

Issues of Wear and Tear on the Shoe Heel Surfaces and Their Effects on Slip Resistance Performances

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The aim of this study was to formulate a clear picture on wear phenomena of shoe heel surfaces during the early stage of dynamic friction measurements and identify the wear effects on slip resistance performance. Novel concepts and theory were suggested to identify underlying wear regimes of the heel surfaces. Dynamic friction tests were conducted using two types of shoes and a floor specimen. Topographic changes and wear developments of each heel surface were quantitatively and qualitatively measured by surface roughness parameters and microscopic observations. All the results clearly identified that various wear modes such as adhesive, abrasive, ploughing, and fatigue were involved as main wear sources and the resultant effects on slip resistance performances. This study suggests that future research on slips and falls should pay attention to the issues on wear and tear behaviors of the footwear and their impacts on slip resistance performance.

Introduction

Slip resistance properties between the footwear and floor surfaces under different walking conditions have been studied for many years. Recent studies have raised issues on wear behaviors of the footwear with slip resistance measurements [Manning et al., 1998; Kim et al., 2001]. These studies reported that surface topographies of the shoes and floors constantly changed in specific ways during slip resistance tests. As a result, extended tests on the shoe heels led to structural changes and affected the coefficient of friction (COF) measurements. Kim et al. [2001] introduced a concept on shoe surface changes and wear developments with dynamic friction tests. Although those studies showed strong relationships between surface roughness and slip resistance properties, fundamental aspects on wear behavior and associated tribological characteristics

of the heel surfaces were infrequently investigated. The present study was, therefore, aimed to develop refined concepts on wear phenomena of the shoe surfaces and suggest a comprehensive wear model. For the validations of the new concepts and the suggested theoretical model, initial and rubbed heel surfaces of two shoes were systematically analyzed by quantitative and qualitative methods during slip resistance tests. New and rubbed heel surface were measured by a number of surface roughness parameters for the quantitative analysis. A series of micrographs were taken by a scanning electron microscope to monitor wear developments and surface changes of the rubbed heel surfaces for the qualitative analysis.

Theory Developments

Basic wear model and assumptions

When a shoe contacts a floor, the two surfaces seem to initially touch only at tiny discrete areas where their highest asperities are in contact. A local pressure at the contact regions would be high enough to cause plastic deformations of the heel asperities even at the lightest load because an elasto-plastic modulus of the heel would be significantly less than that of the floor. If the shoe heel slides on the floor, then the heel surface would be ruptured, deformed and ploughed by wedge-shaped asperities of the floor surface. Based on these assumptions, the following wear model for the shoe was suggested:

- 1) Adhesive wear would take place when the relative movement between the heel and floor surface induce breakage of the junction inside the heel surface rather than at the interface. This would affect only the upper layers, where the tops of asperities would be broken off.

2) Abrasive wear would be considered as events of displacement of polymeric materials from the heel surface, caused during the relative sliding motion by the ploughing effects of hard protuberances on the floor surface. This would affect both upper and lower layers of the heel surface because polymeric materials could be removed from valley and peak areas.

3) Ploughing could take place when the heel-floor interaction does not include any material removal but results only in material relocation on the heel surface. This would affect both upper and lower layers of the heel surface because polymeric materials would be moved on the surface, forming peaks and leaving valleys.

4) Fatigue wear could occur when the heel surface is exposed to a large number of alternating tensile and compressive stresses, which are typical modes of heel striking and sliding during walking activities. This is most likely to occur in cases when the floor surface has more blunt rather than sharp projections, and as a result the heel surface would undergo mainly cyclic deformations leading to surface failure.

Incorporated wear model

With estimated topographic changes of the heel surface rubbed against the floor, an incorporated wear model was suggested with roughness parameters. The details of surface roughness parameters are found in the literature [ISO 1998; Kim et al. 2001]:

- If R_t (maximum peak-to-valley), R_{tm} (maximum mean peak-to-valley), R_p (maximum peak height), R_{pm} (maximum mean peak height) and AS (average slope angle) decrease, adhesive wear is assumed to be predominant.
- If R_t , R_{tm} , R_p and R_{pm} decrease, abrasive wear is assumed to be predominant while an increase of R_t , R_{tm} , R_p and R_{pm} will indicate ploughing.
- If R_v (maximum depth) and R_{vm} (maximum mean depth) increase, fatigue, ploughing or abrasive wear is expected.

- If R_t , R_{tm} , R_p , R_{pm} , R_v and R_{vm} and AS increase, ploughing is assumed to be predominant.

