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FRICTION COEFFICIENT OF GROOVED RUBBER DISC SLIDING AGAINST CERAMICS: I. EFFECT OF MOTION DIRECTION

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ABSTRACT

The present research investigates the effect of grooves on the rubber surface, direction of motion and elasticity of rubber on the static friction coefficient when sliding against ceramic surface. Rubber test specimens were prepared from two types of rubber of 2 and 8 MPa modulus of elasticity and 27 and 53 hardness Shore-A. The specimens had a cylindrical shape of 36 mm diameter and 10 mm high. Test specimens were prepared by introducing single groove of different lengths. The ceramic surface roughness was 0.14 µm R_a.

Friction tests were carried out at different values of normal load. Tests were carried out at dry, water, sand contaminated, water contaminated by sand, water and detergent, water and detergent contaminated by sand, oil, oil contaminated by sand, oil/water dilution, oil/water dilution and contaminated by sand.

Based on the experimental results, it was found that, introducing single groove in the rubber disc greatly influenced friction coefficient. At dry sliding friction coefficient decreased with decreasing contact area in presence of hard rubber while soft rubber showed an increase in friction coefficient. This behavior was attributed to the fact that friction displayed by hard rubber depended mainly on adhesion while that observed for soft rubber depended mainly on deformation. For water lubricated ceramics, the value of friction coefficient drastically decreased compared to dry sliding. Further decrease in friction coefficient was observed when water was diluted by detergent. In the presence of sand, water and detergent the values of friction coefficient showed significant increase due to the embedment of sand particles in rubber surface and consequently abraded ceramic surface. In the presence of water and oil, the sliding directions showed significant effect on friction coefficient, while for relatively soft rubber, sliding directions had slight effect on friction coefficient.

KEYWORDS

Friction coefficient, rubber disc, groove, motion direction, ceramics.

INTRODUCTION

Slipping and falling are common phenomena in both workplaces and daily activities. 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, [1]. Tread pattern of the shoe affects friction especially under liquid-contaminated conditions. Verification of the effects of tread groove depth is significant in assisting designers to propose proper footwear for workers exposed to slippery floor conditions.

Slip resistance of flooring materials is one of the major environmental factors affecting walking and materials handling behavior. Floor slipperiness may be quantified using the static and dynamic friction coefficient, [2]. Certain values of friction coefficient were recommended as the slip-resistant standard for unloaded, normal walking conditions. Relatively higher static and dynamic friction coefficient values may be required for safe walking when handling loads.

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, [3]. 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, [4]. 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.

Recently, quantitative modeling of rubber friction on a fractal surface has been presented based on bulk viscoelastic description of material behavior, [6, 7]. Among the many proposals attempting to rationalize the benefit in wet traction from silica, [8] the existence of a softer skin at the sliding interface for silica-filled rubber appears plausible.

The adhesion component is important only for very clean and smooth rubber surfaces, [9]. The main source of friction in well lubricated sliding arises from deformation. Some tests with spherical and conical specimens sliding against rubber. Presence of fluid between rubber and hard substrate reduces not only the adhesion but also the hysteresis component of friction. On a lubricated substrate the valleys turn into fluid pools which are sealed off and effectively smoothen the substrate surface, [10, 11]. Smoothening reduces the viscoelastic deformation from the surface asperities, and thus reduces rubber friction. Ageing the nitrile rubber in the synthetic ester base fluids leads to reduction of friction coefficient, [12]. This effect in reducing the friction coefficient, especially in perpendicular sliding to the initial lay on the surface, is more considerable for the sample aged in polyolester.

Friction measurement is one of the major approaches to quantify floor slipperiness. Investigations on friction measurement had been focused on liquid-contaminated conditions. It was expected that wet surfaces had significant lower friction coefficient values than those of the dry surfaces, [13]. The friction coefficient difference between the dry and wet surfaces depended on the footwear material and floor combinations.

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, [14 - 15]. 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. Measurements of the static friction coefficient between rubber specimens sliding against the polymeric flooring materials of vinyl of different surface roughness were carried out at dry, water, water and soap, oil, oil and water, [16]. It was observed that, at dry sliding, friction coefficient decreased with increasing surface roughness and applied load.

The effects of sand particles on the friction at the footwear–floor interface are much more complicated than liquid-contaminated conditions. Liquids on the floor tend to decrease the surface friction, but the sand particles on the floor may decrease or increase the friction on the floor, depending on factors such as characteristics of the particles, tread design and hardness of the footwear pad, hardness and roughness of the floor, and so on. Theoretically, the sand particles on the floor prevent a direct contact between the footwear pad and floor, [17]. The number of sand particles on the floor may affect the friction. But the largest particles dominate the effects because they will be the first ones to contact the footwear pad. While balls and rollers had been widely used in reducing friction in bearings, the friction coefficient values for different types of rolling bearing elements had been determined, [18]. This, however, provides little help in determining the effects of the sand particles on friction because most sand particles on the floor are geometrically irregular with various degrees of elasticity and strength.

Increasing the tread groove width with various orientations on the footwear pads was effective in facilitating water and water-detergent drainage between the footwear pad and floor but not for the vegetable oil, [19, 20]. Designing tread grooves with various groove width for better slip resistance was most effective on a wet floor, less effective on the water-detergent-covered floor, and not effective on the oily floor. To achieve the same slip resistant effectiveness as on the wet floor, a more sophisticated tread groove design would be required for a footwear pad stepping on either the water detergent contaminated or oily floor.

Tread grooved shoes may had different groove depth. The depth of the grooves on the sole are initially designed into the footwear. Depth of the grooves may later change due to progressive wear of the shoe on the floor. Footwear with inadequate slip resistance was one of the key factors that increased the risk of falls for mail delivery workers, [21]. The mean ratings of tread condition, determined by the amount of tread remaining on the sole, were either ‘poor’ or ‘very poor’ for all types of footwear.

The tread on the footwear was rated as ‘very poor’ (worn smooth) in 75% of all the investigated slipping cases pointed out that massive wear on footwear mainly occurs on the contact areas of the shoe heel during repetitive bumping and rubbing of the sole on the floor, [22]. The geometry of the shoe sole may be altered because of ploughing, abrasion, and fatigue wear. This normally results in the decrement of the tread groove

depth on the sole. Variations in tread groove depth may affect the capability of the sole to drain the liquid underfoot and be partially responsible for the friction coefficient value at the foot–floor interface.

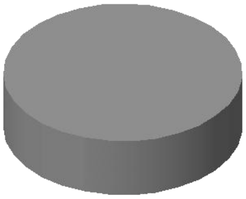
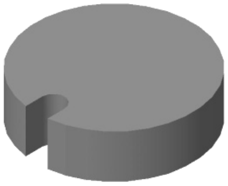
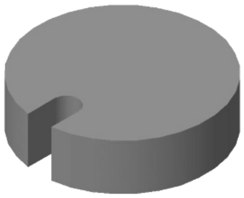
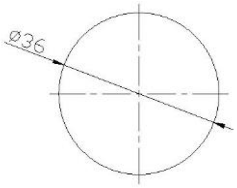
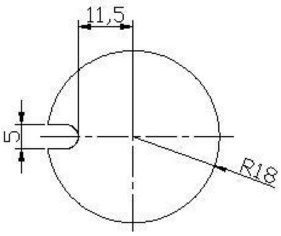
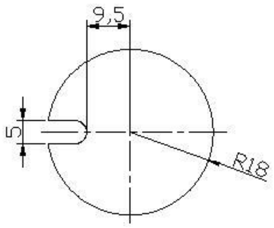
In the present work, the effect of single groove in the rubber disc, direction of motion and hardness of rubber on the static friction coefficient when sliding against ceramic surface were investigated.

