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Polyurethane-foam Midsoles in Running Shoes

- Impact Energy and Damping -

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Abstract

Most running shoe midsoles are made of ethylene vinyl acetate (EVA) foam although excellent mechanical long-term properties of polyurethane (PU) foam are generally known. The aim of this study was to investigate whether PU foam is applicable as midsole material regarding damping properties. Short-term and long-term mechanical tests were conducted for running shoes with midsoles of either PU or EVA foam using the Hydraulic Impact Test. The results of the short-term testing show that PU midsoles can be adjusted to a wide range of damping properties while EVA midsoles attained good average values. In long-term testing, however, the EVA foams exhibited higher relative changes of damping parameters than the PU materials, which confirms the durability and ageing resistance of PU.

Keywords: midsole material; running shoe; ethylene vinyl acetate (EVA); polyurethane (PU); Hydraulic Impact Test;

1. Introduction

One of the most important mechanical properties of running shoes is the damping behaviour of the foam. Damping is strongly related to the absorption and return of energy during deforming and unloading the midsole of the shoe.

Ethylene vinyl acetate (EVA) flexible foam is the standard material for midsoles in running footwear because it provides durability and flexibility at low density [1, 2]. Polyurethane (PU) is currently used in shoe manufacturing mainly as sole material of casual shoes. PU is generally known to exhibit excellent mechanical long-term properties.

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Therefore, the purpose of the present study was to investigate whether PU foam with density and hardness in the range of EVA foam is applicable as midsole material regarding damping properties, especially during long-term testing.

2. Methods

Running shoes with midsoles of seven pure PU and two standard-EVA foam materials (identical upper and outsole design) with a density range of 0.25-0.30 g/cm³ were tested by the mechanical HIT procedure [3]. Reference values are derived from testing 13 commercial running shoes consisting of EVA midsoles while eight of these shoes had additional damping elements in the rear foot area.

A servo-hydraulic testing device described by Heidenfelder et al. [4] has been used to transfer 100 load cycles (short-term testing) and 240.000 load cycles (long-term testing) respectively by a spherically shaped stamp (50 mm diameter) to the heel part of running shoes (fig. 1). Therefore, the characterisation of midsole materials is related to the heel area of the sole. The load-time-profile was derived from biomechanical measurements of ground reaction forces while running at a velocity of 3.5±0.1 m/s. According to Schwanitz et al. [3], the analysed damping parameters of the test are,

Fig. 1. Servo-hydraulic testing device

Energy input [J]: the energy which is induced into the material by the stamp. The energy input equals the area under the load-deformation curve during the loading phase.

Energy loss [J]: the energy which is absorbed by the material and dissipated to thermal energy. The energy loss equals the area within the load-deformation curve during the loading and unloading phases (hysteresis curve).

Relative energy loss [%] is the ratio of energy loss over energy input and can be described as the ability of footwear to reduce impact forces at heel-strike.

Long-term testing parameters were measured after a recovery period of 48 hours by performing an additional short-term test. Short-term testing contains two pairs of each material configuration; long-term test was performed for one shoe of the two pairs.

3. Results

3.1. Short- term testing

The results of short-term testing (fig. 2) show that the examined PU midsoles can be adjusted to match the damping properties of standard EVA midsoles. Furthermore, the results reveal the possibility to achieve properties comparable to those of series-model running shoes. The results of the EVA materials represent good average values within the range of the tested shoes.

Two PU materials obtain higher or respectively lower values than the reference samples (red dashed lines in fig. 2) confirming the wide range of properties of the tested PU materials. Both PU materials attained similarly high values of relative energy loss at different magnitudes of energy input and loss, which shows that the damping properties of the midsole can be adjusted to different requirements by a systematic variation of PU composition.

Energy input and maximum deformation of the running shoe sole exhibit very good linear correlation (R = 0.98) indicating that the energy input depends on the depth of indentation. The often-mentioned dependency of mechanical properties on density [5] could not be verified for the tested materials ($R_{energy\ input-density}$ =

$R_{energy\ loss-density}$ = 0.23).

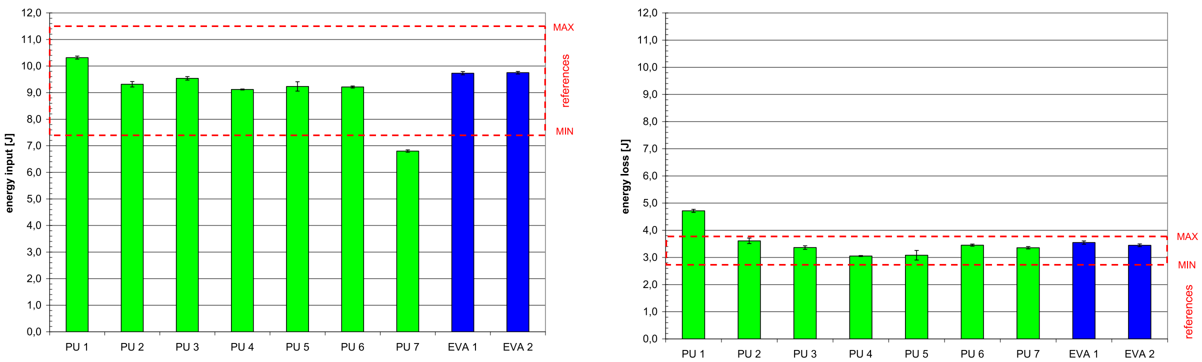

Fig. 2. (a) energy input [J], (b) energy loss [J] of the tested running shoes after short-term testing (mean of two pair of shoes); red dashed lines: results of reference samples

Fig. 3 shows the hysteresis curves of two midsole materials with identical density (0.3 g/cm), albeit different surface hardnesses (37 and 68 Asker C). These two materials exhibit very different damping properties. Due to the lower maximum deformation and the linear increase of the loading curve, the harder material shows lower energy input compared to the softer material. The higher energy input of the latter in turn results in higher energy loss.

