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DRY SLIDING OF TREADED RUBBER ON CERAMICS

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ABSTRACT
In the present work, the frictional behavior of rubber sliding against dry ceramic flooring was investigated. The effect of hardness of the rubber as well as the thickness and the groove width of the treads introduced in the rubber surface on friction coefficient was tested.

It was found that friction coefficient decreased with increasing rubber hardness due to decrease of rubber deformation. Increasing rubber thickness increased deformation and friction coefficient. Presence of grooves in rubber surface facilitated increasing deformation and escaping air bubbles from rubber gaps to grooves so that the adhesion between rubber and ceramic increased which increased friction coefficient. As groove width increased, higher amount of air escaped from surface gaps so that contact area increased and consequently friction coefficient increased. The highest friction coefficient values were recorded for rubber of 8 mm thickness, 6 mm groove width and 30 Shore A hardness. This was due to the high rubber thickness and the wide groove width which increased rubber deformation. It is recommended for walking to use the treaded rubber instead of smooth rubber.

KEYWORDS
Dry sliding, treads, groove width, hardness, thickness.

INTRODUCTION
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 values of the static coefficient of friction may be required for safe walking when handling loads. In Europe, it was suggested that a floor was "very slip resistant" if the coefficient of friction was 0.3 or more, [2]. 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.

Measurements of the static friction coefficient between rubber specimens and flooring surfaces were carried out at (dry, water lubricated, oil, oil diluted by water and sand contaminating the lubricating fluids), [5 - 6]. It was observed that dry sliding of the rubber test specimens displayed the highest value of friction coefficient.
Glazed surface tiles are extensively used as flooring materials. The increasing demand to enhance the degree of surface roughness of the tiles to facilitate for the consumer the cleaning process should be balanced by investigating the effect of surface roughness on the friction coefficient. Slips and falls are a serious problem due to the annual direct cost of occupational injuries, [7]. It was found that a higher friction could potentially improve slip resistance as discussed previously, [8 - 9]. It was observed that dynamic friction is more applicable to human walking than static friction.

Experiments of the natural rubber, absorption proceeds rapidly and then reaches an equilibrium, [10]. Tread groove designs are helpful in facilitating contact between the shoe sole and floor on liquid contaminated surface, [11]. 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 rubber, on the friction coefficient between the rubber surface and flooring surface interface is discussed. Surface roughness is known to be a key factor in determining the slip resistance of floors. The effect of flooring surface roughness on the friction coefficient, when rubber and leather are sliding against it, was investigated, [12]. 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 flooring surface.

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, [13]. 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, [14]. 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, [15]. 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 behavior of rubber, [16]. The friction of rubber on smooth surfaces primarily depends on adhesion, [17], while hysteresis becomes increasingly important for rough surfaces. The frictional behavior of rubber semi-spherical balls of different diameter and hardness to have specific information about their friction coefficient and evaluate their performance in increasing friction coefficient at dry, water, detergent wetted and oil lubricated floorings was investigated, [18]. It was found that friction coefficient showed significant increase with increasing the diameter of the semi-spherical protrusions.

In the present work, the frictional behavior of smooth and treaded rubber sliding against dry ceramic flooring was investigated. The effect of hardness of the rubber as well as the thickness and the groove width of the treads introduced in the rubber surface on friction coefficient was tested.

EXPERIMENTAL

Experiments were carried out using test rig shown in Fig. 1. It consists, mainly, of two load cells one installed in horizontal position and other in vertical one, where the horizontal load cell measured the normal force while the vertical one measured the friction force. Also it consists of upper base that will be covered by the flooring surface (ceramics), and lower base used to make test rig fixed on floor and not move during test. The effect of the tested parameters on friction coefficient of rubber sliding against flooring surface such as rubber thickness, rubber hardness, groove width of the treads and the sliding conditions will be investigated. The tested flooring materials of ceramics were in form of quadratic tiles of 0.3 m × 0.3 m and 5.0 mm thickness. Rubber test specimens were prepared in the form of square sheets of 60 × 60 mm. There are three values of rubber thickness used in experiment 3, 5 and 8 mm thickness as shown in Fig. 2. The hardness of the rubber was 30, 40, 50 and 60 Shore-A. Groove width of the tread of 2, 4 and 6 mm was tested, Fig. 3.

