EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 9, NO. 4, OCTOBER 2012, pp. 28 - 39 ISSN 2090 - 5882

FRICTION COEFFICIENT DISPLAYED BY RUBBER SLIDING AGAINST FLOORING TILES

Mohamed M. K., ElKattan A. A. and Ali W. A.

Faculty of Engineering, Taif University, Al –Taif, Saudi Arabia.

ABSTRACT

The present work describes the frictional behaviour of ceramic tiles as flooring materials when soft and hard rubbers slide against them. The values of friction coefficient displayed by sliding of rubber against different types of flooring materials would be compared to that obtained from ceramic tiles under different sliding conditions: dry, water, water/detergent dilution, oil and water/oil dilution.

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. The same trend was observed when sliding against ceramics wetted by water. The difference in friction coefficient displayed by hard and soft rubber significantly increased as the load increased. Soft rubber displayed lower friction than hard rubber when sliding against oil lubricated ceramic surfaces. In presence of oil/water dilution for soft rubber, friction coefficient showed no change with increasing applied load.

The comparative performance of the tested flooring tiles showed that at dry sliding, epoxy displayed relatively lower friction than cement and marble, while ceramic showed reasonable friction values. Cement tiles gave the highest friction coefficient. In the presence of water on the sliding surface, marble displayed the highest friction coefficient followed by cement and parquet. Ceramic tiles showed the lowest friction among the tested floorings. Sliding of rubber against water/detergent wetted tiles caused drastic decrease of friction coefficient, where marble displayed the highest friction values followed by parquet and cement. PVC, epoxy and ceramic represented the lowest friction values. Hard oily floorings such as cement, marble and ceramic showed higher friction. Parquet, PVC and epoxy tiles showed relatively lower friction. Finally, parquet, epoxy and cement tiles displayed the highest friction, while ceramic, PVC and marble showed the lowest friction when rubber slid against water/oil diluted floorings.

KEYWORDS

Friction coefficient, rubber, ceramic tiles, dry, water, water/detergent dilution, oil and water/oil dilution, load.

INTRODUCTION

Slip resistance of flooring materials is one of the major environmental factors affecting walking and materials handling behavior. Floor slipperiness may be quantified using the static and dynamic friction coefficient, [1]. Certain values of friction coefficient were

recommended as the slip-resistant standard for unloaded, normal walking conditions. Relatively higher static and dynamic friction coefficient values may be required for safe walking when handling loads.

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, [2]. 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. 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, [3]. 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, [4]. 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, [5]. 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.

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, [6]. 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, [7]. If the adhesive force is solely a function of the surface free energy, it has been assumed that this adhesive force per unit area should be constant during any bulk (surface) deformation.

Arising from molecular attractive forces between two closely contact surfaces, adhesion is postulated as the primary cause of the impediment to sliding, [8]. 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. A static friction model between rubber-like material and rigid asperities has been developed taking into account the viscoelastic behaviour of rubber, [9]. The friction of rubber on smooth surfaces primarily depends on adhesion, while hysteresis becomes increasingly important for rough surfaces, [10]. For a tire sliding on a road surface, dry friction was found to be entirely due to the hysteresis contribution, whereas the reduced friction in the wet condition was explained by a sealing effect of rubber, which leads to the entrapment of water in pools of the rough surface, associated with an effective reduction of surface roughness, [11]. 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 ceramic surfaces were carried out at dry, water lubricated, oil, oil diluted by water and sand contaminating the lubricating fluids, [12 - 14]. 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. Measurements of the static friction coefficient between rubber specimens sliding against the polymeric flooring materials of vinyl of different surface roughness were carried out at dry, water, water and soap, oil, oil and water, [15]. It was observed that, at dry sliding, friction coefficient decreased with increasing surface roughness and applied load.

The factors affecting friction coefficient measurement: the material and surface geometry of the footwear and floor, floor contamination conditions and even the slipmeter used, [16, 17]. The effect of surface roughness of ceramic on the friction coefficient, when rubber and leather are sliding against it, was investigated, [18]. 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.