The high increase of load between 14 and 15 mm deformation of the softer material indicates that the cellular foam structure is compressed as far as only the properties of matrix material are measured. Comparable results were ascertained by Heidenfelder et al. [4] and Nigg et al. [6]. Therefore, it can be stated that the PU 1 material is too soft when loaded by an average runner and just adequate for runners of max. 60 kg.

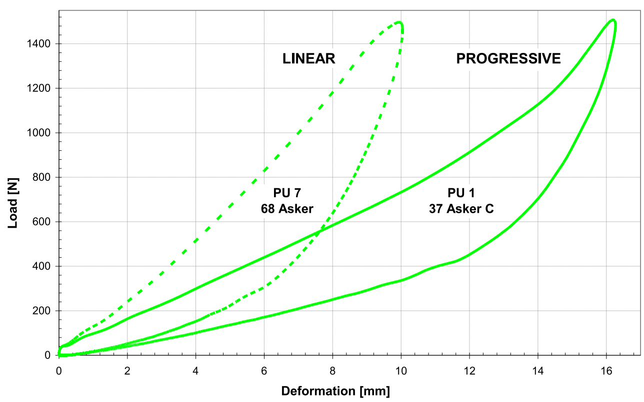

Fig. 3. Load-deformation curve of two shoes with PU midsole materials of different hardness

3.2. Long-term testing

The mechanical long-term test results in a significant reduction of both damping parameters ($p<0.05$) according to the results of Schwanitz et al. [3] (fig. 4). Relative changes of this parameter are considerably higher for the tested EVA than for the PU materials. Thereby it can be stated that PU provides better durability and ageing resistance compared to EVA. In addition, the shoes containing pure EVA midsole materials reveal higher relative changes of damping parameters than the commercial running shoes indicating that improved ageing resistance of EVA can be attained by additional elements - preferably ones made of thermoplastic polyurethane. Non-significant changes ($p<0.05$) of relative energy loss [%] and very high correlation ($R = 0.98$) of relative changes of energy input [J] and energy loss [J] prove that long-term testing influences both energy input and energy loss equally. According to Cook et al. [7], the decrease of energy loss [J] can seriously increase the injury potential.

The high correlations of relative changes of maximum deformation and energy input (Rmax.def.-energy input = 0.78) and, respectively, maximum deformation and energy loss (Rmax.def.-energy loss = 0.75) demonstrate that damping properties depend on deformation mechanics.

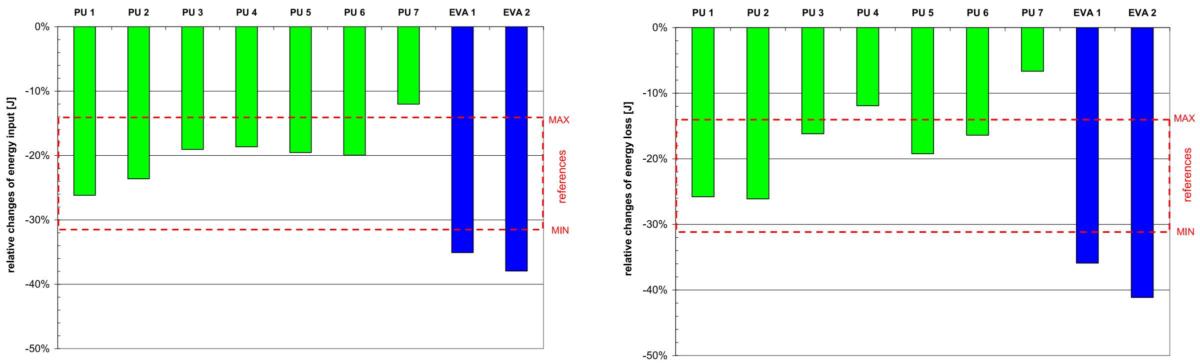

Fig. 4.(a) relative changes of energy input [J], (b) relative changes of energy loss [J] of the tested running shoes after long-term testing (red dashed lines: results of reference samples)

4. Conclusion and outlook

This study demonstrates that PU foams with specified characteristics are suitable as midsole material of running shoes with respect to mechanical impact damping properties. Further mechanical parameters e.g. stiffness at high deformation have to be analysed for complete mechanical characterisation.

For a comprehensive characterisation and further validation of the presented results biomechanical and perceptual tests have to be conducted in future studies [8]. Thereby, the relevance of energy input and energy loss – in other words, the question of how damping properties affect biomechanical parameters – has to be analysed.

As mechanical properties of the foam depend on both its cellular structure and the properties of the polymer [9], the structure-property relationship has to be identified to elucidate the deformation mechanism under mechanical testing by the HIT procedure.

Acknowledgements

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