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FRICTION COEFFICIENT OF RUBBER SLIDING AGAINST DUSTY INDOOR FLOORING

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ABSTRACT

It is well known that in Middle East airborne contaminant levels are particularly high. During severe storm conditions dust concentrations of the order of 100 to 500 times higher may be encountered. 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.

In the present work, the effect of sand particles on the friction coefficient displayed by rubber sliding against ceramic tiles at different sliding conditions was investigated. Experiments were carried out under dry, water, detergent, oil, 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 × 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, sand 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, sand 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, flat rubber embedded by sand particles gave higher friction than surfaces of protrusions, while sand 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 sand particles, displayed the highest friction coefficient.

KEYWORDS

Rubber, cylindrical and square protrusions, ceramic flooring materials, friction coefficient, dry, water, detergent, sand, oil lubrication.

INTRODUCTION

Reducing slip and fall accidents has an increasing demand to avoid occupational injuries. Slip resistance of flooring materials is one of the major environmental factors affecting walking. Floor slip resistance may be quantified using the static coefficient of friction. In the USA, the static coefficient of friction of 0.5 has been recommended as the slip-resistant standard for unloaded, normal walking conditions [1]. Higher the static coefficient of friction 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 coefficient of friction was 0.3 or more. 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. 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 with 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 contaminated by sand sliding 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 is ranging 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, 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 surfaces sliding against ceramic in the presence of water contaminated by sand. 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.

Sand 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. But 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 it is pressed by a shoe sole. 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.

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 from the well adherence of oil on the rubber surface, where a film which is responsible for the friction decrease was formed. 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 caused by 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 sliding against ceramic tiles at different sliding condition in the presence of sand was measured.

EXPERIMENTAL

Experiments were carried out using a 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 could measure the horizontal force (friction force) and the second could measure 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.

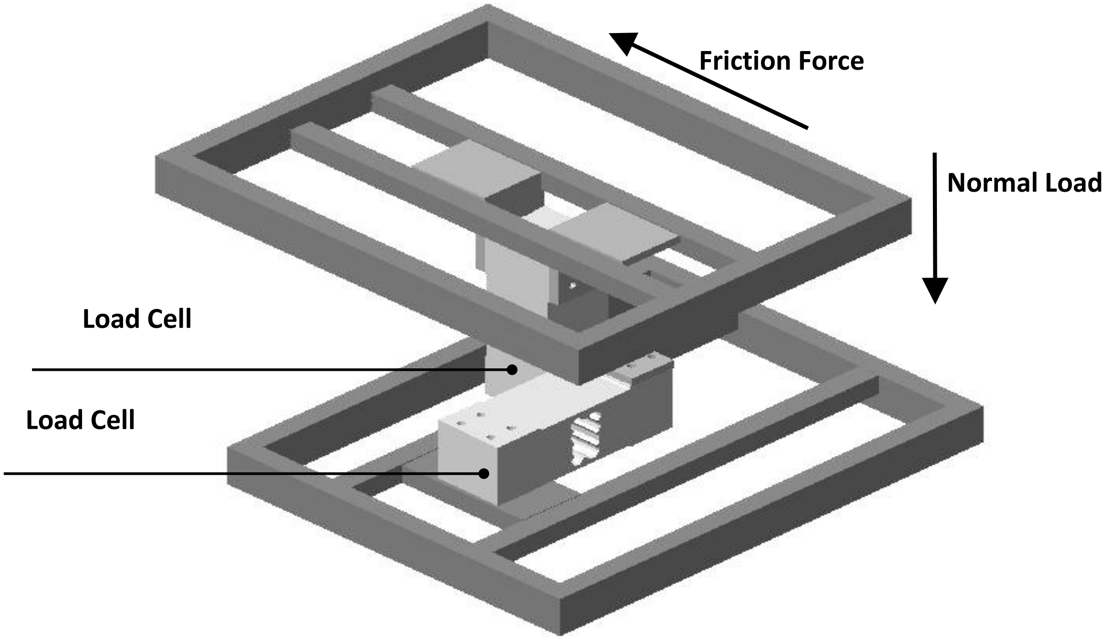

Fig. 1 Arrangement of the test rig.

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 center line 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 adhered on wood blocks. 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. % detergent, oil (sun flower oil), water + 5.0 vol. % oil lubricated ceramic flooring materials. Experiments were carried out with and without sand particles. The sand was silicon oxide (SiO_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.

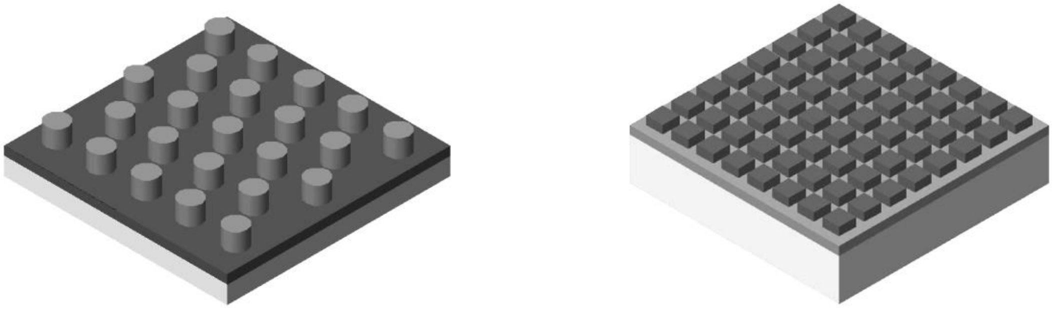

Fig. 2 Rubber test specimens of circular and square protrusions.