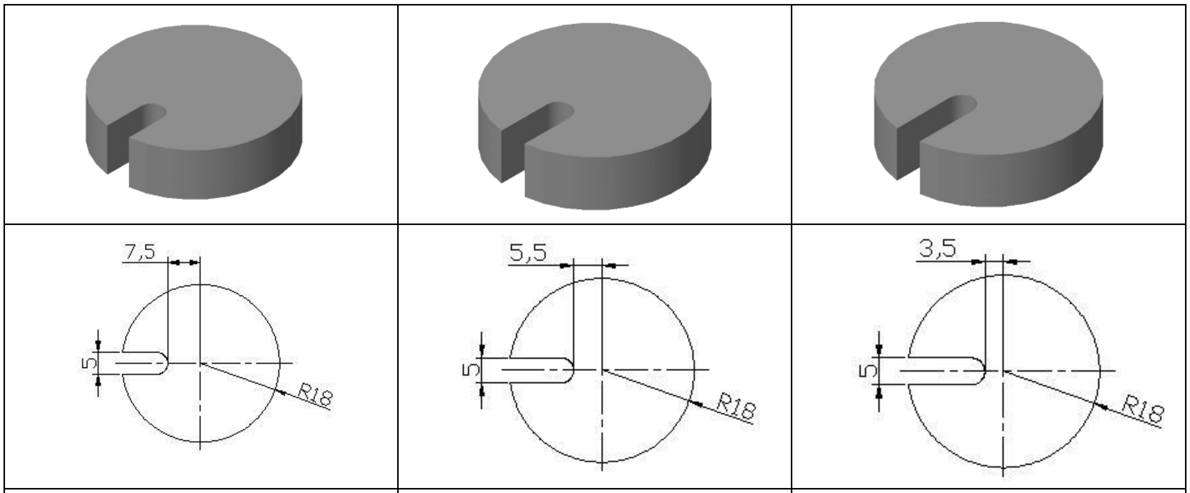
EXPERIMENTAL

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 the friction and normal forces, [21]. The ceramic surface in form of a tile is placed in a base supported by two load cells to measure both the horizontal force (friction force) and 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.

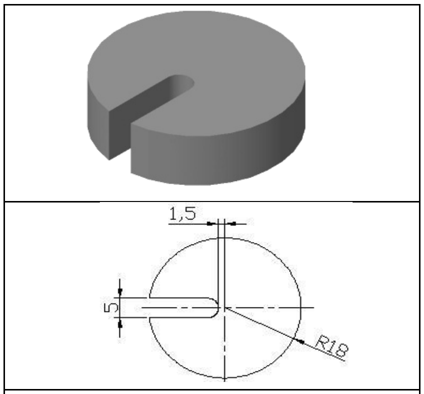
The rubber test specimens were prepared from two types of rubber (soft and hard) of 2 and 8 MP$_a$ modulus of elasticity and 27 and 53 Shore-A hardness respectively. The specimens were in form of cylindrical disc of 36 mm diameter and 10 mm thickness. Test specimens were prepared by introducing single groove in the rubber disc specimens of different lengths. Test specimens are shown in Fig. 1.

Friction tests were carried out at 150 N load. Test specimens were loaded against counterface of dry and lubricated ceramic surfaces. The sliding surfaces were lubricated by water, sand, water contaminated by sand, water + 5.0 vol. % detergent, water + 5.0 vol. % detergent contaminated by sand, oil, oil contaminated by sand, water + 5.0 vol. % oil and water + 5.0 vol. % oil contaminated by sand. The ceramic surface roughness was 0.14 µm R$_a$. The sand used in experiments was silicon oxide (Si O$_2$) of 0 – 1.0 mm particle size.

		
		
100 % Contact Area	**97 % Contact area**	**96 % Contact area**



95 % Contact Area | 94 % Contact area | 93 % Contact area



92 % Contact area

Fig. 1 Complete and single groove rubber test specimens.

RESULTS AND DISCUSSION

At dry sliding, rubber friction is composed of two mechanisms adhesion and deformation. Adhesion is attributed to the bonding of the exposed surface atoms between sliding surfaces. Deformation is attributed to the ability of the rubber elements to elongate until the interface bonds are broken. The dry sliding of hard rubber specimens against ceramic surfaces is shown in Fig. 2. It can be noticed that friction coefficient increased with increasing contact area. This behaviour is attributed to the fact that friction of hard rubber depended mostly on adhesion, while friction due to deformation was insignificant. The decrease in contact area directly affects the adhesion component. For smooth rubber surface, the maximum adhesion was attained, where it represented maximum value of friction coefficient. The sliding directions were insignificant on friction coefficient.

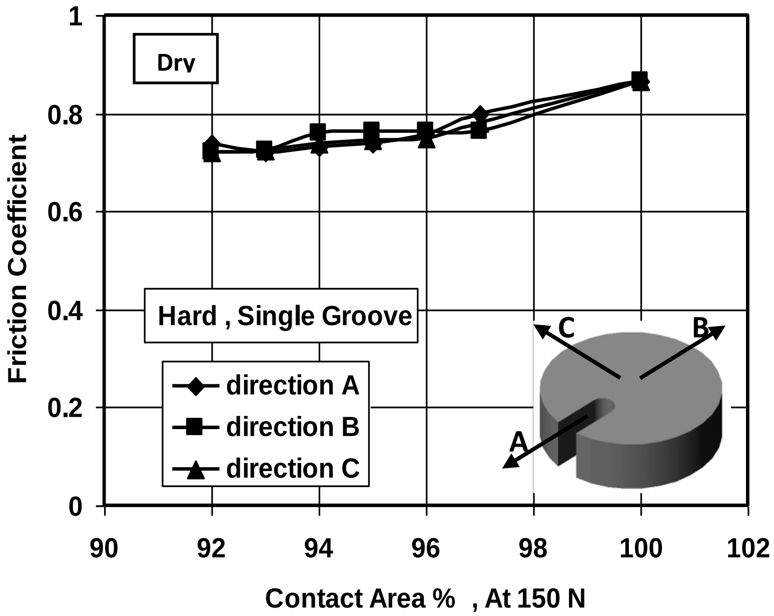


Fig. 2 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

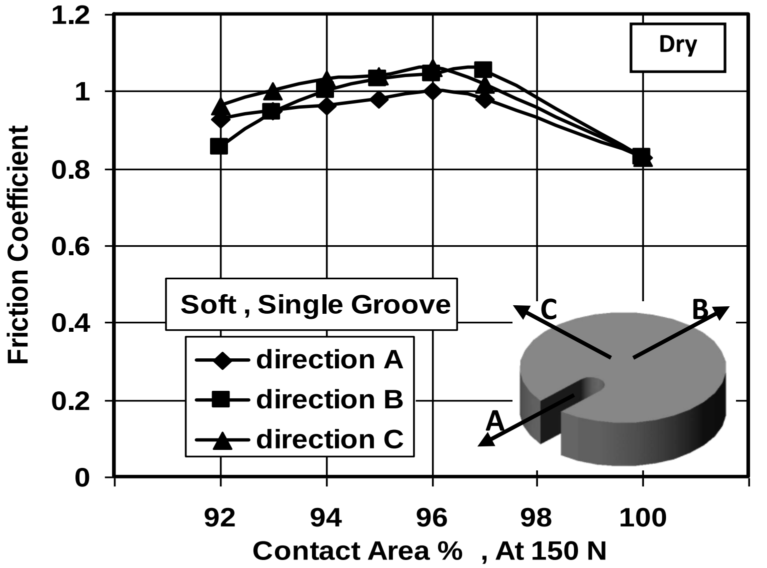


Fig. 3 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

The results of the sliding of soft rubber test specimens on dry ceramic surface are shown in Fig. 3. In this condition, the deformation is more pronounced. It can be noticed that, friction coefficient increased with increasing the contact area up to 96 % followed by slight friction decrease with increasing contact area. This behaviour is attributed to the increase rubber deformation. Further decrease in contact area decreased the adhesion between rubber and ceramic. The maximum value of friction coefficient (1.08) was observed at 96 % contact area at direction "C", while the minimum friction coefficient

(0.82) was observed at smooth rubber specimens. The sliding directions had insignificant effect on friction coefficient.