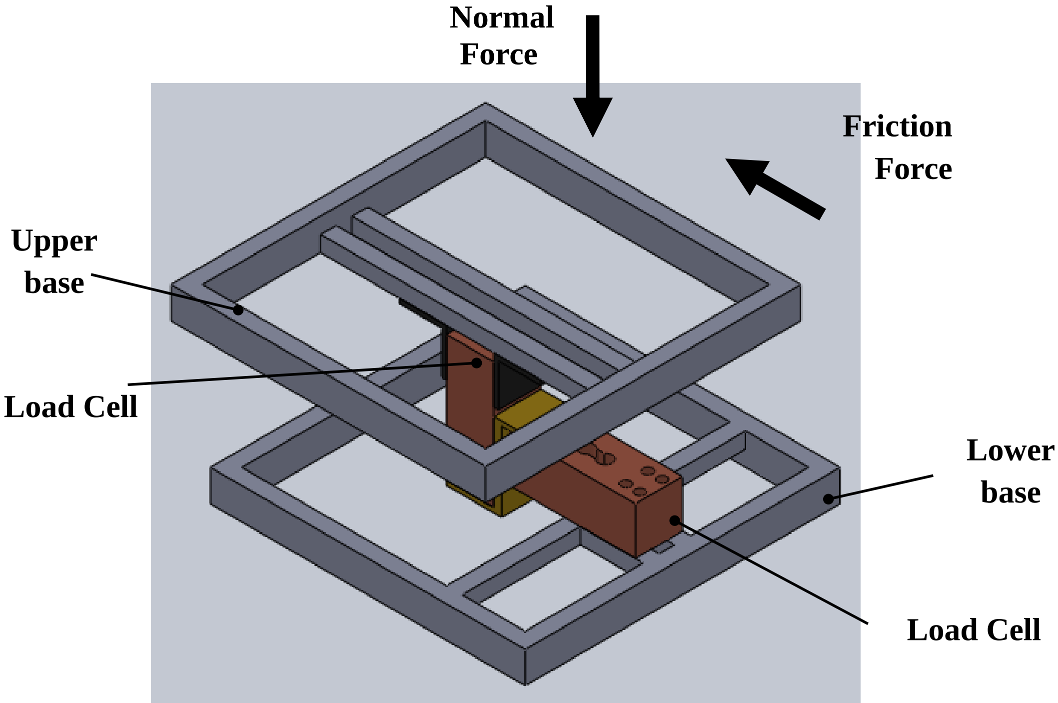
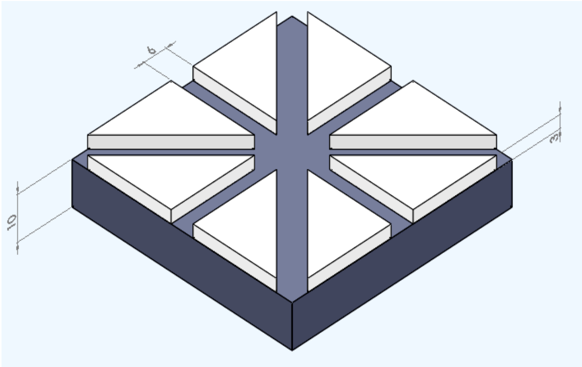
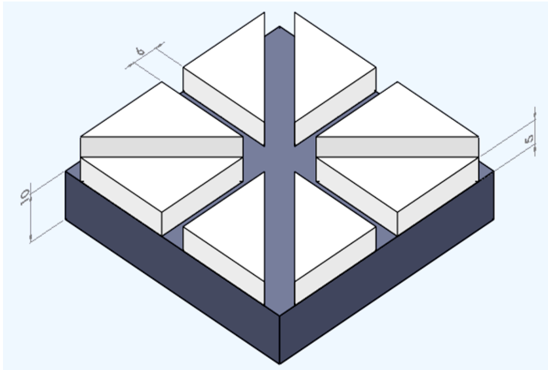


Fig.1 Arrangement of test rig.

Friction coefficient measurement was carried out at different values of load. In the present work, the results of the selected values of load of 40, 80, 120 and 160 N will be considered. First, rubber specimens were adhered on wood block then the flooring materials and the rubber were cleaned with soap water to eliminate any dirt and dust and carefully dried before the test. The rubber test specimens were loaded against dry, water, water + 1.0 vol. % detergent and oil lubricated ceramic flooring materials.



(a)



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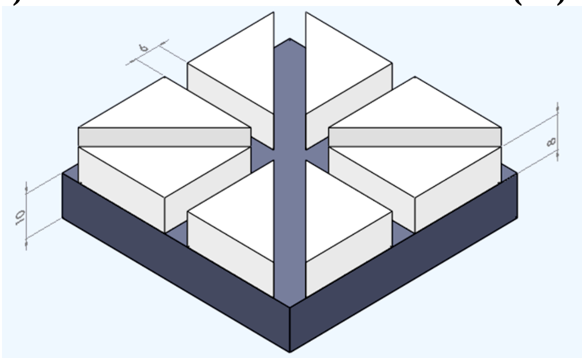
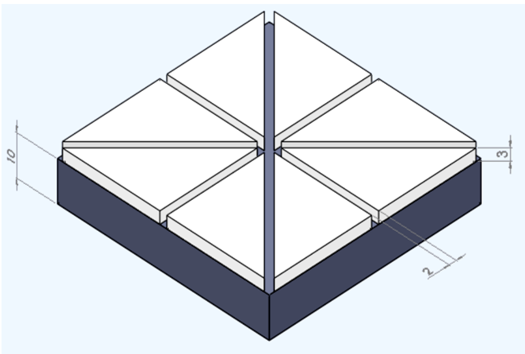
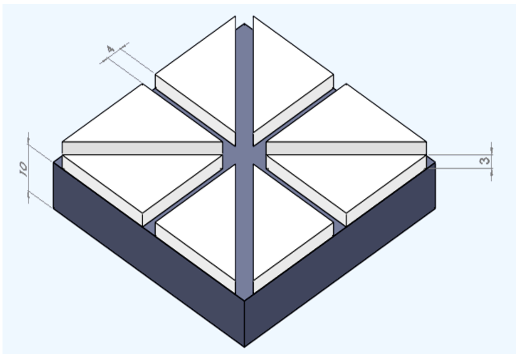


(c)

Fig. 2. Rubber thickness: (a) 3 mm thickness, (b) 5 mm thickness, (c) 8 mm thickness.



(a)



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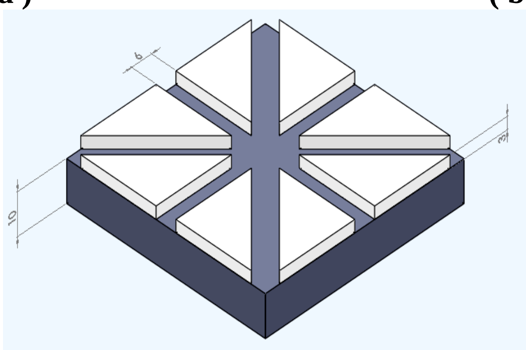

(c)

Fig. 3. Groove width: (a) 2 mm thickness, (b) 4 mm thickness, (c) 6 mm thickness.

During test, horizontal and vertical load cells connected to two monitors detected normal and friction force respectively. Friction coefficient is the ratio between friction and normal force. By taking five values for each test the values of friction coefficient could be calculated.

RESULTS AND DISCUSSION

Effect of rubber hardness on friction coefficient is shown in Fig. 4. Friction coefficient decreased with increasing rubber hardness due to decrease of deformation. Friction coefficient decreased when normal load decreased. Surfaces free of grooves reduced the effect of deformation. Rubber of 30 shore A hardness displayed the highest value of friction coefficient. Also absence of groove prevented escape of air from rubber surface gaps and made rubber with smooth surface leading to decrease in friction coefficient with increasing normal load.