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. But 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.

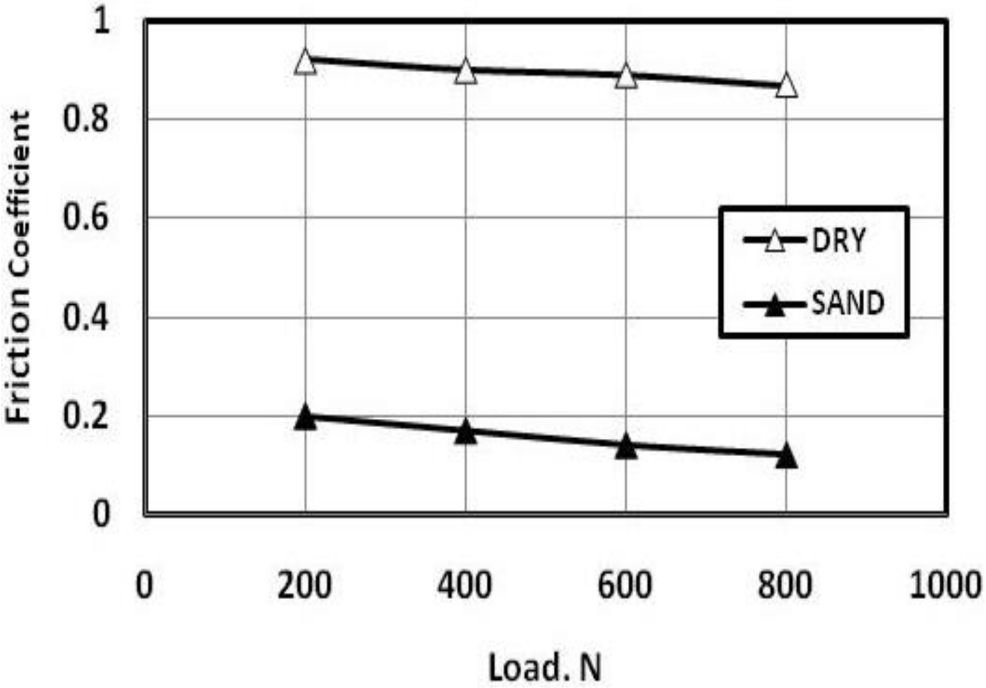

Fig. 3 Friction coefficient of dry sliding of flat rubber against ceramic tiles.

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.

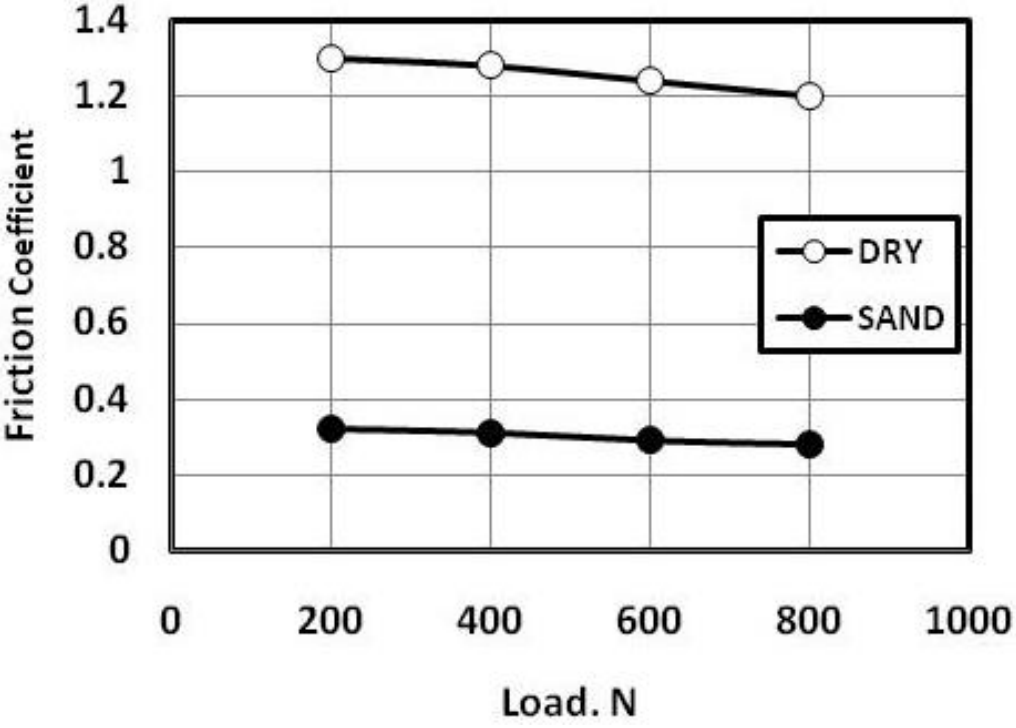

Fig. 4 Friction coefficient of dry sliding of rubber of circular protrusions against ceramic tiles.

When oil lubricating 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 attitude was observed in the presence of sand particles.

