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FRICTIONAL BEHAVIOUR OF BARE FOOT AND RUBBER FOOTWEAR SOLE SLIDING AGAINST POLYPROPYLENE BRAKE PEDAL PADS

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ABSTRACT
The present work discusses the friction coefficient displayed by bare foot and footwear soles sliding against polypropylene brake pedal pads. The frictional performance is compared to that obtained from the rubber conventional pads. 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 reduction in friction coefficient displayed by bare foot and rubber footwear soles sliding against the tested brake pedal pads in dry, sand contaminated, water and oil lubricated conditions is discussed.

It was found that, for bare foot sliding against the tested pedal pads at dry sliding, friction coefficient displayed by PP tested pads was relatively lower than that shown by the conventional and transverse ones. In the presence of sand particles between the foot and the tested pads, friction coefficient increased significantly for PP pads. PP pads displayed the lowest friction coefficient for bare foot sliding against water wetted pads in the longitudinal direction. For oil lubricated pads, values of friction coefficient displayed by PP pads were close to that presented by conventional pads. The experimental findings of rubber footwear slid against the tested pedal pads, rubber shoes displayed relatively lower friction values than bare foot at dry sliding. In the presence of sand particles on the sliding surfaces, friction coefficient significantly increased for PP pads for longitudinal and transverse direction. The worst condition was observed for PP pads when sliding against water wetted foot wear, where drastic decrease in friction coefficient was displayed. At oil contaminated sliding, values of friction coefficient were close to that displayed by bare foot. PP pads displayed relatively higher friction than the conventional pads, while the transverse pads indicated the highest friction values.

KEYWORDS
Friction, bare foot, rubber footwear soles, brake pedal pad, polypropylene.

INTRODUCTION

It is well established that there is an increase in car accidents. It is necessary to introduce laboratory and simulating studies to ensure the safety of the brake pedal pads. Although a number of studies were 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]. 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, [2]. 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 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 a result of the formation of the hydrodynamic wedge. Oily smooth surfaces gave the lowest friction values as a 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 a result of the formation of the hydrodynamic wedge. Oily smooth surfaces gave the lowest friction value as a 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 polypropylene (PP) and rubber brake pedal pads was tested when sliding against bare foot and rubber footwear at dry, water, oil and sand contaminated sliding conditions.

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. The directions of the sliding as well as the forces acting on the tested pads are shown in 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, Fig. 3. 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 0 to 700 N. Then the values of friction coefficient were extracted from the figures at loads of 50, 100, 150 and 200 N.

