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Identifying shoe wear mechanisms and associated tribological characteristics: Importance for slip resistance evaluation

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ABSTRACT

The role of shoe wear on the tendency to slips and falls has been less studied than the contributions of floor surfaces to fall-related injuries. The purpose of this study was to better understand the principal aspects of shoe wear mechanisms and to identify the associated tribological characteristics of shoe/walking surface frictional behaviour. Dynamic friction tests were conducted amongst four types of shoes and two different floor specimens. Wear features and their development on the shoe surfaces were quantitatively and qualitatively examined before and after the tests. Test results showed that the initially unique micro- and macro-tread patterns experienced massive changes and severe damages. The worn surfaces of shoe heels acquired dissimilar wear shapes, sizes, and patterns. The main differences in their wear developments were strongly related to the material characteristics. Findings from this study provided new insights concerning the primary features of shoe wear such as abrasion patterns, crack formations, ruptures, structures, and damage propagation. The abrasion patterns of heel surfaces resulted from crack propagation at the root of the wear tongue and subsequent tearing of those tongues when they reached their maximum sizes. Wear behaviour of the shoe surfaces was significantly affected not only by the rate of crack propagation along a low angle of asperity slope, but also by the rate of crack propagation. Findings of this study may have potential applications to improve shoe designs for safer heels and soles.

1. Introduction

Although a number of causes contribute to the pedestrian fall incidence, the current literature mostly highlights design issues on the walkway surfaces and work environments to enhance slip resistance performance [1–7]. As a result, shoes seem to be treated as one of the last factors to change or modify as they are less effective on slip resistance properties [8]. However, this practice appears to underestimate or misunderstand the complex nature of frictional behaviours between the shoe and floor [6,8].

Because friction is defined as the force resistance to relative motion developed between two bodies in contact with one another, or more comprehensively, as the latent resistive force which opposes incipient movements at and parallels to the slip plane of two interfacing surfaces [9,10]. This means that friction is a property between the two interfacing and interacting surfaces. Hence, surface conditions and tread design issues of the footwear should be fully explored to identify their frictional characteristics and effects on slip resistance properties because they have an equally important role in the prevention of pedestrian slips and falls.

The main functions of shoes are to protect our foot, provide safety and comfort, and enhance performance during various activities. With respect to safety and balanced performance, it is essential that shoes should deliver effectual traction or slip resistance against any slippery situation. However, shoe heels and soles seem to experience heavy attritions and tear developments with repeated walking. Accordingly, initial topographic structures (micro- and macro-tread patterns) of the shoe surface are likely to be significantly modified from their original ones. This fact signifies that wear advances of the shoe surface seem to be a major concern and considerable impact on slip resistance properties.

Despite the importance of this issue, there have been little studies on the role of shoes with respect to available frictional properties and their effects on slip resistance performance with wear developments. To date, few studies had attempted to determine how shoe heels/soles influenced slip resistance results [10–18]. These studies demonstrated that shoe surfaces were altered continuously during friction measurements. For example, initial topographic structures of the shoe surfaces were changed by repeated rubbings and such variations caused to slip resistance outcomes.

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Furthermore, controlled researches were conducted by measuring wear behaviours of shoes against dynamic friction coefficients [13,15–18]. These studies report that surface roughness of the shoe heels and soles significantly affect slip-resistance properties. Surface roughness offers drainage spaces to avoid squeeze film formations under lubricated environments, but quickly becomes incompetent after being worn [15].

A recent study introduced a wear concept for shoe surfaces and investigated shoe wear activities during dynamic friction tests [15]. This study aimed to understand wear mechanisms of shoe surfaces and to examine shoe wear effects on slip resistance performance. To achieve the objectives, a theory model was proposed to study wear behaviours of the shoe surfaces. Initial and rubbed surfaces of two shoes were comprehensively assessed to test the wear model. Test findings presented that the shoe surfaces were largely modified by a chain of wear mechanisms. Although this investigation identified wear behaviors of the shoe surfaces, detailed features on shoe wear activities and related tribo-physical properties were not fully explored.

The present study aims to understand principal aspects of shoe wear behaviours and identify associated tribological characteristics of shoe wear actions such as crack formations, ruptures, structures, and propagations. Specific goals are to:

1) measure topographic changes of shoe surfaces during dynamic friction tests;
2) investigate underlying wear mechanisms of the shoe surfaces;
3) recognize wear behaviours viz.: wear crack formations, break-ups, configurations, and circulations; and
4) investigate shoe wear effects on slip resistance properties.