In the presence of water on the sliding surface, the effect of the contact area on friction coefficient is shown in Fig. 4. Generally, it can be noticed that, friction coefficient increased up to maximum at 95 % of the contact area, then decreased with increasing contact area. The increase of friction coefficient may be attributed to the ability of water to escape from the sliding surface through the groove of the rubber surface, where leakage of water changed the contact condition from water wetted to dry. The maximum value of friction coefficient (0.27) was observed at 95 % contact area, at direction "A". Sliding directions "A" and "B" displayed the highest friction coefficient. This behaviour was attributed to the water leakage from the sliding surface. The sliding direction "C" displayed the lowest values of friction coefficient because the radial edge of the groove restored water and redistributed it on the sliding surfaces.

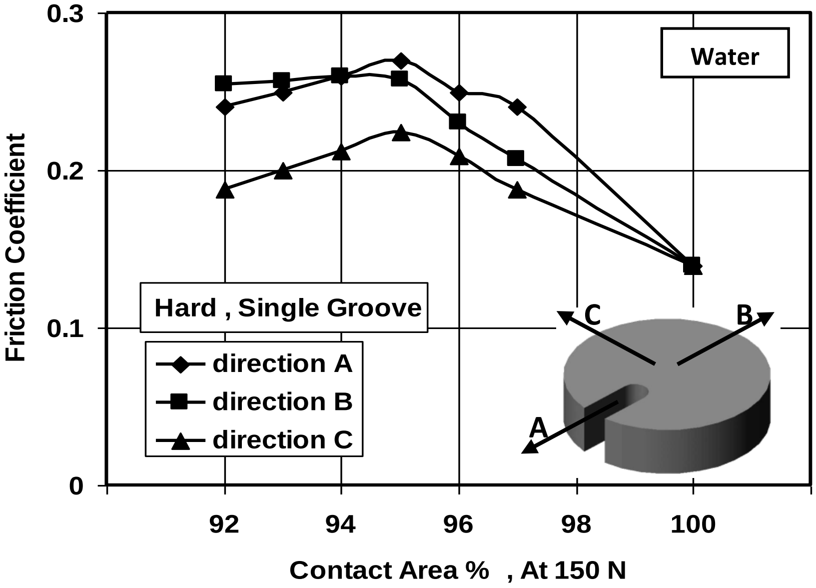


Fig. 4 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

For relatively soft rubber, Fig. 5, it is observed that, friction coefficient decreased with increasing contact area. This behaviour can be interpreted on the basis that increasing the dimension of groove in rubber increased the ability of water to leak from the sliding surface, where water leakage changed the contact condition from water wetted to dry one. Smooth rubber test specimens displayed the lowest value of friction coefficient because water was trapped in the contact area forming a film covering the sliding surfaces. Sliding directions had slight effect on friction coefficient. The maximum value of friction coefficient (0.28) was observed at 91 % contact area at direction "A". The minimum value of friction coefficient (0.15) observed at smooth rubber test specimen (100 % contact area).

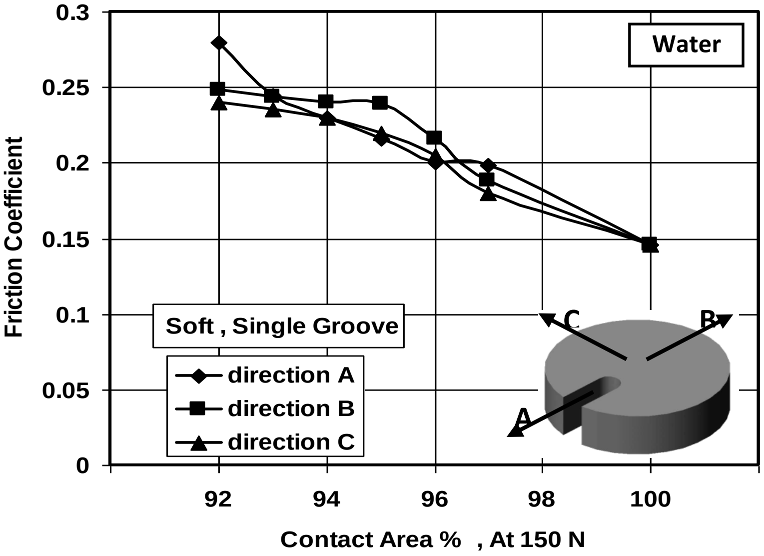


Fig. 5 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

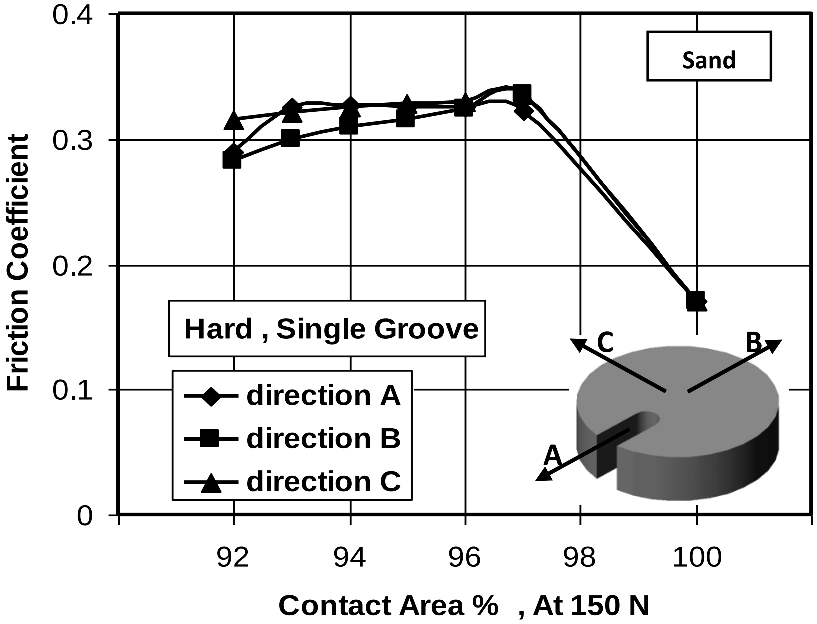


Fig. 6 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

In the presence of sand, the values of friction coefficient were relatively lower than that displayed by dry sliding, Fig. 6. The reason of that behaviour might be from the embedment of sand particles in the rubber surface and contact was partially rubber/ceramic and partially sand/ceramic. Friction coefficient between sand and ceramic was relatively lower than that observed from rubber/ceramic contact. Friction coefficient increased with increasing contact area up to 97 %. The groove in rubber allowed sand particles to roll away from the contact area. The maximum value of friction coefficient (0.33) was observed at 97 % contact area. The sliding directions showed no effect on friction coefficient. Friction coefficient displayed by

soft rubber showed insignificant effect with increasing contact area, Fig. 7. It seems that sand particles were partially embedded in the rubber surface so that the abrasive effect of sand was reduced. Besides, the sliding directions had insignificant effect on friction coefficient. The maximum value of friction coefficient (0.29) was observed at 92 % contact area and direction "C".

