EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 10, NO. 3, JULY 2013, pp. 1 - 12 **ISSN 2090 - 5882**

FRICTION COEFICIENT OF SEMI-SPHERICAL RUBBER PROTRUSIONS SLIDING AGAINST RUBBER

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ABSTRACT
It is necessary to reduce slip and fall in bathrooms, workshops, kid gardens, halls and walking yards. The present work aims to test 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. The tested semi-spherical rubber protrusions were aimed to be used as protrusions in the rubber mat. They were of diameters ranging from 29 to 42 mm. The hardness ranged from 37.1 to 75.3 Shore A. Tests were carried out using test rig designed for that purpose. Loads were applied by wear foot of smooth rubber surface up to 250 N. The normal and friction forces were measured to determine the static friction coefficient.

It was found that friction coefficient decreased with increasing normal load and hardness. Friction coefficient drastically decreased with increasing hardness when sliding against water, detergent and oil lubricated rubber. It showed significant increase with increasing the diameter of the semi-spherical protrusions. This behavior depended on the ability of the semi-spherical protrusion to allow the water to escape from the contact area, where the contact is between rubber against rubber interfaces. Sliding against detergent wetted rubber showed relatively higher friction coefficient up to 0.25 at protrusions diameter of 42 mm. This is a promising result and can be used in application to avoid slip on detergent wetted surfaces.

KEYWORDS
Friction coefficient, rubber floor mat, semi-spherical protrusions, dry, water, detergent, oil.

INTRODUCTION
Slip and fall in bathrooms, workshops, kid gardens, halls and walking yards are caused by the low static friction coefficient displayed by foot sliding on flooring tiles. The presence of water and detergent drastically decreases the friction coefficient and consequently slip increases and accidents occur. The risks associated with slipping and falling is related to the materials of floor, contamination condition, and geometric design of the sole. 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, [1]. 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, [2]. 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, [3]. The friction coefficient difference between the dry and wet surfaces depended on the footwear material and floor combinations. Friction measurements under liquid-contaminated conditions are 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, [4 - 7]. 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 include the material and surface geometry of the footwear and floor, floor contamination conditions and the slip meter used, [8 - 10]. Investigators have focused the friction coefficient measurements on liquid contaminated floors because most slip/fall incidents occur on the surfaces of such floors, [11 - 14]. 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 leaking or 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, [15]. A longer leaking 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 sliding against rubber and leather was investigated [16]. 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 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, [17]. It was found that a higher friction could potentially improve slip resistance as discussed previously, [18 - 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 concluded that certain surface roughness is needed to improve slip resistance.

Tread groove designs are helpful in facilitating contact between the shoe sole and floor on liquid contaminated surface, [26]. 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.

The effect of rubber flooring with cylindrical treads on the friction coefficient was investigated, [27]. It was found that parallel treads showed the highest friction coefficient, while perpendicular treads displayed the lowest friction values. Presence of oil on the sliding surfaces showed a decreasing trend of friction coefficient with increasing tread diameter as a result of the presence of squeeze oil film separating footwear and rubber flooring. The effect of the treads width and depth of the shoe sole, on the friction coefficient between the shoe and ceramic floor interface, was discussed, [28]. It was found that, at dry sliding, friction coefficient slightly increased with increasing treads height. Perpendicular treads displayed the highest friction coefficient due to their increased deformation, while parallel treads showed the lowest values.

The friction coefficient of rubber sliding against different types of flooring materials of different surface roughness was investigated under different sliding conditions: dry, water, water/detergent dilution, oil, water/oil dilution, [29]. The flooring materials are parquet, polyvinyl chloride (PVC), epoxy, marble, cement and ceramic. It was found that sliding of rubber against water/detergent wetted tiles caused drastic decrease of friction coefficient. Parquet displayed the highest friction values followed by cement and marble. PVC, epoxy and ceramic represented relatively lower friction values.

