FRICTIONAL RESPONSE OF MULTIPLE SLIP-RESISTANT FLAT AND BEVELED SHOES TO NORMAL LOADING

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INTRODUCTION

Slips and falls are a serious occupational and health problem and cost the US economy $180B each year [1]. Amongst the biomechanical and environmental factors that influence slip and falls, shoe design is of great importance since it is a controllable factor that affects the available coefficient of friction (COF). Slip risk can be predicted as a function of the difference between the available COF and the required coefficient of friction (RCOF) to maintain walking [2].

Previous research by our group has demonstrated capability of computational modeling in predicting the available COF of shoes on contaminated surfaces [3]. Specifically, a multiscale finite element model of shoe-floor friction has been developed that calculates the available COF based on the microscopic and macroscopic features of the shoe and flooring such as surface roughness, shoe material properties, shoe-floor contact angle, shoe sliding velocity, normal loading, and whole shoe geometry.

Of the design characteristics affecting COF of the footwear, one that has not been thoroughly investigated is the effect of beveling of the shoe heel and how the COF of beveled and flat shoes respond to the changes in normal loading. The effects of normal loading on COF is relevant to understanding the impacts of a person's weight on the resulting COF and slipping risk. To the best knowledge of the authors, one experimental study has investigated the effect of beveled heel on slip-resistance of only one shoe design in one level of normal loading [4]. This abstract fills the knowledge gap by introducing a computational modeling methodology to investigate the effects of beveling shoe heels and kinetics (i.e. normal loading) on the available COF and potential slip-resistance performance of shoes.

METHODS

A multiscale finite element model of shoe-floor friction which simulates the contact between shoe and flooring surfaces in microscopic and macroscopic scales was utilized to investigate the effect of normal loading on shoe-floor COF (LS-Dyna®, LSTC, Livermore, California, USA). The microscopic component of the multiscale model calculates the microscopic COF as a function of contact pressure (*COF(p)*). The macroscopic component of the multiscale model calculates the contact pressure distribution over the macroscopic geometry of the shoe sole and uses the *COF(p)* from the microscopic models to calculate the whole shoe COF on contaminated surfaces.

The multiscale model was applied to simulate the friction between four existing shoe designs against a vinyl flooring at a sliding speed of 0.3 m/s and a shoe-floor angle of 7° consistent with the standard for shoe-floor friction measurement [5]. Four shoes (Fig. 1) that were considered included two flat heel shoes (F1 & F2) and two shoes with beveled heels (B1 & B2). Shore A hardness of the shoes was measured using a durometer and was used in models for quantifying material properties of the shoes (Table 1).

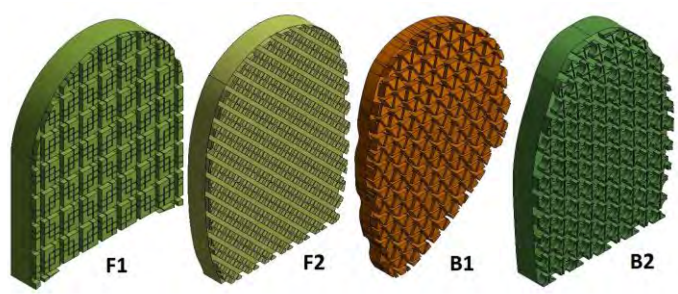

Figure 1: Geometries of the modeled shoes.

Simulations for each macroscopic shoe model were conducted over 10-11 normal load levels to generate a relationship between the normal loading and COF as well as contact area (A_{Model}). Contact area was chosen because higher contact areas between shoe and floorings are demonstrated to lead to a more distributed under-shoe contact pressure and correlate with a better slip-resistance performance [3].

RESULTS AND DISCUSSION

Computational models indicated that an increase in normal loading led to a decrease in COF (Fig. 2) and an increase in A_{Model} (Fig. 3). An exponential decay function (Eq. 1) and a power function (Eq. 2) described the variation in COF and A_{Model} with respect to the change in normal loading, respectively (R^2>0.99). In these equations, λ and b are coefficients that were determined using curve fitting techniques; COF_H and COF_L represent COF in high and low normal loads, respectively.

$$COF = COF_H + (COF_L - COF_H)e^{-\lambda F_{Normal}}, \text{ Eq. 1.}$$

$$A_{Model} = aF_{Normal}{}^{b}, \text{ Eq. 2.}$$

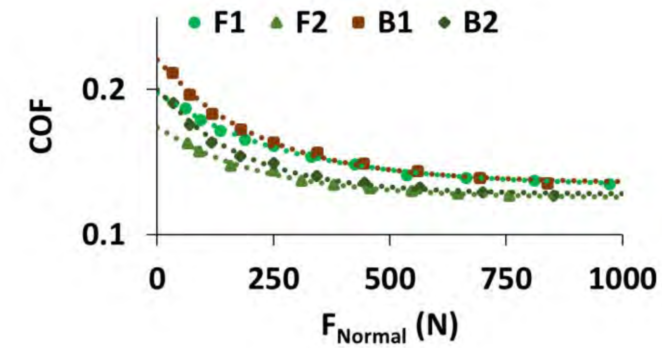

Figure 2: COF versus normal loading.

