Composites Market Report 2018

Market developments, trends, outlooks and challenges

The European **GRP** Market – Dr. Elmar Witten, Volker Mathes (AVK)
The Global **CF and CC** Market – Michael Sauer, Michael Kühnel (CCeV)

November 2018

Contents

The European GRP Market in 2018

The Authors

Dr. Elmar Witten is Managing Director of the AVK – Industrievereinigung Verstärkte Kunststoffe e.V. Volker Mathes is responsible for market information at the AVK.

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 compo-sites confederation EuCIA – the European Composites Industry Association.

The AVK is a foundation member of Composites Germany.

1 The European GRP market in 2018

The trend of growth continues

For the sixth consecutive year, the European glass fibre reinforced plastics (GRP) market grew in the European countries surveyed in this report. Compared to 2017, the European GRP market is expected to grow again by around 2 % to an estimated total of 1.141 million tonnes.

Despite the advances, strong growth, and many innovations in other segments of the fibre reinforced plastics/composites market, GRP still remains the dominant material in the composites market with a market share of over 95 %.

As in previous years, the generally positive trend in the European GRP market is more complex than it first appears with very strong regional and application- or process-specific differences.

For example, while so-called open processes (hand lay-up & spray-up) are growing at only 0.4%, the market for thermoplastic systems is increasing by almost 5%. This year, Southern European countries (e.g. Spain) are enjoying above-average growth while production volumes in most Northern European manufacturing countries are stagnant.

However, it is important to note that production volumes are not currently contracting in any European country/group of countries. This applies to the various processing methods as well. No segment is reporting a reduction in production volumes.

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 again include all glass fibre reinforced plastics with a thermoset matrix and, in the thermoplastics market, glass mat reinforced thermoplastics (GMT), long fibre reinforced thermoplastics (LFT) and 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 2018: Overall development

Following the slump in European GRP production during the economic and financial crisis – between 2007 and 2009 – this branch of the plastics industry is now enjoying its sixth consecutive year of growth. In 2018, the European GRP market in total is expected to grow by 2.1 % to an estimated total of 1.141 million tonnes (see Fig. 2 in chapter 4).

Despite this fundamentally positive trend, the total number is of limited significance. The European market is highly heterogeneous and the trends within it can thus differ enormously. When viewed in detail, the wide range of different materials and processing methods as well as the continuous development of new fields of application has led to the emergence of different growth rates both regionally and in terms of applications.

The two main areas of applications for GRP remain the transport and construction/infrastructure sectors. Fluctuations in these two important industrial sectors of the economy also produce fluctuations in the GRP sector – sometimes with significantly different effects depending on regional industrial priorities.

The major macroeconomic importance of these two principal fields of application for GRP (transport & construction/infrastructure) is one reason why the GRP production volume tends to follow the trend lines for gross domestic product and total industrial production (see Fig. 1). Composites are already well-established in the aforementioned segments and, due to the high processing volume, no sudden changes in total production volume are to be expected over the coming years. Individual projects or new applications usually have only a small effect on the total processing volume or overlap with/are cancelled out by developments in other application areas.

Despite new projects launched by individual companies – some of them major market players – the European market continues to be characterised by a large number of small and even very small businesses. However, in many European countries, 80 - 90 % of the total volume is produced by just 10 - 20 % of the companies.

Fig. 1: Correlation between GRP production and the overall economy (Sources: OECD, The World Bank and independent study)

4 GRP production in Europe

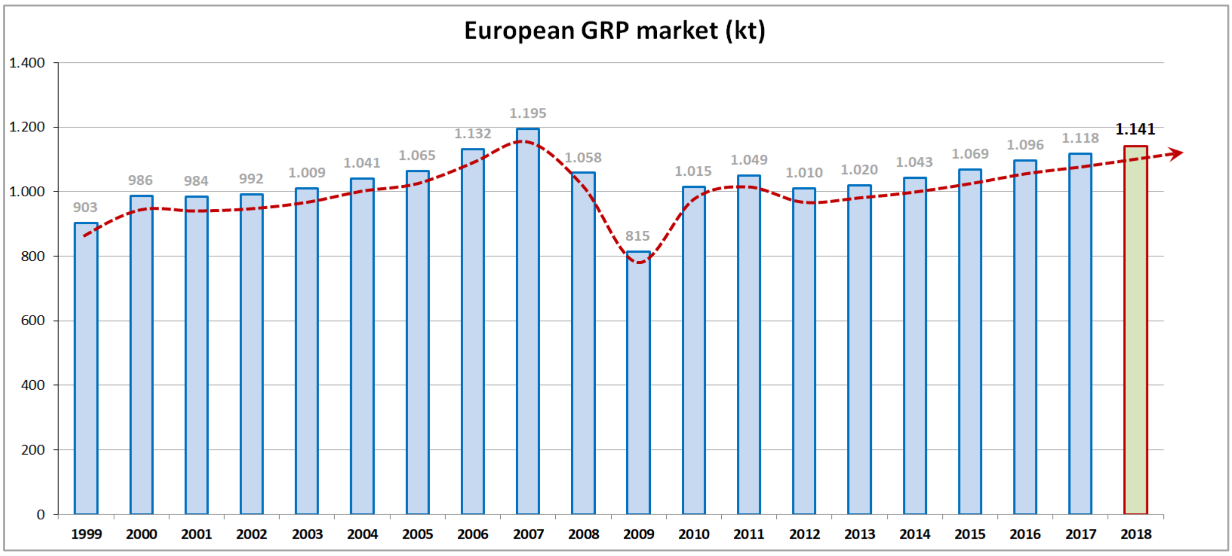


Fig. 2: GRP production volume in Europe since 1999 (in '000 tonnes) (2018 = estimate)

In 2018, the European GRP market is expected to grow by 2.1 % to a total volume of 1.141 million tonnes. The moderate growth already achieved in previous years is thus continuing for a sixth consecutive year. As already described, however, the trends in the various countries/regions, application areas or production sectors considered here can sometimes differ widely. A detailed analysis follows from Section 5.

Although the volume of GRP produced in Europe continues to grow, it seems likely to lag behind the global trend. Other markets, such as Asia and America, have been growing at well over 2% in recent years. As a result, Europe's share of global production continues to fall despite the positive trend in absolute terms. Reasons for this slower growth include the migration of certain manufacturing processes and methods, but also outsourcing of the production of commodities with often low profit margins. In addition, some application and customer industries are developing more dynamically in other regions of the world than in Europe. Overall, the GRP industry is characterised by very strong internationalisation along the entire value chain. Lower labour costs or statutory changes can result in the migration of individual stages of production to other regions of the world.