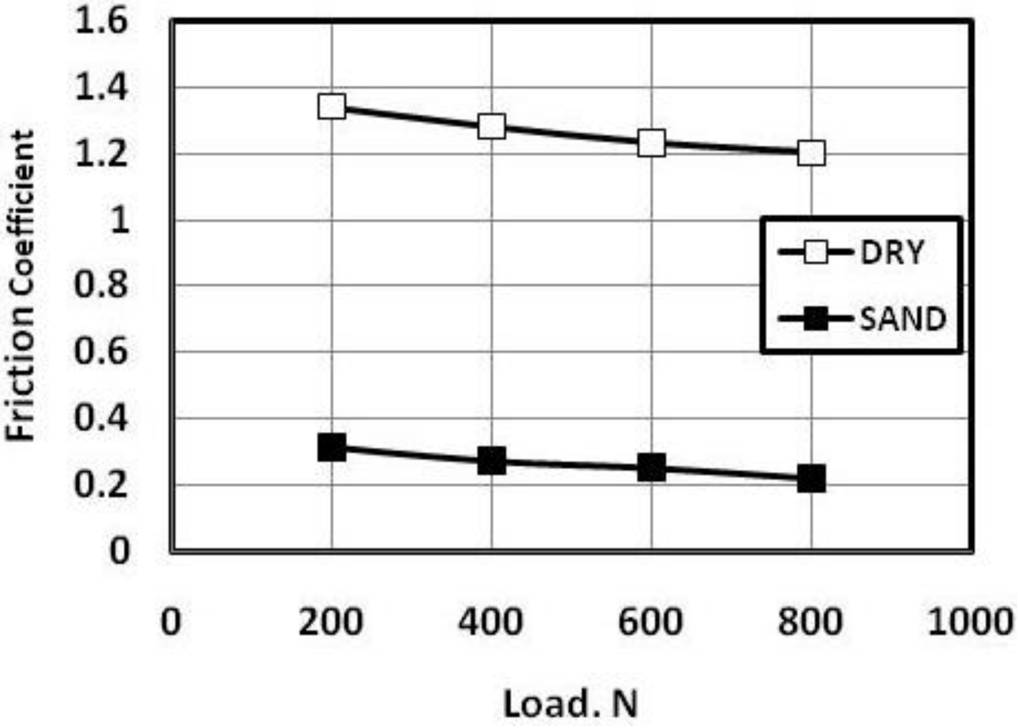

Fig. 5 Friction coefficient of dry sliding of rubber of square protrusions against ceramic tiles.

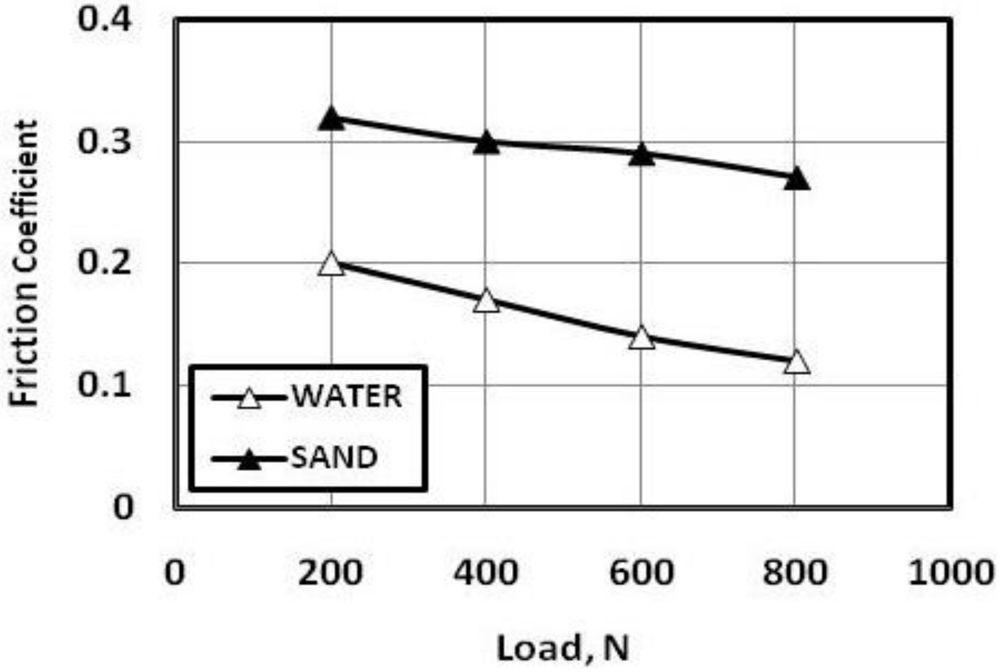

Fig. 6 Friction coefficient of water lubricated sliding of flat rubber against ceramic tiles.

