INDUSTRIEVEREINIGUNG
VERSTÄRKTE KUNSTSTOFFE
FEDERATION OF REINFORCED PLASTICS

CARBON COMPOSITES

Composites Market Report 2017

Market developments, trends, outlook and challenges

The **GRP**-Market Europe – Dr. Elmar Witten (AVK)
The global **CF- and CC-**Market – Michael Sauer, Michael Kühnel (CCeV)

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Content

The European GRP-market 2017

Author

Dr. Elmar Witten is Managing Director of the AVK - Industrievereinigung Verstärkte Kunststoffe e.V. (Federation of Reinforced Plastics). The AVK, as the German professional association for fibre composite plastics/composites, represents the interests of producers and processors of reinforced plastics/composites on a national and a European level.

Its services include organisation of task forces, seminars and conferences as well as providing market relevant information (www.avk-tv.de).

The AVK is one of the four national pillars of the GKV – Gesamtverband Kunststoffverarbeitende Industrie and an international member of the European composites confederation EuCIA – the European Composites Industry Association.

The AVK is a foundation member of Composites Germany.

1 The European GRP Market in 2017

The trend of steady growth continues

Fibre reinforced plastics or composites are manufactured using a variety of reinforcing materials, e.g. glass, carbon or natural fibres. Glass fibre reinforced plastics (GRP) dominate the composites market accounting for approx. 95 % of its total volume.

In 2017, the GRP market grew – for the fifth consecutive year – by 2 % compared to the previous year in the European countries studied in this report.

As in past years, the volume of GRP manufactured in Europe (1.118 million tonnes) reflects the different trends observed in the various market segments. Production of thermoplastics, used primarily in the automobile industry, is generally still growing more strongly than production of most thermosetting materials. However, in 2017, the strongest area of growth in production volume (5 %) was continuous processing – especially the pultrusion process. The majority of these processes use thermosetting materials.

In the European region, Germany remains the country with the largest GRP production in absolute terms and the strongest growth. Growth has been consolidating in Southern Europe – Italy, France, Spain and Portugal. Currently, production volume is not contracting in any European country/region.

2 Markets considered in this report

To ensure the data in this report remain comparable with those of previous years, the GRP materials considered here include all glass fibre reinforced plastics with a thermoset matrix, glass mat reinforced thermoplastics (GMT) and long fibre reinforced thermoplastics (LFT) as well as all the quantities of continuous fibre reinforced thermoplastics this encompasses. Data on European production of short glass fibre reinforced thermoplastics are only available as an overall quantity and therefore stated separately.

Carbon fibre reinforced plastics (CRP) are dealt with separately in the second section of this market report.

The GRP Market Report considers all relevant European countries, for which production figures can be recorded and validated. Turkish production is also considered but still stated separately due to the lack of data for long-term comparison.

3 GRP production in 2017: Overall development

Following the slump in European GRP production during the economic and financial crisis – between 2007 and 2009 – the composites industry is now enjoying its fifth successive year of growth. As in previous years, it is clear that the trend in the first six months of the year is more positive than in the second half. In 2017, the European GRP market is expected to grow by 2 % to an estimated total of 1.118 million tonnes (see Fig. 1). The trends differ from country to country and also in terms of the major manufacturing processes and materials used. Indeed, the corresponding growth rates can diverge quite significantly. The composites industry as a whole and the GRP market are extremely heterogeneous in terms of the machinery and methods used. As in other regions of the world, the European market is characterised by a large number of small and even very small businesses – although in many countries 80 - 90 % of the total volume is produced by just 10 - 20 % of the companies.

4 GRP production in Europe

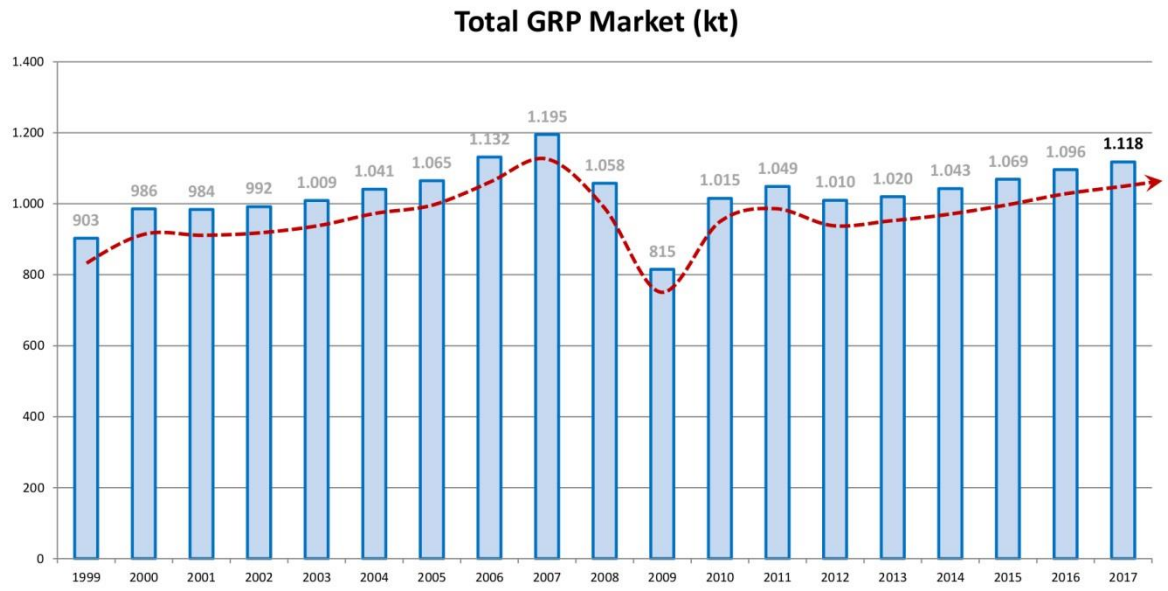


Figure 1: GRP production volume in Europe since 1999 (kt = kilotonnes, 2017 = estimate)

The largest buyers of GRP components are to be found in the transport/mobility and construction sectors. These each consume around one-third of total production and play a major role in national economies. No significant changes have been observed here over recent years. The key role played by these two most important sectors in national economies is one reason why the production of GRP tends to follow the long-term growth trend in GDP. Significant changes in vehicle production in individual countries or a booming construction sector have an immediate knock-on effect for suppliers and thus for the industry. Some GRP components are already firmly established as construction materials. Although there is still excellent potential for new applications, GRP materials are already standard products. As these are in relatively widespread use and production levels are considerable, no dramatic growth in production volume can be expected over the coming years (in contrast to the relatively small CRP segment). Even strong growth in individual segments has a relatively small impact on total production due to the large volumes involved. The diverse nature of the market means that fluctuations in one customer industry are usually “smoothed out” by other applications.

GRP production in Europe continues to grow but is expected to lag behind the global trend. Growth in global production volume is well over 2 %. As a result, Europe's share of global production continues to fall despite the positive trend in absolute terms.

The simple depiction of the total European GRP production is an indicator for the overall trend in the market. As previously mentioned, there are sometimes major differences in the trends for individual countries/regions and applications/manufacturing sectors. It is therefore instructive to look at the individual markets/segments in more detail.

5 Trends in the development of processes/components

	2014	2015	2016	2017
	kt	kt	kt	kt
SMC	190	191	198	202
BMC	74	74	76	78
∑ SMC/BMC	**264**	**265**	**274**	**280**
Hand lay-up	138	139	140	140
Spray-up	94	96	97	98
∑ Open mould	**232**	**235**	**237**	**238**
RTM	**132**	**137**	**141**	**146**
Sheets	84	86	89	93
Pultrusion	48	49	50	53
∑ Continuous processing	**132**	**135**	**139**	**146**
Filament winding	79	80	80	78
Centrifugal casting	66	68	68	67
∑ Pipes and Tanks	**145**	**148**	**148**	**145**
GMT/LFT	**121**	**132**	**140**	**145**
Others	**17**	**17**	**17**	**18**
Sum:	**1.043**	**1.069**	**1.096**	**1.118**

Figure 2: GRP production volumes in Europe according to processes/components – current year and the three previous years (kt = kilotonnes, 2017 = estimate)

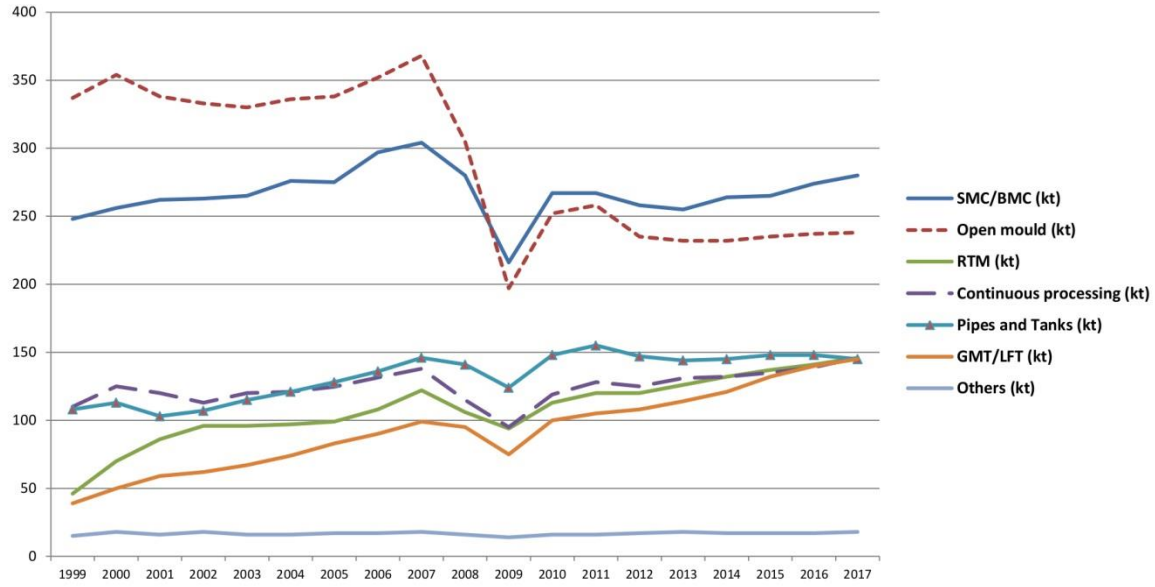


Figure 3: GRP production volumes in Europe according to processes/components – long-term volume trend (kt = kilotonnes, 2017 = estimate)

Fig. 2 shows the volume trends for significant processes/components in GRP manufacturing over recent years. However, in addition to these processes, there are many other production processes/technologies which can essentially be classified under one of the areas mentioned.

Fig. 3 shows the long-term trend over the past 19 years. Clearly, SMC/BMC now make up the largest segment. The next largest continues to be “open processes” – still a segment with a greater emphasis on manual skills and craftsmanship. Growth in the use of SMC/BMC materials has been positive over recent years – in step with the overall market trend – while the open processes of hand lay-up and spray-up have generally declined. Production quantities for all other processes are virtually identical in 2017. The following section takes a closer look at the individual segments and their trends.

In the GRP production considered here (not including short fibre reinforced thermoplastics), over 85 % of all GRP components are made from a thermoset matrix based on either a polyester, vinylester or epoxy resin. Unsaturated polyester resins are still by far the most commonly used. Glass fibre used for reinforcement generally contributes between 15 % and 70% of the material used in these composites depending on

the manufacturing process and application. The average proportion of glass used over all segments is around 25-35 %.

5.1 SMC/BMC

SMC (sheet moulding compound) and BMC (bulk moulding compound) components account for around one quarter of total production and are the largest market segment of the GRP industry. Semi-finished products manufactured using pressing (SMC) and injection moulding (BMC) processes are turned into components which are used primarily in the electro/electronic and transport sectors, especially in the automotive industry.

This year, the SMC/BMC sector is growing is growing slightly more slowly than last year at a rate of 2.2 %. Total production volume this year will be 280,000 tonnes of which over two-thirds is SMC (202,000 tonnes).

The SMC/BMC market has now been relatively stable for decades both in terms of its very high production volume and market share. The size of this market becomes clear when it is compared with the CRP sector which has been the subject of much more media attention over recent years. European SMC/BMC production is around six times larger than that of CRP components in the same region.

While the production volume of SMC/BMC materials is (at best) stable in Central European countries/regions, the trend in Southern and Eastern Europe is currently very good. Transportation and the automotive sector are the key factors driving this growth. Applications in the electro/electronic industry, however, are stagnating or in decline.

In other composites segments, large scale series manufacturing processes are currently a hot topic of discussion. Yet these have been a reality for SMC and BMC components for many years – with production of some parts even exceeding 100,000 pieces per year. Mass-produced car headlamp reflectors are typical components made from BMC. SMC is used in the automotive sector, e.g. for tailgates, interior panelling and cabin components, oil sumps or covers. In the construction industry it is used, e.g. for light shafts, cable ducts and shaft covers, in the electro/electronic sector for switches, control cabinets, home junction boxes, etc.