5 Trends in the development of processes/components

	2015 kt	2016 kt	2017 kt	2018 kt
SMC	191	198	202	204
BMC	74	76	78	81
∑ SMC/BMC	**265**	**274**	**280**	**285**
Hand lay-up	139	140	140	140
Spray-up	96	97	98	99
∑ Open mould	**235**	**237**	**238**	**239**
RTM	**137**	**141**	**146**	**148**
Sheets	86	89	93	96
Pultrusion	49	50	53	55
∑ Continuous processing	**135**	**139**	**146**	**151**
Filament winding	80	80	78	79
Centrifugal casting	68	68	67	69
∑ Pipes and Tanks	**148**	**148**	**145**	**148**
GMT/LFT	**132**	**140**	**145**	**152**
Others	**17**	**17**	**18**	**18**
Sum:	**1.069**	**1.096**	**1.118**	**1.141**

Table 1: GRP production volumes in Europe according to processes/components – current year and the three previous years (kt = kilotonnes, 2018 = estimate)

Table 1 shows the trend in the production volume of essential processes/parts for GRP production over recent years. The names of the individual segments are not always very strict or selective, but this report will continue to use them to enable readers to compare the values as effectively as possible. However, in addition to these processes, there are many other production processes/technologies which can essentially be classified under one of the areas mentioned.

SMC/BMC is the largest segment in terms of volume. This is followed by the so-called “open processes” which often have a strong emphasis on manual skills and craftsmanship. In terms of quantities, the other processes mentioned here are at approximately the same level. However, the absolute figures somewhat obscure the long-term trend seen in Fig. 3.

This shows that open processes, in particular, have lost much of their market share over the last 20 years. For these, the strongest decline in volumes occurred during the years of the economic and financial crisis 2007-2009. SMC/BMC is now the largest segment in the area of GRP processing and its market share remains constant, showing growth in line with the overall market rate of ± 2% per year. There is also clear growth in the area of RTM technology (resin transfer moulding) but particularly in thermoplastic processes. Growth rates in this segment have been outperforming the market as a whole for several years.

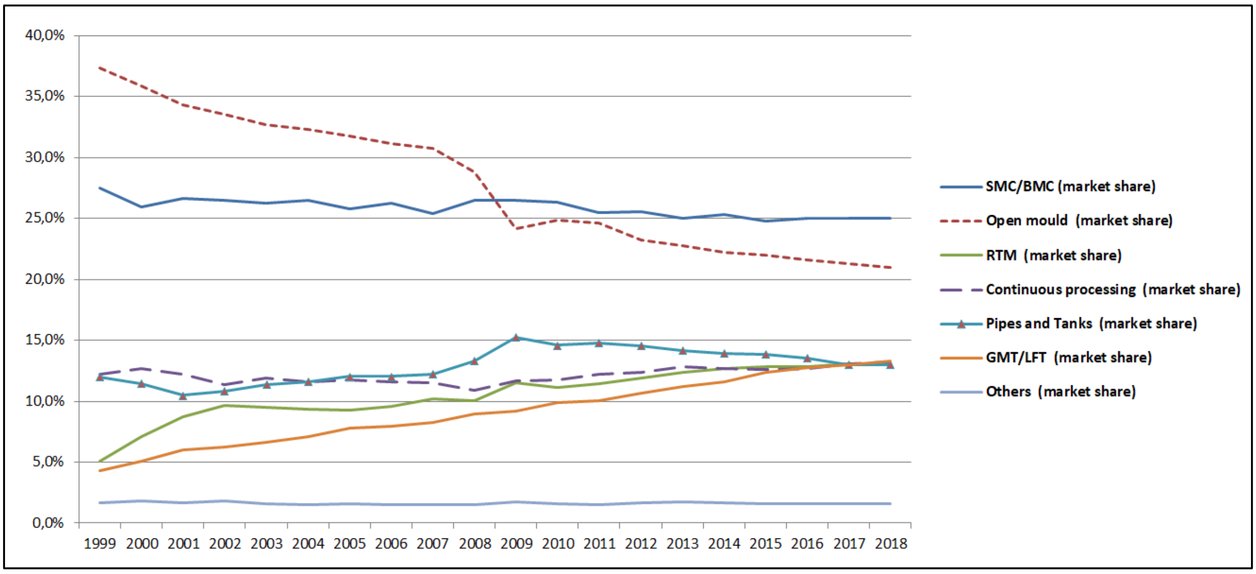


Fig. 3: Long-term trend for GRP market segments (share of total market, 2018 = estimated)

The following section contains individual analyses of the various segments considered in this report:

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 and injection moulding processes are turned into components which are used primarily in the electro/electronic and transport sectors, especially in the automotive industry.

This year, growth in the SMC/BMC sector slowed again slightly to a rate of 1.8 %. Total production volume this year will be 285,000 tonnes. SMC is by far the larger of the two market segments. At 204,000 tonnes, it accounts for more than two-thirds of production volume. However, this year, the BMC sector is growing much faster (3.8 %) than the SMC sector which is growing at only about 1 %. Total BMC production volume is 81,000 tonnes.

SMC/BMC are primarily used in (large scale) series production applications. Both materials have been well-established in the electro/electronics and transport sectors for many years. Typical applications include headlight systems, lamp housings, control cabinets, cases, and exterior components in the commercial vehicle and automotive sectors.

In recent months, interest in the semi-finished products and processing technologies for such products has grown rapidly, both within the composites market and also among players who have not previously worked in this field. This interest is not yet reflected in the actual processing volumes.

Many innovative and pioneering products/product enhancements are not yet mature for series application or are in preliminary development phases. The most important of these are high-performance SMC (carbon fibre reinforced SMC), continuous fibre reinforced SMC and natural fibre reinforced SMC.

These materials are primarily targeted at high-load or structural component applications and have the potential to open new areas of use for this technology. All these solutions are very promising but are so far only found in a few beacon project applications.

The automotive/transportation sector is currently in a state of upheaval which is also affecting the SMC/BMC market. Novel headlamp technologies based on LEDs, for example, change the requirements for the materials used in the headlights. This is the most important application for BMC so these changes affect it in particular.

For many years, lightweight construction was one of the key considerations in the automotive and aerospace sectors. Especially in the automotive sector, a paradigm shift is now underway. Lightweight construction is no longer the dominant issue when selecting materials. Other criteria, such as possibilities for integrating components into existing systems, reducing the complexity of the manufacturing process, etc., are becoming increasingly important. Lightweight properties alone are no longer the key criterion. This change should benefit SMC/BMC materials because they not only offer good mechanical performance at relatively low weight but many other positive characteristics that should favour their use in the long term. To name just a few, these include excellent resistance to corrosion and other media, outstanding fire prevention properties and strong dimensional stability – but above all a stable and often attractive price.