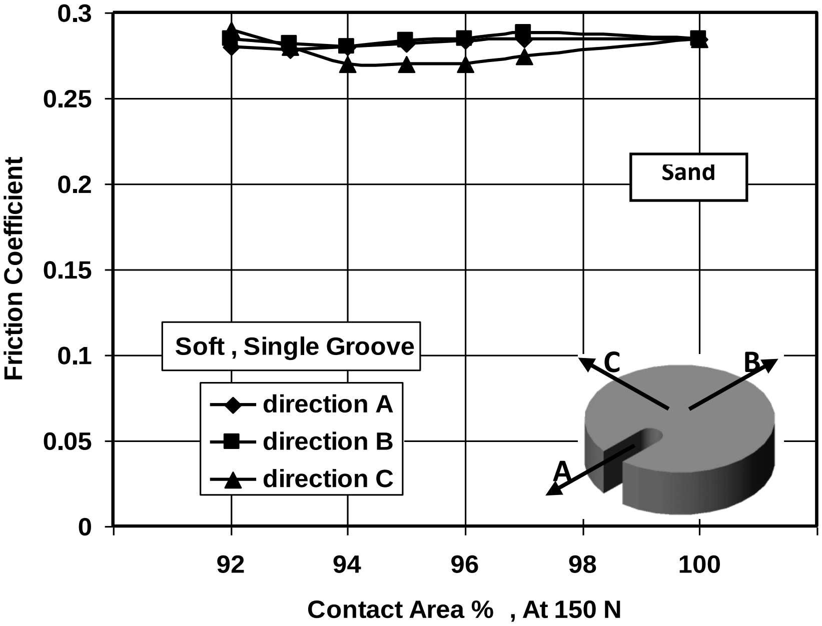


Fig. 7 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

In the presence of water contaminated by sand, friction coefficient displayed by smooth specimen showed relatively higher values than that observed at surfaces contaminated by sand only. This behaviour was due to the water ability to wash sand partials away of the contact area, Fig. 8. Generally, friction coefficient increased with increasing contact area up to 97 %. It seems that sand particles were embedded in the rubber surface and the contact became between sand particles and wetted ceramic surface. Friction coefficient increased with decreasing contact area due to the leakage of water. The maximum value of friction coefficient (0.33) was observed at 97 % contact area. The sliding directions had no effect on friction coefficient. Friction coefficient of soft rubber test specimens sliding against ceramic surface lubricated by water and contaminated by sand is shown in Fig. 9. In the presence of water contaminated by sand friction coefficient increased with increasing contact area up to 97 %. This behaviour is attributed to the water ability to wash sand particles away from the contact area and the groove in rubber surface allowed the water to leak out the contact area. As the contact area increased, friction coefficient decreased because water was trapped in the contact area. The maximum friction coefficient (0.33) was achieved at 97 % contact area. The sliding directions had insignificant effect on friction coefficient values.

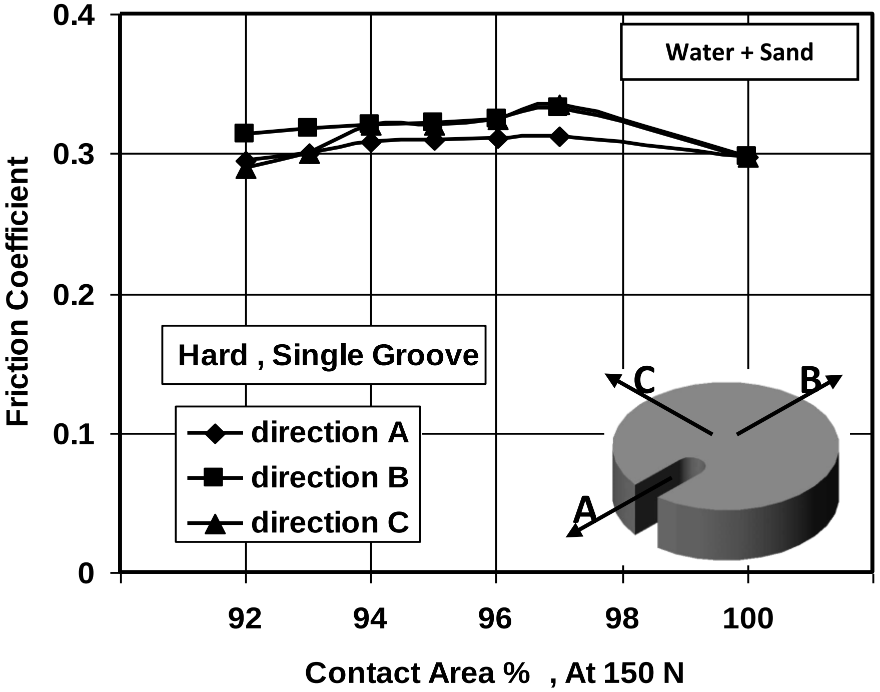


Fig. 8 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

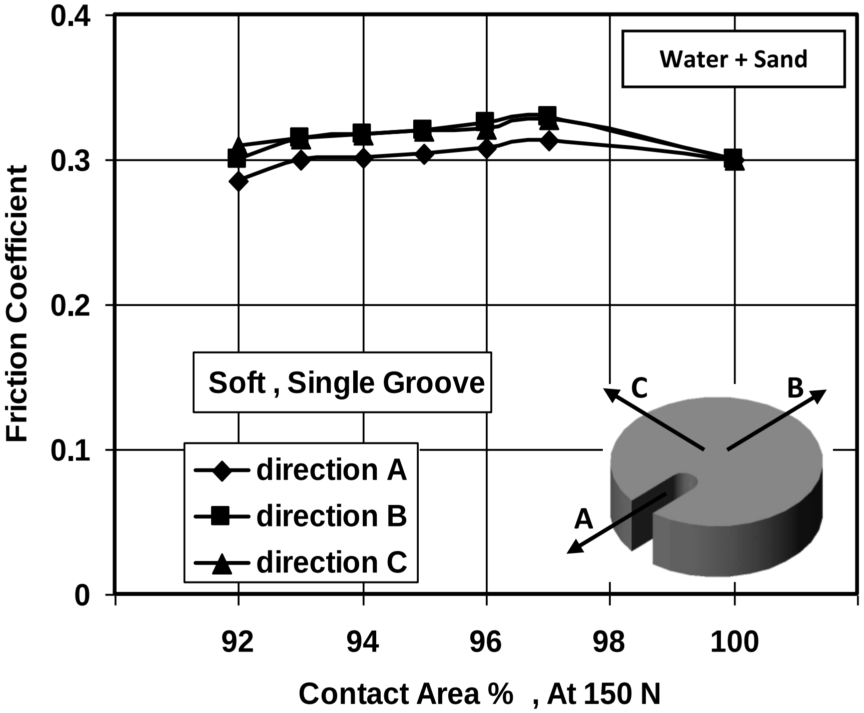


Fig. 9 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

The values of friction coefficient of test specimens sliding against ceramics wetted by water and detergent are illustrated in Fig. 10. Values of friction coefficient showed significant decrease compared to pure water because molecules of detergent were polar and the adhesion between the detergent and the sliding surfaces were relatively stronger. Generally, friction coefficient increased with increasing contact area due to the

easy leakage of fluid from the contact area. The maximum value of friction coefficient (0.055) was observed at 95 % contact area and direction "A", while the minimum value of friction coefficient (0.0256) was observed at smooth rubber specimen (100 % contact area). Sliding directions "A" and "B" displayed the highest friction coefficient. This behaviour was attributed to the ability of fluid leaked from the sliding surface. The sliding direction "C" displayed the lowest values of friction coefficient because it trapped the fluid in the groove space then leaked it to the contact area.

