EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 7, NO. 4, OCTOBER 2010, 11 – 26

FRICTION COEFFICIENT OF RUBBER SLIDING AGAINST DUSTY INDOOR FLOORING

El-Sherbiny Y. M.*, Samy A. M., Ali W. Y.*****

***Dept. of Civil and Architectural Engineering, National Research Center, Dokki, Giza, EGYPT.**
**** Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT.**
***** Faculty of Engineering, Taif University, P. N. 888, Al-Taif, K. S. A.**

ABSTRACT

Bathroom mates are usually made of recycled rubber and or polymers. These are used to eliminate slip and fall in bathrooms and kitchens. Ceramic surfaces contaminated with water usually promote slips and occasionally lead to indoor accidents. Bathtub surfaces are rather smooth and can be very slippery with shower and bath running water. In this particular case, mates with vacuum protrusions are recommended to adhere to the smooth surfaces of ceramics and bathtubs. However, dust and sand contaminations can cause the loss of the sealing actions of protrusions and loss of vacuum and adhesion.

It is well known that in Middle East airborne contaminant levels are particularly high. During severe storm conditions, outdoor dust concentrations of the order of 100 to 500 times higher may be encountered, and indoor concentrations can have one order of magnitude higher. 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 particle size, tread design and hardness of the footwear pad, hardness and roughness of the floor. Similarly such consideration apply for the friction between rubber and polymer mates on one side and plan ceramics and bathtub surfaces on the other side.

In the present work, the effect of sand particles on the friction coefficient displayed by rubber sliding against ceramic tiles at different sliding conditions is investigated. Experiments were carried out under dry, water, detergent, oil, soap, and water oil emulsion. Experiments were carried out with and without sand particles contaminating the sliding surfaces. Rubber test specimens of cylindrical and square protrusions were introduced in the surface of square rubber sheets of 100 $\times$ 100 mm and 10.0 mm thickness. A test rig was designed and manufactured to measure the friction coefficient between the rubber and ceramic flooring materials through measuring the friction and normal forces.

It was found that, at dry sliding, dust particles caused drastic decrease in friction coefficient. In this condition, 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 than surfaces of protrusions, 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.

KEYWORDS
Rubber, cylindrical and square protrusions, ceramic flooring materials, friction coefficient, dry, water, detergent, soap, oil lubrication, bathroom mates.

INTRODUCTION
There is a growing interest in reducing slip and fall accidents to avoid occupational injuries. Slip resistance of flooring materials is one of the major environmental factors affecting walking stability. Floor slip resistance may be quantified using the static coefficient of friction. In the USA, the static coefficient of friction of 0.5 is recommended as the slip-resistant standard for unloaded, normal walking conditions [1]. Higher static coefficient of friction values may be required for safe walking when handling loads. In Europe, [2], it is suggested that a floor is ‘‘very slip-resistant’’ if the coefficient of friction is 0.3 or more. A floor with the coefficient of friction falling within the range 0.2 and 0.29 is considered ‘‘slip resistant’’. A floor is classified as ‘‘unsure’’ if its coefficient of friction falls within the range 0.15 and 0.19. A floor is ‘‘slippery’’ and ‘‘very slippery’’ if the coefficient of friction is lower than 0.15 and 0.05, respectively. These classifications were established to quantify the risk associated with slipping and falling. The subjective ranking of floor slipperiness was compared with the static coefficient of friction (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 Disabilities Act Accessibility Guidelines [5, 6] 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.

The effect of cylindrical protrusions of rubber surface sliding on ceramics under dry, water, water-detergent, oil, water oil emulsion, sand and water contamination conditions was investigated, [7]. It was found that friction coefficient increases as the height of the cylindrical protrusions increases. At dry sliding, the optimum contact area of cylindrical protrusions ranges from 20 – 30 % of the smooth one. When the sliding surfaces are covered by sand, friction coefficient drastically decreases. In water-lubricated surfaces, contact area of cylindrical protrusions of 30 % of the smooth area displays the highest friction coefficient. In the presence of water contaminated by sand, it is recommended to decrease the contact area to 20 % of smooth one. Besides, the optimum contact area is 40% of the smooth one when the sliding surfaces are lubricated by water-detergent. When oil as well as water oil emulsion cover the sliding surfaces, contact area should be lower than 20 % of the smooth one. It was found that the circular protrusions give higher friction than square ones for all the sliding conditions tested in the present work, [8 - 10]. The observation depends on the fact that the deformation of rubber is relatively higher than that displayed by square protrusions. In the presence of oil on the sliding surfaces, typical of kitchen contamination, smooth surfaces give the lowest friction values. Besides, sand particles prevent the contact between rubber and ceramic, where the contact becomes between sand particles and ceramic. The optimum contact areas are 30 and 50 % for circular and square protrusions respectively. In the presence of water on the sliding surface, circular protrusions give relatively higher friction than square ones due to the easy escape of water from the contact area. Circular protrusions of 10 % contact area displays maximum friction value of 0.66. Friction coefficient increases up to 0.80 for 5 % contact area for circular protrusions. This trend is promising in the design of rubber mats designed for use on ceramic floors of bathrooms and kitchens in the presence of water contaminated with dust. 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, [11]. It was observed that, at dry sliding, friction coefficient decreased with increasing surface roughness and applied load. At water lubricated sliding, friction coefficient decreased up to maximum then decreased with increasing surface roughness. Maximum friction values were observed at surface roughness values ranging from 1.5 and 2.0 µm R_a. At water - detergent lubricated sliding, friction coefficient drastically decreased with increasing surface roughness. At oil lubricated sliding, the maximum friction values were noticed at 4.0 µm R_a surface roughness. At water and oil lubricated sliding, smooth flooring surface displayed very low values of friction coefficient (0.08) close to that observed for mixed lubrication where the two sliding surfaces are partially separated by the fluid film. As the roughness increased the fluid, film was broken and friction increased.

Dust particles on the floor prevent a direct contact between the footwear pad and floor, [12]. 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 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.

When rolling or sliding occurs, the measured friction becomes lower as compared to that of the clean floor. Rolling could lead to a more significant reduction in friction than sliding because the rolling friction is normally lower than sliding friction. 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, [13]. 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 such case, the concepts of three bodies Tribology would govern the slipping tendency.

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, [14 - 16]. 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. The decrease may be due to the adherence of oil on the rubber surface, where the oil film is responsible for the reduction in friction. Besides, diluting oil by water displayed values of friction much lower than that observed for oil-lubricated condition. 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 presence of oil and sand on the sliding surface, the friction slightly increased. This behaviour may be attributed to sand embedment in rubber surface and consequently the contact became between ceramic and sand. At lubricated sliding surface by oil and water contaminated by sand, the friction presented higher value than that of oil and sand sliding conditions.

In the present work, the friction coefficient of rubber test specimens of circular and square protrusions in contact with ceramic tiles at different sliding conditions in the presence of sand are measured.

