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FRICTION COEFFICIENT OF RECYCLED RUBBER TILES OF DIFFERENT POROSITY

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ABSTRACT

The present study discusses the frictional behaviour of porous recycled rubber used for a wide variety of architectural applications as flooring tiles. This type of flooring tiles, of the relatively high resilience, are used in schools, boutiques, hospitals, offices, conference rooms, homes, trade fair stands and homes for the aged. Experiments were carried out by the sliding of the bare foot and rubber footwear against the tested rubber tiles of different porosity, where friction coefficient was tested. A test rig was designed and manufactured for the test. Loads were applied by foot up to 300 N. The normal and friction forces were measured to determine the static friction coefficient.

Based on the experimental observations, it was found that friction coefficient displayed by bare foot sliding against dry recycled rubber tiles slightly increased with increasing force reduction ratio. It seems that the presence of pores inside the rubber matrix is responsible for the extra deformation displayed by the porous recycled rubber and consequently the contact area between the foot and the tested flooring materials increased. When rubber shoe slid against dry rubber tiles friction coefficient significantly increased with increasing the force reduction ratio due to the increased deformation of the rubber tiles. No significant effect was observed for increasing the normal load.

Besides, sliding against water wetted rubber tiles showed significant decrease in friction coefficient. This behavior can be attributed to the porosity of the rubber which works as water reservoirs storing the water and feeding it up to the contact area when the normal load is applying on the rubber tiles. Friction coefficient displayed by shoe showed higher friction coefficient. In the presence of detergent between the sliding surfaces friction coefficient drastically decreased to values lower than that displayed by water. Rubber shoe showed significant friction increase compared to that observed for bare foot. In addition, drastic friction decrease was observed for bare foot sliding against oil lubricated tiles. According to the European legislations the sliding condition can be considered as very slippery. Friction coefficient displayed by shoe displayed relatively higher friction values than bare foot.

KEYWORDS
Friction coefficient, bare foot, rubber footwear, recycled rubber tiles.

INTRODUCTION

Flooring tile made of recycled rubber was tested to reduce the risk of slip and fall in schools, boutiques, hospitals, offices, conference rooms, homes, trade fair stands and homes for the aged should be reduced. Ceramic surfaces usually promote slips and occasionally lead to indoor accidents. The frictional behviour of rubber mats made of recycled rubber and filled by polyurethane of different hardness was tested, [1]. 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. 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.

The frictional behaviour of flooring tiles made of recycled rubber was discussed, [2 - 4]. Experiments were carried out by the sliding of the bare foot against the tested rubber tiles of different thickness, [2], where friction coefficient was tested. It was found that at dry sliding, friction coefficient slightly increases with increasing rubber tile thickness and decreases with increasing load. At water and detergent lubricated sliding, friction coefficient decreases with increasing flooring thickness. In the presence of sand particles on the sliding surfaces, friction coefficient is much influenced by the ability of the particles to embed into the rubber surfaces. The embedment of sand particles in the flooring tiles increased with increasing tile thickness. The effect of filling materials on the friction coefficient of recycled rubber floorings was investigated, [3]. 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. The effect of surface roughness was explained, [4]. Surface roughness had insignificant effect on the frictional behaviour. In the presence of water on the sliding surface, rough surface displayed higher friction values than the smooth one. Rough surfaces of rubber tiles filled by polyurethane showed higher friction coefficient than the smooth ones at dry sliding. Detergent lubricated surfaces displayed higher friction coefficient for smooth rubber. In the presence of sand particles, friction coefficient significantly increased for the both smooth and rough surfaces. Rough surfaces displayed higher friction values than smooth ones. Finally, drastic friction decrease for smooth surface was noticed in the presence of water contaminated by sand particles.

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, [5]. 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, [6], but this is only a simplified assumption.

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, [7 - 11]. 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, 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, [12 - 14]. Investigators have concentrated the friction coefficient measurements on liquid contaminated floors because most slip/fall incidents occur on the surfaces of such floors, [15 - 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, [18]. 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.

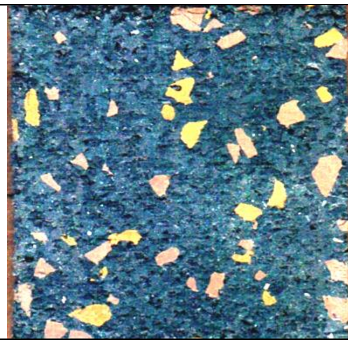
In the present work, recycled rubber tiles of different porosity were tested through sliding of bare foot and smooth rubber footwear against them to determine friction coefficient at dry, water, detergent and oily sliding conditions.