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, [19]. 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, [20]. 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, the frictional behaviour of ceramic tiles as flooring materials when soft and hard rubbers slide against them was investigated. The values of friction coefficient displayed by sliding of rubber against different types of flooring materials was compared to that obtained from ceramic tiles under different sliding conditions: dry, water, water/detergent dilution, oil and water/oil dilution.

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 ceramic tiles through measuring the friction force and normal force, Fig. 1. Ceramic

tiles were placed in a base supported by two load cells to measure both the horizontal force (friction force) and vertical force (normal load). Two digital screens were attached to the load cells to detect the friction and vertical forces. Friction coefficient was determined by the ratio between friction force and normal load.

Smooth rubber test specimens were prepared in the form of square sheets of 100 × 100 mm and 10.0 mm thickness. Then the rubber specimens were adhered to wooden blocks. The rubber test specimens prepared from two type of rubber (soft and hard) of 2 and 8 MPa modulus of elasticity and 27 and 53 Shore-A hardness respectively.

The tested flooring materials were parquet, polyvinyl chloride (PVC), epoxy, marble, cement and ceramic in form of a quadratic sheet of 0.4 m × 0.4 m and 5.0 mm thickness. The surface roughness ranged from 0.22 to 0.45 µm R_a, (the center line average of surface heights, CLA).

Friction test was carried out at normal load of 50, 100, 150 and 200 N. The sliding conditions tested in the experiment were dry, water, water/detergent dilution, oil, and water/oil dilution. Water was replenished on the tested flooring materials, where the amount of water for each replenishment was 10 ml to form consistent water film covering the sliding surface. In the water/detergent condition, a 1.0 vol. % detergent solution was applied to the tested floorings. In the oily condition, 2 ml of vegetable oil (sun flower oil) was spread on the flooring using a paintbrush. After each measurement, all contaminants were removed from the flooring materials and the rubber specimens using absorbent papers. Both the flooring materials and the rubber specimens were then rinsed using water. In the oily condition, the sliding surfaces were cleaned using a detergent solution to remove the oil, rinsed using tap water and blown using hair dryer after the cleaning process.

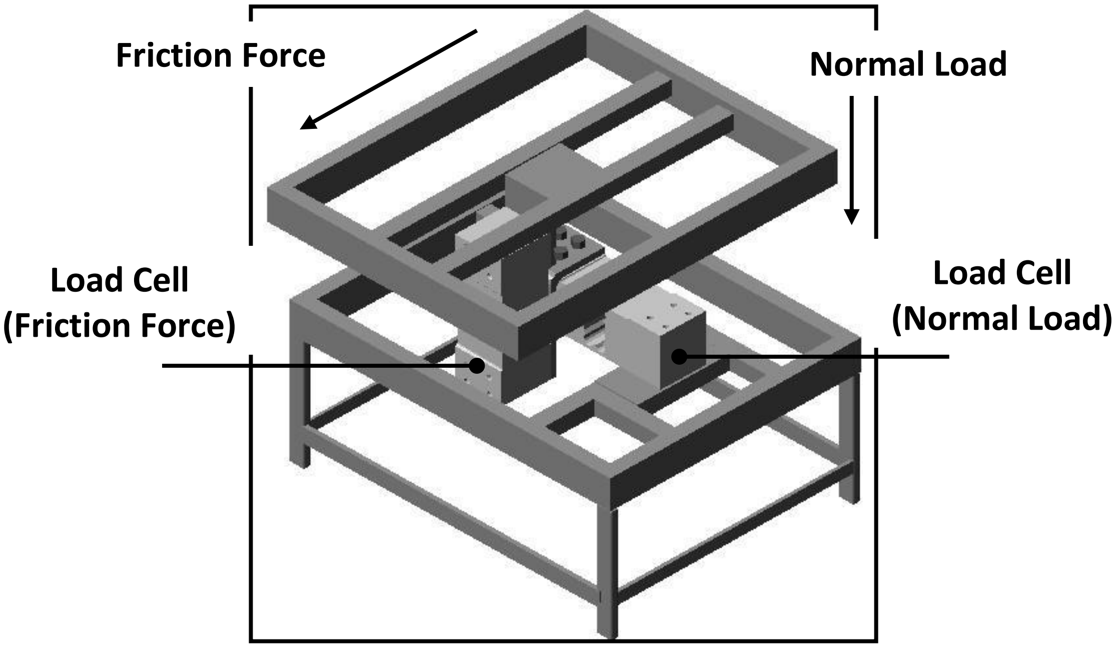

Fig. 1 Arrangement of the friction tester.

