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EFFECT OF FILLING MATERIALS ON THE FRICTION COEFFICIENT OF RECYCLED RUBBER FLOORINGS

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ABSTRACT
The effect of filling materials on the friction coefficient of recycled rubber floorings is discussed in the present work. Experiments were carried out by the sliding of the bare foot against the tested rubber tiles of different thickness. The friction coefficient was investigated. Experiments were carried out using a test rig designed and manufactured for the test. Loads were applied by foot up to 700 N. The normal and friction forces were measured to determine the static friction coefficient.

It was found that, at dry sliding, friction coefficient slightly increased with increasing the content of the filling materials. At water lubricated sliding, friction coefficient significantly decreased with increasing filling material content. Detergent decreased friction coefficient lower than water. The lowest friction values were observed for tiles filled by 70 wt. % polyurethane. As the load increased friction coefficient decreased. Presence of sand particles on the sliding surfaces caused significant friction increase. It was observed that for foot sliding against flooring materials wetted by water and contaminated by sand particles as the filling materials increased friction coefficient decreased. For rougher rubber tiles, at dry sliding, the effect of load on friction coefficient diminished as the filling material increased to 20 %. At water wetted sliding, friction coefficient significantly decreased with increasing filling material. Significant effect was observed for the load on the friction coefficient. In the presence of sand on the rubber surface, friction coefficient increased with increasing filling material content.

KEYWORDS
Friction coefficient, bare foot, recycled rubber, filling materials.

INTRODUCTION
The low static friction coefficient resulted from bare foot sliding on flooring tiles is the major factor in occupational walking accidents indoors. The presence of water and detergent drastically decreases the friction coefficient between bare foot and flooring tiles. The probability of slip increases and consequently accidents occur. The risks associated with slipping and falling are related to the materials of floor, contamination condition, and geometric design of the sole. 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.

The effect of the thickness on the frictional behaviour of polymerically bound recycled rubber filled by coloured polyurethane tiles was investigated, [6]. Experiments were carried out by the sliding of the bare foot against the tested rubber tiles of different thickness. The friction coefficient was tested. The frictional behaviour of rubber mats made of recycled rubber and filled by polyurethane of different hardness was tested, [7]. The research was carried out to have specific information about their friction coefficient and evaluate their performance in increasing friction coefficient at dry, water, detergent wetted flooring. The presence of dust contaminating the floorings was tested. It was found that at dry sliding, friction coefficient slightly decreased with increasing the hardness of the rubber mats. As the load increased friction coefficient decreased. Sliding against water as well as detergent wetted rubber mats showed the same trend observed for dry sliding. In the presence of sand particles, friction coefficient significantly decreased with increasing the hardness for lower loads. Compared to ceramic and polymeric tiles rubber mats showed the highest friction in all the sliding conditions tested. Besides, sliding against ceramic tiles showed very low friction values which resemble an increasing incidence of slip and falling.

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, [8]. This was found in the friction measurements under wet conditions. 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, [9].

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, [10]. 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, [11 - 14]. It was observed that, dry sliding of the rubber test specimens displayed the highest value of friction coefficient. For water lubricated ceramics, the value of the friction coefficient decreased compared to dry sliding. For oil lubricated ceramic, friction coefficient decreased with increasing height of the grooves introduced in the rubber specimens. 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: the material and surface geometry of the footwear and floor, floor contamination conditions and even the slipmeter used, [15 - 17]. Investigators have concentrated the friction coefficient measurements on liquid contaminated floors because most slip/fall incidents occur on the surfaces of such floors, [18 - 20]. 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, [21]. 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.

In the present work, rubber mats of different hardness were tested through sliding of bare foot against them to determine friction coefficient at dry, water, detergent and sandy sliding conditions.

EXPERIMENTAL

Experiments were carried out using a test rig designed and manufactured to measure the friction coefficient displayed by the sliding of the bare foot against the recycled rubber tiles through measuring the friction and normal forces. The tested tiles were placed in a base supported by two load cells, the first can measure the horizontal force (friction force) and the second can measure the vertical force (normal force). Friction coefficient was determined by the ratio between the friction and normal force.

