Tribological approach for the analysis of the pedestrian slipping accident - II

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Abstract

The variations of the surface topographical parameters for the analysis of the pedestrian slip and fall accidents during the sliding friction between the specially prepared floor specimens and three working shoes were investigated. The profile ordinate data for each flooring specimen were obtained at 1.1 μm intervals using a laser scanning confocal microscope system along to the direction of sliding. A number of surface roughness parameters, that is, the centre line average (c.l.a.) and root mean square (r.m.s.) roughness, maximum height (Rtm), maximum mean peak height (Rpm), maximum mean depth (Rvm), and average asperity slope were calculated using a computer program and compared with the dynamic friction results. The analysis showed that the surface parameters undergo marked variations during the sliding process, but the variations were statistically significant. It was found that amongst various surface parameters, the maximum depth (Rvm) and the average asperity slope of the asperities were the biggest variation during the sliding proceeding. This result confirms the previous study and may suggests a new approach to monitoring the flooring environments with their service as the effort to reduce the pedestrian slip accident.

1. Introduction

Almost all real surfaces are rough on a microscopic scale and comprised of an aggregation of micro- and macro-asperities. The friction of footwear sliding against floor surface mainly depends upon the surface topography of the floor counterface which is modified by the transfer of polymer products from the shoe heels. (Kim and Cross, 1996 and Kim, 1995) The studies concerning the quantitative variation in the surface topography of the counterface as a sliding friction have not proceeded so far.

In the previous study, the author investigated the variation of surface topographical parameters for sliding between four metal based floor surfaces and three shoes. (Kim and Cross, 1996 and Kim, 1995) A number of surface roughness parameters, that is, the c.l.a. and r.m.s. roughness, maximum height, maximum mean peak height, maximum mean depth, and average asperity slope were computed. Three point analysis was used to define a peak and calculate the asperity slope. It was found that the surface parameters had a variation during the sliding friction.

The present work extends the previous investigation to the totally different types of floor surfaces, namely, four perspex floor samples, against the same shoes used before. Here, the variations of topographical parameters with the sliding process have been studied for the initial and running-in status of floor surfaces and compared with their dynamic friction coefficients (DFCs).

2. Friction tests

The sliding friction tests were performed on the pendulum type Dynamic Friction Testing Machine, described in detail in the report of Hoang et. al. (1987). The friction tests were conducted with three shoes against four perspex specimens which have different roughness scale. The floor specimens were also very carefully considered for the study of microscopic characteristics of the flooring's geometry to the sliding interface with a shoe heel. At this time, selection of the floor surfaces was based on the comparison with the results of previous friction tests which were conducted with steel based floor surfaces. The floor surfaces selected for this study have similar level of roughness, but totally different mechanical and physical characteristics. That is, a general property of perspex material has a low elastic modulus and relatively easy to prepare smooth surfaces of known shape. (Archard, 1957)

Four floor surfaces were prepared by the same blasting technique, which was used for the steel based floor samples, to achieve a different roughness on each floor surface. These blasted surfaces were named as Perspex 1 to Perspex 4 according to their roughness dimensions. Since these floor specimens were very sensitive to any scratches, it was needed special care to handle them. All the floor surfaces were particularly well preserved to avoid any damages on their surface layers.

Three commonly available work shoes which were used for the previous tests were selected for the friction tests. The selection of the same shoes was considered for the comparison with the previous test results. This is intended to monitor the variations in the surface topographical parameters during the sliding friction. The shoes used were a Polyurethane, PVC, Nitrile Rubber each. As mentioned before, a few trial tests with each shoe were run on a smoothest perspex sample to avoid the possibility of false readings from the friction tests with new shoes.

The friction tests were conducted from the smoothest perspex (Perspex 1) to the roughest one (Perspex 4) according to their roughness magnitude. This was intended to minimise the effect of initial damages of the shoe heel caused by the roughest floor surface so that it made reasonable to monitor the wear-off of the shoe heel gradually. The test order of shoes was also considered in accordance with their hardness; the Polyurethane to the Nitrile Rubber shoe. The friction tests were conducted only on the dry and clean surface conditions in order to investigate the roles of the floor surface geometry itself to its matching shoe heel. Each shoe specimen was tested 10 times on each floor surface according to the test orders mentioned above. After each friction test, the surfaces of floor and shoe heel were thoroughly cleaned with a smooth brush to eliminate the effect of wear particles produced. Two stages of the friction tests were conducted with above mentioned test environments. The results of these two stages of dynamic friction test are shown in Figure 1.

