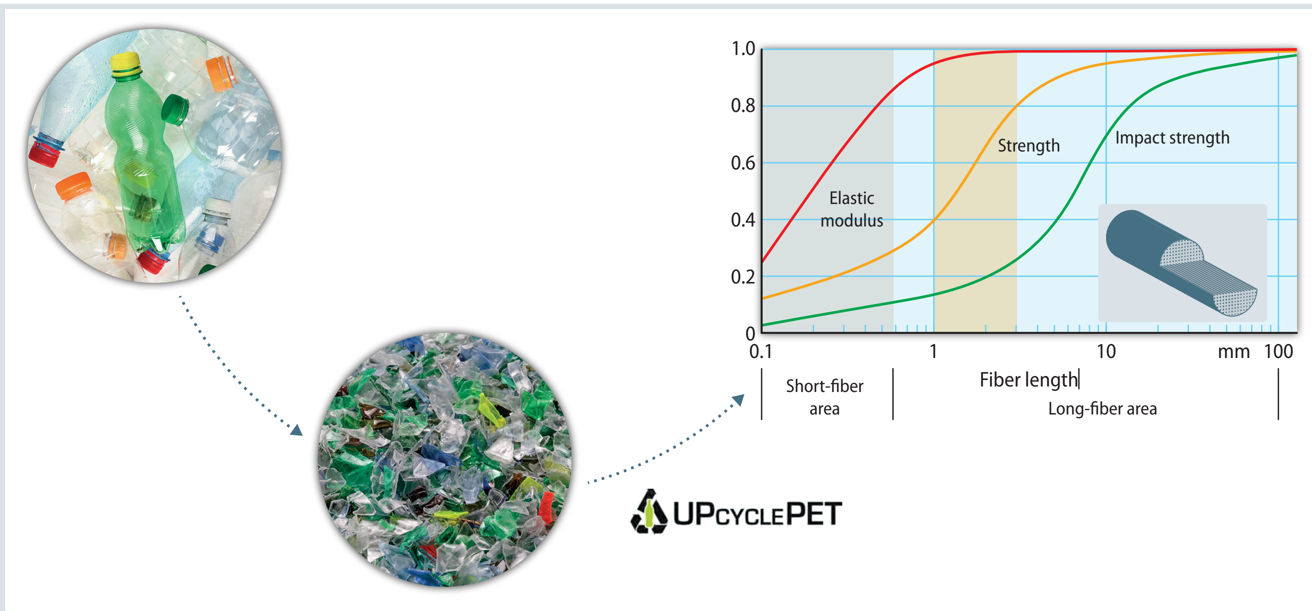
Sustainable Components from PET Flakes

New Compound Materials for Durable Technical Applications

In the research project "UPcyclePET", and together with Easicomp GmbH, Fraunhofer LBF developed a new material that had to prove its qualities in practical tests. The resulting technical component was able to demonstrate the mechanical advantages of long glass fibers, combined with the benefits of PET such as low swellability and high dimensional stability.



Upcycling of used PET beverage bottles into long fiber-reinforced thermoplastics © Bottles: akf – stock.adobe.com; flakes: © Ursula Raapke; Source of graphic: Fraunhofer; graphic: © Hanser

Plastic scrap and its improper handling result in global environmental problems. Particularly problematic hereby are packaging plastics that must be disposed of or find their way into the environment after a relatively short life cycle. One solution for this is to convert short-lived plastic scrap into high-grade materials that find new use in durable technical applications.

In the UPcyclePET research project, and together with Easicomp GmbH – experts for long glass fibers thermoplastics – Fraunhofer LBF developed a novel and low-cost material based on used beverage bottles made of polyethylene terephthalate (PET). Potential applications for the new material are found in lightweight automotive components such as engine supports or cross members.

Sustainable Materials from Used Beverage Bottles

The main feature of this approach is that PET flakes from used beverage bottles (called rPET in the following) are processed directly in a highly integrated manufacturing process that involves compounding and pultrusion. Hereby, the mechanical benefits of the particularly long glass fibers are combined with the advantageous properties of PET, such as low swellability and high dimensional stability.

