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FRICTION COEFFICIENT OF GROOVED RUBBER DISC SLIDING AGAINST CERAMICS: III. EFFECT OF THE GROOVES

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ABSTRACT
The present research investigates the effect of grooves introduced in the rubber surface 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 have a cylindrical shape of 36 mm diameter and 10 mm high. Test specimens were prepared by introducing different grooves with different dimensions. The ceramic surface roughness was 0.14 µm Ra.

Friction tests were carried out at 150 N normal load. Tests were carried out at dry sliding conditions as well as lubricated surfaces were lubricated by water, sand, water contaminated by sand, water and detergent, water and detergent contaminated by sand, oil, oil contaminated by sand, oil mixed by water, oil mixed by water and contaminated by sand.

Based on the experimental results, it was found that at dry sliding test specimens of triple grooves showed the highest friction coefficient for soft rubber. In the presence of water friction coefficient of hard rubber of double grooves displayed significant friction increase. In presence of water contaminated by sand friction coefficient showed significant increase for soft rubber of triple and quadruple grooves. Friction coefficient of soft and hard rubber of quadruple grooves sliding against ceramic surfaces wetted by water and detergent showed relatively high friction. Introducing quadruple grooves in hard rubber increased friction coefficient generated from the sliding against oil lubricated ceramics. For surfaces lubricated by oil/water dilution friction coefficient showed remarkable increase.

KEYWORDS
Friction coefficient, rubber disc, grooves, ceramics.

INTRODUCTION

Slips, associated falls and injuries are prevalent among indoor walkers. Fall events occur most frequently on indoor floorings, which might be due to the difficulty of perceiving the hidden risk. Slipping might be caused by sliding between bare foot and flooring tiles. 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]. 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, [2]. If the adhesive force is solely a function of the surface free energy, it has been assumed that this adhesive force per unit area should be constant during any bulk (surface) deformation.

Arising from molecular attractive forces between two closely contact surfaces, adhesion is postulated as the primary cause of the impediment to sliding, [3]. As a result, rubber supposedly adheres to the track through interfacial bonds, which are periodically sheared by their share of the friction force and then reformed in an advanced position. A static friction model between rubber-like material and rigid asperities has been developed taking into account the viscoelastic behaviour of rubber, [4]. The friction of rubber on smooth surfaces primarily depends on adhesion, while hysteresis becomes increasingly important for rough surfaces, [5]. For a tire sliding on a road surface, dry friction was found to be entirely due to the hysteresis contribution, whereas the reduced friction in the wet condition was explained by a sealing effect of rubber, which leads to the entrapment of water in pools of the rough surface, associated with an effective reduction of surface roughness, [6]. For the slip resistance of shoe soles on floor surfaces covered by a liquid film, the drainage capability of the shoe-floor contact surface, the draping of the sole material about floor surface asperities as well as the true contact area between the surfaces are considered as key factors.

Under both non-sliding and sliding conditions, the process of interfacial energy driven dewetting has also been studied, including the situation where there exists single defect on the glass surface, [7 – 9]. A smooth glass surface is certainly much less complicated than a realistic highway surface. Other than the multi-scale asperities on the road surface, a piece of typical Portland cement concrete can have porosity of 10–20%, [10]. Recently, quantitative modeling of rubber friction on a fractal surface has been presented based on bulk viscoelastic description of material behavior, [11, 12]. Among the many proposals attempting to rationalize the benefit in wet traction from silica, [13], 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, [14]. 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, [15, 16]. 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, [17]. 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 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, [18]. 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, [19 - 21]. 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, [22]. 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, [23]. The number of sand particles on the floor may affect the friction. The largest particles dominate the effects because they will be the first ones to contact the footwear pad. While balls and rollers have been widely used in reducing friction in bearings, the friction coefficient values for different types of rolling bearing elements have been determined, [24]. 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.

The changes in the surface properties and frictional characteristics of flooring materials can be expected in practical use because they are subject to mechanical wear, ageing, soiling and maintenance, [25]. In sport halls the flooring surfaces are probably changed mainly through mechanical wear, periodic cleaning processes and material transfer from shoe soles (elastomer abrasions and dirt particles). Coefficients of friction were measured periodically over a period of 30 months on the surfaces of five types of floor coverings in a new sport complex, [26]. Surface changes through mechanical wear ranged from smoothing to roughening, [27], depending on flooring material and surface characteristics. Surface roughness was known to be a key factor in determining the slip resistance of floors.

In the present work, the effect of the grooves in the rubber disc on the static friction coefficient when sliding against ceramic surface was investigated. Friction tests were

carried out at different values of normal load, at dry and different lubricated sliding condition.

EXPERIMENTAL

The test rig used in the present work, has been 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 force and applied normal force. The ceramic surface in form of a tile was placed in a base supported by two load cells, the first measures the horizontal force (friction force) and the second for the vertical force (applied load). A digital screen was attached to the load cells to detect the friction and vertical forces. Friction coefficient was determined by the ratio between the friction force and the normal load.

