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FRICTION COEFFICIENT DISPALYED BY THE FOOT SLIDING ON SCRATCHED RUBBER BRAKE PEDAL PAD

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ABSTRACT

The present research aims to increase the safety of braking cars by increasing friction coefficient between foot and braking pad. The effect of scratching the rubber pads, to increase their deformation on friction coefficient, was investigated. Four different shapes of rubber braking pads were tested. Friction tests were carried out at normal load ranging from 50 – 250 N. Tests were carried out at dry, water wetted and oil lubricated surfaces. Measurement of friction coefficient is, therefore, of critical importance in assessing the proper friction properties of brake pedal pads and their suitability to be used in application to enhance the safety of the vehicle.

The experimental observations showed that, at dry sliding of bare foot against the tested pads, the friction increase was due to the extra deformation exerted by the pad, where the tread shape allowed for that deformation. The inclined trend of friction coefficient with increasing load is not desirable in braking pad. In the presence of water wetting the tested pads the transverse treads in the pad surface allowed the water to escape easily out of the contact area, while longitudinal treads restored considerable amount of water formed as a layer on the sliding surface. Besides, drastic decrease in friction coefficient was observed in the presence of oil on pad surface. Friction coefficient displayed by the dry sliding of rubber footwear against the tested pads gave lower values of friction than that displayed by bare foot. In the presence of water on the sliding surface, the friction values were much higher than that observed for bare foot. When oil lubricated the sliding surface, rubber footwear gave lower friction coefficient than bare foot at low loads. Finally, scratched test pads experienced relatively higher friction than smooth pads. It seems that the scratches allowed the water and oil to go out the contact surface and increased the rubber/rubber fraction area.

KEYWORDS

Friction coefficient, braking rubber pad, accident prevention.

INTRODUCTION

There is an increasing demand to introduce developments in the braking process in order to enhance accident prevention of vehicle. It is necessary to introduce laboratory and simulating studies to ensure the safety of the brake pedal pads. Although a number of studies was related to safety of the performance of braking system, no reliable diagnostic test was actually taken up that can indicate safety in terms of frictional pad performance. An acceptable value of friction should be obtained to keep the foot from slipping off the

brake pedal. Little attention was exerted to measure the friction coefficient of rubber footwear soles sliding against dry and contaminated brake pedal pads. The reduction in the friction coefficient displayed by bare foot and rubber footwear soles sliding against the brake pedal rubber pads of different hardness in dry, sand contaminated, water and oil lubricated conditions was discussed, [1, 2]. At dry sliding, friction coefficient slightly decreased with increasing the hardness of the rubber pad. For the transverse direction of sliding, friction coefficient displayed relatively lower values than that observed for longitudinal sliding. In the presence of sand particles between the foot and the rubber pad, friction coefficient significantly increased with increasing the hardness. Bare foot sliding against water wetted pedal pads displayed friction coefficient relatively higher than that shown for surfaces contaminated by sand particles. For oil lubricated pedal pad, friction coefficient significantly increased with increasing the hardness of the rubber pad, at longitudinal and transverse sliding directions respectively. Rubber footwear soles, slid against the tested pedal pads, displayed lower friction values than that observed for bare foot at dry sliding. In the presence of sand particles on the sliding surfaces friction coefficient significantly increased, while decreased for water wetted pads with increasing the hardness of the tested pad. Friction coefficient of rubber footwear soles sliding against oil lubricated pedal pad increased with increasing the hardness of the rubber pad. The values of friction coefficient were relatively lower than that displayed by bare foot. It seems that adhesion of oil into the rubber surface was stronger compared to bare foot.

The effect of the treads width of the brake pedal rubber pads on the friction coefficient was investigated, [3]. Experiments of the sliding of bare foot against the pedal pad showed that friction coefficient of dry sliding significantly decreased with increasing the tread width. The sliding direction has no effect on the friction coefficient for the tested pads. In the presence of sand particles separating the two contact surfaces, load had no influence on friction coefficient. Friction coefficient slightly decreased with increasing the tread width. For water wetted pedal pad, friction coefficient displayed higher values than that observed sand particles contaminated surfaces. Friction values showed consistent trend with increasing the tread width. Friction displayed by oil lubricated pedal pads was the lowest and the sliding condition could be considered as unsafe. When rubber shoes slid against the tested rubber pads friction coefficient displayed relatively lower values than that displayed by bare foot. Besides, sliding in the transverse direction displayed higher friction values than longitudinal one at dry sliding. In the presence of sand particles, the shortest tread width displayed the highest friction. Sliding against water wetted pedal pad, the highest values of friction coefficient were displayed by 2 mm tread width due to the water leakage from the contact area. The friction values displayed in the transverse direction were relatively lower than that displayed in the longitudinal direction. Sliding against oil lubricated pedal pad showed relatively low friction values, which were considered as unsafe sliding.

The majority of the previous researches studied the frictional behaviour of the sliding of bare foot as well as foot wear soles against different types of floorings, [3 - 18]. 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]. This was found in the friction measurements under wet conditions. In general, rubber friction is divided into two parts; the bulk hysteresis and the contact adhesive term, [4]. These two contributions are regarded to be independent of each other, but this is only a simplified assumption.

Friction measurement is one of the major approaches to quantify floor slipperiness. Investigations on friction measurement have been focused on liquid contaminated conditions. It was expected that wet surfaces had significant lower friction coefficient values than those of the dry surfaces, [5]. The friction coefficient difference between the dry and wet surfaces depended on the footwear material and floor combinations. Friction measurements under liquid contaminated conditions were very common. The squeeze film theory explains the effects of the liquid on the measured friction. Measurements of the static friction coefficient between rubber specimens and ceramic surfaces were carried out at dry, water lubricated, oil, oil diluted by water and sand contaminating the lubricating fluids, [6 - 9]. 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 the height of the grooves introduced in the rubber specimens. As for ceramic lubricated by detergent and contaminated by sand, friction coefficient increased significantly compared to the sliding on ceramics lubricated by water and soap.