EXPERIMENTAL

Experiments were carried out using a special test rig designed and manufactured to measure the friction coefficient between the rubber test specimens and the tested flooring tiles through measuring the friction and normal forces. The tested flooring tiles are placed in a base supported by two load cells, the first measures the horizontal force (friction force) and the second measures the vertical force (normal load). Friction coefficient is determined by the ratio between the friction and the normal forces. The arrangement of the test rig is shown in Fig. 1. Rubber test specimens were loaded against dry, water and water detergent mixture, oil and oil and water mixture lubricated flooring tiles.

The tested flooring materials of ceramic were in form of quadratic tiles of 0.4 m × 0.4 m and 5.0 mm thickness. The surface roughness is 6.3 μm R_a, (the centerline average of surface heights, CLA). Rubber test specimens were prepared in the form of square sheets of 100 × 100 mm and 10.0 mm thickness. 23 cylindrical protrusions of 7.0 mm diameter and 3 mm height as well as 64 square protrusions of 4.0 × 4.0 mm were introduced in rubber surface, Fig. 2. This selection was based on the experimental observation carried out before, [7, 8], which indicated that those protrusions displayed the highest friction coefficient. Then the rubber specimens were backed on wood plates. The hardness of the rubber was 63 ± 2 measured using a Shore-A hardness meter. The flooring materials and the rubber were thoroughly cleaned with soap water to eliminate any dirt and dust and carefully dried before the tests. The rubber test specimens were loaded against dry, water, water + 5.0 vol. % detergents, oil (Sunflower oil), water + 5.0 vol. % oil lubricated ceramic flooring materials. Experiments were carried out with and without sand particles. The sand was silicon oxide ($Si\,O_2$) of 0 – 1000 μm particle size. The concentration of sand in the experiments was 5.0 wt. %. Tests were carried out at different values of load exerted by foot. In the present work, the results of the selected values of load of 200, 400, 600 and 800 N, which represent the average weights of the children, women and men, are considered.

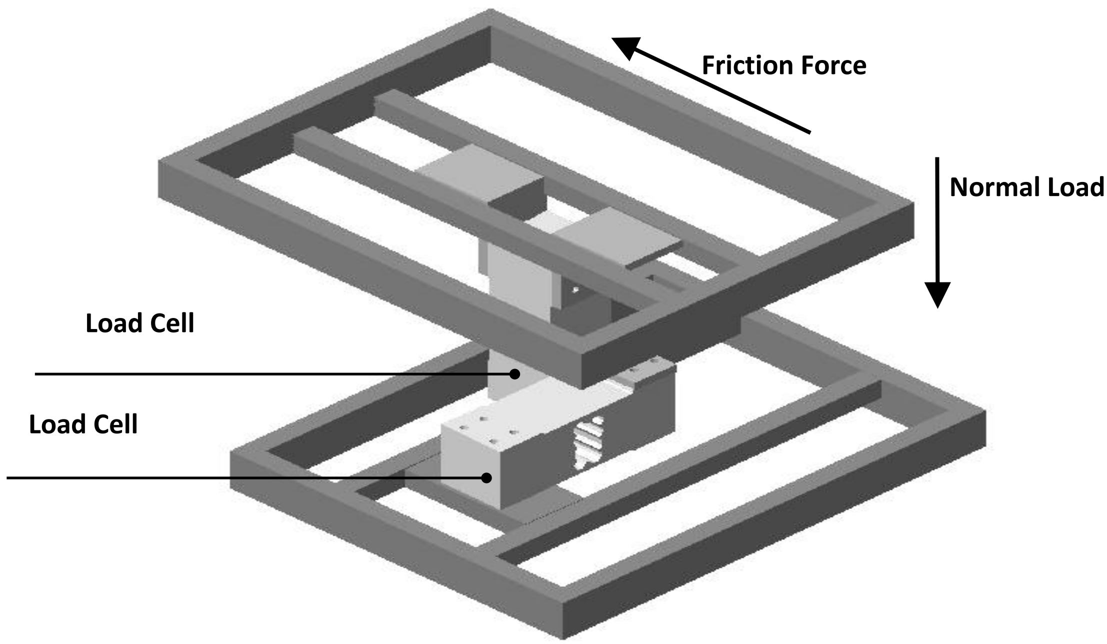

Fig. 1 Basic features of the test rig.

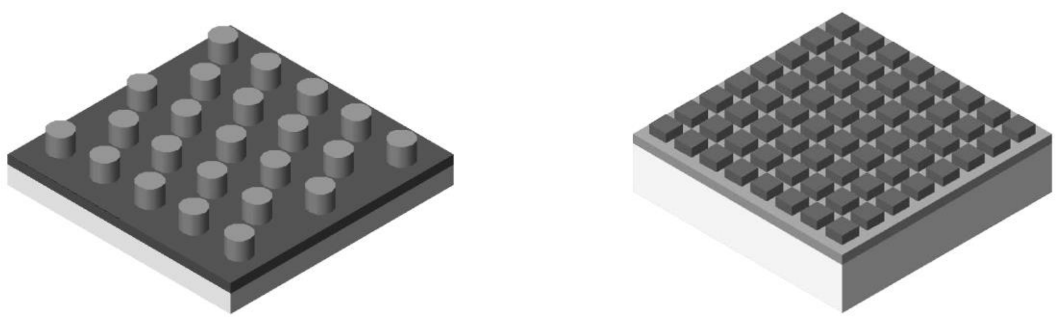

Fig. 2 Rubber test specimens of circular and square protrusions.

RESULTS AND DISCUSSUION

It is proposed that ceramic wear by contaminated sand particles depends on the tendency of the particle either to become locked by partially embedding in the rubber surface or to roll. The partially embedded particle can cut away material from the ceramic surface as it passes, but no abrasive of the rubber will occur, as there is no relative motion between the particle and the rubber surface. Friction coefficient of dry sliding of flat rubber against ceramic tiles is shown in Fig. 3. At dry sliding condition, friction coefficient represented relatively high values, where friction coefficient decreased from 0.92 to 0.85 as the applied load increased from 200 to 800 N. In the presence of sand particles covering the sliding surface, friction coefficient drastically decreased, where the values were 0.2 and 0.13 at 200 and 800 N respectively. This behavior may be attributed to the fact that sand particles prevent the direct contact between the rubber test specimens and floor. 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. In this condition, the contact will be between sand particles and ceramic tiles and consequently friction coefficient will display lower values.

Friction coefficient generated from dry sliding of the rubber test specimens of circular protrusions against ceramic is shown in Fig. 4. Friction coefficient displayed higher values than that represented by flat rubber, where friction decreased from 1.32 to 1.2 as the load increased from 200 to 800 N. This increase may be attributed to the deformation of the circular protrusions. The friction force between rubber and ceramic has two components, adhesion and deformation. The deformation components results from the internal rubber friction, while adhesion will deform the rubber at the ceramic surface, where rubber follows the short-wavelength surface roughness profile. This gives an additional contribution to the friction force. In the presence of sand particles covering the sliding surfaces, friction coefficient decreased due to the embedment of the sand in the rubber surface, but their values were relatively higher than that displayed by flat surface. As for friction coefficient of dry sliding of rubber of square protrusions against ceramic tiles, Fig. 5, sand particles displayed friction values lower than that observed for circular protrusions.