By means of tailored plastic additivation, together with an optimized process design for compounding and pultrusion, the properties of the melt and compound were adapted according to the requirements of the target applications. Hereby, the main focus was on the mechanical properties. For the long glass fiber-reinforced PET made of bottle flakes, the aim of the project partners was to obtain similar mechanical properties as exhibited by short glass fiber-reinforced plastics based on virgin material, e.g. those of polyesters or polyamides (PA-SGF, PET-SGF). On the contrary to clearly defined virgin materials, recyclates place special requirements – in terms of quality – on processing and the formulation to be developed. Numerous properties of PET – e.g. moisture sensitivity, degradation behavior during processing or slow crystallization – repre-

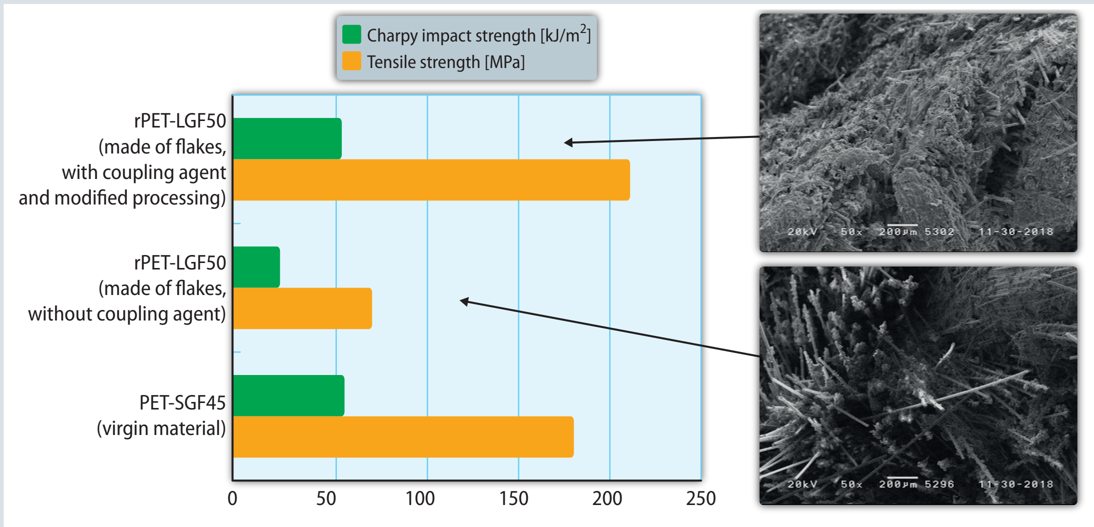


Fig. 1. Comparative REM images after cold fractures in correlation to achieved mechanical characteristics of different rPET-LGF50. These rPET-LGF50 differ in composition and processing and are compared with PET-SGF45 Photos and source of graphic: © Fraunhofer; graphic; © Hanser

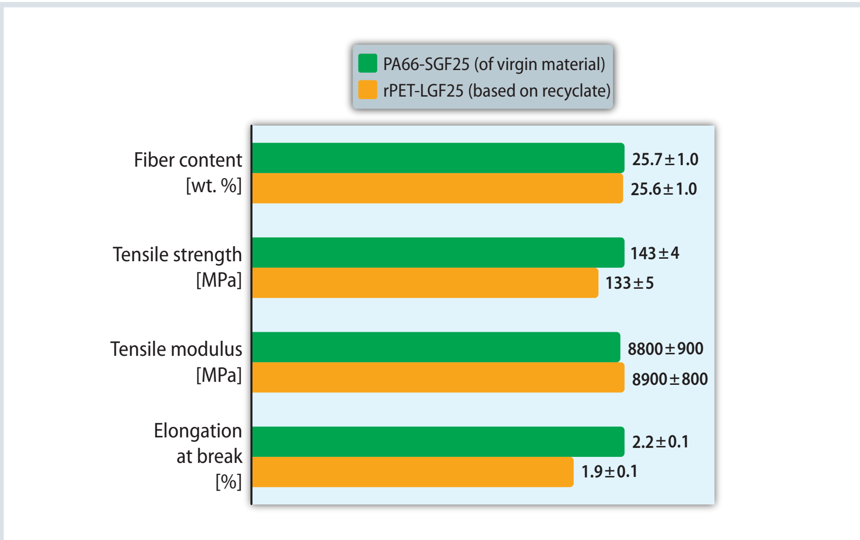


Fig. 2. Mechanical characteristics of rPET-LGF25 compared with those of PA66-SGF25 Source: Fraunhofer; graphic: © Hanser