RESULTS AND DISCUSSION

Dry sliding of hard rubber against ceramics, Fig. 2, displayed slight increase in friction coefficient with increasing load. It is commonly known that as the load increased friction coefficient decreased for elastomeric materials. This contradiction can be attributed to the limited deformation of hard rubber. This behaviour caused an increase in contact area with load increase. For soft rubber, it can be noticed that friction coefficient slightly decreased with increasing normal load. Soft rubber showed higher friction coefficient than hard one. The difference might be attributed to the extra deformation offered by soft rubber.

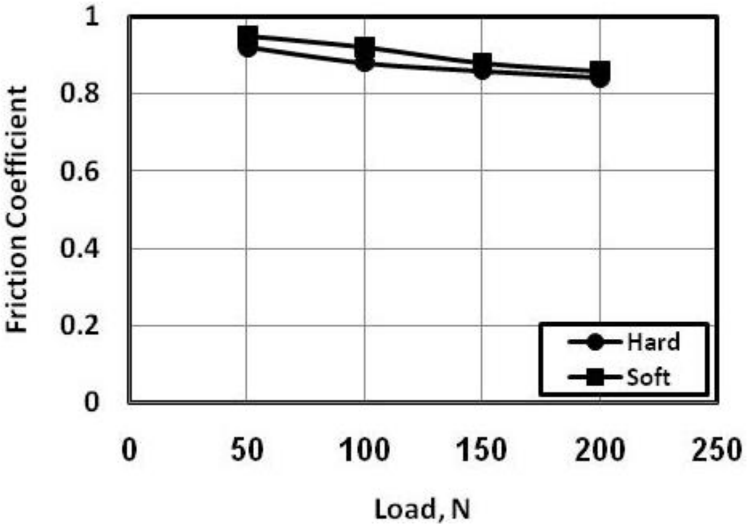

Fig. 2 Friction coefficient displayed by hard and soft rubbers sliding against dry ceramic tiles.

Friction coefficient for rubber specimen sliding against ceramics wetted by water is shown in Fig. 3. Values of friction coefficient were much lower than that observed for dry sliding. At higher loads friction coefficient decreased because water was trapped in the contact area. Generally, friction coefficient decreased with increasing normal load, where lower load increased the ability of water to leak from the sliding surface, but at higher loads friction coefficient decreased because water was trapped in contact area. Soft rubber showed relatively higher friction coefficient than hard rubber.

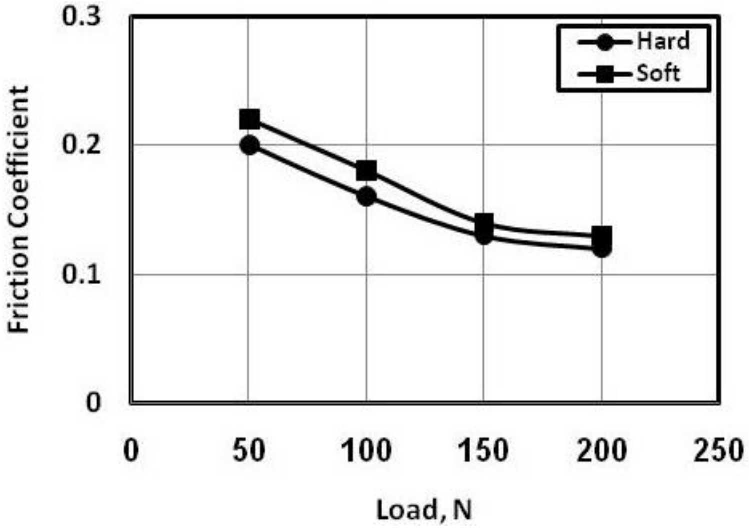

Fig. 3 Friction coefficient displayed by hard and soft rubbers sliding against water wetted ceramic tiles.