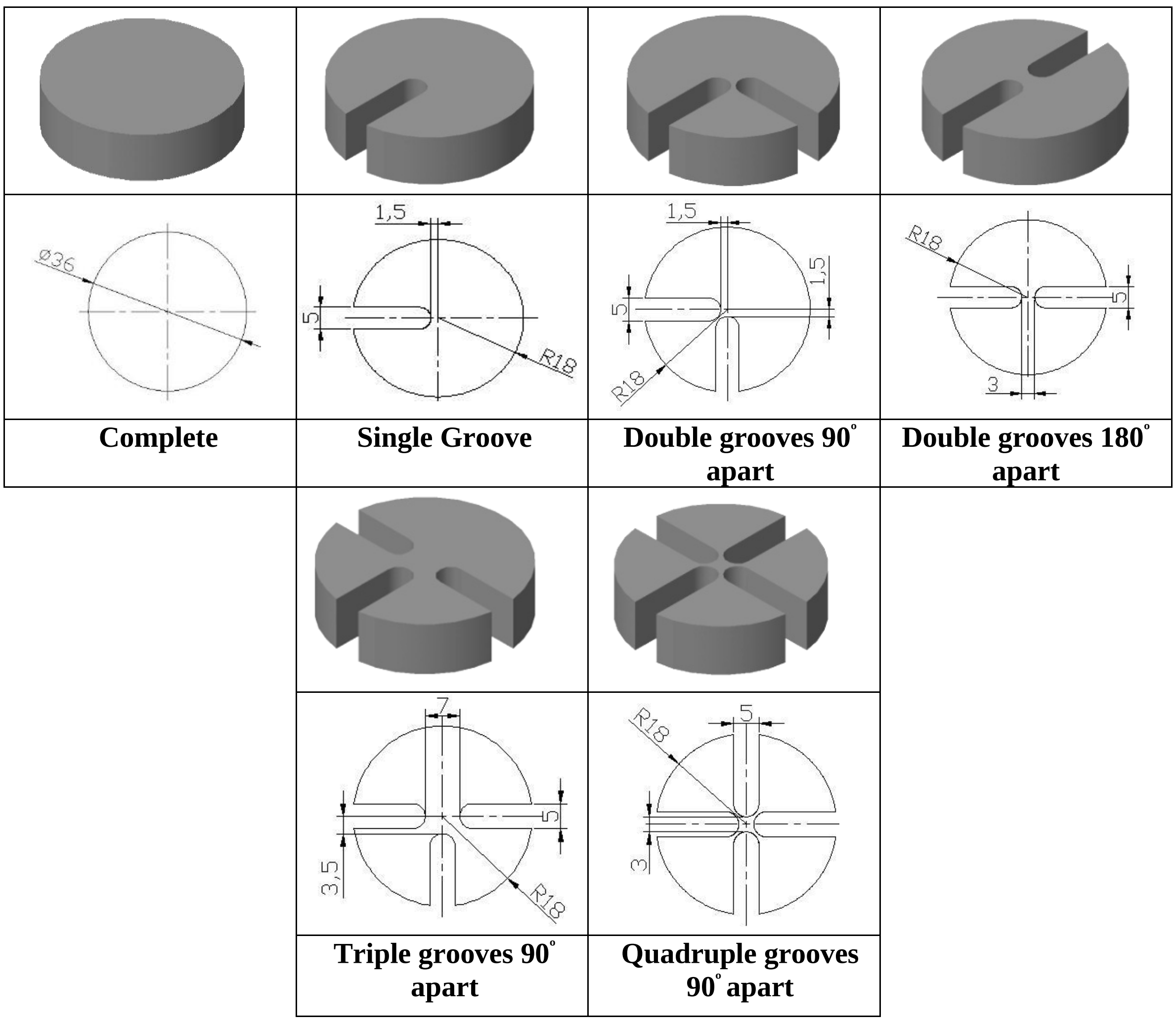

Fig. 1 Complete and grooved rubber test specimens.

The rubber test specimens prepared from tow type 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 a form of cylindrical protrusion shape with 36 mm diameter and 10 mm thickness. Test specimens were prepared by introducing grooves in the rubber specimens with different dimensions and numbers. Friction test were carried out at different values of normal 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. % soap, water + 5.0 vol. % soap 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.

RESULTS AND DISCUSSION

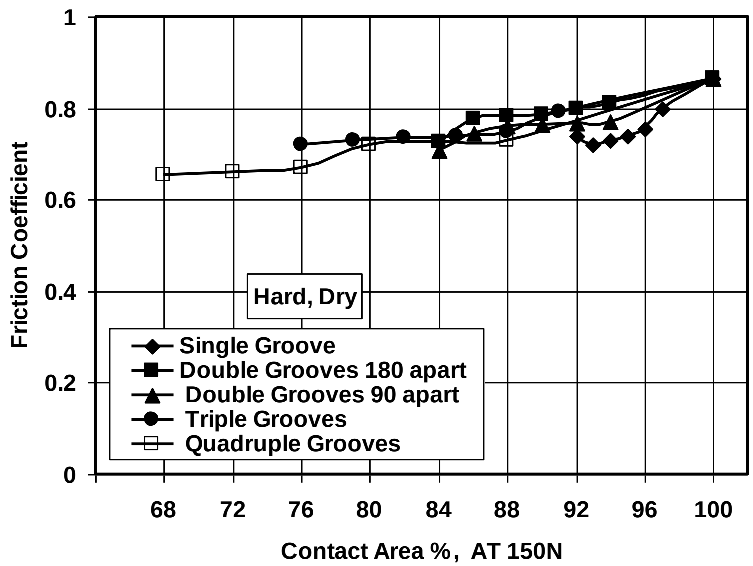

Fig. 1 Friction coefficient for rubber specimen containing different grooves sliding against ceramic surface.

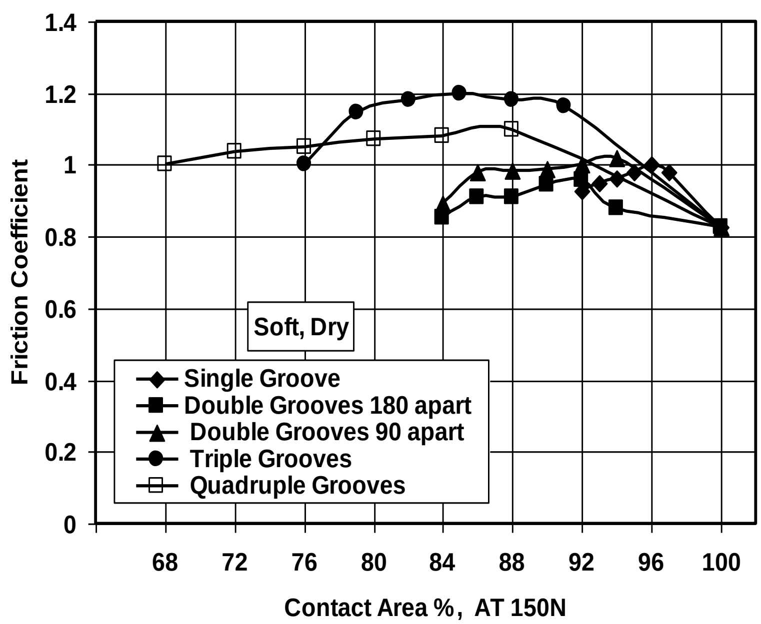

Fig. 2 Friction coefficient of soft rubber specimen containing different grooves and dry sliding against ceramic surface.

