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FRICTION COEFFICIENT DISPLAYED BY SLIDING OF RUBBER SOLE AGAINST RECYCLED RUBBER FLOORING TILES

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ABSTRACT

Recycled rubber tiles are widely used as a flooring material in hospitals, factories, kid gardens and washrooms. In the present work, the main objective is to investigate the effect of their hardness and thickness on the friction coefficient when sliding against the rubber sole.

Based on the experimental observations, it was found that friction coefficient, displayed by sliding of rubber sole against dry flooring tiles, drastically decreased with increasing the hardness of the tested flooring tiles, while increased with increasing normal load. 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. In the presence of detergent and oil on the sliding surfaces, friction coefficient drastically decreased to values lower than that displayed by water. Presence of sand particles on the flooring tiles increased friction coefficient as the thickness and the load increased.

It can be recommended that it is necessary to avoid the use of relatively higher hardness for flooring tiles in bathrooms where water and detergent exist. In the presence of sand particle on the sliding surfaces, friction coefficient recorded relatively lower values. As the hardness increased friction coefficient drastically decreased.

KEYWORDS

Recycled rubber tiles, hardness, thickness, friction coefficient, sliding, rubber.

INTRODUCTION

The presence of water and detergent in bathrooms 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, [1]. Floor slip-resistance may be quantified using the static coefficient of friction.

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. The frictional behavior of ceramic tiles as flooring materials when soft and hard rubbers slide against them was described, [2, 3]. The values of friction coefficient displayed by

sliding of rubber against ceramics flooring materials under different sliding conditions: dry, water, water/detergent dilution and oily condition. Based on the experiments carried out in the present work, it was found that at dry sliding soft rubber slid against ceramic tiles showed higher friction coefficient than hard one. The difference might be attributed to the extra deformation offered by soft rubber. 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, [4]. 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. It is necessary to reduce slip and fall in bathrooms, workshops, kid gardens, halls and walking yards, [5]. The frictional behavior of rubber of different thickness and hardness was tested.

It was found that the treated surface had insignificant effect on the frictional behavior. Generally, friction coefficient slightly increased with increasing the tile thickness, [6]. In the presence of water on the sliding surface, treated surface displayed higher friction values than the smooth one. The highest values of friction coefficient were displayed by 2 mm tread width due to the water leakage from the contact area, [7]. Besides, sliding against oil lubricated pedal pad showed relatively low friction values which were considered as unsafe sliding.

The risks associated with slipping and falling are related to the materials of footwear floor, contamination condition, and geometric design of the sole. Shoe soles of various tread design are very common. Floor slip-resistance may be quantified using the static coefficient of friction. In the USA, the static coefficient of friction of 0.5has been recommended as the slip-resistant standard for unloaded, normal walking conditions. Certain values of friction coefficient were recommended as the slip-resistant standard for unloaded, normal walking conditions, [8]. Higher values of the static coefficient of friction may be required for safe walking when handling loads. In Europe, it was suggested that a floor was very slip resistant if the coefficient of friction was 0.3 or more, The factors affecting friction coefficient measurement are the material, surface geometry of the footwear as well as floor, floor contamination conditions and even the slip meter used, [9]. 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, [10, 11]. 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 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, [12 - 16]. Soft materials like rubber tend to a higher effective contact area and more pronounced microscopic

deformations when mechanically interacting with the surface asperities of a rigid material, larger friction coefficients can be expected for rubber than for plastic.

Investigators have concentrated the friction coefficient measurements on liquid contaminated floors because most slip/fall incidents occur on the surfaces of such floors, [17, 18]. 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. 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.

Arising from molecular attractive forces between two closely contact surfaces, adhesion is postulated as the primary cause of the impediment to sliding, [19]. As a result, rubber supposedly adheres to the track through interfacial bonds, which are periodically sheared by their share of the friction force and then reformed in an advanced position. The friction of rubber on smooth surfaces primarily depends on adhesion, while hysteresis becomes increasingly important for rough surfaces, [20]. For the slip resistance of shoe soles on floor surfaces covered by a liquid film, the drainage capability of the shoe-floor contact surface, the draping of the sole material about floor surface asperities as well as the true contact area between the surfaces are considered as key factors.

The friction coefficient difference between the dry and wet surfaces depended on the footwear material and floor combinations. Measurements of the static friction coefficient between rubber specimens and flooring surfaces were carried out at dry, water lubricated, oil, oil diluted by water and sand contaminating the lubricating fluids, [21, 22].

The effects of sand particles on the friction at the footwear–floor interface are much more complicated than liquid-contaminated conditions. Liquids on the floor tend to decrease the surface friction, but the sand particles on the floor may decrease or increase the friction on the floor, depending on factors such as characteristics of the particles, tread design and hardness of the footwear pad, hardness and roughness of the floor, and so on. Theoretically, the sand particles on the floor prevent a direct contact between the footwear pad and floor, [23]. The number of sand particles on the floor may affect the friction. But the largest particles dominate the effects because they will be the first ones to contact the footwear pad. While balls and rollers have been widely used in reducing friction in bearings, the friction coefficient values for different types of rolling bearing elements have been determined, [24]. This, however, provides little help in determining the effects of the sand particles on friction because most sand particles on the floor are geometrically irregular with various degrees of elasticity and strength.