Friction coefficient for rubber specimens sliding against ceramics wetted by water/detergent is shown in Fig. 4. It is observed that friction coefficient decreased with increasing normal load. This behaviour can be interpreted on the basis that as the load increased the emulsion was trapped in the contact area. At relatively lower loads the emulsion could easily leak from the contact area. Friction coefficient displayed by soft rubber decreased at high loads because the lubricating medium was trapped between rubber and ceramic surface. The difference in friction significantly increased as the load increased. It seems that the porosity of oft rubber surface were responsible for that behaviour, where soft rubber had more porosity than hard one.

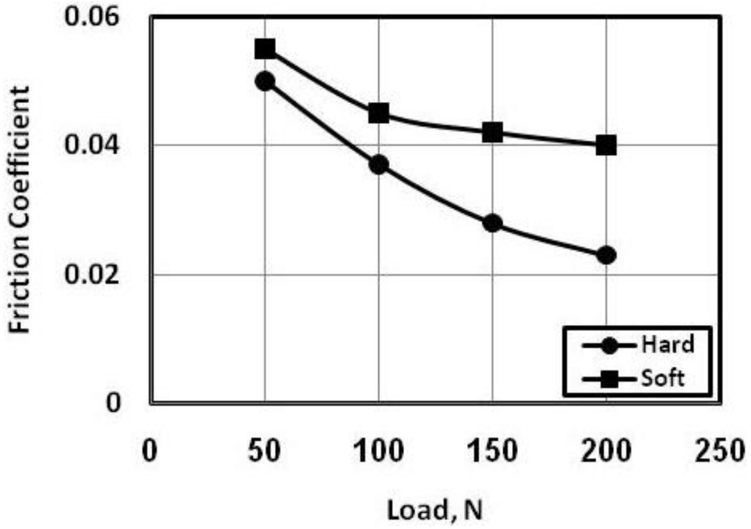

Fig. 4 Friction coefficient displayed by hard and soft rubbers sliding against water/detergent dilution wetted ceramic tiles.

Friction coefficient displayed by sliding of rubber against oil lubricated ceramic tiles is shown in Fig. 5. It can be noticed that, friction coefficient decreased with increasing normal load due to the relatively strong adhesion of oil film in rubber surface as well as

trapping of oil in the contact area. Soft rubber displayed lower friction due to ability of its porosity to absorb oil. As the load was applied on the surface, oil leaked out from the pores and formed oil film on the sliding surface.

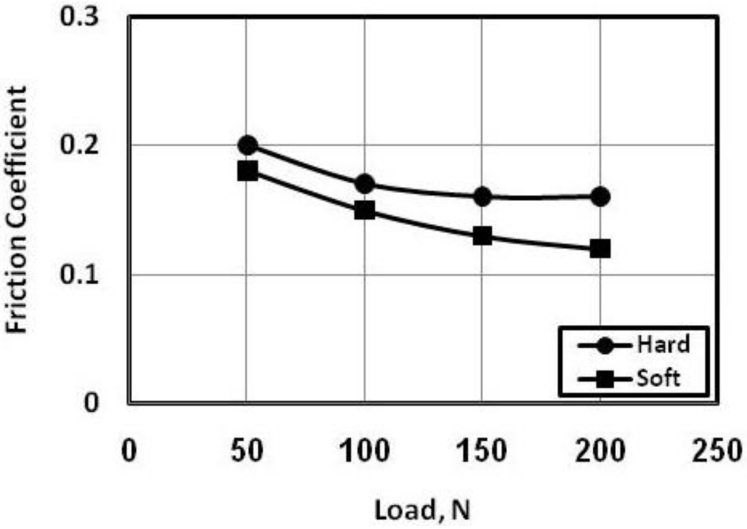

Fig. 5 Friction coefficient displayed by hard and soft rubbers sliding against oil lubricated ceramic tiles.