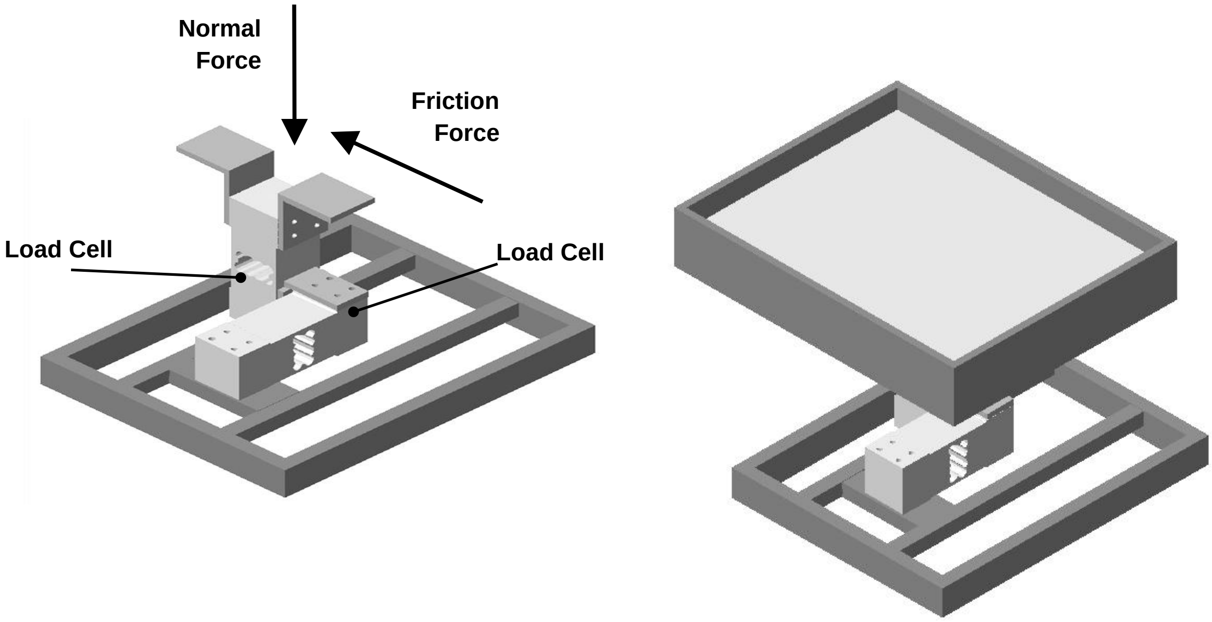

Fig. 1 Arrangement of the test rig.

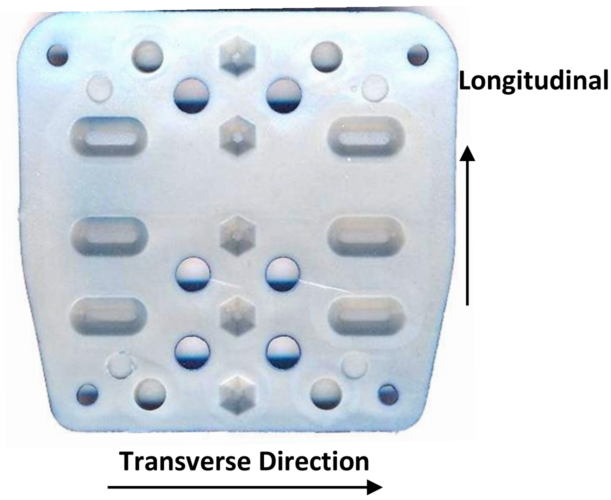

Fig. 2 PP brake pedal pad.

	
Fig. 3 Conventional brake pedal pad.	**Fig. 4 Transverse brake pedal pad.**

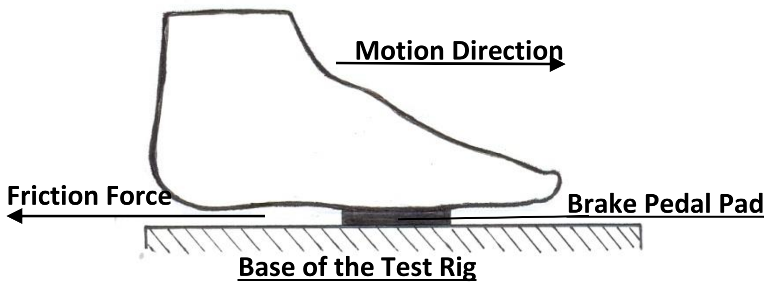

Fig. 5 Arrangement of the test rig.

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. The tested pads were made of polypropylene, Fig. 2. Comparison performance was carried out using rubber footwear of conventional and transverse treads, Figs. 3 and 4, respectively. The sliding conditions tested in the experiment were dry, water lubricated, oil, and sand contaminating the 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. Sand particles used in the experiments were silica of 0 – 80 µm particle size. Vegetables oil (corn oil) was used as liquid contaminant. The arrangement of the test rig is shown in Fig. 5. Two directions of motion (longitudinal and transverse) of the foot against the tested pads were considered.

