Keeping resources in the loop

Programmable Monomaterial for High-Tech Athletic Shoes

High-quality athletic shoes are usually made from a complex combination of materials. This has consequences for both production and recycling. In the ZiProMat project, Fraunhofer researchers have found another way. A sole made of programmable monomaterial performs various functions and is also made of the same material as the upper. The concept combines high-tech, sustainability and recyclability.

The sole fitted to high-quality athletic shoes has different properties in different zones. For example, the heel is especially well-cushioned to absorb the impact on the ground, the midsole is fairly soft to facilitate a smooth roll, and the tip is somewhat firmer. This necessitates the combination and joining of several different material properties.

Fraunhofer researchers have now developed a technology where the sole is made of a single material combining different functional zones. By designing the material structure with a specific configuration of ribs or ridges, Fraunhofer researchers can essentially program the behavior of the material under load.

In collaboration with sportswear manufacturer Puma, a team from the Fraunhofer Cluster of Excellence Programmable Materials CPM has already demonstrated the feasibility and benefits of this technology. Research scientist Christof Hübner from the Fraunhofer Institute for Chemical Technology ICT says: "We have combined our expertise in materials science with Puma's market-oriented product skills. We could thus demonstrate that the fundamental concept of programmable monomaterials can also be usefully implemented in high-quality everyday products, such as athletic shoes."

The Fraunhofer CPM institutes have enlisted additional support in the ZiProMat follow-up project, which focuses on circular programmable materials. They are collaborating with experts from the Fraunhofer Cluster of Excellence Circular Plastics Economy CCPE. The objective is to find ways to recycle the sole together with the upper by manufacturing both using polyester-based materials. Furthermore, new applications are to be developed, focusing especially on further optimizing recycling.

Thermoplastic polyester

The researchers are using a thermoplastic copolyester elastomer as the monomaterial basis for the sole. The upper and outer textile material in athletic shoes are normally also made of polyester. "This opens up the possibility of including a much larger part of the shoe in a sustainable resource cycle," says research scientist Maximilian Wende from the Fraunhofer Institute for Process Engineering and Packaging IVV.

The soles are manufactured starting from sheets of copolyester. These are heated and thermoformed using a vacuum to draw them into a mold that gives the sheet its predefined structure with ridges or ribs. The sheets are then stacked and joined together. This gives not only the outside of the sole but also the interior the special structure that is responsible for its mechanical properties.

The research team is using two processes to develop innovative recycling methods. In the solvent-based process, the materials undergo a targeted, selective dissolution process, with foreign particles being separated out. The resulting product is high-purity polyester. In contrast, the pyrolysis process breaks down polymers into smaller molecules. Appropriate separation methods and chemical processes can then be used to recover high-quality basic chemicals such as terephthalic acid for the chemical industry. "We have succeeded in obtaining pure polyester from old athletic shoes made of a wide variety of materials." Wende is pleased: "Recycling and high quality are no longer in contradiction."

A complete value chain

The collaboration between Fraunhofer CPM and CCPE is a key element of the project's success. "Collaboration between several institutes, each with its specialized expertise, enables the combination of technologies and processes to cover the entire value chain," explains Hübner. This extends from producing smart monomaterials and innovative recycling methods to manufacturing a new generation of products with enhanced functions.

The researchers are working to expand the range of programmable features for high-performance athletic shoes. There are also plans to apply this technology to other products such as work shoes.

The ultimate goal of the ZiProMat project is to establish a technology platform for the use of programmable materials and the development of pioneering recycling methods. The platform is intended to be applicable for various products and to incorporate all the materials used to the greatest possible extent in closed-loop recycling.

The ZiProMat project

Project name: Circular Programmable Materials

Purpose: Development of programmable materials and innovative recycling capabilities

Project partners: Fraunhofer Cluster of Excellence Programmable Materials CPM and Fraunhofer Cluster of Excellence Circular Plastics Economy CCPE

Institutes involved:
- Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT
- Fraunhofer Institute for Chemical Technology ICT
- Fraunhofer Institute for Process Engineering and Packaging IVV
- Fraunhofer Institute for Applied Polymer Research IAP
- Fraunhofer Institute for Silicate Research ISC

Fig. 1 The sole of copolyester elastomer is made up of many individual sheets. The functional zones are established by the structure of ribs and ridges. Each individual sheet exhibits this structure. © Fraunhofer CPM

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Contact

Monika Landgraf
Fraunhofer-Gesellschaft, Munich
Head of Communications
Phone. +49 89 1205-1333
presse@zv.fraunhofer.de

Kristiane von Imhoff
Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, Strategy and Research Management Consultant
Fraunhofer Cluster of Excellence Circular Plastics Economy CCPE, Marketing Officer
Phone: +49 89 0208 8598-1443
kristiane.von-imhoff@umsicht.fraunhofer.de

www.fraunhofer.de