The tested rubber tiles were made of recycled rubber filled by coloured polyurethane, Table 1. Their hardness ranged between 52 – 60 Shore A. The tiles in form of 300 × 300 mm and 5 mm thickness were adhered to the base of the test rig. Two groups of the tiles were tested the first group had 4.7 µm surface roughness, R_a, while the second had 16.7 µm surface roughness, R_a. The tested tiles were made of recycled rubber filled by polyurethane of contents ranging from 0 – 70 and 0 - 35 wt. % for the first and second groups respectively. Friction test was carried out using bare foot applying variable

forces up to 700 N. Friction coefficient was plotted against load then friction values were extracted from the figures at 200, 400 and 600 N. The bare foot was loaded against dry, water and water + 1.0 vol. % detergent wetted mat. Water was replenished on the tested mat, where the amount of water for each replenishment was 300 ml to form consistent water film covering the mat surface. In the water–detergent condition, a 1.0 vol. % detergent solution was applied to the tiles. After each measurement, all contaminants were removed from the tiles surface and bare foot using absorbent papers. Both the bare foot and tested tiles were then rinsed using water and dried by using hair dryer after the cleaning process.

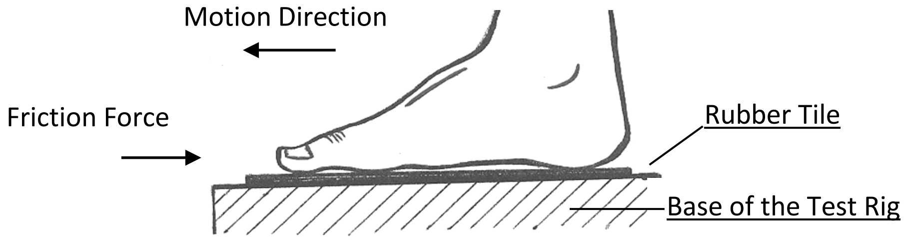
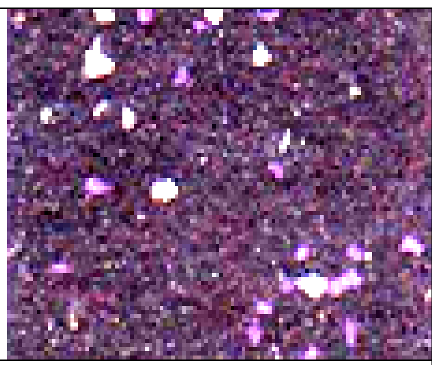
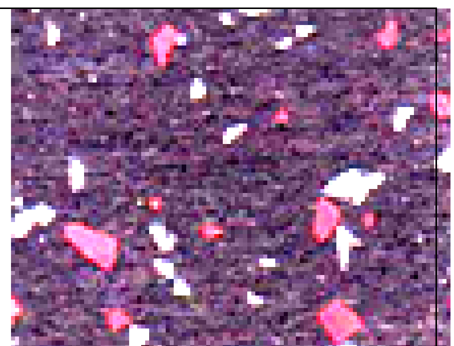
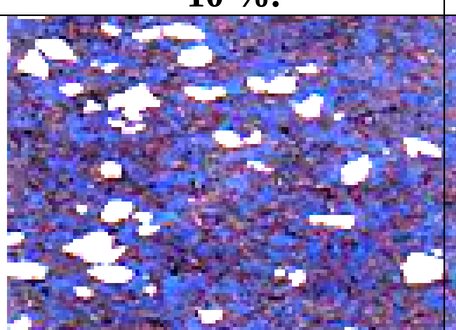
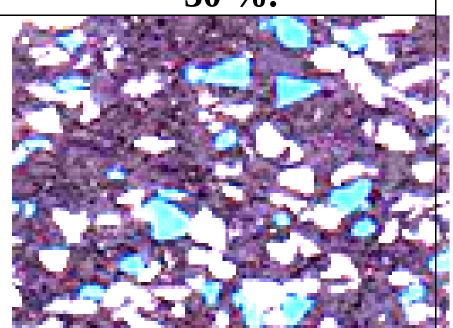


Fig. 1 Arrangement of the sliding conditions.

Table 1 Tested tiles of different contents of filling materials.

	
10 %.	**30 %.**
	
50 %.	**70 %.**

RESULTS AND DISCUSSION

The results of friction coefficient of foot sliding against the tested flooring materials (V) are shown in Figs. 2 – 6. This type had a constant thickness (5 mm) and was filled by coloured polyurethane. The surface roughness is 4.7 µm (R_a). Figure 2 shows that, at dry sliding, friction coefficient slightly increased with increasing the content of the filling materials. The increase offered by the filling material confirmed the suitability of that material for tribological purposes.

