Friction Coefficient of Rubber Shoes Sliding against Ceramic Flooring

Friction coefficient · Rubber shoes · Ceramic flooring Tiles · Treads height and width

The present work discusses the effect of the treads width and depth of the shoe sole on the friction coefficient between the shoe and ceramic floor interface. The friction coefficient between the rubber test specimens of treads of different width and height, and the tested ceramic flooring tiles, was measured by using a test rig designed and manufactured for this purpose. Friction coefficient is determined by the ratio between the friction and the normal forces. Rubber test specimens were loaded against dry, water and water/detergent mixture, oil and oil/water dilution lubricated flooring tiles.

Reibkoeffizient von Gummisohlen auf keramischen Fußböden

Reibkoeffizient · Gummisohlen · Keramiser Fußboden · Profilbreite und -höhe

Die vorliegende Arbeit behandelt den Effekt der Breite und Tiefe von Schuhsohlenprofilen auf keramischen Fußböden. Der Reibkoeffizient der Gummisohlen wurde in einer eigenen Apparatur aus dem Verhältnis der Reibkraft und Normalkraft ermittelt. Die Untersuchungen wurden auf trockenen Flächen wie auch an solchen die mit Wasser, Spülmittel, Öl und Öl/Wasser Emulsion angefeuchtet waren, durchgeführt.

The risks associated with slipping and falling are related to the materials of footwear/floor, contamination condition, and geometric design of the sole. Shoe soles of various tread design are very common. Floor slip-resistance may be quantified using the static coefficient of friction. In the USA, the static coefficient of friction of 0.5 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. 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] 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.

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]. This was found in the friction measurements under wet conditions. In general, rubber friction is divided into two parts; the bulk deformation and the contact adhesive term, [7]. These two contributions are regarded to be independent of each other, but this is only a simplified assumption.

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, [8]. 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, [9 - 12]. 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.

The factors affecting friction coefficient measurement are the material, surface geometry of the footwear as well as floor,

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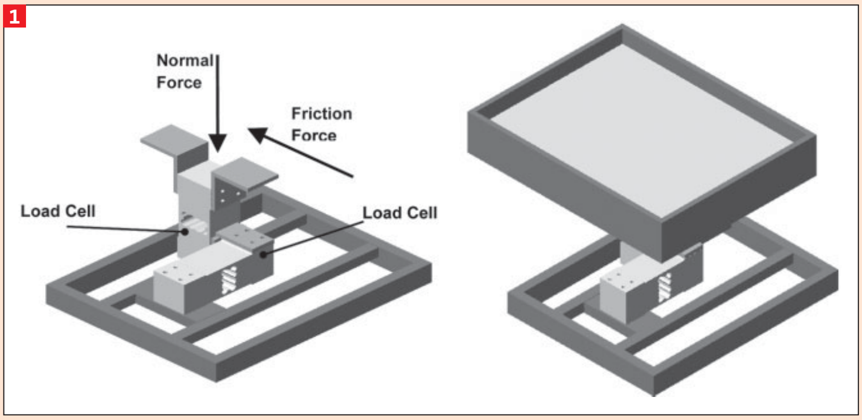
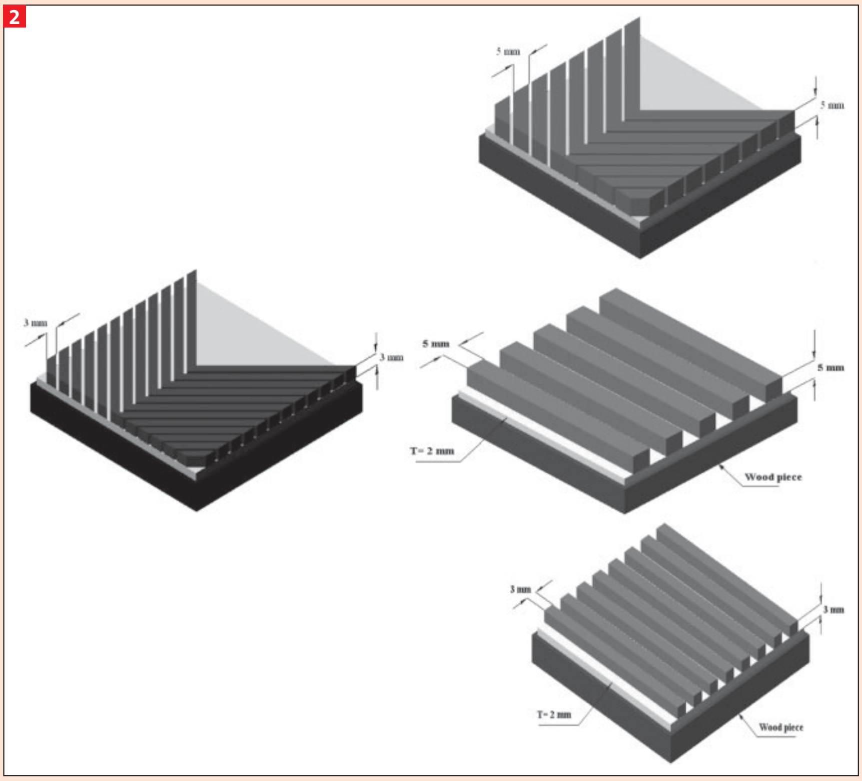


