Plastically Deformable thanks to Staple Fibers

Innovative Organic Sheets Made of Recycled Carbon Fibers

The restricted complexity of components is one of the major drawbacks of conventional organic sheets. A newly developed carbon fiber fabric shall overcome this disadvantage by using a plastically deformable staple fiber yarn and thus open up a new degree of freedom in the thermoforming process of organic sheets.

The market for carbon fibers (CF) with its forecasted double-digit growth is heading into a bright future [1]. The major part of carbon fibers is used in components made of carbon fiber-reinforced plastic (CFRP). Especially the utilization of CFRP in the automotive branch could be identified as growth drivers. One example is the production of the BMW i3, where CFRP is applied in a series production with more than 24,000 sold vehicles in 2015 [2]. Nonetheless, it is not feasible today to substitute all metal parts by CFRP (or other fibers as for example glass fibers). Jointly responsible for this is the advanced experience in metal processing and notably in the production of deep drawn components. These deep drawn parts can be formed thanks to the flowability of metal. Corrugations for example can be deep drawn by locally thinning out the metal.

Complex Organic Sheets with Limits

Out of the perspective of the process development, the flowability clearly distinguishes the metal sheets from CFRP semi-manufactured products, so-called organic sheets. Since the reinforcing carbon fibers are not able to flow, the draping properties, which describe the capability of a two-dimensional material to adopt on three-dimensional shapes, is very low if not non-existent. This article focuses on the project InTeKS (Innovative Textile Structures Made of Carbon Staple Fibers; development of an innovative, plastically deformable organic sheet) and shows a new concept for the production of semi-manufactured thermoplastic products with excellent draping properties. This project will be a push towards the mass application of thermoplastic CFRP.

The increasing spread of CFRP comes along with other challenges though: One of them will be the growing amount of waste as CFRP applications increase. As these wastes today mainly stem from the production of CFRP parts, but there...
will also be end-of-life waste (EOL waste) in the upcoming years. Studies show that in the year 2020 2,000 t of CFRP waste can be expected, which can be divided into 13,800 t of production waste and around 7,200 t of EOL waste [3]. Thus, a second goal of the project InTeKS is to use recycled carbon fibers as raw material for the new, highly drapable organic sheets. These two major goals complement each other ideally.

**Current Barriers**

The restricted complexity of components when using conventional organic sheets has to be seen as disadvantageous for these semi-manufactured products. One cause is the achievable drapability which is directly influenced by the type of binding of the single rovings, especially with woven fabrics. A higher amount on roving crossings leads to lower shear angles and in consequence to a lower drapability. A plain weave has the maximum number of crossings and therefore the highest degree of waviness. An atlas fabric only has one crossing per three to four rovings, which reduces the waviness, increases the maximum shear angle and thus the drapability. But regardless of the type of fabric it is a matter of fact that carbon fibers are not plastically deformable and have a maximum elongation at break significantly below 2%, depending on the type of carbon fiber.

Recycled carbon fibers (rC fibers) only exist in finite and randomly oriented form (Fig. 1). The up-to-date processes for their further processing of rC fibers into semi-finished products do not change this form and create mats and non-woven fabrics without an explicit fiber orientation. Based on this circumstance the rC fibers can only be applied in semi-structural parts. In most cases, however, this represents a "down-cycling" which means that a significant part of the original functionality of the material gets lost. A "real" recycling towards structural components can only be achieved by oriented carbon fibers of infinite length as it is actually the case for organic sheets.

**Staple Fiber Yarns Made of Recycled Carbon Fibers**

The goal of the project InTeKS is to improve the drapability of organic sheets while using recycled carbon fibers. The strategy to achieve this goal is to produce CFRP out of rC staple fibers, which will further be processed into rC staple fiber yarns (Fig. 2). The unique feature of the InTeKS material is the structure of the used rC staple fiber yarns. Single rC and PA6 fibers are forming a yarn mainly due to friction forces. This structure allows the single carbon fibers to slide during thermoforming which leads to a behavior of the material comparable to the plastic flowing of metal when deep drawn. This promises a higher drapability compared to conventional non-crimp-fabrics and therefore increases the possible component complexity as well as the lightweight potential.

The responsible consortium represents the whole process chain from the treatment of the recycled carbon fibers to the production of the yarns and fabrics, the production of the organic sheets as well as their thermoforming into a demonstrator component (Fig. 3). The development of the materials and processes will be accompanied by the development of a model which is supposed to simulate the drapability of the CFRP on the basis of rC fibers.