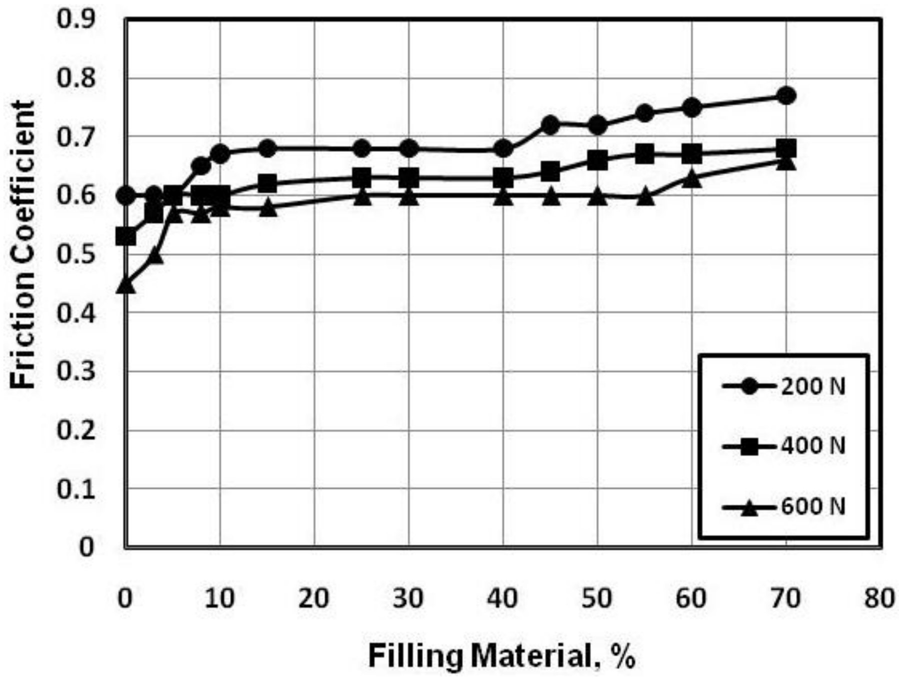


Fig. 2 Friction coefficient of foot sliding against dry flooring materials.

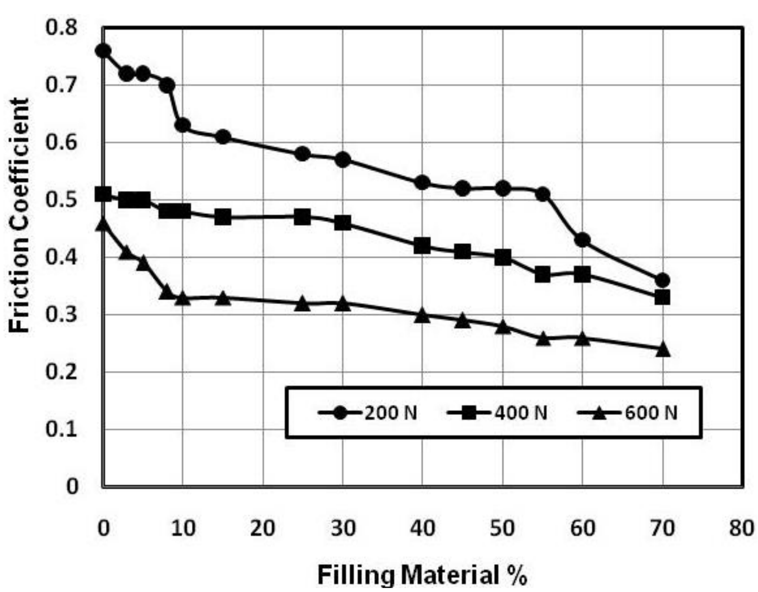


Fig. 3 Friction coefficient of foot sliding against water lubricated flooring materials.

At water lubricated sliding, friction coefficient significantly decreased with increasing filling material content, Fig. 3. At 200 N, friction coefficients were 0.76 and 0.36 at 0 and 70 wt. % filling material content. This behaviour could limit the application of that type in water lubricated surfaces. It seems that the rubber base material contained porosity which absorbed water and the contact was partially foot/rubber and partially covered by water film. As the content of the filling material increased the water film increased and consequently friction coefficient decreased.