The automotive industry is currently in a state of upheaval, especially with regard to electromobility, but also due to increasing demands on engine technology. As a result, many material changes and/or projects have been halted, mothballed, or rolled back. Greater competition from Asia and America is also affecting the European market. Initial projects are emerging in the aerospace segment, especially in the area of cargo and interiors. It remains to be seen how this trend will continue, above all in the field of high-performance materials.

Further moderate growth over the coming year is unlikely to lead to a sudden increase in production volumes because strong growth in one segment can be counterbalanced by different trends in others due to the high level of production. It should also be remembered that SMC/BMC production in Europe alone is many times greater than global CRP production.

5.2 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 239,000 tonnes. As Fig. 3 shows, however, its share of the total market has fallen by more than 15 % in the last 20 years. The trend also shows a further decline in the use of these technologies in Europe. In 2018, open processes are growing at a rate of 0.4 % – once again lagging behind the overall market trend.

Despite further anticipated declines, open processes will continue to be an important area of GRP production over the coming years. Indeed, they are often the method of choice – especially in the field of bespoke and custom-made products or small batch sizes – due to their low investment costs. Even for the production of large, highly complex components or products, spray-up and hand lay-up continue to perform very well as the original techniques for processing glass fibre.

However, a continuous tightening of statutory regulations is making it more difficult/complex to use these methods in Europe, particularly with materials containing styrene. Further tightening is anticipated here over the coming years. In addition to the problem of emissions, open processes (open tool/open mould) and manual processing can sometimes produce inconsistent quality in series or near-series scale production.

This combination of factors often leads manufacturers to seek out substitute closed methods. In addition, there is a noticeable migration to – sometimes very modern and well-equipped – production facilities in non-European countries.

5.3 RTM

The RTM (resin transfer moulding) segment comprises all processes in which resin is infused/injected into a closed cavity. These include a variety of injection methods (HP-RTM, P-RTM, RTM-Light, etc.) as well as some infusion processes. An enormous range of RTM processes have been developed over recent years. These all have the following characteristics in common: they use dry fibres/semi-finished fibre products and the resin flows around or through the dry fibres in the closed mould either by means of pressure and/or vacuum.

As in previous years, the RTM segment continues to grow steadily, albeit at a slightly below-average rate of 1.4 % this year. Production is expected to reach 148,000 tonnes in 2018.

This technology can be used for production on a very wide range of scales – from just a few units to larger series. It can be used to manufacture both small components and larger products. In addition, it is suitable for use with many different fibre and matrix systems. Typically, it also uses corresponding preforms.

As a result, it is used in a wide range of applications – from vehicle construction to wind turbines, boat and ship building, sports and leisure, and aerospace. Until a few years ago, RTM technology was also considered a possible candidate for the large scale production of parts for the automotive segment. However, apart from a few projects in the mid-size vehicle segment (e.g. BMW i series), the technology has not yet prevailed in this field.

Nevertheless, production volume has increased considerably, not least because of this technology's flexibility and range of potential applications. Twenty years ago (1998), production volume was 46,000 tonnes, today it is 148,000 tonnes – an increase of more than 300%.

5.4 Continuous processes

The production of GRP components using continuous processes (pultrusion and flat panel production) has grown by 3.4 % in 2018 – well above the average rate for the sector. This continues the positive trend of recent years. Total production volume is now around 151,000 tonnes.

The larger of the two market segments, the production of flat panels, grew by 3.2 % to 96,000 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 area of facades. The sector has also witnessed the development and promotion of a growing number of innovations in recent years, e.g. antiseptic panels for operating theatres, wakeboards etc. The flat panel segment continues to be dominated by a few large manufacturers. Pultrusion, the other segment in this area, grew by 3.8 % in 2018 – slightly faster even than flat panel production. European production of GRP pultrusion products now totals 55,000 tonnes.

Interest in this segment grew rapidly in 2017 and is now being reflected in rising market numbers. The trend has continued into 2018. It will be interesting to see whether this is reflected in a further increase in production volume.

There have been many new developments and advances in pultrusion in recent months, both in terms of technology and materials. The pultrusion industry considers the construction and infrastructure sectors, in particular, to be major markets of the future. Examples include the public transport sector, bridge construction, window and staircase/ladder profiles, and reinforcement systems. In this area, the specific properties of the materials play a central role in addition to lightweight construction. For example, they should be corrosion resistant, require little or no maintenance, permit load-specific design and be electrical and thermal insulators.

The necessary general industrial approvals and norms/standards have not yet been agreed. This lack of "security" increases the reluctance of many architects and decision makers to adopt these materials. Moreover, many decision makers still know too little about the positive properties of GRP compared to other building materials.

5.5 Pipes and tanks

The market segment of GRP pipes and tanks, manufactured using a centrifugal casting or filament winding process, is expected to grow by an average of 2.1% in 2018. After stagnating in 2016 and declining in 2017, this is a positive signal. Nevertheless, production levels – measured as a share of total European production volume – have declined slightly in recent years.

The market is dominated by a few large manufacturers not least because of the relatively high throughput quantities – 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, reportedly started a number of (re-)investment projects last year. It is impossible to determine accurately whether and to what extent these are responsible for the strong improvement in the trend compared to 2017.

However, it appears that tank and plant construction are becoming an important driver of this market segment in Europe.

As in the pultrusion segment, standardisation can act as both a driving force and a brake on further development. One example is the amended drinking water approval which has made the use of GRP pipes more difficult. This segment is also subject to strong material substitution effects, e.g. by non-reinforced plastics or other material systems.

In plant construction, GRP has numerous potential advantages over other construction materials, especially in terms of material properties in areas subject to mechanical and/or media loads with long service lives/operating times. In addition to requirements resulting from standards, the main obstacle to adoption is a lack of knowledge about the properties of these materials among operators and planners.

There is still strong growth potential in the pipe sector, and especially in tank and plant construction, that could be tapped by further improving general awareness of the materials.

5.6 GMT/LFT

Glass mat reinforced thermoplastics (GMT), long fibre reinforced thermoplastics (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 still reasonable to consider both these areas together. Materials with short glass fibre reinforcement (< 2 mm fibre length) differ significantly from the materials considered in this report in terms of the influence on material properties and (load-specific) alignment. Consequently, they are not included in this survey of the GRP market.

In 2018, the market for GMT and LFT continues to grow at an above-average rate of 4.8 % having already grown at 3.6 % in 2017. From a long-term perspective, this market segment has almost quadrupled since 1999 – reaching a volume of 152,000 tonnes in 2018. During that period, its share of the total market has risen from 5 % to over 13 % (see Fig. 4).