Sliding on dry ceramics is shown in Fig. 1. It can be noticed that friction coefficient increased with increasing the contact area due to the increase of adhesion between hard rubber surface and ceramic flooring. This behaviour might be attributed to the relatively increase of deformation of rubber specimens. The maximum value of friction coefficient (0.8) was obtained at 94 % contact area and double grooves 180° apart. The minimum value of friction coefficient (0.62) was observed at 68 % contact area and quadruple grooves.

The dry sliding of soft rubber specimens against ceramic surfaces is shown in Fig. 2. Friction coefficient increased up to maximum values then decreased with increasing contact area. It seems that the deformation increase was the reason for the friction coefficient increase, while friction decrease could be related to the limitation of rubber deformation and the reduction in contact area that decreased adhesion between rubber and ceramics. The maximum value of friction coefficient (1.2) was observed at 85 % contact area and triple grooves. The minimum value of friction coefficient (0.81) was observed at rubber specimens of 100 % contact area.

Friction coefficient of hard rubber specimens sliding against ceramics surface wetted by water is shown in Fig. 3. It is observed that friction coefficient decreased with increasing contact area. The increased trend in friction coefficient was attributed to the ability of water to leak from the sliding surface through the grooves in rubber surface, where water leakage changed the condition of surface from water wetted to dry. Further decrease in contact area showed slight decrease in friction coefficient. This might be related to the reduction of adhesion between rubber and ceramics. Maximum value of friction coefficient (0.29) was observed at 94 % contact area and double grooves 90° apart, while minimum value (0.14) was obtained at rubber specimen of 100 % contact area.

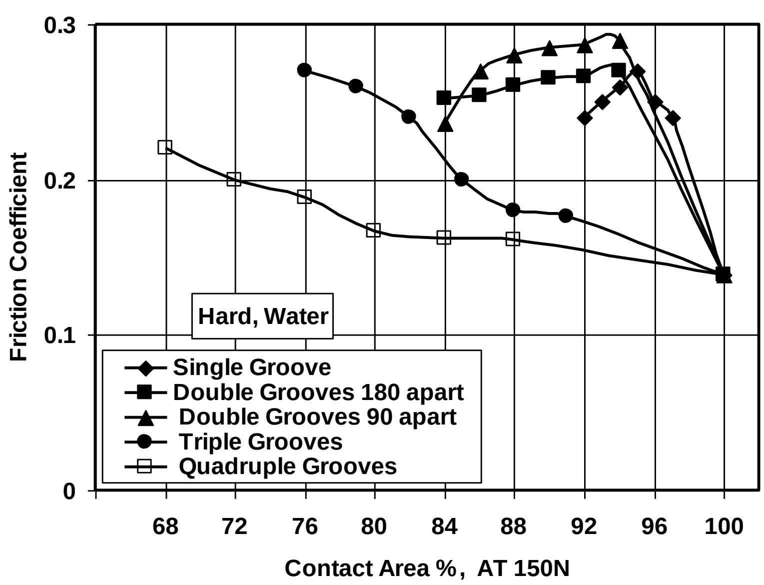

Fig. 3 Friction coefficient for rubber specimen containing different grooves and sliding against ceramic surface.

Figure 4 shows friction coefficient of rubber specimens sliding against ceramic surfaces wetted by water. It can be observed that friction coefficient decreased with increasing contact area. This behaviour could be related to the increasing number of grooves in rubber surface that facilitated easy escape of water from contact area to the grooves. A maximum friction coefficient (0.29) was obtained at 76 % contact area and triple grooves, while minimum value (0.15) was obtained at rubber specimens of 100 % contact area.

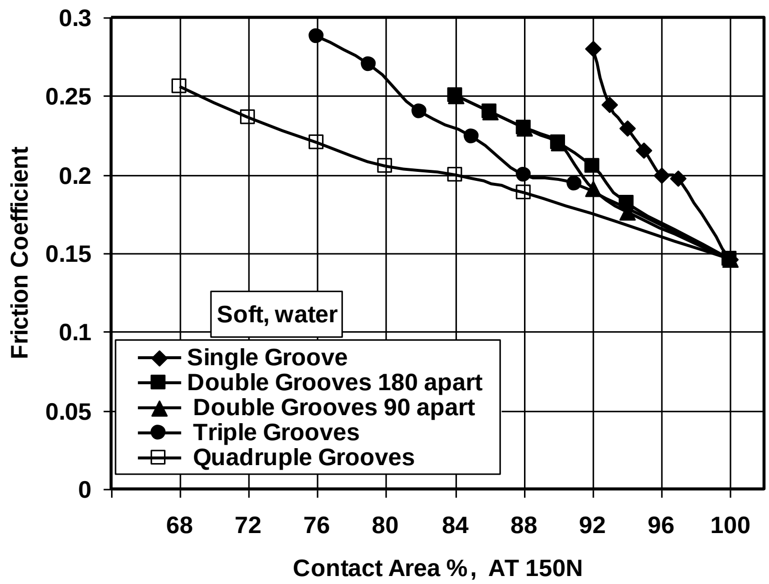

Fig. 4 Friction coefficient of soft rubber specimen containing different grooves and sliding against ceramic surface.

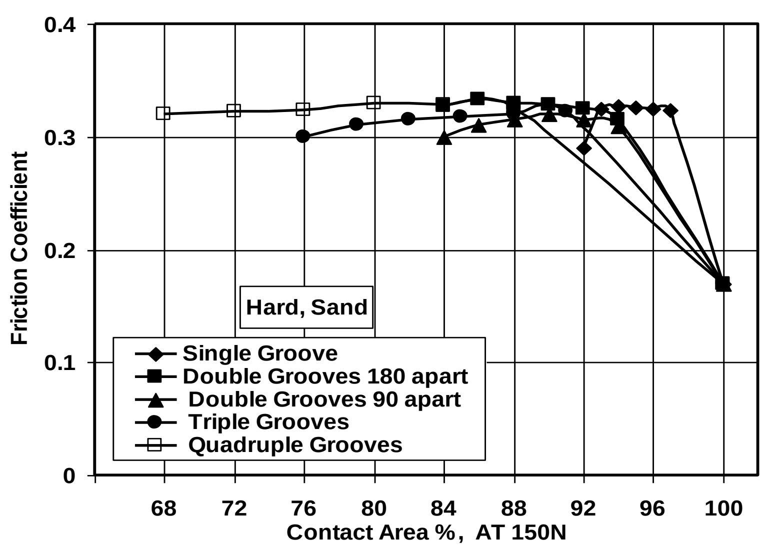

Fig. 5 Friction coefficient of hard rubber specimen containing different grooves and sliding against ceramic surface.