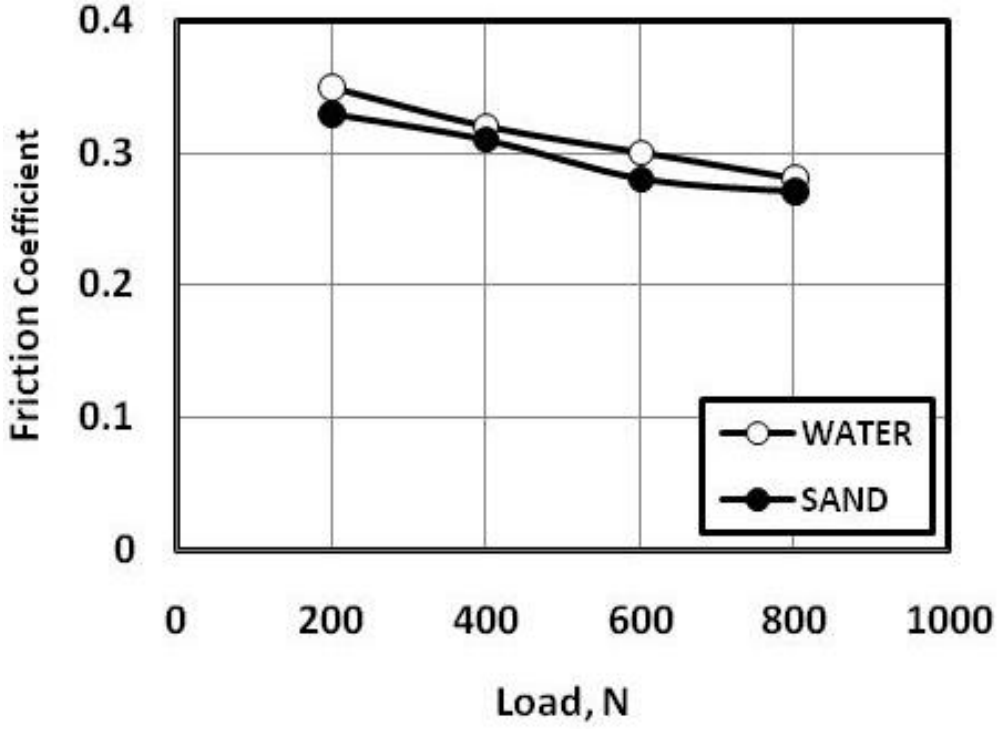

Fig. 7 Friction coefficient of water lubricated sliding of rubber of circular protrusions against ceramic tiles.

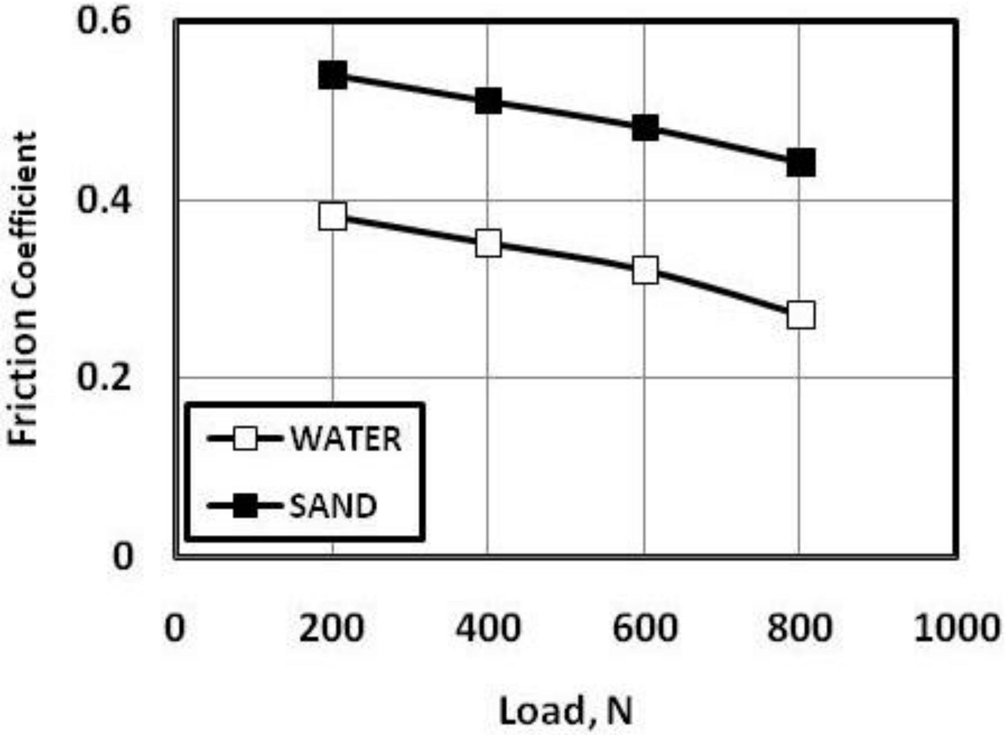

Fig. 8 Friction coefficient of water lubricated sliding of rubber of square protrusions against ceramic tiles.