In the present work, friction coefficient displayed by recycled rubber flooring tiles of different hardness and thickness sliding against rubber sole 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 the tested rubber specimens against the ceramic surface through measuring the friction force and applied normal force. The

rubber sole surface in form of a tile is placed in a base supported by two load cells, the first measures the horizontal force (friction force) and the second for the vertical force (applied load). A digital screen was attached to the load cells to detect the friction and vertical forces. Friction coefficient is determined by the ratio between the friction force and the normal load. The arrangement of the test rig is shown in Fig. 1. The rubber test specimens were prepared recycled rubber free of PVC, plasticizers (phthalates) or halogens (e.g. chlorine).

The recycled rubber tiles were prepared in a square shape of 36 × 39 mm and different thickness ranged from 2 - 9 mm. The hardness of specimens ranged from 72 to 94 shore A. The values of friction coefficient were measured under dry, water and detergent wetted, oil lubricated and sand contaminated sliding conditions.

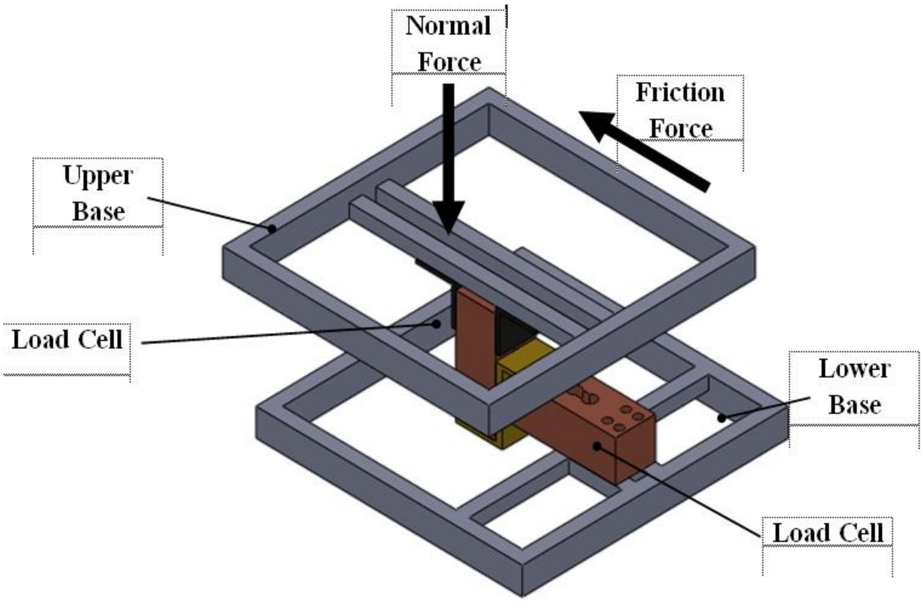

Fig. 1 Arrangement of the friction test rig.

RESULTS AND DISCUSSION

The effect of hardness of the recycled rubber flooring tiles on the friction coefficient at 50, 100 and 150 N is shown in Figs. 1 – 5. Friction coefficient, displayed by dry sliding of rubber sole against flooring tiles, drastically decreased with increasing the hardness of the tested flooring, Fig. 2. Friction coefficient decreased with increasing rubber hardness due to decrease of deformation, while increased with increasing normal load. It seems that increasing rubber hardness made rubber not easily deformed and consequently the escape of air bubbles that trapped in rubber surface gaps was limited so that the contact area and friction coefficient decreased.

At water lubricated sliding, soft flooring tiles showed higher friction coefficient than the harder ones, Fig. 3. As the load increased, friction coefficient increased for lower hardness, while higher hardness showed no effect on friction coefficient. It is clearly shown that increasing friction value with increasing normal load due to squeeze effect. The maximum value of friction coefficient was 0.85 at 72 Shore A hardness and 150 N

load. It seems that as the hardness increased, a water film was trapped between the two sliding surfaces causing the friction drop.

In the presence of detergent on the sliding surfaces, soft rubber tiles displayed relatively higher friction values than the hard ones, Fig. 4, where the friction coefficient decreased from 0.7 to 0.25 at 72 and 94 Shore A harness respectively. This observation confirmed the risk of using relatively higher hardness for flooring tiles in bathrooms where detergent exists.

When the oil was lubricating the sliding surfaces, friction coefficient drastically decreased with increasing the hardness, Fig. 5. As the load increased friction coefficient decreased. Friction showed very low values down to 0.05 at 150 N load and 94 Shore A which significantly increased the risk of slip. The relatively hard tiles had no enough deformation to allow the oil to leak out of the contact area leading to the decrease of friction coefficient.

