Fiber-Reinforced Plastics

The Manifold New Collection of Reactive Systems and Thermoplastic Composites

The traditional markets for glass fiber-reinforced thermoplastics remain stable. Thermoplastic composites are gaining fast with 3D-printing and hybrid processing techniques. The fiber composite industry is tackling the recycling issue with pragmatic ideas.

The Oechsler Drivematic drive actuator can be integrated into the 3D-printed CFRP monocoque frame of an Arevo „e-bike“ (© Arevo)

The fiber composite branch is satisfied with their results worldwide: 88% of all composites manufacturers rate their current business situation as good to very good. However, according to Composites Germany, the domestic branch association, 69% of current estimates are positive, i.e., somewhat lower than half a year ago. With regard to the future general outlook for German companies, the Composites Development Index, which was also ascertained, has fallen significantly over the last two years despite the good investment climate. Even so, the branch is confident that new impulses can brighten the mood considerably, since investment climate indicators in particular are pointing upwards [1].

Glass fiber-reinforced polymers (GFRP) continue to dominate the market. Annual European growth has run about 2% in the last two years, differing widely from one country to another. More than two-thirds of all GFRP applications are tied up in the transport and infrastructure sectors so that, in principle, the trend follows gross domestic product. Although there were no setbacks in any one branch in 2017, in the long run, the open processes for composites with thermosetting matrix will lose importance, while RTM processes will have above average growth. Despite good figures, the European fraction of the GFRP branch is shrinking, since other world regions, such as Asia and America, are growing faster [2].

The Plastixx Composites Index published by KI and based on the price courses of resins and glass fibers used for producing GFRP ran higher in the last three years than in the previous period. Growth was determined by bottlenecks in polyester resin pre-products as well as by crude oil-linked price developments for the reaction partner styrene. In 2019, however, weaker demand from the automobile industry has begun to make itself felt [3].

Vertical Market Integration in CFRP

Carbon fiber-reinforced polymers (CFRP) can continue to be regarded as a worldwide growth driver for the fiber composite branch. Based on strong interest in this lightweight material, fiber manufacturers have created new production capacities. In 2018, the worldwide capacity for car-

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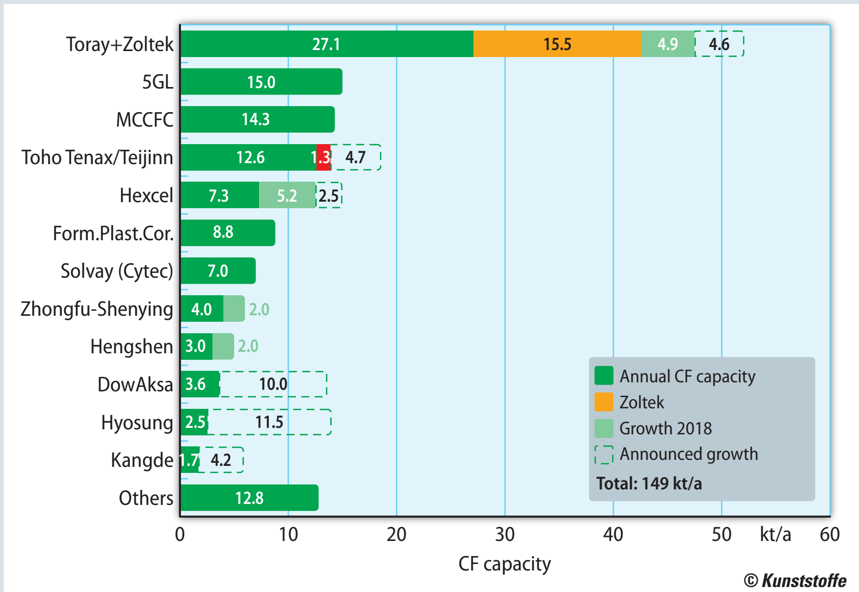

Fig. 1. Theoretical, annual CF production capacities by manufacturer, as 11/2018 (source: Carbon Composites)

bon fibers was just short of 150 kt – at a demand of some 80 kt. For the years ahead, the available quantity of fiber, more than 80 % of which goes into the CFRP market, is expected to grow by about 25 % ([2], **Fig. 1**).

The preeminence of Toray of Tokyo, Japan, will be consolidated by considerable increases at the Zoltek Company of St. Louis, MO/USA, bought by them years ago. Moreover, other, smaller market members, based mostly in Asia, are providing notable growth of carbon fiber capacity. Among the manufacturers, the acquisition of companies in the fiber processing and component manufacturing field has formed a precedent – as a way to make money all along the value chain of the CFRP market. Mainly in Asia, the component manufacturing sector is catching up and will expand with the increasing fiber supply [2].