To achieve the above aims, this study is based on the earlier findings for the wear effect of shoe surfaces during dynamic friction measurements [15,17]. Understanding detailed features on shoe wear growths, accompanying tribo-physical aspects of shoe surfaces and their results on slip resistance properties may provide valuable information to improve validity and reliability of slip resistance assessments. It is wished that findings from this study may have probable appliances to enhance shoe designs for safer heels and soles.

2. Theory

When two solid materials are in contact, two surfaces seem to touch only at tiny discrete areas where their highest asperities interact [19,20]. This hypothesis could be applied to develop a model for the shoe-floor sliding friction system. That is, soft asperities of a shoe heel seem to contact and slide over an array of wedge-shaped hard asperities of a floor surface. Fig. 1 suggests a geometrical model for a contact-sliding interface between the shoe heel and floor surface as a micro- and macro-scopic form, respectively according to the above assumption [15].

As shown in Fig. 1(a), the highest asperities of the floor surface crash and penetrate into the heel surface and make a contact area between the shoe heel and floor surface. Because an elastic modulus of the floor surface is considerably higher than the shoe one, there seems to be an interlocking mechanism between the two bodies (Fig. 1(b)). If the shoe slides on the floor surface, rigid asperities of the floor surface seem to infiltrate, rupture, and deform the heel surface [15]. Additional rubbings would require tough asperities of the floor surface to plough grooves into the shoe surface. Cyclic rubbings or continuous walking would largely contribute to further developments of shoe wear growths and lead to major cracks.

In this process, a peak height-density (denseness of peak asperity within an assessment length) of the floor surface's profile supposes to be an important factor affecting the shoe sliding friction mechanism. This means that the sliding interface between the shoe heel and floor surface can be regarded as a tangential force required to overcome the adhesion at regions of intimate contact plus the tangential force required to lift the asperities over each other. When asperity wedges of the floor surface are drawn across the shoe surface, an attack slope angle (θ) of each asperity wedge of the shoe surface seems to play a critical role to the extent of tangential forces applied in the sliding direction and affect a configuration of the heel surface deformation (See, Fig. 2). Therefore, it would be beneficial to investigate the changes of average asperity slope angles of the shoe surface for identifying wear crack formations. The details of the average asperity slope angle of a surface profile are found in the previous studies [11,21].

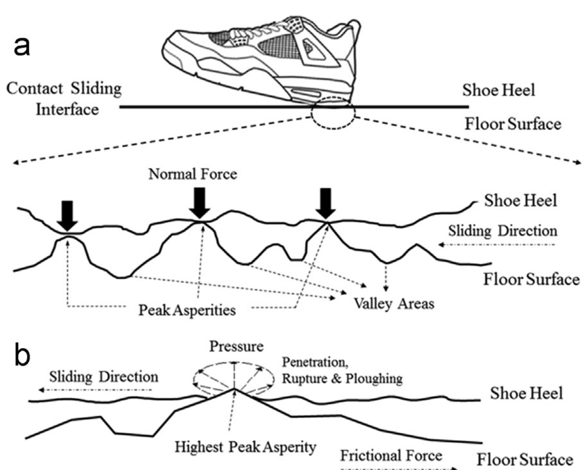

Fig. 1. A schematic diagram of a contact-sliding interface between a shoe heel and floor surface: (a) Microscopic form: initial contact state and (b) Macroscopic form: interlocking mechanism, respectively.

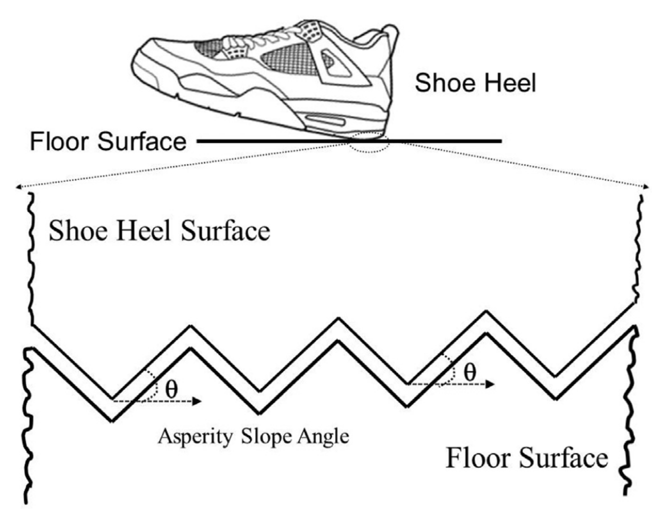

Fig. 2. A schematic illustration of the movement of abrasion patterns from a shoe heel sliding against a floor surface.