In the presence of sand particles on the sliding surfaces, Fig. 6, friction coefficient recorded relatively lower values. As the hardness increased friction coefficient drastically decreased. This behaviour can be attributed to the sand embedment in rubber surface, where sand particles were completely embedded in the relatively soft tiles so that the contact was rubber sole/flooring tiles. In condition of hard tiles, sand particles were partially embedded and the contact surfaces were separated by them. It is well known that friction coefficient displayed by sand against the tested tiles is much lower than that displayed by sole against the flooring tiles.

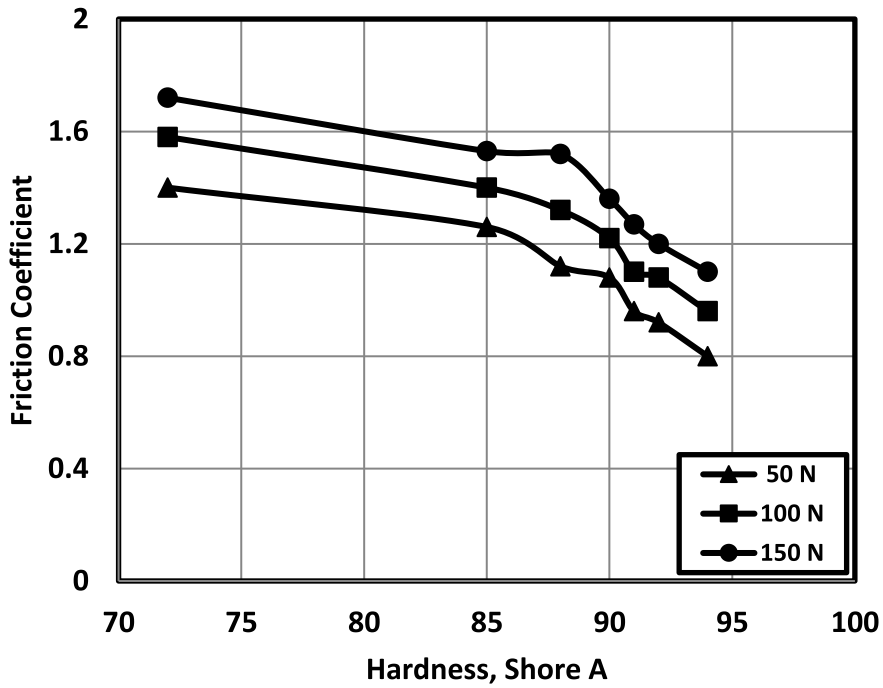

Fig. 2 Friction coefficient displayed by sliding of rubber sole against the dry flooring tiles.

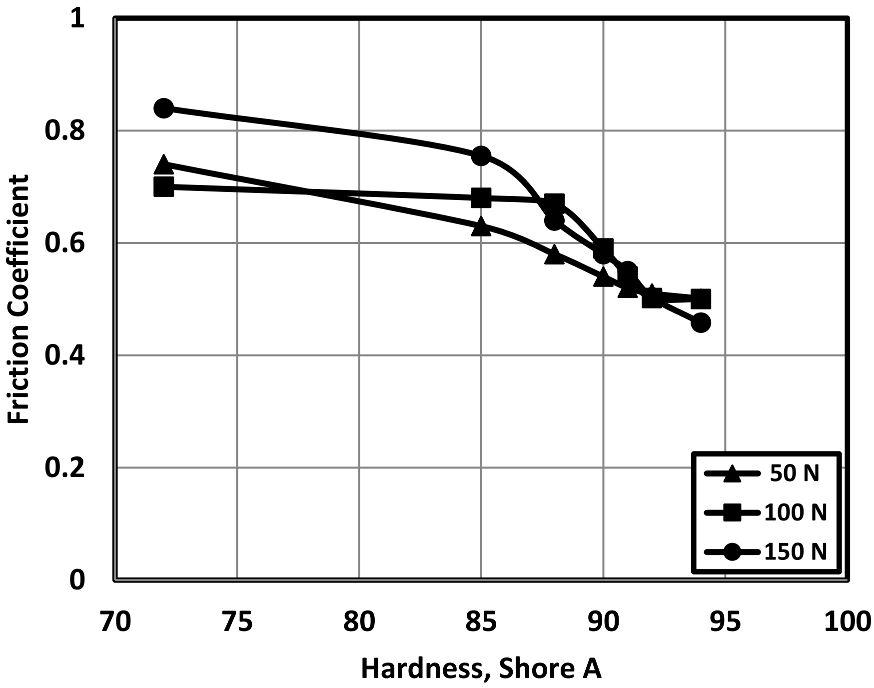

Fig. 3 Friction coefficient displayed by sliding of rubber sole against water wetted flooring tiles.