RESULTS AND DISCUSSION

The results of the experiments carried out on the tested pads compared to the conventional and transverse types are shown in Figs. 6 – 21. Friction coefficient of dry sliding of bare foot against the pedal pad in the longitudinal direction is shown in Figs. 6 and 7. Friction coefficient displayed by PP tested pads was relatively lower than that shown by the conventional and transverse ones. Generally, as the load increased friction coefficient decreased. At 200 N load, friction coefficient displayed the lowest value of 0.47, while the conventional pads displayed friction value of 0.88. For the transverse direction of sliding, friction coefficient displayed by PP pads showed relatively lower values than that shown for longitudinal sliding, Fig. 7. This behaviour may be attributed to the dimensions of the surface protrusions. Further work should be directed to investigate that effect in order to avoid the decrease of friction coefficient in the transverse direction.

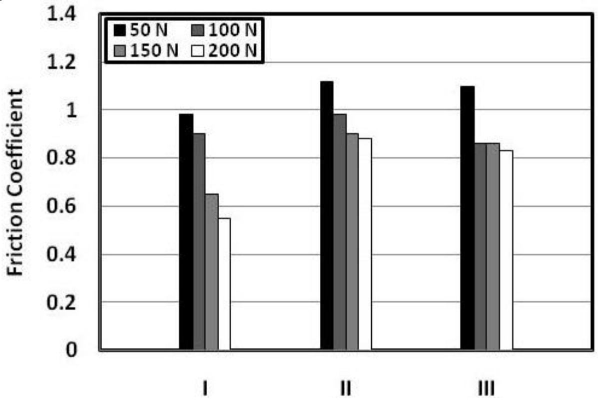

Fig. 6 Friction coefficient of dry sliding of bare foot against the pedal pad. Longitudinal direction.

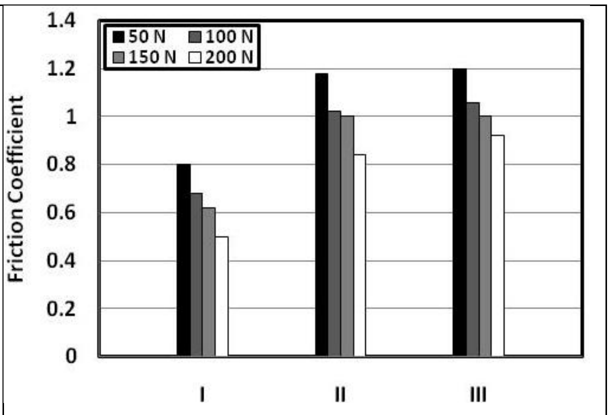

Fig. 7 Friction coefficient of dry sliding of bare foot against the pedal pad. Transverse direction.

In the presence of sand particles between the foot and the tested pads, friction coefficient increased significantly for PP pads, Fig. 8. It seems that sand particles tended to embed in the skin of the bare foot and abraded the polymeric surface of the pads. This behaviour is attributed to the significant difference in hardness of PP and the skin. For conventional pads, the rolling motion of sand particles was prevailing, so that friction coefficient decreased. In the transverse direction, the tread and protrusion sliding direction had slight influence on the friction values, Fig. 9, where the sand particles were forming a layer separating the two contact surfaces. Pads of transverse treads showed the highest friction coefficient due to the easy escape of sand particles from the contact area.

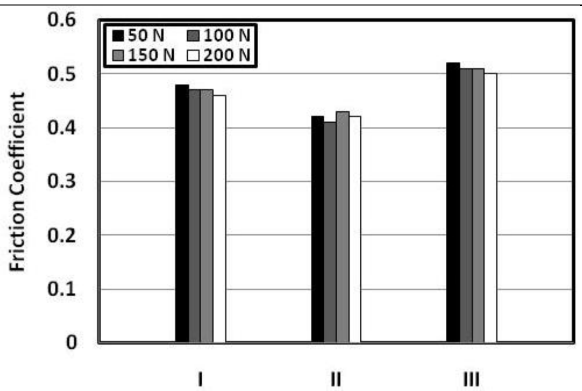

Fig. 8 Friction coefficient of bare foot sliding against sand contaminated pedal pad. Longitudinal direction.

