



waste<sup>2</sup>  
biocomp

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

## Deliverable 4.1

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## List of Abbreviations

Acronyms	Description
D	Deliverable
EVA	Ethylene-vinyl acetate
PHA	Polyhydroxyalkanoates
<b>W2BC</b>	<b>Wast2BioComp</b>

# 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, namely hardness, density, tear strength, elongation, shrinkage and residual indentation. Results are summarized in Table 1. In the shoe sole industry, EVA insole material is mostly characterized by hardness and haptics. The standard (EVA) materials show increasing tear strength with hardness, the density is lower for the softer material, which makes sense, because they need more air enclosed to get softer. The residual indentation increases with more softness, which is also a natural development. We have compared our PHA-containing new developments with pure EVA materials of the same hardness. From an optical and touch and feel perspective (haptics), the materials are as good as EVA and could be used for such insole application.

Taking a closer look at the mechanical properties (Table 1), they showed slightly different performance profile with some results lower than standard (tear test), others better (shrinkage) which is overall acceptable. The PHA based polymer compound seems to be 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.

Due to defect instruments, the results on the residual indentation, which is important for a good performance as a shoe insole, were not available at the time of the first submission of this report but are now presented. These also fit into the overall picture, with minor differences between bio-based **W2BC** and standard EVA materials, but the overall level is comparable and acceptable for the intended use. Looking more into the details, the obvious trend is that the harder materials have less residual indentation than the soft ones. For the hardest material (40 ShA), residual indentation of the bio-based version is even slightly better with 9.5% vs. 10.6% for the standard, while for the medium hardness (30 ShA), it is the other way round (16.0% vs. 14.6%) but considering the reproducibility and exactness of the method, we would consider this to be on the same level. For the softest version (20 ShA), the difference is a bit more pronounced with the bio-based material having a higher residual indentation with 24.1% compared to 18.9% for the standard. A part of the difference might be explainable with the standard being somewhat harder with 22 ShA compared to the 20 ShA of the bio-based compound. The extraordinarily high initial indentation of the soft bio-based foam seems to be an outlier from what we would judge with our experience, but time in the project did not allow for verification. Nonetheless, the 24% residual indentation is still acceptable and in the light of the versions with higher hardness, which had more PHA content, performing on par, the higher indentation does not seem to be a result of the PHA used in the compound.

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)
<b>Hardness [ShA]</b>	20	22	30	30	40	40
<b>PHA content [phr]</b>	44	-	57	-	62.5	-
<b>PHA content [wt.%]</b>	35	-	45	-	50	-
<b>Bio-based content [wt.%]</b>	94	-	94	-	95	-
<b>Density [g/cm<sup>3</sup>]</b>	0.24	0.12	0.28	0.20	0.36	0.20
<b>Tear Strength [N/mm]</b>	0.7	1.5	0.9	1.8	0.9	2.2
<b>Elongation [%]</b>	215	132	89	160	55	128
<b>Shrinkage [%]</b>	0.0	2.5	0.0	2.5	0.3	2.5

Foam	PHA foam (Recipe 700809)	Lunair-flex (106)	PHA foam (Recipe 700702)	Lunasoft SLW (110)	PHA foam (Recipe 700811)	Lunasoft SL (109)
<b>Initial indentation [%] after 100.000 deformations</b>	72.9	25.6	27.8	45.9	19.6	29.4
<b>Residual indentation [%] after 24 hours relaxation</b>	24.1	18.9	16.0	14.6	9.5	10.6

As to the rheological characterisation on compounds NORA used a special version of a rheometer test that was also able to measure the pressure building up during foam formation. Results are shown in Figure 2. It shows that in the pressure curves (solid lines), as expected, the softest material which needs more blowing agent, and thus more gas and pressure is produced. Therefore, the blue curve, depicting the 20 ShA compound, is the highest one, the medium hardness target of 30 ShA leads to the red curve in the middle, and the hardest 40 ShA version shows the lowest pressure, shown by the green curve. Obviously, some of the blowing agent can escape the system, especially in the beginning, when vulcanisation is not that far advanced, so the pressure is declining after hitting its maximum. For the elastic portion (dashed lines), an interpretation is difficult, because the graphs are close to each other, and the 5 minutes measured only show the beginning of the vulcanization process.

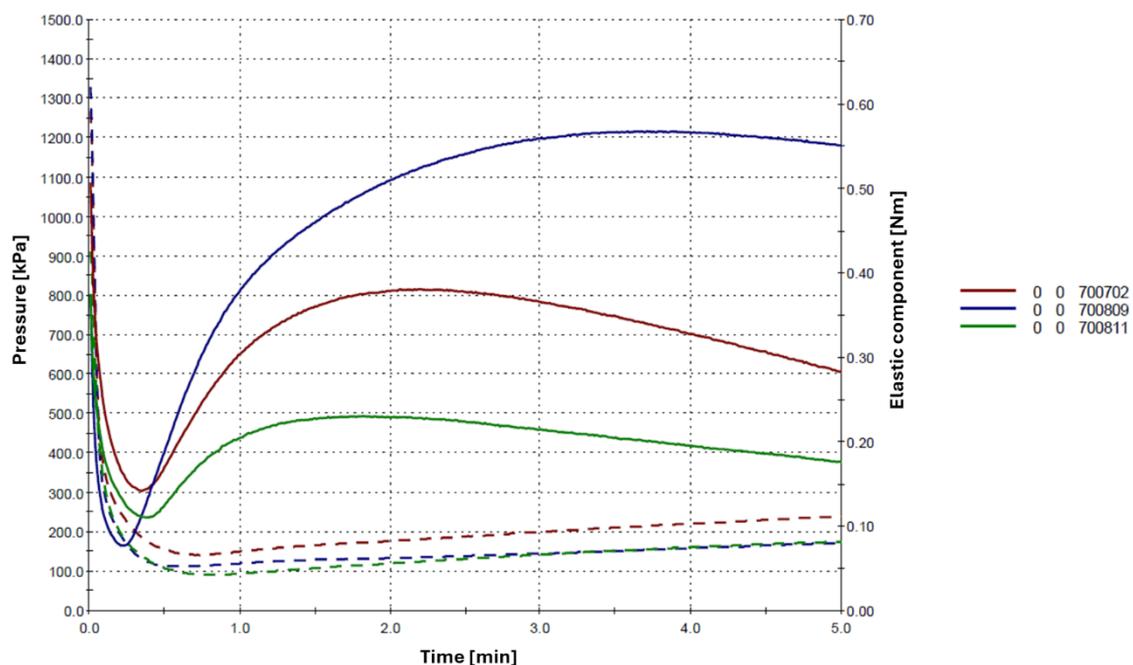


Figure 2 Rheological characterization of the final PHA foams: 20 ShA (recipe 700809), 30 ShA (recipe 700702) and 40 ShA (recipe 700811).

To prove that the resulting insole demonstrator is functioning in a practical environment, NORA did a wear test with one person from the project. Unfortunately, because of low and late material availability it was not possible to produce more test soles to enable the initially planned test group of 5 to 10 users. 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.

### 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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