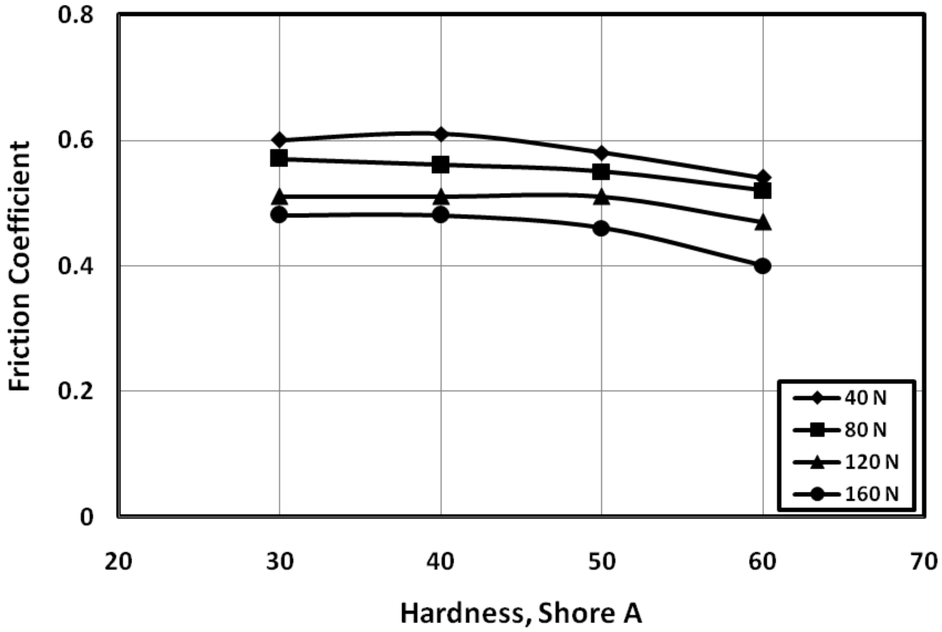

Fig. 4 Effect of hardness on friction coefficient for 3 mm thickness for smooth surface.

Friction coefficient generated from sliding of smooth rubber surface of 5 mm thickness against dry flooring ceramic is shown in Fig. 5. it is clearly shown that, increasing rubber hardness caused slight decrease in friction coefficient due to decreasing deformation. Increasing normal load decreased friction coefficient. Increasing thickness gave significant effect on increasing friction coefficient which displayed a value of 0.85 for 5 mm rubber thickness, while the corresponding value was 0.6 for 3 mm rubber thickness due to the increase in deformation.

Figure. 6 shows the effect of hardness on friction coefficient for smooth rubber surface of 8 mm thickness. Testing smooth rubber surface showed a decrease in friction coefficient with increasing rubber hardness. It is clearly shown that decreasing friction value with increasing normal load due to saturation of the rubber asperities and rubber filling the gaps between the contact asperities. For 8 mm thickness, friction coefficient represented higher values than the observed for 3 and 5 mm rubber thicknesses, where

the maximum value of friction coefficient was 0.94 at 30 shore A hardness and 40 N load.

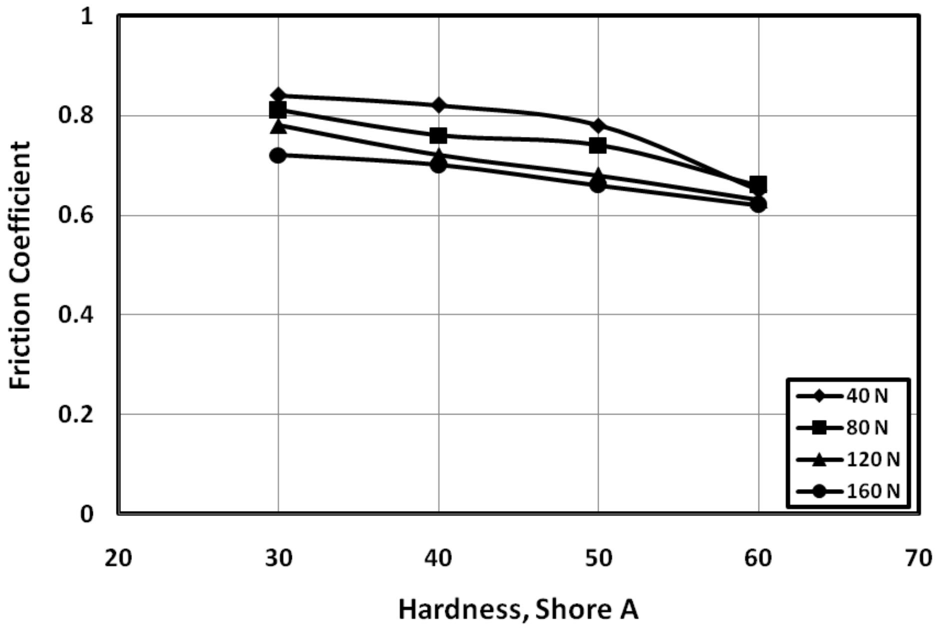

Fig. 5 Effect of hardness on friction coefficient for 5 mm thickness for smooth surface.

The relation between rubber hardness and friction coefficient for 3 mm thickness and 2 mm groove width is shown in Fig. 7. It is clearly shown that the friction coefficient remarkably decreased with increasing rubber hardness. Also friction coefficient increased as the normal load increased due to the increase of rubber deformation. The maximum value of friction coefficient reached 0.9 at 30 shore A hardness and 160 N normal load. 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.

Friction coefficient generated from the sliding of rubber of 3 mm thickness and 4 mm groove width against dry ceramics is shown in Fig. 8. The friction coefficient significantly decreased with increasing rubber hardness. Besides, as the normal load increased, the deformation of the rubber increased causing an increase in friction coefficient. At 30 shore A hardness and 160 N load, the highest friction coefficient was observed. Presence of grooves in rubber surface facilitated increasing deformation which improved friction coefficient with increasing normal load. Wider grooves

improved friction values so that maximum value of friction coefficient for 4 mm groove width is higher than that observed for 2 mm groove width.