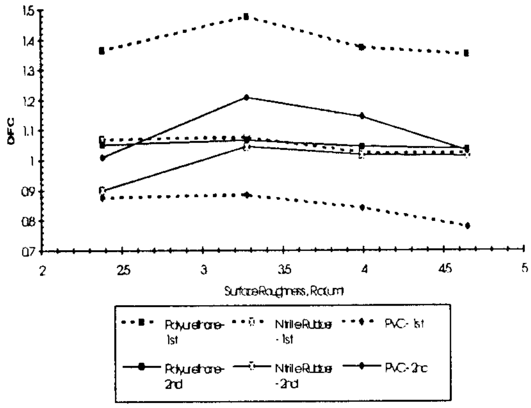


Figure 1. The plot of dynamic friction coefficients for 3 shoes against the Ra roughness of the 4 different floor surface during two stages of friction tests on the dry floor surface conditions.

3. Floor surface roughness parameters

The latest Confocal Laser Scan Microscope (Model; MRC 600; Bio-Rad, England) was used to measure the roughness of the floor surfaces. A detail of the roughness measurement from the confocal scan microscope is found in the earlier study. (Kim, 1995)

The surface roughness were measured 3 times on 5 different positions on each floor surface and averaged. Each profile ordinate data were measured at 1.1 μm intervals and 200 numbers of data were selected for the assessment length. From these roughness measurements, the roughness related information such as profile shape, distribution, and roughness (Ra) were obtained. These information were saved into the computer for the further analysis.

The quantitative analysis of the surface was performed by computation of a number of parameters pertinent to the friction process, namely the c.l.a. and r.m.s. roughness, maximum height, maximum mean peak height, maximum mean depth, mean, standard deviation of asperity heights, and average asperity slope. A surface analysis program was written to process the surface profile data on an 486 personal computer.

The surface parameters considered are as follows. The details of surface parameters are given in the recent studies of author. (Kim and Cross, 1996 and Kim, 1995)

(1) The following parameters represent the height of the asperities:

Ra : the centre line average (cla) roughness
Rq : the root mean square (rms) roughness
Rtm : the maximum mean peak-to-valley height
Rpm : the maximum mean height above the mean line
Rvm : the maximum mean depth below the mean line centre line average roughness

(2) The average asperity slope of the asperities is also used to characterise the surface.

4. Results and Discussions

The friction results for three shoes sliding against the four perspex floors is shown in Figure 1. It can be observed that the friction results of all shoes tested were clearly varied after the friction tests. The slip resistance of the polyurethane and pvc shoes show quite interesting results between the before and after friction tests. The slip resistance of the polyurethane shoe after the friction tests was largely diminished on its DFCs against the all floor surfaces tested. The reduction rate of DFCs was almost 25 % on average.

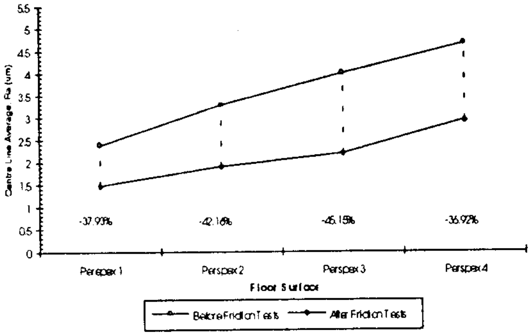
On the other hand, the slip resistance of the pvc shoe after the friction tests was considerably improved. The DFC value of the pvc shoe was dramatically increased over 30 % on average. These results were also found in the pervious friction tests which were conducted with the steel based floor surfaces.

It should be noticed that the friction results with the perspex floor surfaces, however, show more noticeable comparison between the friction tests. After two sets of the friction tests, the DFCs of all shoes tested look like converging on the floor surface of Perspex 4. This trend was also found in the previous friction tests, but was not intensive like the case of perspex floors. In any case, the tendency of astringency on the last floor surface after the friction tests seems to be caused by the surface geometry of the floor surfaces.

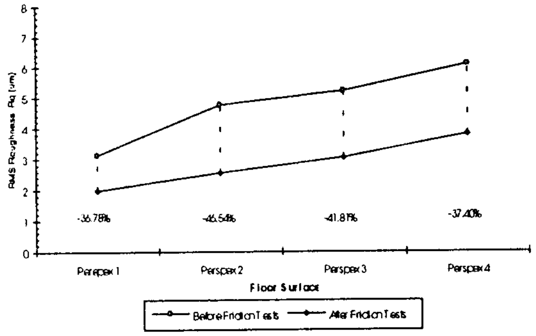
It also could be considered that a general property of perspex has low elastic modulus so that possibility of the perspex itself's deformation from the attack of shoe heel during the sliding process could be happened. Although there are many factors to affect the sliding interface of shoe-floor surface, it is clear that variations in the surface topography of both a shoe heel and floor surface are always accompanied as the results of sliding action. Therefore, it is necessary to monitor a surface topography of both mating materials with the proper surface parameters before and after friction tests.