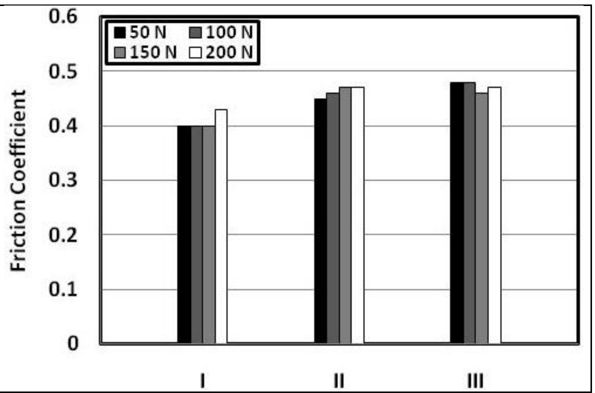

Fig. 9 Friction coefficient of bare foot sliding against sand contaminated pedal pad. Transverse direction.

Friction coefficient of bare foot sliding against water wetted pedal pad in the longitudinal direction is shown in Fig. 10. PP pads displayed the lowest friction coefficient, where the values were 0.47, 0.39, 0.37 and 0.35 at 50, 100, 150 and 200 N load respectively. It seems that hard PP pads did not allow the water to escape away from the contact area due to the relatively low deformation. Generally, friction coefficient displayed relatively higher values than that shown for surfaces contaminated by sand particles. The presence of the treads in the rubber pad surface decreased the influence of water. Besides, the treads direction, Fig. 11, had no effect on the values of friction coefficient.

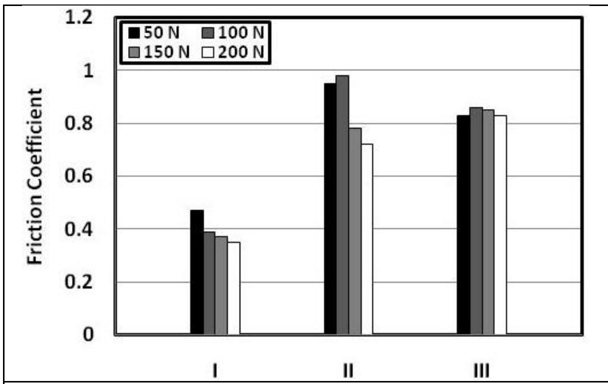

Fig. 10 Friction coefficient of bare foot sliding against water wetted pedal pad. Longitudinal direction.

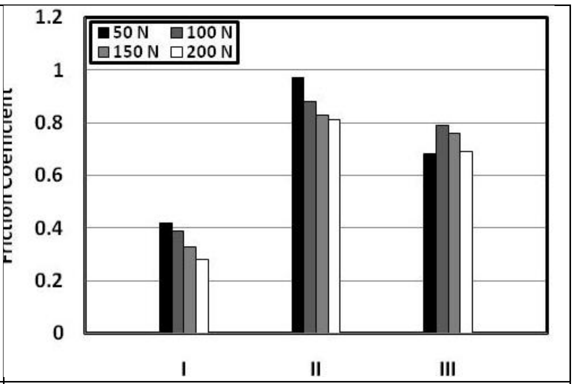

Fig. 11 Friction coefficient of bare foot sliding against water wetted pedal pad. Transverse direction.

For oil lubricated pedal pads, friction coefficient displayed by PP pad values were close to that presented by conventional pads, Figs. 12 and 13 at longitudinal and transverse sliding directions respectively. Transverse sliding direction displayed relatively higher friction values than PP and conventional ones. The friction variation may be due to the ability of the treads to form hydrodynamic wedges depending on the direction of treads relative to the sliding direction. The capacity of treads to scavenge oil away from the contact area was responsible for the friction increase. This behaviour was confirmed by transverse treads. In the transverse sliding direction, formation of hydrodynamic wedges was limited and consequently, friction coefficient decreased for pads of transverse treads.