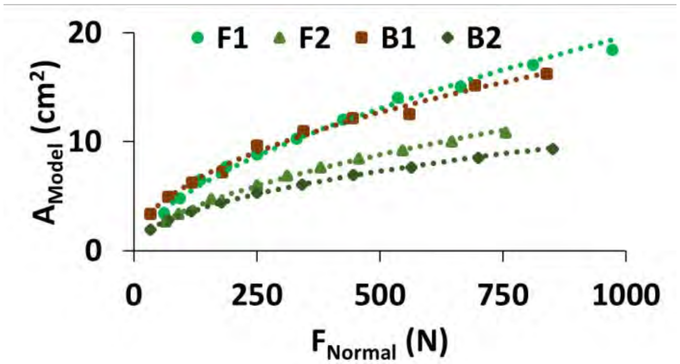

Figure 3: A_{Model} versus normal loading.

An analysis of the exponential decay coefficients in equation 1 (Table 1) revealed that the COF response (Fig. 2) of flat shoes was less sensitive to normal loading (smaller λ in Table 1). The contact area, A_{Model}, (Fig. 3) for flat shoes more closely simulated a linear curve compared to the beveled shoes (b values closer to 1, Table 1). These findings demonstrate a difference in response to normal loading between flat and beveled shoes.

Findings of this study can be applied to simulate the effect of a person's weight on slip-resistance performance. These findings suggest that while certain (beveled) shoes might have superior slip-resistance in lower normal loads, their performance might decay when a heavier person wears those and suggest that slip-resistance performance of flat shoes is less sensitive to a person's weight.

Although it is acknowledged that the range of the normal load that was used for this analysis might not fully represent the body weight of obese people, findings indicate a decrease in COF with increasing normal load, a phenomenon that could be partially responsible for the higher risk of falls in the overweight population [6]. It should be noted that overweight human subjects are reported to have a higher RCOFs in comparison to the non-obese subjects [7]. Therefore, the combination of reduction in COF (observed in the models) and the higher RCOF in overweight people (reported in the literature) is likely to explain the higher chance of slips and falls in overweight people given that the difference between the available COF and RCOF predicts the probability of slips and falls [2].

Table 1: Hardness and curve coefficients for shoes.

Shoe	Shore A Hardness	λ	b
F1	50	0.0035	0.59
F2	56	0.0044	0.56
B1	56	0.0045	0.48
B2	72	0.0054	0.49

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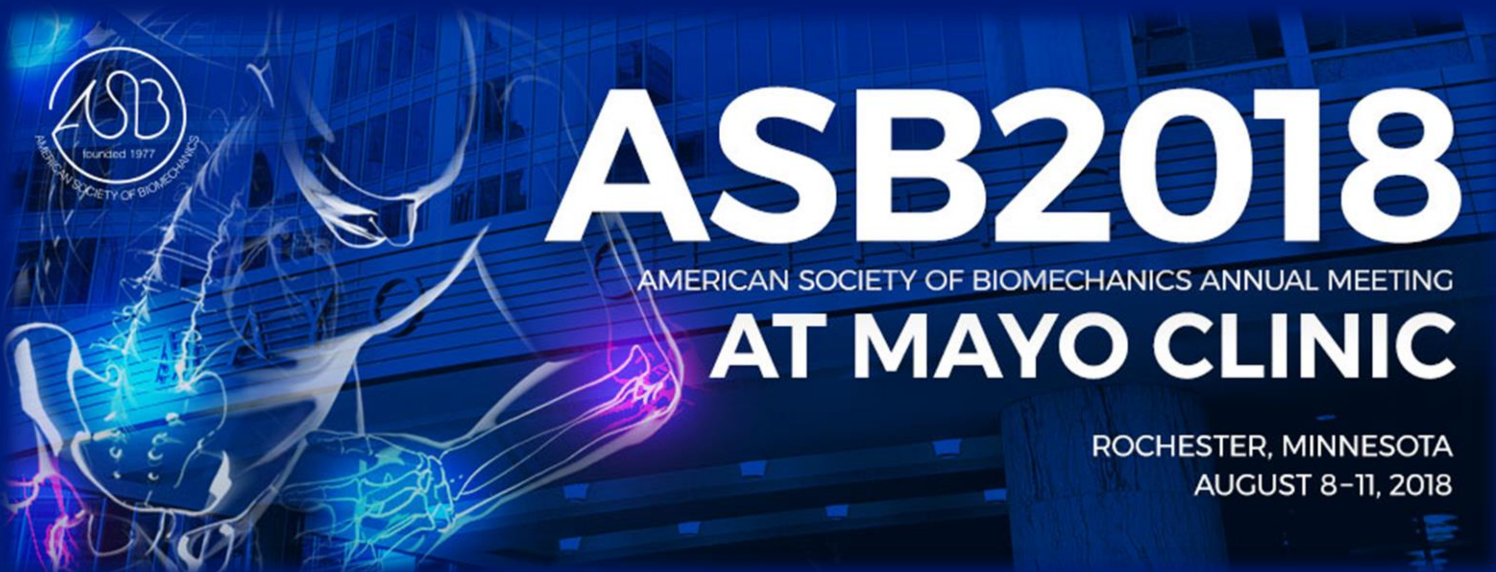
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ABSTRACTS