Experimental Methods

Slip resistance tests

Slip resistance tests were performed on a pendulum-type dynamic friction tester that was designed to simulate the movements of a human foot and the forces applied to the underfoot at the moment of heel strike and initial sliding.

Test arrangements

- Shoes and floor specimens:

Two double density polyurethane shoes with different sole/heel patterns were used for the tests. The two shoes were named as Shoe No. 1 and Shoe No. 2, respectively. For flooring specimens, ceramic plates were used for the slip resistance tests.

- Test conditions and slip resistance measurements:

Test conditions were limited to clean and dry surface environments in order to eliminate any confounding effects of contaminants by agents other than the shoe and flooring specimens. Each shoe was rubbed against a new ceramic plate 50 times.

Characterizations of the shoe wear

Initial and rubbed heel surfaces were comprehensively analyzed by quantitative and qualitative Methods during the tests. For the quantitative measures, a number of surface roughness parameters were measured by a laser scanning confocal microscope. To validate surface roughness data and identify wear phenomena, the heel surfaces were examined by a stereo scanning electron microscope.

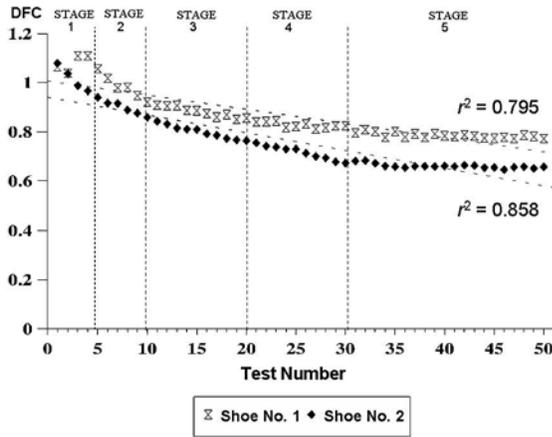
Results

Slip resistance performance Fig. 1 shows test results from the two double density

polyurethane shoes interacting with the ceramic floor specimens. The main observations were summarized in the following:

- The dynamic friction coefficient (DFC) values decreased at the end of the tests by over 33 % (1.164 to 0.772) for shoe No. 1 and by 40 % (1.079 to 0.646) for shoe No. 2.

Figure 1. DFC results from the two shoes tested under dry floor surface conditions.



- Regression results showed significant relationship between the DFC values and the number of rubbings

(r0.80 for shoe No. 1 and r0.86 for shoe No. 2, respectively).

- The DFC value for shoe No. 1 showed higher values than for shoe No. 2 during the tests. At stage 1 (5 times of rubbings), shoe No. 1 showed a maximum DFC value (1.164), but this value slowly decreased until stage 4 (30 times of rubbings).

- Correlation coefficients showed negative values during the tests. This result indicated that the heel surfaces were actively engaged in massive structural changes and surface damages were most likely due to adhesion, abrasion, ploughing, and fatigue wear.

Surface roughness analysis

Fig. 2 shows that all the surface roughness parameters were markedly changed during the tests as compared with their initial values.

