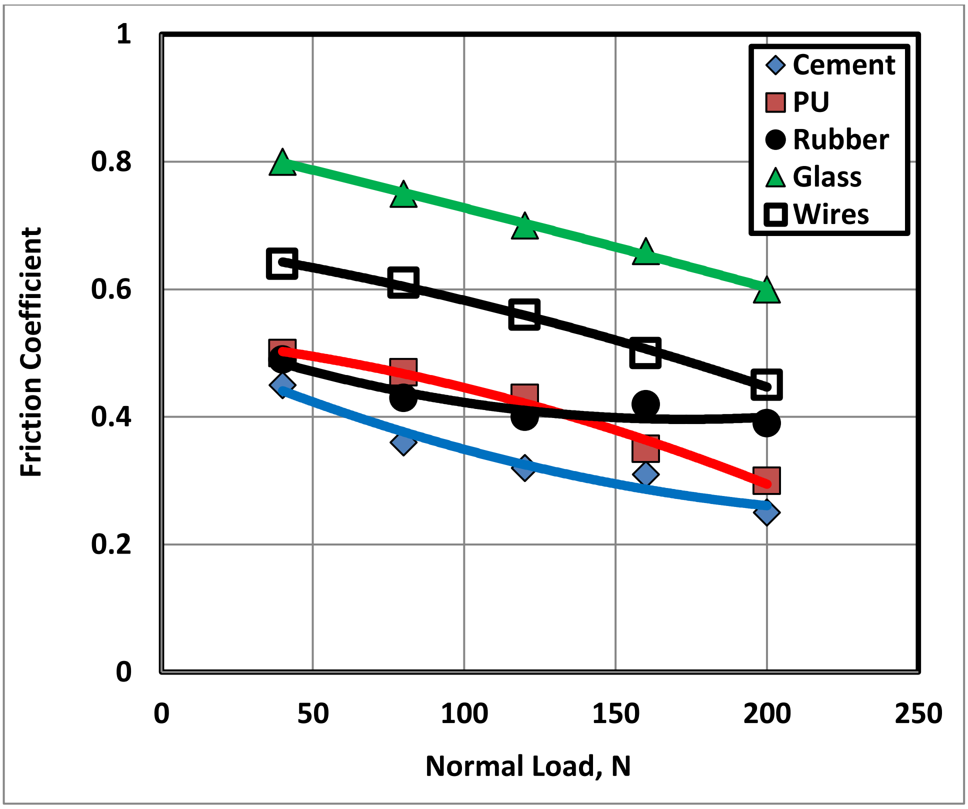


Fig. 6 Friction coefficient displayed by detergent wet sliding of rubber against the tested tiles.

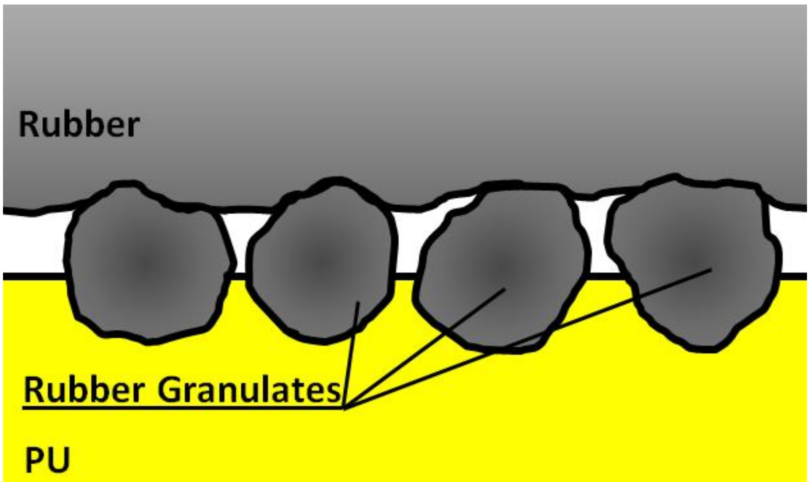


Fig. 7 The actual contact area in condition of rubber sliding on PU coated by rubber granulates.