Lightweight design requirements are often a priority when developing components, especially for vehicle production. However, the special properties of SMC and BMC – e.g. insulation properties, weather and temperature resistance and dimensional stability – also allow them to be used in further wide ranging applications in markets which are driven by specific material requirements.

However, new products are also under development in this market segment alongside these – often familiar – applications, For example, the first projects using “high performance SMC” in the aerospace industry and other high-tech applications are currently in progress, although the quantities involved are not yet important.

5.2 Open mould / Open processes

“Open processes” – hand lay-up and spray-up – continue to be the second largest segment in the European GRP market with total production of 238,000 tonnes. The segment’s trend of comparatively weak growth over recent years continues and is under one percent in 2017. The larger of the two segments – hand lay-up – is stagnating.

The business is characterised by a large number of small companies with few employees and often individual orders. It has a relatively low level of automation. However, there are certainly also companies in this segment which achieve high production volumes thanks to state-of-the-art equipment and a strong workforce.

There are several hundred companies in each of the major European countries which supply various application industries with large and/or complex components or in fairly low numbers. Typical products include housings for wind turbines, swimming pools, boat hulls or attachments, add-on components for special vehicles, prototypes and moulds. Parts using these materials are also found in the construction/infrastructure sectors, e.g. in facades.

The relatively weak growth of this market segment is partly due to substitution effects using other closed processes. However, it is also rooted in a powerful trend towards outsourcing the production of these components to non-European countries. Despite the relatively weak growth in this segment of the GRP industry, the special requirements of products which can only be manufactured using hand lay-up or spray-up

ensure that there will always be a place for these processes in the market, even in Europe.

5.3 RTM

The segment of components manufactured using the RTM (resin transfer moulding) process has continued its trend of stronger than average growth. Expanding at a rate of nearly 3.5 %, it now produces a total of 146,000 tonnes. As in previous years, this category includes all components manufactured using a closed mould. High-tech opportunities for enhancing RTM process technologies (automation capacity, use of different fibres and matrix materials, adjustment of cycle time, etc.) and landmark projects, such as the production of structural components for the BMW i3, have led a large number of companies and research institutes to invest heavily in identifying new applications and refinements. Today, many versions of these production technologies have already reached the market. RTM components can also be manufactured in larger series but it is difficult to reduce cycle times compared to other processes. Applications include vehicle construction, housings for wind turbines, boat and ship building as well as the sport and leisure sector.

The quantities stated here are essentially limited to “traditional” RTM processes and do not include GRP manufactured using the “infusion process”. It is not yet possible to obtain accurate European production figures for this segment but it can be assumed to be in the range of approx. 300,000 tonnes. Around half of this quite large amount is used in the construction of wind turbines. The marine sector is also very important to the industry.

5.4 Continuous Processing

The production of GRP components using continuous processing grew by 5 % in 2017 – the strongest growth of any sector. This continues the positive trend of recent years. Total production volume is now in the region of 146,000 tonnes.

The larger market segment for the production of flat panels grew by 4.5 % to 93,000 tonnes. These products have been used in vehicles for many years, primarily in truck side panels, caravan superstructures or the conversion of commercial vehicles. They are supplemented by applications in the facade sector. However, innovations, such as the production of skis, wakeboards or longboards, are also an important driver in the segment which continues to be dominated by a few large manufacturers.

The market for GRP pultrusion profiles has the strongest growth rate (6 %) in the European GRP industry and a production volume of 53,000 tonnes. Since the beginning of 2017, the industry has become noticeably more interested in pultrusion, in particular. This is now being reflected in production volume data. Its growth is also in line with forecasts based on other studies which predict the global pultrusion industry is set to grow by just over 5 % this year. The largest applications in the segment, each with an approx. 20 % share of the market for pultrusion components, are the consumer/private sector and the construction industry.
Like other composites and GRP market segments, the pultrusion industry is very fragmented. There are probably around 350 pultruders world-wide although the ten largest companies share approx. 40 % of the market. The largest growth area is currently the market for window profiles and reinforcement bars. However, there are also new uses in the transport sector.

Typical applications for GRP profiles currently include, e.g. the production of bridge elements, support or cable duct systems, railings, steps in plant construction and certain areas of the transport industry. They are also used in the consumer/private sector in ladders, device sticks or fishing rods. In addition, pultrusion elements can be found in antenna systems, window frames and fences.
For a number of years, companies have been increasing their investment in developing techniques to optimise pultrusion processes.
In some cases, new opportunities are being hindered by legal regulations. Differences in national approval procedures and a lack of standardisation have slowed the adoption of series produced GRP composites in bridge construction, for example. Although bridges made from GRP are now standard in the Netherlands, they are still

a rarity in Germany. The continuous processing segments are characterised by a relatively high level of automation. However, the processes used by the relatively few manufacturers operating in this sector are adapted very specifically to the requirements of the individual companies and are overwhelmingly in-house developments.

5.5 Pipes and tanks

After last year's stagnation in production volume, the GRP market segment of pipes and tanks manufactured using centrifugal casting or filament winding processes is the only area of European GRP to decline this year. The total volume fell by 2 % to 145,000 tonnes. The market is dominated by a few large manufacturers not least because of the relatively high throughput quantities per order – at least in terms of the GRP industry.

GRP pipes and tanks are principally used in plant construction and public/private pipelines as well as by customers in the oil/gas and chemicals industries. The chemicals industry, in particular, is currently launching a large number of reinvestment projects although any potential boost in demand here will only be felt in years to come. However, material substitutions by and of reinforced and unreinforced plastics or even metal systems are not uncommon. This shows that there is an element of uncertainty in this area. Generally, the potential of the pipe market, for example, is enormous because GRP products only account for around 3 - 5 % of the market for large diameter pipes.

Legal regulations – regarding the use and acceptability of specific materials –also play a key role in some major customer sectors, such as pipes for drinking water.

Although standardisation and approvals from regulatory authorities offer opportunities to open up new markets there is also the risk that regulatory changes could close existing markets. There is currently a very strong trend towards greater regulation and standardisation for applications in the segment. This will also create challenges that the companies involved will have to face on an international level.

The European market for pipes and tanks is relatively small compared with those of some Central European and Middle Eastern countries (Turkey, Saudi Arabia) where the majority of GRP production is used for these products.

5.6 GMT/LFT

GMT, LFT and continuous fibre reinforced thermoplastics are the only thermoplastic materials included in this GRP market report. Their material properties, applications and, in some cases, processing methods are similar to those of long and continuous fibre reinforced thermosetting materials so it is reasonable to consider both these areas together. Materials with short glass fibre reinforcement (< 2 mm) differ significantly from the materials considered in this report in terms of the influence of reinforcement on material properties and (load-specific) alignment.

In 2017, the markets for glass mat reinforced thermoplastics (GMT) and long fibre reinforced thermoplastics (LFT) have continued their above average growth at a rate of 3.6 %, although this is slightly slower than last year. The trend of recent years means that the market share of GMT/LFT products in relation to the total GRP market has risen from 5 % in 2000 to 13 % today (see Fig. 4). The total production of 145,000 tonnes in the segment is split between LFT and GMT in a ratio of around 2:1 with the proportion of LFT rising. These data also include continuous fibre reinforced materials such as organosheets and tapes.

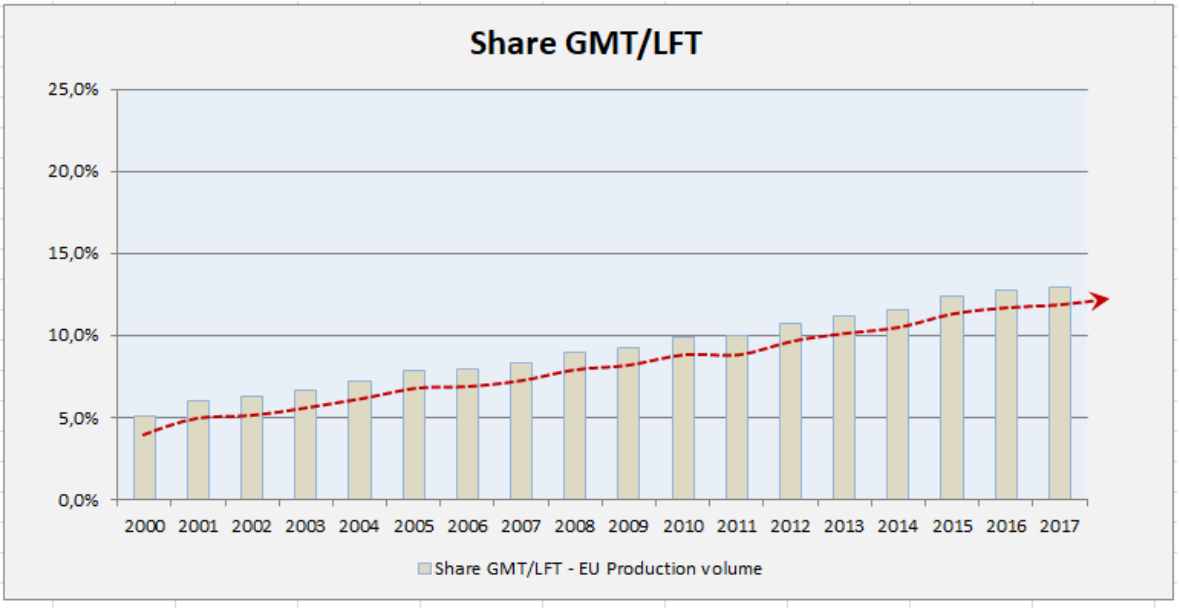


Figure 4: Growth in the market for GMT/LFT as a share of total European GRP production volume

The market share of GMT/LFT has been growing steadily for many years. Demand for these thermoplastics has been driven principally by projects in the automobile in-

dustry. Thermoplastic materials have a number of special properties in terms of ease of processing/cycle times and recyclability as well as combining well with other materials. This often makes them the material of choice. The pressing and injection moulding techniques for manufacturing/processing components are well-understood in the industry and also used for other materials. In principle they can even be used for large series production of components in the range 100,000+. Typically these include products for underbody protection, bumpers, instrument panels or seat structures.

This segment also has great potential due to the possibilities for enhancing and optimising processing methods and materials. For example, a combination of forming and back moulding processes is offering promising results both in terms of material properties and processability.

6 Application industries at a glance

Despite the differing trends observed in the markets for the various manufacturing processes, the proportions of GRP used by the major application industries in Europe remain the same as last year. The transport and construction sectors each consume one third of total production. Other application industries include the electro/electronics sector and the sport and leisure segment (see Fig. 5).

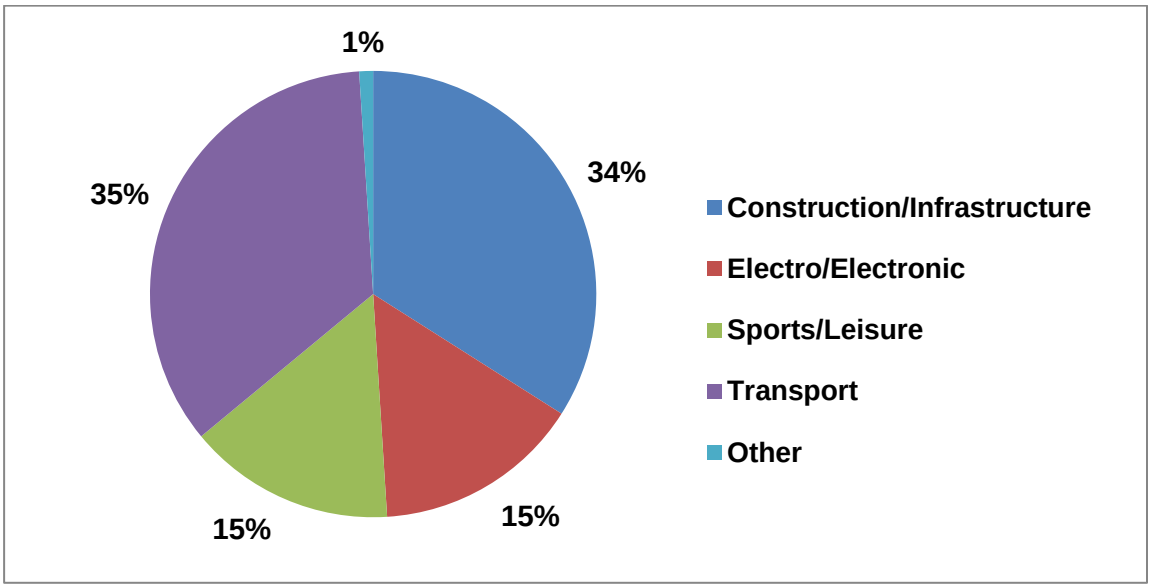


Figure 5: GRP production in Europe by application industry (year: 2017)

7 Short glass fibre reinforced thermoplastics

As already mentioned, there are some clear differences between the material properties of short glass fibre reinforced thermoplastics and long or continuous fibre reinforced systems. However, these important materials are still composites – not least because they are plastics reinforced with fibres. The glass fibres make these materials much stronger than their non-reinforced equivalents. Above all, they have a positive influence on the elastic modulus and rigidity of the materials. As the fibre length increases, the rigidity and impact strength increase as well. At approx. 1.36 million tonnes, the European market for thermoplastic, glass fibre reinforced compounds in 2016 *(Source: AMAC)* was somewhat larger than the observed GRP market for thermosetting materials plus GMT/LFT during the same period. With growth of 5 % in 2016, the trend slowed slightly compared to 2015 but still outperformed the overall GRP market. When GRP components manufactured using the infusion process – not previously included in the GRP figures – are added to the total, the markets for thermosetting and thermoplastic composites are roughly equal in size.