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, [10]. It was found that, at dry sliding, friction coefficient slightly increased with increasing tread height. Perpendicular (relative to the motion direction) treads displayed the highest friction coefficient due to their increased deformation, while parallel treads showed the lowest values. In the presence of water on the sliding surface significant decrease in friction coefficient was observed compared to the dry sliding. For detergent wetted surfaces, friction coefficient drastically decreased to values lower than that displayed by water. Parallel treads showed the highest friction coefficient, while perpendicular treads displayed the lowest friction values as result of the formation of the hydrodynamic wedge. Oily smooth surfaces gave the lowest friction values as result of the presence of squeeze oil film separating rubber and ceramic. Emulsion of water and oil shows slight friction increase compared to oil lubricated sliding. As the tread height increased, friction increased due to the easy escape of the lubricant from the contact area. Tread groove designs are helpful in facilitating contact between the shoe sole and floor on liquid contaminated surface, [11 - 14]. The effectiveness of a tread groove design depends on the contaminant, footwear material and floor. Tread groove design was ineffective in maintaining friction on a floor covered by vegetable oil. Tread grooves should be wide enough to achieve better drainage capability on wet and water detergent contaminated floors.

The effect of rubber flooring provided by rectangular and cylindrical treads on the friction coefficient was investigated, [15, 16]. 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. In the presence of water on the sliding surface significant decrease in friction coefficient was observed. For detergent wetted surfaces, friction coefficient drastically decreased to values lower than that displayed by water. Parallel treads showed the highest friction coefficient, while perpendicular treads displayed the lowest friction values as result of the formation of the hydrodynamic wedge. Oily smooth surfaces gave the lowest friction value as result of the presence of squeeze oil film separating rubber and ceramic. Treads of 45° displayed the highest friction coefficient. Besides, friction coefficient significantly increased up to maximum then slightly decreased

with increasing the treads height. Perpendicular treads displayed the highest friction followed by 45° and parallel treads. At water, detergent and oil lubricated sliding conditions, friction coefficient decreased as the tread width increased due to the increased area of the fluid film. Perpendicular treads caused lower friction coefficient because parallel and 45° treads could scavenge oil away from the contact area more effectively than perpendicular treads. In addition to that, it was found that at dry sliding, friction coefficient significantly increased with increasing treads diameter. As for lubricated sliding surfaces, friction coefficient decreased with increasing treads diameter. Parallel treads showed the highest friction coefficient, while perpendicular treads displayed the lowest friction values.

The factors affecting friction coefficient measurement are the material, surface geometry of the footwear as well as floor, floor contamination conditions and even the slipmeter used, [17 - 20]. Investigators have concentrated on the friction coefficient measurements on liquid contaminated floors because most slip/fall accidents occur on the surfaces of such floors, [21 - 24]. When stepping on a wet or lubricated floor, a shoe sole cannot touch the floor surface without squeezing the liquid out of the contact area. The liquid between the floor and the sole isolates the two contact surfaces, thus reducing the friction between them. The liquid drainage time between the two contact surfaces depends on the viscosity and pressure between the two surfaces. The higher the viscosity is, the longer the time is required for the film thickness to decrease, [25]. A longer drainage time increases the risk of slipping due to the short time available to prevent a slip after the heel touches the floor. The effect of surface roughness of ceramic on the friction coefficient, when rubber and leather are sliding against it, was investigated, [26]. 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.

In the present work, the friction coefficient of brake pedal rubber pad was tested when sliding against bare foot and rubber footwear at dry, water and oil lubricated sliding conditions. The surface of the pad was scratched to increase its deformation.

EXPERIMENTAL

Experiments were carried out using a test rig to measure the friction coefficient between bare foot as well as footwear soles and the tested brake pedal pads through measuring the friction and normal forces. The tested brake pedal pads were adhered in a base supported by two load cells, the first could measure the horizontal force (friction force) and the second could measure the vertical force (normal load). Friction coefficient is determined by the ratio between the friction and the normal forces. The arrangement of the test rig is shown in Fig. 1. The tested brake pedal pads were thoroughly cleaned by soap water to eliminate any dirt and dust and carefully dried before the tests, Fig. 2. The tested pads were adhered to the base of the test rig, where bare foot and shoes were loaded against them to determine friction coefficient. Friction test was carried out at different values of normal load exerted by foot. The relationship between friction coefficient and load was plotted for every test for load ranged from 50 to 250 N.

The aim of the present work is to measure the friction coefficient displayed by bare foot sliding against brake pedal pads to take into consideration that some people, in tropical countries, used to drive their cars without footwear. Comparison performance was carried out by coating the pads by a proposed adhesive and they were scratched to

increase their deformation. The sliding conditions tested in the experiment were dry, water lubricated, and oil lubricated sliding surfaces of bare foot, footwear rubber shoes of smooth surface. Foot and footwear soles were washed by detergent to remove perspiration from the foot skin and dirts from footwear soles then carefully dried before the test. For the contaminated surfaces, water and oil were replenished on the bare foot, footwear soles and the tested pads, where the amount for each replenishment was 10 ml to form consistent liquid film covering the sliding surfaces. After the wet test, all contaminants were removed from the tested sliding surfaces using absorbent papers. The tested pads were then washed by detergent, rinsed using water and blown using hair dryer after the cleaning process. Vegetables oil (corn oil) was used as liquid contaminant.

