EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 11, NO. 2, April 2014, pp. 21 - 38 ISSN 2090 - 5882

FRICTION COEFFICIENT OF GROOVED RUBBER DISC SLIDING AGAINST CERAMICS: II. EFFECT OF LOAD

Samy A. M.[1], Khashaba M. I.[1] and Ali W. Y.[2]

[1]Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT
[2]Faculty of Engineering, Taif University, Al –Taif, Saudi Arabia.

ABSTRACT
The effect of applied load on the static friction coefficient displayed by rubber disc fitted by single groove sliding against ceramics is investigated. 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 height. Test specimens were prepared by introducing single groove with different dimensions. The ceramic surface roughness was 0.14 µm Ra.

Friction tests were carried out at 50, 100, 150 and 200 N loads. 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.

It was found that for dry sliding against ceramics, friction coefficient slightly increased with increasing load. For soft rubber friction coefficient slightly decreased with increasing normal load. In the presence of sand friction coefficient slightly decreased with increasing applied load. For soft rubber load had no effect on the values of friction coefficient. Load has no effect on the friction coefficient displayed by hard rubber specimens sliding against ceramic surface lubricated by water contaminated by sand.

In the presence of detergent friction coefficient decreased with increasing normal load. For hard and soft rubber specimens sliding against ceramics wetted by water and detergent contaminated by sand friction coefficient increased with increasing applied load. Friction coefficient generated from sliding of rubber against oil lubricated ceramic surfaces decreased with increasing normal load. Friction coefficient for rubber test specimens sliding against ceramic surface lubricated by oil and contaminated by sand decreased with increasing normal load. For rubber specimens sliding against ceramic surface lubricated by oil/water dilution and contaminated by sand load showed insignificant effect on friction coefficient.

KEYWORDS

Friction coefficient, rubber disc, groove, ceramics, load.

INTRODUCTION

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, [1]. 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.

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, [2]. Based on the experimental results, 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, [3]. 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 displayed by 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, [4]. 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, [5]. 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.

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, [6]. 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, [7]. 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, [8]. 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, [9]. The friction of rubber on smooth surfaces primarily depends on adhesion, while hysteresis becomes increasingly important for rough surfaces, [10]. 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, [11]. 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.

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, [12 - 14]. It was observed that, dry sliding of the rubber test specimens displayed the highest value of friction coefficient. For water lubricated ceramics, the value of the friction coefficient decreased compared to dry sliding. For oil lubricated ceramic, friction coefficient decreased with increasing height of the grooves introduced in the rubber specimens. 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, [15]. It was observed that, at dry sliding, friction coefficient decreased with increasing surface roughness and applied load.

The factors affecting friction coefficient measurement: the material and surface geometry of the footwear and floor, floor contamination conditions and even the slipmeter used, [16, 17]. The effect of surface roughness of ceramic on the friction coefficient, when rubber and leather are sliding against it, was investigated, [18]. 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.

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, [19]. 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 have been widely used in reducing friction in bearings, the friction coefficient values for different types of rolling bearing elements have been determined, [20]. 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.

In the present work, the effect of load applying on the rubber disc containing single groove on the static friction coefficient when sliding against ceramic surface was investigated.

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, [3]. 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 vertical force (applied load). Two digital screens 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 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 form of cylindrical protrusion shape with 36 mm diameter and 10 mm thickness. Test specimens were prepared by introducing grooves in the rubber specimens of different lengths.

Friction test were carried out at 50, 100, 150 and 200 N loads. 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. The sand used in experiments was silicon oxide ($Si\ O_2$) of 0 – 1.0 mm particle size.

RESULTS AND DISCUSSION

For dry sliding against ceramics, Fig. 1, it can be noticed that friction coefficient slightly increased with increasing load. It is commonly known that as load increased friction coefficient decreased for elastomer materials. This contradiction can be attributed to the deformation increase of hard rubber. This behaviour caused an increase in contact area with load increase. A maximum value of friction coefficient was observed at smooth rubber test specimens due to the increase of the adhesion. For soft rubber, it can be noticed that friction coefficient slightly decreased with increasing normal load. Friction coefficient increased up to maximum then decreased with increasing load. The reason for the rise in friction was attributed to the increase in contact area. The decrease in friction was possibly due to heat generated during sliding at load higher than a critical value. If the temperature was high enough, a layer of low shear strength material will be

expected to be formed at the interface which would provide low values of friction coefficient. A maximum value of friction coefficient (1.15) was observed at 50 N normal load and 92 % contact area. The minimum value of friction coefficient (0.8) was observed at 200 N normal load and rubber specimens of 100 %.

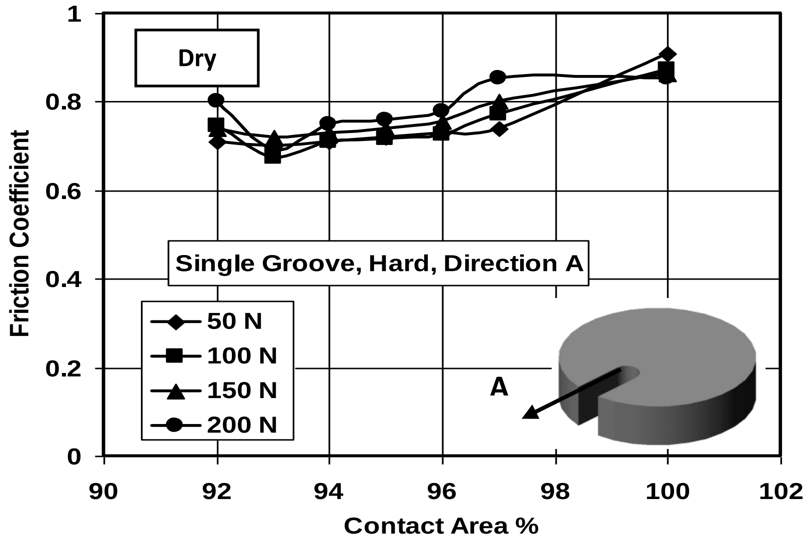

Fig. 1 Friction coefficient of hard rubber sliding against ceramic surface.