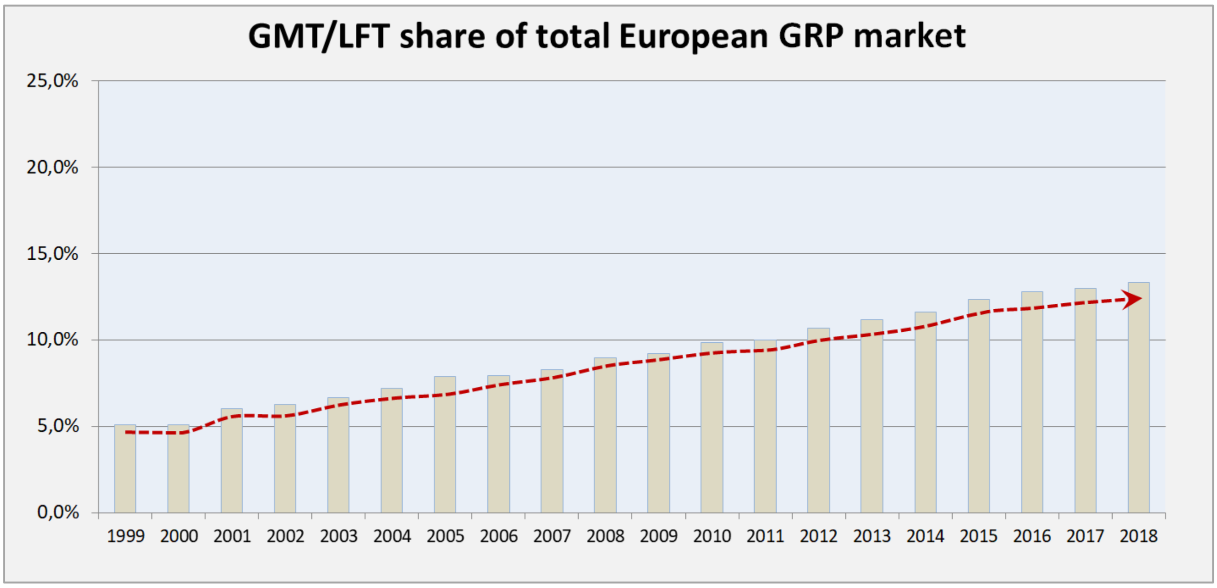


Fig. 4: Growth in the market for GMT/LFT as a share of total European GRP production volume (2018=estimated)

LFTs are the largest category of thermoplastic materials. For some years, however, tapes and pre-consolidated, flat semi-finished products ("organosheets") have increasingly become the focus of attention; the latter particularly in relation to the hybridisation of manufacturing processes, e.g. combination with injection moulding and forming.

Projects in the automotive industry, and some in the electronics sector, are the primary growth drivers for thermoplastic materials. Thermoplastic materials have a number of special properties in terms of ease of processing/cycle times and recycling. They also combine 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+. Typical applications for these products include underbody protection, bumpers, instrument panels or seat structures.

This segment offers enormous growth potential for the future. The new developments and enhancements in the field of LFT, as well as the aforementioned hybrid solutions, are identifying a host of exciting applications, especially in transport but also in the electro/electronics sector.

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 again remain the same as last year. The transport and construction sectors each consume one third of total production (+1 % respectively compared to the previous year). Other application industries include the electro/electronics sector and the sport and leisure segment (see Fig. 5).

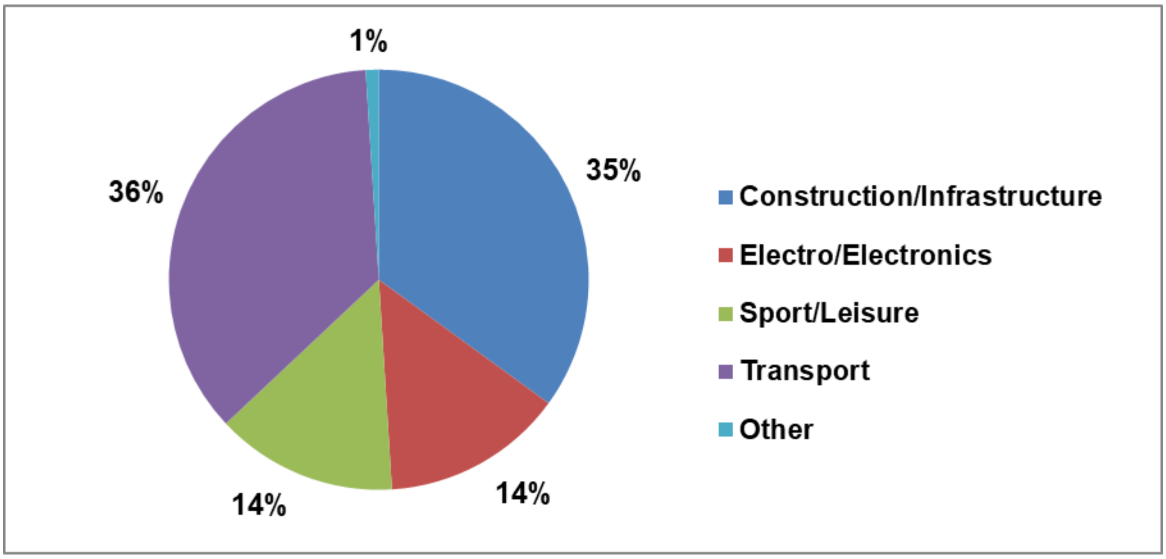


Fig. 5: GRP production in Europe by application industry (year: 2018 = estimated)

7 GRP production in 2018 by country

As mentioned in the introduction, the market trends within Europe have been very different. While the overall market grew year-on-year by 2 % to 1.141 million tonnes, growth in the countries reviewed in this report ranged from 0 % to 3.7 %. Table 2 shows the trends for each country/region in detail.

	2015	2016	2017	2018
	kt	kt	kt	kt
UK / Ireland	150	152	153	155
Belgium / Netherlands / Luxembourg	44	45	46	46
Finland / Norway / Sweden / Denmark	39	40	40	40
Spain / Portugal	156	158	161	167
Italy	150	154	158	162
France	108	110	112	115
Germany	212	220	226	229
Austria / Switzerland	18	18	19	19
Eastern Europe*	192	199	203	208
Sum:	**1.069**	**1.096**	**1.118**	**1.141**
Turkey**	245	265	280	300

Table 2: GRP production volumes in Europe – and Turkey – itemised by country/group of countries (kt = kilotonnes / 2018 = estimated / Eastern Europe* = Poland, Czech Republic, Hungary, Romania, Serbia, Croatia, Macedonia, Latvia, Lithuania, Slovakia and Slovenia / Turkey = Source: TCMA)**

On a positive note, production did not decline in any of the regions reviewed. Above all, the Southern European countries of Spain/Portugal, France and Italy are reporting above-average growth rates this year.

