Optimized smart manufacturing of shoe insoles, their characterization and validation in relevant environment

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

Acronyms	Description
D	Deliverable
EVA	Ethylene-vinyl acetate
PHA	Polyhydroxyalkanoates
W2BC	**Wast2BioComp**

1. Introduction

The target of this report was to demonstrate the use of PHA-based foams to produce shoe insoles as demonstrators of the footwear value-chain, and to test their basic characteristics and performance, comparing with fossil-based benchmarks.

This report, together with D4.2, D4.3 and D4.4, show the accomplishment of MS5 (Bio-based demonstrators for each VC), by showing the production of shoe insoles and their validation in relevant environments (study under real use scenario) displaying properties similar to benchmark insoles.

2. Optimized smart manufacturing of shoe insoles, their characterization and validation in relevant environment

2.1. PHA shoe insoles production

Based on the developed recipes from Task 3.1, three foam sheets with different hardness were produced by mixing the ingredients (PHA developed in **W2BC**, bio-based EVA, bio-filler and additives), calendaring them into a sheet with defined thickness of 24 mm and vulcanizing these sheets at 160 °C under a pressure of 200 bars for 24 minutes in a vulcanization press. The 160 °C are a result of process optimization, as standard EVA based material is cured at 170 °C, consuming more energy. After opening of the press, the vulcanized compound expands heavily by development of air from the blowing agent to give the desired piece of foam.

To produce shoe insoles, the three pieces with 20, 30 and 40 ShA hardness were tempered at 80 °C for 3 hours. For the respective demonstrator, pieces were cut to size, coated with adhesive and then heated in an oven. The hardest compound is placed on the bottom size as the stabilizing component, the softest compound goes on top, where it meets the foot, to give ideal bedding and comfort. The stabilizing 40 ShA sheet was split to 12 mm thickness and heated at 150 °C for 8 minutes, the 30 ShA sheet was split to 4 mm and heated at 150 °C for 2.5 minutes and the 20 ShA material was cut to 3 mm thickness and heated at 150 °C for 2 minutes. Finally, for the individual sole, the three hot sheets were put together and pulled over an individual shoe last and afterwards grinded to shape (Figure 1). Since we found almost no shrinkage of the PHA-based materials, the process could be optimized and simplified by leaving out the tempering process, leading to energy savings.

*Figure 1 Three-layered medical shoe insoles developed with the PHA-based foams developed in **W2BC**.*

2.2. PHA shoe insoles characterization

The PHA based shoe insole materials were characterized by some basic measurements, which are typical for the industry. Results are summarized in Table 1. In the shoe sole industry, EVA insole material is mostly characterized by hardness and haptics. We have compared our PHA-containing new developments with pure EVA materials of the same hardness. From an optical and touch and feel perspective, the materials are as good as EVA and could be used for such insole application. Taking a closer look at the mechanical properties, it looks like the PHA based polymer compound is somewhat softer than standard EVA compounds, because densities are higher at the same hardness level, meaning that not so much air in the material is necessary to make it softer. On the same note, the PHA based material have lower tear strength, but properties are still in a range that is acceptable for the intended application. Moreover, there is a positive effect on the shrinkage (measured after 4 h at 70 °C), which is almost non existing compared to the standard materials. Unfortunately, due to defect instruments, the results on the residual indentation, which is important for a good performance as a shoe insole, are still not available.

To prove that the resulting insole demonstrator is functioning in a practical environment, NORA did a wear test with one person from the project. For this test, demonstrators in size 47 were produced as described in section 2.1 and worn in safety shoes by the proband (>100 kg) for over 40 working days (over 200 h) without any perceivable deterioration in performance. This is a prove that the PHA demonstrators work in a practical environment as desired.

Table 1 Properties of PHA-based insole materials compared to EVA standard materials

Foam	PHA foam (Recipe 700809)	Lunair-flex (106)	PHA foam (Recipe 700702)	Lunasoft SLW (110)	PHA foam (Recipe 700811)	Lunasoft SL (109)
Hardness [ShA]	20	22	30	30	40	40
PHA content [phr]	44	-	57	-	62.5	-
PHA content [wt.%]	35	-	45	-	50	-
Bio-based content [wt.%]	94	-	94	-	95	-
Density [g/cm³]	0.24	0.12	0.28	0.20	0.36	0.20
Tear Strength [N/mm]	0.7	1.5	0.9	1.8	0.9	2.2
Elongation [%]	215	132	89	160	55	128
Shrinkage [%]	0.0	2.5	0.0	2.5	0.3	2.5
Residual Indentation	t.b.d.	t.b.d.	t.b.d.	t.b.d.	t.b.d.	t.b.d.

3. Conclusions

Foams materials for shoe insole production were successfully produced with 3 different hardness: 20, 30 and 40 ShA. The properties of these materials can be considered equivalent to fossil-based benchmarks (EVA foams).

The foam materials were used in the production of three-layered shoe insoles, which were tested under real use conditions, resulting in very good results, showing a performance comparable to that of commercially available EVA insoles.

These foams have a PHA content between 35 and 50 wt.%, while the bio-based content is as high as 95%.

The printability of the foams is shown in Deliverable D4.4; their non-toxicity in deliverable D6.1; their biodegradability in D6.2; and their recyclability in D5.2.

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