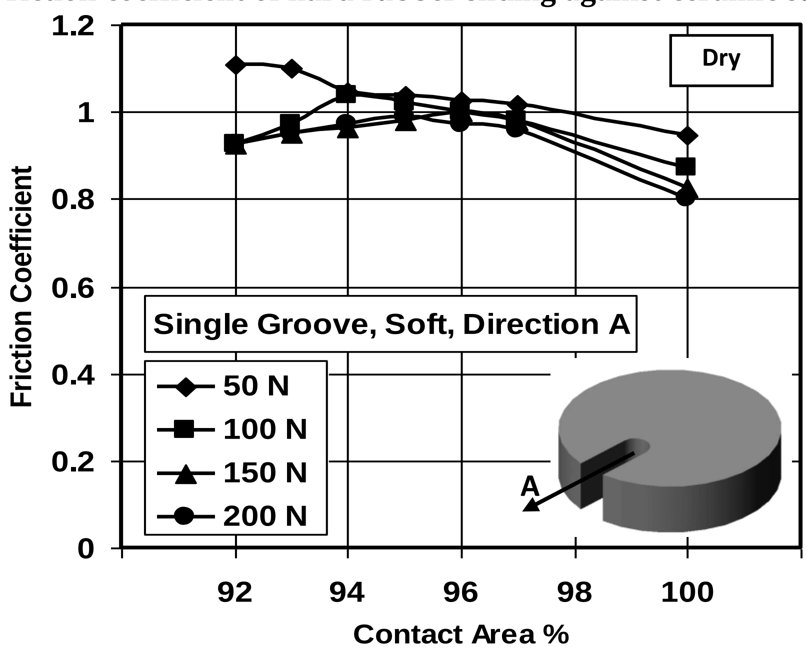

Fig. 2 Friction coefficient of soft rubber sliding against ceramic surface.

Friction coefficient for rubber specimen, when sliding against ceramics lubricated by water is shown in Fig. 3. Values of friction coefficient were much lower than that observed for dry sliding. It can be noticed that, friction coefficient increased with decreasing contact area. The increased friction coefficient was attributed to the ability of water to leak from the sliding surface through the groove in the rubber surface, where water leakage changed the condition of surface from water lubricated to dry one. At

higher loads friction coefficient decreased because water was trapped in the contact area. The maximum value of friction coefficient (0.42) was observed at 93 % contact area and 50 N normal load, while minimum value (0.12) was observed at rubber specimens of 100 % contact area at 200 N normal load. Wetted ceramic surface by water is shown in Fig. 3. Values of friction coefficient are much lower than that observed for dry sliding. Generally, friction coefficient decreased with increasing normal load, where lower load increased the ability of water to leak from the sliding surface, but at higher loads friction coefficient decreased because water was trapped in contact area. The maximum value of friction coefficient (0.38) was detected at 50 N normal load and 92 % contact area, while the minimum value (0.12) was observed at 200 N normal load and rubber specimens of 100 % contact area.

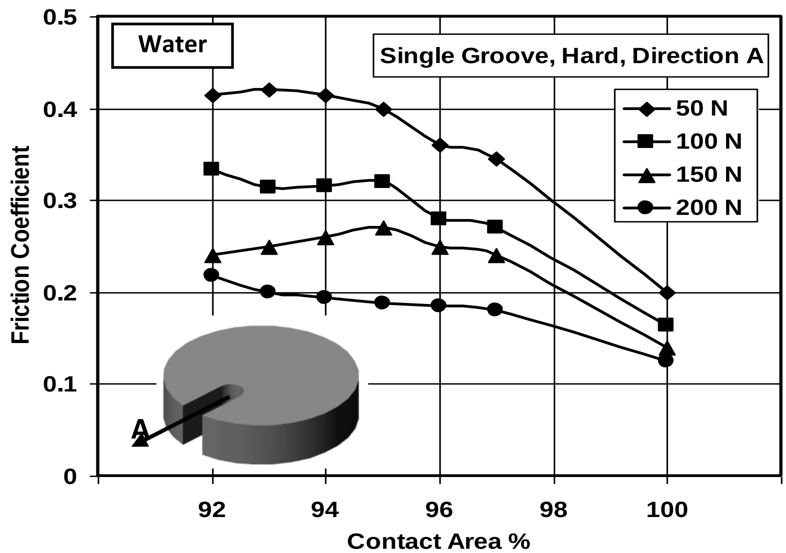

Fig. 3 Friction coefficient of rubber sliding against water wetted ceramic surface.

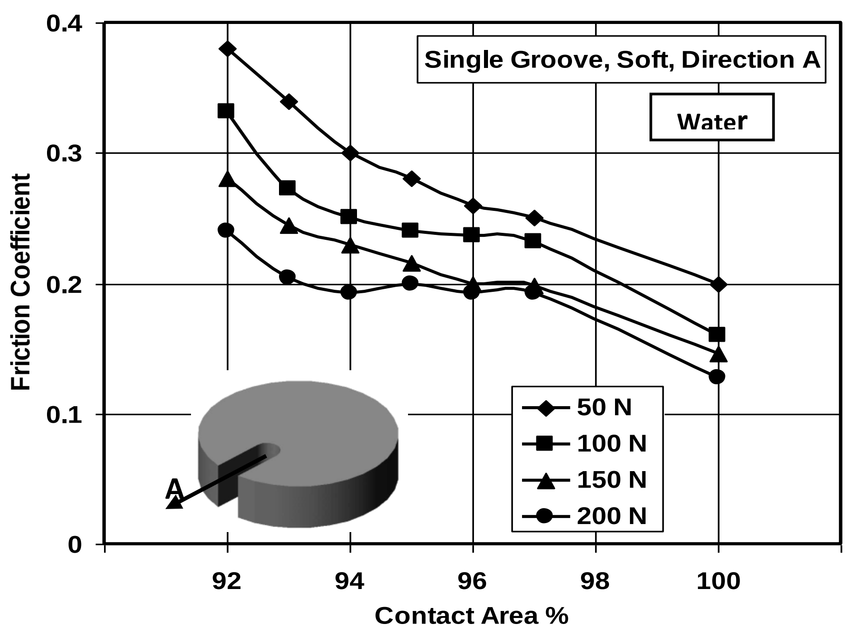

Fig. 4 Friction coefficient of soft rubber sliding against water wetted ceramic surface.