EXPERIMENTAL

The tested tiles were made of recycled rubber, Table 1. Their hardness was ranging from 60 to 65 Shore A. The tiles, in form of 300 × 300 mm and 10 mm thickness, were adhered to the base of the test rig. Eight groups of the tested tiles of different values of force reduction, (6, 8, 10, 12, 16, 20, 39 and 44 %), were selected. The force reduction variation depends on the porosity of the rubber matrix during molding. Friction test was carried out using bare foot and footwear of smooth rubber sole by applying variable forces up to 300 N. Friction coefficient was plotted against load then friction values were extracted from the figures at 50, 100, 150 and 200 N. The bare foot and footwear were loaded against dry, water, water + 1.0 vol. % detergent and oil lubricated tiles. The amount of water for each experiment was 300 ml to form consistent water film covering the tile surface. After each measurement, all contaminants were removed from the tiles surface, bare foot and rubber footwear using absorbent papers. Bare foot, footwear and

tested tiles were then rinsed using water and dried by using hair dryer after the cleaning process.

Table 1 The tested tiles of different force reduction ratio.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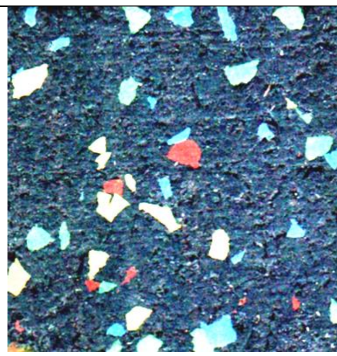	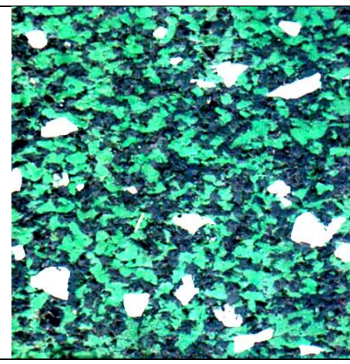
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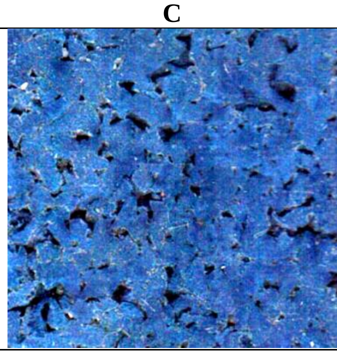	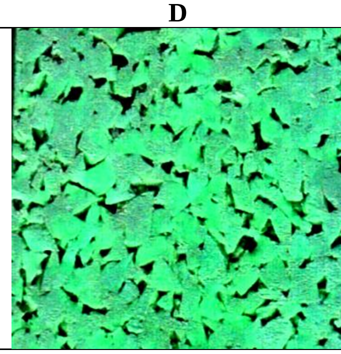
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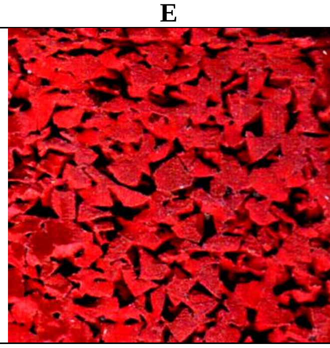	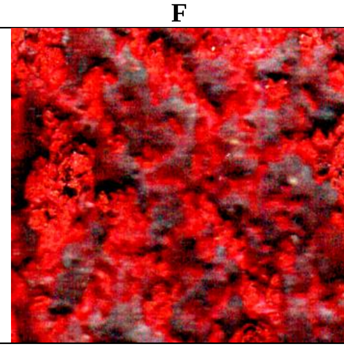
G	**H**

Experiments were carried out using a test rig designed and manufactured to measure friction coefficient displayed by the sliding of the bare foot against the tested rubber tiles through measuring the friction and normal force. The arrangement of the test rig is shown in Fig. 1. 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 load). Friction coefficient was determined by the ratio between friction and normal load.