The effect of semispherical cavities introduced in the rubber flooring mats on the static friction coefficient obtained during their sliding against ceramic flooring under dry, water, water + 5.0 vol. % detergent, oil and water + 5.0 vol. % oil lubricated sliding conditions was investigated, [30]. Based on the experimental observation, it can be concluded that at dry sliding, smooth rubber displayed the lowest friction, while semispherical cavities showed an increased trend of friction. As the height of the cavity increased friction increased.

The effect of holes and leakage grooves introduced in cylindrical protrusion of the rubber flooring mats on the static friction coefficient of rubber footwear under dry, water, water + 5.0 vol. % soap, oil and water + 5.0 vol. % oil lubricated sliding conditions was tested, [31]. At dry sliding, friction coefficient increased with increasing number of holes and grooves. At water lubricated sliding, increasing diameter of holes was insignificant on friction coefficient. As the number of holes and grooves increased friction coefficient increased. This behavior related to the easy escape of water through the holes and grooves out of the contact area.

Recently, flooring tiles made of recycled rubber were tested, [32 - 34]. The effect of surface roughness on the frictional behavior of recycled rubber tiles was discussed. It was found that, for tiles made of recycled rubber, surface roughness had insignificant effect on the frictional behavior. Friction coefficient slightly increased with increasing the tile thickness. In the presence of water on the sliding surface, rough surface displayed higher friction values than the smooth one. Values of friction for detergent

lubricated surfaces were lower than that observed for water lubricated surface. 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.

In the present work, rubber semi-spherical protrusions of different diameter and hardness were tested for their sliding against smooth rubber surface to determine friction coefficient at dry, water, detergent and oily sliding conditions.

EXPERIMENTAL

Experiments were carried out using a test rig designed and manufactured to measure the friction coefficient displayed by the sliding of rubber semi-spherical protrusions against rubber surface representing the footwear through measuring the friction force and applied normal force. The rubber surface was 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 (applied load). Friction coefficient was determined by the ratio between the friction force and the normal load. The arrangement of the test rig is described in earlier works [27-34].

The tested semi-spherical rubber protrusions were of 29, 30, 32, 37, 41 and 42 mm diameters and 37, 43, 53, 58, 60, 63, 64, 67, 68 and 76 Shore A hardness. Half rubber spheres were adhered to wooden block of 100 × 100 mm and 20 mm thickness. Loads up to 250 N were applied manually by sliding the tested semi-spherical balls against smooth rubber surface, of 100 Shore "A" hardness, adhered to the base of the test rig. The normal and friction forces were measured to determine the static friction coefficient. The friction values were extracted from the figure indicating the friction coefficient at 50, 100, 150 and 200 N. The semi-spherical rubber balls were loaded against dry, water, water + 1.0 vol. % detergent and oily rubber mat.

Water was replenished on the tested rubber surface, where the amount of water was 300 ml for each replenishment to form consistent water film covering the rubber 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 rubber protrusions and rubber surface using absorbent papers then rinsed using water and dried by using hair dryer after the cleaning process.

RESULTS AND DISCUSSION

The relationship between friction coefficient and hardness of the rubber balls sliding against dry rubber is illustrated in Fig.1. Friction coefficient decreased with increasing normal load and hardness. Slight decrease in friction was observed in the hardness range from 37 to 64 Shore A, and then drastic decrease was noticed for further hardness increase. It was noted that the friction values were relatively low for the sliding condition of rubber against rubber. This behavior may be attributed to the relatively small area of contact.

Friction coefficient displayed by rubber protrusions of different hardness sliding against water wetted rubber, Fig. 2, drastically decreased with increasing hardness. The behavior could be divided into two parts according to the hardness value. The first was from 37 to 58 Shore A, where the decrease was less steep. The values of friction

coefficient were relatively high. The second was from 58 to 76 Shore A, where the decrease was steeper. This performance could be explained on the basis that as the hardness increased the area of contact decreased and consequently friction coefficient decreased.