sent special challenges for material development and process design. In addition, the specific requirements of the pultrusion process and the glass fiber compound (e.g. regarding viscosity limits and wettability of the glass filaments) must be taken into account. This interaction, plus targeted optimization, requires deep understanding and experience of formulation and process design for the composite materials. Therefore, selected formulations with different methods were investigated systematically in the UPcyclePET project. As an example, this procedure will be described on the basis of two formulations with a 50 % content of long glass fibers (rPET-LGF50) in terms of the fiber/matrix adhesion. The behavior of these compounds were compared by scanning electron microscopy after a cold fracture (**Fig. 1**). By means of a coupling agent and a modified processing, it was possible to reduce the fiber pull-out; the latter is typically observed when poor interactions between fiber and polymer matrix exist. Reduction of fiber pull-out improves the mechanical properties of the composite considerably.

Furthermore, the analysis of crystallization behavior and morphology, provided a comprehensive understanding of the structure/property relationships for the upcycling of such recyclates. Subsequently, the final recipe of the new long glass fiber-reinforced rPET (called UPcyclePET in the following) was compiled. It has a 25 % glass fiber content and is named as rPET-LGF25 in the following. »

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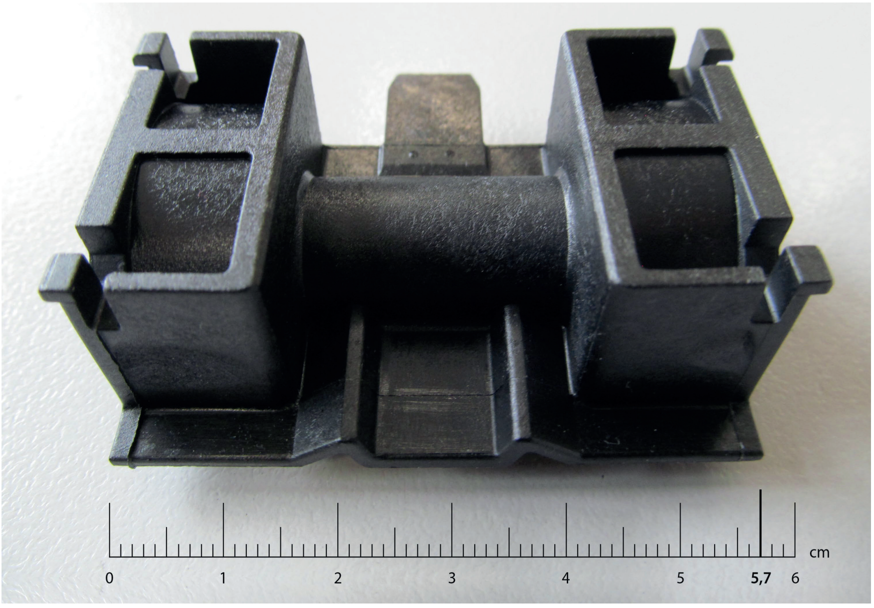


Fig. 3. The selected component made of rPET-LGF25 is a technical part in a window roller blind system that places high demands on geometrical accuracy and mechanical properties © Easicomp