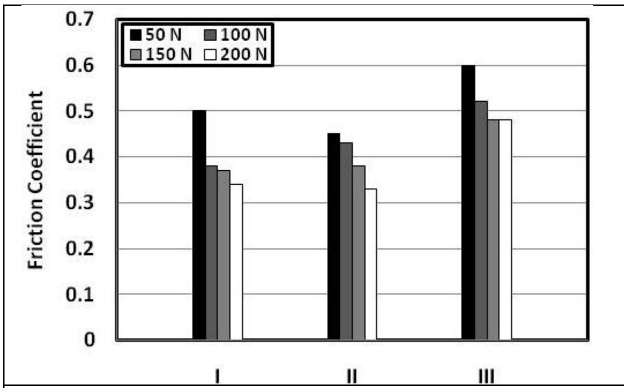

Fig. 12 Friction coefficient of bare foot sliding against oil lubricated pedal pad. Longitudinal direction.

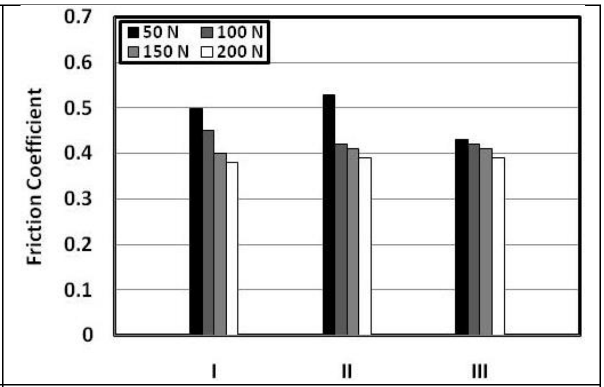

Fig. 13 Friction coefficient of bare foot sliding against oil lubricated pedal pad. Transverse direction.

The results of experiments carried out using rubber shoes sliding against the tested pads are shown in Figs. 14 - 21. Friction coefficient of dry sliding of rubber shoes against the pedal pads in the longitudinal and transverse directions is shown in Figs. 14 and 15 respectively.

Compared to the results of bare foot, rubber shoes displayed relatively lower friction values than bare foot. This performance may be attributed to the fact that adhesion of bare foot into pad surface was stronger than that shown for footwear and pad. Significant friction reduction was observed in the transverse sliding direction. PP pads displayed the lowest friction compared to the conventional and transverse ones. All friction values at the tested loads are lower than 0.6. Based on those observations, it is recommended to reconsider the direction of the protrusions and treads in the surface of the tested pads and the influence of the width and depth of the protrusions and treads on the frictional behaviour.

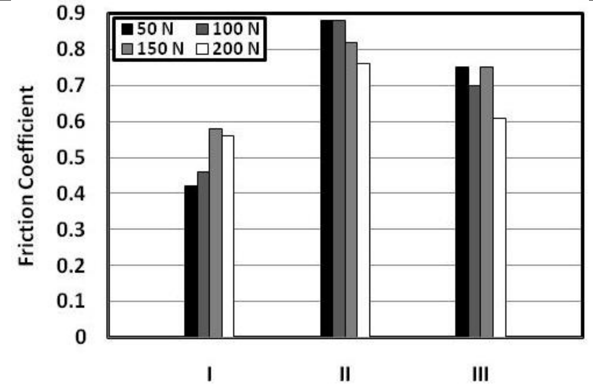

Fig. 14 Friction coefficient of dry sliding of rubber shoes against the pedal pad. Longitudinal direction.

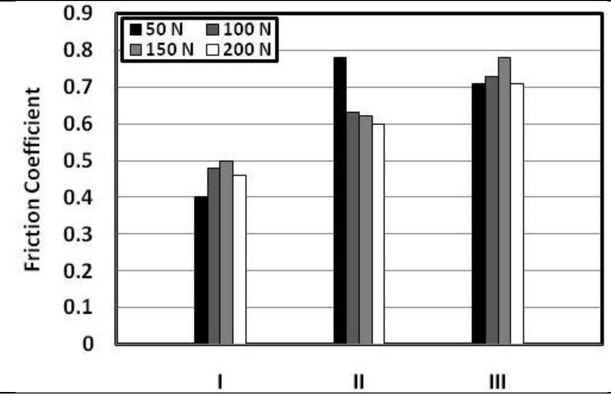

Fig. 15 Friction coefficient of dry sliding of rubber shoes against the pedal pad. Transverse direction.