For the condition of sliding against detergent wetted rubber the same trend was observed with lower values of friction values, Fig. 3. The low friction compared to the water wetted condition may be caused by the strong adhesion of detergent molecules into the sliding surfaces.

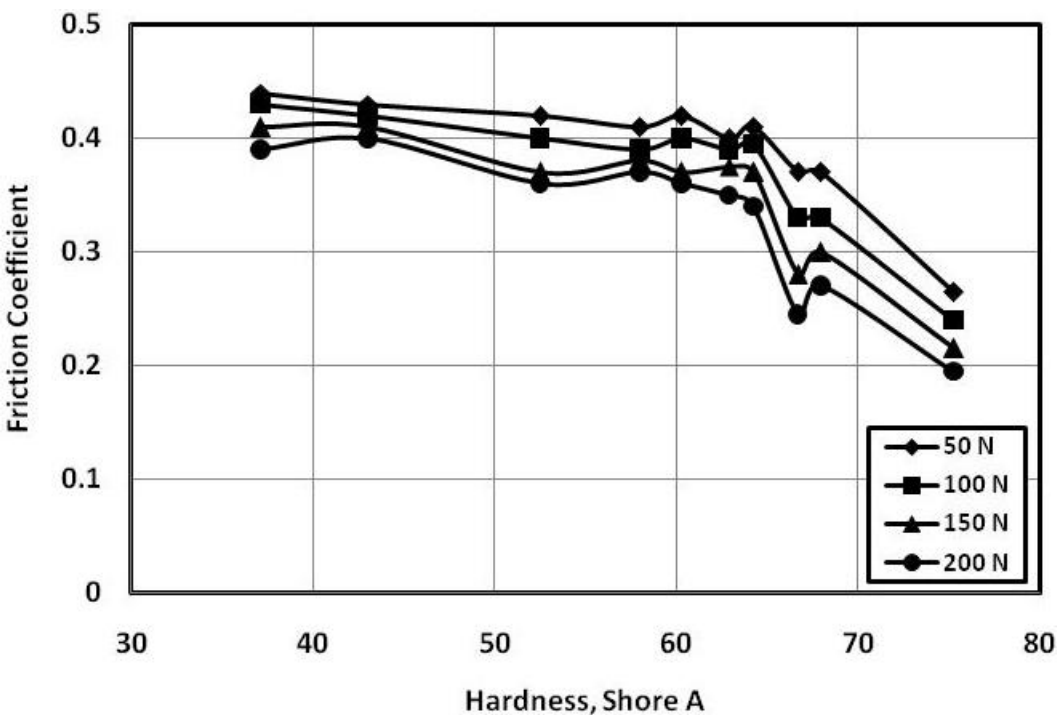

Fig. 1 Friction coefficient of rubber protrusions of different hardness sliding against dry rubber.

Further friction decrease was observed for the rubber protrusions of different hardness sliding against oil lubricated rubber, Fig. 4. In the hardness range from 63 to 76 Shore-A, friction coefficient showed very low values, where the highest and lowest values were 0.0104 and 0.0015 respectively. These friction values indicated that the presence of hydrodynamic sliding condition, where the oil film completely separated the two sliding surfaces. This observation recommended that the hardness of the ball should not exceed 53 Shore A.