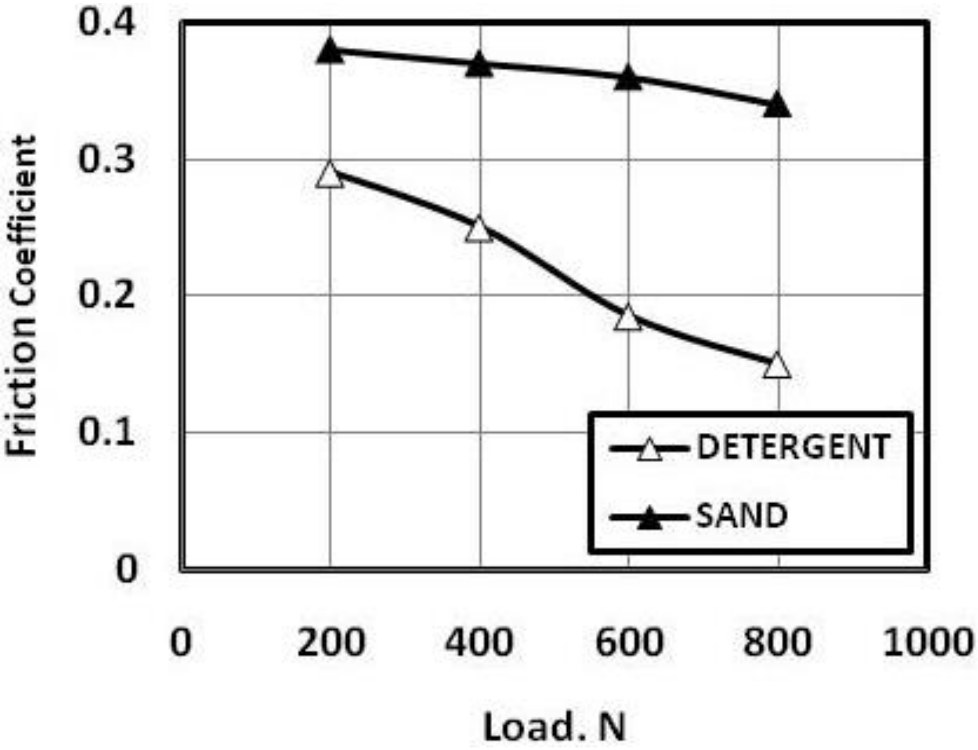

Fig. 9 Friction coefficient of detergent lubricated sliding of flat rubber against ceramic tiles.

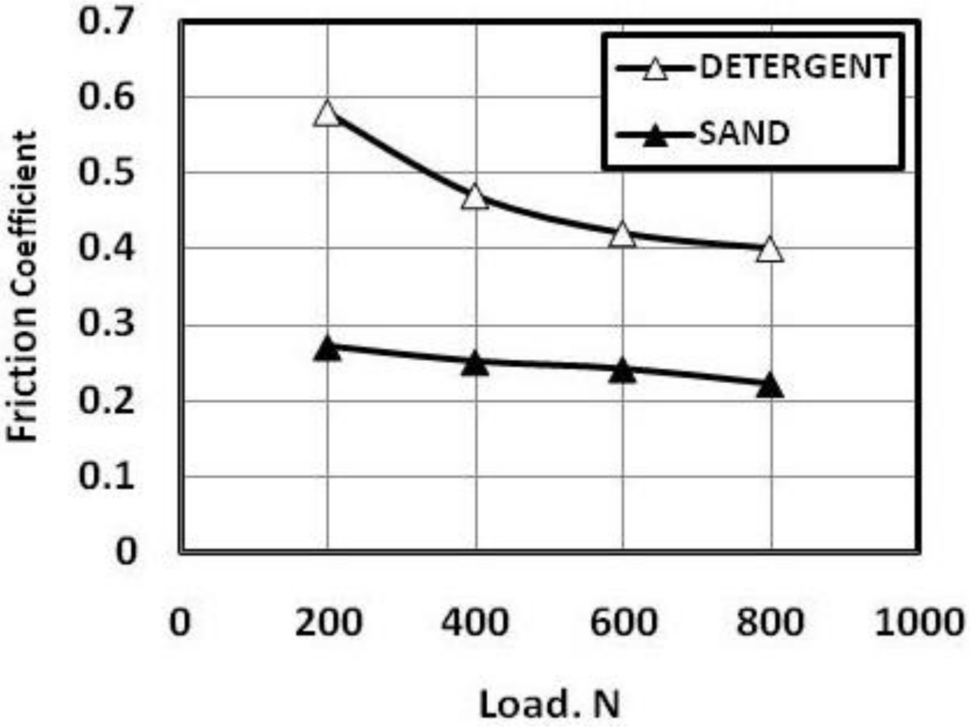

Fig. 10 Friction coefficient of detergent lubricated sliding of rubber of circular protrusions against ceramic tiles.

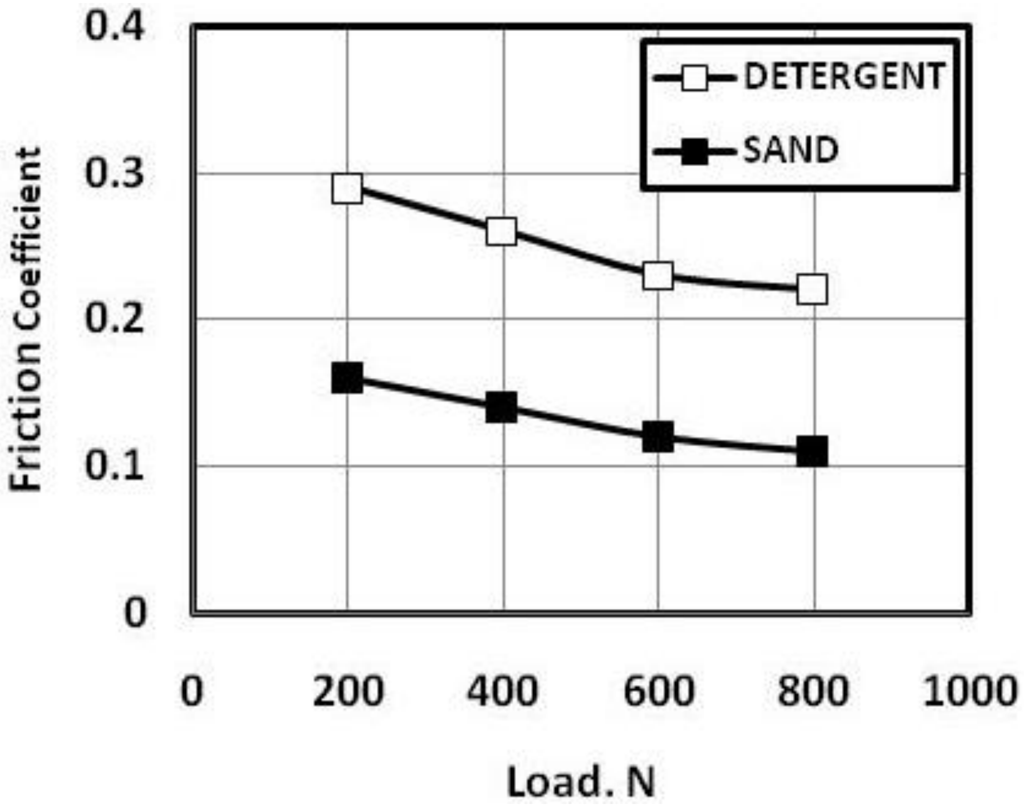

Fig. 11 Friction coefficient of detergent lubricated sliding of rubber of square protrusions against ceramic tiles.

