EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 9, NO. 3, JULY 2012, pp. 53 - 65 **ISSN 2090 - 5882**

FRICTION COEFFICIENT OF SMOOTH AND ROUGH RECYCLED RUBBER FLOORING TILES

Elham B. R.[1], Khashaba M. I.[1] and Ali W. Y.[2]

[1]Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT
[2]Faculty of Engineering, Taif University, Al –Taif, Saudi Arabia.

ABSTRACT

The effect of surface roughness on the frictional behaviour of recycled rubber tiles is discussed. Experiments were carried out by the sliding of the bare foot against smooth and rough groups of rubber tiles of different thickness. The friction coefficient was investigated. Experiments were carried out using a test rig designed and manufactured for the test. Loads were applied by foot up to 700 N. The normal and friction forces were measured to determine the static friction coefficient.

It was found that, for tiles made of recycled rubber, surface roughness had insignificant effect on the frictional behaviour. Generally, 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. Generally, friction coefficient decreased with increasing tiles thickness. Values of friction for detergent lubricated surfaces were lower than that observed for water lubricated surface. In the presence of sand particles on the sliding surface, friction coefficient increased for rough surface and decreased for smooth one with increasing the tile thickness. For tiles wetted by water and contaminated by sand particles rough surface displayed relatively higher friction than smooth one. In contradiction to the condition of presence of sand particles only, friction coefficient displayed by rough surface decreased with increasing tiles thickness.

Rough surfaces rubber tiles filled by polyurethane showed higher friction coefficient than the smooth ones at dry sliding. Friction coefficient increased as polyurethane content increased up to 20 wt. %. Further polyurethane increase had insignificant effect on friction coefficient. Friction coefficient drastically decreased with increasing polyurethane content for sliding against water lubricated tested tiles. Detergent lubricated surfaces displayed higher friction coefficient for smooth rubber. As the polyurethane content of the rubber tiles increased friction coefficient decreased. In the presence of sand particles, friction coefficient significantly increased for the both smooth and rough surfaces. Rough surfaces displayed higher friction values than smooth ones. Finally, drastic friction decrease for smooth surface was noticed for smooth tested rubber in the presence of water contaminated by sand particles.

KEYWORDS
Friction coefficient, bare foot, smooth, rough, recycled rubber tiles, dry, sand, water, detergent wetted sliding.

INTRODUCTION

Floor slip-resistance is quantified by the static friction coefficient. In the USA, the static friction coefficient of 0.5 has been recommended as the slip-resistant standard for unloaded, normal walking conditions [1]. Higher the static friction coefficient values may be required for safe walking when handling loads. In Europe, [2], it was suggested that a floor was ‘‘very slip-resistant’’ if the friction coefficient was 0.3 or more. A floor with the friction coefficient between 0.2 and 0.29 was ‘‘slip resistant’’. A floor was classified as ‘‘unsure’’ if its friction coefficient was between 0.15 and 0.19. A floor was ‘‘slippery’’ and ‘‘very slippery’’ if the friction coefficient of was lower than 0.15 and 0.05, respectively. The subjective ranking of floor slipperiness was compared with the static friction coefficient (μ) and found that the two measures were consistent, [3, 4]. 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 [5] contain advisory recommendations for static friction coefficient of $\mu \geq 0.60$ for accessible routes (e.g. walkways and elevators) and $\mu \geq 0.80$ for ramps. The effect of surface roughness of ceramic on the friction coefficient, when rubber and leather are sliding against it, was investigated, [6]. Glazed floor tiles of different roughness ranging from 0.05 and 6.0 μm were tested. The test results showed that, friction coefficient decreased down to minimum then increased with increasing the surface roughness of the ceramic surface.

Glazed ceramics tiles are extensively used as flooring materials. The increasing demand to enhance the degree of surface roughness of the tiles to facilitate for the consumer the cleaning process should be balanced by investigating the effect of surface roughness on the friction coefficient. Slips and falls are a serious problem due to the annual direct cost of occupational injuries, [7]. It was found that a higher friction could potentially improve slip resistance as discussed previously, [8 - 14]. It was observed that dynamic friction is more applicable to human walking than static friction. Surface roughness also plays a role in floor slipperiness even in hydrodynamic squeeze-film sliding, [15], where it was investigated that certain surface roughness is needed to improve slip resistance. Tread groove designs are helpful in facilitating contact between the shoe 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 provided by cylindrical treads on friction coefficient was investigated, [17]. It was found that at dry sliding, friction coefficient significantly increased with increasing treads diameter, where the tread directions displayed

significant role in increasing the 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.

