C45 Progress in the Characterization of Barefoot Pedestrian Friction

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After attending this session, attendees will appreciate the difficulties inherent in using current methods for measuring barefoot slip resistance. The current state of the art in barefoot tribometry will be discussed, and this paper will focus on improvements in the development of biofidelic test feet.

This presentation will impact the forensic science community by giving current knowledge in barefoot-pedestrian friction metrology. This is significant because it can help determine whether or not a given walkway surface is or is not hazardous to barefoot pedestrians.

Barefoot slip resistance has not received the attention – either through standards, research, or on-site testing – as has the slip resistance of footwear. However, slips and falls in bathrooms, tubs, and showers occur frequently and result in significant injury. The materials in a typical bathroom/shower enclosure are non-resilient which can increase the severity of injury upon contact. Characterization of the friction between the plantar aspect of the heel and a contaminated floor surface would assist architects and interior designers in choosing appropriate materials for those environments where pedestrians can be expected to be barefoot.

The ASTM F462 Standard Consumer Safety Specifications for Slip-Resistant Bathing Facilities, first approved in 1979, used a smooth Silicone Rubber (Silastic 382) test foot in a soapy-water-filled bathtub to determine the slip-safety of a bathtub.[1] More recently, barefoot pedestrian slip resistance has been evaluated using an inclinable ramp to measure the slip resistance of a barefoot pedestrian on a water contaminated walkway surface (DIN 51097 (1992)).[2] Medoff, et al. developed an inclinable Step Meter using an *in vivo* test subject to measure the slip resistance of footwear/walkway combinations, dry and wet.[3] This Step Meter was used with barefoot test subjects, "stepping" onto a varying angle, water-contaminated walkway surface.[4] When the motion of the lower leg was both constrained and passive, it was found that the results were consistent and repeatable. Recently a number of researchers have published studies on the coefficient of friction of a bare foot sliding against marble floor (Sariisik, Ali).[5,6] The Sariisik study used the DIN 51097 Ramp test, with different roughness values of wet marble, while the Ali study was focused on level walking with bare feet on marble with different concentrations of detergent in the water-covered marble flooring.

Medoff, et al.[7] measured the available friction, as determined by a barefoot pedestrian walking on a smooth, water-contaminated, instrumented walking surface, and compared these results with walkway-safety tribometry (WST) measured values on this same water contaminated surface using a smooth silastic 382 test foot. It was found that the tribometer with this silastic test foot was unable to characterize the slip resistance under these conditions, giving essentially zero values for the slip resistance. Siegmund, et al. measured utilized friction when entering and exiting a dry and wet bathtub, barefoot.[8] The bathtub base (porcelain on steel) was modified by adding "slip resistant medallions." They found a wide variation in utilized friction (0.102 to 0.442).

A problem with barefoot WST is that the test feet currently in use lack biofidelity. Our long-term goal is to develop a biofidelic WST test foot. In this paper, we use non-contact optical techniques to characterize the surface morphology of the plantar aspect of the heel.

Methods: Skin morphology was characterized as follows. Plaster casts were prepared of the plantar aspect of the heels of six adults (3M, 3F, ages 21-54). Plaster1 was prepared and placed in a shallow container. The seated subjects' heels were pressed down into the plaster, with the subjects remaining seated until the plaster set (approximately 30 minutes). Subjects' heels were then removed from the plaster, and the plaster was permitted to fully harden for 24 hours.

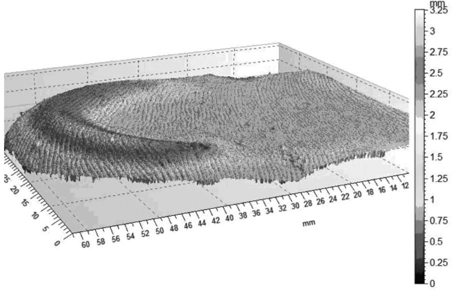
Positive models of the heel were then prepared as follows: Room Temperature Vulcanizing Rubber2 (similar to Silastic 382 medical grade silicone rubber) was mixed according to manufacturer's instructions, poured into the plaster molds, and permitted to harden. This created heel-surface replicates with the associated skin friction-ridge patterns.

The surface morphology of two sample heels was measured using interferometry. These systems use a white light source, where light is focused through an objective lens onto the specimen, and the reflected light is captured. By focusing the lens, the distance from the objective to the sample is captured. Two companies were sent samples for analysis.

The first sample, sent to Zygo,[3] was scanned with a NewView™ 7300 system. This system uses an interferometric objective mounted in a closed loop piezo-scanning device that moves vertically (in the Z direction) over the sample. Data is collected from a CCD camera and processed. The phase relationships of individual components of the white light spectrum in the interferogram are analyzed by Zygo's frequency-domain analysis, resulting in a surface map with ultra-high Z resolution, independent of the objective magnification, with up to one angstrom resolution.