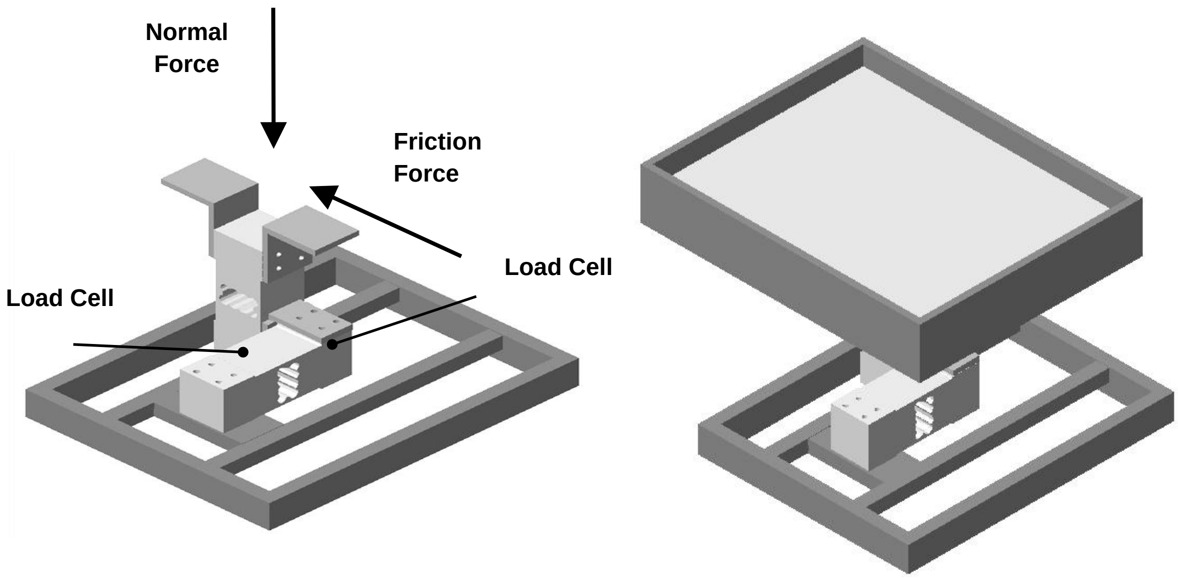

Fig. 1 Arrangement of the test rig.

RESULTS AND DISCUSSION

Friction coefficient displayed by bare foot sliding against dry recycled rubber tiles is shown in Fig. 2. Friction coefficient slightly increased with increasing force reduction ratio. Based on the fact that the force reduction of the recycled rubber increases as the porosity of the recycled rubber increases. The presence of pores inside the rubber matrix is responsible for the extra deformation displayed by the porous recycled rubber and consequently the contact area between the foot and the tested flooring materials increased. As the load increased friction coefficient decreased.

Significant increase in friction coefficient was observed when rubber shoe slid against dry rubber tiles. Friction coefficient increased with increasing the force reduction ratio, Fig. 3, due to the increased deformation of the rubber tiles. No significant effect was observed for increasing the normal load. Values of friction coefficient represented very safe values for rubber of high force reduction ratio. Footwear showed relatively higher friction coefficient than bare foot. It is well known rubber tiles of higher force reduction are suitable to be used in indoors floorings in schools, boutiques, hospitals, offices, conference rooms, homes, trade fair stands and homes for the aged to reduce the risk of fall accidents. Based on the present study those tiles are convenient to reduce slip accidents.