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, [18]. Based on the experimental results, 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. In the presence of water on the sliding surface significant decrease in friction coefficient was observed compared to the dry sliding. For detergent wetted surfaces, 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 as a result of the formation of the hydrodynamic wedge.

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 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, [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.

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, [22]. This was found in the friction measurements under wet conditions. In general, rubber friction is divided into two parts; the bulk hysteresis and the contact adhesive term. These two contributions are regarded to be independent of each other, but this is only a simplified assumption, [23].

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, [24]. The friction coefficient difference between the dry and wet surfaces depended on the footwear material and floor combinations. Friction measurements under liquid-contaminated conditions were 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 ceramic surfaces were carried out at dry, water lubricated, oil, oil diluted by water and sand contaminating the lubricating fluids, [25 - 27]. 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.

In the present work, comparative performance was carried out between smooth and rough recycled rubber tiles through sliding of bare foot against them to determine friction coefficient at dry, water, detergent and sandy sliding conditions.

EXPERIMENTAL

Experiments were carried out using a test rig designed and manufactured to measure the friction coefficient displayed by the sliding of the bare foot against the tested rubber tiles through measuring the friction and normal forces. The tested tiles were placed in a base supported by two load cells, the first can measure the horizontal force (friction force) and the second can measure the vertical force (normal load). Friction coefficient was determined by the ratio between the friction force and the normal load.

The tested rubber tiles were made of recycled rubber, Table 1. Their hardness was 65 Shore A. Two surfaces were prepared from the tested tiles, the first was smooth (4.7 µm, Ra), while the other was corrugated. The corrugated tiles will be referred as rough ones in the present text. The corrugation can be expressed in 20 mm wave length and 3 mm height. The tiles were made of recycled rubber and filled by polyurethane of content ranged from 0 – 45 wt. %. The tiles, in form of 300 × 300 mm and thickness ranged between 6 – 14 mm, were adhered to the base of the test rig. Friction test was carried out using bare foot applying variable forces up to 700 N. Friction coefficient was plotted

against load then friction values were extracted from the figures at 200, 400 and 600 N. The bare foot was loaded against dry, water and water + 1.0 vol. % detergent wetted tiles. Water was replenished on the tested tiles, where the amount of water for each replenishment was 300 ml to form consistent water film covering the tile surface. In the water–detergent condition, a 1.0 vol. % detergent solution was applied to the tiles. After each measurement, all contaminants were removed from the tiles surface and bare foot using absorbent papers. Both the bare foot and tested tiles were then rinsed using water and dried by using hair dryer after the cleaning process.

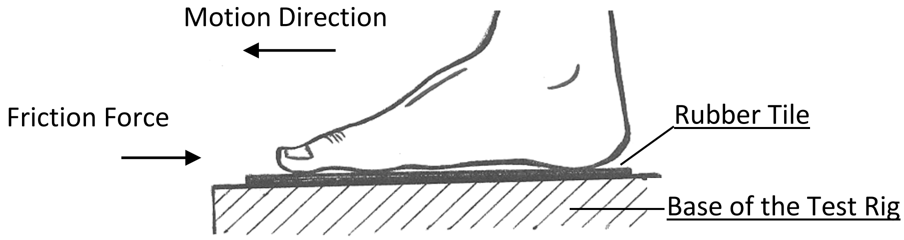
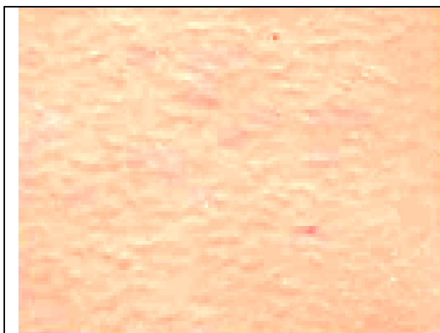
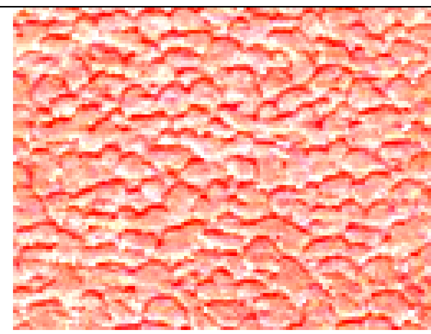


Fig. 1 Arrangement of the sliding conditions.