At nearly 155 kt (2018), the demand for related carbon composites (CC) has reached a new high point. Carbon fiber-reinforced polymers make up the vast majority of these. Aerospace is the far-away leader with 36 % of all CC applications (revenue-related). The most important growth drivers are civilian aircraft, but for the future, the ambitious space missions of private companies are making themselves felt [2].

Wind energy, however, has been far exceeded by automobile applications that command 24 % of the CFRP demand (revenue-related). Increasingly, the fiber manufacturers are catching up to the demand for so-called "heavy tow" products – relatively economical carbon fiber bundles with a very high number of single filaments. Highly integrated applications, often in multi-material design, offer future automotive prospects, not in the least for vehicles with new drive technologies.

Still a Niche despite the Boom

Composites with thermoplastic matrix stand for high storage stability, short processing cycles, and simple further processing, including recycling. Correspondingly, this cost-efficient materials group is currently enjoying a genuine boom.

Thermoplastic glass fiber-reinforced polymers are growing above average worldwide by 5 % – their fraction of GFRP applications has almost quadrupled over the last 20 years [2]. In addition to glass-mat-reinforced thermoplastics (GMT) and traditional long fiber-reinforced thermoplastics (LFRT), continuous fiber-reinforced composites show the greatest potential: organosheets and thermoplastic tapes enable functionalized high-strength surface components. »

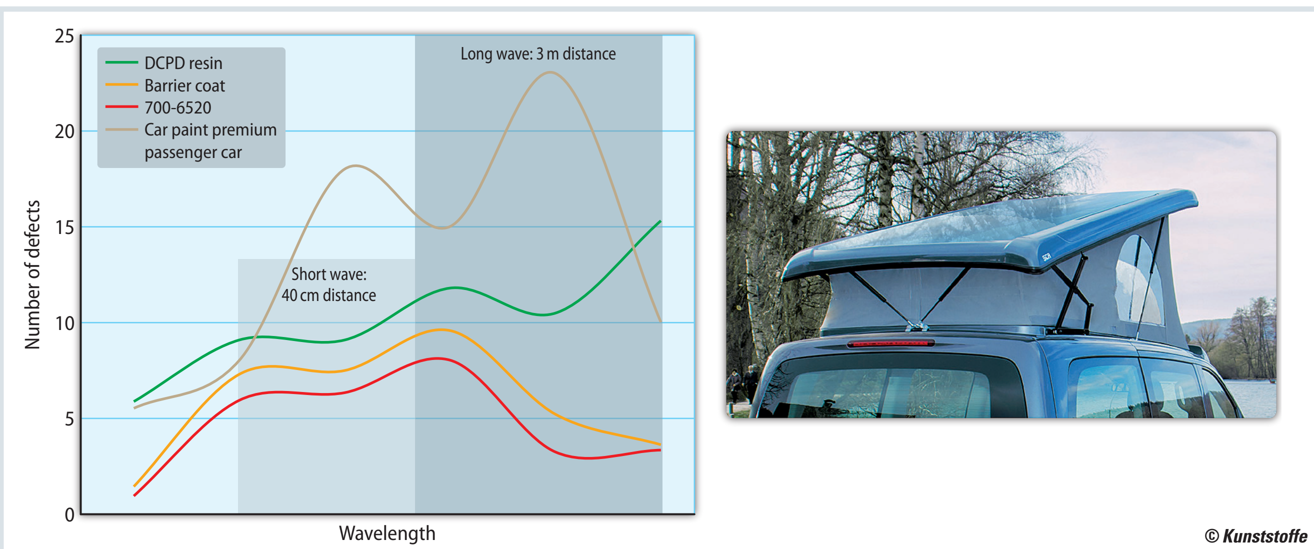

Fig. 2. For high surface qualities by the RTM process: quality comparison from WaveScan measurements (left). For SCA roofs of various car makers, C. F. Maier uses the VE 6520 Büfa resin in the RTM light process (right) (source: left: BYK-Gardner, © right: C.F. Maier)

Table 1. Various principles of 3D printing with continuous fiber-reinforced thermoplastics (types of fiber: CF: carbon, AF: aramid, GF: glass, BF: basalt) (source: Markforged, Cead, 9T labs, Anisoprint, Arevo)

