Process Technology for Recyclable Materials

Lightweight Design with Just One Material

In many cases fiber-reinforced polymers (FRP) are ideal for lightweight design. However, they are generally difficult to recycle. Self-reinforced mono-materials are an alternative to conventional fiber reinforced composites. Their lightweight design potential can be further increased by using specialized process technology, and by combining them with thermoplastic foams.

A major advantage of self-reinforced plastics is that they can be used in the morphology best suited to the application.
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The problem of waste means that plastics are viewed critically by both policy-makers and society. This is increasingly reflected in legislation on both national and international level. One current example is the planned amendment of the EU End-of-Life Vehicles Regulation. This requires the use of 25 % recycled plastic in new vehicles, a proportion of which must come from end-of-life vehicles. To achieve this, it is necessary to expand recycling operations.

At the same time, resource consumption for products must also be reduced in order to curb climate change. One solution in the automotive sector is the use of fiber-reinforced plastics (FRPs) for lightweight components. These materials have various advantages during the use phase, but they are difficult to recycle due to the shortening of fibers during the recycling process. Thermoplastic, self-reinforced polymers, which are based on only one material, represent an alternative solution.

The key to self-reinforced plastics is the utilization of molecular structures. For example, the bonding energies within a molecular chain are many times higher than those existing between molecules. In order to exploit this effect, a targeted orientation of the molecules is required (**Fig. 1**). The degree of orientation and thus the mechanics can be specifically adjusted by fiber spinning and subsequent stretching. This enables polymer fibers to be used as reinforcing fibers. The fibers are embedded in a matrix based on the same polymer, resulting in a self-reinforced plastic. Current research projects at the Fraunhofer Institute for Chemical Technology ICT focus on the processing of recyclate-based polyethylene terephthalate (PET) and the bio-based plastic polylactide (PLA). Besides these materials, the principle can also be applied to other polymers such as polypropylene (PP) and polyamides (PA).

Density is the Key

The mechanics of self-reinforced plastics differ from those of conventionally reinforced composite laminates (see **Table** and **Fig. 2** for tensile properties). In an absolute comparison of the tensile moduli and tensile strengths, the self-reinforced mono-materials lose out. However, if the density and the weight-specific values are considered, the properties become more similar. This applies in particular to the breaking strength. Another advantage of self-reinforced plastics is the significantly higher elon-

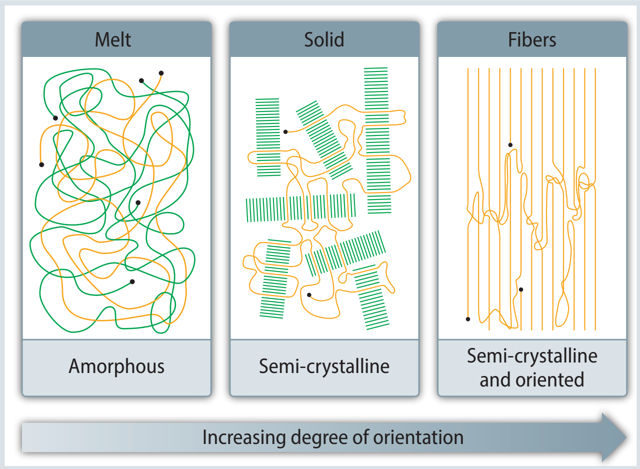

Fig. 1. The mechanics can be regulated by specifically adjusting the orientation of the polymer molecules. Source: Fraunhofer ICT; graphic: © Hanser

gation at break and the associated energy absorption capacity. Nevertheless, they still show a deficit in terms of stiffness.

Maximizing the Potential of Lightweight Design

At first glance, this deficit limits the potential application areas for self-reinforced plastics. However, polymers are not limited to the compact and fiber form but rather can be processed into other morphologies, such as structural foams. Using a fusion-bonding process, all these morphologies can be combined without adhesives to form a mono-material sandwich structure. The resulting geometric stiffening leads to a significant increase in performance with a minimal increase in mass (**Fig. 3**).

In order to further exploit the lightweight design potential, the percentage of reinforcing fibers can also be increased without affecting the overall density, as the reinforcing and matrix fibers have approximately the same density. Utilizing the sandwich approach and self-reinforcement, it is possible to achieve properties comparable to those of a conventional FRP with just one material.

Self-reinforced plastics differ from FRPs not only in terms of their mechanical properties and structures, but also in terms of the processing methods required. However, conventional industrial units can still be used if the parameters and molding technologies are slightly adjusted. Depending on the basic polymer, there are various methods to achieve a difference in melting point between the fiber and the matrix.