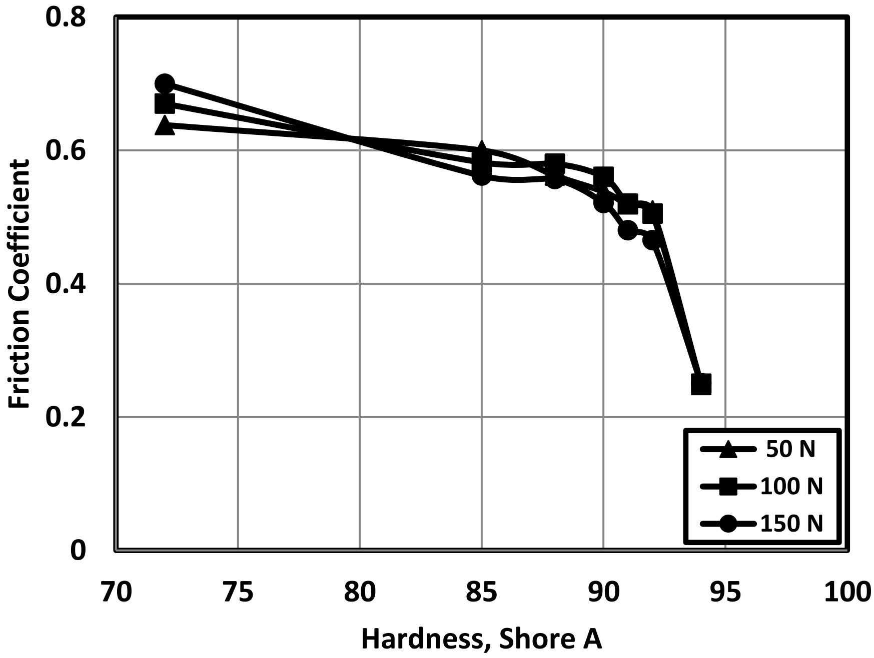

Fig. 4 Friction coefficient displayed by sliding of rubber sole against the detergent wetted flooring tiles.

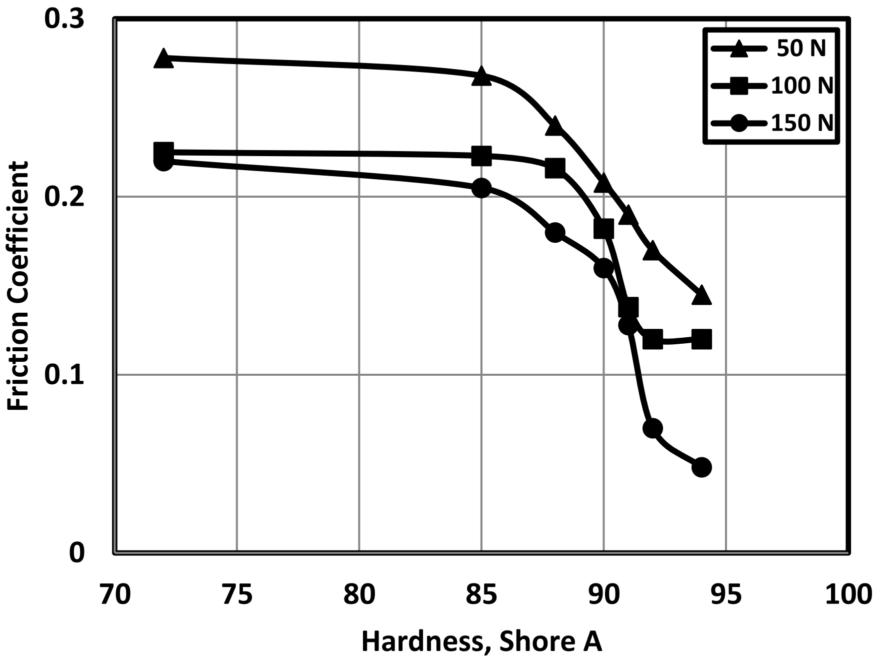

Fig. 5 Friction coefficient displayed by sliding of rubber sole against the oil lubricated flooring tiles.

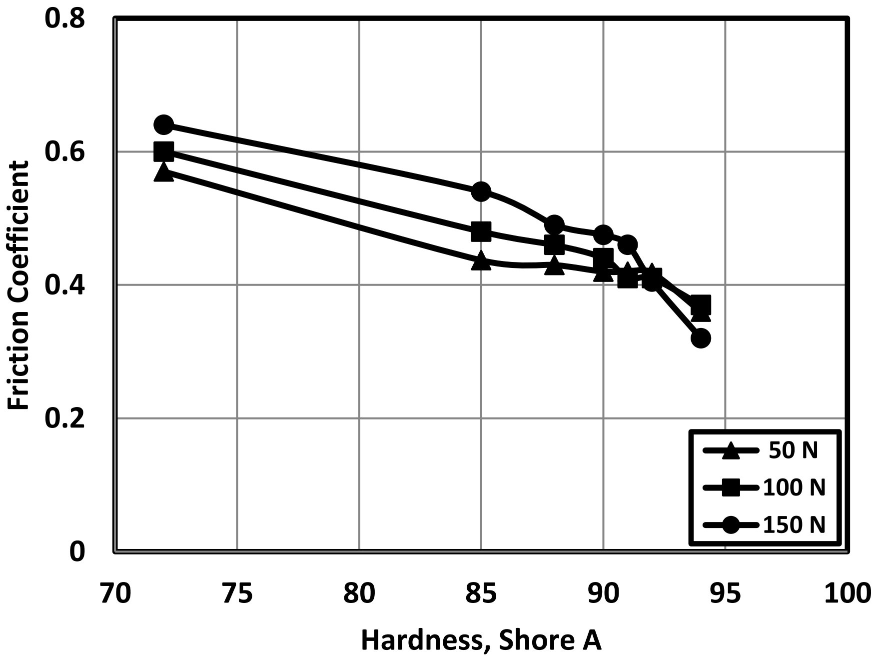

Fig. 6 Friction coefficient displayed by sliding of rubber sole against the sand contaminated flooring tiles.