Table 1 Smooth and rough tested tiles.

	
Smooth	**Rough**

RESULTS AND DISCUSSION

The results of friction coefficient of foot sliding against the tested rubber tiles are shown in Figs. 2 – 6. At dry sliding, Fig. 2, it is clearly shown that surface roughness had insignificant effect on the frictional behaviour. Generally, friction coefficient slightly increased with increasing the tiles thickness. The highest friction values did not exceed 0.63 at 14 mm thickness.

In the presence of water on the sliding surface, rough surface displayed higher friction values than the smooth one, Fig. 3. It seems that the roughness asperities broke the water film formed on the sliding surface leading to an increase of the friction coefficient. Besides, the valleys of the surface roughness allowed the water to go out the contact area. Generally, friction coefficient decreased with increasing tiles thickness. Friction coefficient varied from 0.48 to 0.31 at flooring thickness of 6, 14 mm respectively for

rough surface, while smooth surface displayed friction values of 0.36 and 0.23 at flooring thickness of 6, 14 mm respectively.

The same trend was noticed at detergent lubricated surfaces, Fig. 4, where the difference increased with increasing flooring thickness. Values of friction were lower than that observed for water lubricated surface. The lowest friction value (0.26) for rough surface was displayed at 14 mm flooring thickness. Smooth surface displayed the lowest friction value of 0.15 at 14 mm tile thickness.

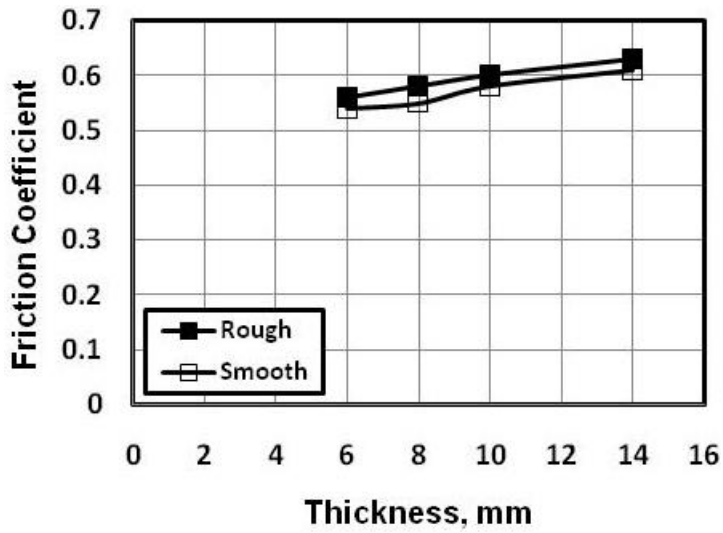


Fig. 2 Friction coefficient of foot sliding against dry flooring tiles.

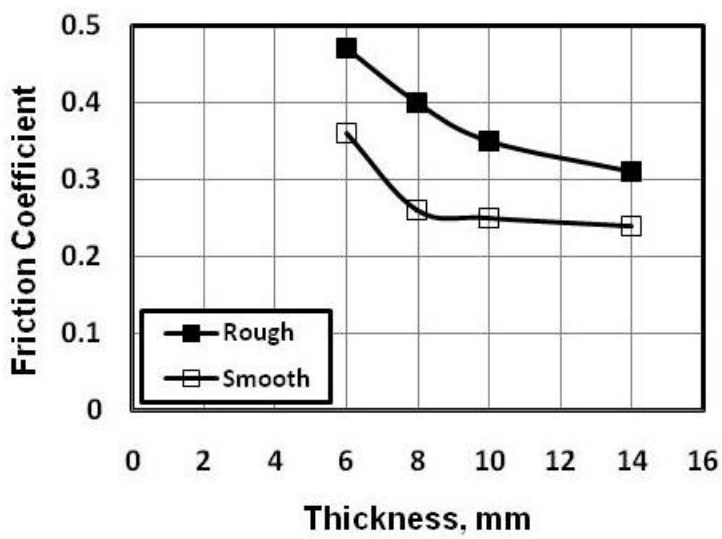


Fig. 3 Friction coefficient of foot sliding against water lubricated flooring tiles.