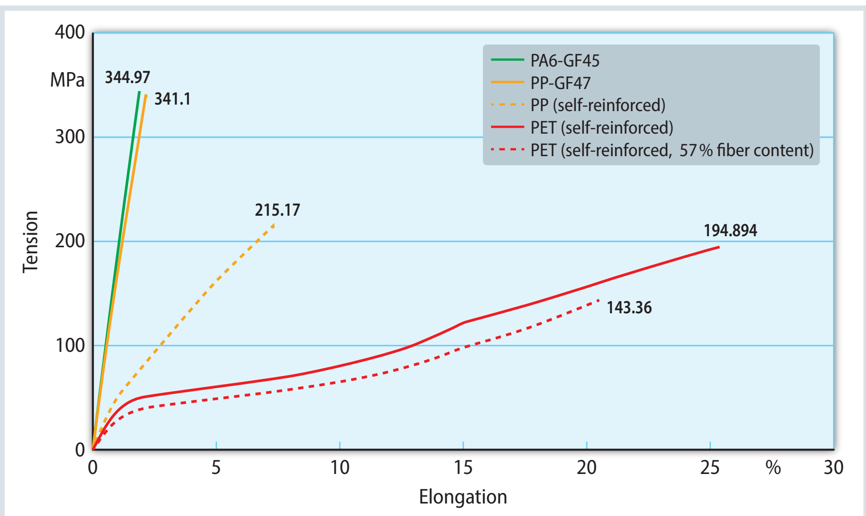

Fig. 2. Stress-strain diagram of FRPs and self-reinforced materials: In comparison, the FRPs perform better than the self-reinforced materials.
Source: Fraunhofer ICT; graphic: © Hanser

A commingled yarn is first produced from both morphology types, and then further processed into fabrics (for example woven fabrics) using textile processes. As with conventional laminar composites, the monolithic semi-finished product is manufactured by melt impregnation. In order to avoid relaxation, i.e. the decreased internal stress of the reinforcing fibers in the stretched state, the effect of temperature on the material should be minimized throughout all process steps. This also applies to the fusion bonding of face-sheets and foam core, where excessive processing pressures and temperatures can lead to the collapse of the core.

Morphology-Based Lightweight Design in Application

The full potential of thermoplastic sandwich composites can only be exploited through large-scale functionalization processes such as thermoforming. For example, these processes enable complex 2.5D geometries to be achieved with different radii, wall thicknesses and degrees of thermoforming. In addition, the targeted compaction of the core enables local adjustment of the wall thickness and thus the stiffness. Forming is carried out in the same way as for conventional fiber composites, but at temperatures below the melting »

Info

Text

Sascha Kilian, M. Sc., has been a research scientist and project manager at Fraunhofer ICT since 2015, and Head of the Application and Demonstration Department at Fraunhofer CCPE since 2019.
Anna Krüger, M. Sc., has been a research scientist and project manager at Fraunhofer ICT since 2022.

Cooperation Partners

The results presented were developed in cooperation with the Fraunhofer Institute for Applied Polymer Research IAP (PLA fiber development), and as part of the Fraunhofer Cluster of Excellence "Circular Plastics Economy" CCPE. The PET-based sandwiches shown were produced using face-sheets from Comfil. Extrusion foams from Airex were used as the core material.

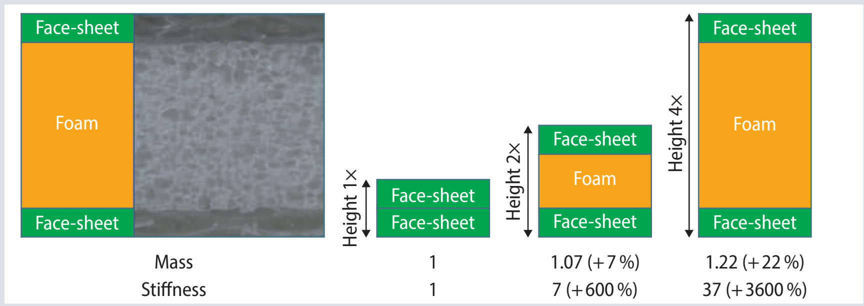

Fig. 3. The sandwich approach increases the performance significantly with only a very small increase in mass. Source: Fraunhofer ICT, graphic © Hanser