8 GRP production in 2017 by country

Growth was recorded in all the European countries included in this report apart from those in Scandinavia where a relatively small production volume stagnated. Growth is relatively similar in most of these countries at approx. 1-3 %. In contrast to the past decade, the European GRP production volume trend now appears to be consolidating. The regional markets are stable and no major declines were reported.

Germany remains the largest GRP and composites market in Europe (see Fig. 6 and 7) producing a total volume of 226,000 tonnes and recording slightly above-average growth of 3 %. When other composite materials (short fibre reinforced thermoplastics, carbon fibre and natural fibre reinforced plastics) are included in the data, it becomes clear that Germany is a significantly larger composites producer than any of the other countries considered here.

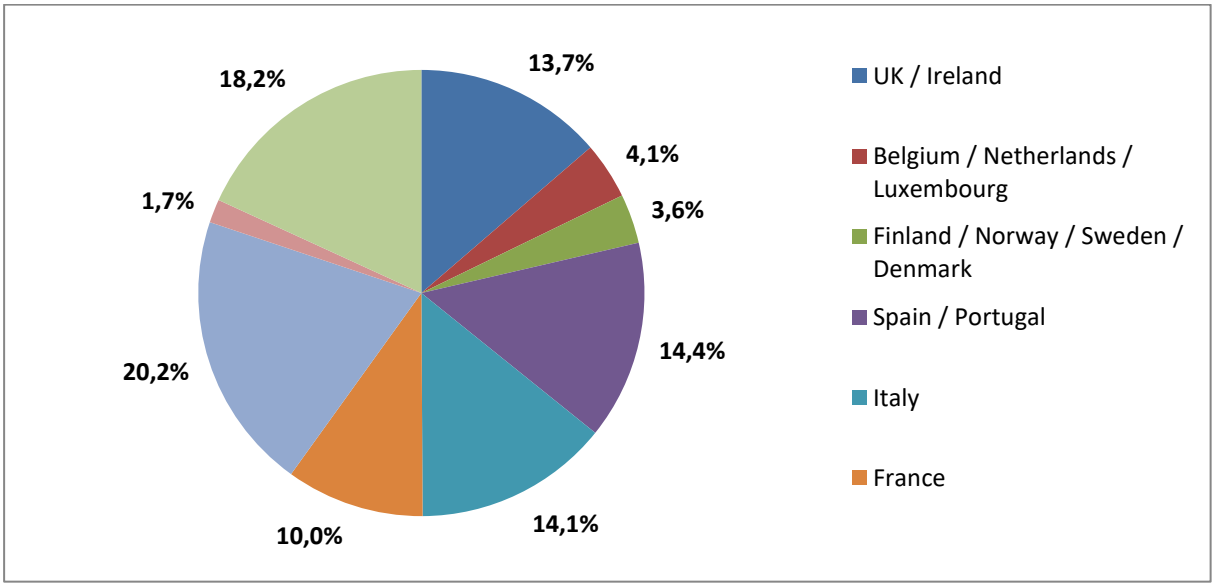


Figure 6: Percentage distribution of European GRP production by country (Date: 2017)

As the general economic recovery continues in Southern European countries, GRP markets in Italy, Spain/Portugal and France are also growing: to 158,000 tonnes in Italy, 161,000 tonnes in Spain/Portugal and 112,000 in France. Although still below the absolute level they achieved in the years before the economic and financial crisis,

they are stabilising at a relatively high level. For example, the automotive industry consumes around one-third of composites in France and is the country's largest consumer – as it is in Germany – followed by the construction industry which uses more than 20 % of the total. The construction industry was and remains one of the central pillars of the composites market, especially in Southern Europe.

The UK/Ireland are also important players in the composites market with a total volume of 153,000 tonnes. As last year, the two countries have achieved a moderate level of growth.

The Benelux countries, Scandinavia and Austria/Switzerland are smaller volume markets in the GRP sector and either stable or growing slightly: Belgium/Netherlands/Luxemburg have grown to 46,000 tonnes, Austria/Switzerland to 19,000 tonnes and Denmark/Sweden/Norway/Finland are steady at 40,000 tonnes.

Market data has been available for Turkey since 2011 and is stated separately. This enables us to continue showing a consistent, long term trend for the GRP market (see Fig. 7). The strong growth reported last year continues. The sector is expected to grow by 5% to a total of 280,000 tonnes in 2017 according to the Turkish composites association TCMA. Turkish GRP production therefore remains higher than in any other European country. The applications differ from those in the other countries included in this report: 60 % of production volume is used in the construction sector and manufacturing pipes and tanks. Pipes and tanks made using the centrifugal casting and filament winding processes account for around 35 % of the Turkish market – almost three times as much as in other European countries. The automotive and transport sectors make up approx. 20 % of the Turkish market.

	2014	2015	2016	2017
	kt	kt	kt	kt
UK / Ireland	146	150	152	153
Belgium / Netherlands / Luxembourg	43	44	45	46
Finland / Norway / Sweden / Denmark	42	39	40	40
Spain / Portugal	154	156	158	161
Italy	148	150	154	158
France	108	108	110	112
Germany	200	212	220	226
Austria / Switzerland	18	18	18	19
Eastern Europe*	184	192	199	203
Sum:	**1.043**	**1.069**	**1.096**	**1.118**
Turkey**	245	245	265	280

Figure 7: GRP production volumes in Europe – and Turkey – itemised by country/group of countries (kt = kilo-tonnes / 2017 = estimated / Eastern Europe* = Poland, Czech Republic, Hungary, Romania, Serbia, Croatia, Macedonia, Latvia, Lithuania, Slovakia and Slovenia / Turkey = Source: TCMA)**

9 Other composite materials

Although current media reports and presentations at many conventions and trade fairs may create a different impression, GRP continues to be the largest material group in the composites industry by some distance. Glass fibres are used for reinforcement in over 95% of the total volume of composites (short and long fibres, rovings, woven fabrics, mats …).

Of the over 10 million tonnes of composites manufactured globally in 2016 *(Source: JEC Composites),* 2.8 million tonnes were glass fibre reinforced plastics produced in Europe (Date: 2016). Of these, the GRP products studied in detail in this report accounted for 1.096 million tonnes and short fibre reinforced thermoplastics for 1.36 million tonnes in 2016. This does not include the quantity of GRP produced using infusion processes which can be assumed to be in the range of approx. 300,000 tonnes. Around half of this quite large amount is used in the construction of wind turbines. The marine sector is also very important to the industry.

Global demand for carbon fibre reinforced plastics (CRP) was estimated at 112,000 tonnes in 2017 (see the second section of this market report) and for Europe approx. 38,000 tonnes.

No further updates to market data have become available for components made from natural fibre reinforced plastics. 92,000 t of components made from NRP, mostly used in the automotive sector, were produced in the EU in 2012. Germany is by far the largest market for these products *(Source: nova-Institut GmbH)*.

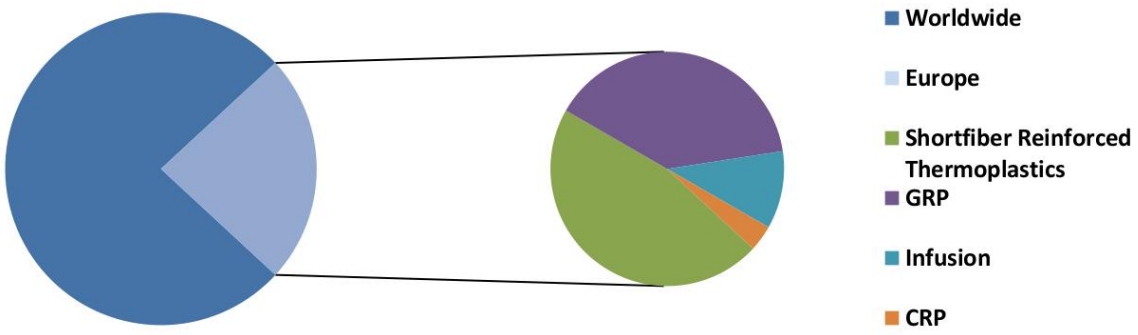


Figure 8: The global and European composites markets (Date: 2017)

10 Outlook

Often classified as futuristic lightweight materials used primarily in the automotive and aerospace industries, existing applications for composites in existing markets – some of them used for decades – are frequently overlooked. These already include many applications in large scale (automotive) series production – a segment where many observers believe that composites have yet to gain a foothold. Moreover, lightweight design is not the only advantage that composites enjoy over other construction materials. Fibre reinforced plastics have many other useful properties which make them ideal in a number of specific applications. These include outstanding corrosion-resistance, high dimensional stability, low maintenance, long service intervals,

excellent durability, load-specific structures and a high level of design freedom. Composites are thus much more than “simply” lightweight materials. In some cases, this potential has already been identified. However, many decision-makers are still unfamiliar with these products. Improving this situation is one of the most important challenges facing the industry as a whole.

Often, the full potential of the material is not achieved purely through substitution but by finding new applications. Yet this requires material-dependent planning and design from the outset. In some cases, developers, designers and architects are discovering sometimes completely new possibilities – designed to bring the best out of the material. A large number of architectural projects – including many in the Arab world – showcase the opportunities that composites offer.

This is especially true for thermoplastic material systems. These are currently enjoying a period of well above average growth which is expected to continue (combinations of formed continuous fibre-reinforced semi-finished products with over- or back moulding are still a focus of interest). Organosheets are a source of particular excitement in this segment at the moment. Reductions in the costs of continuous fibre reinforced materials/organosheets, fast cycle times and the ability to design optimised, load-specific components should ensure that industry’s interest in this type of process technology continues to burn brightly.

But even “established” processes such as pultrusion (thermoplastic pultrusion, radius pultrusion or combinations of pultrusion and pressing) and in the SMC sector (carbon fibre SMC and SMC semi-finished products with the addition of continuous fibre structures) are being refined and enhanced. The continuing automation and optimisation of industrial processes – and the associated challenges of Industry 4.0 – thus continue to be important themes.

As well as the previously outlined difficulties of establishing composites in the construction/infrastructure sector, changing requirements and developments in the area of mobility present many questions to which the industry must find answers quickly.

Composites as materials and the whole industry have enormous potential which, in many cases, has yet to be revealed. The opportunities and capabilities of this still young class of materials are starting to become apparent. The industry must accept

and overcome the many challenges it faces and work on perceived weaknesses. If it does so, the composites industry will continue along the successful path it has been following for many years. Companies in the sector can certainly look to the future with a sense of optimism. According to the latest half-yearly composites market survey in Germany (Source: Composites Germany) only 1 % expect their involvement in the sector to decline; nearly half of correspondents believe their companies will become increasingly engaged in the area of composites.

The global CF- and CC-Market 2017

CCeV and the Authors

Michael Sauer and Michael Kühnel are project architects at Carbon Composites e.V. (CCeV) and have created the CCeV Market report since 2014.

Carbon Composites e.V. (CCeV) is a network of Companies and Research institutes, which cover the entire value chain of high performance fiber composite materials. CCeV links research and business in Germany, Austria and Switzerland.

CCeV sees itself as a competence network to promote the application of fiber composite materials. The activities of the CCeV are directed towards the marketable high performance fiber composite structures product group. The focus points lie on fiber composite structures with plastic matrixes as familiar to the general public from a range of applications, as well as on fiber composite structures with ceramic matrixes with their high resistance to temperature and wear and on high performance fiber composite materials for the construction industry.