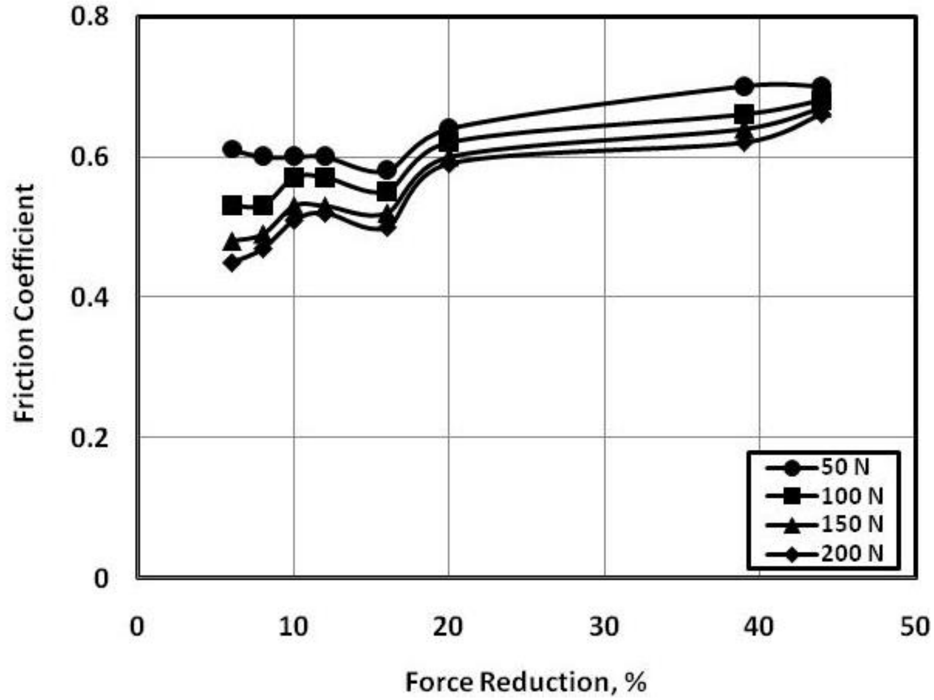

Fig. 2 Friction coefficient displayed by bare foot sliding against dry recycled rubber tiles.

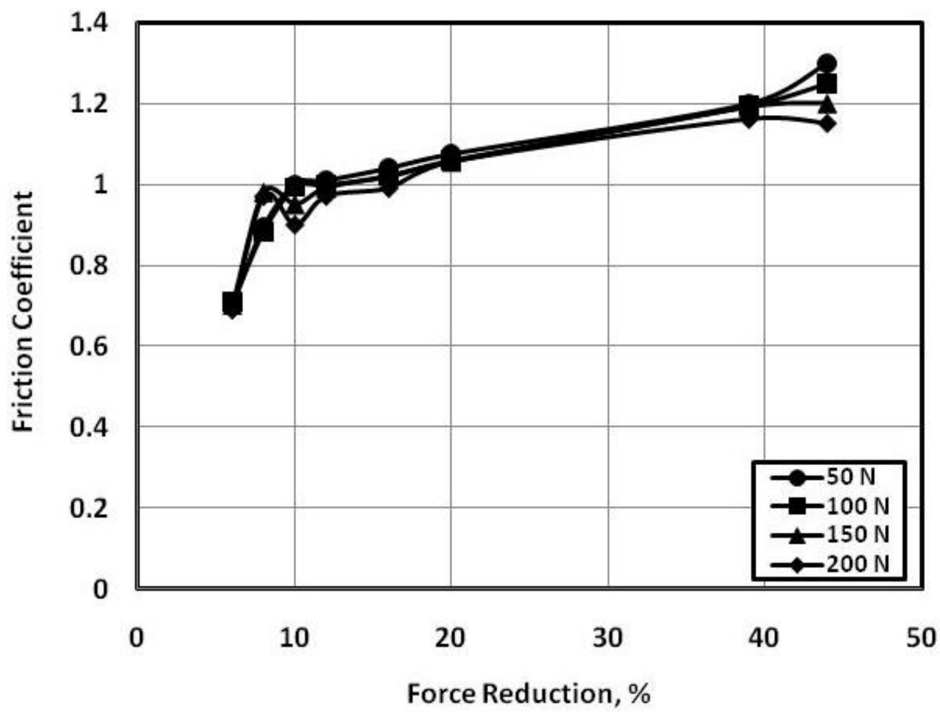

Fig. 3 Friction coefficient displayed by rubber shoe sliding against dry recycled rubber tiles.