Values of friction coefficient in presence of oil/water diluted ceramic tiles is shown in Fig. 6. Friction coefficient showed significant decrease compared to the condition of oil sliding. Generally, friction coefficient decreased with increasing normal load, because the lower load facilitated oil/water to escape from the contact area. It can be noticed that for soft rubber, friction coefficient showed no change with increasing applied load. It seems that water/oil dilution was able to fill the pores in the soft rubber surface, so that the fluid got out of the pores and formed continuous film on the sliding surface.

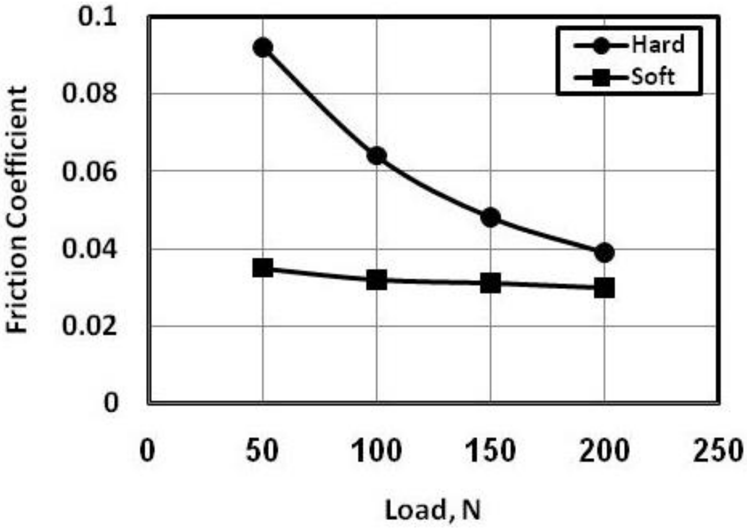

Fig. 6 Friction coefficient displayed by hard and soft rubbers sliding against water/oil dilution lubricated ceramic tiles.

The effect of load applying on the tested flooring materials is shown in Figs. 7 – 11 at the different tested sliding conditions. The dry sliding of rubber specimens against flooring materials is shown in Fig. 7. Friction coefficient decreased with increasing load. For low loads, maximum adhesion was attained, the interfacial area had a maximum value, the mechanism of molecular stick slip process was responsible for the increased adhesion component of friction and consequently friction coefficient displayed relatively higher values. Increasing surface roughness decreased friction coefficient due to the decrease of the contact area as well as adhesion. It is clearly shown that there was a drastic decrease in the friction values with increasing normal load due to saturation of the rubber asperities and rubber filling the gaps between the track asperities, where the rubber in the contact area deformed in such a manner as to completely follow the short-wavelength surface roughness profile of the counterface. Epoxy displayed relatively lower friction than cement and marble, while ceramic showed reasonable friction values. Cement tiles gave the highest friction coefficient.

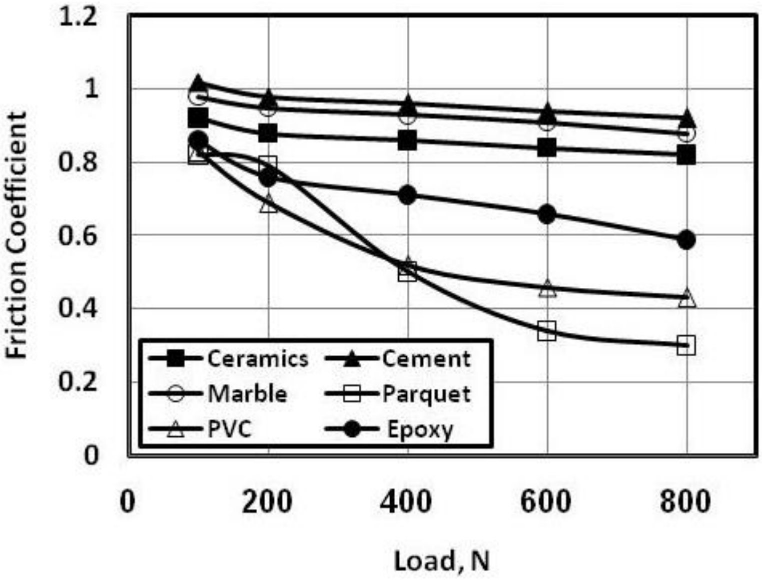

Fig. 7 Friction coefficient displayed by rubber sliding against dry flooring materials.