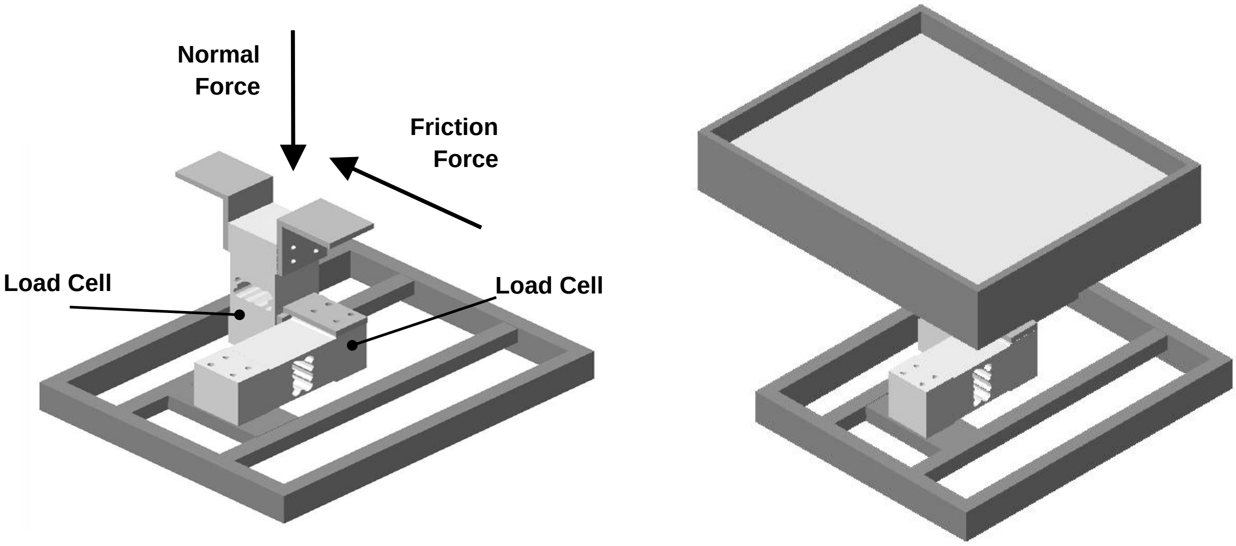

Fig. 1 Arrangement of the test rig.

	
A	**B**
	
C	**D**

Fig. 2 The tested braking pads.

	
Scratched pad B	**Scratched pad D**

Fig. 3 The tested scratched braking pads.

RESULTS AND DISCUSSION

The observations of experiments carried out to measure friction coefficient displayed by the sliding of bare foot against the tested pads are shown in Figs. 4 – 6. At dry sliding, Fig. 4, pad (B) showed the highest friction coefficient followed by (D) then (C) and (A) at 200 N. Friction coefficient significantly decreased with increasing normal load, where the values represented very low trend. The friction increase observed for Pad (B) displayed the highest value due to the extra deformation exerted by the pad, where the tread shape allowed for that deformation. Pad (C) showed very inclined trend of friction coefficient with increasing load, which is not desirable in braking. Friction coefficient displayed by the sliding of bare foot against water wetted tested pads is shown in Fig. 5, where pad (C) showed the highest friction coefficient. This behavior can be explained on the basis that the transverse treads in the pad surface allowed the water to escape easily out of the contact area, while longitudinal treads restored considerable amount of water formed as a layer on the sliding surface. In that condition, the contact was partially bare foot/rubber and partially water wetted contact. Drastic decrease in friction coefficient was observed by the sliding of bare foot against oil lubricated tested pads, Fig. 6. Pad (D) displayed the highest friction coefficient due to the presence of relatively valley area that could store the oil and made the contact between asperities free of oil. Pad (B) showed the lowest friction because the oblique treads made oil squeeze from the contact area more difficult due to the increased viscosity.

Friction coefficient displayed by the dry sliding of rubber footwear against the tested pads is shown in Figs. 7 - 9. At dry sliding, Fig. 7, values of friction were lower than that displayed by bare foot. It seems that the contact area generated from bare foot sliding against rubber pad was higher than that produced from rubber footwear. Besides, the adhesion of bare foot skin into the rubber pad surface was higher than that expected from rubber footwear. Pad (B) showed the highest friction coefficient due to the extra surface deformation. In the presence of water on the sliding surface, Fig. 8, pad (A) gave the highest friction coefficient. Generally, the friction values were much higher than that observed for bare foot. This behavior might be from the strong adhesion of water into the skin of bare foot. Pad (B) showed the lowest friction. When oil lubricated the sliding surface, Fig. 9, rubber footwear gave lower friction coefficient than bare foot at low loads. As the load increased, footwear gave relatively higher values than bare foot. The relatively soft bare foot could deform when pressing the rubber pad and squeeze the oil out of the

contact area, while the adhesion of oil molecules into bare foot was relatively stronger than footwear.

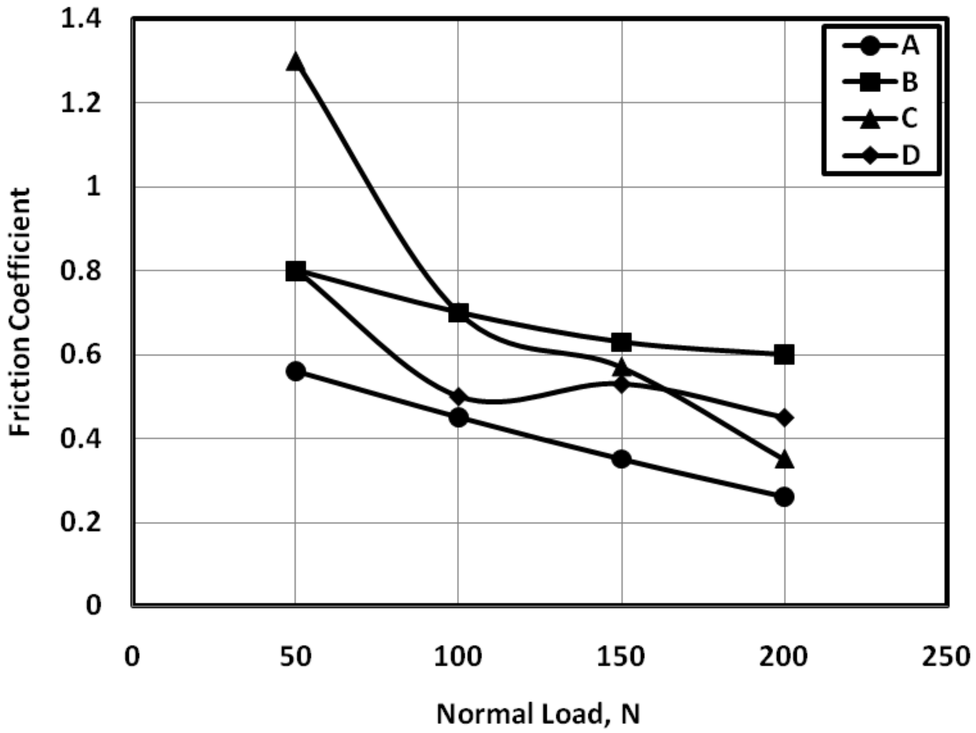

Fig. 4 Friction coefficient displayed by the dry sliding of bare foot against the tested pads.