1 Arrangement of the test rig



2 Test specimens

floor contamination conditions and even the slipmeter used, [2, 13, 14]. Investigators have concentrated the friction coefficient measurements on liquid contaminated floors because most slip/fall incidents occur on the surfaces of such floors, [14 - 17]. When stepping on a wet or lubricated floor, a shoe sole cannot touch the floor surface without squeezing the liquid out of the contact area. The liquid between the floor and the sole isolates the two contact surfaces, thus reducing the friction between them. The liquid drainage time between the two contact surfaces depends on the viscosity and pressure between the two surfaces. The higher the viscosity is, the longer the time is required for the film thickness to decrease, [2]. A longer drainage time increases the risk of slipping due to the short time available to prevent a slip after the heel touches the floor.

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.

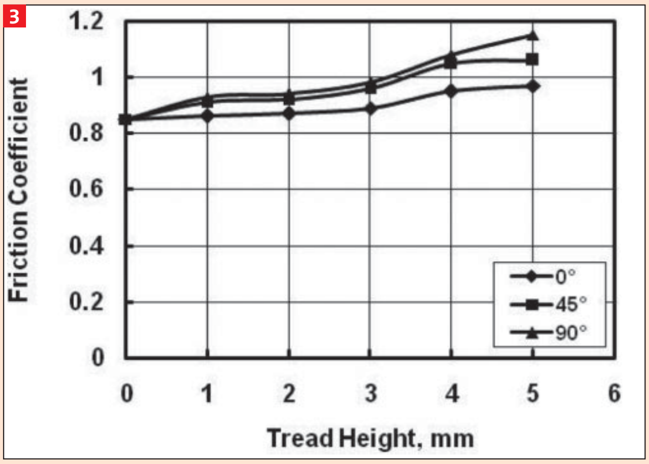
Glazed ceramics tiles are extensively used as flooring materials. The increasing demand to enhance the degree of surface roughness of the tiles to facilitate for the consumer the cleaning process should be balanced by investigating the effect of surface roughness on the friction coefficient. Slips and falls are a serious problem due to the annual direct cost of occupational injuries, [16]. It was found that a higher friction could potentially improve slip resistance as discussed previously, [19-24]. 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, [25], where it was investigated that certain surface roughness is needed to improve slip resistance.

Lubrication is known to facilitate the relative motion of the solids and to reduce friction by the creation of a separating lubricant film within the contact. Although grease lubricated elastomer contacts are commonly studied in the field of sealing application, [26,27], only few authors have focused on water lubricated elastomer contacts. In the wet conditions, the mechanical properties of the vulcanized elastomer were modified by liquid absorption. Experiments of the natural rubber, absorption proceeds rapidly and then reaches an equilibrium, [28]. This deepened understanding of liquid entrapment phenomenon in the context of road/tire application. Tread groove designs are helpful in facilitating contact between the shoe sole and floor on liquid contaminated surface, [29]. 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.

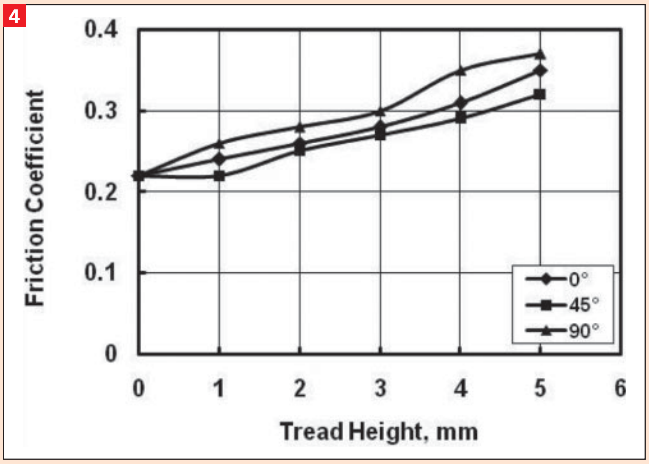
In the present work, the effect of the width and depth, of the treads of the shoe sole, on the friction coefficient between the shoe and ceramic floor interface is discussed.