From the roughness records of the unrubbed and rubbed floor surfaces, obtained in direction along sliding, a number of surface parameters and their contributions were computed. The variations of these parameters with the sliding process are discussed below:

1. The variations of the arithmetic average, Ra, and rms, Rq, roughness of each flooring were compared in Fig. 2 as before and after the friction tests. The reduction rate of the roughness of the Perspex 2 floor surface was recorded over 46 % in the Rq roughness parameter. The reduction rates of the perspex floor surfaces in their Ra and Rq readings were over two times higher than them of the steel based floor surfaces tested before. It is considered that this large amount of reduction could be caused by possible damages of the floor surface themselves from new shoe heels during the friction process because the perspex is less rigid material than the steel. Therefore, it is urged that observation of the topographical changes of the shoe heel also should be considered to control the interaction of shoe-floor sliding interface. Therefore both geometry of the mating materials should be simultaneously considered as approaching the friction problem.



(a) CLA Roughness, Ra



(b) RMS Roughness, Rq

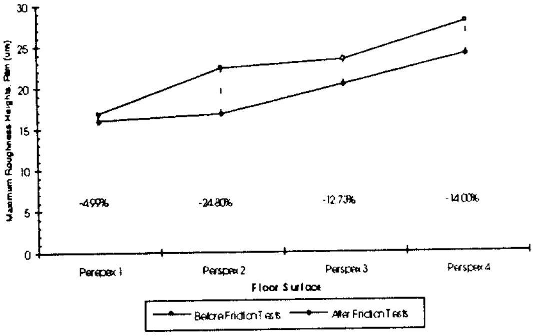
Figure 2. Changes of the roughness parameters of floor surface between before and after the friction tests - Ra and Rq.

The variation rates of Rq roughness were exactly showing the trend of the friction results from Figure 1. It might be assumed that the Rq is more suitable parameter than Ra for monitoring a friction process. This arises as a result of the form of the definition of Ra. Ra is assessed by reference to a mean line positioned so that the areas enclosed by the profile above it and below it are equal. Any redistribution of material from one side of the mean line to the other will cause a shift in the position of the mean line and may leave the Ra value unchanged.

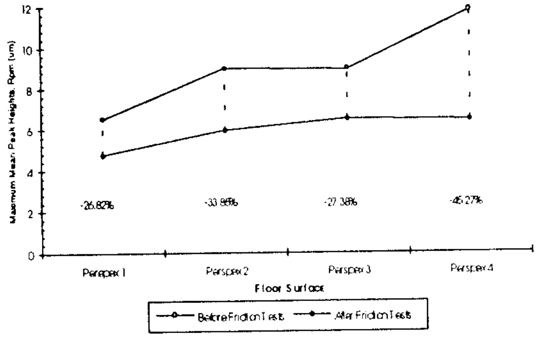
It is noted that Ra and Rq roughness are largely decreased after the friction tests. This must be due to the transfer of polymer film from each shoe heel on the perspex surfaces as mentioned before. (Kim and Cross, 1996 and Kim, 1995) That is, the polymer fragments from each shoe heel has begun to deposit into the valley of asperities of floor surfaces and formed a uniform film depending on the roughness scale of asperity depth of each floor surface. Any such variation has to do with the size and shape of wear particles from each shoe and with the manner in which these are deposited on the floor surface. This tends to decrease the surface roughness to a minimum value achieved by the deposition of a stable polymer film. With the further sliding process, the sliding friction of the shoe heel and floor surface is seemed to occur between this deposited polymer film and the shoe heel.

It becomes obvious that roughness of the floor surfaces after the friction tests are changed from above observation but it is still unclear that what parts of surface height are changed and how are they varied to this type of floor surface. For the answers of these questions, the variations of the asperity heights and valleys of each floor surface should be examined.

2. The maximum peak-to-valley height, Rtm, and maximum mean height, Rpm, of the profile above the centre line were compared in Figure 3 as the initial and rubbed status of the floor surface .



(a) Maximum peak-to-valley height, Rtm



(b) Maximum mean height above the mean line, Rpm

Figure 3. Changes of the roughness parameters of the floor surface between before and after the friction tests - Rtm and Rpm.

It can be observed that both height parameters (Rtm and Rpm) of all floor surfaces tested after the friction tests were clearly decreased and the variation rates were on average about 14.1 % in Rtm and 33.3 % in Rpm each. These figures indicate that the asperity heights of this type of floor surface are largely affected by the friction events. When compare with the results from the steel based floor surfaces, the variation rate of the Rtm in the perspex floor surfaces was almost six times higher than steel ones. This result seems to be caused by mechanical and physical property of perspex floorings.