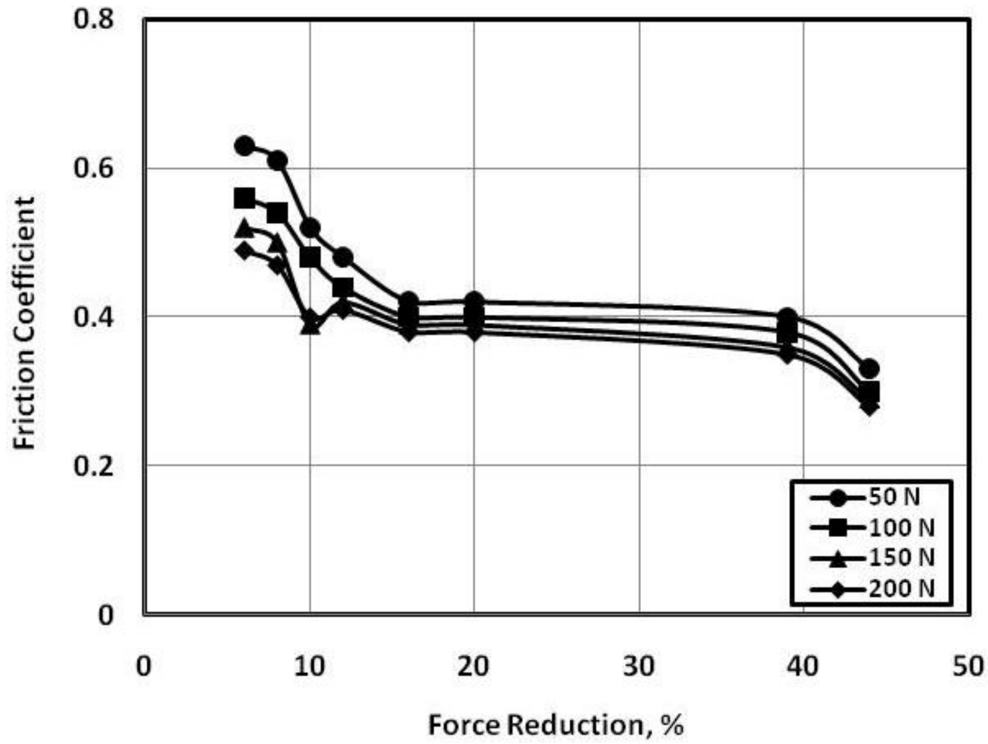

Fig. 4 Friction coefficient displayed by bare foot sliding against water wetted recycled rubber tiles.

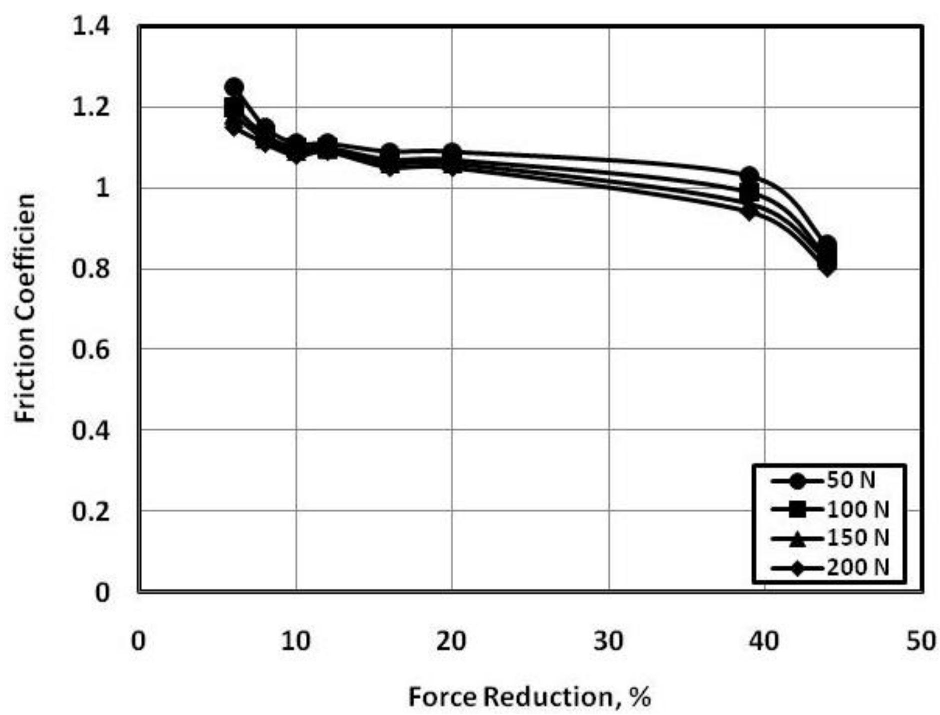

Fig. 5 Friction coefficient displayed by shoe sliding against water wetted recycled rubber tiles.

Sliding against water wetted flooring materials showed significant decrease in friction coefficient, Fig. 4. Generally, friction coefficient decreased with increasing the force reduction ratio of the flooring materials. This behavior can be attributed to the porosity of the rubber which work as water reservoirs storing the water. As the normal load is applying into the rubber tiles water leaks up the contact area and forms a uniform film on the contact area. In this condition, a part of the contact area would be performed under dry friction and the other would be water lubricated. Minimum values of friction coefficient were 0.33, 0.30, 0.29 and 0.28 at load of 50, 100, 150 and 200 N respectively. Referring to the values, it should be noted that they were lower than that displayed by dry sliding.