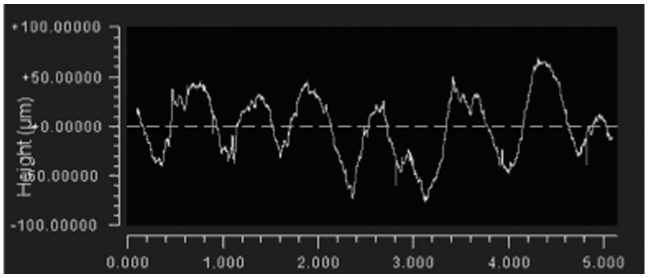
A second sample, sent to Nanovea,4 was scanned with their ST400 Optical Profiler. This system uses "axial chromatism," where white light passes through an objective lens having a high degree of chromatic aberration. (The refractive index of the objective lens varies in relation to the wavelength of the light. In effect, each separate wavelength of the incident white light re-focuses at a different distance from the lens). Due to the confocal configuration of the system, only the focused wavelength will pass through the spatial filter with high efficiency, thus causing all other wavelengths to be out of focus. The spectral analysis is done using a diffraction grating. This technique separates each wavelength and allows direct correspondence to the Z height position. With a measurement range of 10mm, this system has a Z resolution of 280nm and an accuracy of 900nm, with lateral resolution of 2.6 µm.

Results: Overall picture of the 3-D friction-ridge pattern. The three-dimensional graph just below gives an overall view of a typical plantar heel friction-ridge pattern. It has not yet been filtered through a high-pass filter, which would eliminate the low-frequency, i.e., gross height variations.

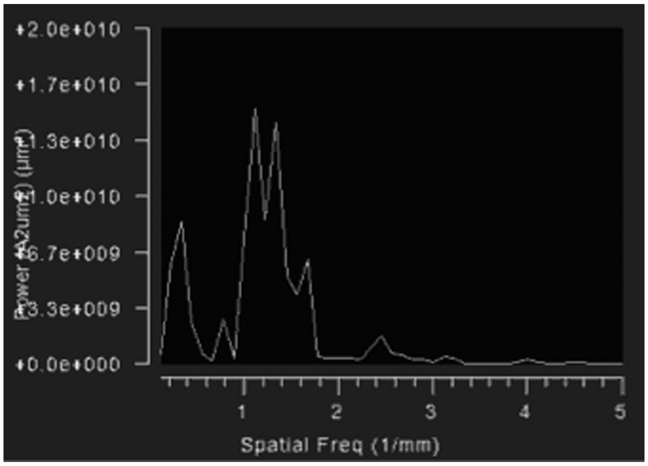


The friction-ridge pattern impressed upon the gross height variations can be seen. A typical cross-sectional result.

Figure 2, below, shows one cross-section of the heel, showing the actual dimensions of a friction-ridge pattern. The ridge-pattern period is roughly 0.8mm with a peak-to-trough extent of roughly 0.1mm. The pattern is very roughly sinusoidal.



In figure 3, below, translation to the frequency domain shows the spacing of the friction ridges (the period) to be between 0.75–0.9mm.



Future Research Directions

The Big Picture: The goal is to produce test feet that, when used with conventional WST instruments, mimic the Available friction of a pedestrian ambulating with bare feet. The friction-ridge pattern in the plantar surface of the foot has been optimized over evolutionary millennia, forming an essential component of the friction picture. Presently, test feet used to characterize barefoot friction have been smooth. To compensate for the lack of biofidelity inherent is smooth-surfaced test feet, artificially low threshold values for acceptable available friction have been utilized. If the friction-ridge pattern were able to be characterized and implemented in test feet, this would go a long way to making test feet biofidelic, and hopefully eliminate the need for artificially low threshold values.

Mathematical Modeling of the Friction Ridge Patterns: It would be better to develop a generic friction-ridge pattern, versus having someone's friction ridge pattern serve as the standard pattern (in much the same way as the inch was formerly defined as the size of some king's thumb). One approach would be to mill a pattern of grooves in a mold that corresponded to an idealized groove pattern as generated by, say, the averaged-over-multiple subjects' first (or first and second) terms of the Fourier transform of the friction-ridge pattern.

Multi-Phase "Hardness" Characterization: Another important area for friction research is the development of a biofidelic model for the hardness of the friction-ridge pattern. The plantar surface of the heel is comprised of various biologic structures, viz., the epidermis, which contains the friction-ridge pattern, the endodermis, fat pad, the fascia, and the calcaneus (the heel bone). It is rather unlikely, to say the least, that this layered structure could be reasonably characterized by a homogenous material. It is speculated that, at the very minimum, a three-layer test foot is necessary: an outer layer representing the friction-ridge pattern, an inner layer representing the fat pad, and a backing plate representing the calcaneus.

References:

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Forensic Science, Walkway-Safety Tribometry, Barefoot Pedestrian