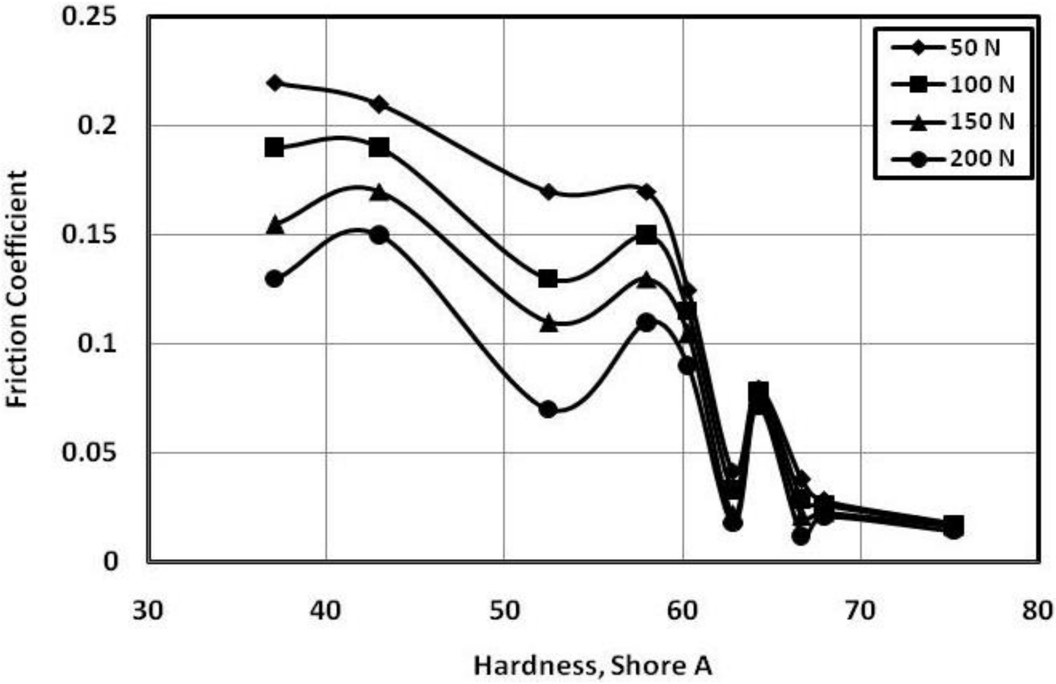

Fig. 2 Friction coefficient of rubber protrusions of different hardness sliding against water wetted rubber.

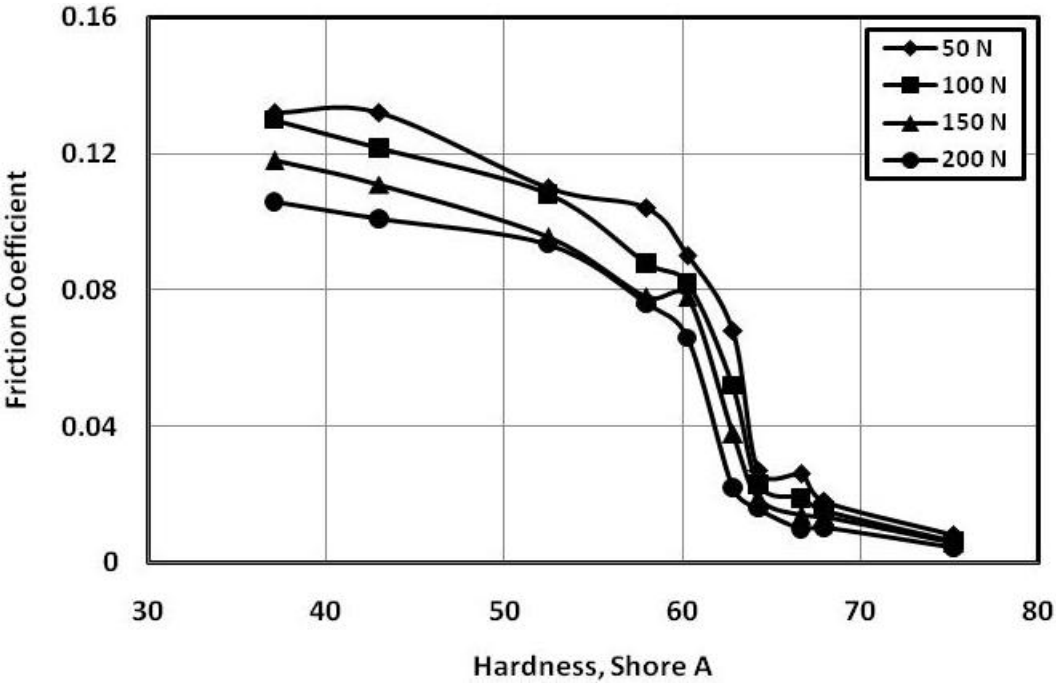

Fig. 3 Friction coefficient of rubber protrusions of different hardness sliding against detergent wetted rubber.