In the presence of water on the sliding surface, the effect of load on friction coefficient is shown in Fig. 8. Friction coefficient slightly decreased with increasing load. The decrease of friction coefficient can be attributed to the ability of the flooring tiles to store more water in the valleys of the voids between asperities, where they acted as reservoirs for the water, and the pressure distribution at each asperity summit promoted local drainage effects. Marble displayed the highest friction coefficient followed by cement and parquet. Ceramic tiles showed the lowest friction among the tested floorings.

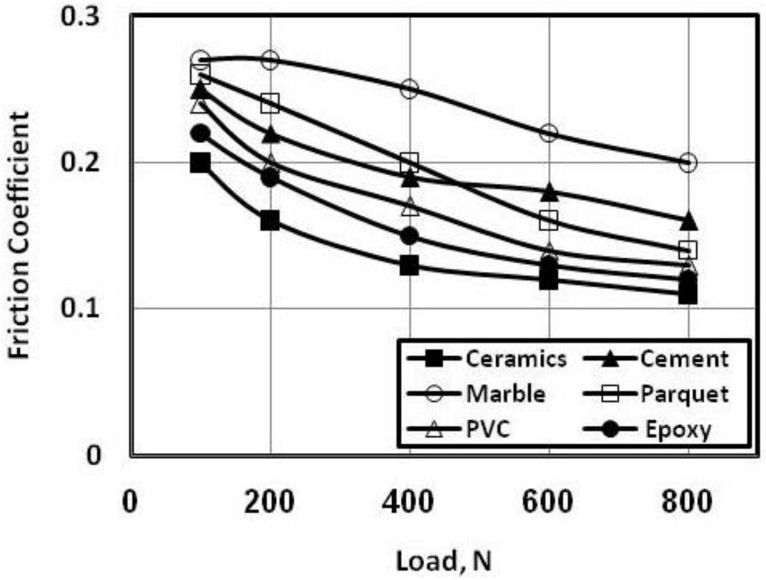

Fig. 8 Friction coefficient displayed by rubber sliding against water wetted flooring materials.

Sliding of rubber against water/detergent wetted tiles caused drastic decrease of friction coefficient, Fig. 9. As the load increased, surface area adhered by water film increased and consequently friction decreased. It is noted that friction coefficient for wetted tiles by water/detergent represented lower values than that displayed by water only. Marble displayed the highest friction values followed by parquet and cement. PVC, epoxy and ceramic represented the lowest friction values.

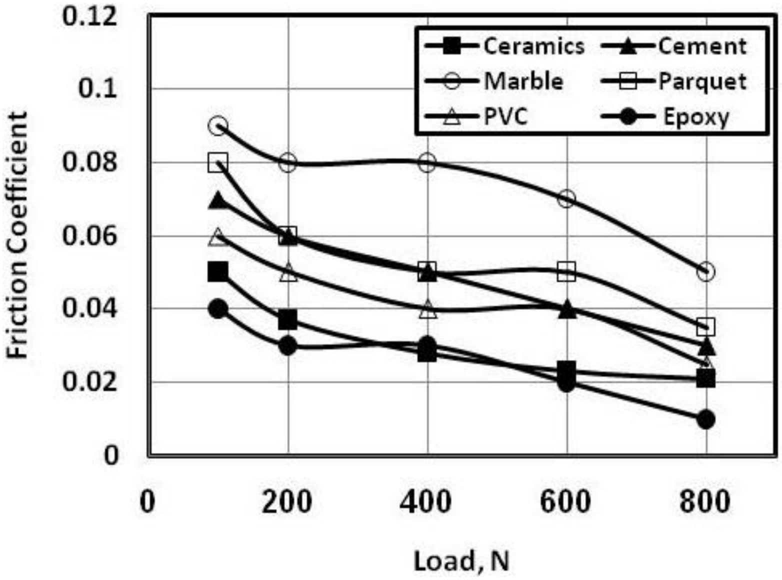

Fig. 9 Friction coefficient displayed by rubber sliding against water/detergent dilution wetted flooring materials.