Experimental

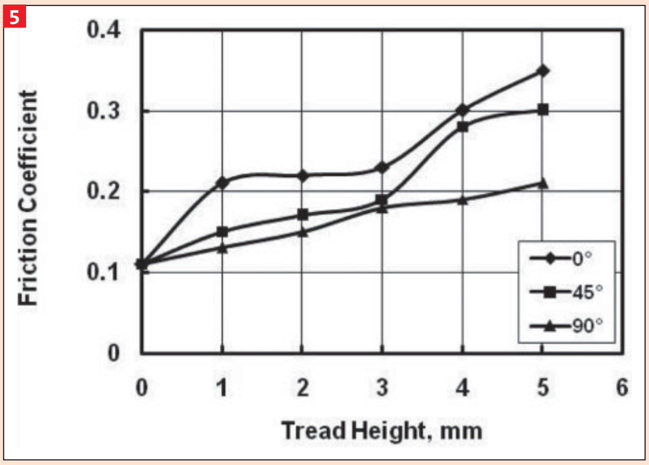
The test rig used in the present work was designed and manufactured to measure the friction coefficient displayed by the sliding of the tested rubber specimens against the ceramic surface through measuring both the friction and normal forces. The ceramic surface in form of a tile of 400 × 400 mm was placed in a base supported by two load cells, the first measures the horizontal force



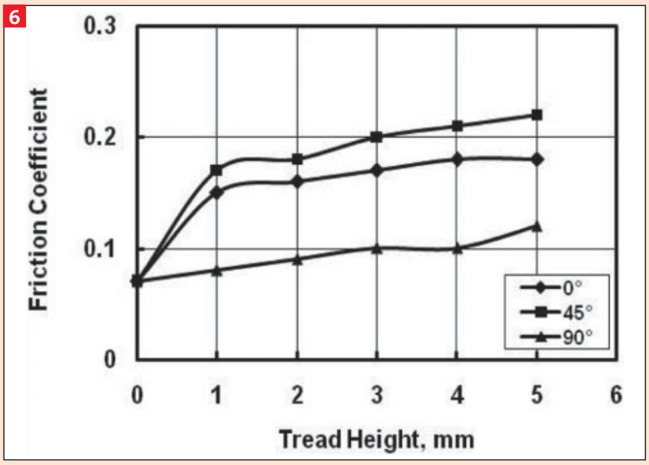
3 Friction coefficient generated from dry sliding



4 Friction coefficient generated from water sliding



5 Friction coefficient generated from detergent sliding



6 Friction coefficient generated from oil sliding

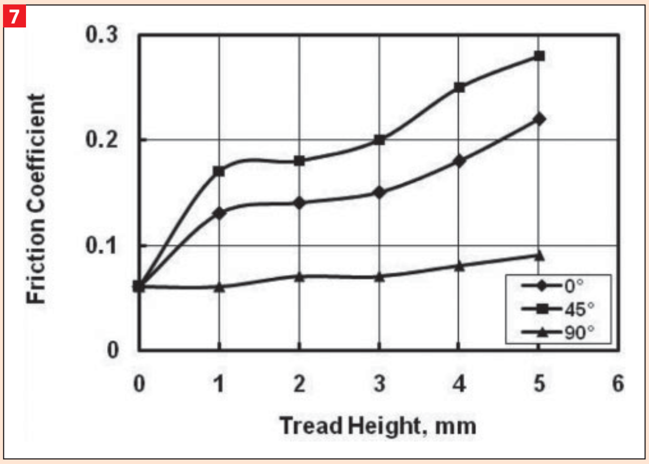
(friction force) and the second for the vertical force (applied load). A digital screen was attached to the load cells to detect the friction and vertical forces. Friction coefficient is determined by the ratio between the friction force and the normal load. The arrangement of the test rig is shown in Figure 1.