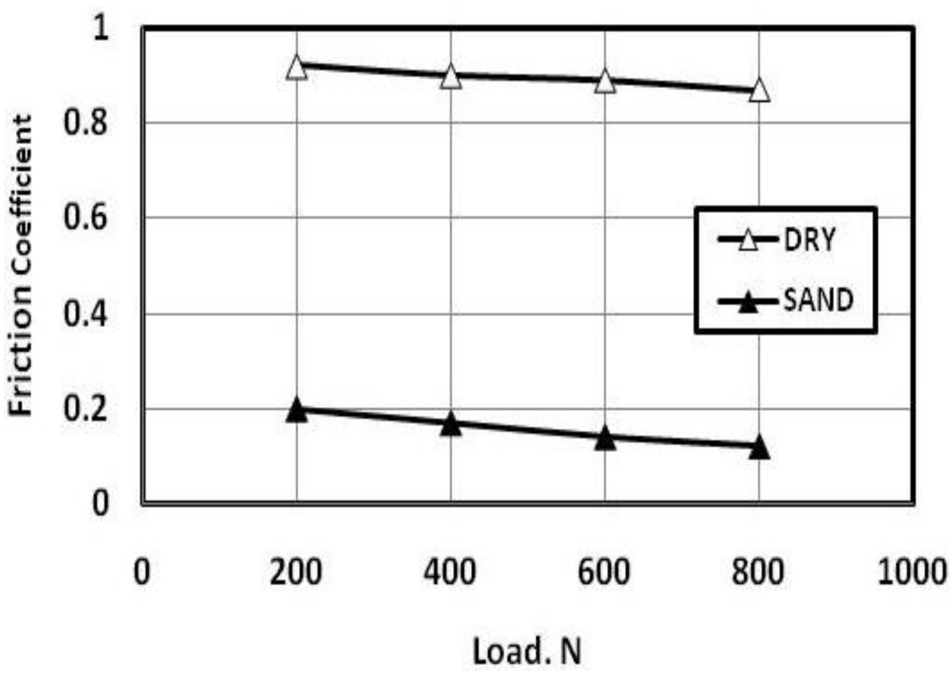

Fig. 3 Friction coefficient of dry sliding of flat rubber against ceramic tiles.

Sliding of the tested rubber against ceramic lubricated by water showed relatively higher friction coefficient in the presence of sand, Fig. 6. It seems that, sand particles embedded in rubber allowed the water to escape out of the contact area. Flat rubber specimens displayed lower friction due to the formation of the water film trapped in the contact area. Friction coefficient of circular and square protrusions, Figs. 7 and 8 respectively, free of sand displayed values higher than displayed by flat rubber. Square protrusions showed higher friction values in the presence of sand contaminated water, Fig. 8. The friction increase might be attributed to the easy escape of water from the contact area embedded by sand particles. Water decreased the adhesion action due to the formation of the water film separating the two contact surfaces. Generally, surfaces of protrusions gave higher friction coefficient than smooth ones due to their ability to break the water film. Values of friction coefficient revealed that the type of contact was of mixed lubrication, where a part of the contact area was wetted by water film and the rest was dry. The formation of water film on the smooth surface was significant, so that the friction coefficient showed the lowest values.

In the presence of the detergent on the sliding surface, sand showed higher friction coefficient for flat rubber than that displayed by detergent free of sand, Fig. 9. The friction values were 0.38 and 0.34 at load of 200 and 800 N respectively, while friction coefficient decreased for clean detergent to 0.15 at load of 800 N. The friction increase was attributed to the detergent drainage away from the contact area, where sand particles reduced the resistance against the drainage and allowed the detergent to escape out of the contact area. Circular protrusions displayed relatively higher friction values than that displayed by square ones, Figs. 10 and 11, for detergent free of sand, while flat rubber displayed the highest friction values in the presence of sand. This behavior can explained on the fact that the ability of flat rubber to embed sand particles is relatively higher than the protruded surfaces.

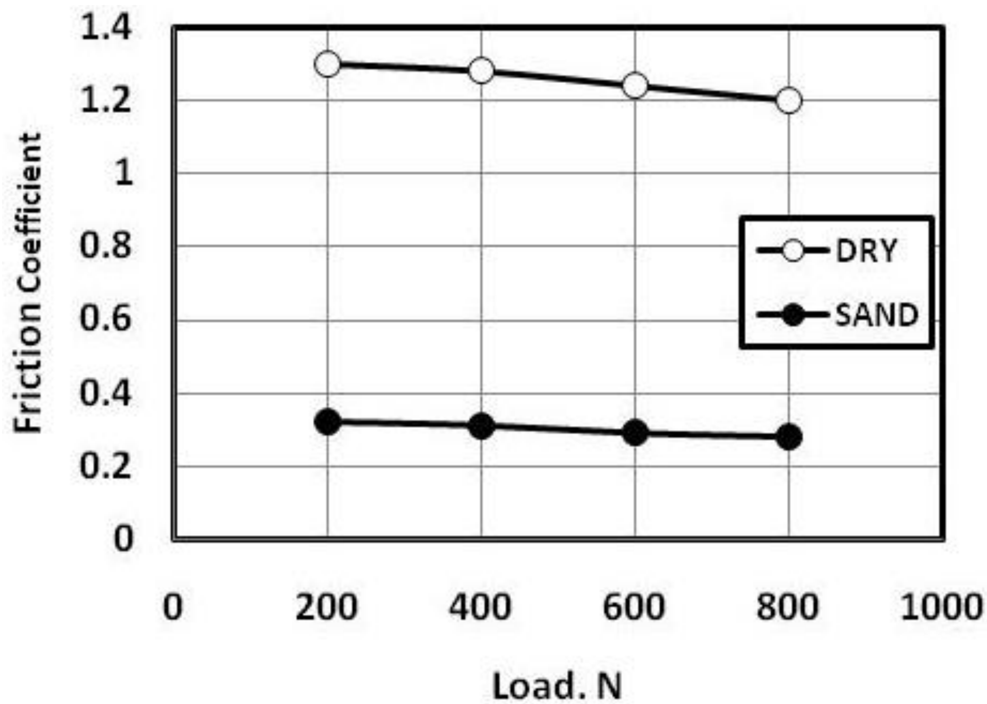

Fig. 4 Friction coefficient of dry sliding of rubber circular protrusions against ceramic tiles.

When oil lubricated the sliding surfaces, drastic friction decrease was observed, Fig. 12. where flat rubber displayed friction coefficient of 0.05 at load of 800 N. Sand contaminating oil significantly increased friction coefficient. Circular and square protrusins showed increased values of friction coefficient, Figs. 13 and 14. Friction increase may be explained on the basis that the gaps among the protrusions were responsible for the easy escape of oil away from the contact area.