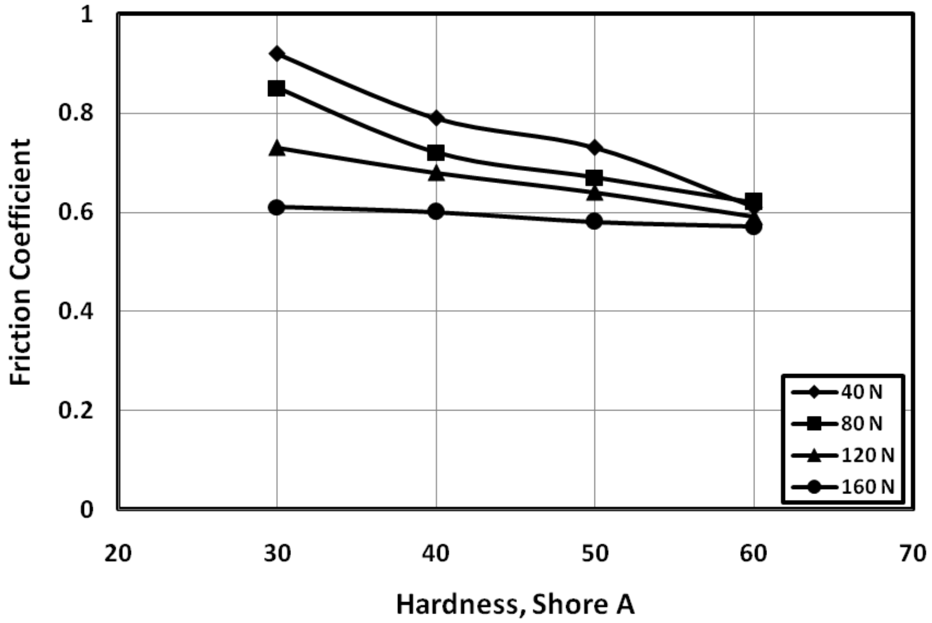

Fig. 6 Effect of hardness on friction coefficient for 8 mm thickness for smooth surface.

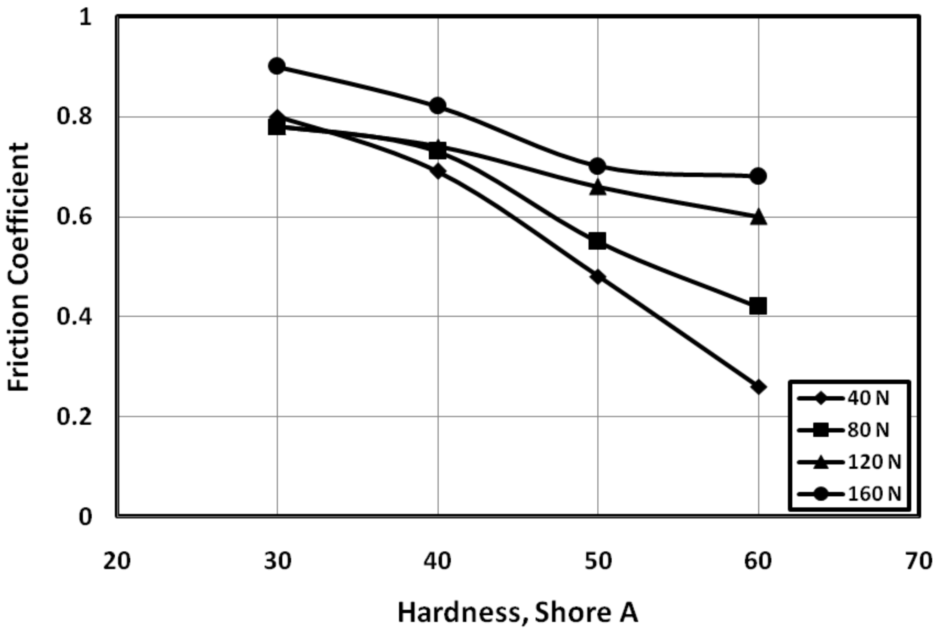

Fig.7 Effect of hardness on friction coefficient for 3 mm thickness and 2 mm groove width.

The effect of rubber hardness on friction coefficient is shown in Fig. 9, where friction coefficient decreased with increasing hardness. Friction coefficient of rubber increased with increasing normal load. The maximum friction value reached to 0.75 at 30 shore A hardness and 160 N load. Maximum value of friction recorded was higher than that

displayed by 3 and 4 mm groove width rubber due to the increased rubber deformation which strongly affected friction values.

According to Fig. 10, It is shown that friction coefficient decreased with increasing rubber hardness. It is also shown that friction coefficient increased due to the increase of the normal load where it gave the maximum value of friction coefficient (1.1) at 30 shore A hardness and 160 N. Increasing thickness had an influence on friction values compared to values recorded for 3 mm rubber thickness due to increasing deformation.

In case of 5 mm thickness and 4 mm groove width shown in Fig. 11, it can be noted that increasing deformation at 30 shore A hardness made friction coefficient had the highest value then it decreased with increasing rubber hardness, while friction coefficient increased with increasing normal load. Increasing rubber hardness made rubber not easily deformed and consequently escape of air bubbles that trapped in rubber surface gaps was limited so that the contact area and friction coefficient decreased.