Figure 5 shows friction coefficient of hard rubber specimens sliding against ceramic surface contaminated by sand. Generally, friction coefficient decreased with increasing contact area due to the ability of sand particles to embed in rubber surface, where the contact became between sand particles and rubber as well as ceramic. A maximum value of friction coefficient (0.33) was obtained at 80 % contact area and quadruple grooves. Minimum value of friction coefficient (0.17) was observed at rubber specimens of 100 % contact area.

For soft rubber test specimens friction coefficient increased with increasing contact area, Fig. 6. This behaviour was attributed to sand particles partially embedded in rubber surface. Friction decreased as the contact area decreased and consequently adhesion between rubber and ceramics decreased. Maximum value of friction coefficient (0.28) was observed at rubber specimens of 100 % contact area. Minimum value of friction coefficient (0.16) was observed at 88 % contact area and quadruple grooves.

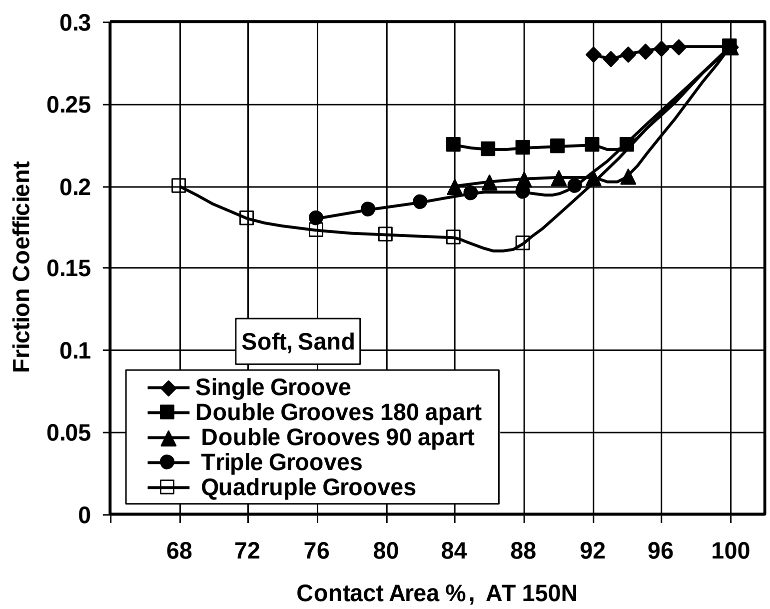

Fig. 6 Friction coefficient soft rubber specimens containing different grooves and sliding against ceramic surface.

Friction coefficient of hard rubber specimens sliding against ceramic surface wetted by water and contaminated by sand is shown in Fig. 7. In the presence of sand in water, friction coefficient increased for rubber surface free of grooves, where water facilitated sand particles to roll away from the contact area. Generally, friction coefficient slightly decreased with increasing contact area because of the rolling of sand particles and leakage of water to the grooves in rubber surface. The maximum value of friction coefficient (0.33) was observed at 68 % contact area and quadruple grooves, while minimum value (0.3) was obtained at rubber specimens free of grooves.

Friction coefficient for rubber specimens sliding against ceramic surfaces wetted by water and contaminated by sand is shown in Fig. 8. In presence of water with sand friction coefficient shows significant increase compared to sand sliding. It seems that water was trapped in the contact area of rubber specimen free of grooves, while introducing grooves in the rubber surface facilitated the water to leak from contact area. Generally, it is observed that, the friction coefficient decreased with increasing contact area. A maximum friction coefficient (0.38) was obtained for 88 % contact area at triple and quadruple grooves, while minimum value (0.28) was obtained at 92 % contact area of single groove.

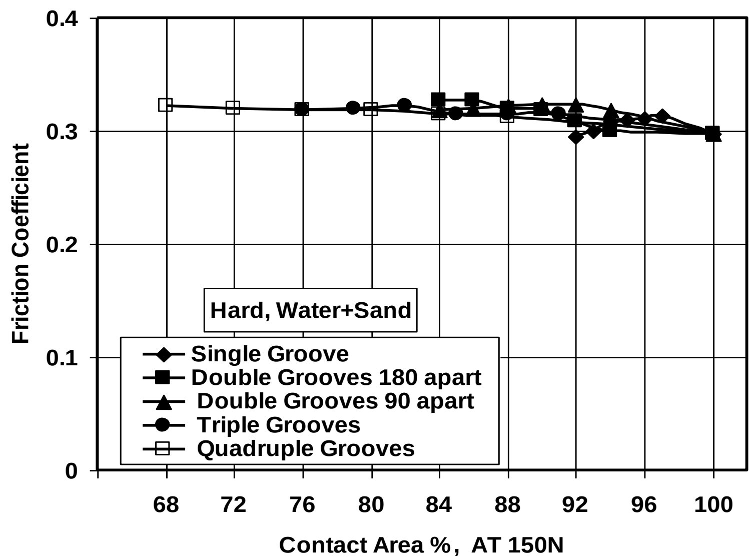

Fig. 7 Friction coefficient of hard rubber specimen containing different grooves and sliding against ceramic surface.