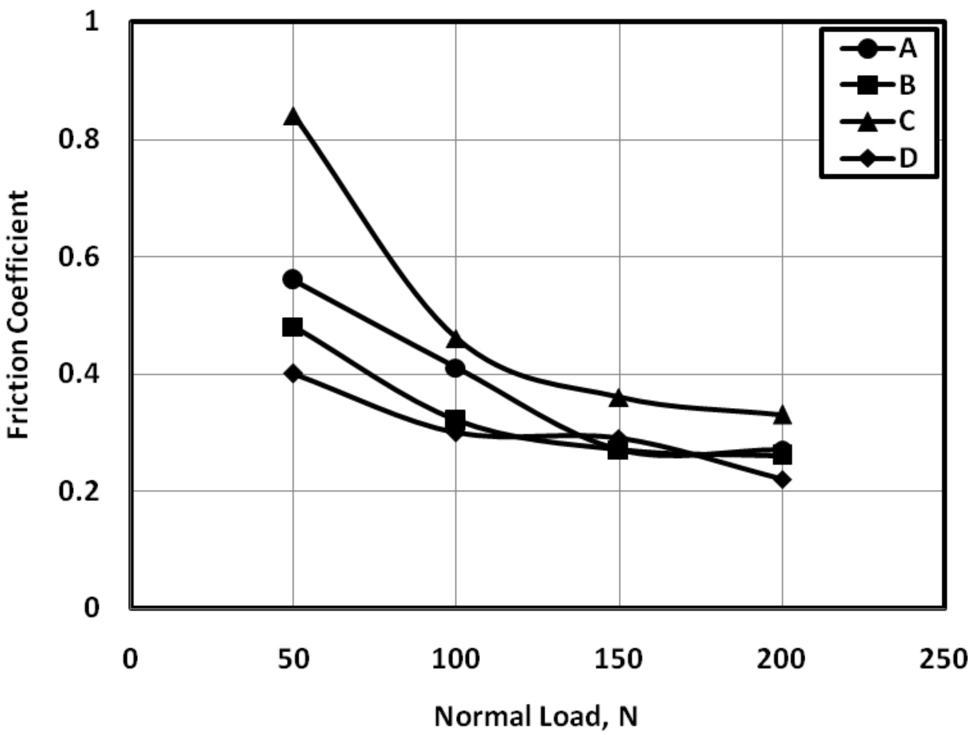

Fig. 5 Friction coefficient displayed by the sliding of bare foot against water wetted tested pads.

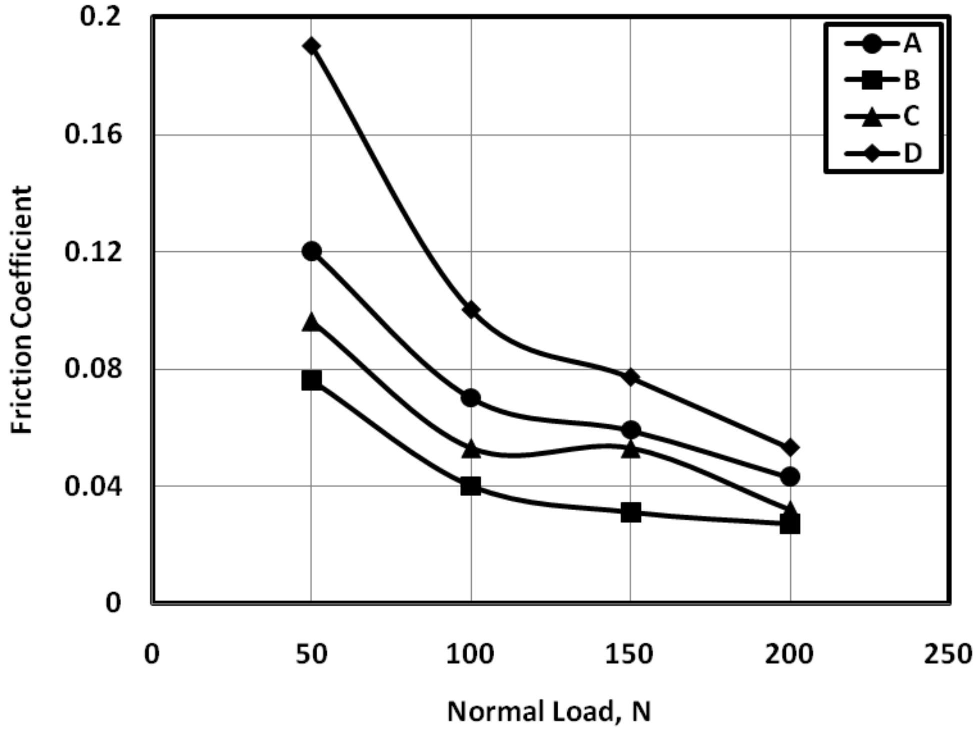

Fig. 6 Friction coefficient displayed by the sliding of bare foot against oil lubricated tested pads.