Friction coefficient for rubber specimens sliding against ceramics contaminated by sand is shown in Fig. 4. Friction coefficient slightly decreased with increasing applied load. At lower load some of sand particles were embedded in rubber surface, while the rest were displaced from the contact area to the groove in the rubber surface. At higher load sand particles were trapped in the contact area. This behaviour could lead to decreasing friction coefficient. The maximum value of friction coefficient (0.36) was obtained at 94 % contact area and 50 N normal load. Minimum value of friction coefficient (0.17) was observed at rubber specimens of 100 % contact area and 200 N normal load.

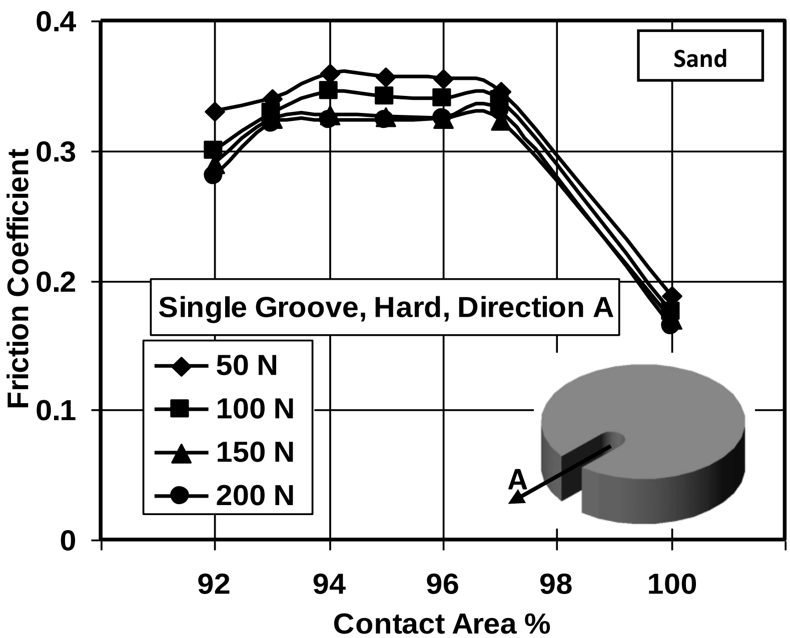

Fig. 5 Friction coefficient of hard rubber sliding against sand contaminated ceramic surface.

Friction coefficient for rubber specimens sliding against ceramics contaminated by sand is shown in Fig. 6. It can be noticed that, values of friction coefficient suggested that the contact was between sand particles and ceramic. Based on the suggestion, sand was embedded in rubber and slid against ceramic. The load had no effect on the values of friction coefficient. The maximum value of friction coefficient (0.31) was observed at 50 N normal load and 97 % contact area.

Figure 7 shows friction coefficient of hard rubber specimens sliding against ceramic surface lubricated by water contaminated by sand. It can be noticed that increasing applied load has no effect on the friction coefficient. It seems that sand particles were

embedded in rubber and abraded ceramic surface. Values of friction coefficient for smooth rubber increased compared to the presence of sand, because water increased the embedment of sand particles in rubber surface. Maximum value of friction coefficient (0.34) was achieved at 92% contact area and 50 N normal load, while minimum value (0.28) was observed at complete rubber specimens and 200 N normal load.

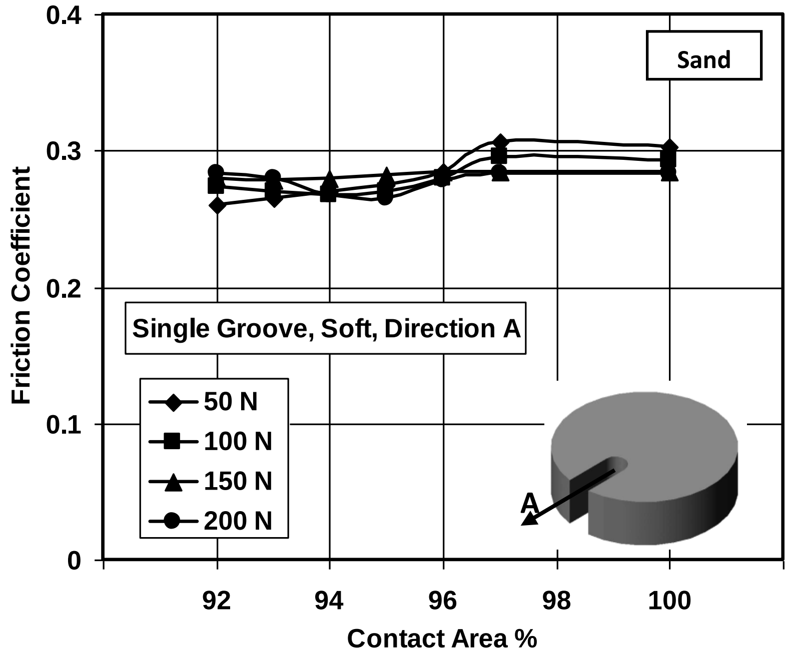

Fig. 6 Friction coefficient of hard rubber sliding against ceramic surface.

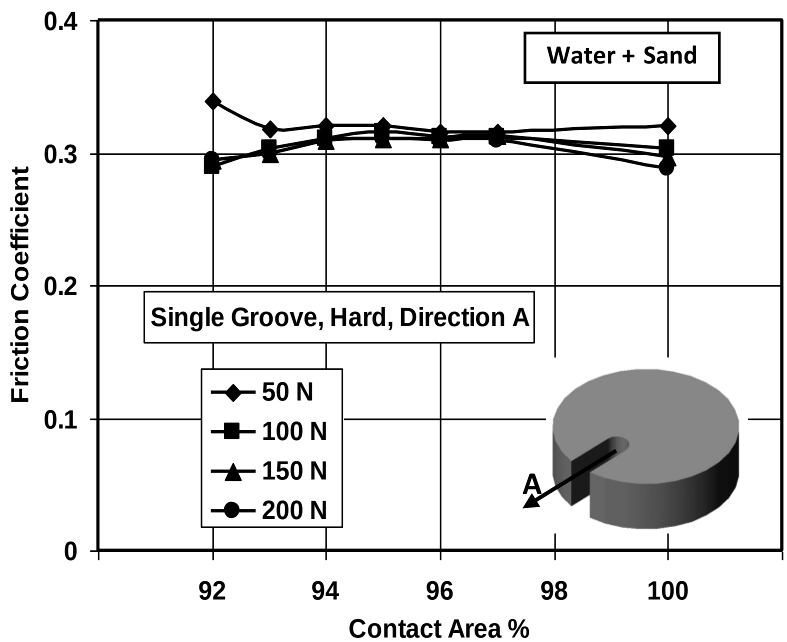

Fig. 7 Friction coefficient of hard rubber specimen sliding against ceramic surface wetted by water and contaminated by sand

In the presence of water wetted ceramic and contaminated by sand, Fig. 8 showed no effect on friction coefficient. The contact was between sand and ceramic. The maximum value of friction coefficient (0.34) was achieved at 50 N normal load and 97 % contact area, while minimum value of friction coefficient (0.28) was obtained at all normal loads and contact area 92%.