Emulsion of water and oil gave relatively higher friction values than that observed for oil-lubricated surfaces, Fig. 15. It seems that the reduced viscosity of the emulsion was the cause of the friction increase. For sliding of rubber against ceramic lubricated by the emulsion and contaminated by sand particles, friction coefficient increased up to 0.36 at load of 800 N. Circular and square protrusions slightly decreased friction coefficient for surfaces lubricated by the emulsion free of sand, Figs. 16 and 17. The same tendency was observed in the presence of sand particles.

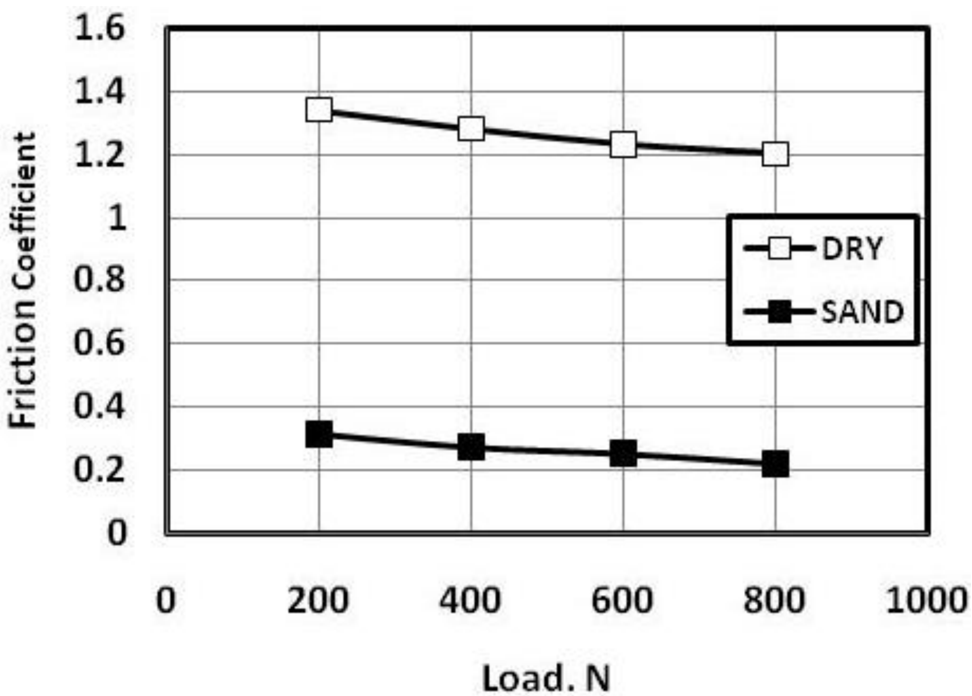

Fig. 5 Friction coefficient of dry sliding of rubber square protrusions against ceramic tiles.

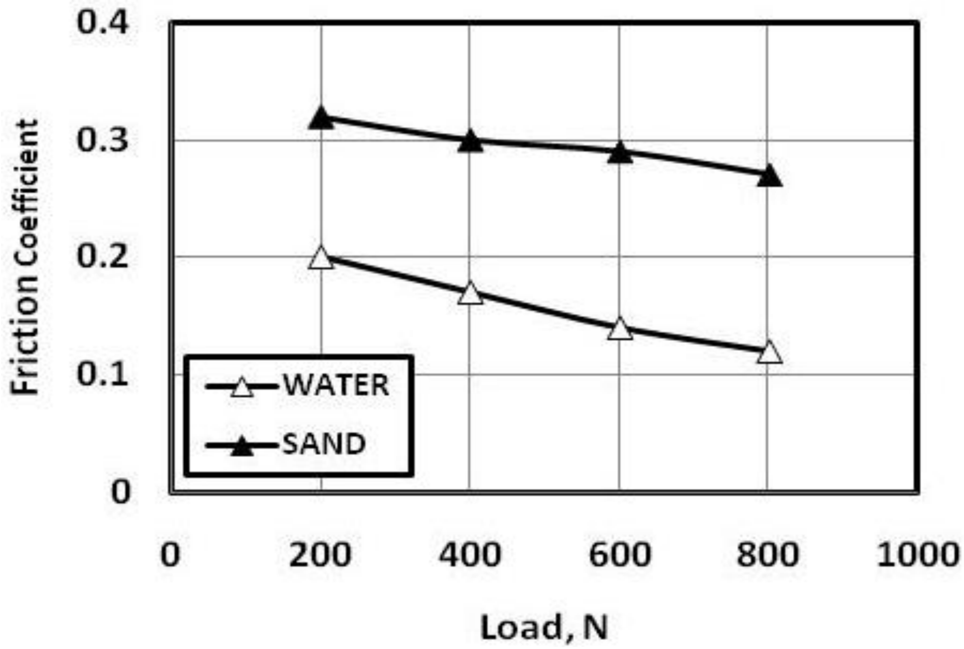

Fig. 6 Friction coefficient of water lubricated sliding of flat rubber against ceramic tiles.

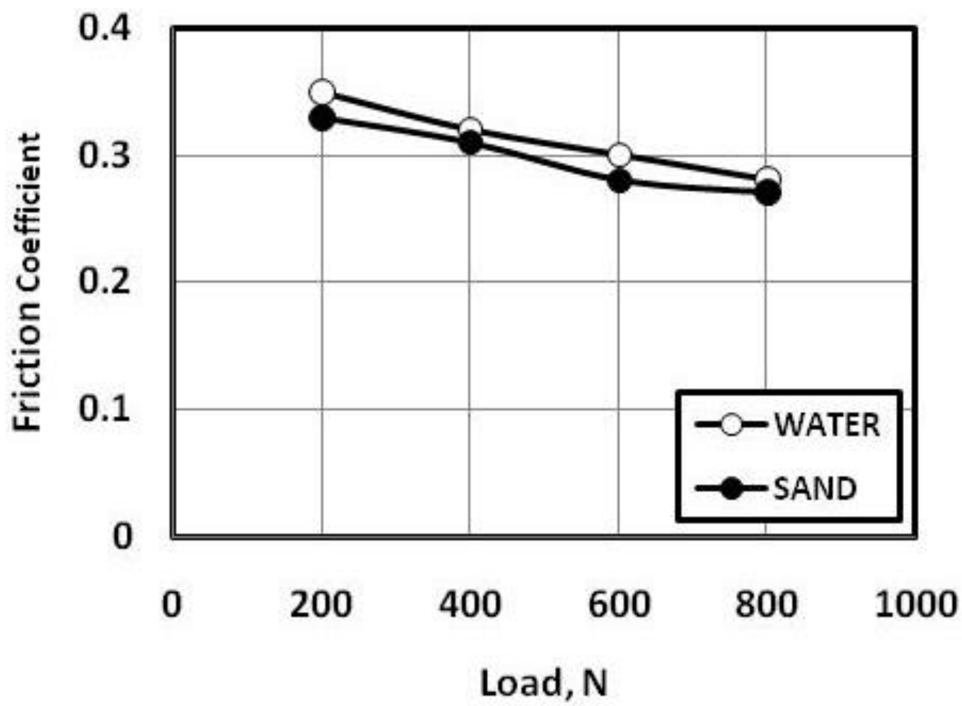

Fig. 7 Friction coefficient of water lubricated sliding of rubber circular protrusions against ceramic tiles.