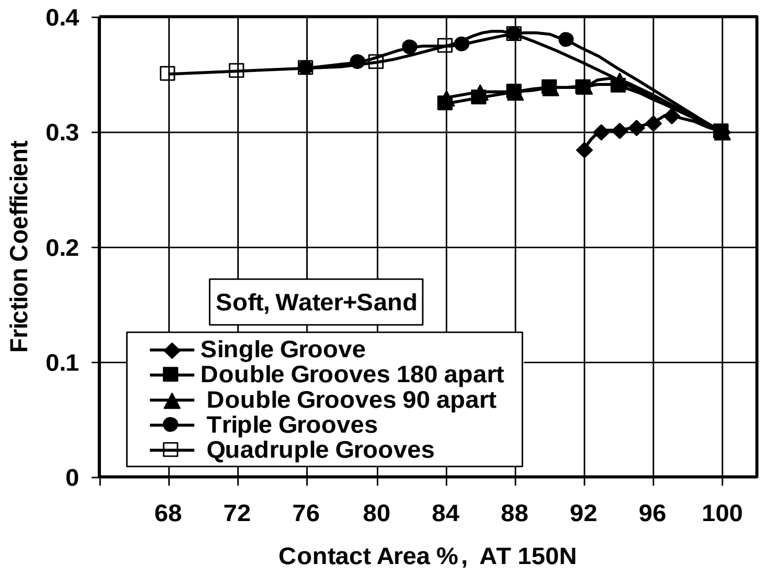

Fig. 8 Friction coefficient of soft rubber specimen containing different grooves and sliding against ceramic surface.

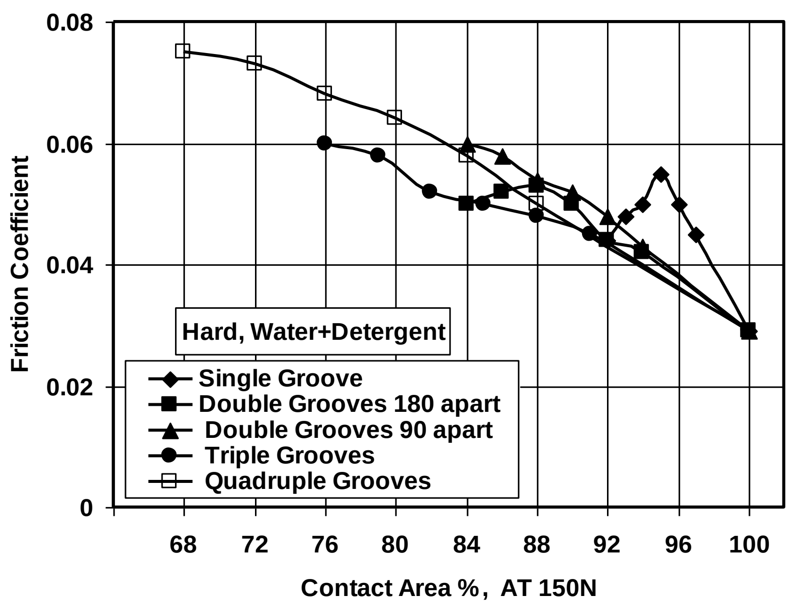

Fig. 9 Friction coefficient for rubber specimen containing different grooves and sliding against ceramic surface.

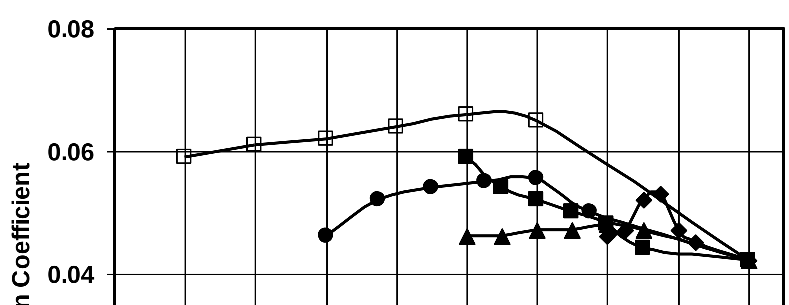

Fig. 10 Friction coefficient for rubber specimen containing different grooves and sliding against ceramic surface.

Friction coefficient for rubber specimens sliding against ceramic surfaces lubricated by water and detergent is shown in Fig. 9. It can be noticed that, the friction coefficient decreases with increasing contact area, as the number of grooves increase friction coefficient increasing due to the easy leakage of lubricating medium from the contact area. The maximum value of friction coefficient (0.075) was observed at 68 % contact area and quadruple grooves, while minimum value (0.027) was obtained at rubber specimen free of grooves.

Figure 10 shows friction coefficient of rubber specimens sliding against ceramic surfaces wetted by water and detergent. It can be noticed that friction coefficient decreased with increasing contact area. As the number of grooves increased the ability of lubricant medium to escape from contact area increased. Values of friction coefficient decreased compared to water sliding. This was attributed to the strong adhesion of detergent on rubber surface. Maximum value of friction coefficient (0.07) was observed at 84 % contact area for quadruple grooves, while minimum value of (0.04) was obtained at rubber specimen free of grooves.

Figure 11 shows the friction coefficient for hard rubber specimens sliding against ceramic surfaces wetted by water/detergent dilution and contaminated by sand. Generally, friction coefficient slightly decreased with increasing contact area. The number of grooves was insignificant on friction coefficient. A maximum value of friction coefficient (0.4) was observed at 97 % contact area of single groove, while minimum value (0.34) was obtained at 84 % contact area and double grooves 90° apart.

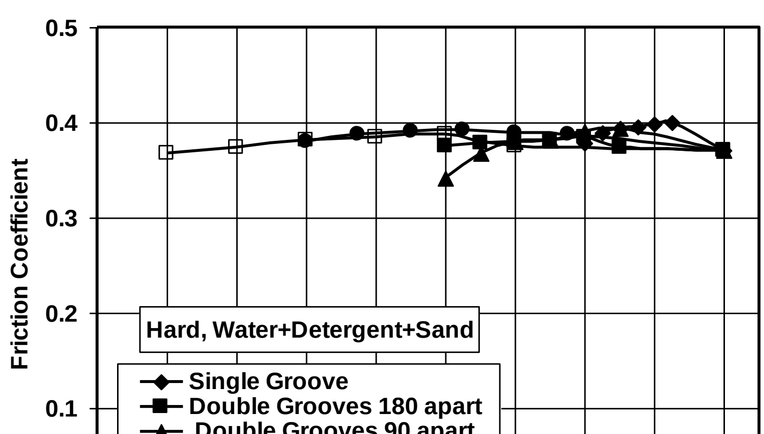

Fig. 11 Friction coefficient of hard rubber specimen containing different grooves and sliding against ceramic surface.