Supplier	Markforged [16]	Cead [17]	9T labs [18]	Anisoprint [19]	Arevo [20]
Term	X7	CFAM Prime (Continuous Fiber Additive Manufacturing) and flexbot	AFT (Additive Fusion Technology)	Anisoprint Composer / CFC (Composite Fiber Co-Extrusion)	DED (Direct Energy Deposition)
Principle	Pre-impregnated fiber strand and matrix strand are melted and deposited together	Matrix is melted in the extruder and consolidated with pre-impregnated fiber bundle in the nozzle	Deposition of continuous fiber strand with matrix + downstream process for optimum consolidation	Fiber strand with hardened thermoset is deposited together with melted matrix strand	Pre-impregnated fiber strand and substrate are melted by laser and consolidated in-situ under pressure
Fiber type	CF, AF, GF	CF, GF	CF	CF, BF	CF
Matrix type	PA-CF (short fibers)	Practically arbitrary, usually short fiber-reinforced	PA12, PEI, PEKK	Polymers with melt temperatures as high as 270 °C	PEEK
Strand deposition	Planar	CFAM Prime: planar / flexbot: 6-axis-robot	Planar	Planar	Multi-axial, 6-axis robot
Fiber volume content	-	20–50 % / fiber strand 5–50 % / matrix	≥50 %	25 %	≥50 %
Shrink hole content	-	-	<2 %	about 2 %	<1 %
Installment space	330x270x200 mm^3	CFAM Prime: 4000x2000x1500 mm^3 flexbot: track length x 1800x1500	300x300 x250 mm^3	297x210x145 mm^3 and 420x297x210 mm^3	1200x1200x1000 mm^3

Whereas 13% of all GFRP components have a thermoplastic matrix, 29% of the turnover among the increasingly large-scale production-oriented CFRP applications is achieved by PA, PEEK & Co. Even though the segment of carbon fiber-reinforced thermoplastics is growing currently by almost 17%, this development affects only a fraction of the total market for composites: the amount of CFRP in all of Europe is less than 5% of all fiber-composite applications [2].

King customer loves unblemished surfaces – in vehicles this has been a challenge to manufacturers of fiber composite plastics (FCP) since time began. If the costly lacquer layer is to be dropped, innovative thinking is on order. Whereas diverse in-mold coating technologies have become established for sheet molding compound (SMC) or resin transfer molding (RTM) [4–7], a practical, shrink-free vinyl ester resin system is now available for RTM and RTM-light processing. A-1 surfaces with no outstanding fibers or metal inserts can be produced without barrier coats or supplementary near-surface layers ([8], **Fig. 2**). High-quality SAN- or PP-based vehicle surfaces can also be realized using thermoformable types from the StyLight Aesthetic series of fiber-composites [9].

Although GFRP pipes offer great potential – especially for the still scarcely developed field of large cross-sections [10] – they are regularly substituted by other materials, or are subject to normative imponderables such as the recently changed drinking water approval. Tank and plant construction appear to be the driving force behind centrifugally cast or wound GFRP products, as witnessed by reinvestment measures in the chemical industry, and other developments [2]. Corrosion-free GFC tanks up to 100 m^3 can also be used for heat- or cold-storage, thanks to their high design flexibility as well as low thermal loss [11]. The energy efficiency of manufacturing companies is appreciably increased when waste heat, cold and/or warm process water, or superfluous photovoltaic current are utilized appropriately (**Fig. 3**). The shell laminate in the tank consists of UV-hardened sheet material; spray lay-up is used for floors and covers.

Fig. 3. Installation of insulated GFRP heat and cold storage in combination with heat pumps for heating and cooling the process water of a fruit drink producer (© Haase Tank)

Continuous Reinforcement from Press and Printer

Continuous fiber-reinforced thermoplastics are increasingly successful in mass production. The production of hybrid components in specially developed injection molding machines has become established: a single processing step creates highly rigid flat components from molded organosheets that can be functionalized with short or long fiber-reinforced molding compounds into ready-to-assemble components. Among other things, frontends, electrical or electronic module carriers, battery components, and covers for mobile communication devices can be manufactured this way. Deserving of special attention in this one-shot hybrid approach is the draping of pre-warmed organosheet right in the injection mold [12].

The same market segment, however, is also served by processing methods in which a much greater volume of parts stems from the compounding process: Melts with 10 to 12 mm long fibers manufactured in the direct process are locally reinforced by subsequent impact extrusion in a pressing stroke with UD profiles, tape layers, or organosheets (**Fig. 4**). Compared to injection molding, design freedom is somewhat limited by this E-LFT process (long fiber technology with continuous fiber-reinforcement), but very large parts – up to 3 m^2 surface – can be manufactured economically with this method [13].