In the presence of sand particles on the sliding surface, Fig. 5, friction coefficient increased for rough surface and decreased for smooth one with increasing the tile thickness. This effect might be from the embedment of sand particles in the tested

rubber surface, where smooth tiles ability to embed sand particle is much higher than that observed for the rough tiles. This behaviour can be explained on the basis that sand particles could be stored in the valleys of the rough surface so that the contact would be bare foot/rubber.

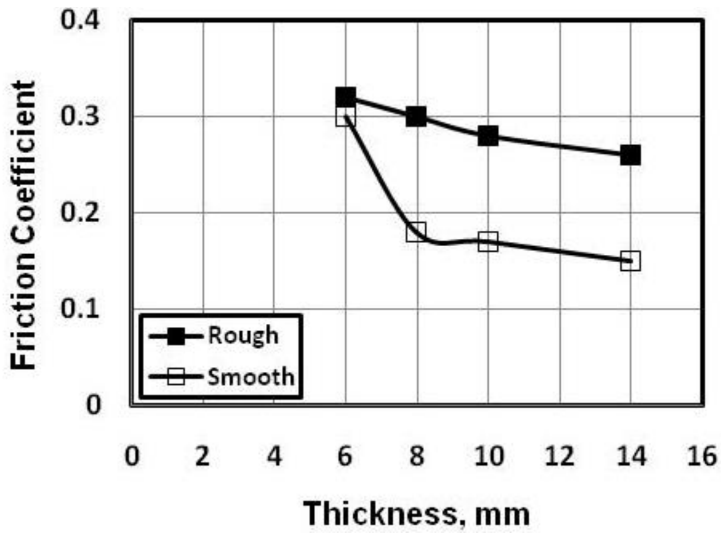


Fig. 4 Friction coefficient of foot sliding against detergent lubricated flooring tiles.

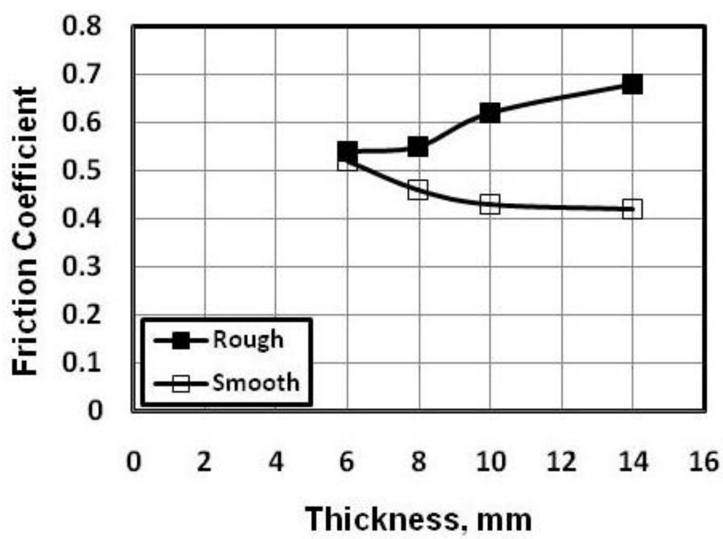


Fig. 5 Friction coefficient of foot sliding against flooring tiles contaminated by sand particles.

Friction coefficient of bare foot sliding against the tested tiles wetted by water and contaminated by sand particles is shown in Fig. 6. Rough surface displayed relatively higher friction than smooth one. In contradiction to the condition of presence of sand particles only, friction coefficient displayed by rough surface decreased with increasing tiles thickness. This behaviour might be from the increased embedment of sand particles in the rubber surface as the tile thickness increased.

Figures 7 - 11 show the effect of filling polyurethane content of the tested rubber tiles on friction coefficient. At dry sliding, rough surfaces showed higher friction coefficient than smooth ones due to the asperities deformation of the rough rubber, Fig. 7. The friction difference was noticed for tiles filled by polyurethane content higher than 20 wt. %. Further polyurethane increase had insignificant effect on friction coefficient.