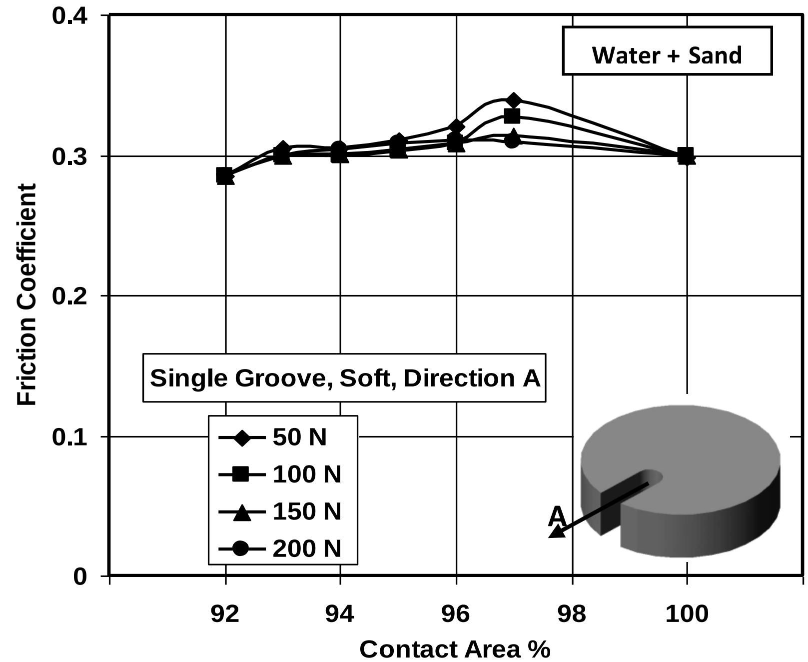

Fig. 8 Friction coefficient of soft rubber sliding against ceramic surface wetted by water and contaminated by sand.

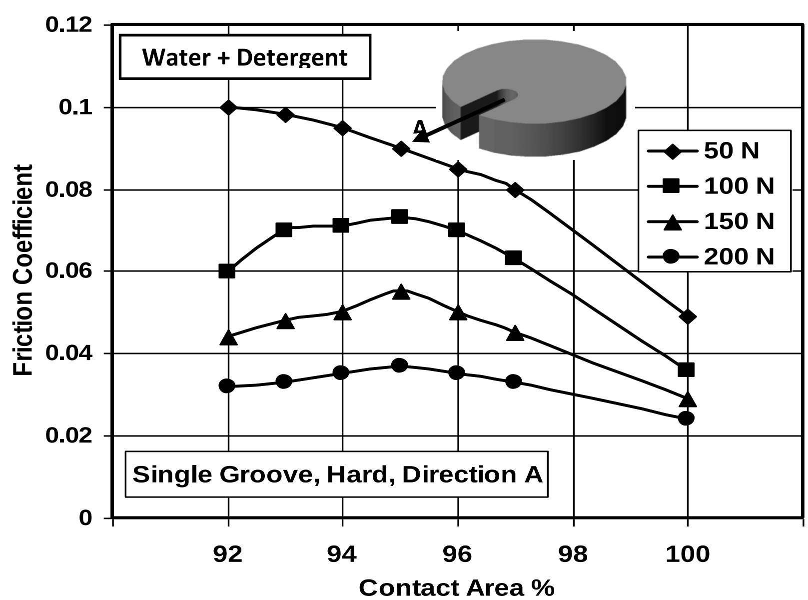

Fig. 9 Friction coefficient of rubber sliding against ceramic surface wetted by water and detergent.

Friction coefficient for rubber specimens sliding against ceramics wetted by water and detergent is shown in Fig. 9. It is observed that friction coefficient decreases with increasing normal load. This behaviour can be interpreted on the base that as the load increases the emulsion was trapped in the contact area. At relatively lower loads the emulsion could easily leak from the contact area. The maximum value of friction coefficient (0.1) was obtained at 92 % contact area and 50 N normal load. The minimum value of friction coefficient (0.025) was observed at rubber specimen of 100 % contact area and 200 N normal load.

Friction coefficient for rubber specimens sliding against ceramics surface wetted by water and detergent is shown in Fig. 10. It is observed that friction coefficient decreased with increasing normal load. Friction coefficient decreased at high loads because the lubricating medium was trapped between rubber and ceramic surface. The maximum value of friction coefficient (0.08) was obtained at 50 N normal load and 92 % contact area. Minimum value of friction coefficient (0.035) was observed at 200 N normal load and 92 % contact area.

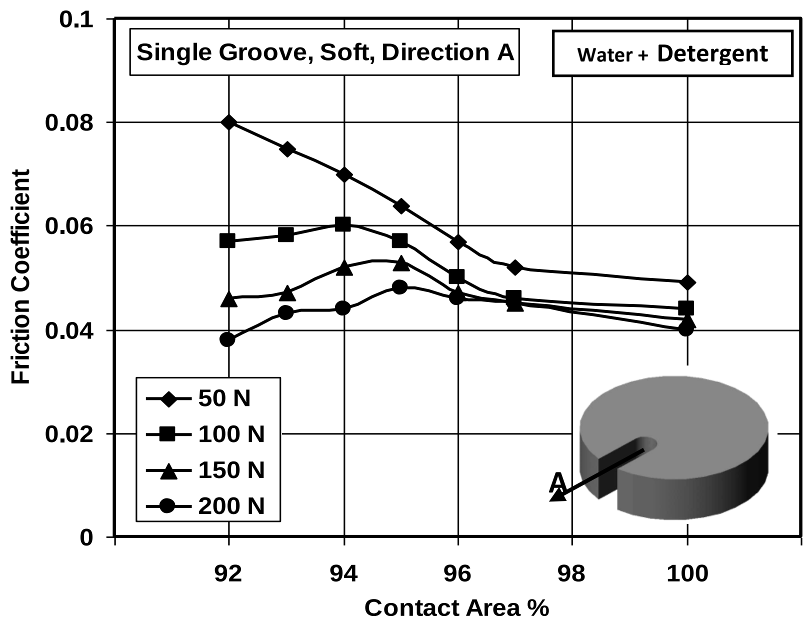

Fig. 10 Friction coefficient of soft rubber sliding against ceramic surface wetted by water and detergent.