Hardly any other development has shaken up the plastics industry as much as has the option to produce parts additively. The elimination of costly molds, the promise of batch size 1 for special versions without additional expense, as well as design options have led to the sudden entry of 3D printing into manufacturing operations. As a rule, 3D-composite printing is a variant of thermoplastic based FDM (fused deposition modeling, also FFF = fused filament fabrication or FLM = fused layer manufacturing); thermosetting is the exception [14, 15].

Fig. 4. Car seat back parts in E-LFT technology from compounded PA6-GF40 with 10 mm long glass fibers and unidirectional pultrusion profiles positioned according to the load cases (© Weber Fibertech)

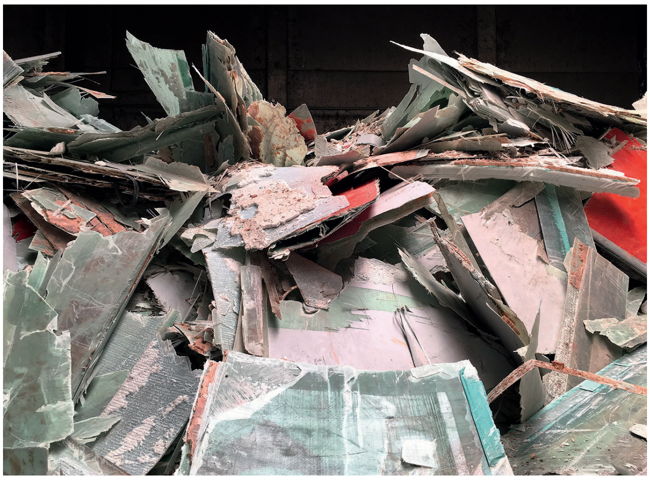

Fig. 5. Dismounted rotor blades replace traditional resources: roughly crushed and shredded, they serve as fuel and substitute for raw sand in cement factories (© Neowa)

Not the smallest challenge consists in achieving very good mechanical properties with good impregnation quality and high fiber volume content – for continuous fiber-reinforced applications there are various approaches (**Table 1**). Very high fiber volume contents above 50 vol.% are achieved by the so-called Direct Energy Deposition (DED) process in which both the shrinking, pre-impregnated filaments as well as the substrate are melted by a laser during build-up and compacted in-situ (**Title figure**). If, as in many printing concepts, construction is done by stacking 2D planes, three-dimensional strand deposition by 6-axis robots enables maximum design freedom with load-path-compatible fiber reinforcement [20].

Circulating Fibers

Plastics recycling is once again at the top of the agenda everywhere. Glass fiber-reinforced polymers amount to a large portion of all wastes – the disassembling and renewal of aging wind energy plant alone are generating some 40,000 t of residual material in Germany every year [21].

Waste management of GFRP is established by and large: dismounted and crushed rotor blades as well as waste from plant construction, marine, and buildings are utilized thermally as well as materially; however they then no longer remain within the plastics branch. The main customer is cement production which uses ground GFRP as a resource-saving substitute fuel in clinker production (**Fig. 5**). The resulting silicon dioxide ash is returned to the production process as a substitute for raw sand [22].

The CFRP industry is currently less concerned with the end-of-life issue than with production waste and practices recycling mainly for reasons of cost. Circulation use for dry CFRP offcuts or expired prepregs is in the making. Resin-wetted fibers have to be pre-treated, whereby pyrolysis, i.e., oxygen-free degradation of the plastic matrix at high temperature, seems to be prevailing. The recycled fibers then become new reinforcement materials – often in the form of nonwovens, some of which are offered as hybrids solidified with thermoplastic fibers, or by sewing and kneading them. Heavily shortened fibers can also be reused in injection molding applications. At the same time, low-waste tape-laying processes are being worked on intensely [21].

The fiberEUse project is looking for new approaches to FRP recycling, such as "custom manufacturing", e.g., by means of repairs to automotive and aerospace components, as well as by "custom reforming" in the form of creative products from residual composite material [23]. Designers are practicing upcycling with the material Glebanite made from ground GFRP waste and fresh polyester resin. Cast, compressed, or cold-extruded semi-finished products have great potential here for sculpturing [24, 25].

Outlook

The last years have gone well for the fiber composite branch. We must wait and see how strongly the upheavals in the vehicle industry will affect Germany as a producer of plastics. Whether the CFRP euphoria will continue, is uncertain. ■

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