Properties	Unit	PA6-GF47	PP-GF47	PP (self-reinforced)	PET (self-reinforced)	PET (self-reinforced, 57 % fiber content)
Density	g/cm³	1.8	1.68	0.78	1.38	1.38
Tensile modulus	GPa	19.9	18	6.4	3.5	4.6
Weight-specific tensile modulus	10^6 m²/s²	11.06	10.71	8.21	2.54	3.33
Tensile strength	MPa	343	338	215	143	195
Weight-specific tensile strength	10^3 m²/s²	190.56	201.19	275.64	103.62	141.30
Elongation at break	%	1.9	2.1	7.7	22.8	24.7

Table. Comparison of the tensile properties of FRP and self-reinforced materials according to DIN EN ISO 527–1. Source: Fraunhofer ICT

point for the reasons described above. Fraunhofer ICT is currently researching and optimizing the processing of mono-materials, from semi-finished textile products through to adapted foam technologies and the final component, using large-scale production facilities.

The unique property profile of mono-material sandwich structures with self-reinforced face-sheets enables their use in the sports and leisure industry (for example for helmets and back protectors), as well as for semi-structural components in the mobility sector. The heat resistance requirements of the component should be considered when selecting the materials. The modular approach makes it possible to combine material morphologies to create a solution tailored to requirements in terms of reinforcement, installation space, load application, haptics and other properties (**Fig. 4**).

As the approach presented is based on the use of just one material, material recycling is simplified. This means that components can usually be shredded at the end of their service life, melted down and then reprocessed into components of the morphology kit. A practical demonstration using PET was provided in collaboration with the fiber and textile manufacturer Comfil, and another using PLA-based structures was provided by the Fraunhofer Institute for Applied Polymer Research IAP. The fibers obtained from the recycled material could be processed with a high process stability, and they showed comparable mechanical properties to their counterparts made from virgin material.

Conclusion

The overriding aim of using mono-materials is to conserve resources. This is possible due to the complete recycling of materials without downcycling. As reinforced components, they also offer significant potential for lightweight design. Mono-material sandwiches are therefore a promising variation on conventional FRPs, paving the way to a more sustainable use of plastics. The targeted use of the right morphology in the right place enables lightweight construction from just one material. ■

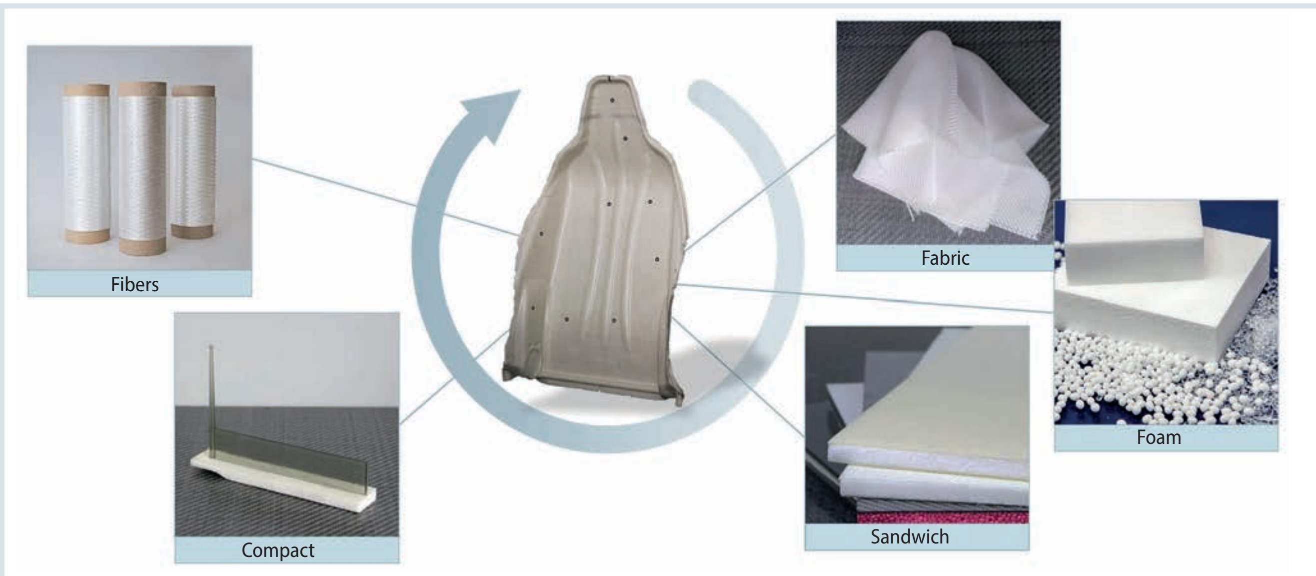

Fig. 4. The modular system makes it possible to select the right morphology for the site of application. © Fraunhofer IAP, Fraunhofer ICT