Detergent decreased friction coefficient lower than water, Fig. 4. It seems that the relatively strong adhesion of detergent molecules into the sliding surfaces was responsible for that behaviour. Friction coefficient drastically decreased with increasing filling materials, where the lowest friction values were observed for tiles filled by 70 wt. % polyurethane. As the load increased friction coefficient decreased.

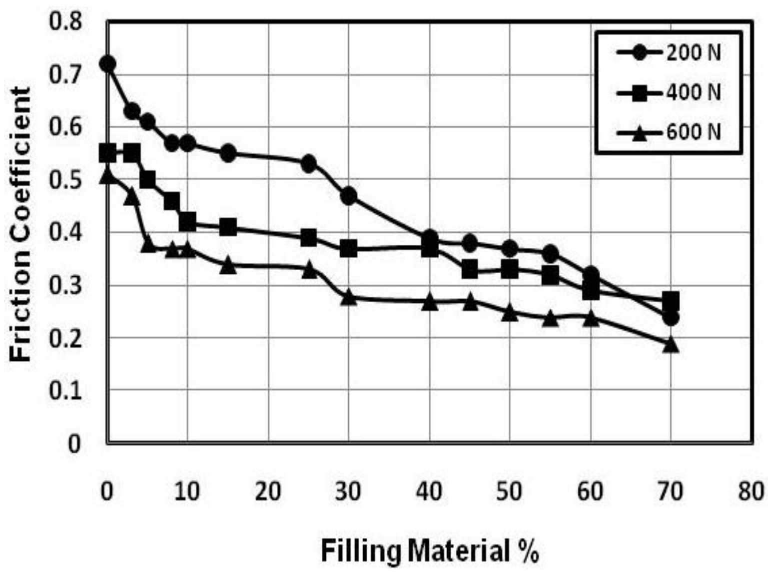


Fig. 4 Friction coefficient of foot sliding against detergent lubricated flooring materials.

Presence of sand particles on the sliding surfaces caused significant friction increase, Fig. 5. It seems that filling material was more able to embed sand particles more than the base material. Relatively low friction coefficient was observed for the base material, where the values were 0.15, 0.25 and 0.17 at 200, 400 and 600 N respectively. For tiles containing 70 % filling material higher friction values were observed (0.38, 0.36 and 0.52 at 200, 400 and 600 N respectively).

Friction coefficient of foot sliding against flooring materials wetted by water and contaminated by sand particles is shown in Fig. 6. Presence of water decreased the ability of sand particles to be embedded in the tested rubber surfaces so that the sand particles tended to roll than to embed. Besides, water washed sand particles away the contact area so that water film covered the contact area. As the filling materials increased friction coefficient decreased.

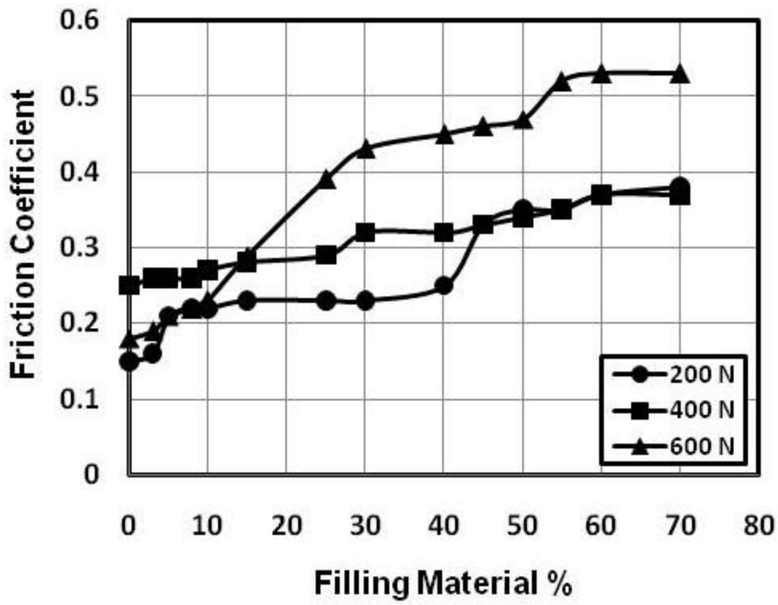


Fig. 5 Friction coefficient of foot sliding against flooring materials contaminated by sand particles.