Although it has been expected for the past two years, this improvement in the market environment now seems to have finally arrived.

The largest GRP or composite country in Europe continues to be Germany with a total production volume of 229,000 tonnes. However, its growth this year will lag behind the overall market trend. Germany has thus lost a small proportion of its market share compared to the other countries but still maintains its leading position (see Fig 6).

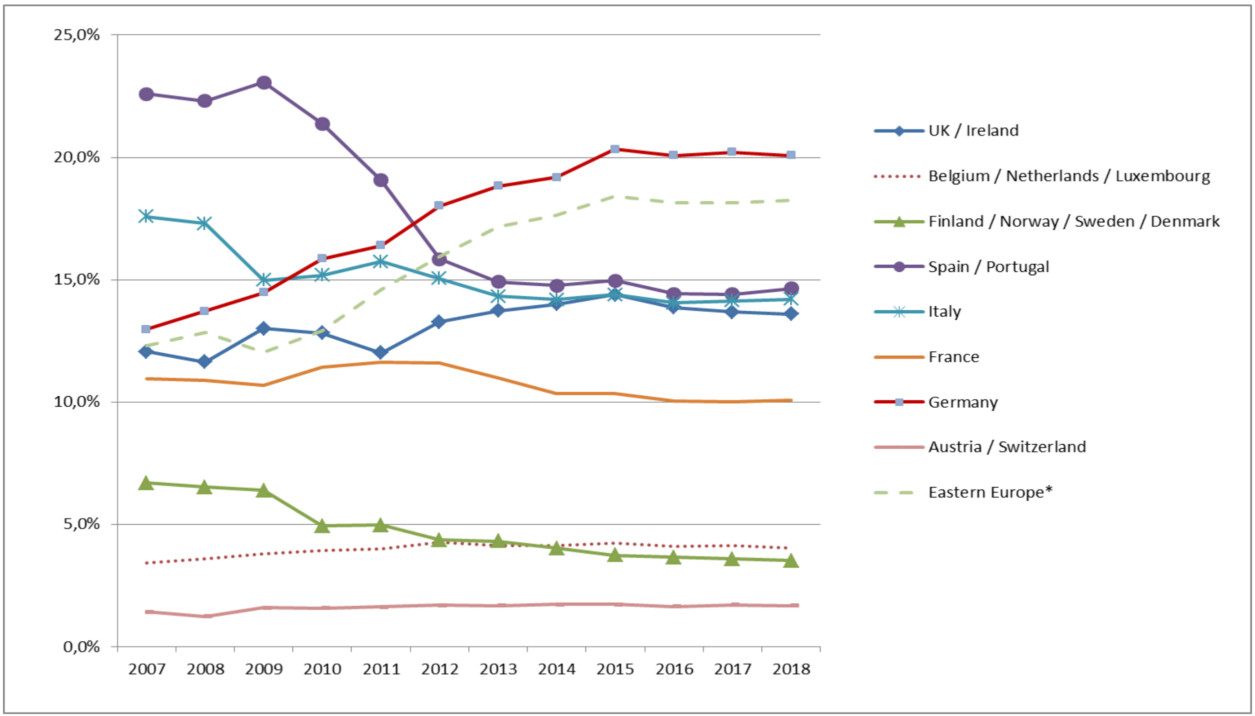


Fig. 6: Market share of European GRP production by country (Date: 2018)

The massive decline in production volume, especially in Italy and Spain/Portugal, during the economic and financial crisis is easy to identify. The industry has yet to recover fully from these declines. Since 2012, however, production volume has clearly stabilised and the recent trend has been upward.

Market growth in Eastern European countries is above average at 2.5%. Unfortunately, no detailed analyses are available for the individual countries.

Reported levels remain unchanged and thus below average in the Benelux countries, Scandinavia and Austria/Switzerland this year. The UK/Ireland grew by just 1.3 %.

The Turkish trade association is once again reporting strong growth of 7 % to a total volume of 300,000 tonnes. This means that Turkish GRP production is again growing faster than in any other European country and total production volume is also significantly higher. The applications differ from those in the other countries included in this report: 55 % of production volume is used in the construction sector and manufacturing pipes and tanks. The automotive and transport sectors account for 25 %. Wind energy is the third largest application area with 9 %.

The analysis by country highlights the various trends within Europe. These are due to divergences between regional markets. For example, GRP processing in Germany has a strong focus on the transport sector and the electro/electronics industry. The market structure is different in Turkey (principally infrastructure) or Norway/Sweden (principally oil and gas industry). To analyse potential trends, it is always important to look at each market individually.

8 Other composite materials

8.1 Carbon fibre reinforced plastics

The CRP market will be studied in detail in the second part of this report.

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 …). In 2018, global demand for carbon fibre reinforced plastics (CRP) was estimated at 128,000 tonnes. Europe accounted for about 40,000 tonnes. Thus, CRP accounts for 1-2 % of the market for fibre reinforced plastics.

8.2 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 generally have a length of < 2mm. Nevertheless, they make the 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. 1.47 million tonnes, the European market for thermoplastic, short glass fibre reinforced compounds in 2017 *(Source: AMAC)* was much larger than the GRP market considered here over the same period. In 2016, the market grew by 8 % – market volume 1.36 million tonnes – and was thus significantly higher than in all other sectors reviewed here. Moreover, the rate of growth is significantly faster than in previous years, once again confirming the significance of this group of materials. Polyamide is the dominant matrix material in this segment, followed at some distance by polypropylene.

Applications are primarily in the automotive sector but also in the electro/electronics sector and consumer goods.

8.3 Natural fibre reinforced plastics

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)*.

9 Outlook

"It's difficult to make predictions. Especially about the future." (Mark Twain).

Despite the difficulty of predicting future trends, it is possible to identify more general tides and currents which have the potential to influence the ongoing development of the GRP market:

The automotive sector is currently undergoing major changes. A wide range of forces are reshaping the industry in addition to stricter exhaust emission standards. These include, for example, autonomous vehicles, increasing inner city traffic congestion problems, a greater degree of networking with digital systems, the collection and recording of corresponding vehicle data and, not least, new engine concepts and the expanded platform strategies of OEMs. The combination of all these developments is triggering nothing less than a restructuring of the industry on an enormous scale. This is also forcing vehicle manufacturers to make related decisions regarding materials. The industry will change, probably not quickly, but certainly in the medium term. New players are entering the market and long-established supplier structures are changing or at least being questioned. This time of upheaval is also creating opportunities for manufacturers to choose and invest in new materials. In addition to being light, GRP offers a wide range of advantages for many segments of the transport sector (including electromobility!). The lower weight reduces energy consumption whether from fossil fuels or electricity. Furthermore, these materials are not only very durable but require little maintenance and do not conduct electricity or interfere with data transmission – unlike many metals. In addition, some of them open up completely new opportunities for functional integration as well as offering excellent performance at low cost. Alongside established materials used in automotive series production, such as SMC and BMC, thermoplastics are currently the most important products entering this sector.