Friction coefficient for rubber specimens sliding against ceramics wetted by water and detergent contaminated by sand is shown in Fig. 11. The lubricating effect of water and detergent was reduced due to the action of sand particles. Generally, friction coefficient increased with increasing applied load. It seems that sand particles were partially embedded in the rubber surface and the contact was

rubber/ceramics as well as sand/ceramics. Maximum value of friction coefficient (0.42) was observed at 97 % contact area and 200 N normal load, while minimum value of friction coefficient (0.34) was displayed at 50 N normal load and rubber specimens of 100 % contact area.

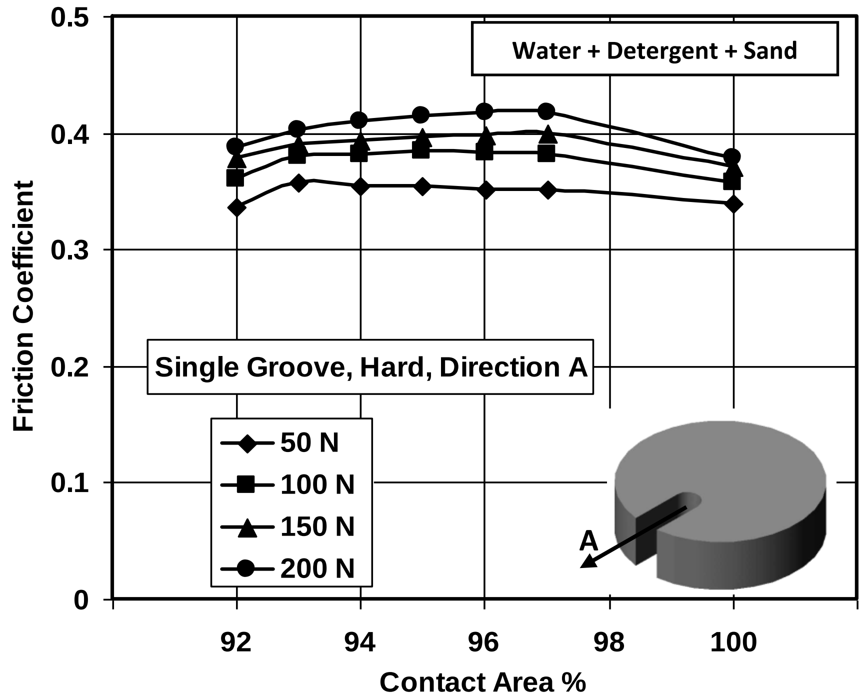

Fig. 11 Friction coefficient of hard rubber sliding against ceramic surface wetted by water, detergent and contaminated by sand.

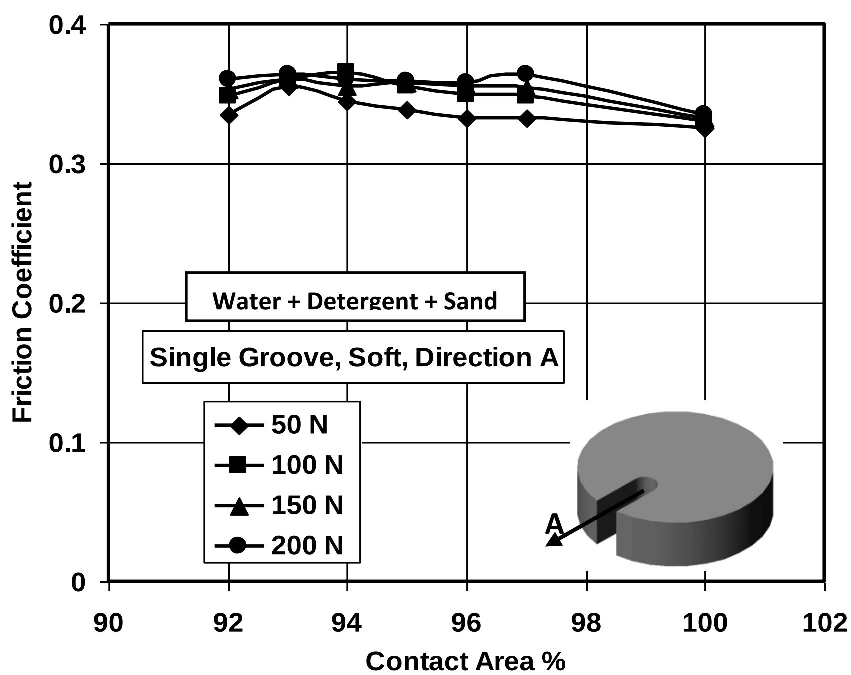

Fig. 12 Friction coefficient for soft rubber sliding against ceramic surface wetted by water, detergent and contaminated by sand.

Friction coefficient for rubber specimens sliding against ceramic surface wetted by water detergent by detergent and contaminated by sand is shown in Fig. 3. 46. It was observed that, there is no difference between the frictional behaviour of hard and soft rubber. Generally, the friction coefficient slightly increases with increasing normal load. This behaviour attributed to the partially increases embedded of sand particles in rubber surface. A maximum value of friction coefficient (0.37) is observed at 200 N normal load and 97 % contact area. The minimum value of friction coefficient (0.32) is obtained at 50 N normal load and complete rubber specimens.

Friction coefficient generated from sliding of rubber against oil lubricated ceramic surfaces is shown in Fig. 13. Generally, it can be noticed that, the friction coefficient decreased with increasing normal load due to the relatively strong adhesion of oil film in rubber surface as well as trapping of oil in the contact area. Maximum value of friction coefficient (0.055) was observed at 50 N normal load, and 96 % contact area. The minimum value of friction coefficient (0.02) was observed at 200 N normal load and rubber specimens of 100 % contact area.