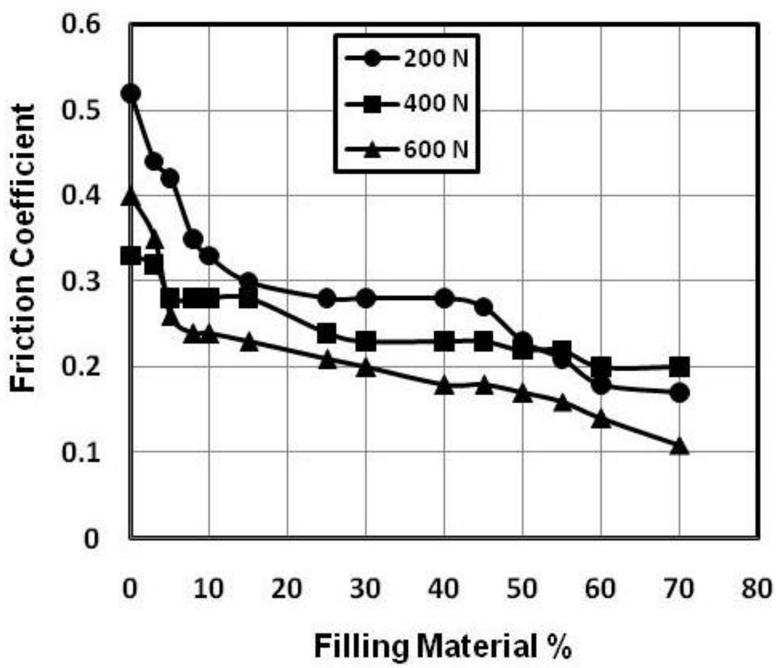


Fig. 6 Friction coefficient of foot sliding against flooring materials wetted by water and contaminated by sand particles.

The results of the friction coefficient of foot sliding against the tested flooring materials of relatively rougher surface are shown in Figs. 7 – 11. The content of the filling materials was ranging between 0 – 35 wt. %. At dry sliding, friction coefficient slightly increased with increasing filling material, Fig. 7. This type of tested rubber tiles is more rougher than the first group shown in Figs. 2 – 6. The surface roughness for the second

group is 16.7 µm (R_a). It is noted that the effect of load on friction coefficient diminished as the filling material increased to 20 %. This behavior can be useful for using this type at heavy loads.

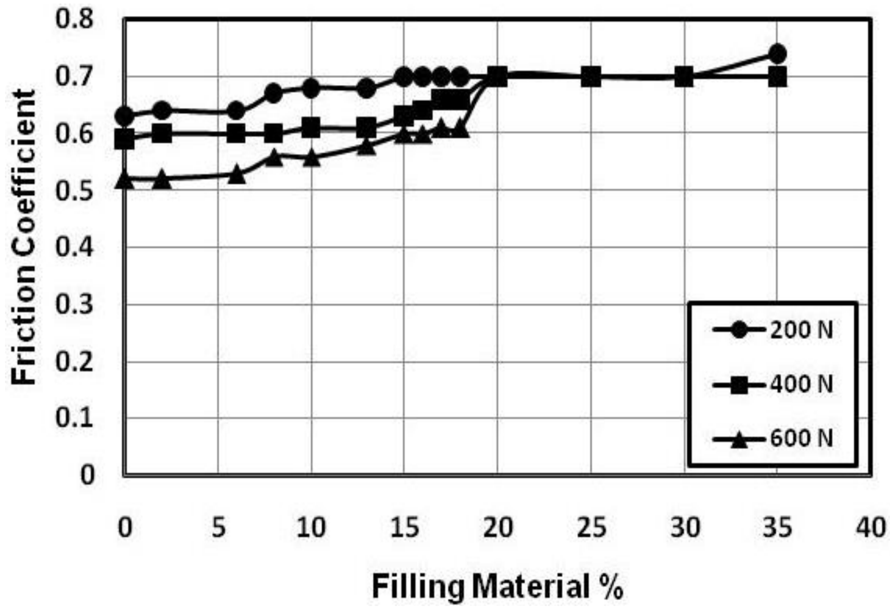


Fig. 7 Friction coefficient of foot sliding against dry flooring materials.