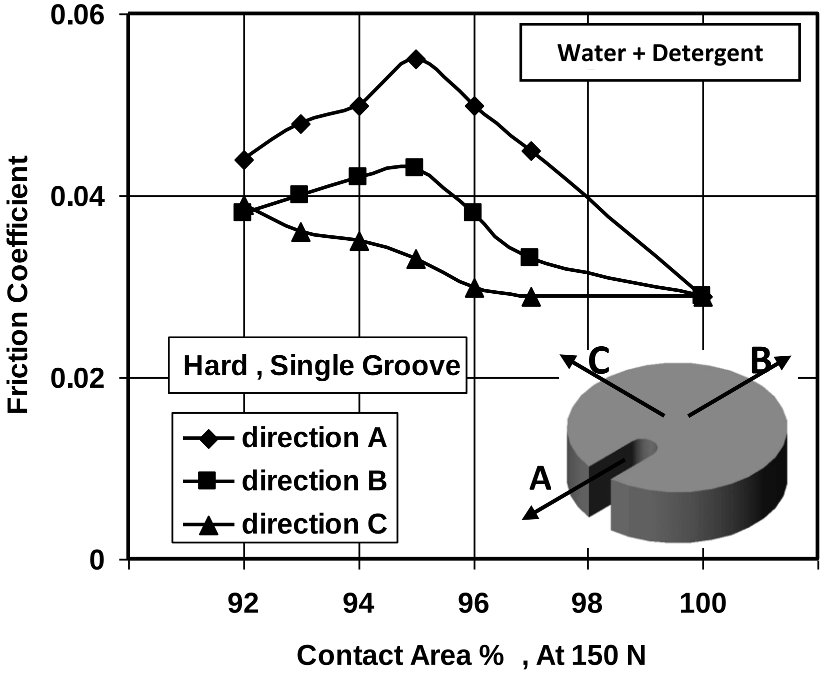


Fig. 10 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

Friction coefficient of soft rubber sliding against ceramic wetted by water and detergent is illustrated in Fig. 11. Values of friction coefficient showed significant decrease compared to water only. Friction coefficient increased with increasing contact area up to 95 %, This behaviour can be related to the groove that allowed the fluid to escape from contact area. As contact area increased, friction coefficient decreased. The maximum friction coefficient (0.053) was observed at 95 % contact area, while the minimum friction coefficient (0.042) was observed at smooth rubber specimens (100 % contact area). The sliding directions had insignificant effect on friction coefficient.

Contaminating water and detergent by sand caused remarkable friction increase due to embedment of sand particles in rubber surface, Fig. 12. Then sand particles began to abrade the ceramic surface. Fiction coefficient exceeded 0.4 for rubber surfaces of 96 % contact area. It seems that sand particles were embedded in the rubber and the contact was partially between sand and ceramic, where the fluid leaked out easily in presence of detergent through the groove out of contact area. Generally, friction coefficient slightly increased with increasing contact area up to 96 %. The sliding directions had no effect on friction coefficient.

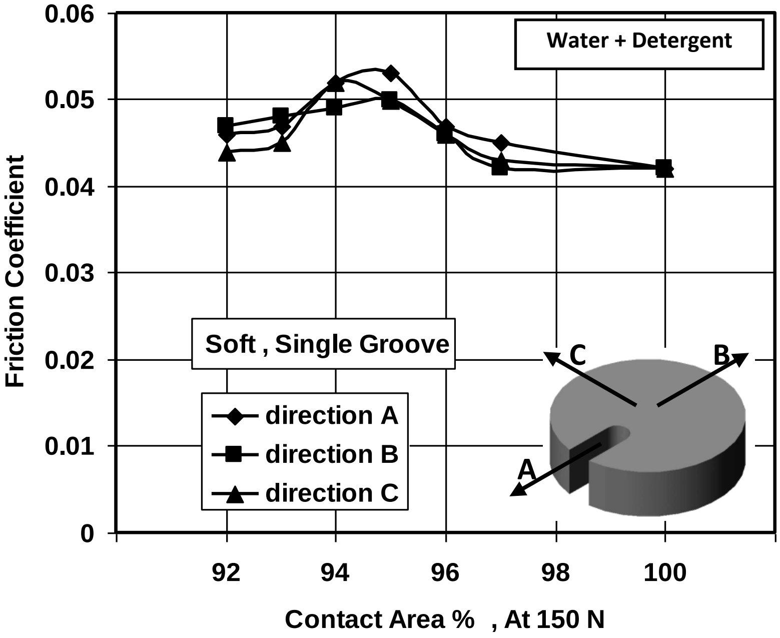


Fig. 11 Friction coefficient of rubber specimen containing single groove and sliding against ceramics surface.

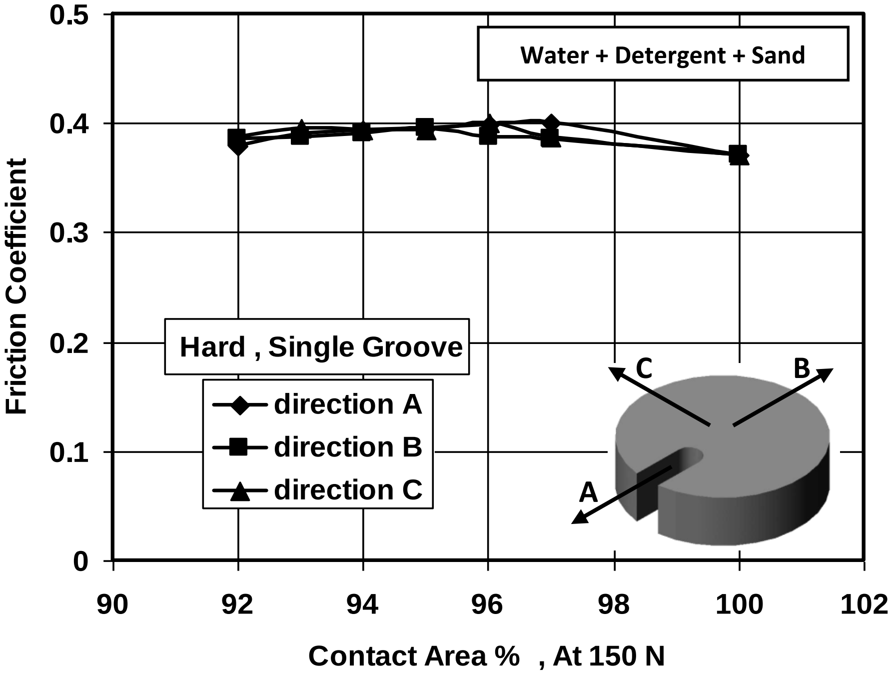


Fig. 12 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

Figure 13 shows the friction coefficient of soft rubber sliding against ceramic surface wetted by water and detergent and contaminated by sand. It can be noticed that, friction coefficient increased significantly compared to water and detergent only. Friction coefficient decreased with increasing contact area. This behaviour was attributed to sand particles embedded in the rubber, where the groove in rubber surface facilitated the easy leakage of water and detergent from the contact area. Friction coefficient reached to 0.36 for the contact area of 93 %. The minimum value of friction coefficient (0.33) was observed at smooth rubber test specimens due to the trapped water and detergent in the contact area. The sliding directions had insignificant effect on friction coefficient.