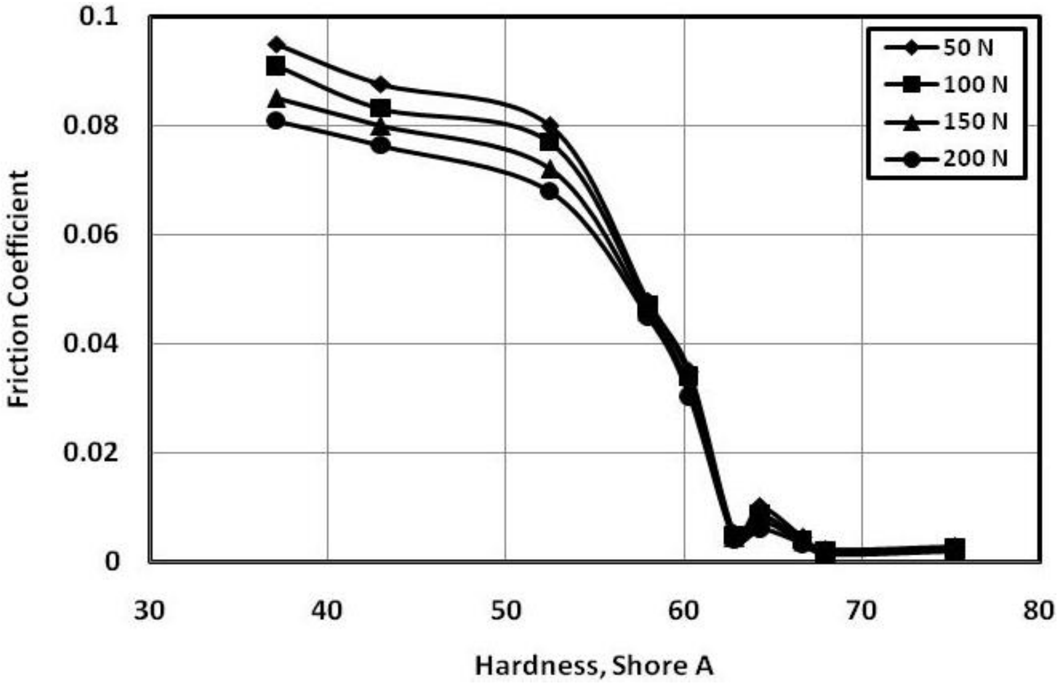

Fig. 4 Friction coefficient of rubber protrusions of different hardness sliding against oil lubricated rubber.