Friction coefficient displayed by shoe sliding against water wetted recycled rubber tiles is shown in Fig. 5. Rubber test specimens of relatively low force reduction ratio showed higher friction coefficient. As the porosity of the rubber increased friction coefficient slightly decreased. The minimum friction values were displayed by rubber of the highest force reduction ratio.

In the presence of detergent between the sliding surfaces, Fig. 6, friction coefficient drastically decreased to values lower than that displayed by water Fig. 4. As the force reduction ratio increased friction coefficient decreased and changed the condition into slippery sliding. This behaviour can be attributed to the strong adhesion of the detergent molecules into the bare foot. Rubber shoe sliding against recycled rubber showed significant friction increase compared to that observed for bare foot. Generally, friction coefficient values exceeded 0.6. This behavior is explained on the basis that smooth rubber shoe squeezed the detergent out of the contact area, Fig. 7, where the contact would be partially rubber/rubber contact. Besides, it seems that the adhesion of detergent molecules into the rubber surfaces was not enough strong, as was for bare foot, to form a detergent film on the contact area. Besides, the electric static charge generated from the friction of bare foot with rubber tiles enhanced the adhesion of the detergent molecules into the sliding surfaces. In condition of the rubber/rubber contact the electric static charge was weaker due to the similarity of the materials of the sliding surfaces. Detergent molecular structures consist of a long hydrocarbon chain and a water soluble negative ionic group. They are alky sulfates or surfactants (from surface active agents) which are generally known as alkyl benzene sulfonates. The detergent molecules must have some polar parts to provide the necessary water solubility. The polar part of the molecule consists of three alcohol groups and an ester group. The polarity of the detergent molecules might be responsible for friction increase.

Drastic friction decrease was observed for bare foot sliding against oil lubricated tiles, Fig. 8. According to the European legislations this sliding condition could be considered as very slippery. The very low friction values confirm the formation of a thin oil film on the sliding surfaces. They are attributed to the ability of the porous recycled rubber to absorb oil and feed it into the contact area as the normal load is applied. As the porosity increased friction coefficient decreased. This observation confirms the dangerous use of such materials in environment where oil is contaminating flooring tiles. Although friction coefficient displayed by shoe sliding against oil lubricated recycled rubber tiles

showed higher friction values than that displayed by bare foot, Fig. 9, the sliding condition was still very slippery.

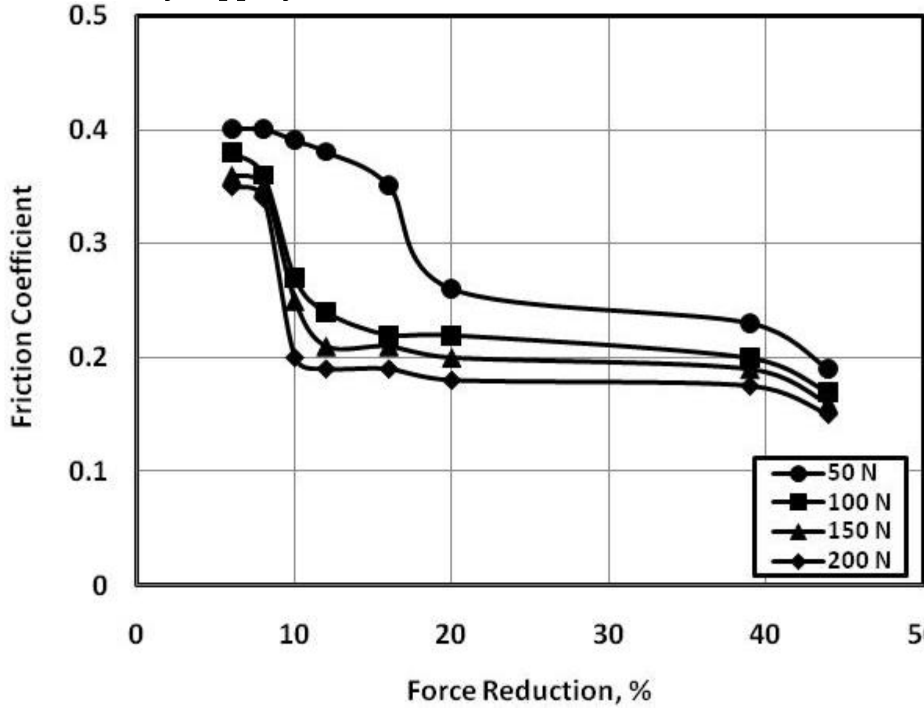

Fig. 6 Friction coefficient displayed by bare foot sliding against detergent wetted recycled rubber tiles.