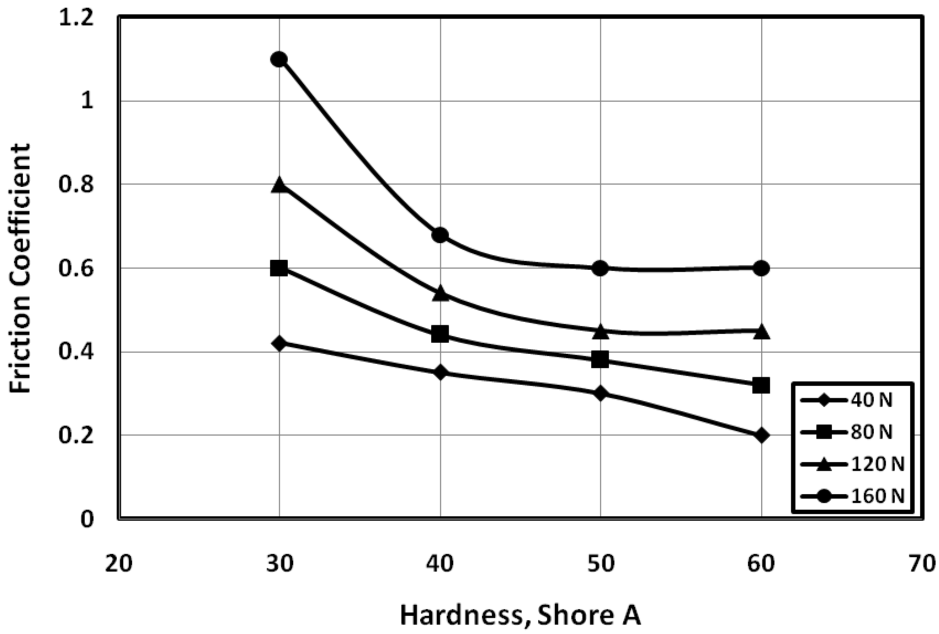

Fig. 8 Effect of hardness on friction coefficient for 3 mm thickness and 4 mm groove width.

Figure 12 shows the relationship between rubber hardness and friction coefficient for 5 mm thickness and 6 mm groove width. It is noticed that significant decrease in friction coefficient happened accompanied to the increase of rubber hardness because rubber became relatively harder to be deformed. Maximum value of friction coefficient occurred at 30 shore A hardness and 160 N normal load. As groove width increased, larger amount of air escaped from surface gaps so that contact area increased and consequently friction coefficient increased. Higher friction values were observed due to the groove width increase which increased rubber deformation.

The effect of hardness on friction coefficient for 8 mm thickness and 2 mm groove width is shown in Fig. 13. Increasing of rubber hardness slightly decreased friction coefficient. But friction coefficient increased with increasing normal load, where the highest value was more than 1 at 30 shore A hardness and 160 N load. It is observed that deformation

increased friction values due to increasing rubber thickness compared to the conditions of 3 and 5 mm thicknesses.

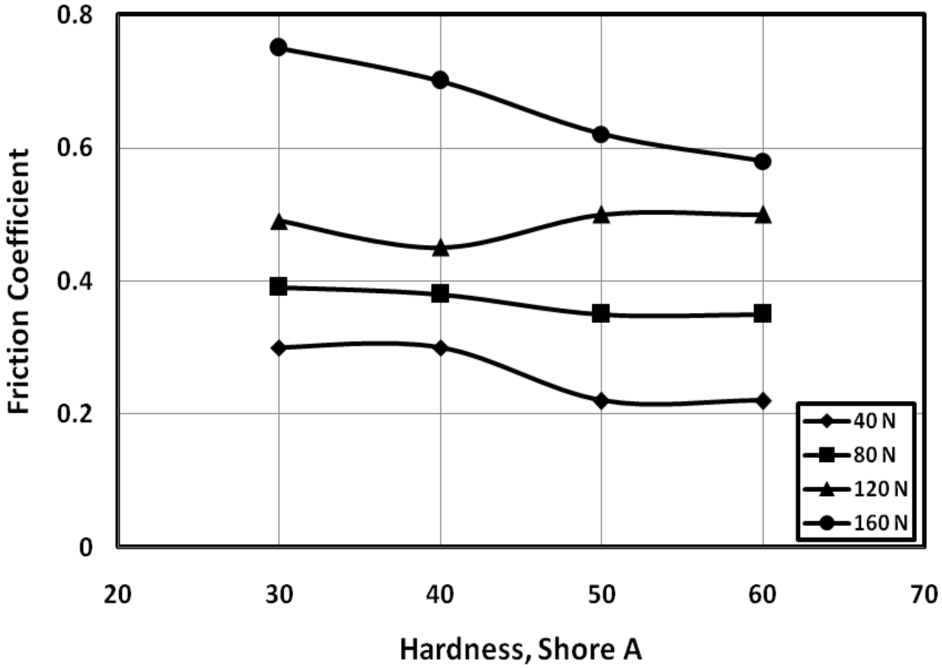

Fig. 9 Effect of hardness on friction coefficient for 3 mm thickness and 6 mm groove width.

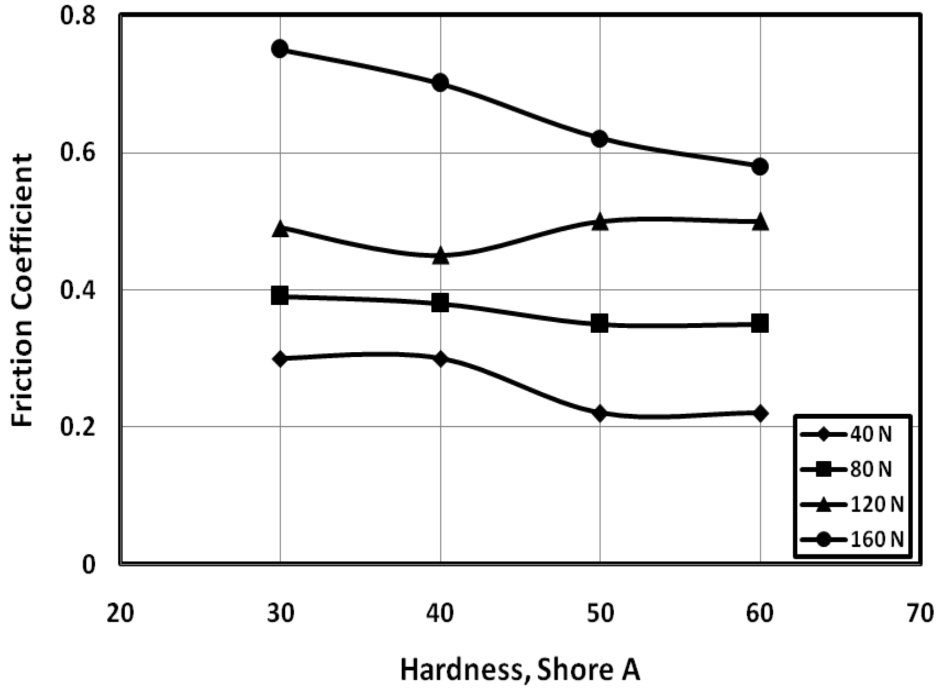

Fig. 10 Effect of hardness on friction coefficient for 5 mm thickness and 2 mm groove width.