In the presence of sand particles on the sliding surfaces, friction coefficient significantly increased for PP pads, Figs. 16 and 17 for longitudinal and transverse direction respectively. The friction increase can be explained on the basis that sand particles were embedded in the softer rubber surface and abraded the PP one. Friction coefficient displayed by transverse pads represented the highest values due to the easy escape of sand particles from the contact area. Conventional rubber pads showed the lowest friction coefficient, where the values were lower than 0.4. The friction values of PP in longitudinal and transverse directions were close to each other. Their values were higher than that displayed by bare foot.

In the presence of water on the sliding surface, drastic decrease in friction coefficient was observed for PP pads, Figs. 18 and 19. This behaviour can be attributed to the fact that water film trapped between rubber footwear and PP pads increased. In this condition, a part of the contact area performed dry friction and the other was water lubricated. Both bare foot/pad and footwear/pad displayed the same values of friction coefficient. The relatively soft rubber easily deformed and consequently washed away water from the contact area, while PP kept the water film deposited on the contact area.

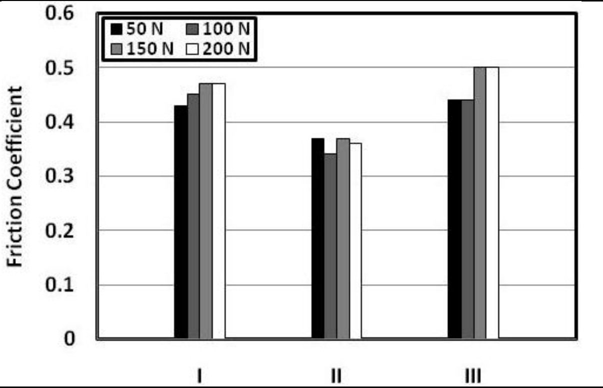

Fig. 16 Friction coefficient of rubber shoes sliding against sand contaminated pedal pad. Longitudinal direction.

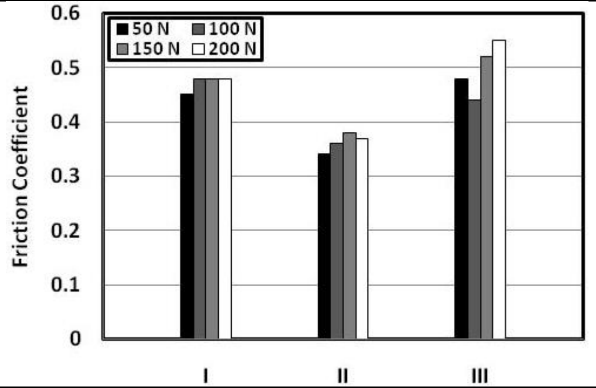

Fig. 17 Friction coefficient of rubber shoes sliding against sand contaminated pedal pad. Transverse direction.

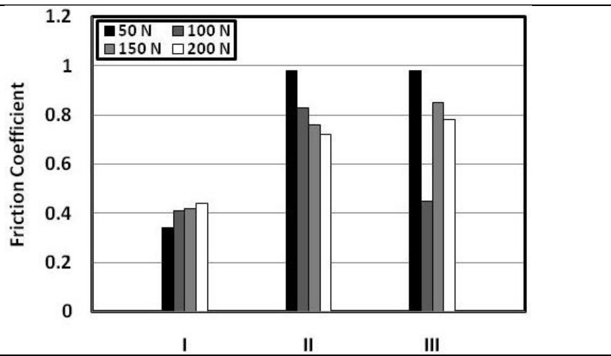

Fig. 18 Friction coefficient of rubber shoes sliding against water wetted pedal pad. Longitudinal direction.