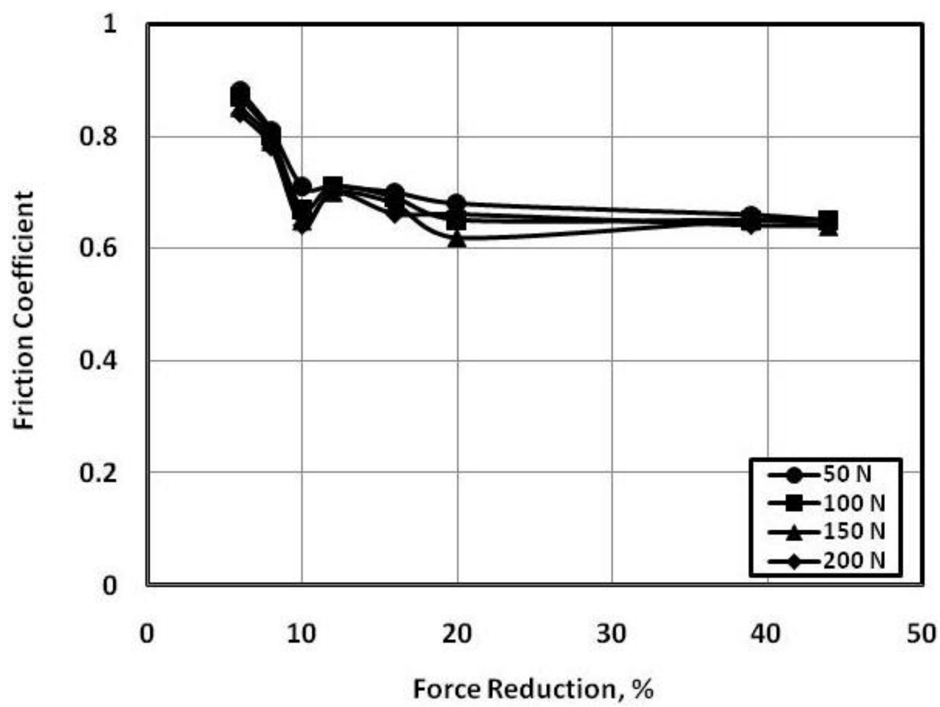

Fig. 7 Friction coefficient displayed by shoe sliding against detergent wetted recycled rubber tiles.