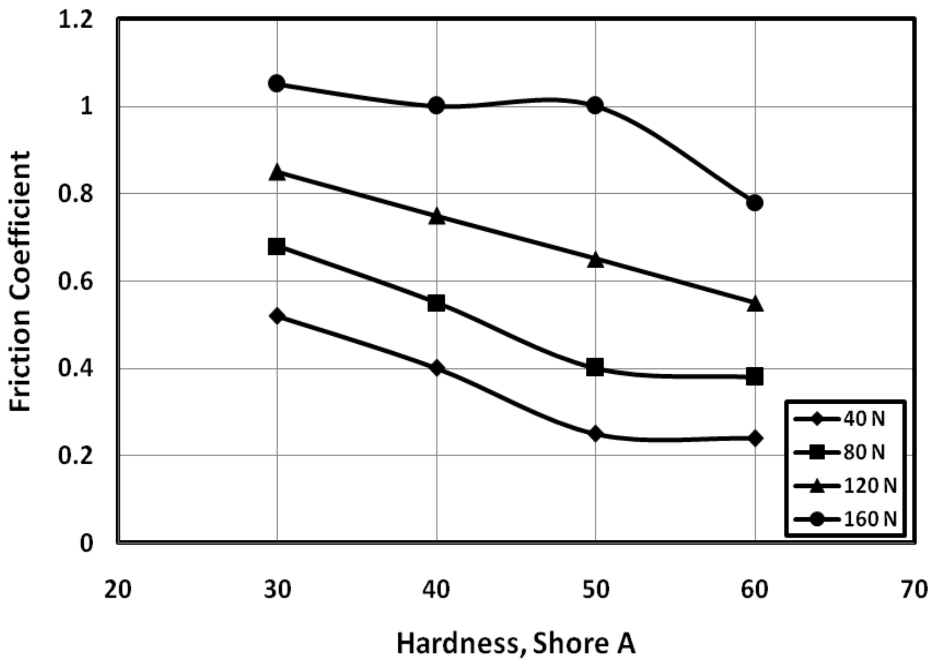

Fig. 11 Effect of hardness on friction coefficient for 5 mm thickness and 4 mm groove width.

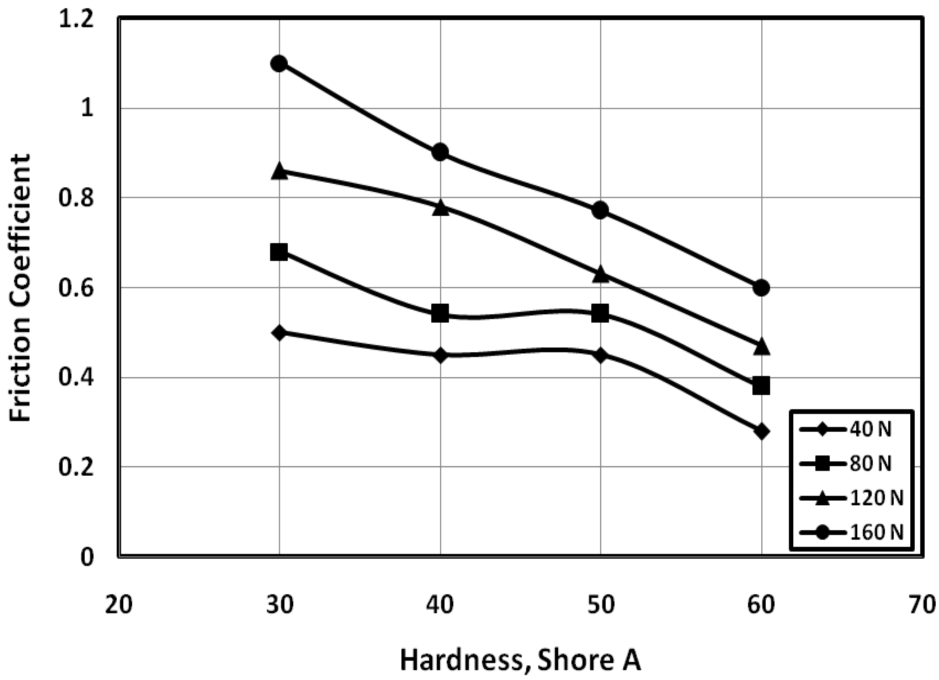

Fig. 12 Effect of hardness on friction coefficient for 5 mm thickness and 6 mm groove width.

The relationship between friction coefficient and rubber hardness is illustrated in Fig. 14. It is clearly shown that friction coefficient significantly decreased as rubber hardness increased. This behavior may be attributed to the decrease of deformation accompanied to the increased hardness of the rubber. As the load increased friction coefficient increased due to the increase of deformation. The maximum friction value reached to 1.3

at 30 shore A hardness. Also increasing groove width had a big effect on friction values compared to 3 mm and 5 mm rubber thickness and compared to 2 mm groove width.