Statutory requirements for many chemical substances, such as styrene, cobalt octoate and titanium dioxide, are currently being tightened. The imposition of stricter limit values and guidelines always affects manufacturers' ability to process these materials. It remains to be seen to what extent this will influence future market trends in individual segments.

In addition to SMC/BMC and thermoplastic composites, a number of established continuous processes are currently attracting considerable attention, above all pultrusion. This area offers enormous growth potential if the necessary standards/norms can generate increased acceptance of pultrusion products among decision-makers (public or private). After all, GRP (and composites in general) have clear advantages over other, established materials. The appropriate decision makers must be informed about these benefits.

Another development trend seems likely to boost GRP production over the next few years. The ongoing digitisation of society (Internet of Things, big data and 5G) demands an ever greater degree of networking among all its participants and systems. This requires a free flow of data. GRP has non-conductive properties and thus offers significant added value in applications such antennae, building facades etc.

In the aviation sector, passenger and freight numbers are rising steadily. This translates into a growing demand for aircraft which must be as efficient as possible to keep prices low. Lightweight construction concepts are essential and composites already play an important role which will continue going forward.

Our planet has finite natural resources. Progress in the field of energy generation will be essential over the coming years. We need to tap new sources of energy and expand our use of existing alternatives – whether wind, solar, tidal or completely new, undiscovered technologies. Composites are vital for almost all of these technologies.

The energy sector is already a key market and its importance seems likely to increase.

These are just a few examples of technologies with the potential to drive future trends in the composites sector. In summary: due to their versatility and exceptional suitability for combination with other materials, GRP and other composites offer outstanding potential in many applications. However, awareness of the materials is still too low for them to be widely considered by the responsible decision makers. This must change because composites are a good, if not better, choice. If customers can reassess these materials and composites become acknowledged by standards/norms, then market growth (at an even faster rate than already experienced) is assured for the coming years.

The global CF- und CC-Market 2018

Market developments, trends, outlook and challenges

Michael Sauer, Michael Kühnel (CCeV)

10 General introduction

In its now ninth edition, the annual composites market report is published since 2010 by the CCeV and AVK and in the meantime has been attracting more and more attention and recognition, also outside of German-speaking areas. Counting 282 members (status 11/2018) the CCeV well represents companies, research institutes and other organizations in the carbon fiber (CF) and carbon composites (CC) market in Germany, Austria and Switzerland.

Shown data was provided by CCeV members or collected by the CCeV as well as verified an complemented with the help of external partners, such as Lucintel [1], [2], Acmite [3] [4], Industry Experts [5] [6], Visiongain [7] and Grand View Research [8].

CCeV and the authors

Michael Sauer and Michael Kühnel are project architects for Carbon Composites e.V. (CCeV) and issue the CCeV market report since 2014.

The Carbon Composites e.V. (CCeV) is a network of companies and research institutions that covers the complete value chain of high performance carbon fiber composites. The CCeV links research and industry in Germany, Austria and Switzerland.

CCeV sees itself as a competence network for promoting the application of fiber composite materials. The CCeV activities are directed towards the product category "Market-ready high performance fiber composite structures". The emphasis is placed on fiber composite structures with polymer matrices, as they are known to a broader public from a great number of applications, as well as fiber composite structures with ceramic matrices, that enable higher temperature and wear resistance, and also high performance composite materials for civil engineering and infrastructure.

11 Explanation of terms

In order to enable a better comparability with other market reports and to assure a higher plausibility of the shown information, the two most common growth rates and their calculations are used as shown below:

- **Averaged Annual Growth Rate (AAGR)** = Arithmetic Mean Return (AMR) = Arithmetic average 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 over n years assuming a proportionally constant growth:

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

In this report, growth rates are calculated exclusively on the basis of CAGR, since it better replicated the exponential growth prospects occuring under constant market growth rates. The trend lines displayed in the following graphics are therefore also based on exponential curves.

12 The global Carbon Fiber Market

12.1 Development of the global CF-Demand

For 2017, a global demand for CF of 70,5k tons was evaluated. This represents a growth of about 11% and slightly exceeds the expectations of previous year`s report. Since 2010, the annual growth rate is found to be 11,45% (CAGR). On this basis, for 2018 a global CF-Demand of about 78,5k tons can be estimated. The worldwide turnover for CF in 2017 was about 2,59 bn US$, achieving a growth of 10,7% compared to the year before. This corresponds to an average annual growth of 11,10% since 2013 (CAGR). Thus an overall turnover of 2,88 bn US$ can be outlined for 2018.

Looking at the required quantity as well as the achieved turnover, after 2015 (58kt; 2,15 bn US$) and 2016 (63,5 kt; 2,34 bn US$), a further increase of the annual growth rates becomes apparent, being particularly significant for the current survey period. This development is seen as a recovery effect after the economic recession 2009 which had a persistent negative effect on the composites market until 2015. For the upcoming years expectations are equally positive. The current data allows the assumption that the previously predicted balance-targets, e.g. 10-13%/a for CF-Demand, can even be outperformed at the point the annual growth rates level off.

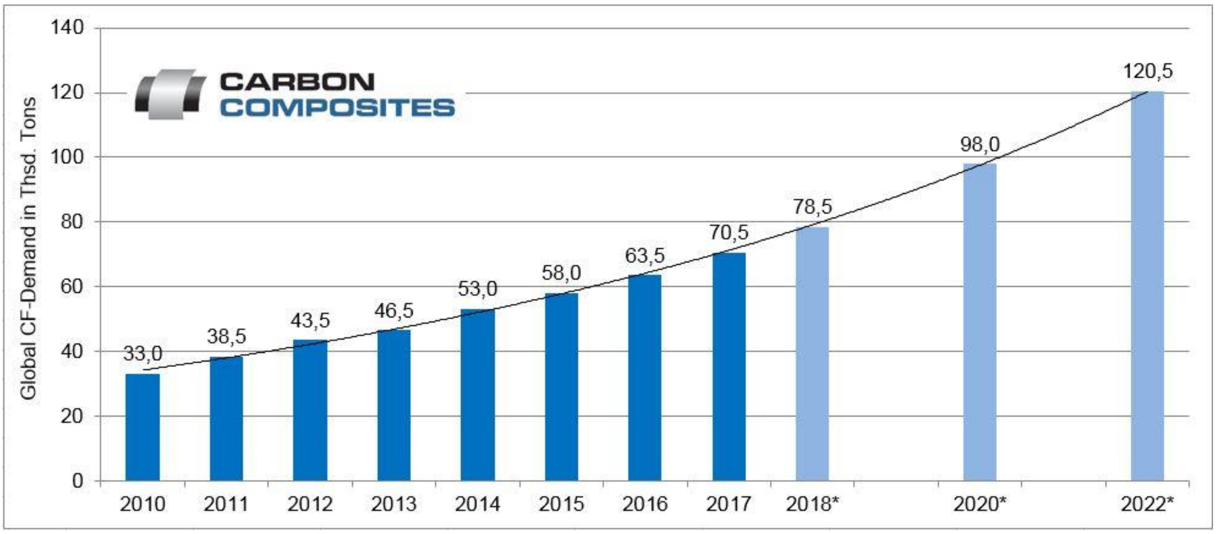


Figure 7: Development of the global CF-Demand in Thousand Tons (*Estimations; 11/2018).