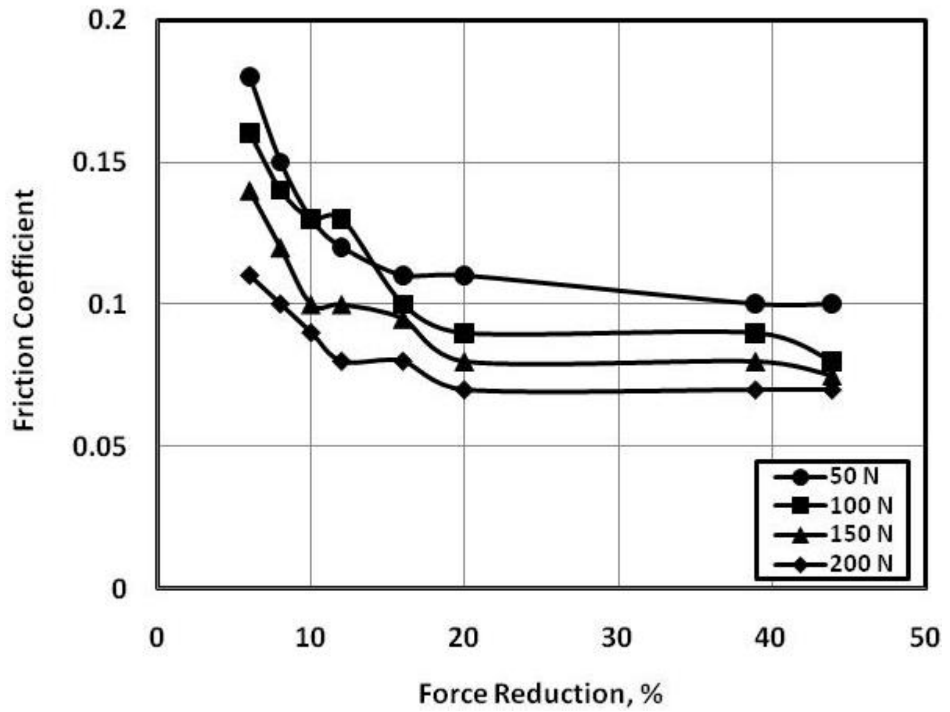

Fig. 8 Friction coefficient displayed by bare foot sliding against oil lubricated recycled rubber tiles.

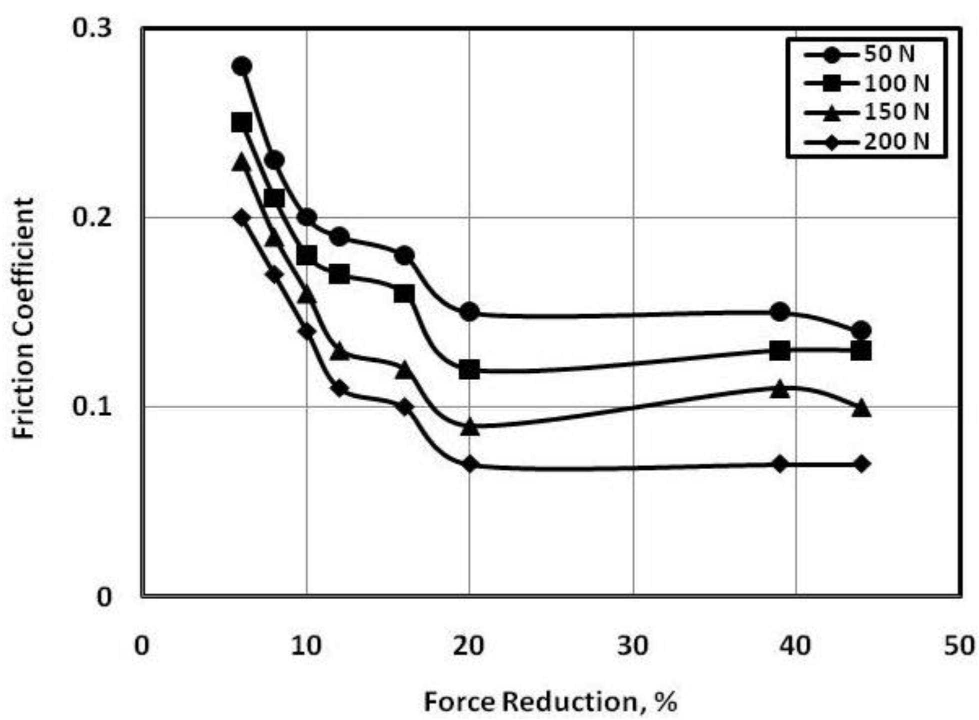

Fig. 9 Friction coefficient displayed by shoe sliding against oil lubricated recycled rubber tiles.

It is well known that the static coefficient of friction of 0.5 was recommended as the slip-resistant standard for unloaded, normal walking conditions [17], while higher static coefficient of friction values 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. 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. Rubber tends to provide 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. The above characteristic frictional behaviour of rubber was greatly disturbed when fluid film separating the two sliding surfaces.

CONCLUSIONS

1. Friction coefficient displayed by bare foot sliding against dry recycled rubber tiles slightly increased with increasing force reduction ratio. As the load increased friction coefficient decreased. Rubber footwear showed relatively higher friction coefficient than bare foot.

2. Sliding against water wetted flooring materials showed significant decrease in friction coefficient with increasing the force reduction ratio of the rubber tiles. Friction coefficient displayed by shoe sliding against water wetted recycled rubber tiles showed higher friction coefficient.

3. In the presence of detergent on the sliding surfaces, friction coefficient drastically decreased to values lower than that displayed by water. Rubber shoe showed significant friction increase compared to that observed for bare foot.

4. Drastic friction decrease was observed for bare foot sliding against oil lubricated tiles. Friction coefficient displayed by shoe sliding against oil lubricated recycled rubber tiles displayed relatively higher friction values than bare foot.

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