11 General

Now in its eighth issue, the composites market report from CCeV and AVK has been published yearly since 2010 and in the meantime has been attracting more and more attention and recognition, also outside the German language spectrum. With a total of 289 members (Status 09/2017) CCeV represents a significant number of companies, research institutes and other sundry organisations in the Carbon Fiber (CF) and Carbon Composite (CC) markets in Germany, Austria and Switzerland.

As part of our contribution our members prepared information and data, also with the help of current market data from among others, Lucintel [1], [2] and Acmite [3], [4], Industry Experts [5] and Visiongain [6], who were also able to check and complement said information.

12 Explanation of terms

Because some reports make no mention of how the reported growth rates are calculated, or indeed that these are sometimes mixed up, both of the most prevalent growth rates as well as their calculation, are listed below:

- **Averaged Annual Growth Rate (AAGR)** = Arithmetic Mean Return (AMR) = Arithmetic Mean from n annual growth rates (AGR):

$$AAGR(t_1, t_n) = \frac{AGR(t_1) + AGR(t_2) + \cdots + AGR(t_n)}{n} = \frac{1}{n}\sum_{i=1}^{n} AGR(t_i)$$

- **Compound Annual Growth Rate (CAGR)** = annual growth rate between n years assuming a constant growth in percentage terms:

$$CAGR(t_1, t_n) = \left(\frac{A(t_n)}{A(t_1)}\right)^{\frac{1}{n}} - 1 \quad \leftrightarrow \quad A(t_n) = A(t_1)(1 + CAGR)^n$$

This market report calculates growth rates exclusively on the basis of the CAGR as this better represents exponential growth rate relationships when we have constant market growth rates. The represented trend lines in the following diagrams are based on exponential curves also for this reason.

13 The global Carbon Fibre Market

13.1 Development of the global CF-Demand

The global demand for carbon fibres (CF) for the year 2016 stands at around 63,5k tons and corresponds quite accurately to the expectations of the previous year's report, with a growth of 9,8% on the previous year (58k tons). This then results in a yearly growth rate (CAGR) of around 11.5%, since the year 2010.

The total worldwide turnover for CF in 2016 amounts to approximately 2.34 billion US$, corresponding to a growth of 8,7% with reference to the previous year.

A strong annual growth rate of over 15% with a characteristic lateral movement in the years from 2009-2015 resulted in the wake of the global financial crisis in 2009. Since then the annual growth rate has been sitting steadily above 9% and rose from a previous 9,4% in 2015 to 9,8% in 2016. This confirms a positive outlook for the following years, with the current expectation that the annual growth figures will plateau in the double-digit range from 10 - 13 %. With this the case, the prominent 100k ton CF demand volume mark could already be exceeded by the end of 2020.

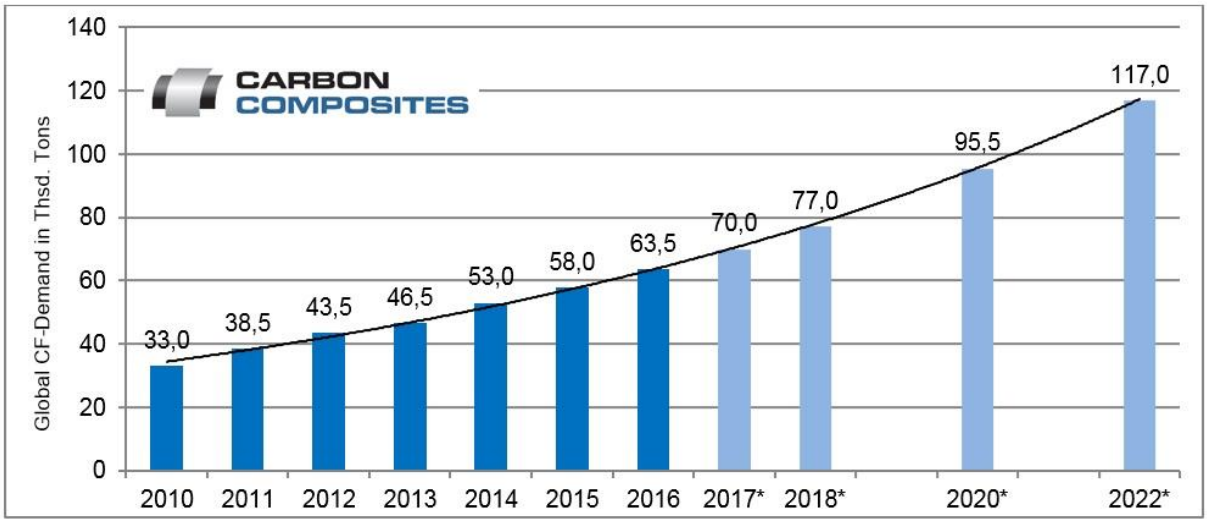


Figure 9: Development of global CF-Demand in Thousand Tons from 2010 until 2022 (*Estimations; 09/2017).

13.2 The global CF capacity by manufacturer

This demand is offset by a theoretical annual production capacity which is displayed in figure 10 for the 12 leading carbon fibre manufacturers. In total, production capacities of approximately 136.5k t/a carbon fibres based on polyacrylonitrile (PAN) and Pitch were available in 2016. Furthermore, based on the current demand of approximately 63,5k t/a, there exists a clear overcapacity, which would lead to the assumption that the current CF production would be working at a theoretical occupancy rate of only 46.5%. However, it must also be considered that, in reality, the capacities cited in the quoted sources are more than likely not achievable due to the lower overall plant efficiency (increased downtime, reduced plant availability, increased discard etc.) and the worldwide demand for CF production cannot be completely apprehended and therefore will tend to be higher. Thus, it is to be assumed, that the real utilisation rates are distinctly higher. In addition, the current strong willingness of the CF manufacturers to invest, reflects on one hand their great confidence in a market which is still growing strongly in the future, and on the other hand suggests that the utilisation quotes are significantly higher and evidently a cost-effective business model exists. Currently, an accelerated development in demand with an annual increasing growth rate is expected. The manufacturers are now already adjusting themselves for this scenario, as indicated by the additional expansions announced and construction proposals.

For the year 2016, and since the acquisition of Zoltek in 2014, Toray continues to hold the highest share, by quite a margin, with approx. 42,6k t/a or 31.2% of the worldwide production capacity. Following in second place is SGL with 15k t/a, due to the strong expansion at Moses Lake plant (USA) in the joint venture SGL-ACF with BMW and also the SGL plant in Muir of Ord (Scotland). The manufacturers “Mitsubishi Chemical Carbon Fiber and Composites” (MCCFC) and “Toho Tenax” hold themselves also at a comparable standard. For MCCFC, the further increase is attributable to the investment in the Otake plant (Japan), whereby approx. 1,2k t/a can be achieved [7]. In addition, the overtaking of the SGL plant in Wyoming with a capacity of 1k t/a was also concluded in January 2017 (SGL deferred the capacity from Wyoming to the expanded plant in Scotland) bringing MCCFC’s annual capacity to a total of approx. 14,3k t/a [8].

In the case of Toho Tenax, it could be ascertained that the expansion stage of the US plant is now beyond previous assumptions, which would explain why an alteration up to 13.9K t/a was now made. Additionally, the Teijin Group, to whom Toho Tenax also belongs to, announced at the end of 2016 that a further 600 million US$ will be invested in several new carbon fibre lines in Greenwood County (USA) [9]. Regarding similar projects, it can be estimated that this correlates to an additional 6k t/a in production volume. The exact stage of expansion and planned opening of the new plant has however not yet been announced.

Hexcel is currently building up a new precursor and carbon fibre manufacturing line in Roussillon (France) and invests US $250 million in the facility near the Osiris Chemical Industry Platform. The target applications include Airbus A350XWB and also the aircraft engine CFM LEAP (Snecma/Safran Group). The plant should be functional at the beginning of 2018 and increases the total capacity of Hexcel to around 9,5k t/a [10].

DowAksa, the strategic partnership of the turkish fibre manufacturer AKSACA carbon fibers and the US American company Dow Chemicals Co. existing since 2012, have announced they will be investing US $1 billion to expand its carbon fibre capacity, with a plant in both the USA and Russia. This corresponds roughly to an increase in the annual production capacity of 10k tons and with that describes the threefold of the existing DowAksa manufacturing capacity [11].

As already announced in last year’s report, Hyosung would like to increase its CF capacity in Jeonju (South Korea) to 5k t/a by 2018, to 8k t/a by 2020 and to 14K t/a by 2020 [11] [12]. By doing so the company would immediately join the ranks of SGL, Toho and MCCFC. In current aerial photos, reserved construction sites can be recognised which would accommodate such a project, or at least make such a project technically possible. Up until now however, only one identifiable manufacturing line has been installed. The given sources of information deviate strongly in this case, so that only a capacity of approx. 2,5k t/a can be confirmed. As one of the target applications of the Tansome-Fiber from Hyosung, an automotive cooperation with Hyundai in the form of the cross over model Intrado (crossover/ SUV) is reported.

For the first time this year, an Indian fiber manufacturer (Kemrock Industries and Exports Ltd.) managed to be among the leading companies. Steady development provisions have led to a current production capacity of around 2,5k t/a [11]. India as a whole can be valued as an exciting future market for the fibre composite technology and for this reason further investments can be expected here in the following years.

Grouped together under “Miscellaneous” are for the most part several small Chinese manufacturers such as Dalian Xingke Carbon Fibre Co. Ltd., Yingyou Group Corp., Bluestar Fibres Co. Ltd., and Ordos Yaxin Carbon Fibre Co. Ltd. Above all, the latter company enters the scene already on a considerable scale with an existing 2k t/a and, according to indications, aim to increase to 10k t/a within the next years [4]. China proves also considerably willing to invest in the area of carbon fibre manufacturing and could possibly also introduce its collectively strong economic expansion into the CF industry in the next few years. Also worth mentioning under “Miscellaneous” is the Russian manufacturer Alabuga-Fibre LLC with an estimated capacity of 1,7k t/a [11].

Referring to the described breakdown (see figure 2), the 10 leading fibre manufacturers conceive approximately 119,5k t/a, and 87,5% of the production capacity available in the year 2017, respectively. Alone the top 5 already achieve a share of 94,6k t/a, or 69.3% of the worldwide capacity. The strong dominance of only a few producers characterises a very strong market concentration.

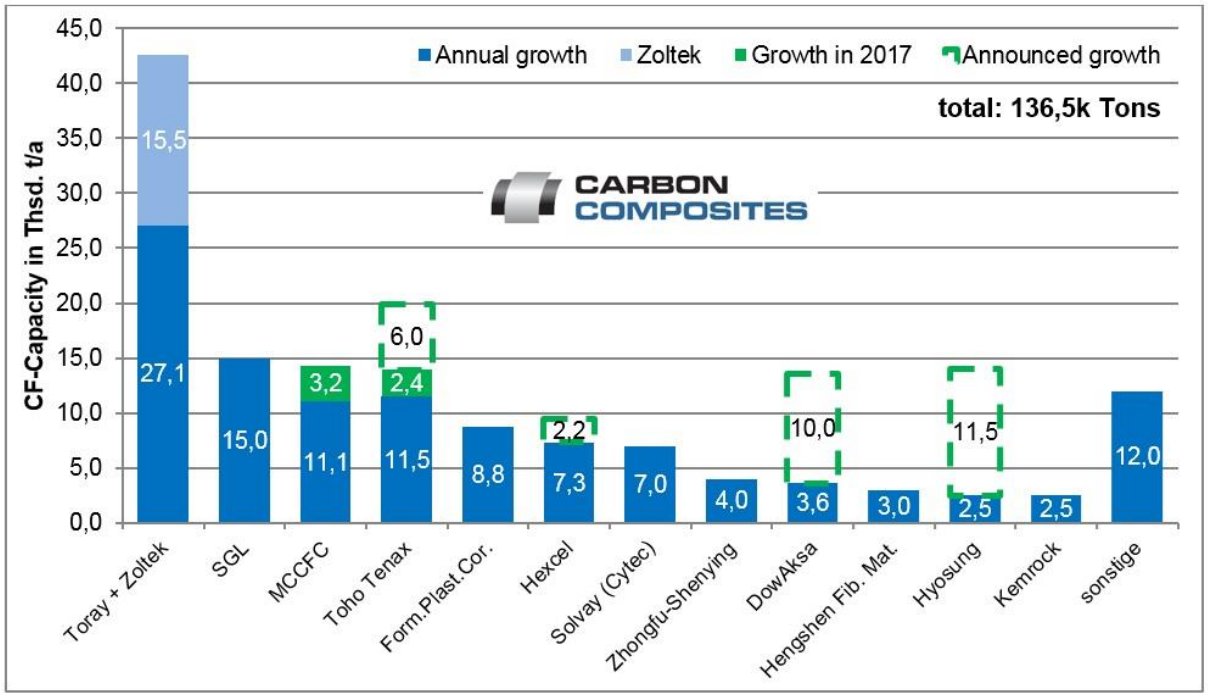


Figure 10: Theoretical, annual CF-Production capacity in Thousand Tons by manufacturer (09/2017).