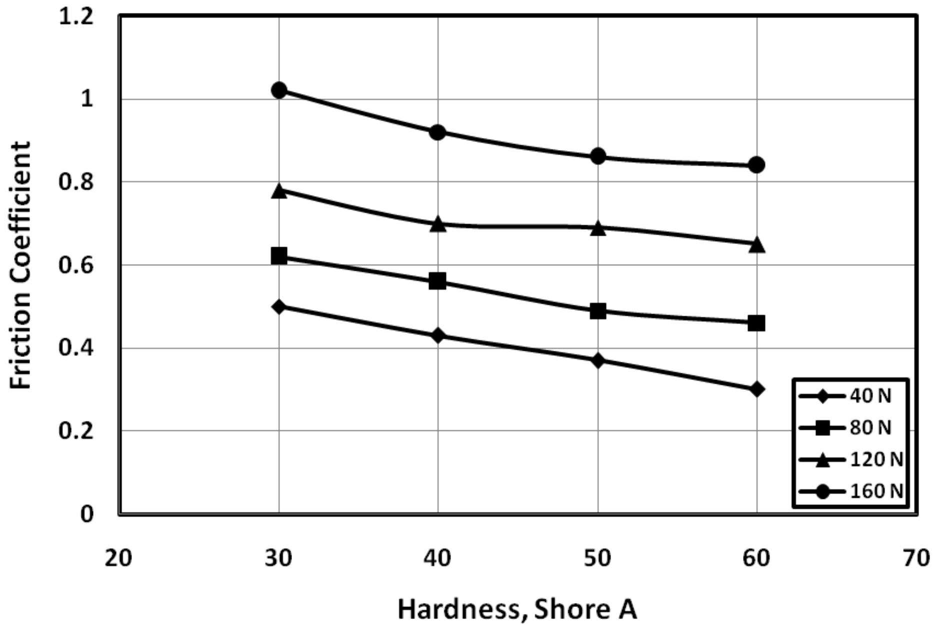

Fig. 13 Effect of hardness on friction coefficient for 8 mm thickness and 2 mm groove width.

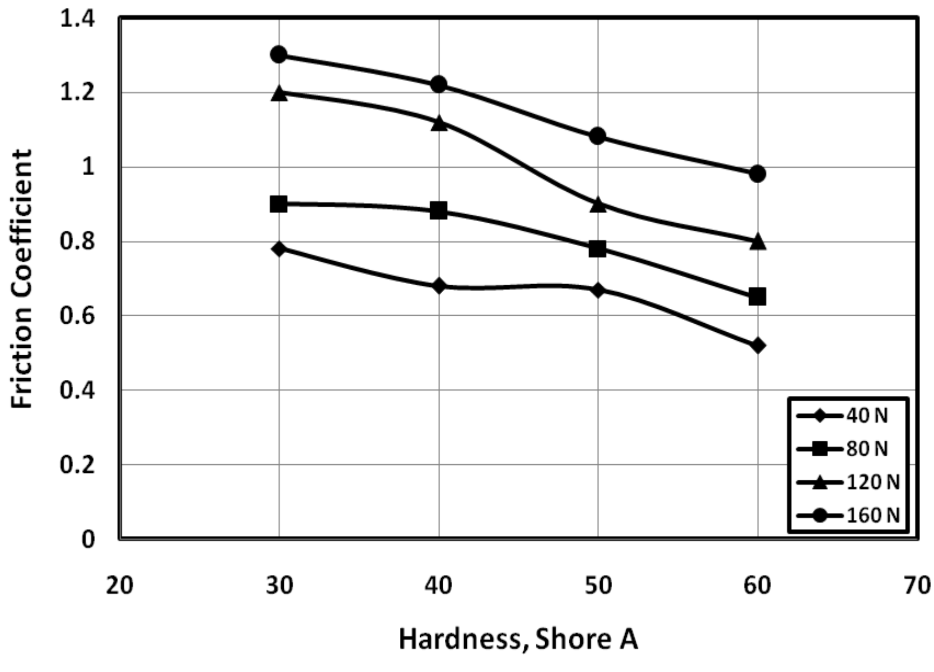

Fig. 14 Effect of hardness on friction coefficient for 8 mm thickness and 4 mm groove width.

The same trend shown in Fig. 14 was observed in Fig. 15. Decreasing deformation decreased friction coefficient with increasing in rubber hardness and increasing in normal load. Figure 15 recorded the highest friction coefficient values on dry sliding condition. This was due to high rubber thickness and the wide groove width which increased rubber deformation and consequently friction coefficient increased. It is recommended for walking on smooth flooring surfaces to use the treaded rubber instead of smooth rubber.

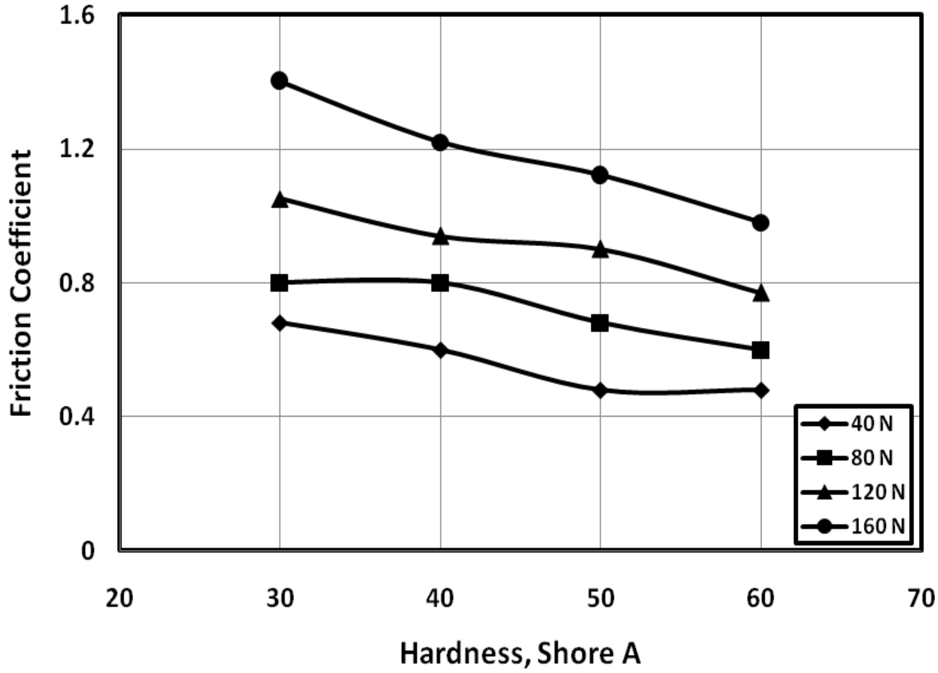

Fig.15 Effect of hardness on friction coefficient for 8 mm thickness and 6 mm groove width.