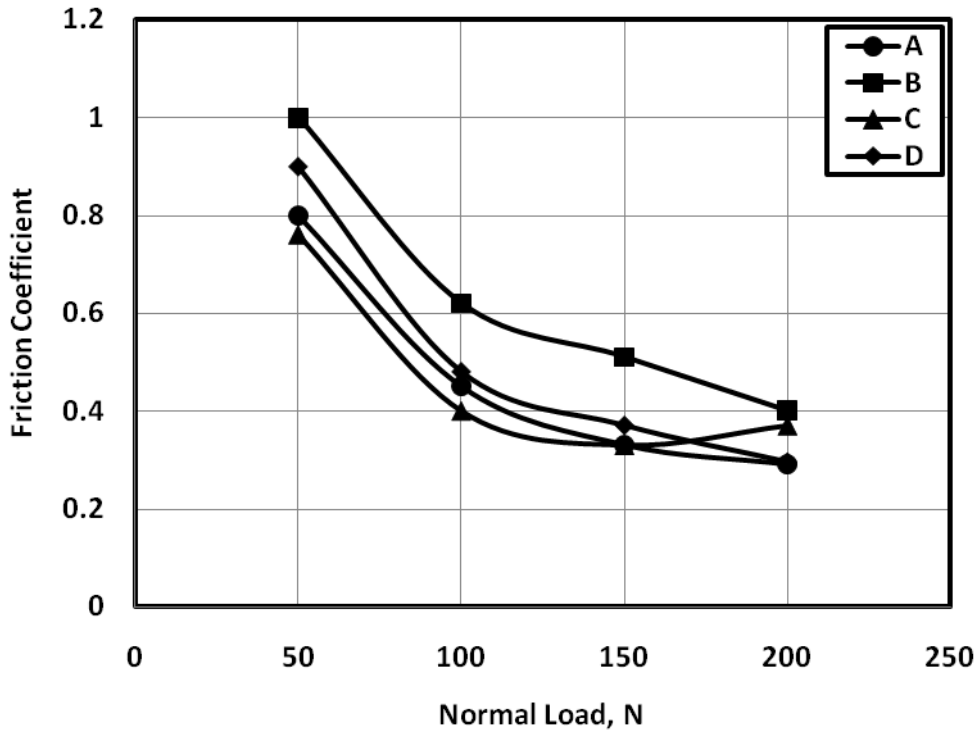

Fig. 7 Friction coefficient displayed by the dry sliding of rubber footwear against the tested pads.

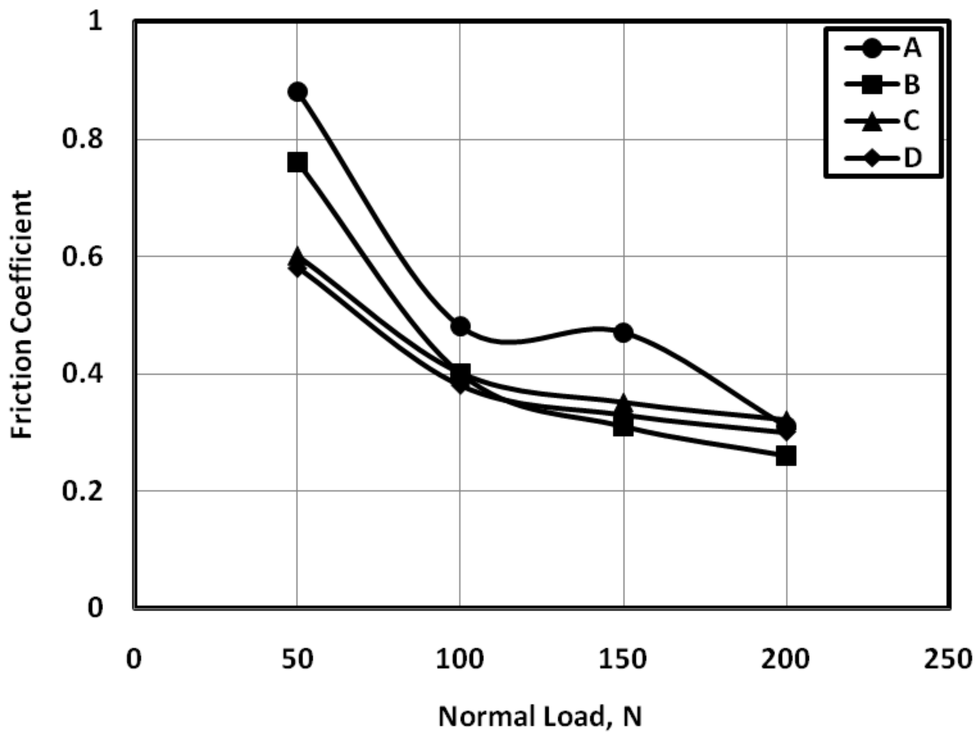

Fig. 8 Friction coefficient displayed by the sliding of rubber footwear against the water wetted tested pads.

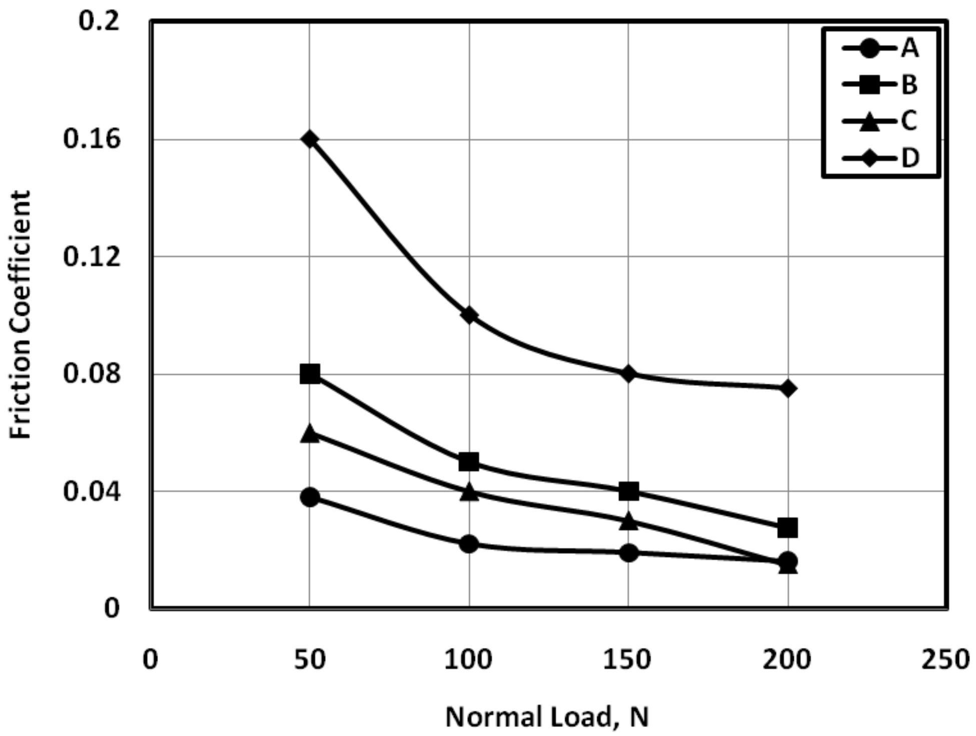

Fig. 9 Friction coefficient displayed by the sliding of rubber footwear against oil lubricated tested pads.