The rubber test specimens prepared of rubber of 8 MPa modulus of elasticity and 53 Shore A hardness respectively. Two groups of test specimens were prepared by introducing treads in the rubber surfaces. The first was of 1, 2, 3, 4 and 5 mm height and constant tread width (5 mm), while the second was of 1, 2, 3, 4 and 5 mm height and constant tread width (5 mm), Figure 2. The test specimens consisted of rubber sheet of 2 mm thickness adhered to wood blocks of 50 × 50 mm. Then the treads were adhered to the rubber surface. For parallel treads, the tread groove width was the same as the tread width, while treads of 45° had 2 mm tread grooves. Rubber test specimens of smooth surface were used for comparison. Relative to the tread length, three directions of motion of the test specimen were carried out. The sliding directions were parallel, perpendicular and 45 °. The flooring tiles were thoroughly cleaned with soap water to eliminate any dirt and dust and carefully dried before the tests. The dilution was replenished on the tested flooring tiles, where the amount for each replenishment was 10 ml to form consistent fluid film covering the sliding surface. After each measurement, all contaminants were removed from the flooring materials using absorbent papers. The flooring materials were then rinsed using water and blown using hair dryer after the cleaning process. Tests were carried out at different values of load exerted by foot. In the present work, the results of load of 400 N were considered.

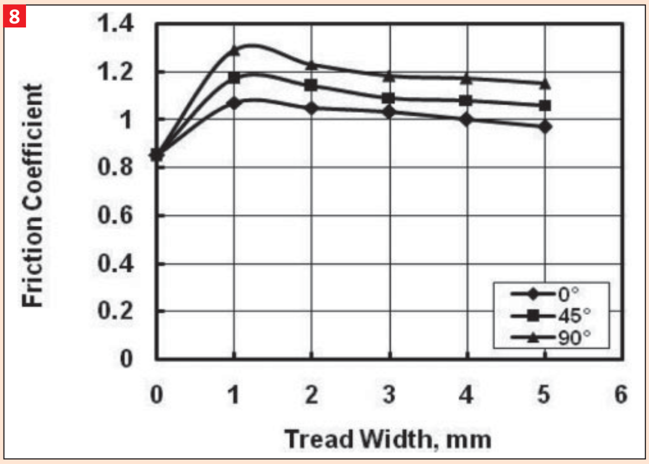
Results and Discussion

The effect of the height of the treads on the friction coefficient is discussed in Figures 3 - 7, for test specimens of constant tread width of 5 mm. The effect of the treads height, of the rubber test specimens, on the friction coefficient displayed by the dry sliding is shown in Figure 3. Friction coefficient slightly increased with increasing treads height. The increase may be from the deformation of the contact treads surface which increases with the increase of the treads height. The direction of the treads has an influence on the friction coefficient, where parallel treads to the motion direction showed the lowest values. Perpendicular treads displayed the highest friction coefficient (1.14). This relatively high friction is attributed to the very low elastic modulus of rubber and its high internal friction. 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.

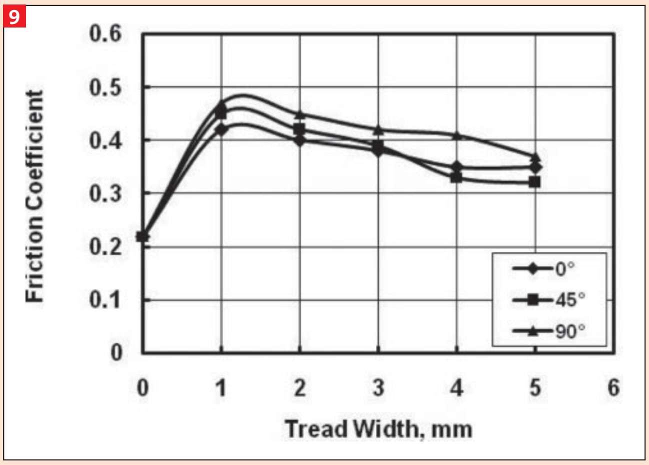
In the presence of water on the sliding surface significant decrease in friction coeffi-