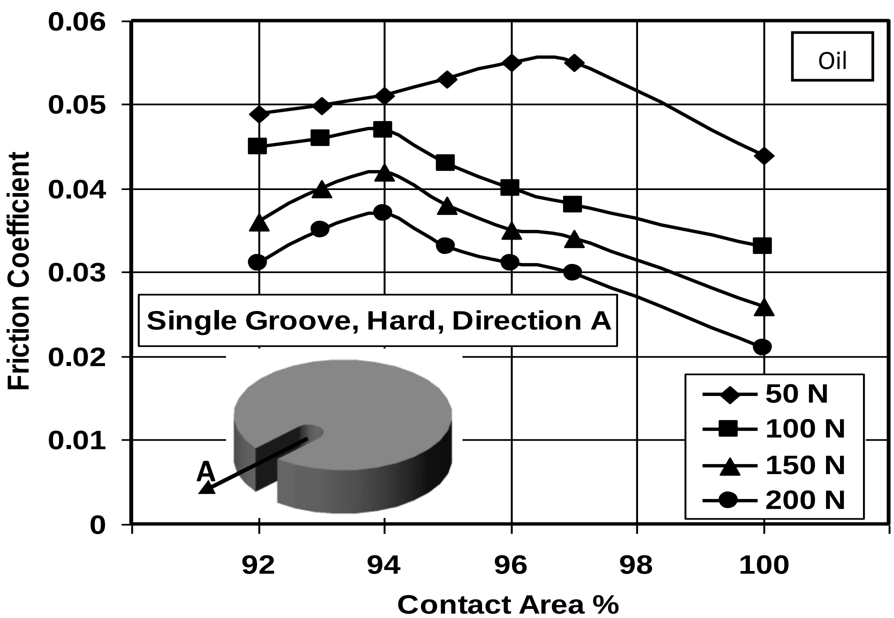

Fig. 13 Friction coefficient of hard rubber sliding against oil lubricated ceramic surface.

In presence of oil lubricated ceramic surface, friction coefficient decreased with increasing normal load, Fig. 14. It seems that porosity of soft rubber absorbed oil and as the pressure was applied on the surface, oil leaks out of the pores and makes oil film on the sliding surface. Maximum value of friction coefficient (0.03) was observed at 50 N

normal load and 94 % contact area. Minimum value of friction coefficient (0.01) was achieved at 200 N normal load and rubber specimen of 100 % contact area.

The values of friction coefficient in presence of oil and water lubricated ceramic surface is shown in Fig. 15. The values of friction coefficient showed significant increase compared to the condition of oil sliding. It seems that, the water decreases the bond between rubber and oil molecules. Generally, friction coefficient decreases with increasing normal load, because the lower load facilitates oil and water to escape from the contact area. The maximum value of friction coefficient (0.105) is observed at 50 N normal load and 92 % contact area, while minimum value (0.038) was measured at 200 N normal load and rubber specimens of 100 % contact area.

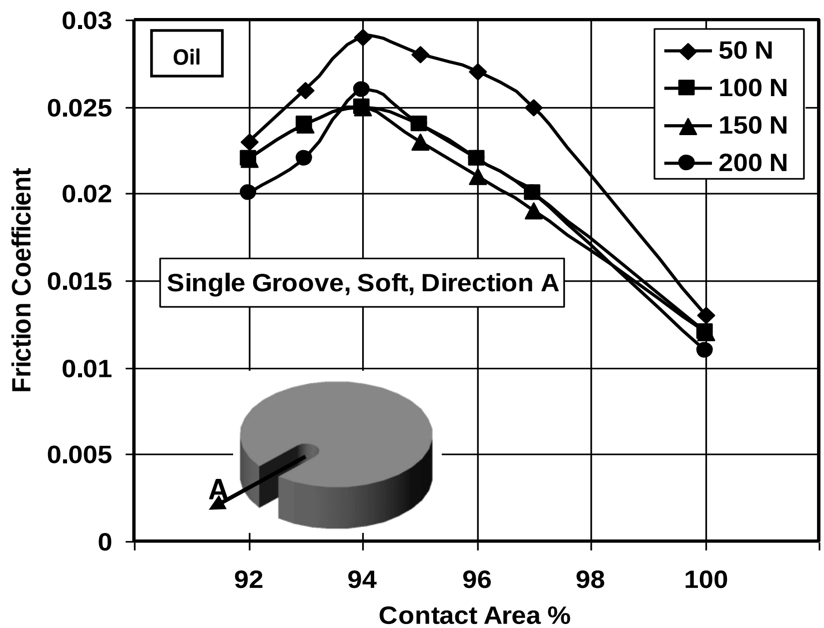

Fig. 14 Friction coefficient of soft rubber sliding against oil lubricated ceramic surface.

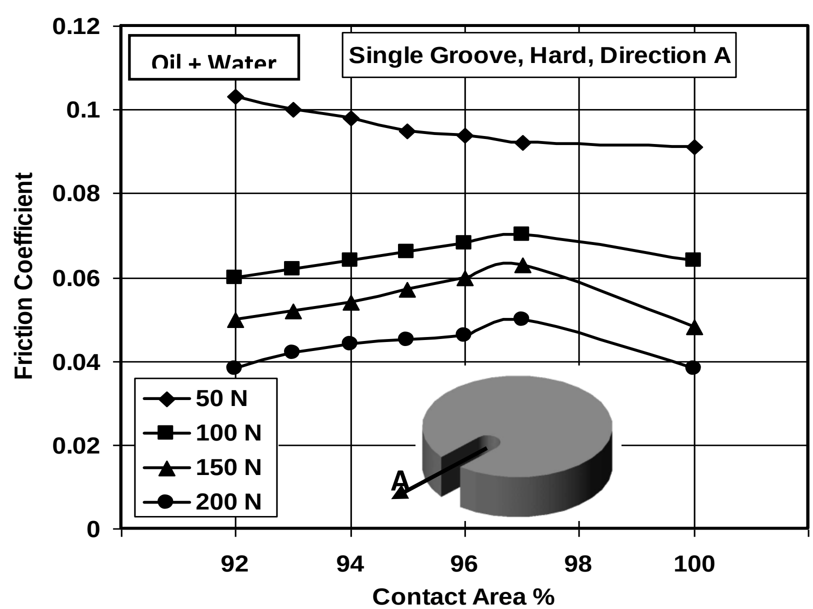

Fig. 15 Friction coefficient of hard rubber sliding against oil diluted by water lubricated ceramic surface.