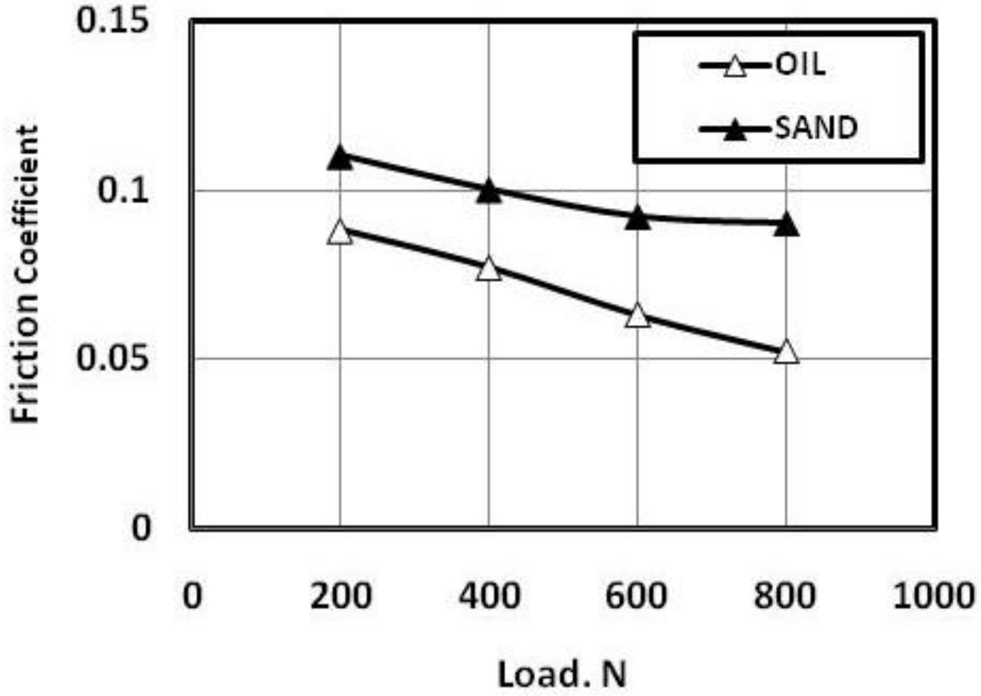

Fig. 12 Friction coefficient of oil lubricated sliding of flat rubber against ceramic tiles.

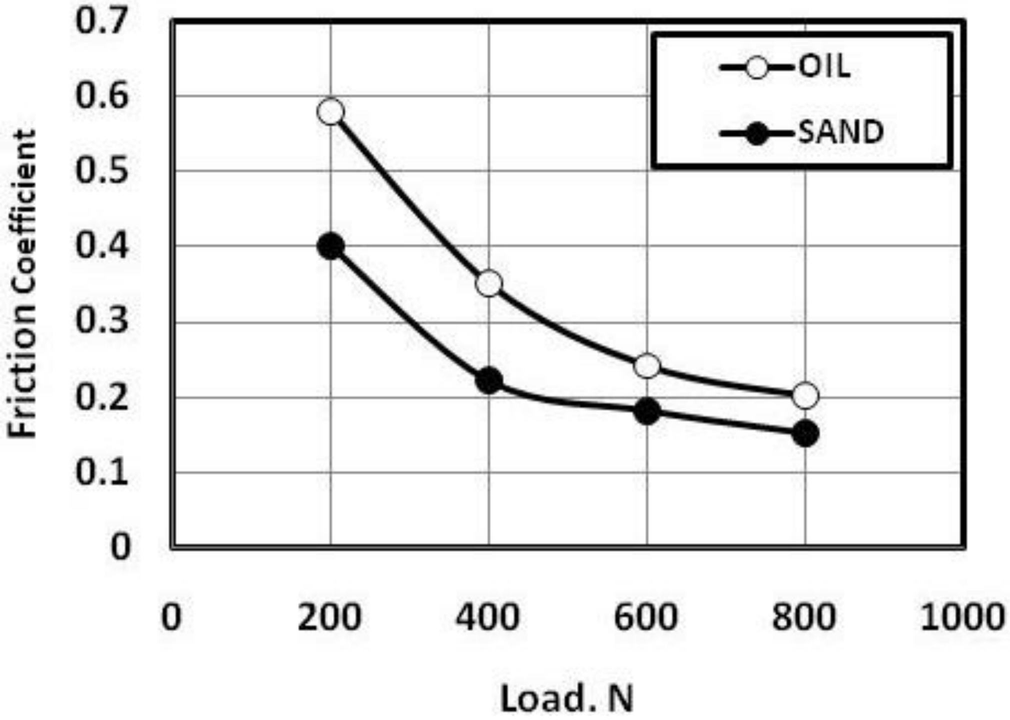

Fig. 13 Friction coefficient of oil lubricated sliding of rubber of circular protrusions against ceramic tiles.