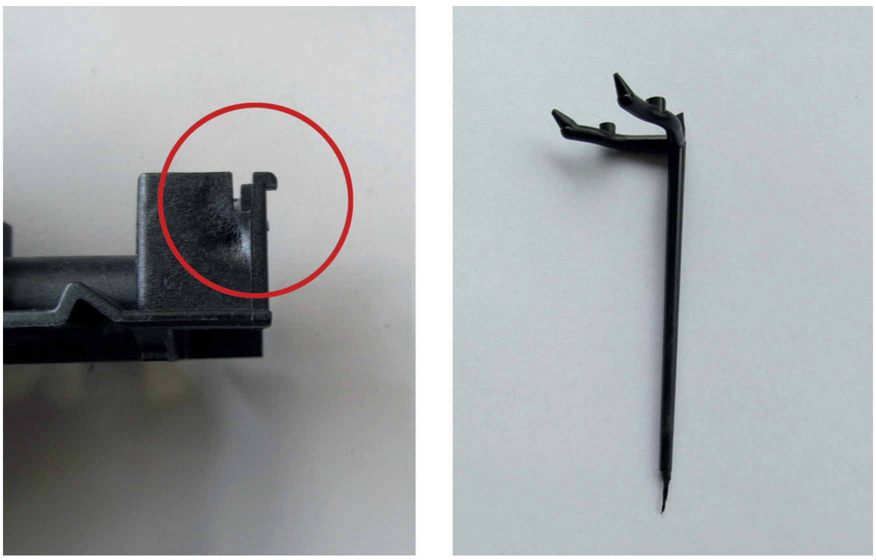


Fig. 4. Challenges: the left photo shows an encircled sink mark, whilst the long fibers at the sprue end are visible in the photo at right © Easicomp

CO_2 Footprint of rPET and PA66

Figure 2 shows the stress-strain properties (dry as molded) of rPET-LGF25 based on PET recyclate as compared to that of PA66-SGF made of virgin material. The material properties of PA66-SGF25 and rPET-LGF25 exhibit a comparable tensile modulus, but differ slightly in tensile strength and elongation at break. Regarding CO_2 footprint, the new material rPET-LGF25 based on recyclate has a decisive advantage over PA66-SGF25 based on virgin material polyamides. An indicative life cycle assessment, conducted by the project partner Öko-Institut, on material production revealed that the material UPcyclePET has a CO_2 footprint of 5.1 kg CO_2 equivalents/kg, whilst the material based on PA66-SGF25 has about twice as high with 11.0 kg CO_2 equivalents/kg.

Component with UPcyclePET

Based on the newly developed formulation, a component was selected which is currently being produced with short glass fiber-reinforced polyamide, and used in automotive construction. In order to evaluate the limit case (long versus short glass fiber-reinforced thermoplastics, produced in the existing mold which is designed and optimized for short glass fiber-reinforced polyamide 66), a relatively small component was chosen intentionally.

The PA66 component has a size of about 57 mm x 48 mm x 23 mm (length x width x height, see **Figure 3**) and consists of PA66-SGF25. The component was produced by K.S. Kunststoff-Innovation GmbH, who is a specialist for high-quality technical injection molded parts.

It was shown that injection molding of long glass fiber-reinforced rPET-LGF25 (length of LGF granulates: 11 mm) was possible with the same mold, normally used for processing the short glass fiber-reinforced PA66-SGF25, just by varying the injection molding parameters. As expected, the filling process was sub-optimal due to the longer glass fibers compared to the much shorter glass fibers of PA66-SGF25. As a result the component homogeneity and thus the quality of the component were affected. This indicates clearly through the typical sink mark near the sprue (**Fig. 4**). The reason for this is that due to its long fibers, rPET-LGF25 melt cannot flow unhindered through the narrow channels in the mold within the needed short time. The result is "freezing" in the sprue region. Accordingly, the dwell pressure cannot be maintained, which leads to the sink marks. Identification of suitable components (e.g. larger, less complex components) plus optimization of fiber and granulate length of rPET-LGF25 represent the next qualification steps for the new material.

By comparison, the component made of PET-LGF25 exhibited far less shrinkage and higher dimensional accuracy than that of PA66-SGF25. A non-contact photo-optical measurement of the PET-LGF25 component showed that local shrinkage was far less than that of PA66-SGF25 component (**Fig. 5**). This is due to the inherent properties of PET.

Summary and Outlook

In summary, the project UPcyclePET supported by the Federal Ministry of Education and Research (BMBF) successfully developed a new long glass fiber-reinforced material based on a secondary PET. It exhibits mechanical properties that