The results of the effect of the thickness of the tested tiles on the friction coefficient are shown in Figs. 7 – 11. Dry sliding of rubber sole against the tested flooring tiles is shown in Fig. 7. Friction coefficient significantly increased with increasing the tiles thickness. It seems that as the thickness increased, the elastic deformation of the flooring tiles increased and consequently the contact area increased. As the load increased friction coefficient increased due to the increase of the contact area. At load of 150 N, friction value reached 1.7 which guaranteed safe walking.

Sliding against water wetted flooring tiles showed slight increase in friction coefficient with increasing the thickness, Fig. 8. Generally, friction coefficient increased with increasing the thickness of the flooring tiles. This behavior can be attributed to the fact that as the thickness increased, the ability of the flooring tiles to absorb water increased and consequently the area of the water film trapped between the sliding surfaces decreased. In this condition, the part of the contact area being performed under dry friction increased. Concentrating in the values of friction coefficient, it should be noted that they were quite high for safe walking.

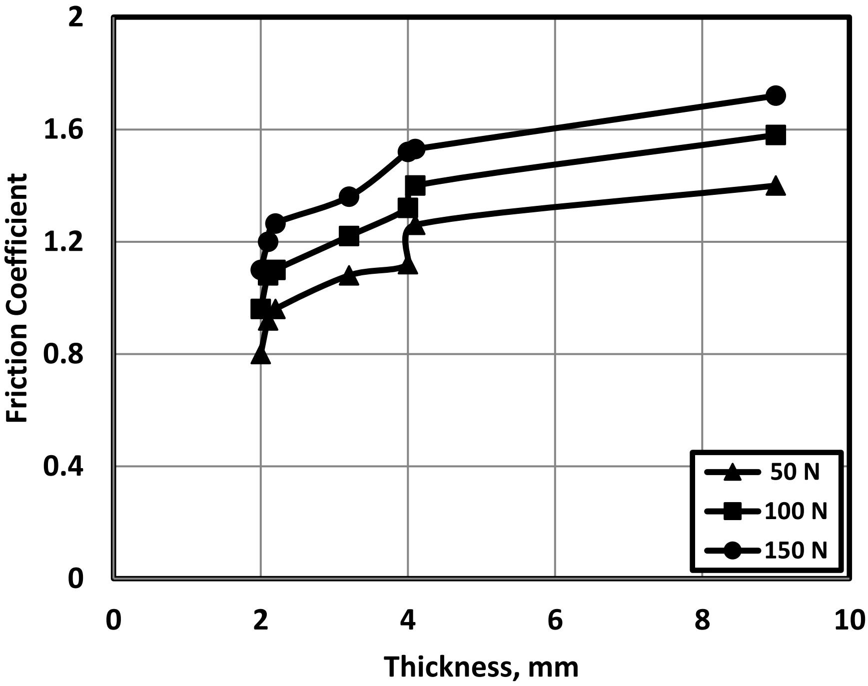

Fig. 7 Friction coefficient displayed by sliding of rubber sole against dry flooring tiles.

In the presence of detergent between the sliding surfaces, friction coefficient drastically decreased to values lower than that displayed by water, Fig. 9. At 9 mm thickness of the flooring tiles, friction coefficient ranged between 0.46 and 0.5. This behaviour can be explained on the basis that the detergent molecules were adhered to the sliding surfaces and as the flooring thickness increased the contact area increased and consequently friction decreased due to the action of the detergent molecules.