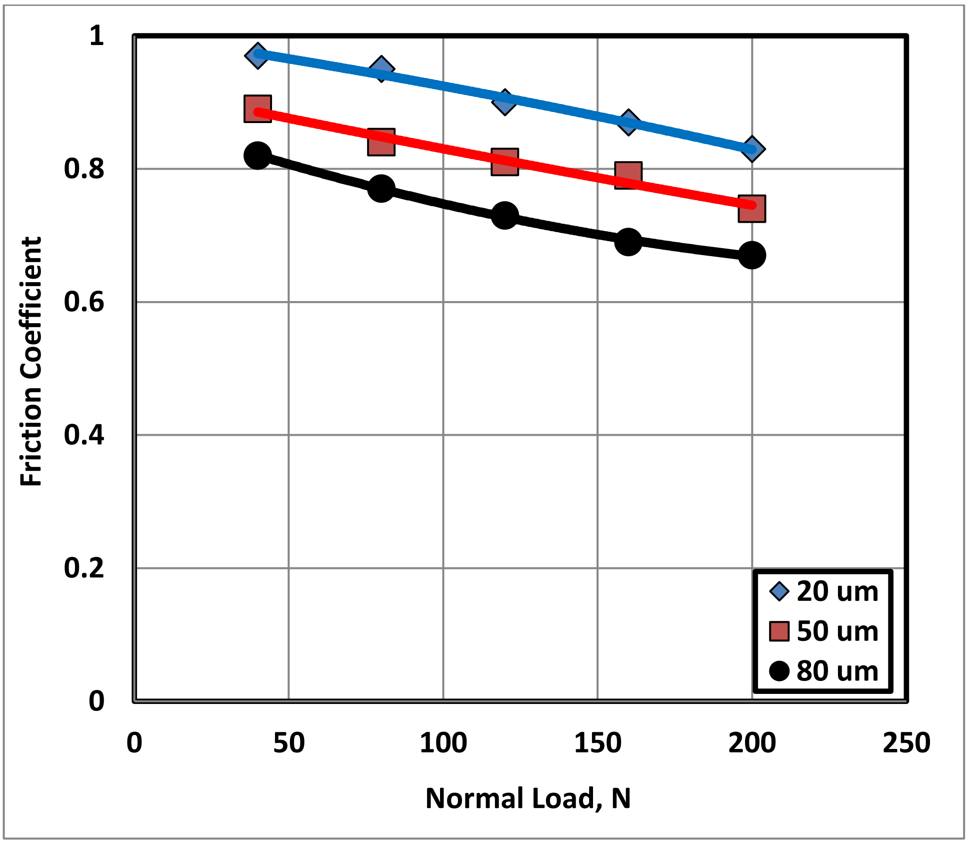


Fig. 8 Friction coefficient displayed by dry sliding of rubber against the tested tiles coated by sand particles.

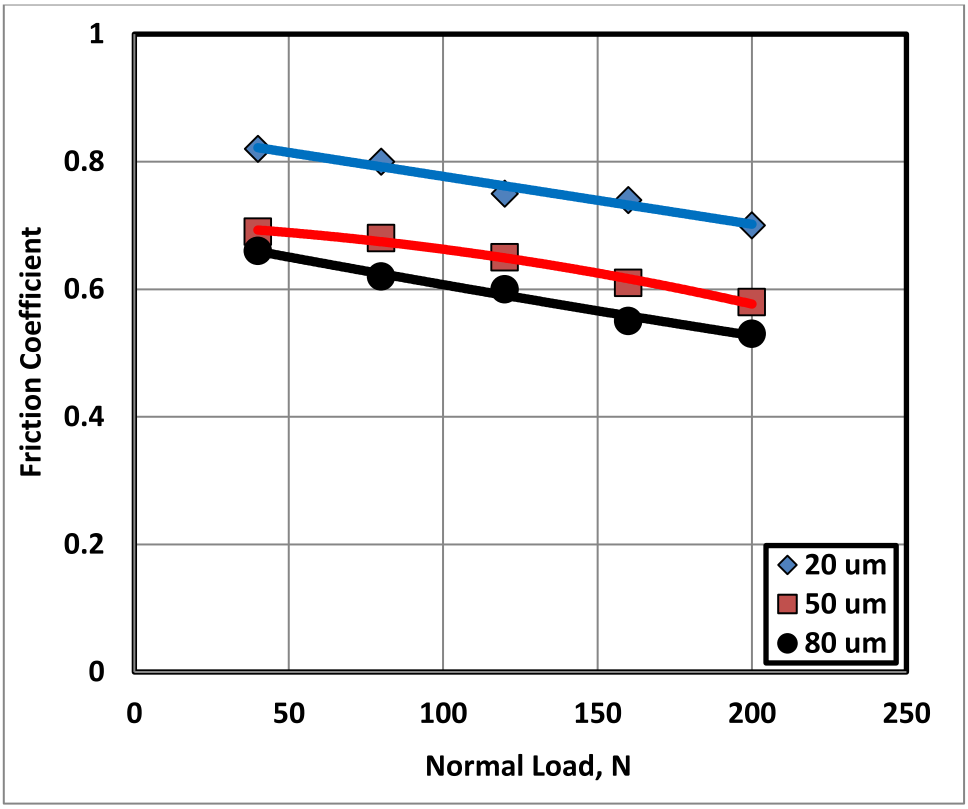


Fig. 9 Friction coefficient displayed by water wet sliding of rubber against the tested tiles coated by sand particles.