13.3 CF-Demand and CF-Capacity by region

The Global annual demand for carbon fibres of approx. 63,5k tons and the global production capacity of approx. 136,5k t/a are represented in figures 3 and 4 and itemised by regions. The divisions regarding capacities can be carried out in a much more detailed manner here due to the availability of data, as the exact locations and associated capacities of the individual plants are known.

Together North America and Western Europe cover the majority of the worldwide CF-Demand at approx. 60%. Asia (including the Pacific region and China) comes to a total of about 23%, with a major share coming from China. Japan, represented as a single country, comes to 12%.

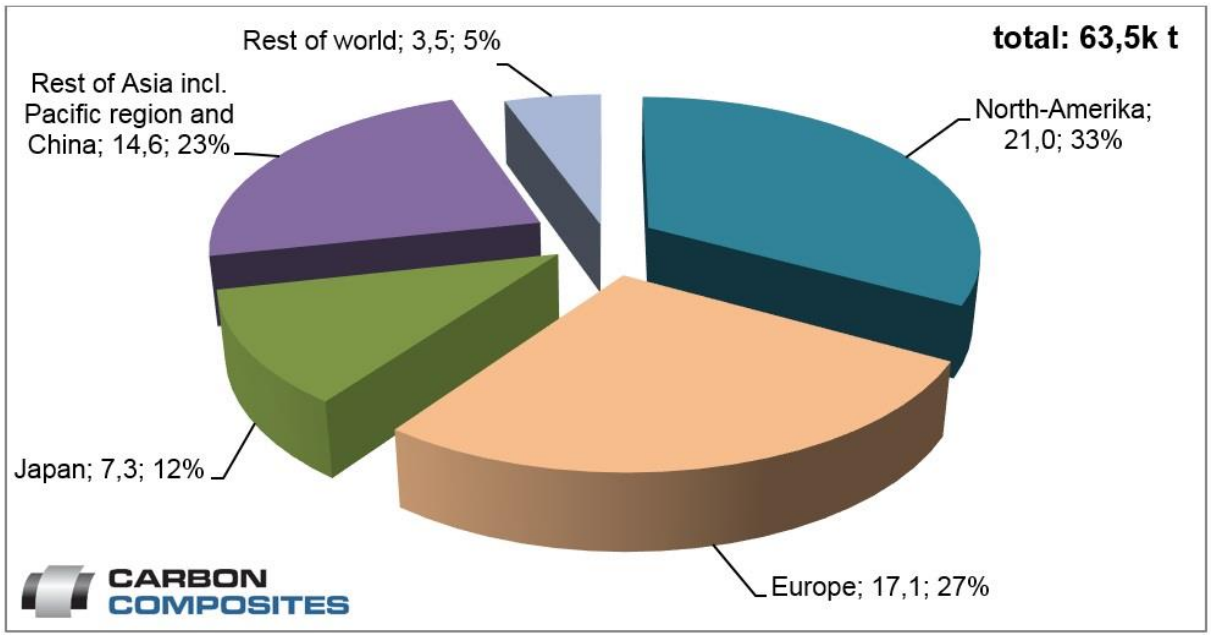


Figure 11: Global CF-Demand in Thsd. Tons by region (09/2017).

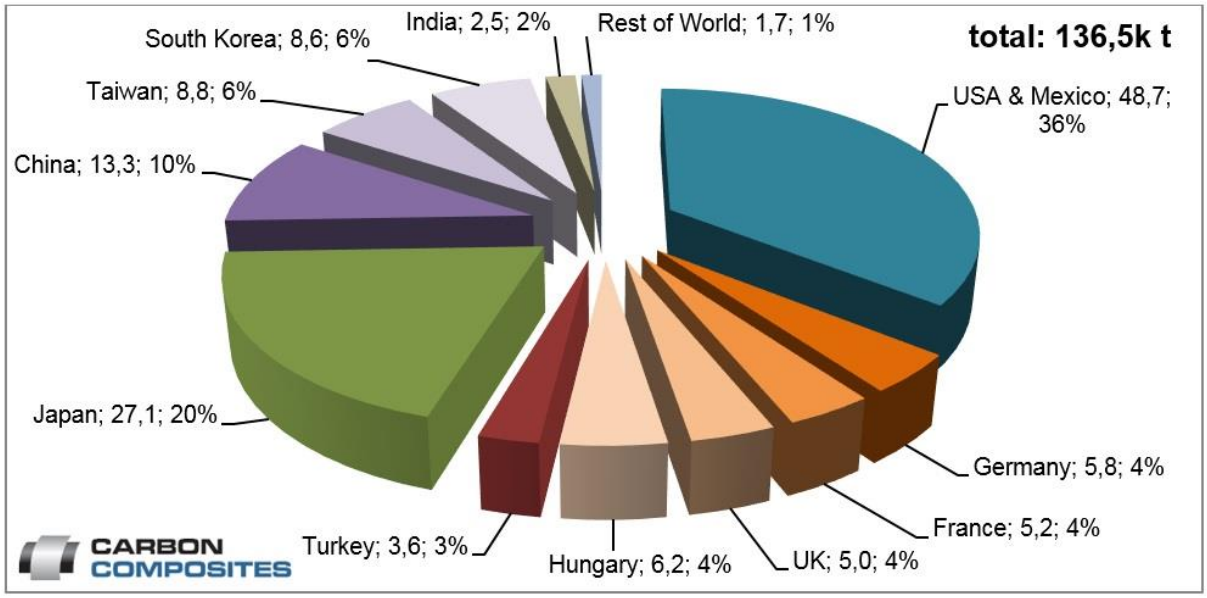


Figure 12: Theoretical, annual CF-capacity in Thsd. Tons by region (09/2017).

Regarding CF capacity, USA & Mexico are the largest single segment, followed by Japan. Together, they cover more than half of the worldwide production capacity and it is expected that this tendency will continue into the following years. The activity of Toho Tenax in the USA (2,4k t/a) together with the expansion of the MCCFC plant in Otake (Japan; 1,2k t/a), had also aided in emphasising this division between 2015 and 2016. On top of that, further large investments from Toho Tenax (Greenwood County, US $600 million [9]) and DowAksa (US $1 billion together with the invest-

ments in the new Russian factory [11]) in US locations have already been announced. It is also striking to see that Japan exhibits a significantly higher domestic manufacturing capacity (27,1k t/a, 20%) than what is currently nationally demanded (7,3k t/a, 12%). Although it is not possible to directly compare production capacity and demand by means of the given different fiber types, this large difference could be regarded as a characteristic of the Japanese market direction. The situation is exactly the opposite for the European sites and associated economic trends. While there is a comparable demand volume of around 17,1k tons (27%) compared to North America (21,0k tons, 33%), the existing production capacity is comparatively lower (about 22,2k tons, 16%). China follows in third place based on domestic capacity. Even though at present there still exist many comparatively small fiber manufacturers parallel to each other, collectively they amount to a total of 13,3k t/a and 10% of the worldwide capacity, respectively. Considering the strong protectionist shaped strategy that China exercises in other economic sectors, it can be assumed that in the following years foreign companies will either go into a strategic partnership with Chinese companies or build up their own capacities in China in order to gain market access to this large economic realm. In an overview, the Asian region, including the Pacific region, represent around 57,8k t/a and 42,3% of the worldwide production capacity, respectively.

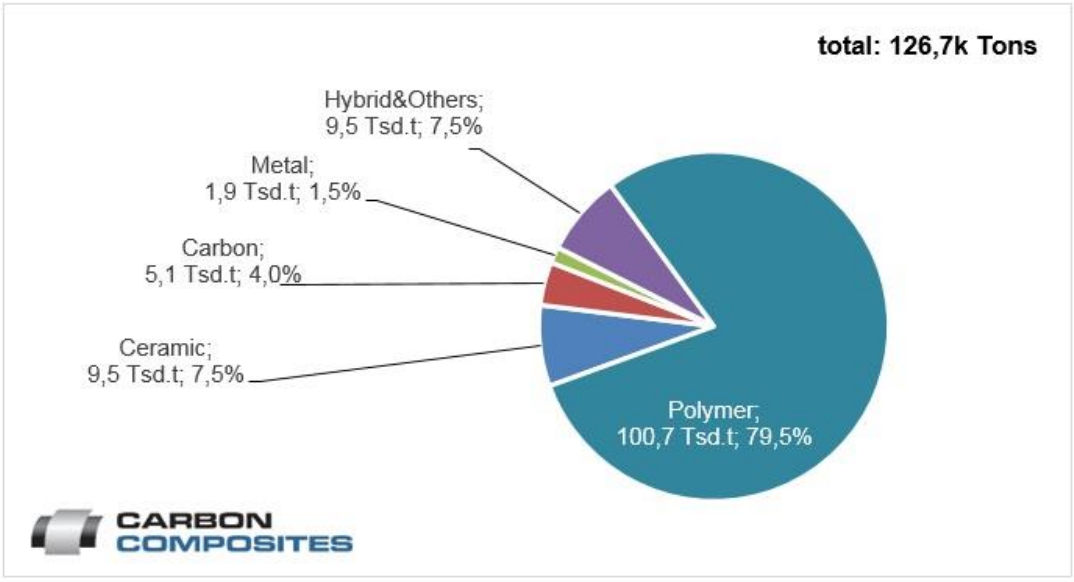
14 The global Carbon Composites Market

14.1 Distribution by matrix materials

Almost all of the carbon fibres produced are further processed into composites. In each case, the fibres are embedded in a matrix material to combine the best properties of the two diverse material classes into a single material. Along with many other advantages, carbon fibre composites have above all a particularly high potential in lightweight design. Depending on the application, various metal alloys (Metal-Matrix-Composites; MMC), ceramic materials (Ceramic-Matrix-Composites; CMC) or also Carbon (Carbon-Fibre-Reinforced Carbon; CFC) can serve as a matrix material. However, the majority of composites are assembled with a polymer matrix (carbon-fibre-reinforced polymer, CFRP). Figure 5 depicts a breakdown of carbon composites according to matrix material and is itemised according to demand volume and quantity. The largest market segment CFRP (by turnover) is again further broken down regarding the polymer matrix employed. Here a more detailed description of turnover could be shown based on data provided.

It is evident that the majority of carbon composites, based on turnover generated (approx. US $13,23 billion; 70%) as well as regarding to volumetric amount (approx. 109,6k tons; 86.5%), fall under the CFRP sector. Thermoset matrix systems dominate this market with around 71.5% (approx. US $9,46 billion). However, over the past few years, a steady increase in the proportions of thermoplastics from approx. 24% (2014), over 25% (2015) and up to a present 26,3% (2016) can be seen. All other polymer matrix materials currently only appear in a very small market volume. Although, in the future, the area of elastomers could prove to be interesting, for example for hinge-free elastic connecting elements or as form-variable adaptive structural components. Non-polymer matrix materials occupy around 20% of the whole market and with that, generate a relatively high turnover. This is mainly due to the fact that these material combinations are frequently applied to individual niche applications (e.g. aerospace) and a particularly high price is paid for such special solutions.

In summary, the year 2016 consisted of a global demand for carbon fibre composites of approx. 126,7k tons, whereby an overall turnover of US $19,31 billion was generated. Compared to the previous year (116,5k tons; US $17,9 billion), a growth of around 8,76% based on the demand volume and around 7,88% based on the turnover can be observed.



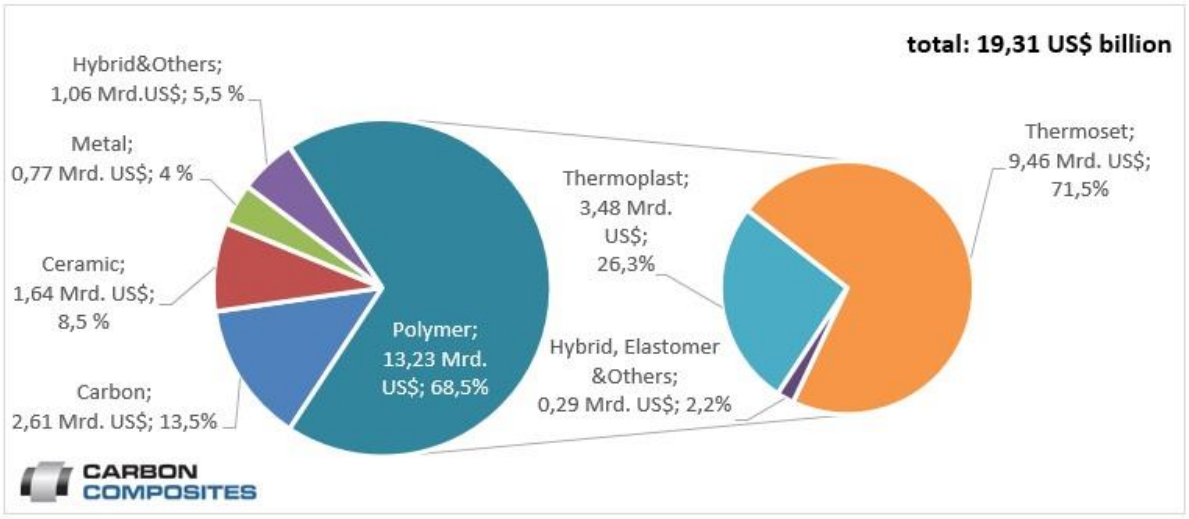


Figure 13: Distribution of the global Carbon-Composites market by matrix-materials with reference to demand (above) and turnover (below; 09/2017).