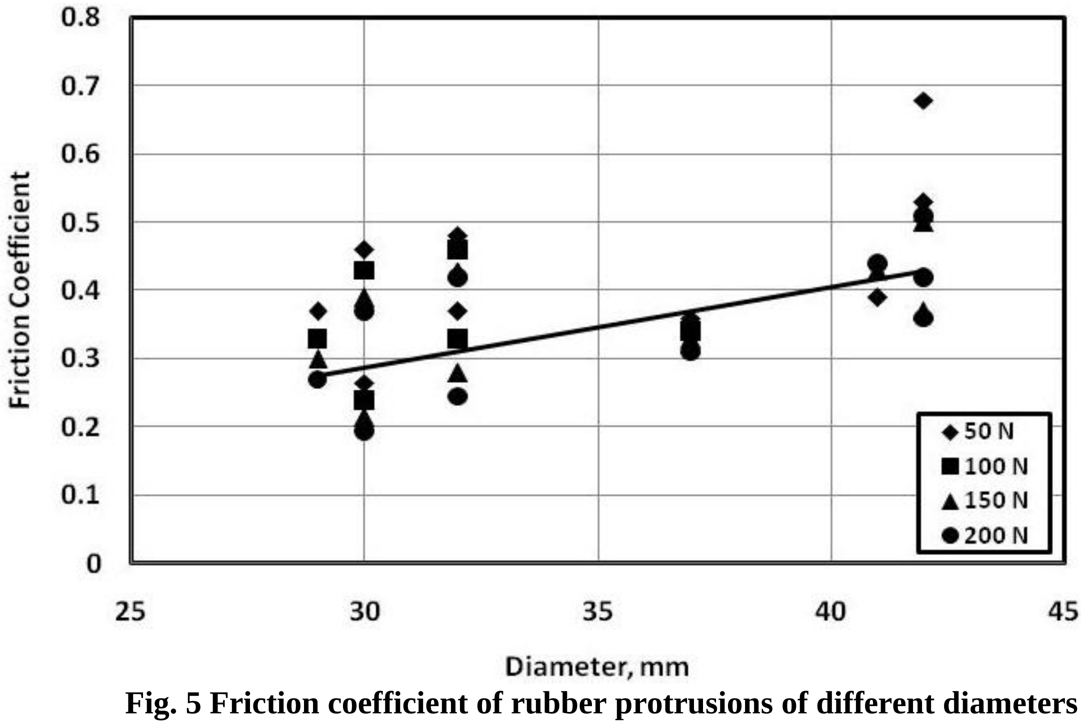

Fig. 5 Friction coefficient of rubber protrusions of different diameters sliding against dry rubber.

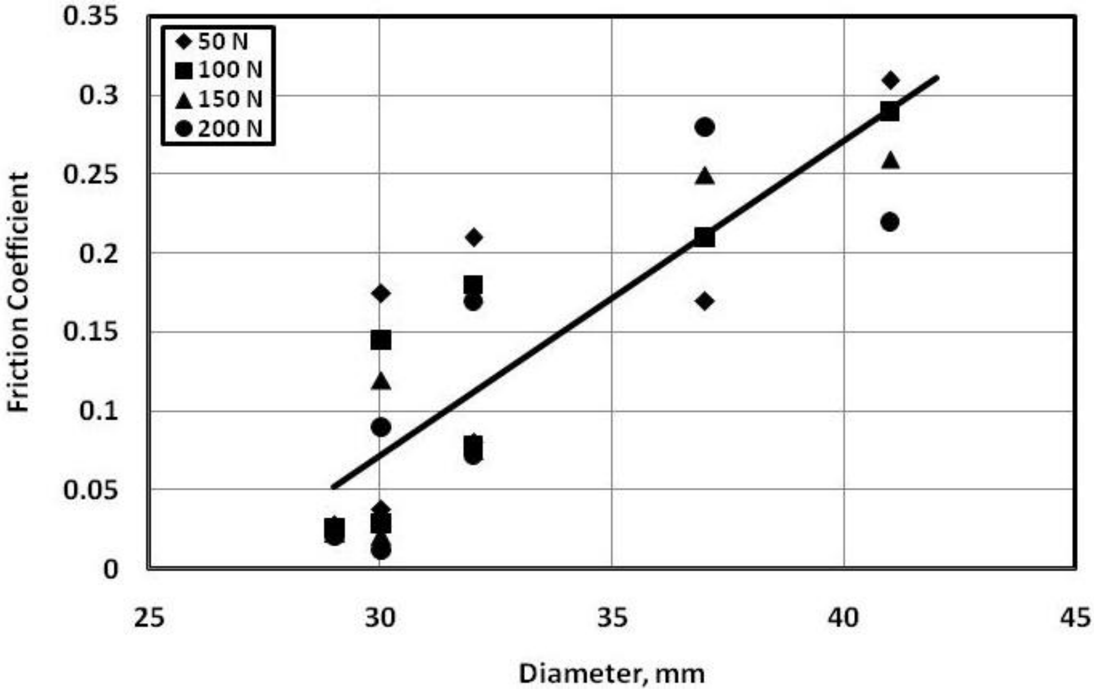

Fig. 6 Friction coefficient of rubber protrusions of different diameters sliding against water wetted rubber.