At water wetted sliding, friction coefficient significantly decreased with increasing filling material, Fig. 8. The base rubber material showed high friction coefficient as a result of the porosity which absorb the water film formed on the sliding surface. The effect of load on friction coefficient was significant. This behavior might be attributed to the rough surface which stored water in the valleys of the roughness.

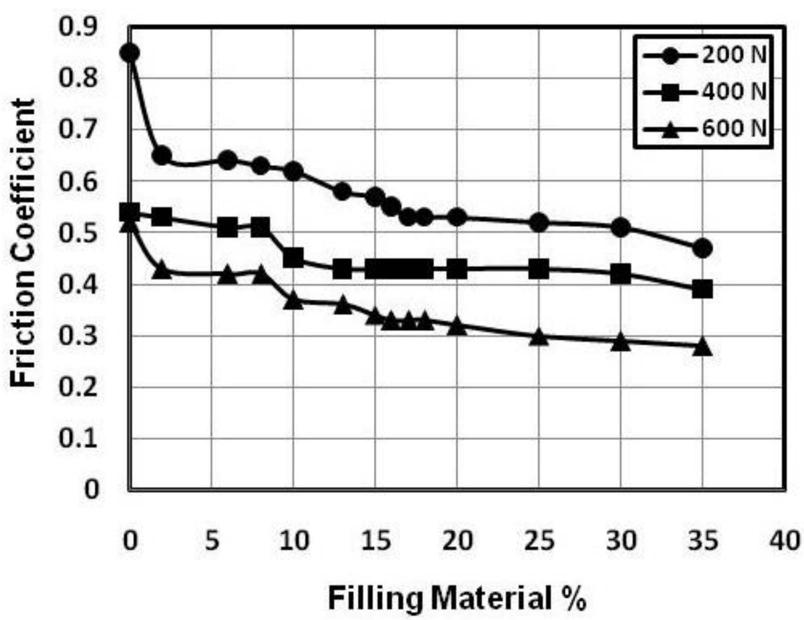


Fig. 8 Friction coefficient of foot sliding against water lubricated flooring materials.

The same trend was observed for the sliding against detergent lubricated rubber, Fig. 9. Significant effect was observed for the load on the friction coefficient, where friction coefficient significantly decreased with increasing load. As the content of the filling materials increased friction coefficient decreased.

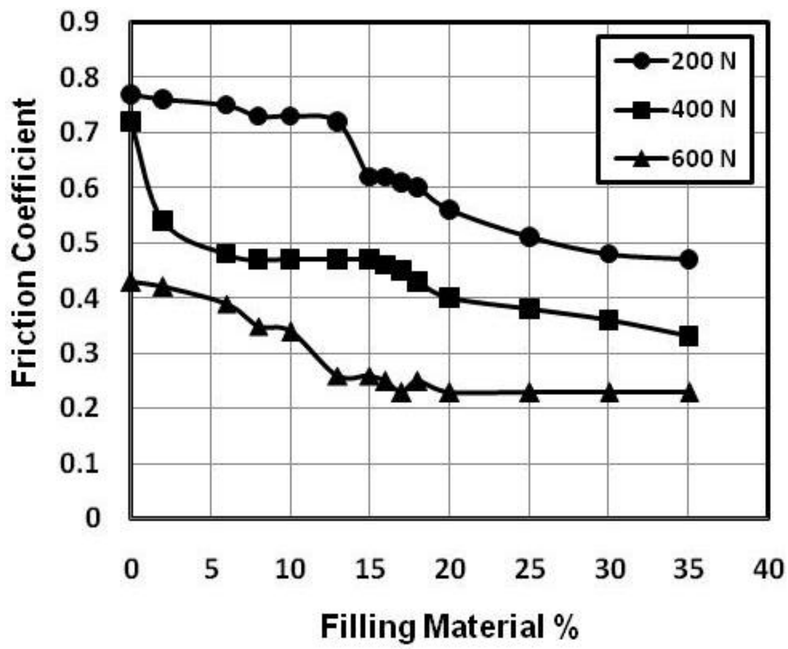


Fig. 9 Friction coefficient of foot sliding against detergent lubricated flooring materials.