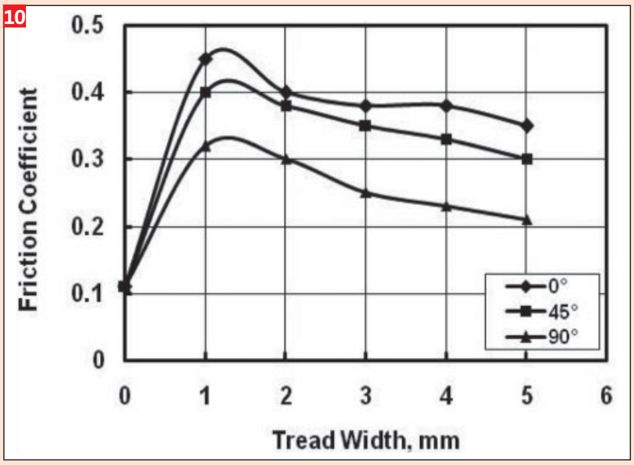
7 **Friction coefficient generated from oil water dilution sliding**



8 **Friction coefficient generated from dry sliding**



9 **Friction coefficient generated from water sliding**



10 **Friction coefficient generated from detergent sliding**

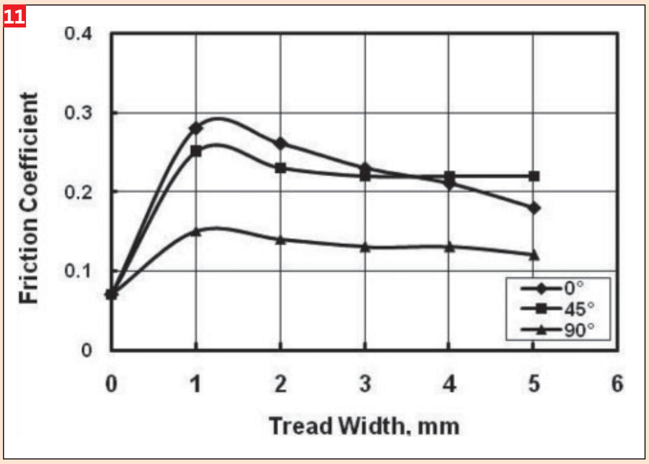
cient was observed, Figure 4, compared to the dry sliding. Generally, friction coefficient increased with increasing the treads height. This behaviour can be attributed to the fact that water will escape away from the contact area into the tread grooves and consequently the area of the water film trapped between rubber specimen and ceramic tile will decrease. In this condition, a part of the contact area will be performed under dry friction and the other will be water lubricated. At tread height of 5 mm, the highest friction values were 0.37, 0.35 and 0.32 for perpendicular, parallel and 45° tread direction respectively.

In the presence of water/detergent dilution between the sliding surfaces, friction coefficient drastically decreased to values lower than that displayed by water, Figure 5. Parallel treads showed the highest friction coefficient, while perpendicular treads displayed the lowest friction values. This behaviour could be explained on the basis that perpendicular treads formed a hydrodynamic wedge easier than the parallel one, so that the friction coefficient experienced relatively lower values. As the height of the treads increased friction coefficient increased due to the increased volume of the tread grooves which enabled the fluid to be drained out of the contact area.

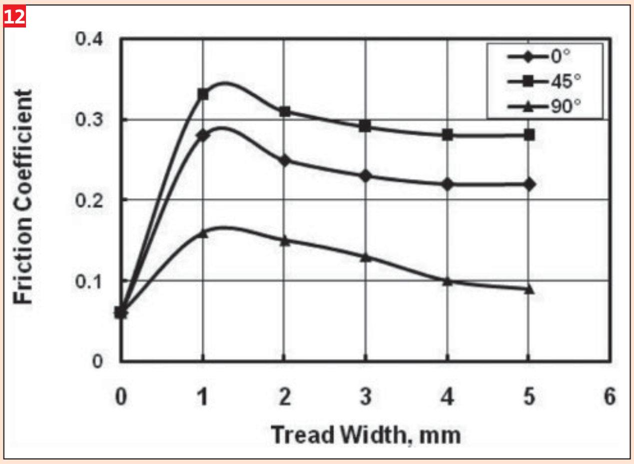
In the presence of oil on the sliding surfaces, smooth surfaces gave the lowest friction value (0.07), Figure 6, as a result of the presence of squeeze oil film separating rubber and ceramic. As the treads height increased, friction coefficient increased to give values of 0.22, 0.18 and 0.13 for 45°, parallel and perpendicular treads respectively. The significant difference among the values of friction coefficient indicates that the direction of the treads remarkably influences the friction values. It seems that 45° treads well scavenge the oil away from the contact area.