14.2 Development of the global CFRP market

As seen in figure 5, the material class CFRP currently represents the most relevant segment for the carbon composites market. This material combination, primarily based on its excellent lightweight design potential, will be considered as an essential growth engine within the industry for the next few years. Correspondingly, the global demand volume for the CFRP sector in 2016 is around 101k tons so that this year the significant benchmark of 100k tons CFRP demand volume was successfully exceeded. This corresponds to a growth of 10,99% based on the previous year (91k tons) and lies just above the predicted development. This results in annual growth rate (CAGR) of around 11,98% from the year 2010. A further positive development with double-digit growth figures in the range from 10 to 13% is also expected for the following years.

The overall worldwide turnover for CFRP in 2016 totals to approx. US $13,23 billion. This corresponds to a growth rate of approx. 14,05% compared to the previous year (US $11,6 billion).

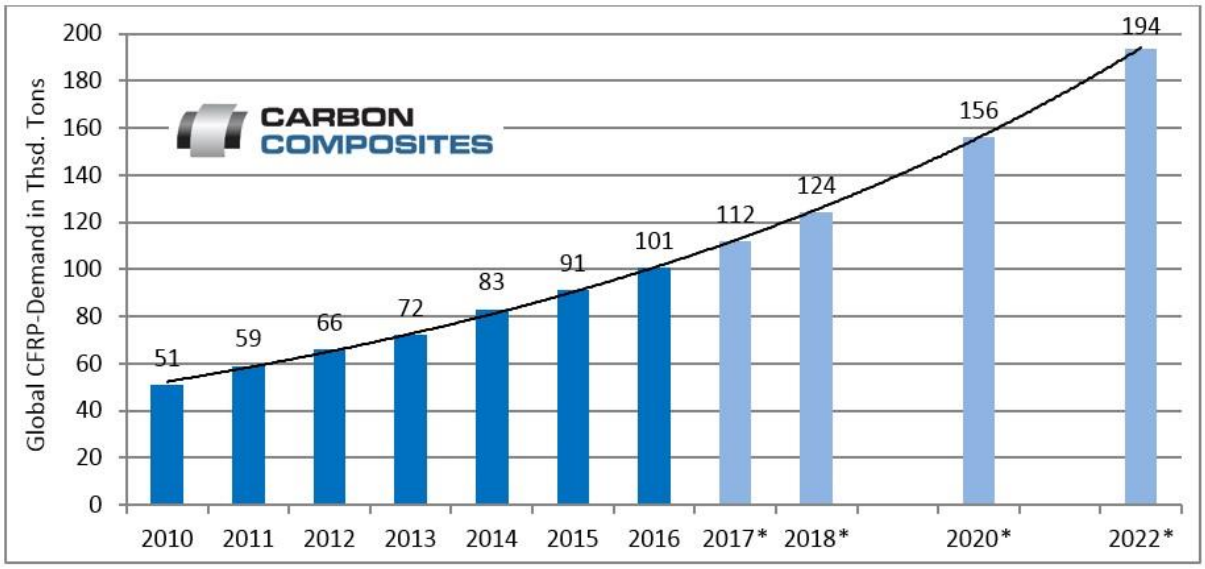


Figure 14: Development of the global CFRP-Demand in Thsd. Tons from 2010 until 2022 (*Estimation; 09/2017).

The development of the global CFRP-Demand happens to be relatively similar to the CF market (see fig. 1). This is for the most part due to the dominating portion of the CFRP within the CC industry, by which a use for the majority of the CF production is

found. Just as for the CF segment, a characteristic transverse correction movement based on the growth figures can also be observed for the CFRP region in the years following 2009, the course of which now seems to have plateaued in the double-digit range between 10% and 13%. It is also noticeable that over the last several years the growth rate for CFRP regarding turnover now lies above that of the CF segment. This difference turned out to be quite large in 2016 (14.05% and 8.7% respectively), which possibly is partly attributed to the natural market fluctuations. A more general reason for this occurrence could also be due to the strong progress of (highly automated) process technology within recent years, while the prices and profit margins for the previous carbon fiber production remained relatively constant over many years. In addition, CFRP finds itself in a less concentrated market compared to CF, that is to say, that the process volumes along with the revenues generated are spread among a considerably larger number of players. This situation creates an increased competitive pressure, which in fact narrows the profit margins of the individual competitors, but on the other hand accelerates the development of the market as a whole.

At present, it can be estimated that the ten leading CFRP manufacturers can manage the 41,32% and 41,73k tons respectively (CF comparison: 87,5% prod. cap.) of the CFRP demand volumes presented in 2016. Even the top 5 add up to approx. 36,3% and 36,66k tons respectively (CF comparison: 69,3% prod. cap.). It is, however, important at this point to note that the values of the CF segment are based on the theoretical CF production capacity based on data provided, while those for the CFK sector were determined on the basis of the demand volume. Since there exists no real correlation between capacity and demand volume due to the given overcapacity, these values cannot be directly compared with one another. Nevertheless, the CFRP market, whose structure is completely different when compared to the CF market can be outlined by its significantly lower market concentration and the considerably larger presence of competing players.

14.3 CC-Demand and –Turnover by region

The global annual demand for carbon composites of approx. 126,7k tons, along with the associated generated turnover of US $19,31 billion are depicted in figures 7 and

8 by region. Based on the given data, all Asian regions incl. the Pacific region and Japan are summarized.

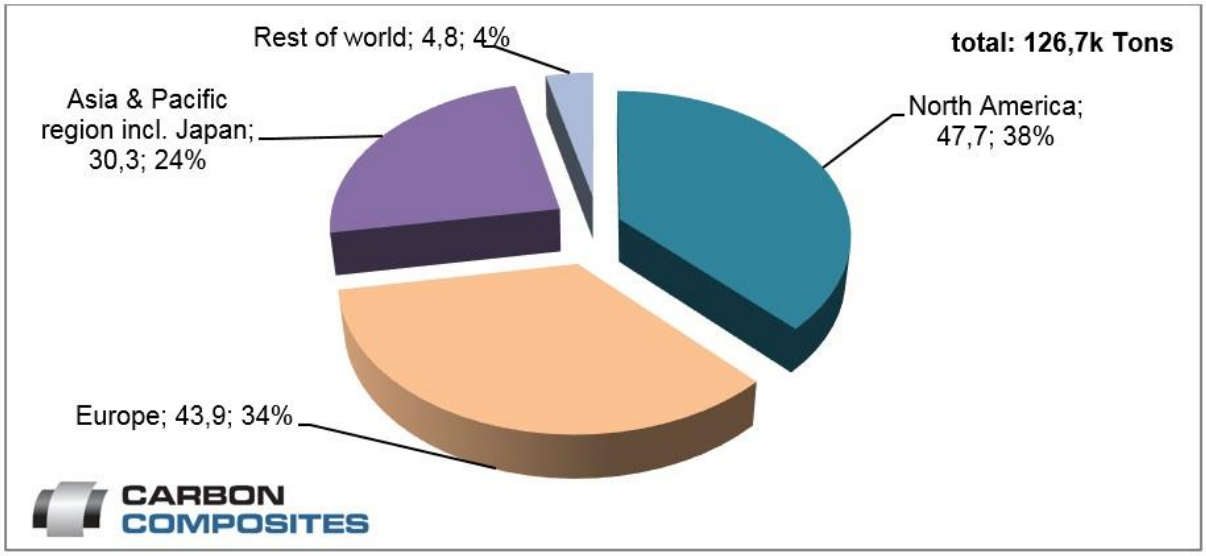


Figure 15: Global CC-Demand in Thsd. Tons by region (09/2017).

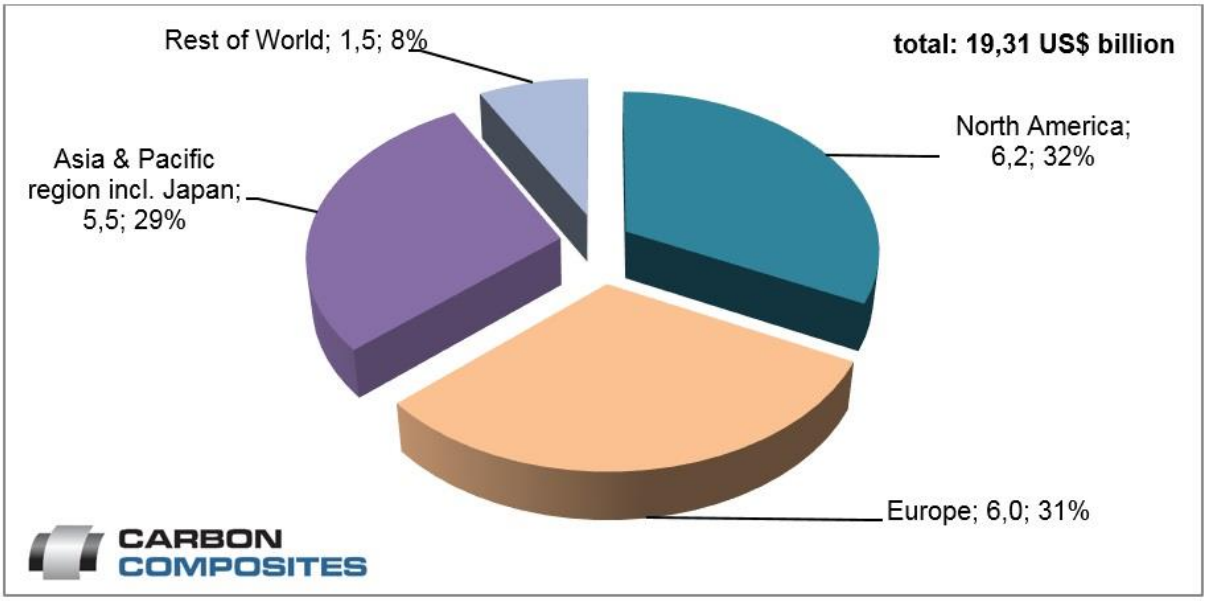


Figure 16: Global CC-Turnover in US$ billion by region (09/2017).

It can be seen that the turnover generated worldwide in the CC sector is distributed almost equally between the three regions shown. This distribution correlates quite well with the worldwide CF-Demand shown in figure 3, subdivided into regions. It can then be reasoned that almost the entire carbon fiber production will be allocated for the manufacturing of composite materials. The respective development of the CC-Demand volume thus proceeds not only with regards to the total quantity analogous

to the CF market, as the comparison between figure 1 and 6 indicates, but the regional breakdown of this demand also currently proceeds very similarly. In comparison to the previous year and referring to demand volume, a particularly strong growth rate of 13,06% (2015: 26,9k tons) for the Asian region can be determined. Other regions also boast significant growth rates of 7,67% (North America; 2015: 44,3k tons) and 7,8% (Western Europe; 2015: 40.8k tons). For the rest of the world, there is a smaller growth rate of roughly 4,2% (2015: 4,6k tons). As already annotated in the interpretation of figures 3 and 4, it is assumed that this development is attributed to the Asian economic structure within the entire carbon market. At the same time, large CF production capacities are already being established in the respective countries in 2016, of which clearly exceed their own requirements. Accordingly, it is assumed that the domestic demand for composite materials on this basis only increases somewhat over time. On top of that comes strong government programs, such as activities in South Korea (economic hub of Northeast Asia), and especially those connected with the announced investments from Hyosung. Furthermore, it can also be assumed that an economic protectionist strategy could lead the subsequent manufacturing industry to settle domestically or to fix it by means of strategic partnerships in Asian locations. Therefore, given the current status, this trend is expected to continue further into the following years.

14.4 CC-Demand and –Turnover by application

The global annual demand for carbon composites of approx. 126,7k tons, along with the associated generated turnover of US $19,31 billion are depicted in figures 9 and 10 by application areas.