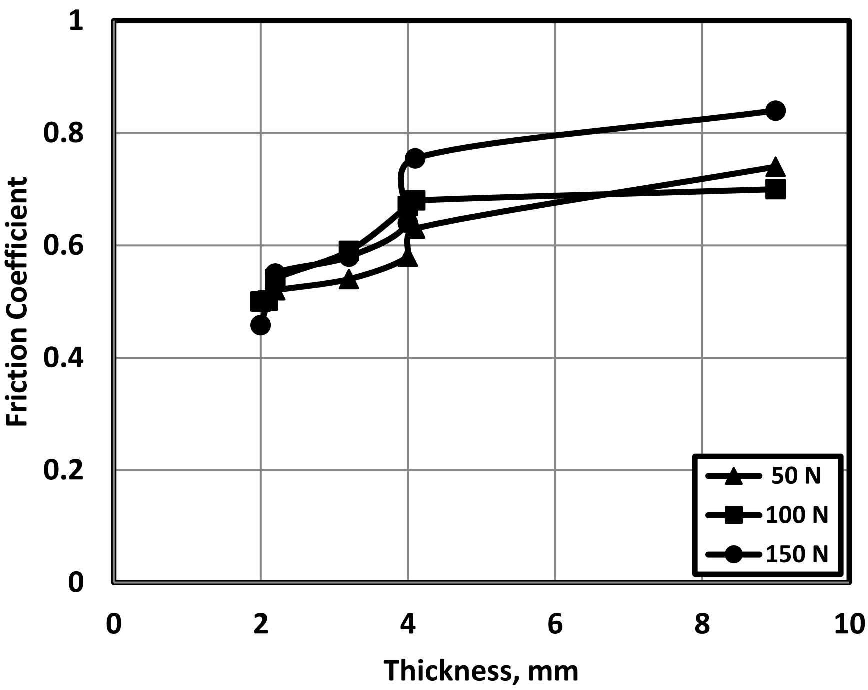

Fig. 8 Friction coefficient displayed by sliding of rubber sole against water wetted flooring tiles.

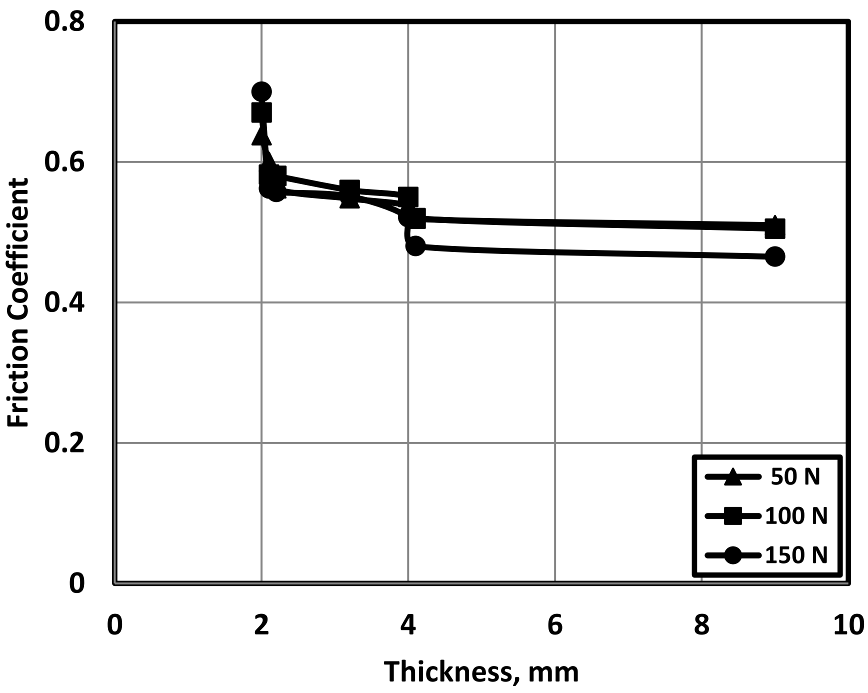

Fig. 9 Friction coefficient displayed by sliding of rubber sole against the detergent wetted flooring tiles.

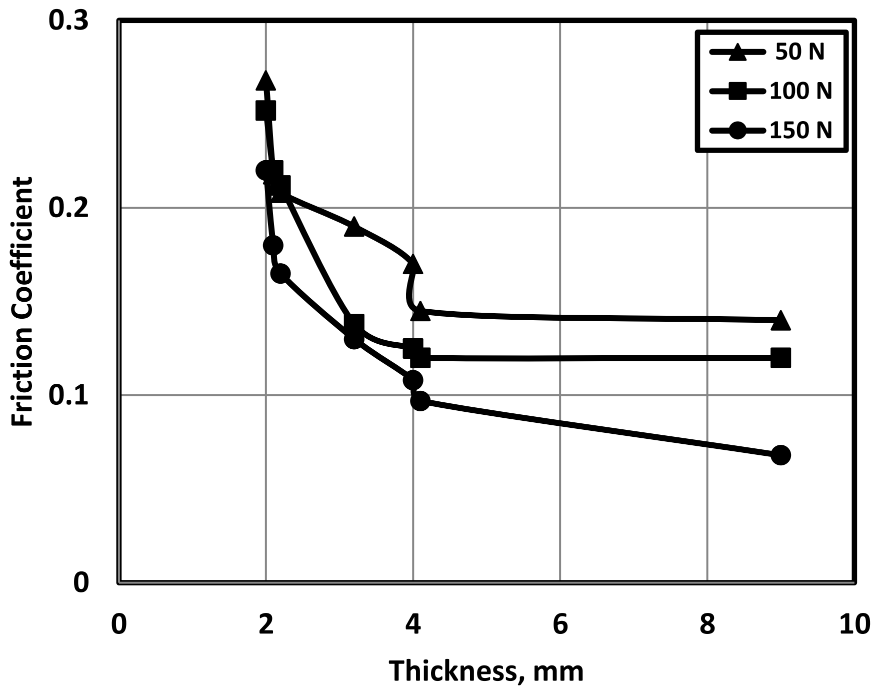

Fig. 10 Friction coefficient displayed by sliding of rubber sole against the oil lubricated flooring tiles.