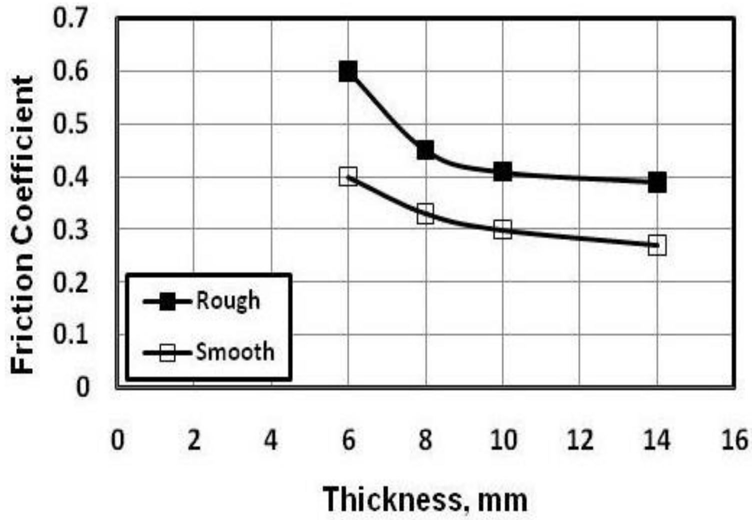


Fig. 6 Friction coefficient of foot sliding against flooring tiles wetted by water and contaminated by sand particles.

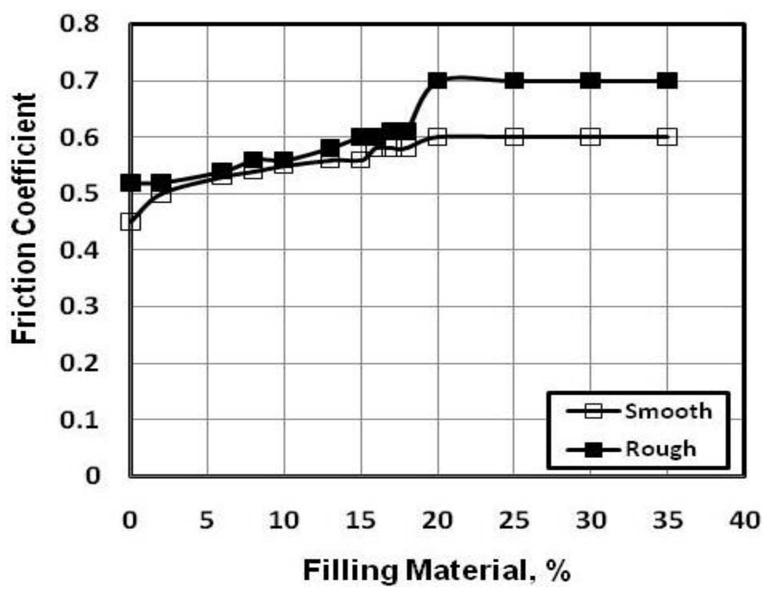


Fig. 7 Friction coefficient of foot sliding against dry flooring tiles.

Friction coefficient of bare foot sliding against water lubricated tiles showed insignificant difference for rough and smooth tested rubber, Fig. 8. Friction coefficient drastically decreased with increasing polyurethane content. It seems that polyurethane content increased the elastic deformation of the tested tiles which allowed the formation of water film on the contact area.

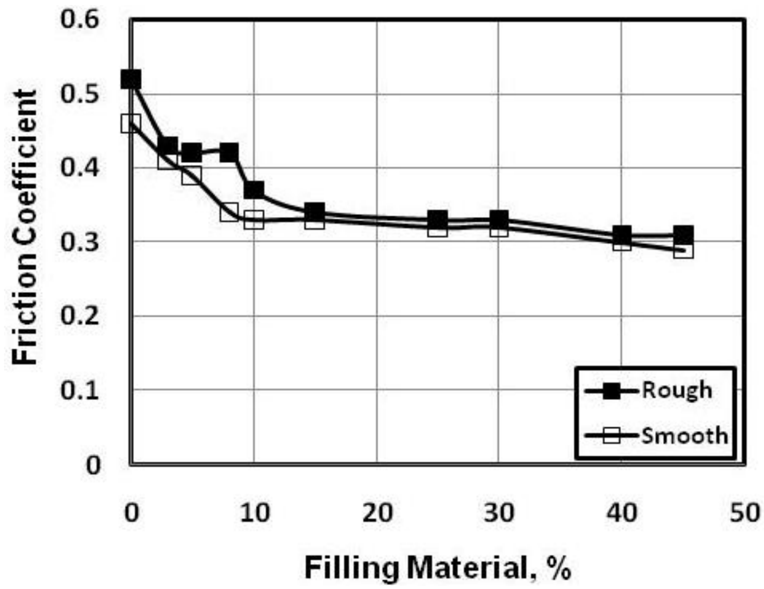


Fig. 8 Friction coefficient of foot sliding against water lubricated flooring tiles.