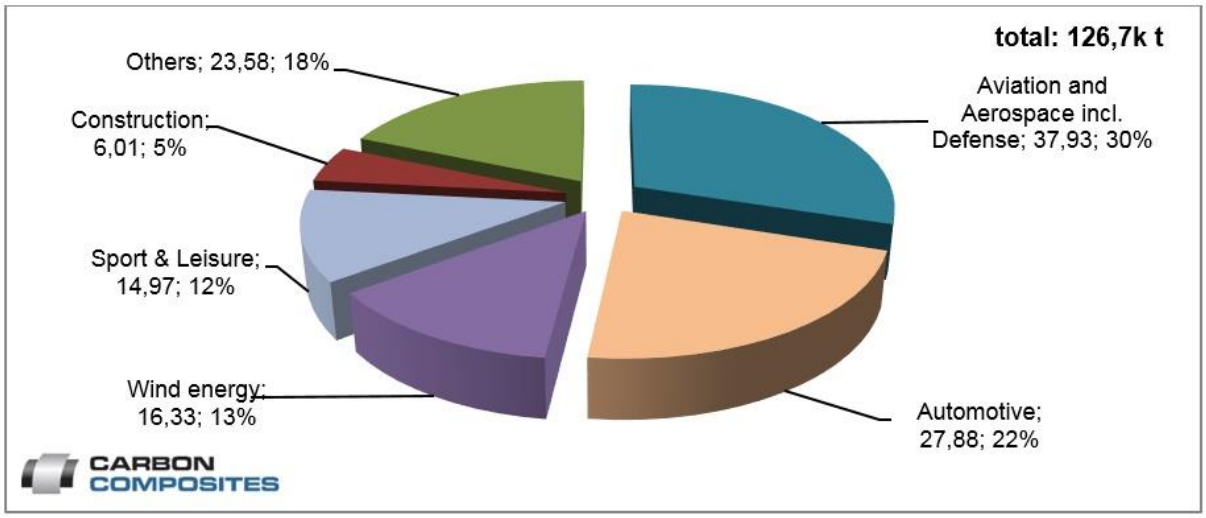


Figure 17: Global CC-Demand in Thsd. Tons by application field (09/2017).

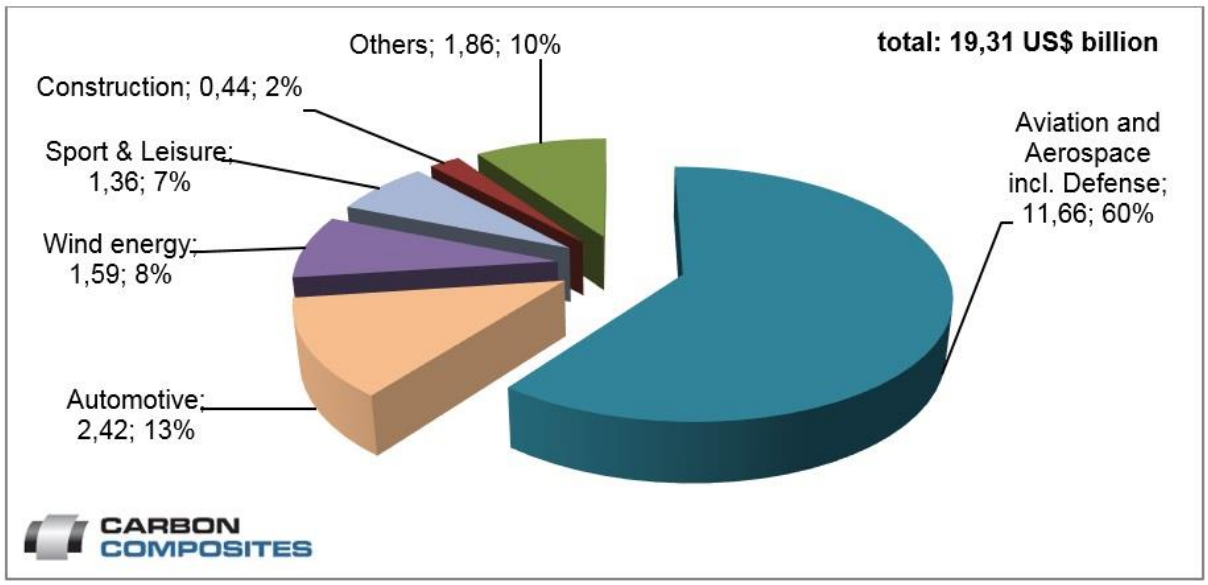


Figure 18: Global CC-Turnover in Thsd. Tons by application field (09/2017).

Here it is clear that the aviation and aerospace sector, as in previous years, currently represents the most significant market segment in terms of turnover. Even though the requested demand volume (37,93k tons; 30%) only just lies above the demand vol-

ume of the automotive sector (27,88k tons; 22%), the turnover, which is roughly 60% of the total worldwide turnover for the CC market, is considerably higher. This is due to the higher quality expectations and approval costs, which lead to comparably higher prices per kilo. The establishment of the A350XWB, A380, B787 and B777X programs in the commercial aviation sector is a major contributor to this development, with growth rates of around 8% between 2015 and 2016 recorded [6] [13] [14]. Furthermore, there is also currently activities in the area of carrier rockets in the space travel segment. Both the Falcon9 (SpaceX) as well as Ariane 6 (ESA/ASL) will be designed in large proportions with the aid of CC [15]. The CFRP-boosters of the Ariane 6 for example are being developed and subsequently built by MT Aerospace (Augsburg, Germany) and AVIO (Collefero, Italy) [16]. There are also increasing efforts in the Asian region to expand the national aerospace segment considerably. In addition to new large-scale activities in India, the development in China is particularly interesting. In the commercial aviation sector, the Comac C919, which successfully conducted its maiden flight in Mai 2017, should act as a direct competitor to Airbus A320 and Boeing B737. Aside from this, the space travel program is also being strongly propelled forward by the construction of China’s own space station for the time succeeding the “closure” of the ISS.

he automotive sector makes up the second largest segment for the demand volume and turnover. Here, the joint venture between BMW and SGL take on a leading role. Within the scope of the i-series project, it has already been successfully demonstrated that the use of carbon fibre composites in automotive serial applications is possible, whereby the achieved high lightweight design potential synergises very well with the emerging trend of E-mobility. Approximately 24.000 units of the i3 and 5500 i8 were sold in 2015, for 2018 a sell-off of approx. 33.000 i3 is expected [17]. It can be anticipated that by 2021, the i-Portfolio will be expanded to the new iNext model, whose format up until now strongly resembles that of the BMW 5er series and is expected to close the existing gap for to an electric car. Electric or hybrid versions of the X3 and Mini models are also expected to be released onto the market, with the latter model ready by 2019. While no complete composite structural vehicle body is planned at this stage, it is however probable from today's point of view that the experience from the i-series projects will also be transferred over to individual assemblies.

Such a transfer has already been successfully performed in the 7er series by BMW through the skillfull combination of metal and CFRP called “Carbon Core Technology”, whereby 64.000 saled units have already been achieved in 2016 and a 100k order of magnitude is conceivable on long-term [18]. An exciting development is also expected for Volvo in the upcoming years. For their XC90, S90 and V90 models, a composite transverse-leaf spring will be put into service. Through collaboration between Benteler-SGL and Henkel, an innovative high-speed RTM process based on the two component polyurethane resin system Loctite MAX2 has been developed for this specific application [19]. At present, the spring is implemented with glass fibre reinforcement. Although, a transferability to carbon fibre reinforced structures seems possible and offers the potential for a high-volume application in the automotive industry with over 500.000 units per year from 2018. In addition, the activities of Hyundai in collaboration with their Intrado model (Crossover/SUV) are of particular interest for the ongoing development in the following years. The associated concept car was already presented in 2014 and exhibits a significant amount of CFRP, whereby large assemblies are to be implemented in a braiding process with the help of the Axontex system. The assigned carbon fibres will be coming from Hyosung (Tansome fiber) out of South Korea [20] [21]. In light of the announced investments, an earlier entry into the market seems possible here. In summary, a growth rate of 12,5% (turnover related) and 9,4% (based on demand volume) could be determined for the automotive sector between the years 2015 and 2016.

The wind energy sector also experienced a strong upswing of around 11,5% (turnover) and 12,7% (demand volume) with reference to the previous year. This development is presumably due to the further intensified ambitions of energy transition, and the growing interest in large wind power plants. Particularly in Europe and Asia there is a growing willingness towards the comprehensive implementation of climate change objectives, and here renewable energies will always play an important role in the future. Virtually all of the latest generation of large design wind power models implement significant volumes of carbon fiber composites, especially in the tension- and compression-chords.

Based on the given data sets, not all fields of application can be represented in detail and as a result the “Medical Technology" sector (primarily prostheses and X-ray-boards) has been intergraded into the category "Other".

Figure 11 shows a forecast of CC demand worldwide in thousands of tons by 2022, broken down by field of application. Assuming that the growth within the automotive sectors will continue to be relatively high, the corresponding demand of the aviation and aerospace sector (incl. defence) will be exceeded by the end of 2020. In this scenario, approximately 30% of the global demand of approximately 239k tons is attributable to the automotive sector. The three following fields of application exhibit very similar growth potential and maintain their fundamental allocation. The “Sports & Leisure” and “Construction” fields show a somewhat weaker growth here and must provide new innovations for a higher evaluation. It should be noted here that, in principle, very large application potentials with comparatively very large numbers and quantity are available, especially in the construction sector. Therefore, as soon as only a few application points are passed through, the conservative benchmark shown here can be clearly exceeded.

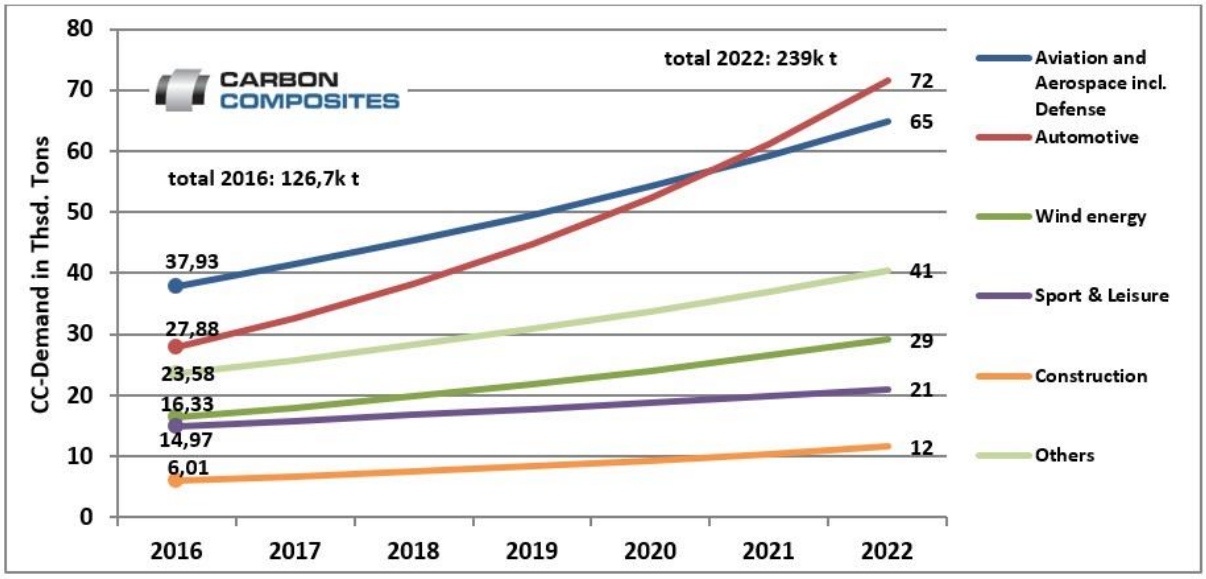


Figure 19: Global CC-Demand in Thsd. Tons by application field (09/2017).

If you were to divide the worldwide turnover of CFRP generated in 2016 of US $19,31 billion by the worldwide CC demand in 2016 of 126,7k tons, you would re-

ceive an “imaginary” weight-based CC price – averaged across all sectors and applications – of 152 US$/kg. A corresponding calculation alone for the CFRP sector (turnover: US $13,23 billion, demand: 101k tons) gives a sector average of 131 US$/kg.

ven if the significance of these figures is only small, it is nevertheless still possible to obtain an outline of the market overall. The best cross-industry kilo-price available can therefore only be within a frequency distribution around this average value. Using the data presented in figures 9 and 10, the following sector-specific values for the CC market can be determined:

Aviation and Aerospace incl. Defence:	307 US$/kg	Wind Energy:	97 US$/kg
Automotive:	87 US$/kg	Sport & Leisure:	91 US$/kg

As expected, the aviation and aerospace sector depicts the high-price segment. On the other hand, the average value for automotive applications is the lowest and is still surprisingly high given the high prevailing price pressure. The average value obtained can partly be explained by very high-priced applications in the luxury sector. For the wind energy, it must be pointed out that the price shown here only depicts the CF portion in the wind rotor blade (CF-belts), i.e. it entails only a small specific weight of the entire system. The stated price for the sport & leisure section is within the expectation horizon of the authors. This consists of approximately equal parts of high-priced applications (above all golf), including the corresponding market impacts of image-rich manufacturers, and cost-specific low-cost fields of applications (hockey sticks, skis, bicycles). Although the average values shown are not fully reliable, they give an idea for the price segment of the respective sector, and shows that their development is something to be followed in the coming years. Compared to the previous year, the sector averages, with the exception of the automotive sector (previous year: 86 US$/ kg), have declined slightly.