Emulsion of water and oil shows slight friction increase compared to oil lubricated sliding, Figure 7. As the tread height increased friction increased due to the easy escape of the lubricant from the contact area. The relatively easy escape of the emulsion away from the contact area showed that high friction coefficient values were obtained at 5 mm tread height. Perpendicular treads showed the lowest friction values as a result of the formation of hydrodynamic wedges, where friction values were 0.07 and 0.09 for smooth and 5 mm tread height respectively.

The effect of the treads width on the friction coefficient of test specimens of constant tread depth of 5 mm is shown in Figs. 8 – 12. For dry sliding, friction coefficient significantly increased up to maximum then slightly decreased with increasing the treads height, Figure 8. The maximum friction value (1.29) was observed at 1 mm tread width. This behaviour may be attributed to the maximum deformation of the tread at that width. As the tread width increased the deformation of the rubber surface decreased and consequently friction coefficient decreased. The direction of the treads influenced the values of the friction coefficient, where perpendicular treads displayed the highest friction followed by 45° and parallel treads.



11 **Friction coefficient generated from oil sliding**



12 **Friction coefficient generated from oil water dilution sliding**

Friction coefficient of rubber test specimens sliding against water lubricated ceramic tiles is shown in Figure 9, where friction values were relatively lower than that displayed by dry sliding. Generally, the water film formed on the sliding surfaces was responsible for the friction decrease. Tread width of 1 mm displayed the highest friction coefficient (0.47, 0.45 and 0.42) for perpendicular, 45° and parallel tread direction respectively. As the tread width increased friction coefficient slightly decreased due to the increased area of the water film. Smooth rubber showedthe lowest friction values.

In the presence of detergent, Figure 10, friction coefficient displayed lower values than that recorded for water. It seems that the decrease in friction coefficient may be explained on the basis that the influence of detergent is to dissolve the greases as well as fats and remove solid contaminants such as dust from the sliding surfaces. This mechanism is carried out by adhering a film of the detergent molecules into the sliding surface preventing the contaminants to be adhered to the sliding surface. The detergent molecules must have some polar parts to provide the necessary water solubility. The polarity of the detergent molecules might be responsible for friction decrease.

In the presence of oil on the sliding surfaces, smooth surfaces give the lowest friction value (0.07), Figure 11, as a result of the presence of squeeze oil film separating rubber test specimens and ceramic tiles. For test specimens of 1 mm tread width, friction coefficient increased up to maximum (0.28) followed by slight friction decrease with further increase of the tread width. The friction decrease may be due to the increased ability of the tread to form hydrodynamic wedge as the tread width increased. Parallel and 45° treads could scavenge oil away from the contact area more effectively than perpendicular treads. As a result of that, perpendicular treads displayed lower friction coefficient.

Water/oil dilution showed slight friction increase compared to oil lubricated sliding, Figure 12. The maximum friction value (0.33) was displayed by rubber surface of 1 mm tread width. The effect of treads direction relative to motion was significant, where 45° treads displayed the highest friction followed by parallel and perpendicular treads. The relatively easy escape of the dilution away from the contact area was responsible for the relative friction increase.

Conclusions

1. At dry sliding, friction coefficient slightly increased with increasing treads height. Perpendicular treads displayed the highest friction coefficient, while parallel treads showed the lowest values.
2. In the presence of water, on the sliding surface significant decrease in friction coefficient was observed compared to the dry sliding.
3. 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.
4. Oily smooth surfaces gave the lowest friction value as a result of the presence of squeeze oil film separating rubber and ceramic. Treads of 45° displayed the highest friction coefficient.
5. Emulsion of water and oil shows slight friction increase compared to oil lubricated sliding. As the tread height increased friction increased due to the easy escape of the lubricant from the contact area.
6. Friction coefficient significantly increased up to maximum then slightly decreased with increasing the treads height. The maximum friction value (1.29) was observed at 1 mm tread width. Perpendicular treads displayed the highest friction followed by 45° and parallel treads.
7. At water, detergent and oil lubricated sliding conditions, friction coefficient decreased as the tread width increased due to the increased area of the fluid film. Smooth surfaces gave the lowest friction values as a result of the presence of squeeze oil film separating rubber test specimens and ceramic tiles. The friction decrease may be due to the increased ability of the tread to form hydrodynamic wedge as the tread width increased. Perpendicular treads caused lower friction coefficient because parallel and 45° treads could scavenge oil away from the contact area more effectively than perpendicular treads.

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