Friction coefficient for rubber specimens sliding against ceramic surfaces wetted by water/detergent dilution and contaminated by sand is shown in Fig. 12. Friction coefficient slightly increased with increasing contact area up to maximum value then decreased with increasing contact area. This behaviour can be related to the water/detergent dilution leakage to the grooves in rubber surface and sand particles were partially embedded in rubber surface. Further decrease in contact area decreased adhesion between rubber and ceramic. A maximum friction coefficient (0.36) was observed at 88 % contact area of triple grooves, while minimum value (0.3) was obtained at 84 % contact area of double grooves 90° apart.

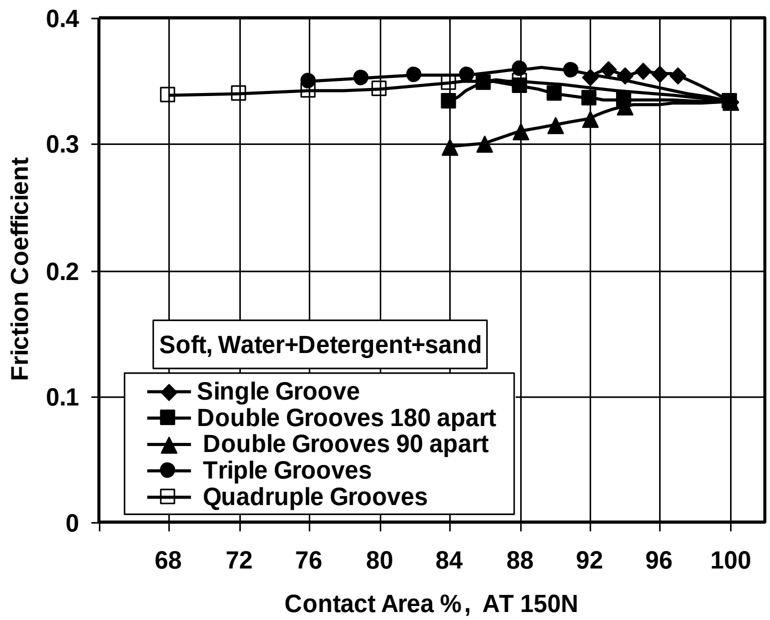

Fig. 12 Friction coefficient of soft rubber specimen containing different grooves and sliding against ceramic surface.

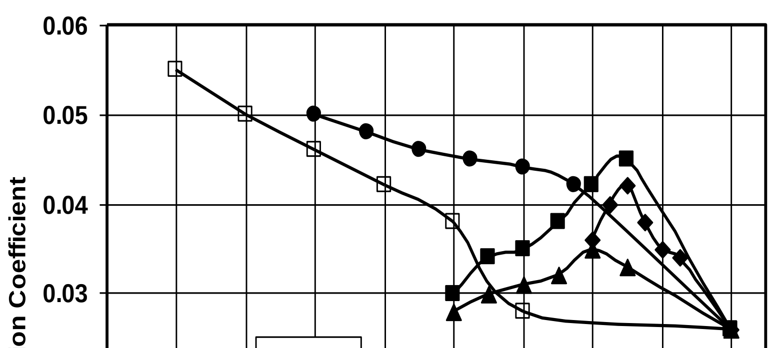

Fig. 13 Friction coefficient of hard rubber specimens containing different grooves and sliding against ceramic surface.

Friction coefficient generated from the sliding of hard rubber against oil lubricated ceramics is shown in Fig. 13. Friction coefficient decreased with increasing contact area. As number of grooves increased the ability of oil to escape from contact area increased. At double grooves friction coefficient increased up to maximum values then decreased with increasing contact area. This might be related to trapping of oil between rubber and ceramics. Maximum value of friction coefficient (0.055) was observed at 68 % contact area and quadruple grooves, while minimum value of friction coefficient (0.026) was obtained at rubber specimens free of grooves.

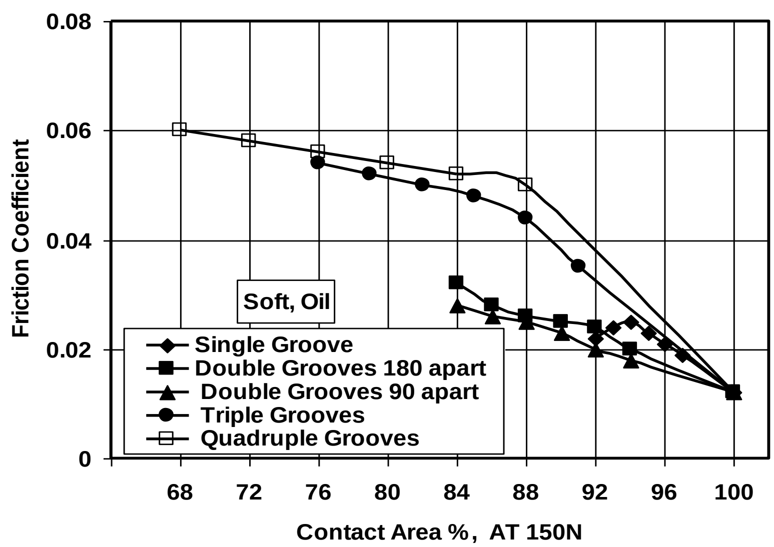

Fig. 14 Friction coefficient for rubber specimen containing different grooves sliding against ceramic surface.

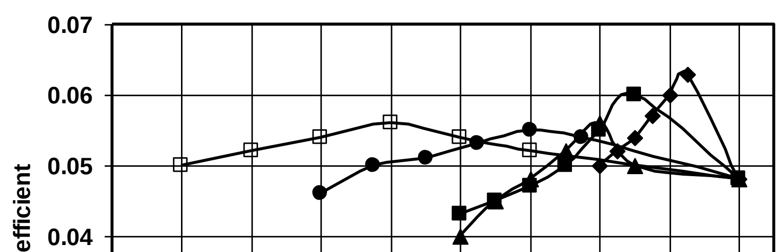

Fig. 15 Friction coefficient of hard rubber specimens containing different grooves and sliding against ceramic surface.