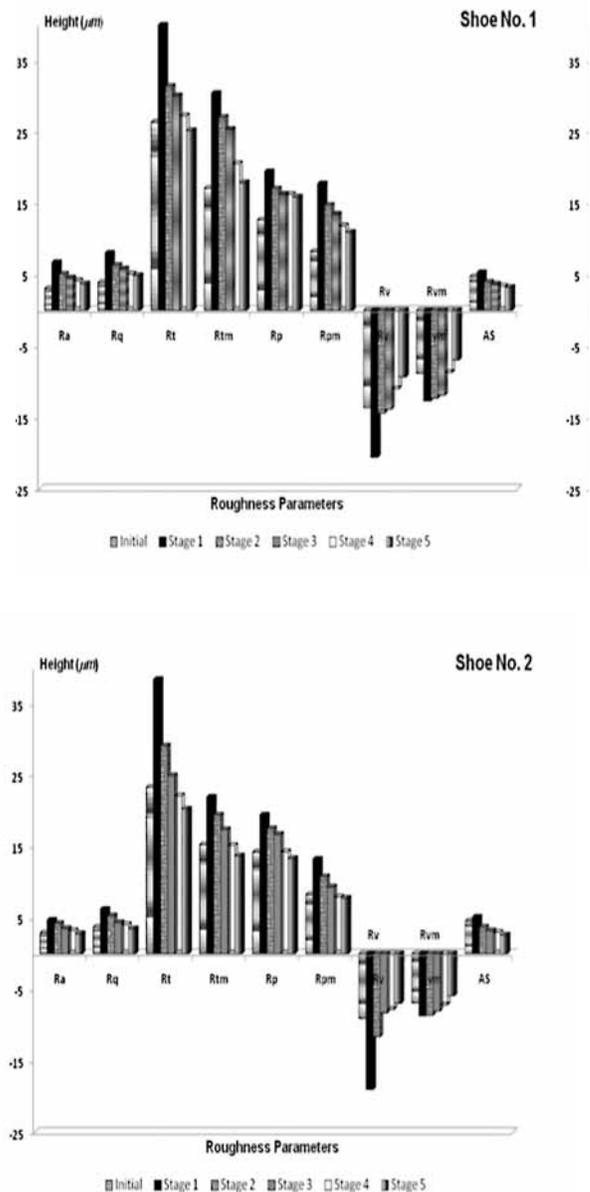


Figure 2. Changes of surface roughness parameters of the shoes during the tests. Microscopic analysis

Microscopic analysis

1) Shoe No. 1 The rubbed heel surface of shoe No. 1 showed a number of parallel tearing traces and micro-layered textures as shown in Fig. 3 (i(b)). Width and depth of the tearing traces were gradually increased with rubbings. The edge areas were more severely damaged than the middle areas. This finding suggested that wear proceeded from outside to inside areas on the heel surface so that wear patterns looked curled up and formed thick layers, showing clear evidence of severe abrasion, ploughing, and fatigue.

2) Shoe No. 2

The rubbed heel surface of shoe No. 2 showed totally different features. It was initially covered with a number of small micro-porosities. During the rubbings, the smooth and porous surface was broken open and formed a lot of cavities on its surface layer, creating a new rough surface (Fig. 3 (ii (b))). The heel surface was heavily deformed by the sliding direction. This result showed a strong evidence of abrasive wear. The worn surface was characterized by scratched traces and micro-layered surface textures.

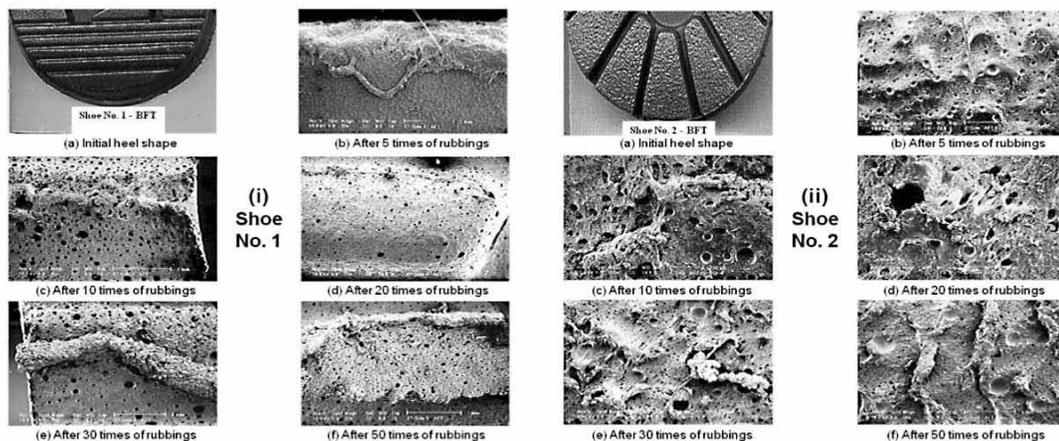


Figure 3. Micrographs of wear tracks of the shoes during the slip resistance tests.

Conclusions

This study was concerned with identifying wear phenomena of the shoe surfaces in an early stage of sliding friction and its effects on slip resistance properties. Novel concepts on wear phenomena of the heel surfaces were proposed in order to gain fundamental insight into the anatomical picture of the tribological characteristics involved. A series of dynamic slip resistance tests were conducted between two polyurethane shoes and ceramic plates under dry conditions. Worn surfaces of the heels were comprehensively analyzed by quantitative and qualitative methods during the tests. The results clearly revealed that plastic deformations and cuttings by relatively sharp asperities and fatigue

by more rounded asperities were identified as main mechanisms for the shoe wear. Although fatigue wear was not clear, microscopic observations of crack formations and propagations on the heel surfaces provided strong evidences to ascertain this aspect. Whilst the proposed wear concepts and model for the shoes would require further investigations, this study suggests that future research on slips and falls should pay attention to the issues on wear and tear behaviors of the footwear and their impacts on slip resistance performance.

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