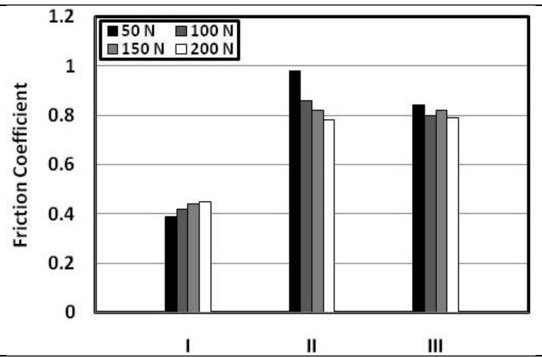

Fig. 19 Friction coefficient of rubber shoes sliding against water wetted pedal pad. Transverse direction.

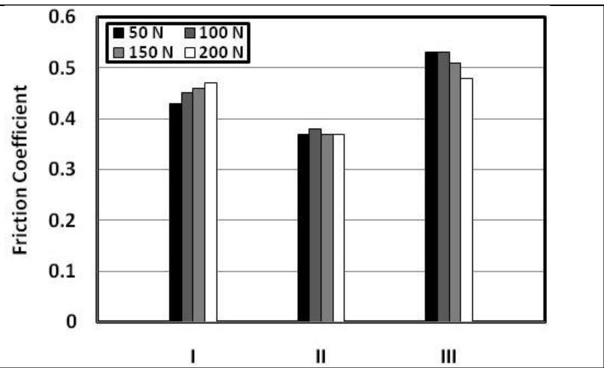

Fig. 20 Friction coefficient of rubber shoes sliding against oil lubricated pedal pad. Longitudinal direction.

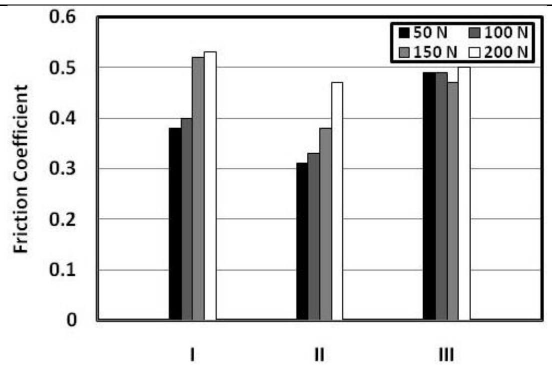

Fig. 21 Friction coefficient of rubber shoes sliding against oil lubricated pedal pad. Transverse direction.

Friction coefficient of rubber footwear sliding against oil lubricated pedal pads in the longitudinal and transverse directions is shown in Figs. 20 and 21. The values of friction coefficient were close to that displayed by bare foot. PP pads displayed relatively higher friction than the conventional pads, while the transverse pads indicated the highest friction values.

CONCLUSIONS

For bare foot sliding against the tested pedal pads the following conclusions can be withdrawn:

1. At dry sliding, friction coefficient displayed by PP tested pads was relatively lower than that shown by the conventional and transverse ones.
2. In the presence of sand particles between the foot and the tested pads, friction coefficient increased significantly for PP pads.
3. PP pads displayed the lowest friction coefficient for bare foot sliding against water wetted pedal pad in the longitudinal direction.
4. For oil lubricated pedal pads, friction coefficient displayed by PP pad values were close to that presented by conventional pads.

For rubber footwear slid against the tested pedal pads, it can be concluded that:

1. At dry sliding, rubber shoes displayed relatively lower friction values than bare foot.
2. In the presence of sand particles on the sliding surfaces, friction coefficient significantly increased for PP pads for longitudinal and transverse directions.
3. Drastic decrease in friction coefficient was observed for PP pads when sliding on water wetted foot wear.
4. The values of friction coefficient were close to that displayed by bare foot. PP pads displayed relatively higher friction than the conventional pads, while the transverse pads indicated the highest friction values.

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