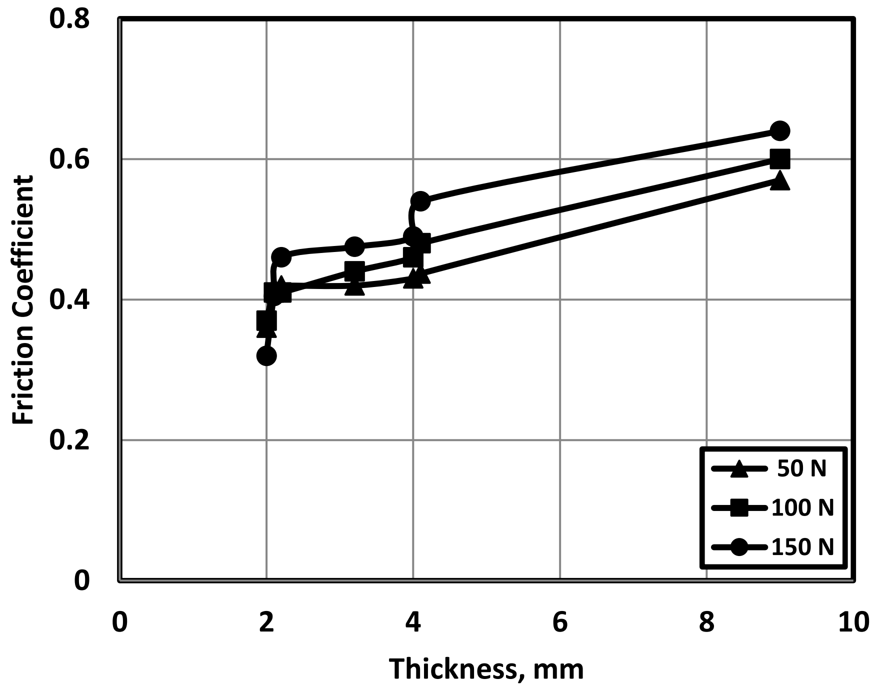

Fig. 11 Friction coefficient displayed by sliding of rubber sole against the sand contaminated flooring tiles.

Friction coefficient displayed by sliding of rubber sole against oil lubricated flooring tiles showed drastic decrease, Fig. 10. As the thickness of the tested tiles increased,

friction decreased. It seems that as the thickness increased the oil absorbability of the tested tiles increased and during friction the oil was fed up to the sliding surfaces forming a film which was responsible of decreasing friction.

Presence of sand particles on the flooring tiles increased friction coefficient as the thickness and the load increased. The performance may be from the increased embedment of sand particles with increasing the load so that rubber sole/tested tiles contact increased, Fig. 11. The relatively high friction values observed confirmed that, where the contact was partially between rubber sole and tested tiles. Friction coefficient slightly increased with increasing load. It seems that as the sand particles deeply embedded in the contact area so that the rolling motion of sand particles became limited. The decreased embedment of sand particles due to the low value of the thickness may be responsible for the lower values of friction coefficient. In this condition, the contact can be classified as rubber sole/tested tiles, rubber sole/sand particles and tested tiles/sand particles. It is recommended to use relatively high flooring thickness to obtain relatively higher friction values.

CONCLUSIONS

Friction coefficient, displayed by sliding of rubber sole against the dry flooring tiles, drastically decreased with increasing the hardness of the tested flooring, while increased with increasing normal load. At water and detergent wetted as well as oil lubricated sliding, soft tested rubber showed higher friction coefficient than the harder one. This observation confirmed the risk of using relatively higher hardness for flooring tiles in bath rooms where detergent exists. In the presence of sand particle on the sliding surfaces, friction coefficient recorded relatively lower values. As the hardness increased friction coefficient drastically decreased.

Dry sliding of rubber sole against the tested flooring tiles showed significant increase of friction coefficient with increasing material thickness, while sliding against water wetted flooring tiles showed slight increase. In the presence of detergent and oil between the sliding surfaces, friction coefficient drastically decreased to values lower than that displayed by water. Presence of sand particles on the flooring increased friction coefficient as the thickness and the load increased.