Friction coefficient generated from the sliding of rubber against oil lubricated flooring materials is shown in Fig. 10. Friction coefficient slightly decreased with increasing load. It seems that, oil film formed on the sliding surface was responsible for friction decrease. The increase of load helped oil to escape from the contact. Hard floorings such as cement, marble and ceramic showed higher friction. Parquet, PVC and epoxy tiles showed relatively lower friction.

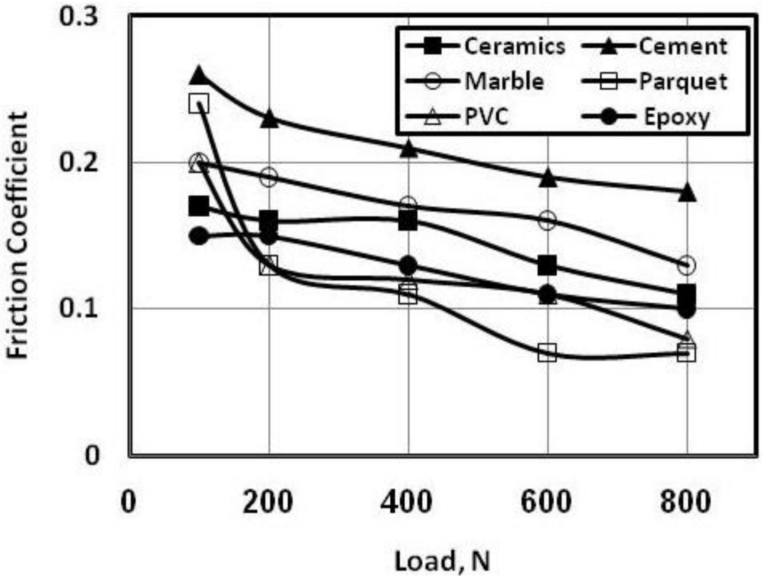

Fig. 10 Friction coefficient displayed by rubber sliding against oil lubricated flooring materials.

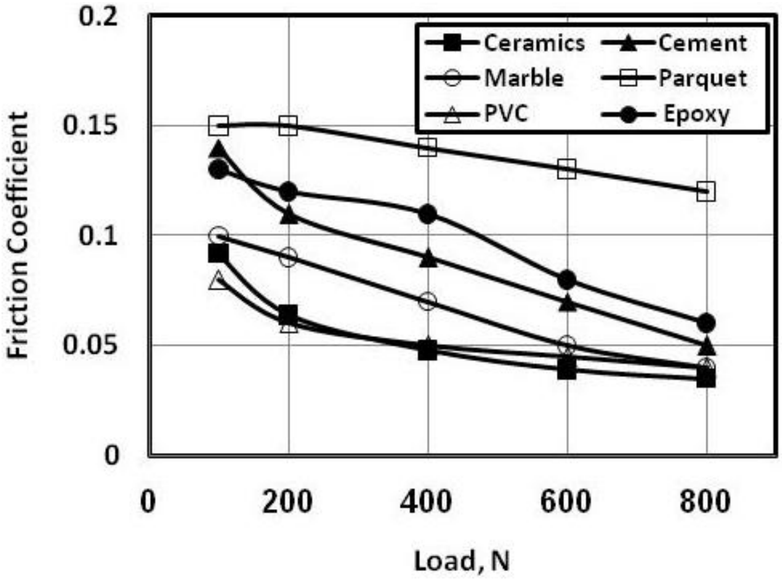

Fig. 11 Friction coefficient displayed by rubber sliding against oil/water dilution lubricated flooring materials.