12.2 The global CF-Capacity by manufacturer

Figure 2 shows the theoretical annual production capacity of worldwide leading carbon fiber manufacturers, that currently amounts to 149,3k tons per year. Compared to the previous year the production capacity of various manufacturers has been increased by overall 12,8k tons, which equals a growth of approx. 9,4%. Apart from the programs already under construction, further expansionary steps have been announced for the upcoming years, so an additional capacity of 37,5kt/a can be expected, respectively an increase of 25% compared to the current overall capacity. It should be noted that this estimation initially considers only the first expansion stage of the large announcement of Chinese manufacturer Kangde Group (until 2019). On a mid-term scale an extension to 66kt/a is planned hereof. These ambitious targets along with the respective investment confidence substantiate very positive expectations regarding future growth of the market.

In comparison to a current demand of approx. 78,5kt (estimation for 2018), a distinct overcapacity becomes obvious, which can be interpreted to a theoretical occupancy rate of approx. 52,6%. However, this theoretical value does not take into account restrictions of the machine efficiency caused by batch changes, rejected material and unexpected downtime. For the preceding survey periods this theoretical key figure has constantly risen (e.g. 2016: 46,5%). The ongoing investment readiness of CF-Manufacturers indicates a reaction to this trend, as well as significantly higher real values of the utilization rates. Obviously this attitude is also supported by continuing trust in the future prospects of a strongly growing fiber composites market. The elaborate steps for investments and expansions are taken at an early stage in order to prepare for these scenarios and secure market shares on long term timeline. The concentrated market environment allows quick opportunities for dominant positions in pertinent areas that are occupied effectively. At the same time, the manufacturers' balance sheets start to point out that they already could establish stable and profitable business models. This inspires their willingness for further investments supplementary. On this basis, substantial expansions have been completed in this survey period and additional significant expansions have been announced.

Toray has actively worked on fortifying their world leadership during the past year. At the end of 2017, the expansion of their plant in Jalisco (Mexico) was successfully completed for this reason [9]. Meanwhile the business group holds an overall capacity of 47,5kt/a which equals approx. 31,8% of the worldwide manufacturing capacity [10]. As compared to 2016 (approx. 31,2%) their position could be enhanced accordingly. Toray already signaled their next expansion for their plant in Nyergesùjfalu (Hungary) in April 2018 [11]. Both current expansion projects are placed within subsidiary Zoltek and apply their large-tow products (50K) [12]. Increasing demand from the automotive sector, such as from Cadillac ATS/ CTS or Audi A8/ R8 latest, are causing this evolution [9] [13]. Alongside with the already strong market position in the aeronautical field, Toray once again emphasize their efforts to establish themselves in the automotive sector and have since reached a leading position in this field.

Ranked as the second and third most important manufacturers, SGL Carbon and Mitsubishi Chemical Carbon Fiber and Composites (MCCFC) are following a clear margin. After their large programs within recent years, no new announcements are known yet. Both companies currently focus on developing their integrated vertical value chain using corresponding acquisitions, especially focusing on processing and part manufacturing [14] [15].

The actual chase for the podium positions is led by Teijin, respectively their affiliate Toho Tenax, and Hexcel. Teijin has already started activities worth 600 million US$ for a new plan in Greenwood (USA), already founded another subsidiary company (Teijin Carbon Fiber Inc.) at the end of 2017 for that purpose and even celebrated the groundbreaking ceremony [16] [17]. On the short term Tohos capacity will slightly decrease due to a carbon fiber production line in Rockwood (USA) being restructured to the production of oxidized PAN fibers (Pyromex®). The expansion in Greenwood is however supposed to overcompensate this decrease in the near future [18].

Hexcel as well looks back to a year with plenty of investments. The first construction stage of the largest invest project in Hexcel`s history, including the CF lines, has been completed and put into operation in Roussillon (France) in 2017 [19]. In addition to this, the plant in Salt Lake City (USA) was expanded in order to reach the stated objective of an overall capacity of 15kt/a until 2020 [20] [21].

Chinese fiber manufacturers equally continue to work on upgrading their capacities. Zhongfu-Shenying is extending to an overall amount of 6kt/a and thus is the leading producer in China today. Their recent developments are oriented towards high performance applications with a new fiber on T1000 standard being available according to company information [22]. Hengshen Co. Ltd. increased their overall capacity to 5kt/a against the background of a new strategic partnership with Bombardier. The objective is a joint aviation certification of Hengshen´s prepreg materials, building the basis of a supplier contract subsequently [23].

The comparatively new market participant Kangde Group has attracted special attention, already holding a production capacity of about 1,7kt/a at their plant in Langfang (China). The current announcements however exceed this status by far. Using an investment volume of approx. 50 bn CNY (about 7,3 bn US$), the biggest CF production plant worldwide is being planned. An enormous area has yet been made accessible in Rongcheng (China) for this purpose. In the first expansion stage, a capacity of 6kt/a is supposed to be reached until 2019. On a mid-term scale an objective of 66kt/a has been stated. This would equal 44% of the current global name plate capacity at one single site and would significantly surpass the actual position of global market leader Toray. Since announcing this ambitious target level in September 2017, a timeline until completion before 2023 has been specified. This appears to be very ambitious even with current activities indicating a very fast buildup at this location, so the exact scope remains to be seen.

The long-term investment projects announced by DowAksa for plants in the USA and Russia, as well as Hyosung for a big production site in Jeonju (South Korea), remain unchanged. In the case of Jeonju the necessary area is already fully tapped, so an expansion is expected in the near future. Originally a first expansion stage was announced to be about 5kt/a until the end of 2018, but for now a further extension cannot be confirmed [24].