Figure 16 shows friction coefficient for rubber specimens sliding against ceramic surface lubricated by oil and water. It can be noticed that, friction coefficient decreased with increasing applied load. It seems that water increased the ability of oil to fill the pores in the rubber surface, as the load increased oil and water escaped from the pores to the sliding surface. Maximum value of friction coefficient (0.036) is obtained at 50 N normal load and complete rubber specimen, while the minimum value of friction coefficient (0.02) is observed at 200 N normal load and 92 % contact area.

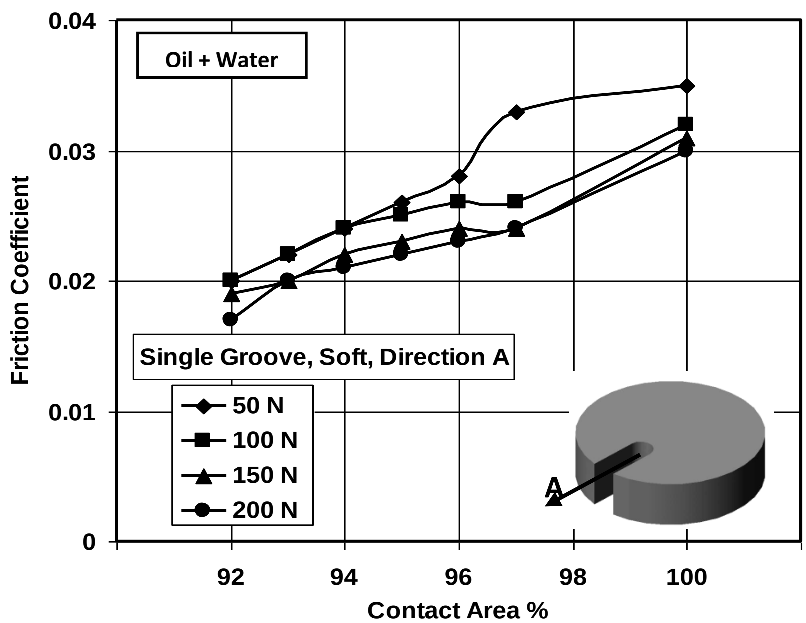

Fig. 16 Friction coefficient of soft rubber specimen sliding against oil diluted by water lubricated ceramic surface.

Friction coefficient for rubber test specimens sliding against ceramic surface lubricated by oil and contaminated by sand is shown in Fig. 17. It can be noticed that friction coefficient decreased with increasing normal load because the lubricating medium was trapped between rubber and ceramic surface. Friction increased, compared to oil sliding, might be from the action of sand particles, where they separated the two sliding surface. Maximum value of friction coefficient (0.115) was observed at 50 N normal load and 97 % contact area, while minimum value of friction coefficient (0.087) was achieved at 200 N normal load and 92 % contact area.

Friction coefficient for rubber specimens sliding against ceramic surface lubricated by oil and contaminated by sand is shown in Fig. 18. It can be noticed that friction coefficient decreases with increasing applied load. It seems that, oil was trapping in

contact area. The relatively low friction coefficient values might be due to the presence of oil film covering the sliding surface. Oil film decreased the ability of sand particles to be partially embeded in rubber surface and made the motion of sand rolling more than sliding. Maximum value of friction coefficient (0.13) was observed at 50 N normal load and 93 % contact area, while minimum value (0.09) was obtained at 200 N normal load ant 97 % contact area.

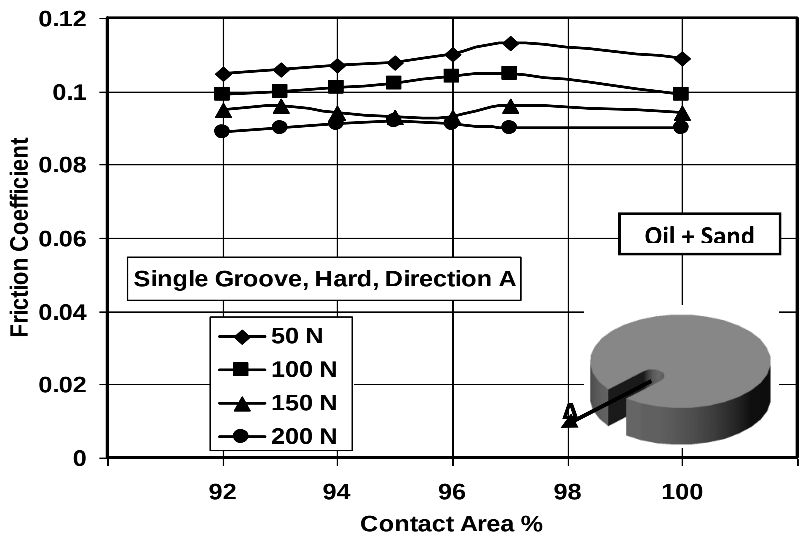

Fig. 17 Friction coefficient of hard rubber sliding against ceramic surface contaminated by oil and sand.

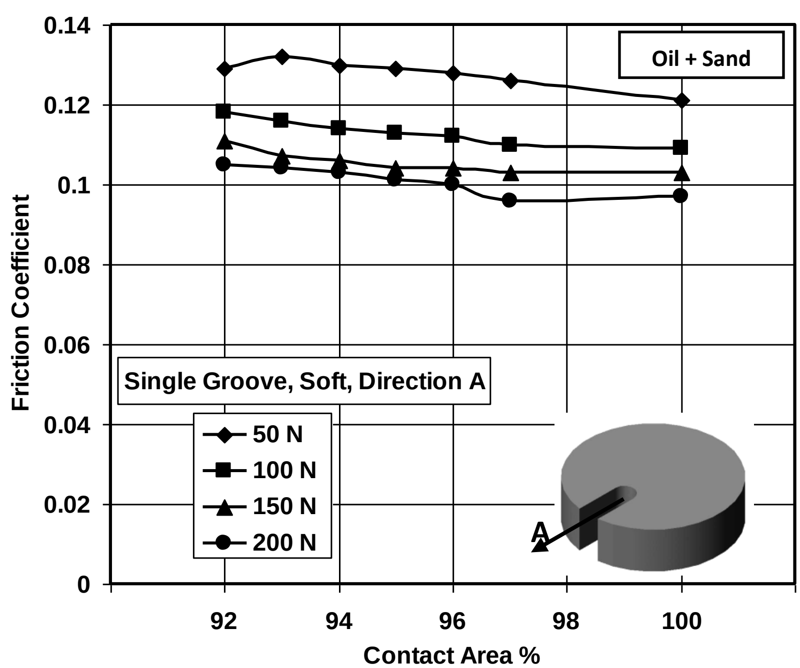

Fig. 18 Friction coefficient of soft rubber sliding against ceramic surface contaminated by oil and sand.