Sliding of rubber against water/oil diluted floorings caused significant decrease in friction coefficient, Fig. 11. Friction coefficient represented values close to that observed for mixed lubrication where the two sliding surfaces were partially separated by the fluid film. Increasing the applied load caused relative friction decrease due to the increased rubber deformation which displaced the fluid up to the sliding surface, where rubber was completely deformed and filled-out the short-wavelength surface roughness profile of the flooring material. This behaviour gave an additional contribution to the friction force and consequently, friction coefficient increased. Parquet, epoxy and cement tiles still displayed the highest friction, while ceramic, PVC and marble showed the lowest friction.

CONCLUSIONS

1. At dry sliding soft rubber showed higher friction coefficient than hard one.

2. Soft rubber showed relatively higher friction coefficient than hard rubber when sliding against ceramics wetted by water.

3. The difference in friction coefficient displayed by hard and soft rubber significantly increased as load increased.

4. Soft rubber displayed lower friction than hard rubber when rubber slid against oil lubricated ceramic tiles.

5. For soft rubber, friction coefficient showed no change with increasing applied load in presence of oil and water.

6. At dry sliding, epoxy displayed relatively lower friction than cement and marble, while ceramic showed reasonable friction values. Cement tiles gave the highest friction coefficient.

7. In the presence of water on the sliding surface, marble displayed the highest friction coefficient followed by cement and parquet. Ceramic tiles showed the lowest friction among the tested floorings.

8. Sliding of rubber against water/detergent diluted tiles caused drastic decrease of friction coefficient, where marble displayed the highest friction values followed by parquet and cement. PVC, epoxy and ceramic represented the lowest friction values.

9. Hard oily floorings such as cement, marble and ceramic showed higher friction. Parquet, PVC and epoxy tiles showed relatively lower friction.

10. Parquet, epoxy and cement tiles displayed the highest friction, while ceramic, PVC and marble showed the lowest friction when rubber slid against water/oil diluted floorings.

REFERENCES

1. Li K. W., Yu R., Han X. L., "Physiological and psychophysical responses in handling maximum acceptable weights under different footwear–floor friction conditions", Applied Ergonomics 38, pp. 259 – 265, (2007).

2. 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).

3. 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. 4, October 2010, pp. 11 – 25, (2010), KGK - March 2012, (2012).

4. El-Sherbiny Y. M., Hasouna A. T. and Ali W. Y., "Friction Coefficient of Rubber Sliding Against Flooring Materials", KGK – April 2011, pp. 44 – 49, (2011).

5. Derler S., Kausch F., Huber R., "Analysis of factors influencing the friction coefficients of shoe sole materials", Safety Science 46, pp. 822 - 832, (2008).

6. Maeda K., Bismarck A., Briscoe B., "Effect of bulk deformation on rubber adhesion", Wear 263, pp. 1016 – 1022, (2007).

7. Deladi E. L., de Rooij M. B., Schipper D. J., "Modelling of static friction in rubber–metal contact", Tribology International 40, pp. 588 – 594, (2007).

8. 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).

9. Chang W. R., Gronqvist R., Leclercq S., Myung R., Makkonen L., Strandberg L., Brungraber R. J., Mattke U., Thorpe S. C., "The role of friction in the measurement of slipperiness, Part 1: friction mechanisms and definition of test conditions", Ergonomics 44 , pp. 1217 - 1232, (2001).

10. Martin A., Buguin A., Brochard-Wyart F., “Dewetting nucleation centers at soft interfaces”, Langmuir 17, pp. 6553 - 6559, (2001).

11. 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).

12. 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).

13. 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).

14. Chang W. R., "The effects of slip criteria and time on friction measurements", Safety Science 40 , pp. 593 – 611, (2002).

15. Chang W. R., Matz S., "The slip resistance of common footwear materials measured with two slipmeters", Applied Ergonomics 32, pp. 540 – 558, (2001).

16. 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).

17. 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).

18. Khonsari, M. M., Booser, E. R., "Applied Tribology ", John Wiley & Sons, pp. 456 - 483, (2001).

19. Persson B. N. J., Et A., “Rubber friction on wet and dry road surfaces: sealing effect”, Phys Rev B, (2005).

20. 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).