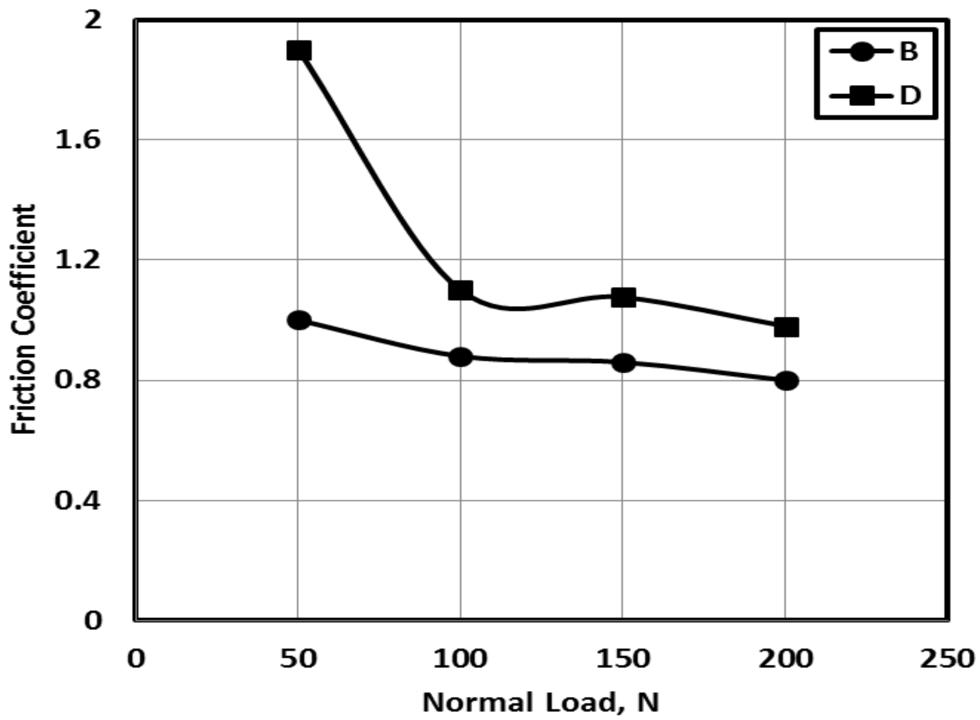

Fig. 10 Friction coefficient displayed by the dry sliding of bare foot against the scratched tested pads.

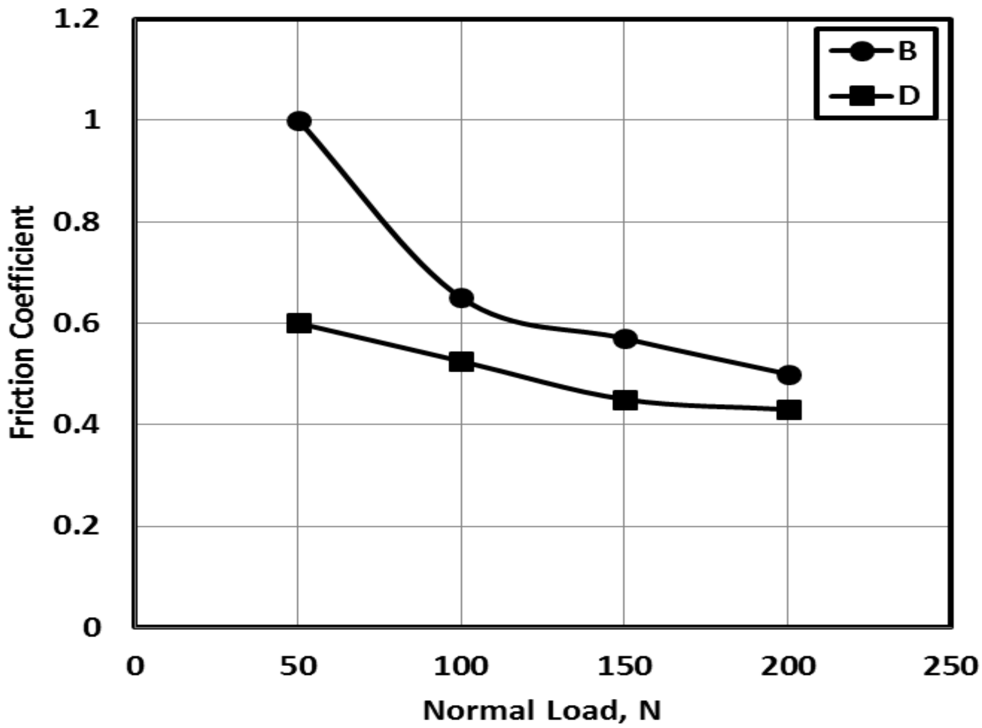

Fig. 11 Friction coefficient displayed by the sliding of bare foot against water wetted scratched tested pads.