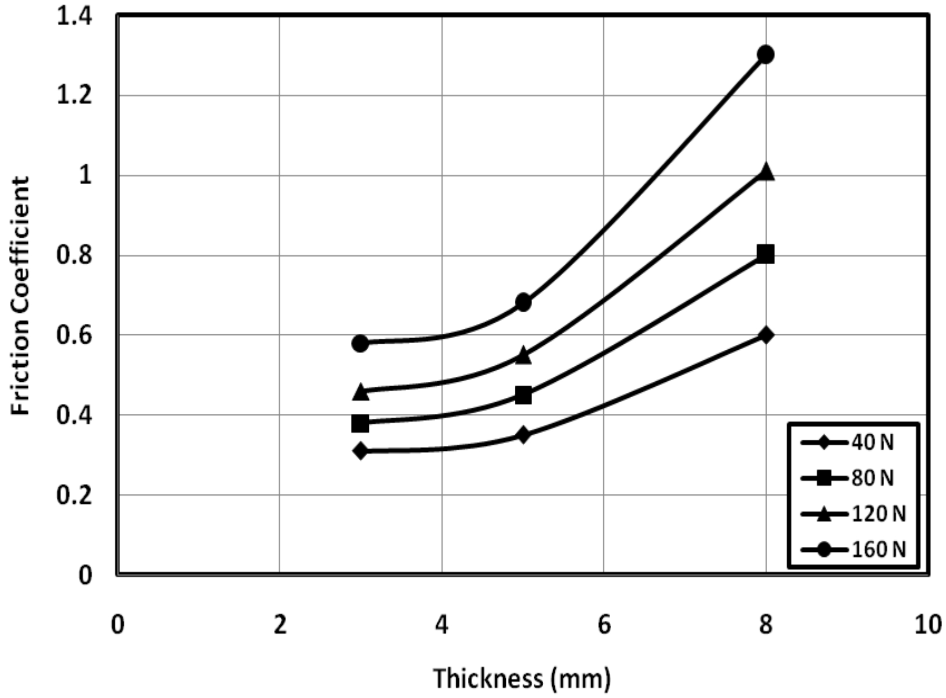

Fig. 16 Effect of rubber thickness on friction coefficient.

Effect of rubber thickness on friction coefficient is shown in Fig. 16. Experiment recorded remarkable increase in friction coefficient as rubber thickness increased due to the significant effect of rubber deformation. Also friction coefficient increased as normal load increased, where the maximum value of friction coefficient reached value above 1.3 at 8 mm thickness and 160 N normal load.

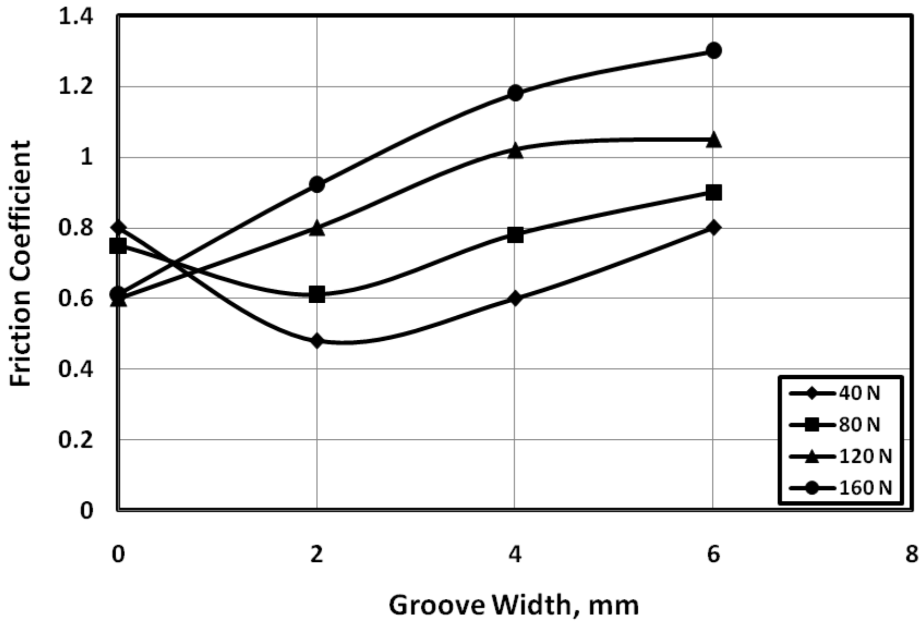

Fig. 17 Effect of Groove width on friction coefficient.

The relationship between friction coefficient and rubber thickness is illustrated in Fig. 17. It is clearly shown that friction coefficient remarkably increased with increasing thickness. This behavior may be attributed to the increased deformation accompanied to the increased groove width of the rubber. As the load increased friction coefficient increased due to the increase of deformation. The experiment recorded maximum value of friction coefficient (1.3) at 6 mm groove thickness and 160 N normal load. At smooth surface, friction coefficient decreased with increasing normal load due to trapping air bubbles in rubber surface gaps after that friction coefficient increased with increasing normal load for 2, 4 and 6 mm groove width due to the easy escape of air forming negative pressure which increased friction coefficient.

CONCLUSIONS

1. Friction coefficient decreased with increasing rubber hardness due to decrease of deformation.
2. Increasing rubber thickness increased deformation and friction coefficient.
3. Presence of grooves in rubber surface facilitated increasing deformation. Wider grooves improved friction values.
4. As groove width increased friction coefficient increased.
5. The highest friction coefficient values were recorded for rubber of 8 mm thickness, 6 mm groove width and 30 Shore A hardness. This was due to the high rubber thickness and the wide groove width which increased rubber deformation and consequently friction coefficient increased. It is recommended for walking on ceramic flooring surfaces to use the treaded rubber instead of smooth one.

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