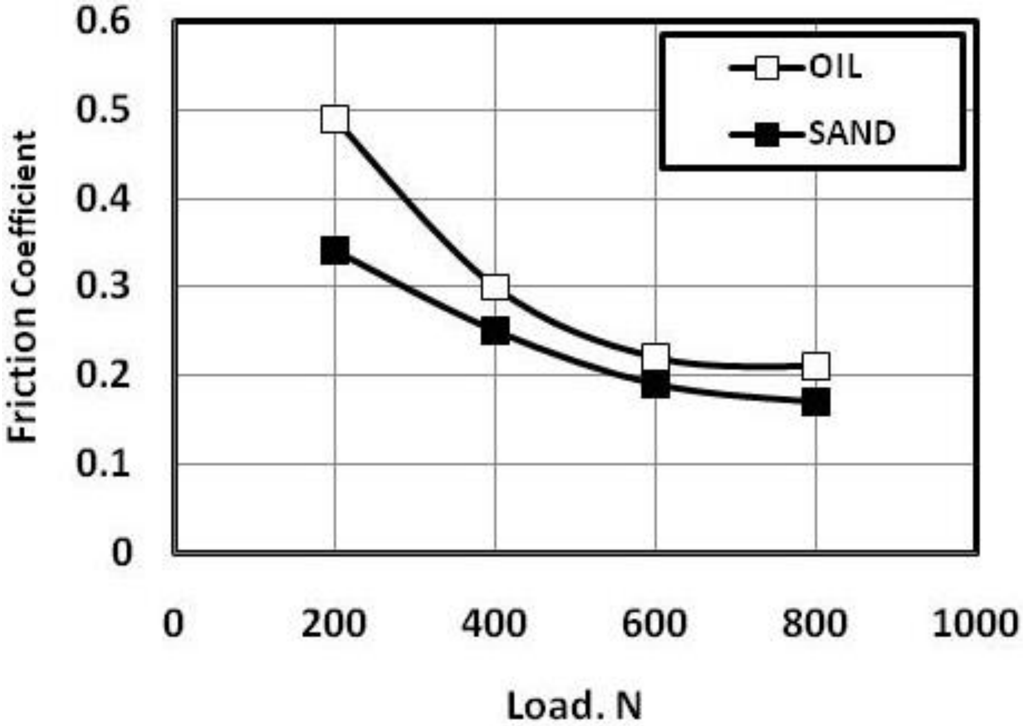

Fig. 14 Friction coefficient of oil lubricated sliding of rubber of square protrusions against ceramic tiles.

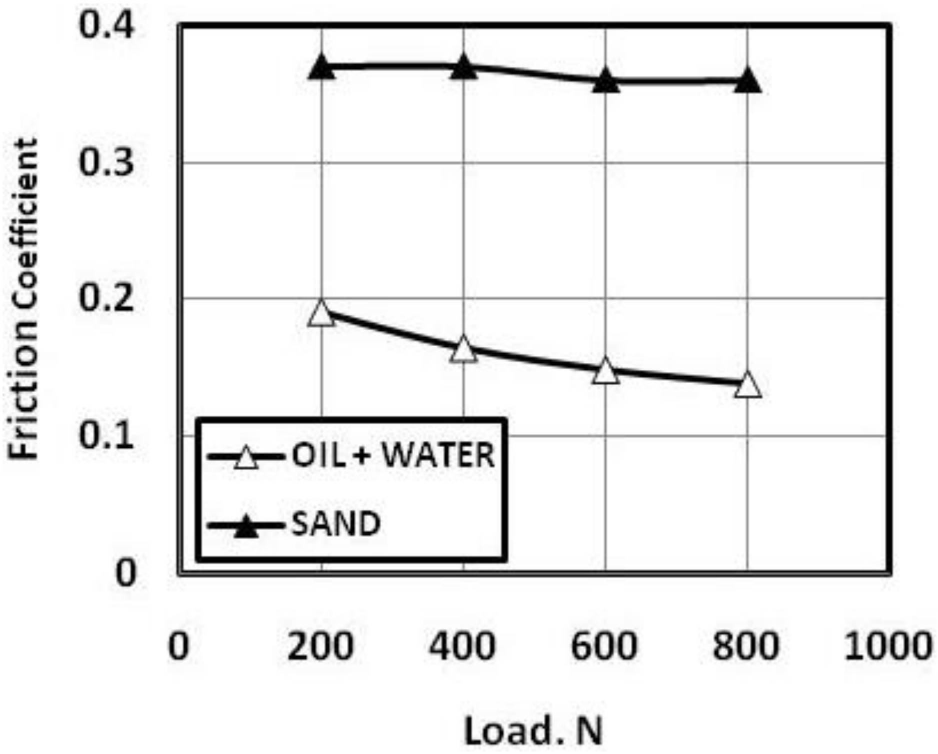

Fig. 15 Friction coefficient of oil and water lubricated sliding of flat rubber against ceramic tiles.