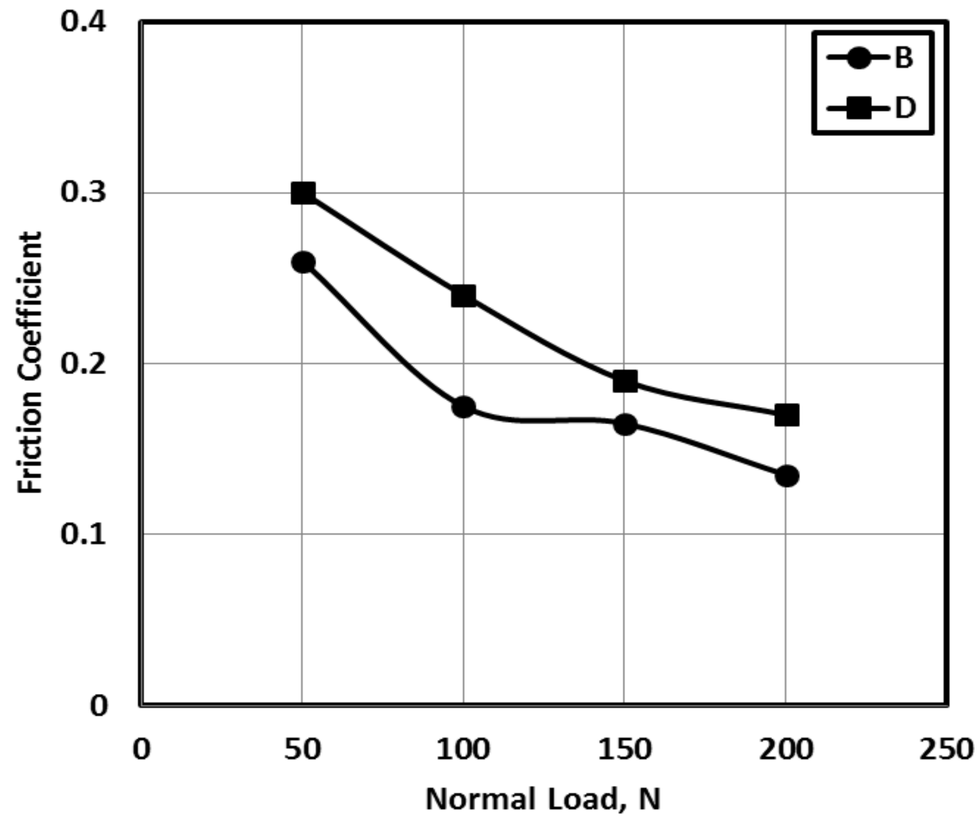

Fig. 12 Friction coefficient displayed by the sliding of bare foot against oil lubricated scratched tested pads.

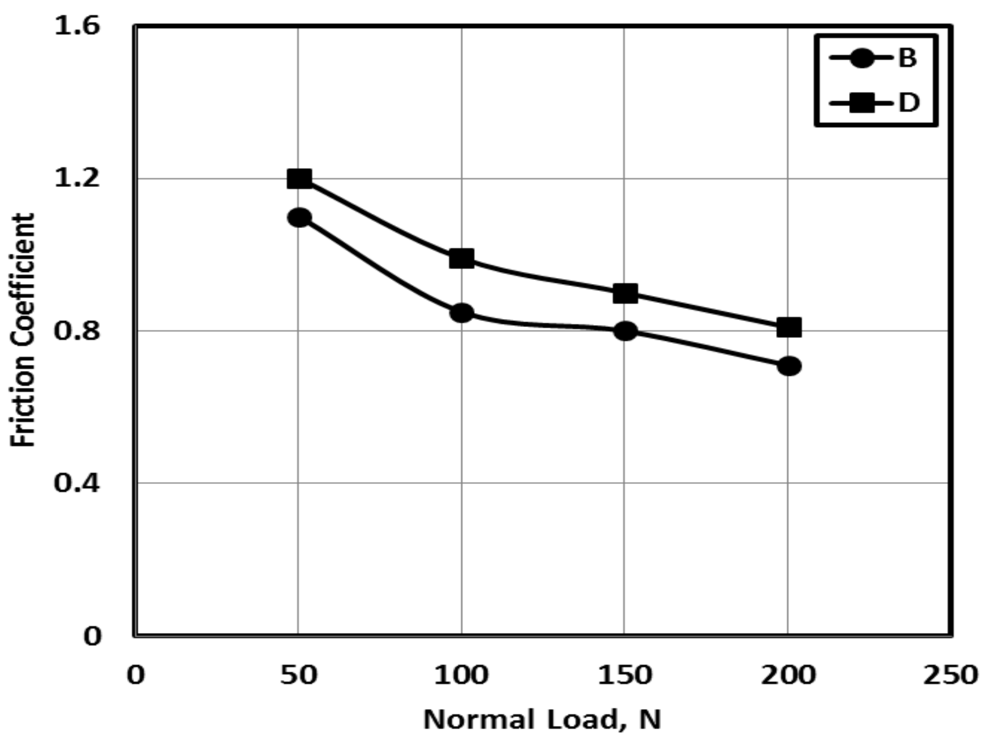

Fig. 13 Friction coefficient displayed by the dry sliding of rubber footwear against the scratched tested pads.

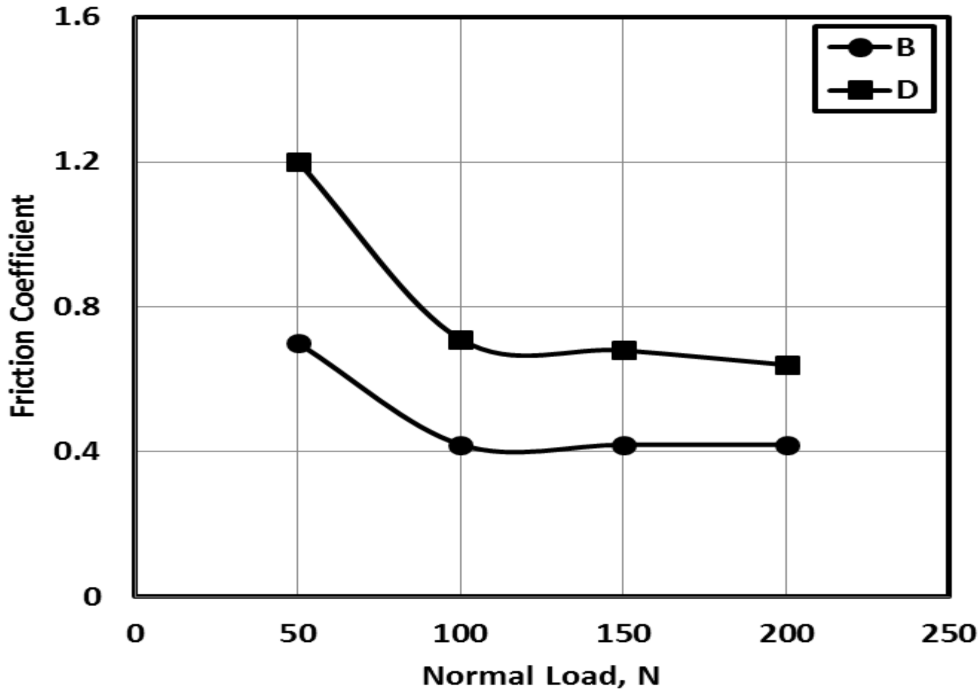

Fig. 14 Friction coefficient displayed by the sliding of rubber footwear against water wetted scratched tested pads.