Friction coefficient of rubber specimen sliding against ceramic surface lubricated by oil/water dilution and contaminated by sand is shows in Fig. 19. It is observed that friction coefficient showed significant increase compared to oil and sand because water decreased adhesion of oil in rubber surface. The load showed insignificant effect on friction coefficient.

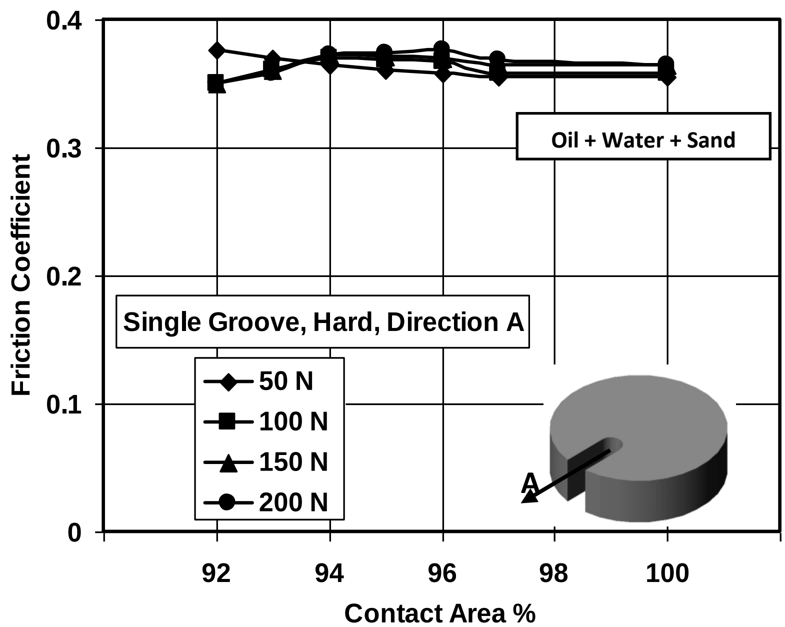

Fig. 19 Friction coefficient of hard rubber sliding against ceramic surface lubricated by oil/water dilution and contaminated by sand.

Friction coefficient of rubber specimens sliding against ceramic surface lubricated by oil/water dilution and contaminated by sand is shown in Fig. 20. The load had no effect on friction coefficient. A maximum value of friction coefficient (0.26) was observed at 100 N normal load and 94 % contact area, while minimum value (0.22) was obtained at 50 N normal load and rubber specimen free of groove.

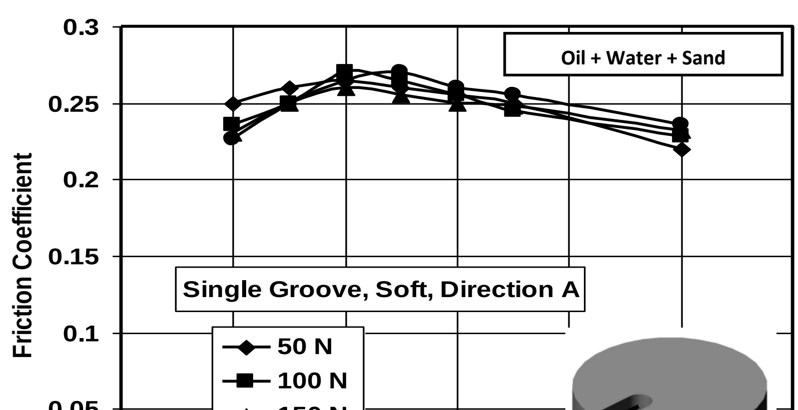

Fig. 20 Friction coefficient of soft rubber sliding against ceramic surface lubricated by oil/water dilution and contaminated by sand.

CONCLUSIONS

1. For dry sliding against ceramics, friction coefficient slightly increased with increasing load. For soft rubber friction coefficient slightly decreased with increasing normal load. The maximum value of friction coefficient (1.15) was observed at 50 N normal load and 92 % contact area, while minimum value (0.8) was observed at 200 N normal load and rubber specimens of 100 %.

2. Friction coefficient for rubber specimens sliding against ceramics contaminated by sand slightly decreased with increasing applied load. For soft rubber load had no effect on the values of friction coefficient.

3. Load has no effect on the friction coefficient displayed by hard rubber specimens sliding against ceramic surface lubricated by water contaminated by sand.

4. Friction coefficient for hard rubber specimens sliding against ceramics wetted by water and detergent decreased with increasing normal load. For soft rubber friction coefficient decreased with increasing normal load.

5. For hard and soft rubber specimens sliding against ceramics wetted by water and detergent contaminated by sand friction coefficient increased with increasing applied load.

6. Friction coefficient generated from sliding of rubber against oil lubricated ceramic surfaces decreased with increasing normal load.

7. Values of friction coefficient in presence of oil and water lubricated ceramic surface showed significant increase compared to the condition of oil sliding. Friction coefficient decreased with increasing applied load.

8. Friction coefficient for rubber test specimens sliding against ceramic surface lubricated by oil and contaminated by sand decreased with increasing normal load.

9. Friction coefficient for rubber specimens sliding against ceramic surface lubricated by oil and contaminated by sand decreased with increasing applied load.

10. Friction coefficient of rubber specimen sliding against ceramic surface lubricated by oil/water dilution and contaminated by sand showed significant increase compared to oil and sand because water decreased adhesion of oil in rubber surface. The load showed insignificant effect on friction coefficient.

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