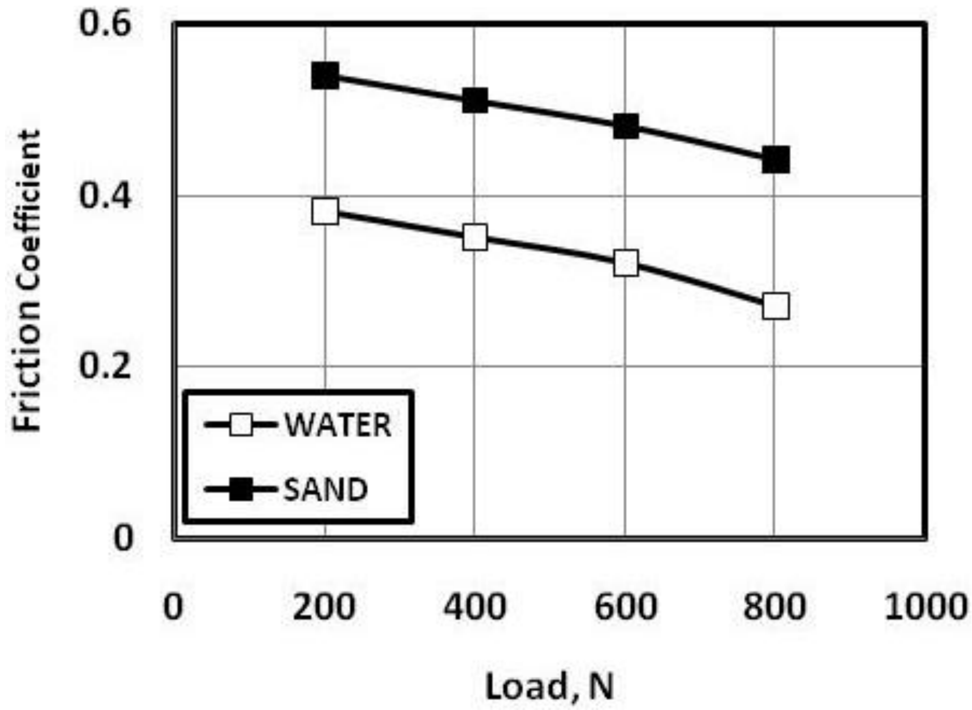

Fig. 8 Friction coefficient of water lubricated sliding of rubber square protrusions against ceramic tiles.

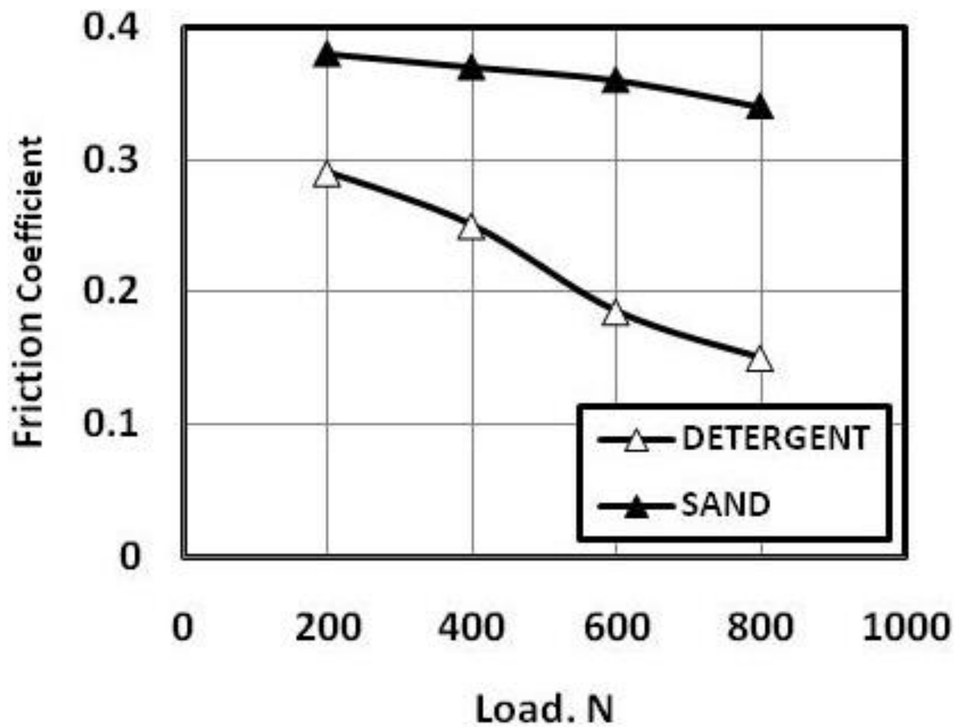

Fig. 9 Friction coefficient of detergent lubricated sliding of flat rubber against ceramic tiles.

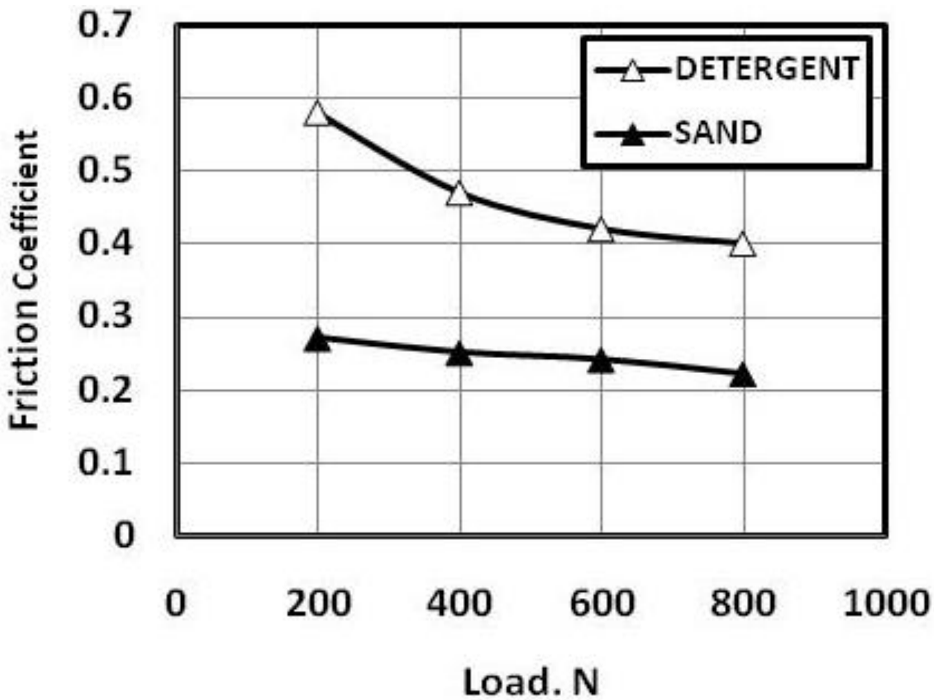

Fig. 10 Friction coefficient of detergent lubricated sliding of rubber circular protrusions against ceramic tiles.