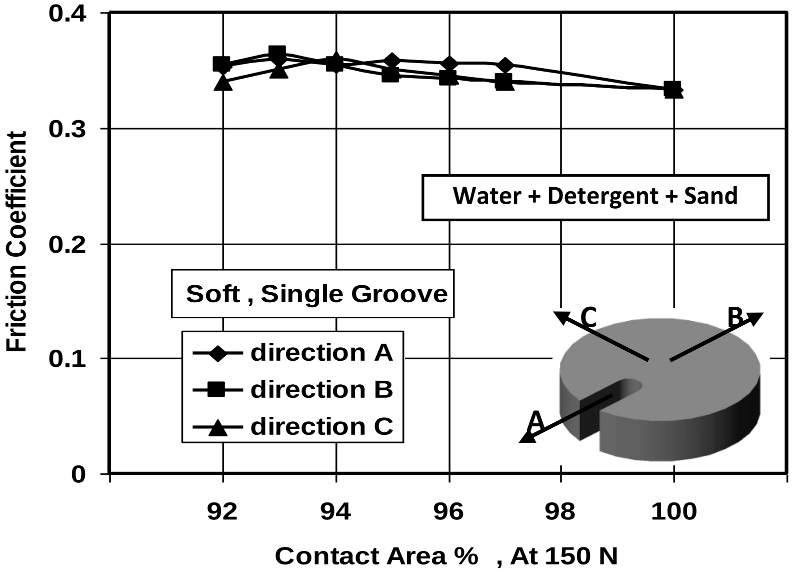


Fig. 13 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

In the presence of oil as lubricant on the ceramic surface, Fig. 14, smooth rubber specimens displayed the lowest friction values (0.026). Friction coefficient decreased as the contact area increased. This behaviour could be interpreted on the basis that groove in rubber specimens with large width would help the oil to escape out of the contact area. The maximum value of friction coefficient (0.048) was observed at 93 % contact area and sliding direction "C". The sliding directions had insignificant effect on values of friction coefficient. The relatively high value of friction known for rubber/ceramic contact was reduced as a function of the oil film. As the oil film increased, friction coefficient drastically decreased. In the presence of oil covering soft rubber, the friction coefficient displayed values lower than that observed for hard rubber, Fig. 15. The pores in soft rubber could store oil and fed it up to the contact area during sliding. Generally, friction coefficient decreased with increasing contact area due to the easy escape of the oil through the groove in rubber surface. The maximum value of friction coefficient (0.031) was observed at 94 % contact area at direction "C", while the minimum value (0.011) was observed for smooth rubber. The sliding direction "C" showed the highest values of friction coefficient. This behaviour was attributed to the fact that sliding in direction "C" increased ability of oil to escape from the sliding surface through the groove in rubber surface.

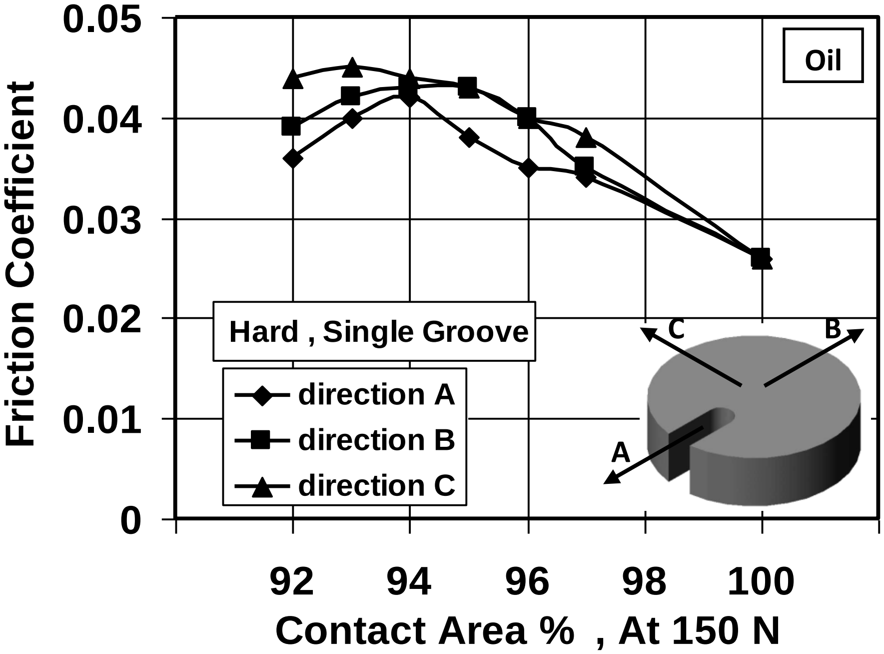


Fig. 14 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

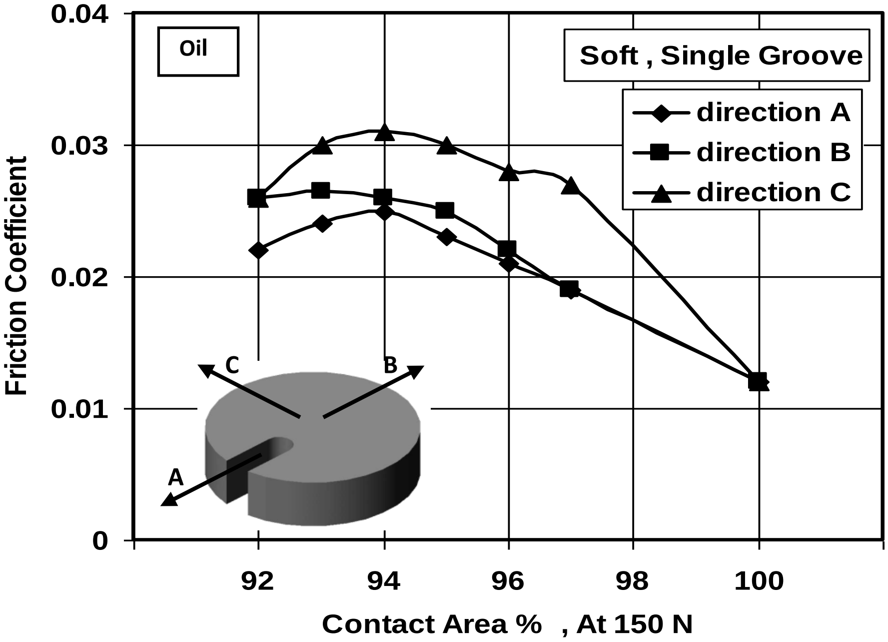


Fig. 15 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

Friction coefficient for rubber specimens sliding against ceramics, lubricated by oil diluted by water is shown in Fig. 16. Friction coefficient increased significantly compared to the condition of oil only. This behaviour was attributed to the effect of water which decreased the adhesion of oil on the sliding surfaces. As the contact area

increased friction coefficient decreased due to the trapped oil/water dilution in the contact area. The maximum value of friction coefficient (0.063) was observed at 94 % contact area and direction “C”, while the minimum value (0.049) was observed at smooth rubber specimens. The sliding directions were insignificant. Figure 17 showed friction coefficient for soft rubber sliding against ceramic surface lubricated by oil/water dilution. It can be noticed that the friction coefficient decreased to the lowest values with decreasing the contact area. As the groove length increased water/oil dilution was trapped in the grooves. Friction coefficient increased with increasing contact area. The sliding directions had insignificant effect on friction coefficient.