REFERENCES

1. El-Sherbiny Y.M., Khashaba M. I. and Ali W. Y., “Prevention of Slip Accidents by using Floor Mat”, KGK Kautschuk Gummi Kunststoffe 60. Jahrgang, September 2012, pp. 39 - 44, (2012)
2. Al-Osalmy A.S.. and Ali W. Y., “Friction Coefficient of Bare Foot and Footwear Sole Sliding Against Rubber Brake Pedal Pads”, KGK KautschukGummiKunststoffe 60. Jahrgang, July/August 2011, pp. 47 - 53, (2011).
3. Mohamed M.K., SamyA.M.and Ali W. Y., “Friction Coefficient of Rubber Shoes Sliding against Ceramic Flooring”, KGK KautschukGummiKunststoffe 60. Jahrgang, November/December 2011, pp. 2 - 7, (2011).
4. Mohamed M.K., El-Kattan A.A., Ali W.A., “Friction Coefficient Displayed by Rubber Sliding Against Flooring Tiles”, International Journal of Engineering & Technology IJET-IJENS Vol:12 No:06, December 2012,pp. 144 -149, (2012).
5. El-Sherbiny Y. M., Al-Qaham Y. G. and W. Y. Ali, “Friction coefficient of semi-spherical rubber protrusionsliding against rubber” Journal of the Egyptian Society of Tribology 7 VOLUME 10, NO. 3, JULY 2013, pp. 1 - 12 (2013). 11

6. Elham B. R., Khashaba M. I.and W. Y. Ali, “Friction coefficient of smooth and rough recycled rubber flooring tiles” Journal of the Egyptian Society of Tribology 7 VOLUME 9, NO. 3, JULY 2012, pp. 53 - 65 (2012). 11
7. Al-Osaimy A. S. and Ali W. Y., “Influence of Tread Width of the Brake Pedal Pads on the Friction Coefficient Generated by Bare Foot and Footwear Soles”, JKAU: Eng. Sci., Vol. 23 No. 1, jan.2010, pp: 227-245 (2010)
8. Miller J. M., "‘‘Slippery’’ work surface: toward a performance definition and quantitative friction coefficientcriteria", J. Saf. Res. 14, pp. 145 - 158, (1983).
9. Grönqvist R., "Mechanisms of friction and assessment of slip resistance of new and used footwear soles on contaminated floors", Ergonomics 38, pp. 224 - 241, (1995)
10. Myung, R., Smith, J. L., Leamon, T. B., "Subjective assessment of floor slipperiness", Int. J. Ind. Ergon. 11, pp. 313 - 319, (1993).
11. Kai W. L., Rui-feng Y., Xiao L. H., “Physiological and psychophysical responses in handling maximum acceptable weights under different footwear–floor friction conditions”, Applied Ergonomics 38, pp. 259 – 265, (2007).
12. Burnfield J. M., Tsai Y. J., Powers Ch. M., “Comparison of utilized friction coefficientduring different walking tasks in persons with and without a disability’, Gait & Posture 22, pp. 82 – 88, (2005).
13. Samy A. M., Mahmoud M. M., Khashaba M. I. and Ali W. Y., “Friction of Rubber Sliding Against Ceramics, I. Dry And Water Lubricated Conditions”, KGK KautschukGummiKunststoffe 60. Jahrgang, Nr 607, Juni 2007, pp. 322 – 327, (2007).
14. Samy A. M., Mahmoud M. M., Khashaba M. I. and Ali W. Y., “Friction of Rubber Sliding Against Ceramics, II. Oil And Oil Diluted By Water Lubricated Conditions”, KGK KautschukGummiKunststoffe 60. Jahrgang, Nr 607, December 2007, pp. 693 - 696, (2007).
15. Chang W. R., “The effect of surface roughness on the measurements of slip resistance”, International Journal of Industrial Ergonomics 24, (3), pp 299 – 313, (1999).
16. Leclercq S., Tisserand M., Saulnier H., “Tribological concepts involved in slipping accidents analysis”, Ergonomics 38(2), pp. 197 – 208, (1995).
17. Strandberg L., “The effect of conditions underfoot on falling and overexertion accidents”, Ergonomics 28(1), pp. 131 – 147, (1985).
18. Persson B. N. J., Tartaglino U., Albohr O., Tosatti E., “Rubber friction on wet and dry road surfaces: the sealing effect”, Physical Review B 71, 035428, (2005).
19. Martin A., Buguin A., Brochard-Wyart F., “Dewetting nucleation centers at soft interfaces”, Langmuir 17, pp. 6553 - 6559, (2001).
20. Samy A. M., Mahmoud M. M., Khashaba M. I. and Ali W. Y., “Friction of Rubber Sliding Against Ceramics, III. Sand Contaminating The Lubricating Fluids”, KGK KautschukGummiKunststoffe 60. Jahrgang, Nr 607, January/February 2008, pp. 43 - 48, (2008).
21. Chang W. R., "The effects of slip criteria and time on friction measurements", Safety Science 40 , pp. 593 – 611, (2002).
22. Ezzat 41. Li K W., Yao-Wen H., Wen-Ruey C., Ching-Hua L., "Friction measurements on three commonly used floors on a college campus under dry, wet, and sand-covered conditions ", Safety Science 45 , pp. 980 - 992 , (2007).
23. Khonsari, M. M., Booser, E. R., "Applied Tribology ", John Wiley & Sons, pp. 456 - 483, (2001).
24. Li K W., Yao-Wen H., Wen-Ruey C., Ching-Hua L., "Friction measurements on three commonly used floors on a college campus under dry, wet, and sand-covered conditions", Safety Science 45 , pp. 980 - 992 , (2007).