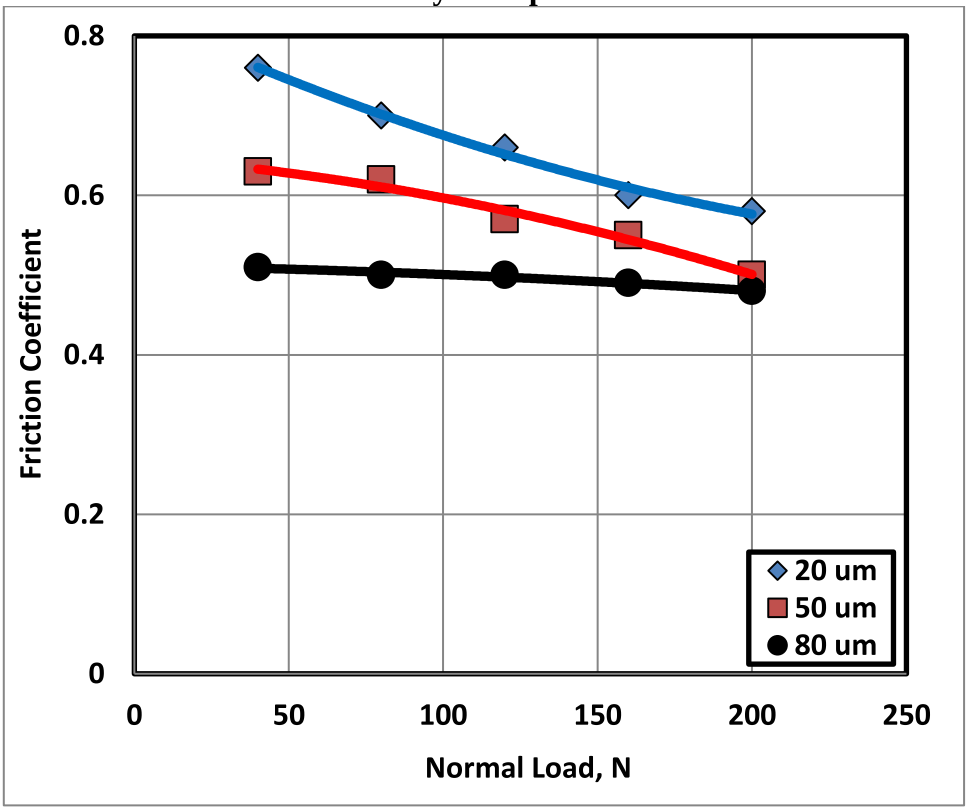


Fig. 10 Friction coefficient displayed by detergent wet sliding of rubber against the tested tiles coated by sand particles.

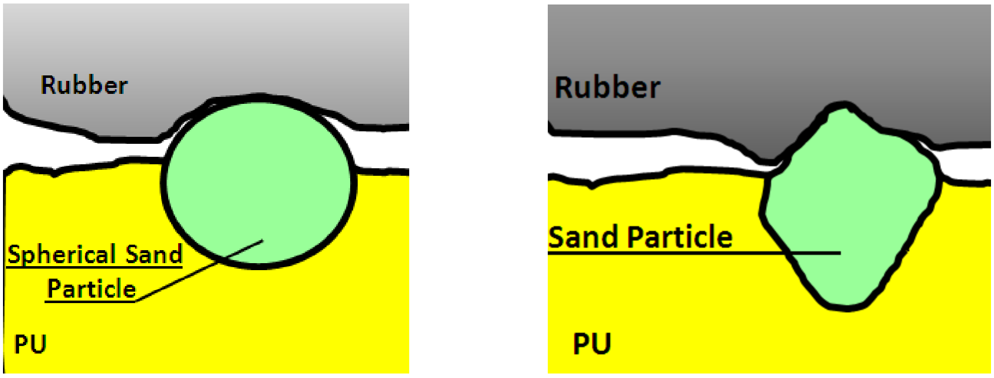


Fig. 11 The contact area of sand particles and rubber surface.

Coating the tested tiles by PU filled by sand particles of different particle size, Figs. 8 - 10, showed that as the sand particles were smaller, friction coefficient at dry, water and detergent wet sliding, was higher due to the fact that small sand particles have sharp edges, while big particles have relatively rounded ones. It is easy for sharp edges to penetrate the rubber surface then the resistance to the sliding increases. At water and detergent wet sliding, friction values recorded drastic decrease, Figs. 9 and 10. This observation may be explained on the basis that the valleys among the sand particles contain fluid film that covers the sliding surface. Sand particles of 80 µm particle size showed the lowest values, Fig. 11, where the contact area decreases for relatively big particles.

CONCLUSIONS

1. Friction coefficient displayed by dry sliding of rubber against the tested materials of floor tiles decreased with increasing normal load. The tested tile coated by glass granulates showed the highest friction values. Rubber coating PU displayed relatively lower value of friction coefficient followed by the unfilled PU coating. Cement tiles and PU coated tiles and PU reinforced by steel wires offered lower values.
2. Tiles coated by PU and filled by glass granulates showed promising friction values in the presence of water and detergent on the sliding surfaces. In contradiction to that, PU coatings displayed the lowest friction values.
3. Sliding of rubber against abrasive particles such as glass or sand causes an increase in the value of friction coefficient. At dry sliding, PU showed relatively higher friction than PU reinforced by steel wires.
4. At dry sliding, PU filled by sand particles significant friction increase, while at water and detergent wet sliding, a drastic decrease was recorded. Sand particles of relatively smaller particle size showed the highest values.

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