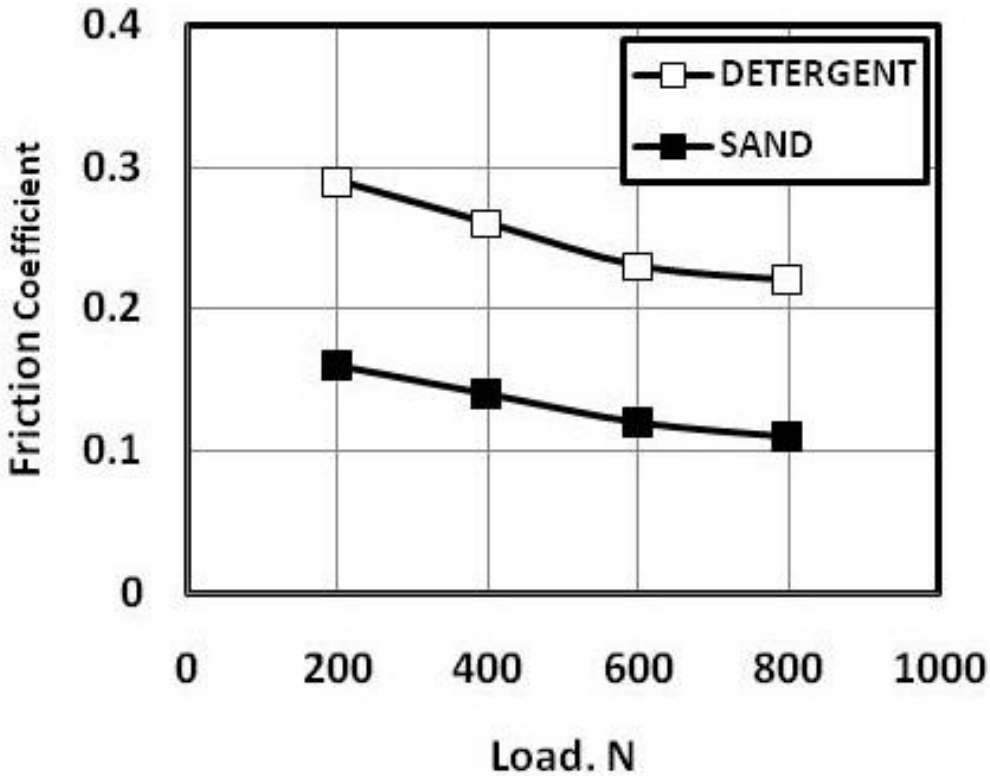

Fig. 11 Friction coefficient of detergent lubricated sliding of rubber square protrusions against ceramic tiles.

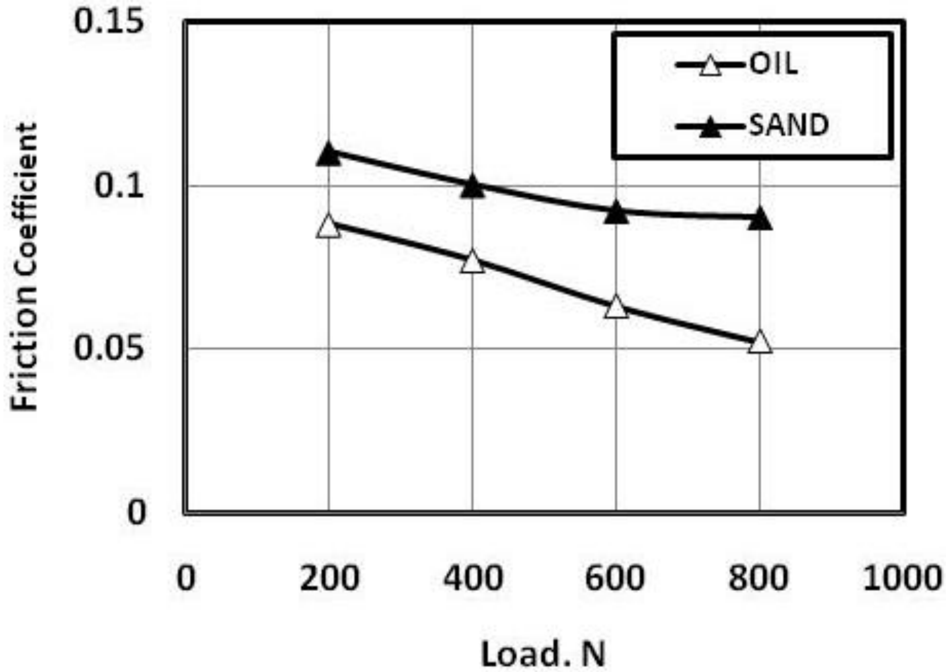

Fig. 12 Friction coefficient of oil lubricated sliding of flat rubber against ceramic tiles.

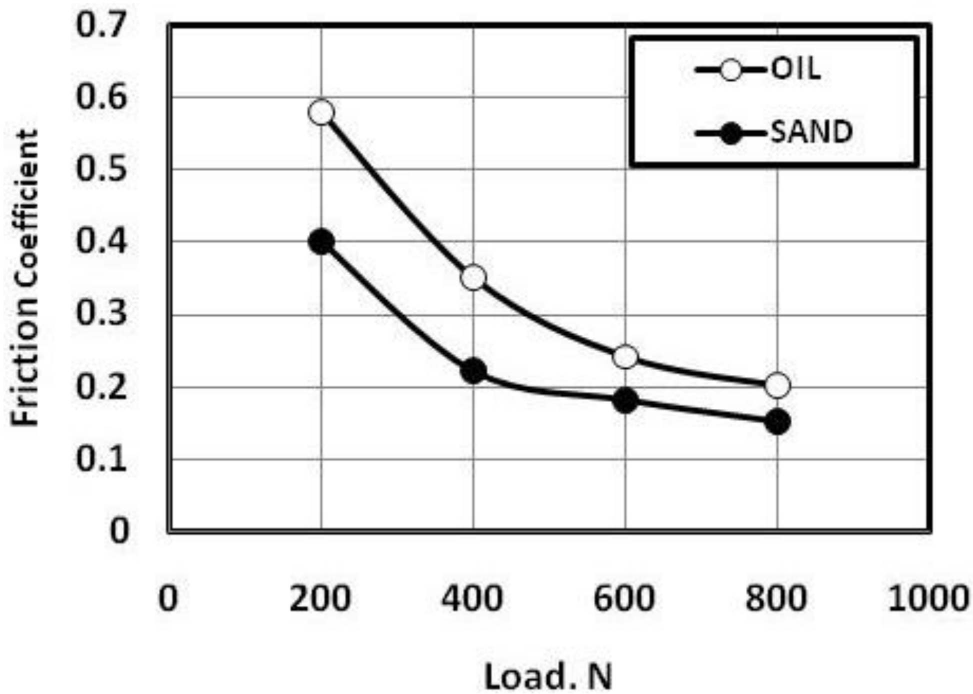

Fig. 13 Friction coefficient of oil lubricated sliding of rubber circular protrusions against ceramic tiles.