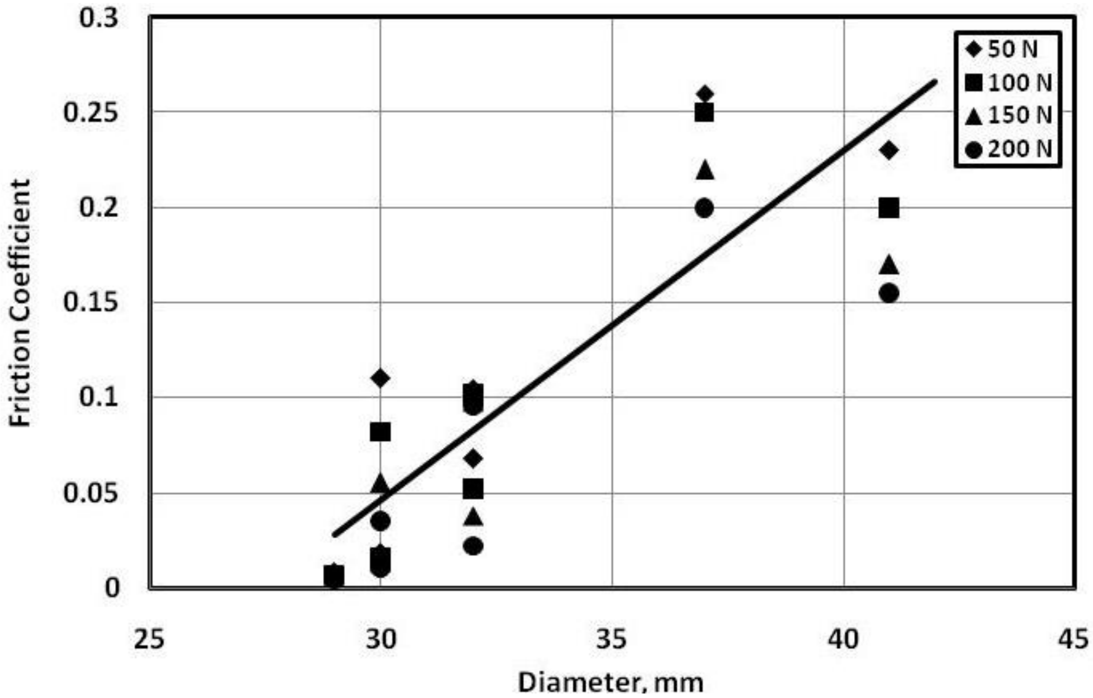

Fig. 7 Friction coefficient of rubber protrusions of different diameters sliding against detergent wetted rubber.