In the presence of sand on the rubber surface, Fig. 10, friction coefficient increased with increasing filling material content. That effect was clearly noticed for the highest load (600 N), where sand particles were able to embed in the contact area of the filling material of higher plasticity. The highest friction value (0.53) was observed at 600 N for 35 % filling material content. The based rubber material showed lower embedment than the filling material so that friction coefficient showed relatively lower values.

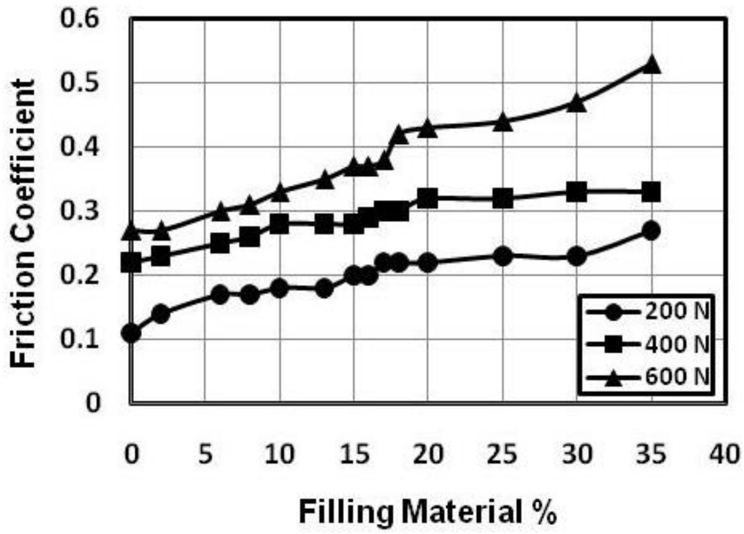


Fig. 10 Friction coefficient of foot sliding against flooring materials contaminated by sand particles.

Friction coefficient displayed by foot sliding against flooring materials wetted by water and contaminated by sand particles, showed slight increase compared to that observed in the condition of the presence of sand particles only, Fig. 11. It seems that water washed sand particles away the contact area.

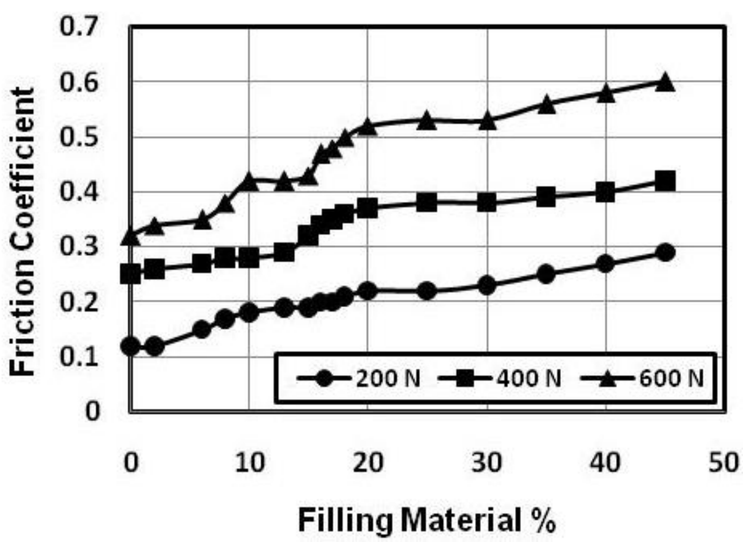


Fig. 11 Friction coefficient of foot sliding against flooring materials wetted by water and contaminated by sand particles.

CONCLUSIONS

1. At dry sliding, friction coefficient slightly increased with increasing the content of the filling materials.

2. At water lubricated sliding, friction coefficient significantly decreased with increasing filling material content.

3. Detergent decreased friction coefficient lower than water. The lowest friction values were observed for tiles filled by 70 wt. % polyurethane. As the load increased friction coefficient decreased.
4. Presence of sand particles on the sliding surfaces caused significant friction increase.
5. As for foot sliding against flooring materials wetted by water and contaminated by sand particles as the filling materials increased friction coefficient decreased.
6. For rougher rubber tiles, at dry sliding, the effect of load on friction coefficient diminished as the filling material increased to 20 %.
7. At water wetted sliding, friction coefficient significantly decreased with increasing filling material.
8. Significant effect was observed for the load on the friction coefficient.
9. In the presence of sand on the rubber surface, friction coefficient increased with increasing filling material content.

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