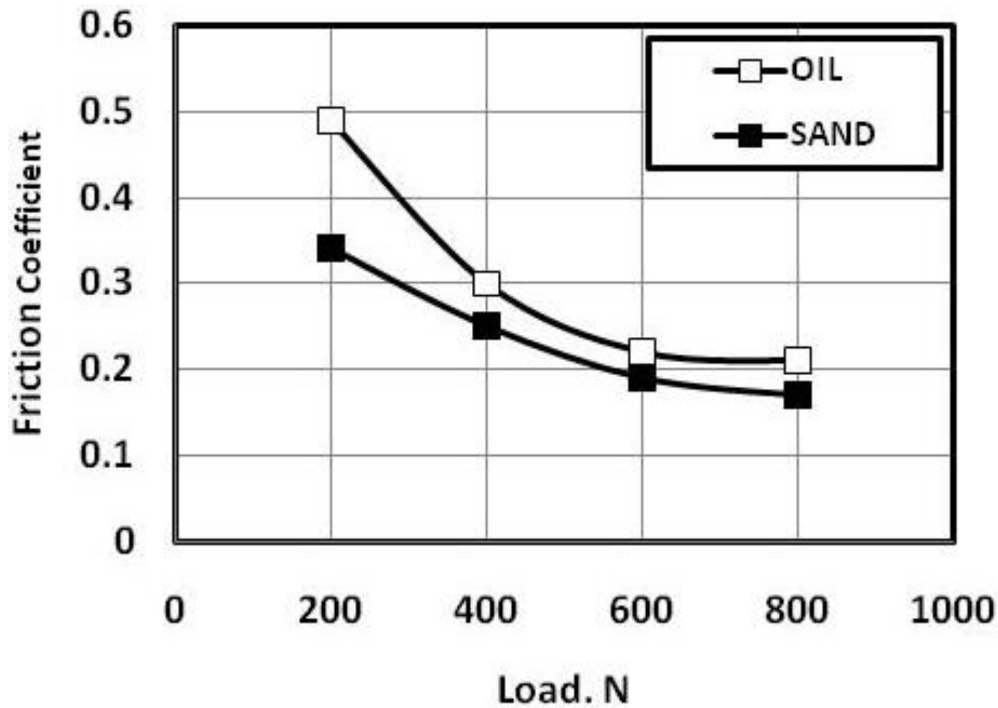

Fig. 14 Friction coefficient of oil lubricated sliding of rubber square protrusions against ceramic tiles.

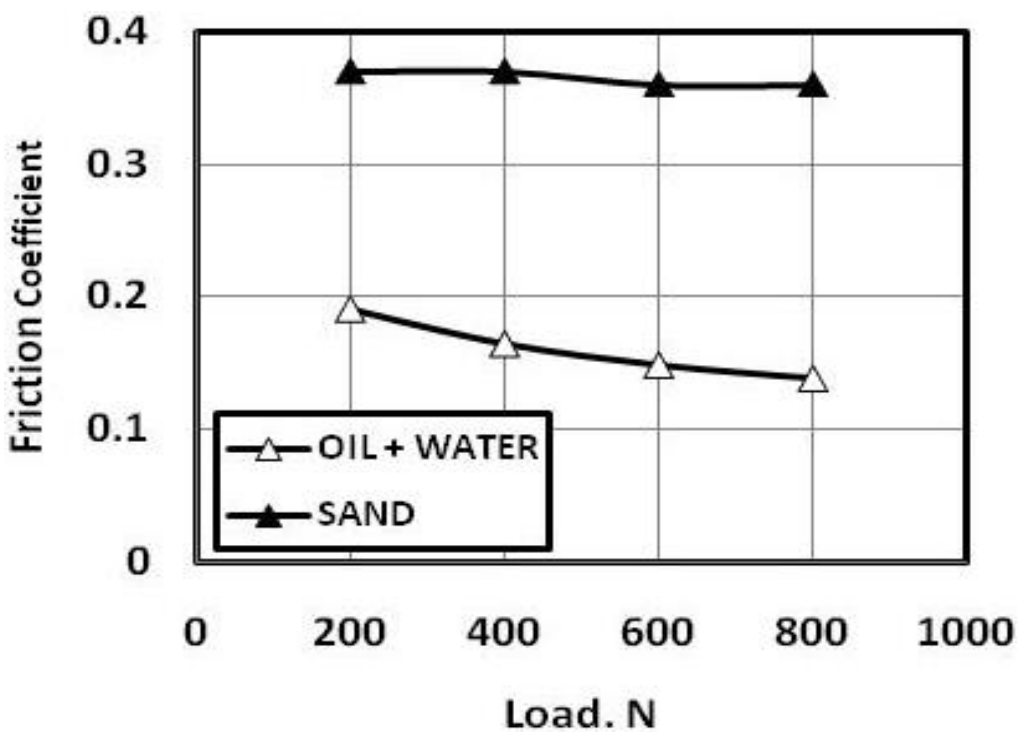

Fig. 15 Friction coefficient of oil and water lubricated sliding of flat rubber against ceramic tiles.