Figure 14 shows friction coefficient displayed by rubber specimens sliding against ceramic surfaces lubricated by oil. In presence of oil rubber specimens free of grooves showed the lowest values of friction coefficient, where it decreased with increasing contact area. This behaviour could be interpreted on the action of grooves that allowed oil leakage from contact area to the grooves. Maximum value of friction coefficient (0.06) was observed at 68 % contact area of quadruple grooves, while minimum value (0.012) was obtained at rubber specimen free of grooves. Figure 15 shows friction coefficient of rubber specimens sliding against ceramic surfaces lubricated by oil/water dilution. It can be noticed that, friction coefficient increased up to maximum values then decreased with increasing contact area. It seems that water decreased adhesion between rubber and oil. This behaviour helped to leak lubricant medium from contact area. Maximum value of friction coefficient (0.062) was observed at 97 % contact area of single groove, while minimum value (0.04) was achieved at 84 % contact area of double grooves 90° apart.

Figure 16 shows friction coefficient of soft rubber specimens sliding against ceramic surfaces lubricated by oil/water dilution. Friction coefficient increased up to maximum then decreased with increasing contact area. It seems that, increasing number of grooves allowed the lubricant to escape from contact area and decreased the ability of rubber to be adhered by oil/water dilution. As the groove length increased water/oil dilution could go in the pores located at the sides of the grooves and feed the fluid back to the contact area. Friction coefficient of rubber specimens sliding against ceramic surfaces lubricated by oil contaminated by sand is shown in Fig. 17. Generally, it is observed that friction coefficient slightly decreased with increasing contact area. This behavior was attributed to the grooves in rubber surface that increased the ability of oil to leak from contact area and sand particles were embedded in rubber surface. A maximum value of friction coefficient (0.11) was observed at 76 % contact area of quadruple grooves, while minimum value (0.09) was obtained at rubber specimens free of grooves.

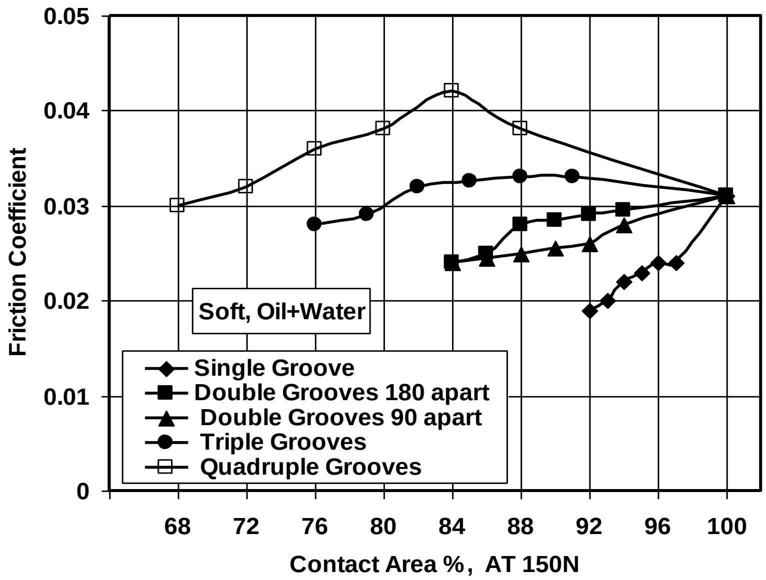

Fig. 16 Friction coefficient of soft rubber specimens containing different grooves and sliding against ceramic surface.

Friction coefficient of soft rubber specimens sliding against ceramic surfaces lubricated by oil contaminated by sand is shown in Fig. 18. It can be noticed that friction coefficient slightly increased with increasing contact area because due to the presence of the grooves that leaked oil from contact area. Maximum value of friction coefficient (0.18) was observed at 82 % contact area of triple grooves. The minimum value of friction coefficient (0.102) was obtained at rubber specimens free of grooves.

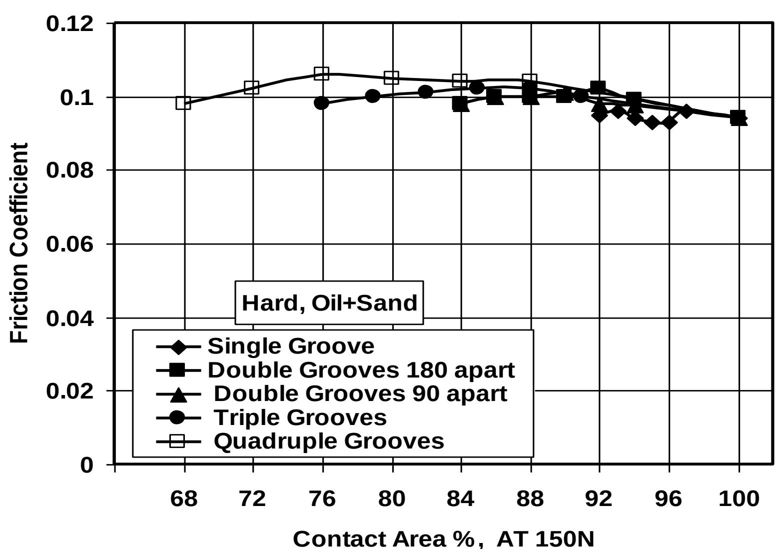

Fig. 17 Friction coefficient for rubber specimen containing different grooves sliding against ceramic surface.

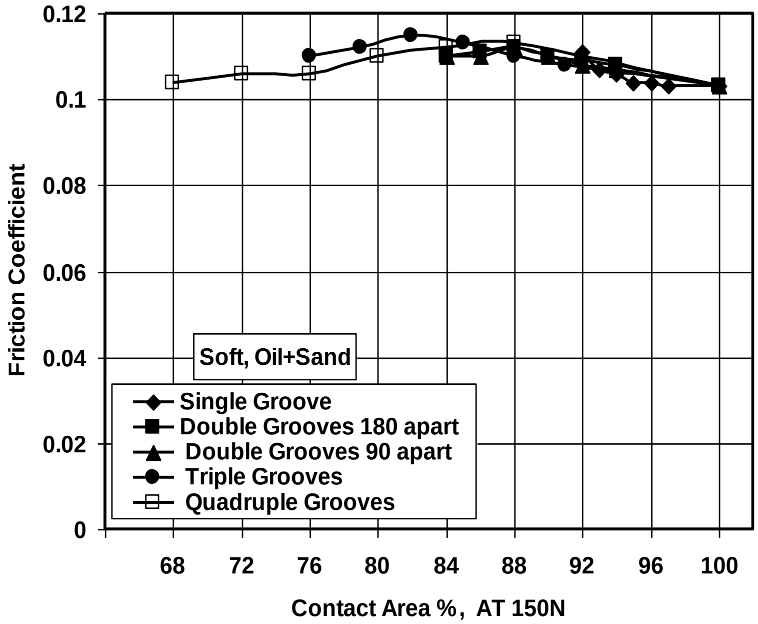

Fig. 18 Friction coefficient for rubber specimen containing different grooves and sliding against ceramic surface.