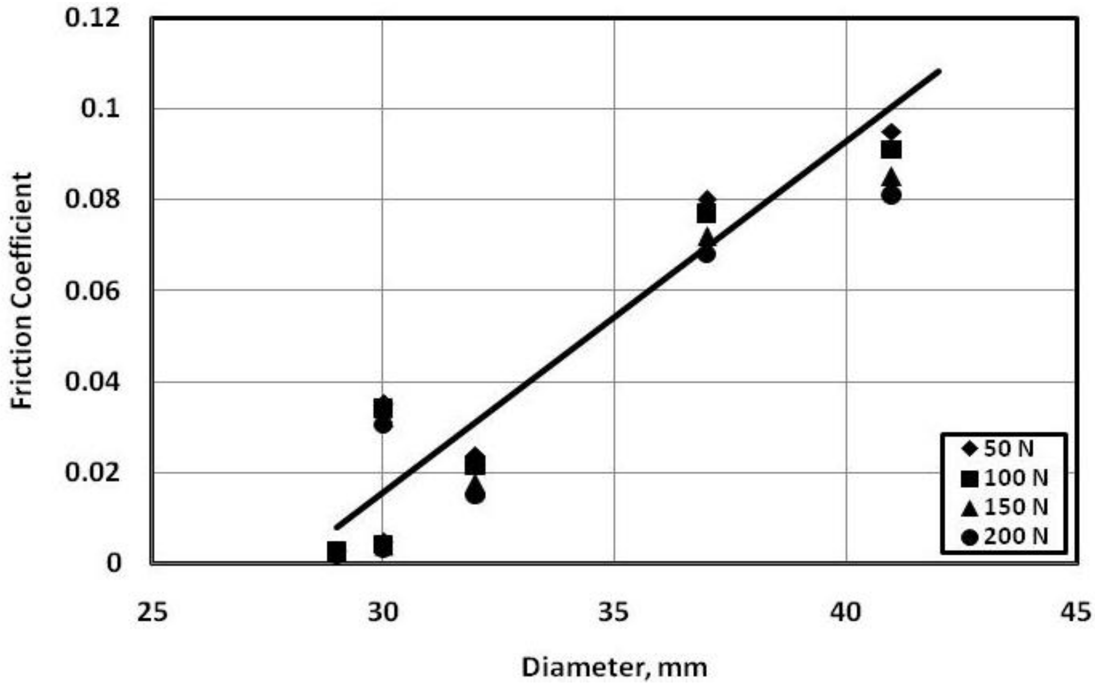

Fig. 8 Friction coefficient of rubber protrusions of different diameters sliding against oil lubricated rubber.

The effect of the protrusions diameter on friction coefficient is shown in Figs. 5 – 8, where friction coefficient of dry sliding is shown, Fig. 5. Slight friction increase was observed as the protrusions diameter increased. The highest friction values were presented by 42 mm protrusions diameter.
Friction coefficient of rubber protrusions of different diameters sliding against water wetted rubber, Fig. 6, showed significant increase with diameter increasing. For water wetted sliding, friction values up to 0.29 could be obtained. This behavior depended on the ability of the semi-spherical protrusion to allow the water to escape from the contact area, where the contact was rubber/rubber.

Sliding against detergent wetted rubber, Fig. 7, showed relatively higher friction coefficient up to 0.25 at protrusions diameter of 42 mm. This is a promising result and can be used in application to avoid slip on detergent wetted surfaces like bathrooms or during washing halls and yards.

Remarkable friction increase was observed for rubber protrusions of different diameters sliding against oil lubricated rubber, Fig. 8. Friction coefficient up to 0.10 could be obtained at 42 mm protrusions diameter. Based on these results friction coefficient values can be increased by increasing the diameter of the semi-spherical protrusion.

CONCLUSIONS

1. At dry sliding, friction coefficient decreased with increasing normal load and hardness.
2. Friction coefficient of water wetted sliding drastically decreased with increasing hardness.

3. Sliding against detergent wetted rubber showed lower friction values than that observed for water wetted sliding.
4. Friction coefficient showed significant increase with increasing the protrusions diameter. For water wetted sliding friction values up to 0.29 could be obtained.
5. Sliding against detergent wetted rubber showed relatively higher friction coefficient up to 0.25 at protrusions diameter of 42 mm. This is a promising result and can be used in application to avoid slip on detergent wetted surfaces like bathrooms or within washing halls and walking yards.
6. Remarkable friction increase was observed for rubber protrusions of different diameters sliding against oil lubricated rubber. Based on these results, friction coefficient values can be increased by increasing the diameter of the semi-spherical protrusion.

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