As can be seen in Figure 3, there is a large difference between the readings of the Rtm and Rpm parameters. As mentioned before, the Rtm parameter simply describe the maximum height of a floor surface so that it is difficult to know the effectiveness of highest asperities to the friction process. On the other hand, because the Rpm parameter indicates the change of maximum height above the centre line, this could be a more sensible factor searching for the variation of the asperity heights during the friction tests.

This means that a real area of contact between two mating surfaces is only formed at the highest asperities of both mating members so that the highest asperities over centre line at the time of initial contact play a vital role to their adhesive bonding. With reduction of the maximum heights of asperities, the adhesion between both members will be diminished and will consequently affect to DFC result. As long as friction tests are proceeding, it is an inevitable fact that the topography of the floor surfaces become smoother and/or the surface asperities become less sharp.

3. The variations of maximum mean depths (Rvm) below centre line of the floor surface profiles between the unrubbed and rubbed status of the floor surfaces were compared in Figure 4. As observed at the steel floor surfaces, the maximum mean depths of each floor surface were clearly reduced on average about over 50 %. This reduction rate is exactly two times higher than that of the steel floor surfaces.

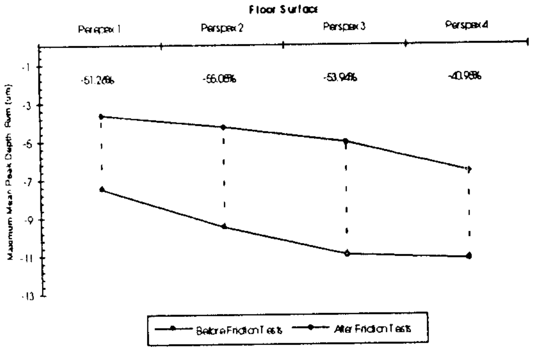


Figure 4. Changes of the roughness parameters of the floor surface between before and after the friction tests - Rvm.

This rate also shows the biggest variation amongst height related parameters in this type of floor surface.

This result verify that the fragments of polymeric particles from each shoe heel were embedded into the valley of the floor surface profiles and a uniform film of the deposited material was formed. The variation of the profile asperity depth, therefore, become an one of the major causes to the reduction of surface roughness scale. This roughness reduction of the floor surfaces consequently affect to the values of DFC

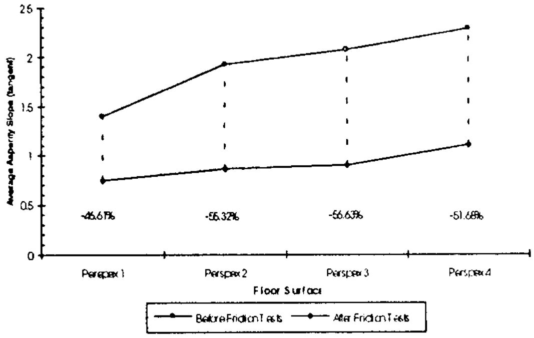


Figure 5. Changes of the roughness parameters of the floor surface between before and after the friction tests - average asperity slope.

4. Another important parameter which may affect the friction process is the slope of the asperities. (Sherrington and Smith, 1987) The variations of the average asperity slope of the floor surfaces with the friction process are shown in Figure 5. It is observed that the asperity slope in the sliding direction varies in a manner similar to Ra (Figure 2 (a)), and hence the same explanation is true in this case also. The identical variation of these two parameters suggest a direct relationship between them, as reported earlier by Endo and Kotani (1973). In searching the reasons of large variation of asperity roughness in the perspex floorings after the friction tests, it was assumed the possibility of plastic deformations of the floor surfaces themselves as a result of sliding process. With large amounts of reduction in the maximum heights of asperities, it was also found that over 50 % of asperity slopes were changed after the friction tests. This means that the surface layers of perspex floorings themselves were damaged after the friction tests.

5. Conclusions

From two stages of the friction tests which were conducted with the three normal work shoes sliding against the four perspex based surfaces, the following results can be summarised:

1. During the sliding friction between the floor surface and the shoe heel, the topography of floor surface is modified. This is seemed to be caused by transfer of the polymeric materials from shoe heels into the floor surface.
2. The surface parameters undergo large variation during the sliding process. Amongst various surface parameters examined, the average asperity slope and maximum depth (Rvm) of the asperities are recorded the biggest variations during the sliding proceeding.

Consequently, the analysis showed that the surface parameters of the floor surfaces seemed to have large variations by more or less stable conditions after the friction processes. Because concept of the friction coefficient, regardless of how it is measured, only has the character of a performance value and is not a material property, this study may suggests a new approach to monitor the flooring environments with their service as the effort to reduce the pedestrian slipping and falling accidents.

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