Detergent lubricated surfaces displayed higher friction coefficient for smooth rubber, Fig. 9. This effect might be from the mechanism of action of the detergent molecules that working more efficiently on the smooth surfaces. Generally, friction coefficient displayed relatively lower values than that observed from surfaces wetted by water. As the thickness of the rubber tiles increased friction coefficient decreased. Based on the friction values the tiles were considered as slip resistant.

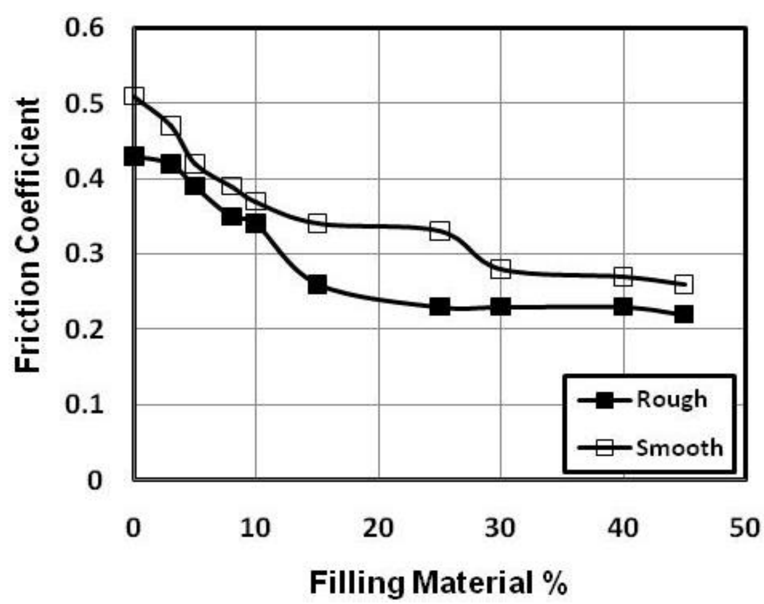


Fig. 9 Friction coefficient of foot sliding against detergent lubricated flooring tiles.

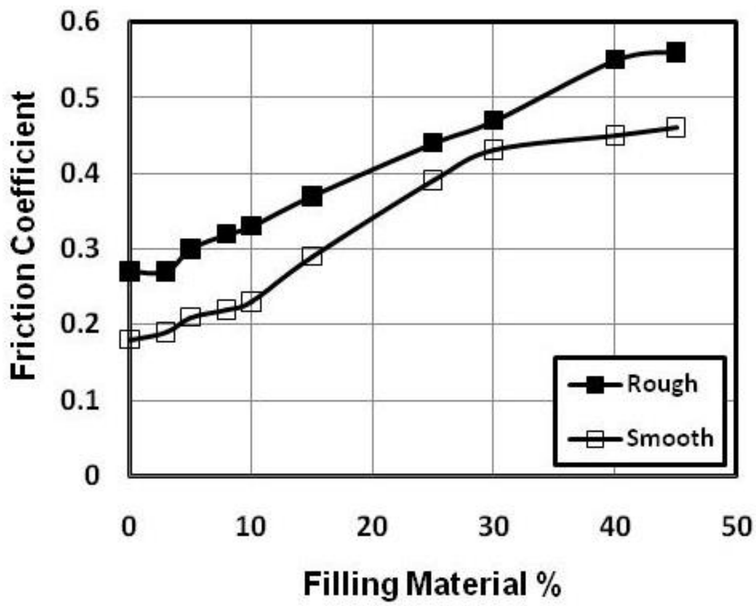


Fig. 10 Friction coefficient of foot sliding against flooring tiles contaminated by sand particles.