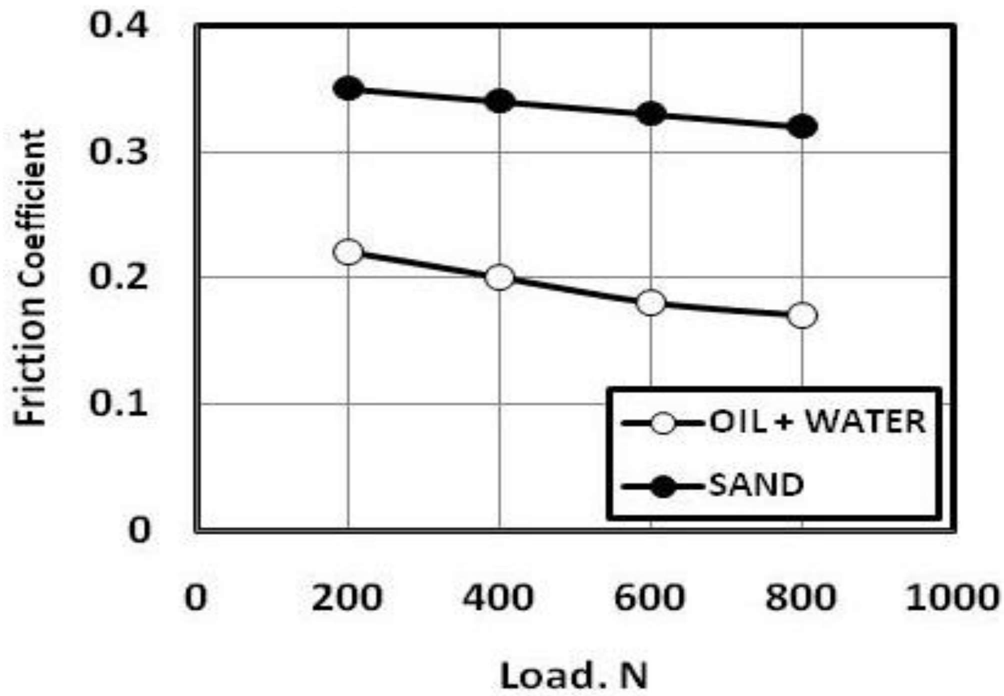

Fig. 16 Friction coefficient of oil and water lubricated sliding of rubber circular protrusions against ceramic tiles.

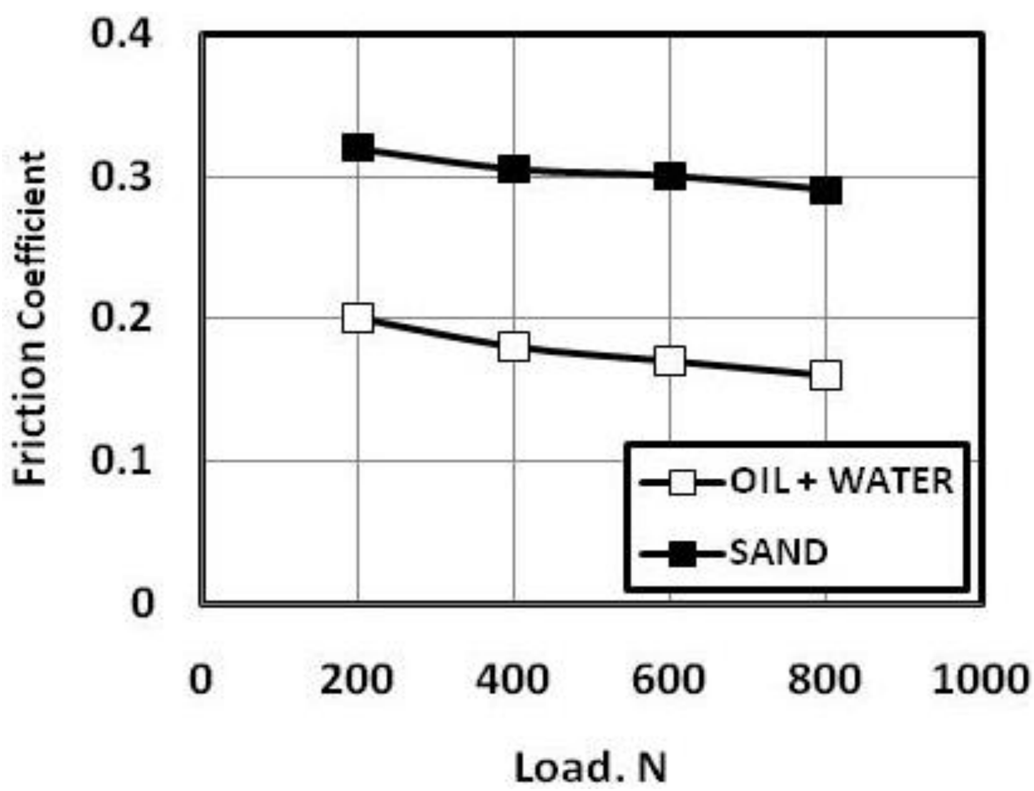

Fig. 17 Friction coefficient of oil and water lubricated sliding of rubber square protrusions against ceramic tiles.

CONCLUSIONS

In Egypt, Ceramic tiles are the common flooring materials for bathrooms and kitchens which promotes high rate of slips and fall under both dry and wet conditions. Therefore, rubber mats are generally used to minimize such accidents. In such case, under the above mentioned different sliding conditions, the following recommendations are concluded:

1. At dry sliding, sand particles caused drastic decrease in friction coefficient. It is recommended to use mats with circular rubber protrusion on dust contaminated tiles.
2. In the presence of water, sand particles embedded in rubber surface increased friction coefficient. Mats with square rubber protrusions are recommended.
3. For ceramic surfaces contaminated by detergent, flat rubber mates embedded sand particles gave higherfriction than protruded mat surfaces.
4. Sand particles embedded in kitchen flat rubber mats contaminated with oil significantly increased Friction coefficient. Circular protrusions gave higher the highest friction.
5. Flat rubber surfaces, contaminated with water/oil emulsion and sand particles, display the highest friction coefficient.

REFERENCES

1. Miller, J. M., ‘‘Slippery’’ work surface: toward a performance definition and quantitative coefficient of friction criteria”, 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 inhandling 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 coefficient of friction during different walking tasks in persons with and without a disability’, Gait & Posture 22, pp. 82 – 88, (2005).
6. Architectural and Transportation Barriers Compliance Board. Americans with disabilitiesact (ADA) accessibility guidelines for buildings and facilities. Final Guidelines Federal Register, 56, pp. 35408 – 542, (1991).
7. Mohamed M. K., Abdel-Jaber G. T., Ali W. Y., "Effect of Cylindrical Protrusions of Rubber Surface Sliding on Ceramics", The First International Conference of Energy, Aswan, December, (2008). Journal of the Egyptian Society of Tribology, Vol. 6, No. 2, April 2009, pp. 38 – 46, (2009).
8. Mohamed M. K., Abdel-Jaber G. T., and Ali W. Y., "Comparative Performance of Rubber Protrusions Sliding Against Ceramics", The First International Conference of Energy, Aswan, December, (2008). Journal of the Egyptian Society of Tribology, Vol. 6, No. 2, April 2009, pp. 47 – 56, (2009).
9. Mohamed M. K., Mahmoud M. M. and Ali W. Y., “Frictional Behaviour of the Cylindrical Protrusions and Holes in Rubber Surfaces Sliding on Ceramics”, Bulletin of the Faculty of Engineering, Minia University, Vol. 20, No. 1., July 2008, (2008).
10. Senossi M. I., Khashaba M. I., Mousa M. O. and Ali W. Y., "Effect of Number of Holes

on Coefficient of Friction of Rubber Specimen Sliding on Ceramic Surface", First Minia International Conference on "Investment in Technology", 7^{th} – 8^{th} May 2007, Faculty of Engineering, Minia University, El-Minia, Egypt, C – 9, (2007).

11. 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, VOLUME 4, NO. 4, JANUARY 2007, pp. 37 - 45, (2007).

12. 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).

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

14. 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).

15. 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).

16. 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).