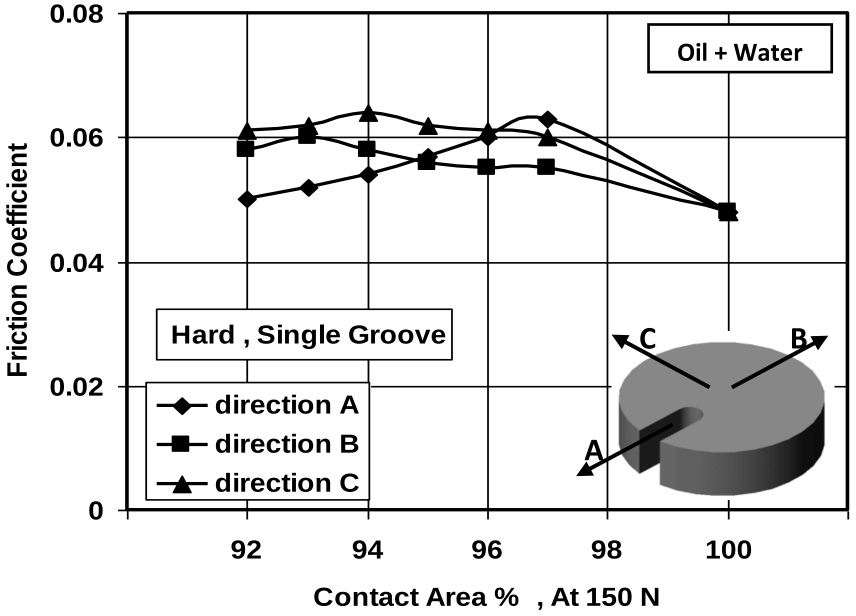


Fig. 16 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

In the presence of oil contaminated by sand, friction coefficient increased for smooth rubber surface, Fig. 18. The embedment of some of the sand particles in rubber surface was responsible for the friction increase. Presence of oil decreased the embedment of sand in the rubber. Besides, oil decreased the abrasion of ceramics by sand particles. Friction coefficient slightly increased with increasing the contact area up to 96 % due to the leakage of oil out of the contact area. The maximum value of friction coefficient (0.11) was obtained at 96 % contact area and direction “B”. The minimum value of friction coefficient (0.09) was observed at smooth rubber specimens. The effect of the sliding directions was insignificant.

Contaminating oil by sand caused significant increase in friction for all contact area tested of soft rubber, Fig. 19. Contact area showed no effect on friction coefficient. The increase of friction coefficient might be from the ability of sand particles to break the oil film and abrade ceramic surface. The values of friction coefficient confirmed the presence of oil film. The maximum value of friction coefficient (0.108) was observed at 92 % contact area at direction "A". The minimum value of friction coefficient (0.1) was

obtained at 92 % contact area at direction "C". Sliding directions showed no effect on friction coefficient.

