IDENTIFICATION OF FOOTWEAR INSOLE MATERIAL RESPONSE FOR OPTIMAL REDUCTION OF PLANTAR HEEL PRESSURE

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INTRODUCTION

Reduction of heel pressures is important to relieve plantar heel pain, to prevent heel ulceration in people with diabetes, and to promote comfort [1]. Using finite element analysis and mechanical responses of commonly available insole materials, Goske et al. [2] showed that insole conformity and thickness are the most important parameters in reducing high heel pressures. While the mechanical response of the insole material was not found to be as influential, the insole materials evaluated in their study were limited to a narrow range of deformation characteristics. It is possible that the material properties of an insole can be optimized to further the benefits of fully conforming and thick insole designs. Therefore, our goal is to find an optimal insole material response to relieve heel pressure maximally. If successful, our approach could guide the design of new footwear materials.

METHODS

A two-dimensional plane strain finite element model of the heel pad and footwear from an earlier study by Goske et al. [2] was used (Figure 1). The model was capable of predicting peak heel pressures for different insole material coefficients. A vertical compressive load of 678 N was used to simulate the first step of walking.

The mechanical response of the insole material was represented by a hyperfoam material model [3]. The strain energy function was:

$$U=\frac{(2\mu)}{\alpha^2}\left[\lambda_1^{\alpha}+\lambda_2^{\alpha}+\lambda_3^{\alpha}-3+\frac{1}{\beta}\left(J_{el}^{(-\alpha\beta)}-1\right)\right] \quad (1)$$

where:

$$\beta=\frac{\nu}{(1-2\nu)} \quad (2)$$

μ is the shear modulus, α specifies the large strain behavior (shape of stress-strain curve), ν is the effective Poisson's ratio and β relates to the volumetric response (indicating degree of compressibility). $\lambda_{(1\text{-}3)}$ are the principal stretches.

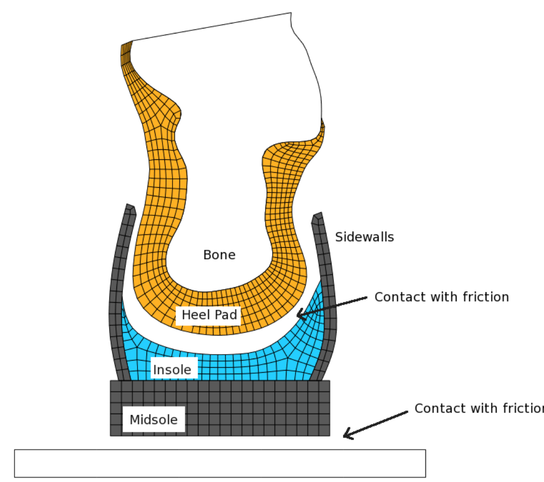

Figure 1: Finite element model of the heel pad and footwear [1].

The optimal insole parameters were found by iteratively changing μ, α and ν to minimize peak heel pad pressures predicted from the finite element model. The finite element analysis was conducted in Abaqus (Abaqus, Inc., Providence, RI) . Iterations were handled through a gradient-based optimization protocol using Matlab (The Mathworks, Inc., Natick, MA), where μ, α and ν were the optimization variables (bound to be $>$ 0) and the peak pressure was the objective. The best design proposed by Goske et al. [2] for favorable pressure relief was used as a starting point to identify an optimal insole material. Their design incorporated a 12.5 mm thick, full conforming insole, made out of Microcel Puff

Lite. Following optimization, the stress-strain response of the initial material (Microcel Puff Lite) and the optimized material were calculated for uniaxial compression (confined), simple shear, and volumetric compression [3].

RESULTS AND DISCUSSION

Predictions of peak pressures for barefoot and Microcel Puff Lite conditions are provided in Table 1, along with the performance of the optimized material. A combination of Microcel Puff Lite and a full conforming insole with a thickness of 12.5 mm resulted in a 41.3 % reduction compared to barefoot condition. The optimized material resulted in a 15% reduction in the peak pressure compared to Microcel Puff Lite. This was accomplished by decreasing the initial shear modulus (μ) and increasing the compressibility of the material. The latter was suggested by the drop in the Poisson's ratio. These changes were also evident in the mechanical response of the optimized material when compared against that of Microcel Puff Lite (Figure 2). The optimized material was softer, less resistant to shear and more compressible than Microcel Puff Lite.

Table 1: Material coefficients and predicted plantar heel pressures for barefoot and insole conditions.

	μ (MPa)	α	ν	Peak Pressure (MPa)
Barefoot	-	-	-	0.435[2]
Microcel Puff Lite	1.220	48.28	0.0280	0.255[2]
Optimized	0.217	48.68	0.0001	0.216

CONCLUSION

A highly compressible and softer foam material, used in combination with a full conforming and thick insole design, will likely lead to an optimal reduction in plantar pressures. It is possible that open foam insole materials may exhibit such characteristics and potential candidates can be found from studies characterizing insole material response, e.g. Petre et al. [4]. Further investigations are warranted to explore the manufacturability of such designs and evaluate their real life performance.

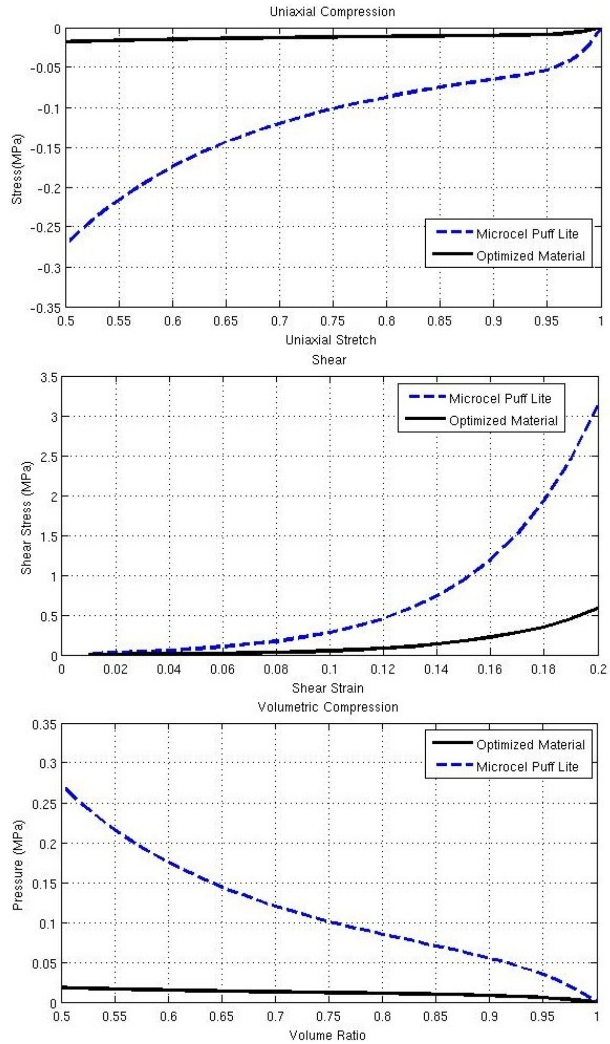

Figure 2 : Mechanical response of Microcel Puff Lite against the response of the optimized insole material.

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