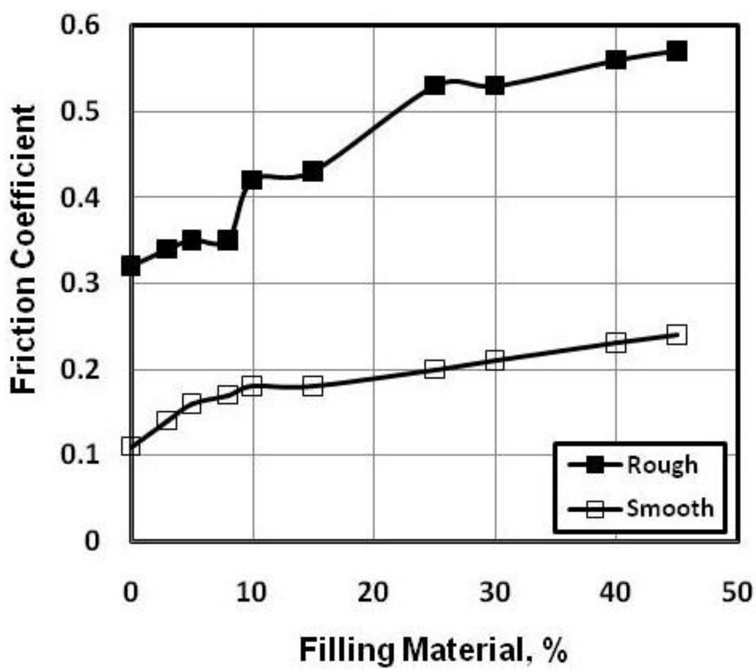


Fig. 11 Friction coefficient of foot sliding against flooring tiles wetted by water and contaminated by sand particles.

In the presence of sand particles contaminating the sliding surfaces, friction coefficient significantly increased for both smooth and rough surfaces, Fig. 10. Rough surfaces displayed higher friction values than smooth ones due to the easy escape of sand

particles from the contact area. The highest friction values were observed at 45 % filling material.

Drastic friction decrease for smooth surface was noticed for smooth tested rubber, Fig. 11, in the presence of water contaminated by sand particles. This behaviour can be explained on the fact that the ability of sand particle to be embeded in the smooth surface was pronounced. The highest friction value (0.57) was observed for the rough surface at 45 % filling material.

CONCLUSIONS

1. Surface roughness had insignificant effect on the friction coefficient. Generally, friction coefficient slightly increased with increasing tile thickness.
2. In the presence of water on the sliding surface, rough surfaces displayed higher friction values than smooth ones. Generally, friction coefficient decreased with increasing tiles thickness.
3. Values of friction for detergent lubricated surfaces were lower than that observed for water lubricated surface.
4. In the presence of sand particles on the sliding surface, friction coefficient increased for rough surface and decreased for smooth one with increasing the tile thickness.
5. For tested tiles wetted by water and contaminated by sand particles rough surface displayed relatively higher friction than smooth one. In contradiction to the condition of presence of sand particles only, friction coefficient displayed by rough surface decreased with increasing tiles thickness.
6. At dry sliding, rough surfaces showed higher friction coefficient than smooth ones for rubber filled by polyurethane. The friction difference was noticed for tiles filled by polyurethane content higher than 20 wt. %. Further polyurethane increase had insignificant effect on friction coefficient.
7. Friction coefficient drastically decreased with increasing polyurethane content for sliding against water lubricated tested tiles.
8. Detergent lubricated surfaces displayed higher friction coefficient for smooth rubber. As the polyurethane content of the rubber tiles increased friction coefficient decreased.
9. In the presence of sand particles, friction coefficient significantly increased for the both smooth and rough surfaces. Rough surfaces displayed higher friction values than smooth ones.
10. Drastic friction decrease for smooth surface was noticed for smooth tested rubber in the presence of water contaminated by sand particles.

REFERENCES

1. Miller J. M., "‘‘Slippery’’ work surface: toward a performance definition and quantitative friction coefficientcriteria", J. Saf. Res. 14, pp. 145 - 158, (1983).
2. 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).
3. Myung, R., Smith, J. L., Leamon, T. B., "Subjective assessment of floor slipperiness", Int. J. Ind. Ergon. 11, pp. 313 - 319, (1993).