The process chain starts at Altex Textil-Recycling GmbH & Co. KG based in...
Gronau, Germany, with the extraction of rC fibers out of waste bobbins. The fibers get homogenized by a cutting machine (manufacturer: Pierret Industries, Corbion, Belgium) to a defined length of around 80 mm. The treated rC fibers will then be processed by the Institute of Textile Technology and Process Engineering (ITV), Denkendorf, Germany (Fig. 4). The first step is the preopening of the rC fiber rovings (here the fibers get separated from each other partly down to single fibers) through a machine from Laroche S.A., Cours la Ville, France, before they are oriented by a carding machine by Memmingen Textil Engineering GmbH, Berlin, Germany (formerly Maschinenfabrik Memmingen) and processed into a rC fiber sliver (Fig. 5). Afterwards, the rC fiber sliver is spun into a rC staple fiber yarn with the help of a self-developed machine of the ITV (Fig. 6) and finally get wound onto bobbins. These are delivered to another project partner, Gerster TechTex, a division of the company Gustav Gerster GmbH & Co. KG, that is responsible of creating non-crimp fabrics out of the rC staple fiber yarns.

Rovings Made of rC Staple Fiber Yarn

Gerster TechTex is already experienced in producing highly drapable rovings as for example their product “Drapfix”. The task for them is to create processable rovings from rC staple fiber yarn. First trials showed the principal feasibility by exposing the yarns to sharp radial stress (Fig. 8). Thus, the most critical step in the process of the creation of non-crimp fabric has been mastered.

The finished non-crimp fabrics will be sent to the Institute of Composite Materials (IVW) in Kaiserslautern, Germany, where they will be pressed to organic sheets in cooperation with the project associate Bond-Laminates GmbH, Brilon, Germany. In the following the organic sheets will be thoroughly characterized and especially the draping behavior will be investigated with various specifically developed testing tools from the IVW.
in cooperation with the tooling company Kunststoff Wagner, Donzdorf, Germany. One important aspect in that process is the testing of the plastic elongation of the rC staple fiber yarns. Towards the end of the project a challenging tool with various demanding features like radii of around 1 mm, draft angles of 1°, edges etc. shall demonstrate the outstanding performance of the material regarding its draping properties.

The development of the new organic sheets will be accompanied by a simulation model, which shall be able to predict the draping process of the material during thermoforming. It will be developed at the IVW in cooperation with the Dynamore Gesellschaft für FEM-Ingenieurndienstleistungen mbH, Stuttgart, Germany. The model will detect typical malformations as for example the spreading of rovings, changes in fiber orientation (shearing), folded areas and thinning of the material.

**Structural Parts Made of rC Fibers**

Even though the project InTeKS is still in its first year, the first milestones are already accomplished. The successful production of continuous, oriented rC staple fiber yarns is an important step towards structural parts made of recycled carbon fibers. The characterization of the yarns and the determination of their mechanical properties will be the next milestones.

Alongside the new degrees of freedom in the component complexity the material costs can be reduced by the utilization of recycled carbon fibers. This makes the InTeKS material interesting to the automotive industry, since the new possibilities in the field of carbon recycling will help to implement the European law for EoL waste caused by old motor vehicles which stipulates a recycling ratio of 95 wt.-% from January 1st, 2015 on [4].

The possibility to recycle the utilized CFRP in these vehicles without significantly downgrading their mechanical properties will make the application of CFRP even more attractive. But the major goal of the project, i.e. to improve the drapability of organic sheets by enabling the material to plastically elongate, will also set impulses for further research in that area.

**Hyblow Series Expanded**

**High-Capacity Production of Milk Containers**

The current packaging machine series by Bekum Maschinenfabriken GmbH, Berlin, Germany, with its patented and proven C-frame closing unit for electrical and hydraulic closing actuators, has been expanded by two additional models. The “multi-cavity” twin station machines of the hydraulic Hyblow series was manufactured for the high-capacity production of milk containers for a Peruvian customer.

For the range expansion, Bekum delivered a Hyblow 407 DL for a 12-fold production of 200 ml containers with an 860 mm mold width and a Hyblow 607 DL for a 9-fold production of 1000 ml containers with a 1000 mm mold width. A new screw geometry enabled the optimized processing of viscous HDPE with TiO₂. The new design of grooved bushing, feeding zone and barrier geometry allows a 20% increase in the output with improved service life and lower wear due to the uniform load distribution over the entire machine length. This improves the homogeneity of the compound without an additional, costly mixing component.

About 70 to 80% of the energy used in a blow molding machine is consumed in melting and cooling the plastic required for processing. The optimized extruder screw lowers the energy consumption required to melt the HDPE to a mere 200 Wh/kg. At the same time, the drive train of the extruder is also optimized so that the motor runs with the highest efficiency at a nearly optimal operating point.

In addition to the energy benefits, the machines also provide exceptional handling with trouble-free production start-up, uniform extrusion of the 9-fold and 12-fold parisons as well as reproducible article quality in terms of wall thickness distribution and weight. The aluminum molds used by Bekum are designed for the shortest cooling times and high piece counts. Using modern, high-speed and precision article measurement technology, an immediate feedback can be given to the processing engineers and the mold maker.

To the manufacturer’s product presentation: www.kunststoffe-international.com/1346049