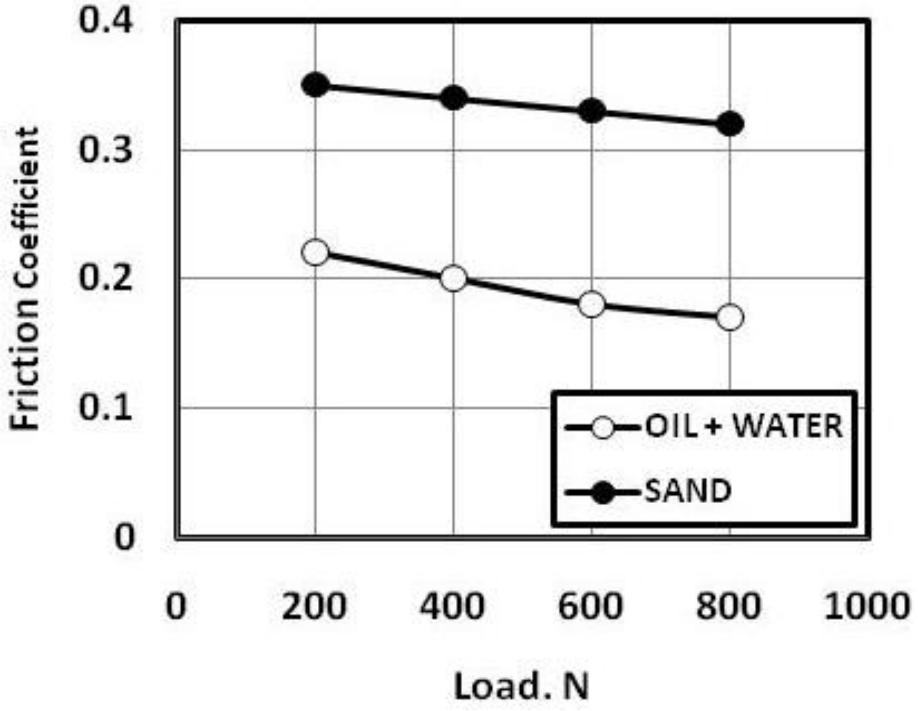

Fig. 16 Friction coefficient of oil and water lubricated sliding of rubber of circular protrusions against ceramic tiles.

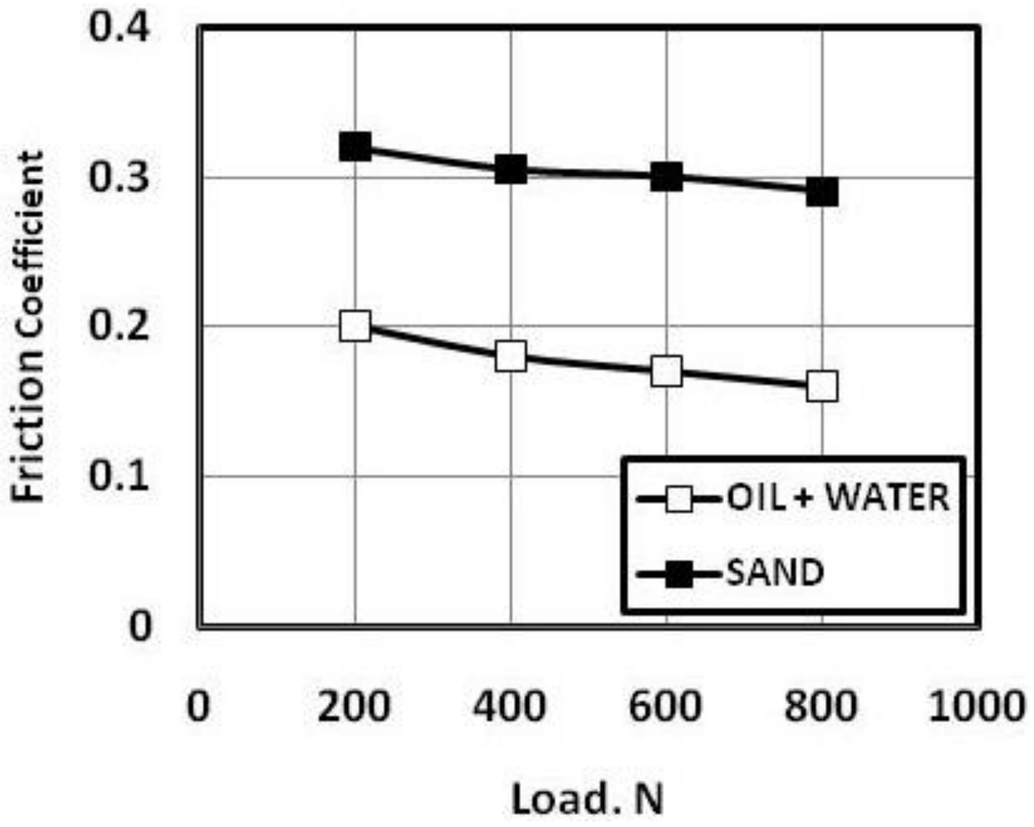

Fig. 17 Friction coefficient of oil and water lubricated sliding of rubber of square protrusions against ceramic tiles.

CONCLUSIONS

For the different sliding conditions, the following conclusions can be withdrawn:

1. At dry sliding, sand particles caused drastic decrease in friction coefficient. It is recommended to use circular protrusion.
2. In the presence of water, sand particles embedded in rubber surface increased friction coefficient. Square protrusions are recommended.
3. For surfaces lubricated by detergent, flat rubber embedded by sand particles gave higher friction than surfaces of protrusions.
4. Sand particles embedded in rubber lubricated by oil significantly increased friction coefficient. Circular protrusions gave higher friction than flat and square protrusions.
5. Flat rubber surfaces, lubricated by water oil emulsion and contaminated by sand particles, displayed the highest friction coefficient.

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