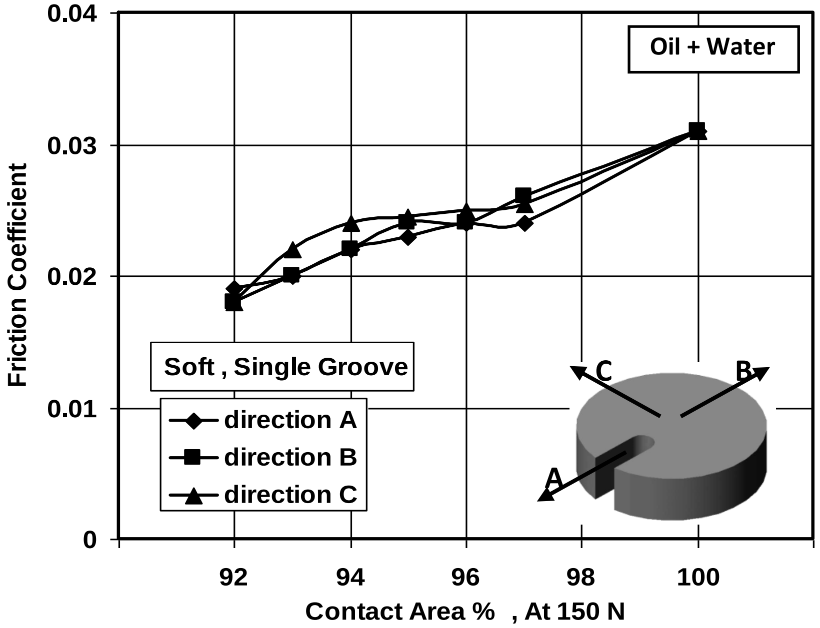


Fig. 17 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

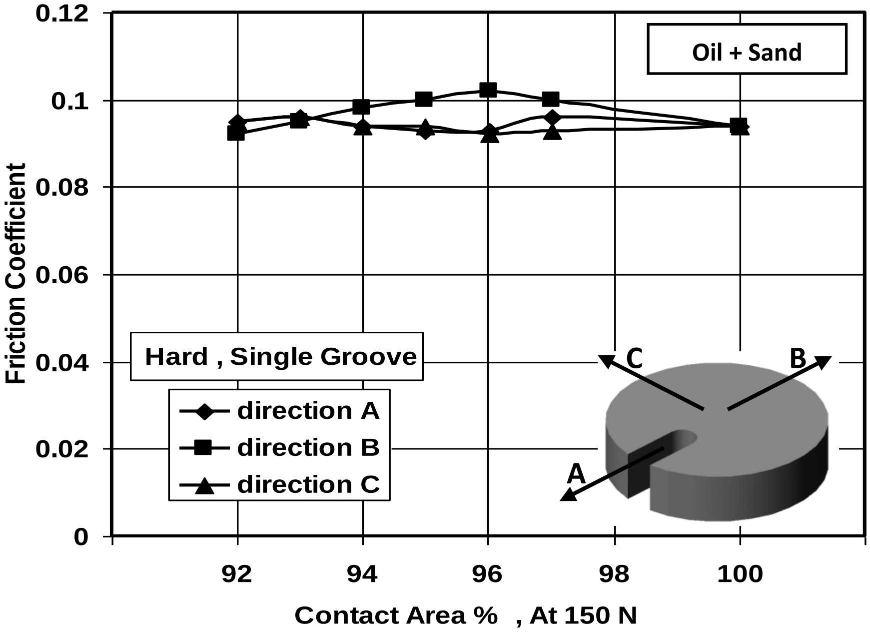


Fig. 18 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

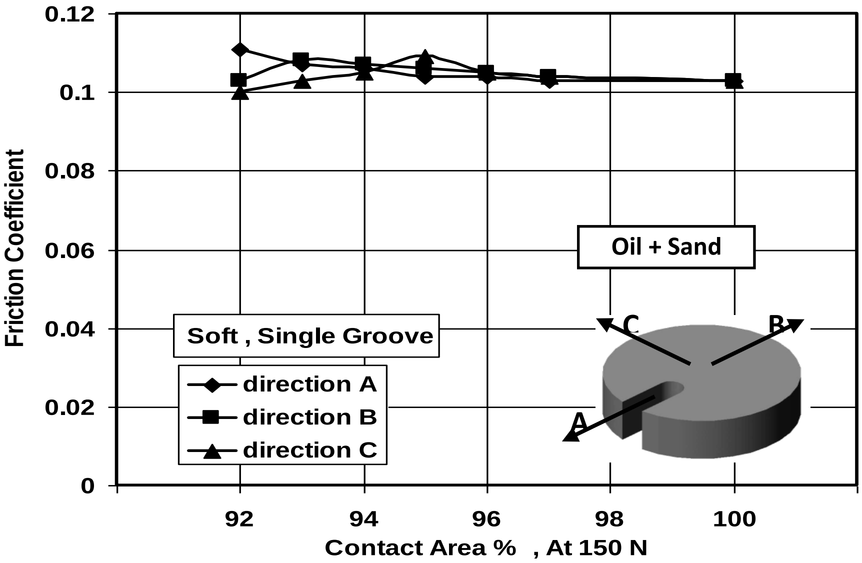


Fig. 19 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

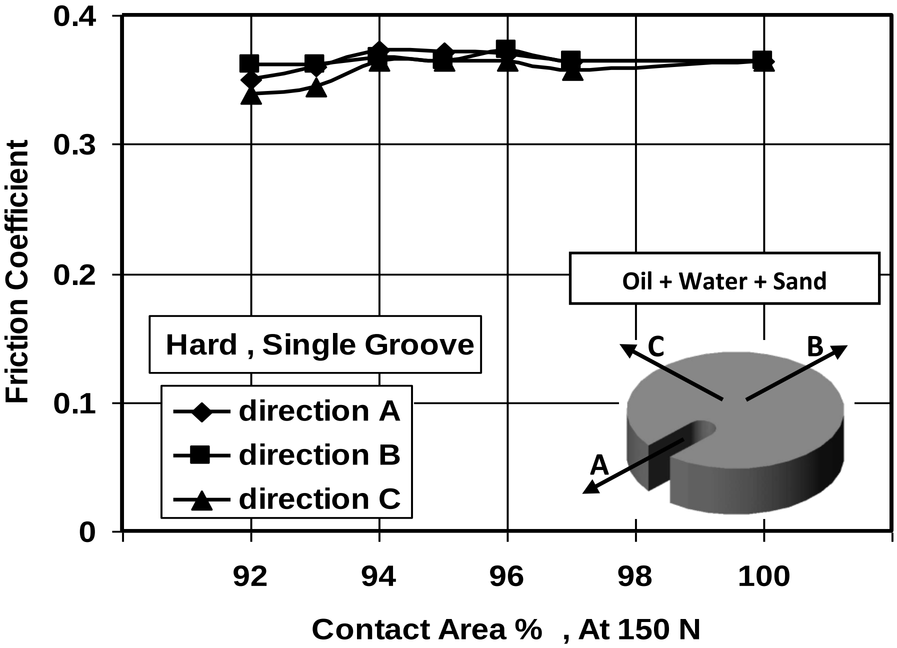


Fig. 20 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

In the presence of oil diluted by water and contaminated by sand, friction coefficient displayed relatively higher values than that observed in condition of water/oil dilution or oil contaminated by sand, Fig. 20. The presence of water decreased the adhesion of oil into the sliding surfaces. This behaviour was observed in condition of lubricating the surfaces by oil diluted by water. Friction coefficient slightly increased with increasing contact area. The maximum value of friction coefficient (0.38) was observed at 94 % contact area, while the minimum value (0.36) was observed at smooth rubber specimen. The sliding directions had no effect on value of friction coefficient. For soft rubber

friction coefficient showed significant increase compared to oil/water dilution, Fig. 21. This behaviour was attributed to the ability of water to decrease the lubricating action of oil. Generally, friction coefficient increased with increasing contact area up to 96 %. The sliding directions had insignificant effect on friction coefficient. The maximum value of friction coefficient (0.27) was observed at 96 % contact area.

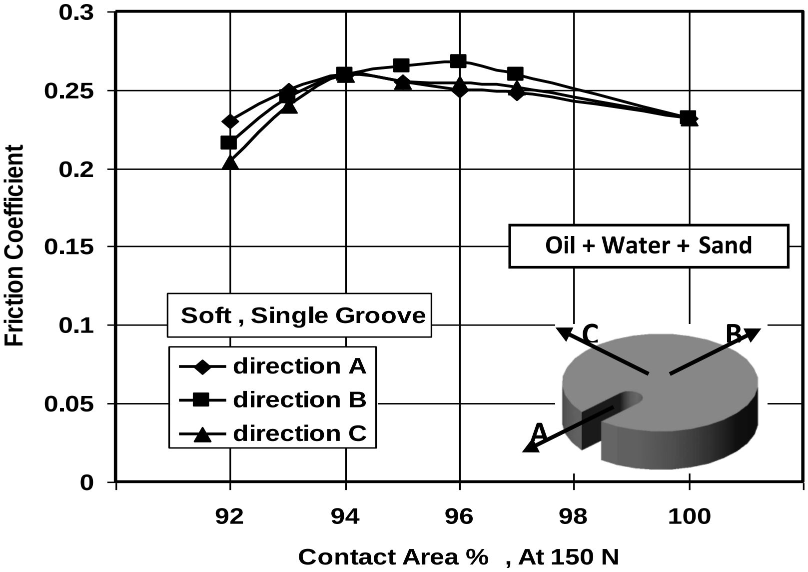


Fig. 21 Friction coefficient of rubber specimen containing single groove and sliding against ceramic surface.

CONCLUSIONS

1. At dry sliding, friction coefficient increased with increasing contact area. The sliding directions were insignificant on friction coefficient. For soft rubber friction coefficient increased with increasing contact area up to 96 % followed by slight friction decrease with increasing contact area.

2. In the presence of water, friction coefficient increased up to maximum then decreased with increasing contact area. The sliding directions had significant effect on friction coefficient. For relatively soft rubber, friction coefficient decreased with increasing contact area. Sliding directions had slight effect on friction coefficient.

3. In the presence of sand, the values of friction coefficient were relatively lower than that displayed by dry sliding due to the embedment of sand particles in rubber surface. Friction coefficient displayed by soft rubber showed insignificant effect with increasing contact area.

4. In the presence of water contaminated by sand values of friction coefficient for smooth specimen showed significant increase. Friction coefficient increases with decreasing contact area due to the leakage of water from the contact area. Soft rubber had higher capacity to trap water in the contact area. Friction coefficient decreased as the contact area increased.

5. Friction coefficient of rubber sliding against ceramics lubricated by water and detergent showed significant decrease compared to water sliding. Friction coefficient increased with increasing contact area due to the easy leakage of the fluid out of the contact area. For soft rubber the sliding directions had insignificant on friction coefficient.

6. Contaminating water and detergent by sand caused remarkable friction increase due to embedment of sand particles in rubber surface. Soft rubber sliding against ceramic surface wetted by water and detergent and contaminated by sand increased significantly compared to water/detergent dilution.
7. In the presence of oil smooth rubber displayed the lowest friction values. Friction coefficient decreased as the contact area increased. Soft rubber displayed friction coefficient values lower than that observed for hard rubber.
8. Friction coefficient for rubber wetted by oil/water dilution increased significantly compared to the condition of oil only. Friction coefficient displayed by soft rubber decreased to minimum with decreasing the contact area.
9. In the presence of oil contaminated by sand, friction coefficient increased for smooth rubber surface due to the embedment of sand particles in rubber surface. Soft rubber showed significant increase in friction.
10. In the presence of oil diluted by water and contaminated by sand, friction coefficient displayed relatively higher values than that observed in the condition of water/oil dilution or oil and sand. For soft rubber, friction coefficient showed significant increase compared to oil and water only.

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