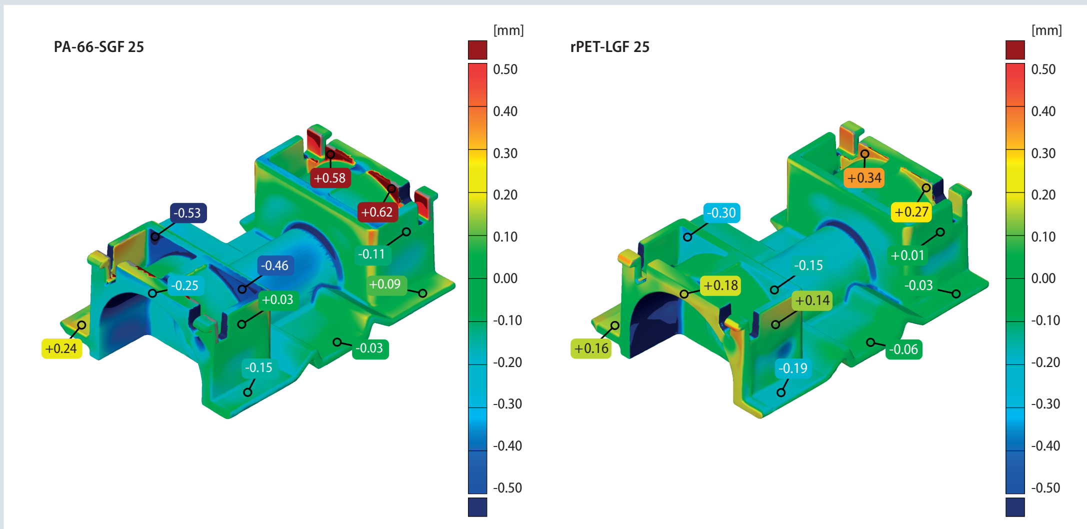


Fig. 5. Non-contact photo-optical measurement of components. At left, the original component made of PA66 – at right, the demonstration component made of UPcyclePET © ZiMatec

are comparable to those of virgin plastics reinforced with short glass fibers (PET SGF and PA66-SGF). The material rPET-LGF25 exhibits a significantly lower CO_2 footprint as compared to PA66-SGF25.

Moreover, the BMBF UPcyclePET project also showed that it is possible to use rPET-LGF25 to produce a small component with complex geometry (previously made of PA66-SGF25) in the same mold as the established product.

The demonstrator component of rPET-LGF25 features low shrinkage and particularly high dimensional accuracy.

Within the scope of the subsequent project UPcyclePETPlus, material flows other than used PET bottle flakes will be investigated. Also larger demonstrator components will be aimed for, which can be produced in molds with wider channels and sprues. ■

Two-Stage Process Enables a More Compact System Design

Processing Plastic Flakes Directly

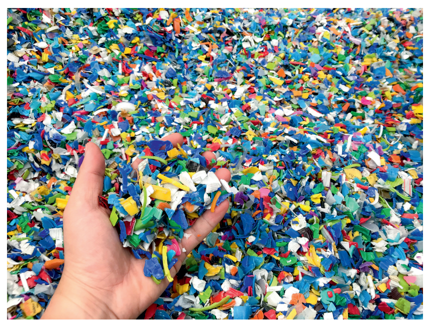
With a new process, **Engel** makes it possible to process plastic waste as flakes in injection molding directly after grinding. Since a complete process step, pelletizing, is eliminated, the innovation significantly improves cost efficiency in plastics recycling. The new process also offers benefits in the production of very large and thick-walled components with high shot weights.

The key to shortening the recycling process is breaking down plasticizing and injection into two independent process steps that are very well tuned with each other. In the first stage, the raw material, for example plastic flakes originating from post-consumer collection, is melted in a conventional plasticizing screw. In the second stage of the process the melt is transferred to a second screw for injection into the cavity. The two-stage process makes it possible to integrate a melt filter and a degassing unit on the injection unit side of the injection molding machine, so that products with a consistently high quality are obtained even from contaminated plastic flakes.

This innovation sees Engel make a further contribution to the establishment of a circular economy for plastics. Pelletizing the recycled material is an energy-intensive process which typically also involves logistics overhead. If this step can be eliminated, the CO_2 footprint is improved and recycling costs are also significantly reduced.

As an alternative to an injection screw, the plasticizing screw used for creating the melt can be combined with a piston unit. This variant of the two-stage process is also very efficient for processing very large shot weights of up to 160 kg with a comparatively low injection pressure requirement. The two-stage process enables a more compact system design and a lower unit cost than is possible with a conventional single-stage plasticizing and injection process.

Engel has developed a new piston design to eliminate the typical disadvantages of piston injection units when changing materials. The rheologically optimized piston tip supports uniform flushing around the piston, enabling fast material and color changes.



The aim of the innovation is to process plastic flakes, for example, from post-consumer collection, directly in injection molding without pelletizing © iStock

Typical applications are containers, pallets or even large fittings. Starting at a shot weight of 20 kg, processing efficiency increases significantly thanks to keeping the plasticizing and injection processes separate.

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