15 Trends and Outlook

15.1 Expected development of the market

The global market for carbon fibers and carbon composites has shown a strong and stable growth since 2009. This progress has continued into 2016 across the individual market sectors and applications, and in doing so, was able to exceed the significant milestone of 100k tons for the CFRP demand volume. In the coming years, it is expected for the CF market as well as for the CFRP market, which represents the largest sector within the CC segment, to achieve average annual growth rates in the range between 10% and 13%. The necessary quantities required for this in 2016 were around 63,5k tons for CF, approx. 101k tons for CFRP and approx. 126,7k tons for CC. This generated a turnover amounting to approx. US $2,34 billion (CF), approx. US $13,23 billion (CFRP) and approx. US $19,31 (CC). In view of the development of the turnover, growth figures comparable to the demand volume are expected in the next few years. These positive expectations will be driven along the entire supply chain of the carbon fiber by various factors:

- Continued large investment by the carbon fiber manufacturers for the expansion of existing plants and the opening of new sites
- National and international politically arranged promotional tools
- Strong growth of material understanding and process know-how
- Cooperative and strategic partnerships between manufacturers, processors, and end-users

The profitability of the existing business model was further underpinned in the past few years through large planned investment measures of the fiber manufacturers and also through the steady new announcements in 2016. The activities and notifications for the American sites (MCCFC, Toho Tenax, DowAksa) have been particularly high within this year. Almost all of the leading fiber producers are currently pursuing a strong expansion strategy concerning their capacities. It can be assumed that this constant procedure reflects not only the strong confidence in the ongoing growth of the industry, but also underlines the current high profitability of the strongly focused market.

Moreover, the industry will continue to be supported by intensive support measures. The Institute for Advanced Composites Manufacturing Innovation (IACMI, USA), which is founded in 2015, is a particularly strong source of strength, supported by an initial funding of approximately US$ 250 million. Up until now, a large number of major US companies, research facilities and universities from the field of carbon composites have been registered as members (currently 167 members). A particular focus within the participating players is within the automotive and wind power sectors [22]. Also of great importance are the activities in South Korea around the "Carbon Valley" South Korea in Jeonju. In this coherency, approximately US $200 million was made available to initiate research and development projects between currently around 50 cluster members [23]. In the light of such large-scale hot-spot activities with governmental and political support, the international cooperation between these focus centers will become particularly important in the coming years in order to accelerate the global carbon industry together in the future.

In general, the carbon fiber reinforced composites are a comparatively new material class. The broad range of potentials is traditionally opposed to a certain degree of market inertia until a broad acceptance is achieved. Especially within the last few years, remarkable progress has been made in all fields of research and development, so that today CFRP is fully recognized as a construction material in many fields of application. Nevertheless, new performance potentials are continuing to be revealed in all areas and the resulting knowledge transferred to ever new fields of applications. In a global perspective, numerous new regional competence centers are being set up and existing structures are being expanded.

Furthermore, the CFRP light-weight segment also benefits from the general growth of other fiber-reinforced composites, such as aramid and glass fibers, due to frequently transferable processing processes and the possibility of hybrid solutions. For example, the aramid segment currently reported strong growth figures, with DuPont investing around US $500 million to increase their aramid fiber production (trade name: Kevlar) by approx. 25%. The main competitor Teijin has also recently incorporated a fourth fiber type in their portfolio (trade names: Twaron, Technora, Sulfron, Teijinconex) and increased their production volumes for Twaron fibers by about 15-20% [11].

At present, the sector is clearly developing in the direction of a highly vertically integrated market. Strategy partnerships right up to joint ventures are often being built on the initiative of fiber manufacturers. This means that a large part of the supply chain can be maintained within the company and, on the other hand, favorable delivery conditions can be negotiated and comprehensive solutions can be offered to the outside. Since then almost every one of the leading fiber manufacturers has its own activities in the preliminary step of precursor production. For the subsequent textile processing and CC production there exists also however, extensive close business relationships, particularly in the direction of the automotive sectors, such as Toray – CMTH [24], SGL – BMW, MCCFC – Wethje, DowAksa – Ford [25], Hyosung – Hyundai [12]. It is expected that in the following years the remaining fiber manufacturers will also enter into similar collaborations, extending the existing models.

15.2 Subsequent CFRP-Recycling market

The strong increasing production of carbon composites leads to a collateral increasing flow of waste containing carbon fibre. This internationally spread problem represents not only a challenge but also a big opportunity. On one hand, the special composition (fibre, matrix) of carbon composites requires innovative recycling strategies. But on the other hand, despite the small amounts of waste that are generated compared to other material classes (metals, plastics, paper), there is the chance of profitable business models for recycled carbon fibres (rCF), with regard to the high use of energy and resources in the production of new fibres.

At present, particularly dry waste residues, or uncured and expired PrePreg material represent undoubtedly the largest share of these waste streams. A functioning recycling industry is currently being built here. Dry off-cuts will be further processed by means of textile processing methods e.g. into nonwovens. This process step will mostly be taken over by specialised companies (i.e. Tenowo GmbH, Sigmatex Ltd.), but also has the possibility of becoming an “In-house solution” within the individual companies. For example, SGL-ACF is further processing dry off-cuts, accrued from the BMW production, into a nonwoven material which is then used as a component of the i-series (rear seat shell, roof). Here the material-specific advantages (e.g. drapability) can be utilised, while also making a significant contribution to the compliance with legal directives (e.g. the end-of-life vehicle directive) which, among other things, impose a recycling quota for substantial recycling of more than 85% of a vehicle’s material.

This is also the case for Pre-Preg waste material, most often originating from the aviation industry, which has an accordingly high quality. The waste material is now being commercially operated with the pyrolysis/partial oxidation, a first process variant for the recovery of the fibres. Here the companies ELG Carbon Fibre Ltd. (Coseley, UK), Carbon Conversions (formerly: MIT-RFC; Lake City, SC, USA) and CarboNXT GmbH (Wischhafen, GER) are taking on a leading position. The thermal process used can also be applied to components that are fully impregnated with resin (end-of-life, rejects). In doing so the matrix-material is unfortunately not retrievable, but will however be used as an energy generation source to help compensate for large proportions of the process energy [26].

In the future, the balance will shift more strongly towards a waste flow filled with resin, since the associated components are still in the usage-phase of their lifecycle. Furthermore, this progression is strengthened by the provisioning of processes with fewer waste material, e.g. near-net-shape-processing.

Another important factor influencing the development of the CFRP recycling market is the overall growing interest and the demand for sustainable product solutions and material systems. Not only is there a mere economic benefit associated with the closure of a material lifecycle, but also an ecologic (CO_2 footprint) and even social impact (circular economy). Correspondingly, a "green label" has become a politically effective image carrier, especially for high-tech segments such as CFRP.

The development of the CF- and CC-industry in the direction of a vertically integrated market through extensive strategic colaborations along the supply chain, as described in section 5.1, already extends up to the recycling segment in several cases. The described activities of SGL-ACF form a prime example of a comprehensive overall strategy starting from the production of CF up until the recycling concept within the company's own structure. With the new TENAX-E-series, Toho Tenax also supplies recycled products with a PEEK matrix, whereby offcuts from the processing of thermoplastic organic sheets (e.g. from stamping) are reused. These organic sheets are primarily designed and qualified for aeronautical applications (e.g. A350XWB in the segment “clips and brackets”) so that Toho can demonstrate a very direct recycling strategy for this high-quality and cost-intensive material source [27] [28].

For the following years, it is expected that the development outlined will carry on and that the recycling market will continue to grow alongside the CF- and CC-market. It is therefore crucial to use rCF-based materials as a new material class with its own requirements in order to exploit material-specific potentials.

15.3 Comparison with the Composites Germany market survey

The half yearly market survey from Composites Germany, which has been conducted since 2013 by members from the four large organizations of the composite industry in Germany (AVK, CCeV, CFK Valley Stade and VDMA Forum Composite Technology), reflects a positive market outlook for this year [26]. Both the current assessment

of the general as well as individual / individual business situation are analyzed, each subdivided into a global, a European and a Germany-focused observation point-of-view. In addition, an assessment of the development for the next six months is included. As a result of the market survey this year, among others, came the following core statements:

In terms of the general state of business, the situation for the outright majority of those polled worldwide (93%), Europe (88%) and in Germany (88), looks to be “positive” or even “very positive”. All subdivisions are following in a positive trend when compared to the previous 6 months, which turned out exceptionally high for the worldwide observation period (see Fig. 11). With regard to their own business situation, a more polarized image of opinion can be outlined, with an increase in the percentages of both the “very positive” as well as “quite negative” ratings (“very negative” remaining 0%). Particularly the evaluation of the distinct market situation in Germany is reflected in rather skeptical and strongly optimistic views, whereas a continuing positive outlook of 83% significantly outweighs.

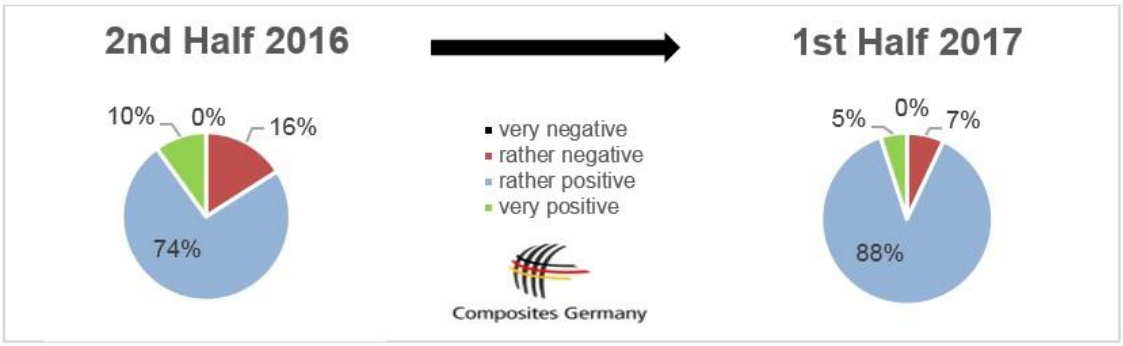


Figure 20: Estimation of the general business situation worldwide, Composites Germany market survey

The future development of the general and individual business situation is predominately estimated to be approximately 97%, with "consistent" (approx. 71%) or "positive" (approx. 26%). In summary, a positive business climate can be ascertained, with a rating slightly somewhat better on average compared to 2016.

16 Final Review

In summary, the CF- and CC-market can be classified as a promising and future-oriented business segment. The annual growth rates are stable at a high level of 10% to 13%.

Hence, for 2016 the motto "Neither hype nor stagnation", which was titled in the previous year's report, is still up-to-date. On average, this year's evaluations are even a little ahead of the analysis from 2016. Thus, in the meantime, the bench mark 100k tons for the CFRP demand volume could eventually be exceeded.

Since 2014, a stable and strong growth has emerged without any sudden corrective movements. This development covers all areas and applications and this year the aviation and aerospace industry (incl. defense) will continue to be named as the largest and highest-grossing sector. The highest growth rate figures are expected from the automotive sector (incl. commercial vehicles) for the following year. Also in light of the current political discussions (Diesel scandal, progression of the E-mobility, enhanced energy transition, tighter CO_2 emissions), further legislation and tax adjustments could lead to a positive stimulation of the lightweight construction market. Carbon fiber-reinforced composites are a key driver of growth within the overall market environment of (fiber-reinforced) lightweight construction materials. Special impetus is also expected from the new investments made by leading fiber manufacturers this year, as well as many announcements for further expansion measures in the coming years.

These influencing factors characterize the progress of the relatively young CF and CC market to its fast journey to an established high technology market. The associated materials systems are already establishing themselves as fixed players in the material mix of the future.

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Illustrations

Authors:

GRP market report: +49 69 2710 770
Dr. Elmar Witten
Elmar.Witten@avk-tv.de

CRP market report: +49 821 2684 110
Michael Sauer
Michael.Sauer@carbon-composites.eu

Michael Kühnel
Michael.Kuehnel@carbon-composites.eu