Friction coefficient of rubber specimens sliding against ceramic surfaces lubricated by oil, water and contaminated by sand is shown in Fig. 19. Friction coefficient slightly increased with increasing contact area. Maximum value of friction coefficient (0.37) was observed at 94 % contact area of single groove, while minimum value (0.32) was achieved at 84 % contact area and double grooves 90° apart.

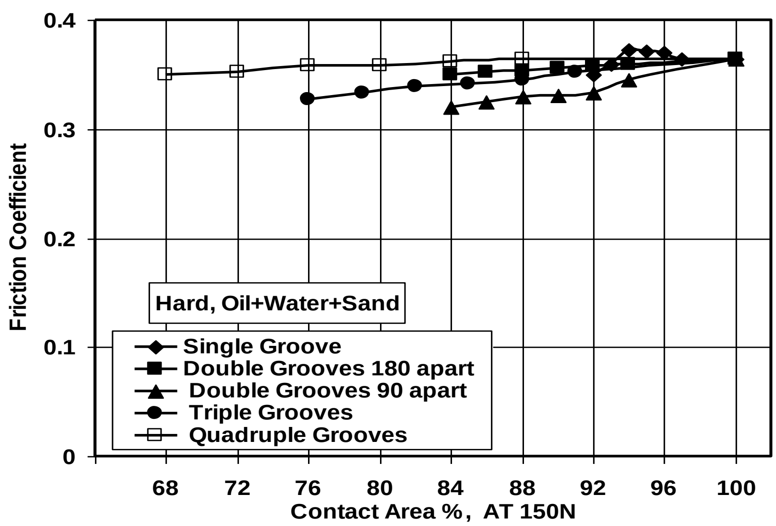

Fig. 19 Friction coefficient of rubber specimen containing different groovesand sliding against ceramic surface.

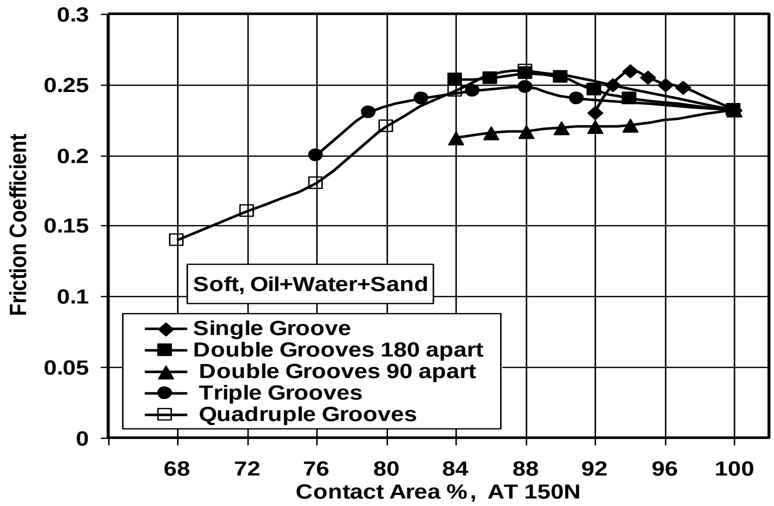

Fig. 20 Friction coefficient for rubber specimen containing different grooves and sliding against ceramic surface.

Friction coefficient for rubber specimens sliding against ceramic surfaces lubricated by oil, water and contaminated by sand is shown in Fig. 20. Friction coefficient increased up to maximum values then decreased with increasing contact area. Maximum friction coefficient (0.36) was observed at 88 % contact area of quadruple grooves, while minimum value (0.14) was obtained at 68 % contact area of quadruple grooves.

CONCLUSIONS

1. Dry sliding caused an increase in friction coefficient for hard rubber, while friction coefficient of soft rubber increased up to maximum values then decreased with increasing contact area. The highest values were represented by triple grooves rubber discs.

2. Friction coefficient of hard and soft rubber specimens sliding against ceramics surface wetted by water decreased with increasing contact area. The highest friction values were displayed by double grooves rubber.

3. Friction coefficient of hard rubber specimens sliding against ceramic surface contaminated by sand decreased with increasing contact area. For soft rubber friction coefficient increased with increasing contact area.

4. In the presence of sand in water friction coefficient increased for hard rubber surface free of grooves. In presence of water contaminated by sand friction coefficient shows significant increase compared to sand sliding for soft rubber. Triple and quadruple grooves showed the highest friction.

5. Friction coefficient of rubber specimens sliding against ceramic surfaces wetted by water and detergent decreased with increasing contact area.

6. Friction coefficient for hard rubber specimens sliding against ceramic surfaces wetted by water/detergent dilution and contaminated by sand slightly decreased with increasing contact area. For soft rubber friction coefficient slightly increased with increasing

contact area up to maximum value then decreased with increasing contact area. Quadruple grooves showed the highest friction.
7. Friction coefficient generated from the sliding of hard rubber against oil lubricated ceramics decreased with increasing contact area. Soft rubber displayed friction values decreased with increasing contact area. Quadruple grooves showed the highest friction.
8. Friction coefficient of hard and soft rubber specimens sliding against ceramic surfaces lubricated by oil/water dilution increased up to maximum values then decreased with increasing contact area. Quadruple grooves showed the highest friction.
9. Friction coefficient of rubber specimens sliding against ceramic surfaces lubricated by oil contaminated by sand slightly decreased with increasing contact area. For soft rubber friction showed slight increase.
10. Friction coefficient of rubber specimens sliding against ceramic surfaces lubricated by oil, water and contaminated by sand slightly increased with increasing contact area. For soft rubber friction coefficient increased up to maximum values then decreased with increasing contact area.

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