4. 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).
5. 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).
6. Leclercq S., Tisserand M., Saulnier H., "Tribological concepts involved in slipping accidents analysis", Ergonomics 38(2), pp. 197 – 208, (1995).
7. Manning D. P., Jones C., "The effect of roughness, floor polish, water, oil and ice on underfoot friction: Current safety footwear solings are less slip resistant than microcellular polyurethane", Applied Ergonomics 32, pp. 185 – 196, (2001).
8. Proctor T. D., Coleman V., "Slipping, tripping, and falling accidents in Great Britain − Present and future", Journal of Occupational Accidents 9, pp. 269 – 285, (1988).
9. Strandberg L., "The effect of conditions underfoot on falling and overexertion accidents", Ergonomics 28(1), pp. 131 – 147, (1985).
10. Strandberg L., Lanshammar H., "The dynamics of slipping accidents", Journal of Occupational Accidents 3, pp. 153 – 162, (1981).
11. Ezzat F. H., Abdel-Jaber G. T. and Ali W. Y., "Dry Sliding of Rubber on Glazed Ceramic Tiles", Proceedings of the 7th International Conference of Tribology, EGTRIB 7, December 27 - 28, 2006, Faculty of Engineering, Cairo University, pp. CI, 1 – 9, (2006).
12. Leamon T. B., Murphy P. L., "Occupational slips and falls: more than a trivial problem", Ergonomics 38, pp. 487 - 498, (1995).
13. Chang W. R., "The effect of surface roughness on dynamic friction between neolite and quarry tile", Safety Sci. 29 (2), pp. 89 - 105, (1998).
14. Strandberg L., Lanshammar H., "The dynamics of slipping accidents", J. Occup. Accidents 3, pp. 153 - 162, (1981).
15. Lanshammar H., Strandberg L., "Horizontal floor reaction forces and heel movements during the initial stance phase", In: Matsui, H. and Kobayashi K. (Eds.), Biomechanics VIII. University Park Press, Baltimore, pp. 1123 - 1128, (1983).
16. Li K. W., Chen C. J., "The effect of shoe soling tread groove width on the friction coefficientwith different sole materials, floors, and contaminants", Applied Ergonomics 35, pp. 499 – 507, (2004).
17. El-Sherbiny Y. M., Mohamed M. K., Ali W. Y., "Friction Coefficient Displayed by Footwear Walking Against Rubber Floorings Fitted by Cylindrical Treads", Journal of the Egyptian Society of Tribology, Vol. 8, No. 1, January 2011, pp. 1 – 12, (2011).
18. El-Sherbiny Y. M., Samy A. M. and Ali W. Y., "Friction Coefficient of Rubber Sliding Against Dusty Indoor Flooring", Journal of the Egyptian Society of Tribology, Vol. 7, No. 2, April 2010, pp. 11 – 25, (2010).
19. El-Sherbiny Y. M., Hasouna A. T. and Ali W. Y., "Friction Coefficient of Rubber Sliding Against Flooring Materials", Journal of the Egyptian Society of Tribology Vol. 8, No. 4, October 2011, pp. 1 – 11, (2011).
20. Samy A. M., El-Sherbiny Y. M. and Hasouna A. T., "Reducing the Slip of Rubber Mats on Ceramic Floorings", EGTRIB, Journal of the Egyptian Society of Tribology, Vol. 8, No. 3, July 2011, pp. 1 – 14, (2011).
21. Samy A. M., El-Sherbiny Y. M., and Khashaba M. I., "Friction Coefficinet of

Perforated Bathroom Rubber Mats with Leakage Grooves", EGTRIB, Journal of the Egyptian Society of Tribology, Vol. 8, No. 2, April 2011, pp. 1 – 12, (2011).
22. Derler S., Kausch F., Huber R., "Analysis of factors influencing the friction coefficients of shoe sole materials", Safety Science 46, pp. 822 - 832, (2008).
23. Maeda K., Bismarck A., Briscoe B., "Effect of bulk deformation on rubber adhesion ", Wear 263, pp. 1016 – 1022, (2007).
24. 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 Kautschuk Gummi Kunststoffe 60. Jahrgang, Nr 607, Juni 2007, pp. 322 – 327, (2007).
25. 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 Kautschuk Gummi Kunststoffe 60. Jahrgang, Nr 607, December 2007, pp. 693 – 696, (2007).
26. 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 Kautschuk Gummi Kunststoffe 60. Jahrgang, Nr 607, January/February 2008, pp. 43 – 48, (2008).
28. Ezzat F. H., Hasouna A. T., Ali W. Y., "Friction Coefficient of Rubber Sliding Against Polymeric Indoor Flooring Materials of Different Surface Roughness", Journal of the Egyptian Society of Tribology, Vol. 4, No. 4, January 2007, pp. 37 – 45, (2007).
27. 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).