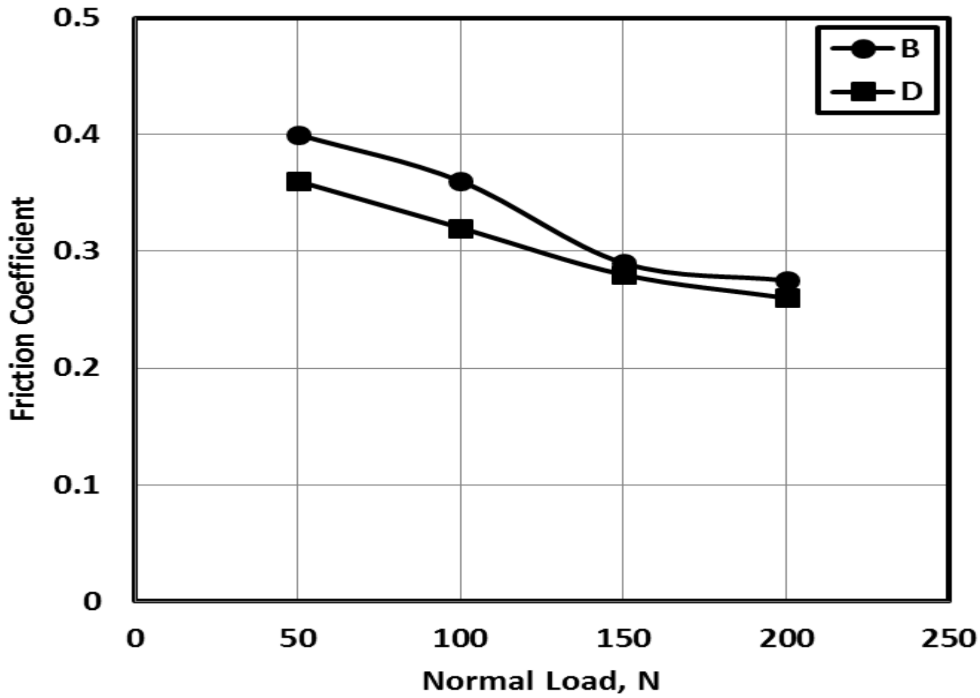

Fig. 15 Friction coefficient displayed by the sliding of rubber footwear against oil lubricated scratched tested pads.

Figures 10 – 15 illustrate the effect of the scratch of the surfaces of the pads (B) and (D) on friction coefficient. At dry sliding, Fig. 10, pad (D) experienced relatively higher friction than pad (B). The difference decreased with increasing normal load. It seems that the scratches increased the deformation of the rubber. It is well known that rubber

friction has two components; adhesion and deformation. The deformation component is called hysteresis friction and caused by the delayed recovery (viscoelastic behavior) of the deformed rubber, where the energy is dissipated through the internal damping in the rubber. Friction coefficient displayed by the sliding of bare foot against water wetted scratched tested pads is shown in Fig. 11. Pad (B) represented relatively higher friction values than pad (D). Based on that observation it can be seen that the tread direction as well as tread width and depth are much affecting friction coefficient. As the load increased, the tread would be deformed and water would cover the majority of the contact surface. Presence of oil on the scratched tested pads displayed higher friction coefficient for pad (D) than pad (B), Fig. 12. Values of friction coefficient were much higher than that observed for smooth pads. This behavior might be attributed to the fact that the scratches allowed the oil to escape from the contact area so that the contact was footwear/rubber pad.

Dry sliding of rubber footwear against the scratched tested pads showed higher friction values than that observed for smooth pads, Fig. 13. Pad (D) showed higher friction coefficient than pad (B) due to the higher deformation of the tread surface made by the scratches. In the presence of water on the sliding surfaces, friction coefficient showed higher values due to the easy escape of water from the contact area, Fig. 14. Friction coefficient showed consistent values with increasing normal load. Pad (D) gave reasonable friction values, where the minimum value was 0.65, which is considered as safe values based on the American Standards. Friction coefficient displayed by the sliding of rubber footwear against oil lubricated scratched tested pads showed significant increase compared to the smooth pads, Fig. 15. It seems that the scratches allowed the oil to go out the contact surface and increased the rubber/rubber fraction area.

CONCLUSIONS

1. At dry sliding of bare foot against the tested pads, Fig. 3, pad (B) showed the highest friction coefficient followed by (D) then (C) and (A) at 200 N. The friction increase was due to the extra deformation exerted by the pad, where the tread shape allowed for that deformation. Pad (C) showed very inclined trend of friction coefficient with increasing load, which is not desirable in braking. Sliding of bare foot against water wetted tested pads showed that the transverse treads in the pad surface allowed the water to escape easily out of the contact area, while longitudinal treads restored considerable amount of water formed as a layer on the sliding surface. Drastic decrease in friction coefficient was observed in the presence of oil on pad surface.

2. Friction coefficient displayed by the dry sliding of rubber footwear against the tested pads gave lower values of friction than that displayed by bare foot. In the presence of water on the sliding surface, the friction values were much higher than that observed for bare foot. When oil lubricated the sliding surface, rubber footwear gave lower friction coefficient than bare foot at low loads. As the load increased, footwear gave relatively higher values than bare foot.

3. At dry, water wetted and oil lubricated sliding, scratched test pads experienced relatively higher friction than smooth pads.

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