Another 12,8kt/a of name plate capacity are accounted for „Other“ fiber producers in the report period. A number of smaller Asian manufacturers such as Yingyou Group Corp., Dalian Xingke Carbon Fibre Co. Ltd., Kureha Corp., Weihai Guangwei Composites Co. Ltd., Shenzhen Xiangu High-Tech. Co. Ltd., Osaka Gas Chemicals Co. Ltd. and Bluestar Fibres Co. Ltd. (a subsidiary of ChemChina) are aggregated within this estimation amongst others [1] [4] [6] [8]. Chinese producer Ordos Yaxin Carbon Fibre Co. Ltd. (approx. 2kt/a) had announced plans for extension during last year`s survey period, which still can´t be confirmed yet [4]. The russian manufacturer Alabuga-Fibre LLC (approx. 1,7 kt/a) as well as Indian CF producer Reliance Industries (approx. 2,5kt/a; former Kemrock Industries and Exports Ltd.) are also comprised [25]. Reliance Industries being one of the most influential corporations of India`s economy, particularly in the sector of textiles and polymer fibers, facilitates a very attractive potential for the future.

In sum, this submits to a very strong market concentration, pronouncedly dominated by a small number of major market players. The Top Ten leading CF producers according to today´s status hold approx. 132,3kt/a of the annual production capacity, respectively 88,6% (2016: 87,5%). The Top Five reach 101,9kt/a or 68,3% (2016: 69,3%); For the Top Three the overall capacity amounts to 76,8kt/a or 51,4% (2016: 52,7%) of the global name plate capacity.

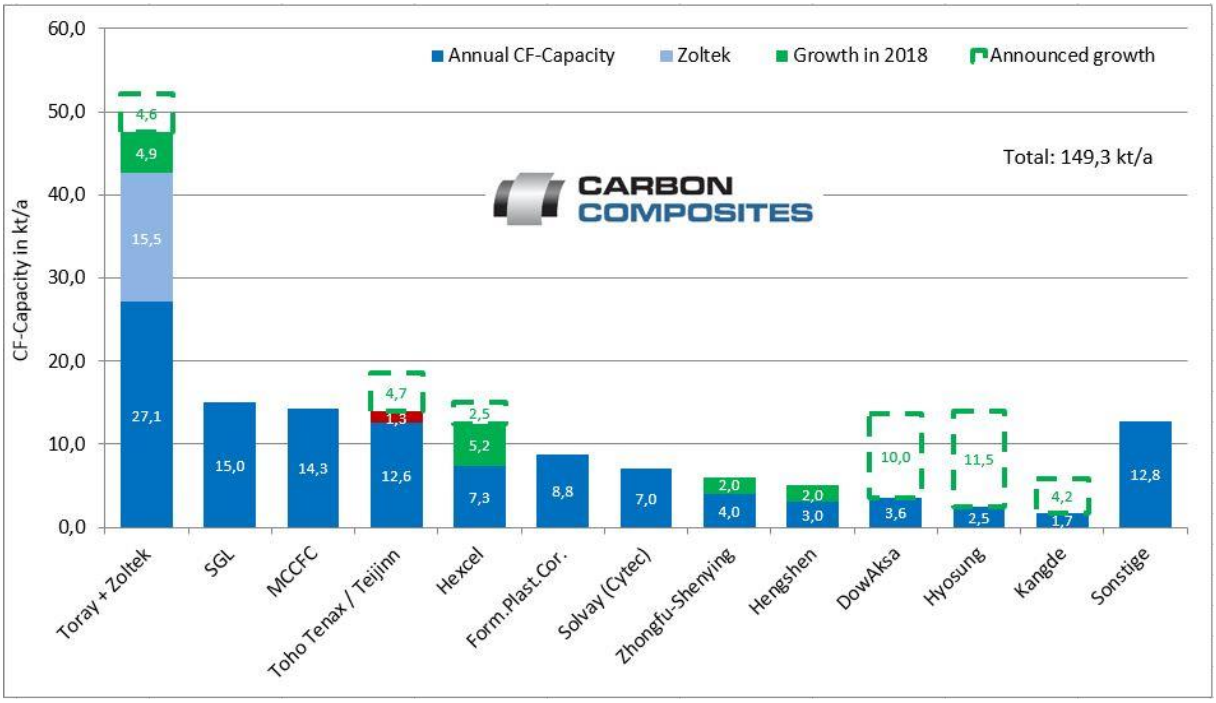


Figure 8: Theoretical, annual CF-Production capacity in Thousand Tons by manufacturer (11/2018).

12.3 CF-Demand and CF-Capacity by region

The global production capacity of 149,3 kt/a as well as the annual demand for carbon fiber of approx. 78,5 kt (estimation for 2018) are displaced in Figure 3 and Figure 4 being itemized by individual region. It should be noted that due to different types and qualities and also due to varying country-specific applications, a direct comparability between national production and own demand can´t be ensured. Yet some characteristics can indeed be used to sketch superordinate market structures. The segmentation of CF-Capacities can be more detailed on basis of available data in direct comparison to CF-Demand as nearly all production sites are known by their distinct location.

It is shown that the recently largest name plate capacity in located in the USA (45,3kt/a; 30%), followed by Japan (27,1 kt/a; 18%) and China (17,3 kt/a; 12%). Following countries are mostly represented by only one or two established plants each. In view of the comparatively small number of major CF manufacturers already holding several sites, a quite highly dispersed overall picture is still created. Even though a great number of framework conditions influence the manufacturers' decision for the definition of locations, it seems reasonable to conclude that the following sales channels and also R&D-structures could be a favored factor. Impact of toll and currency exchange rates are minimized at the same time. Local plant capacities adapted to individually required fiber qualities are built in immediate proximity to processors and end users. This also applies to the two major build-up programs by Kangde and Hyosung. Large facilities in Rongcheng (China), res. Jeonju (South Korea) are established predominantly aiming at national processors and applicants. In the case of Hyosung, LG Hausys and Hyundai are considered to be the major customers. The Kangde Group is planning its own value chain including part production at a neighbouring site in Changzhou, looking for an entrance to the Chinese automobile market, i.a. in the field of E-mobility, as well as the national aviation program connected to COMAC C919 and CRAIC CR929.

Using a similar styled large-scaled split like Figure3, approx. 55,3kt/a (37%) fall to the capacities of North-America (incl. Mexico) compared to 24,4kt/a (16%) for Europe, 27,1kt/a (18%) for Japan and 37,2kt/a (26%) for the "remaining parts of Asia including the pacific region and China" (rAPC), leaving some 5,3kt/a (3%) to the "rest of the world” (RoW). In relation to the reporting period of the previous year, strongest capacity growth is seen in North-America (+13,6%), followed by rAPC (+12,05%) and Europe (+9,91%). The expansion programs that have just been launched by Kangde and Hyosung are expected to shift this order quite soon. For Japan and RoW no changes has been recorded in this year´s survey period.

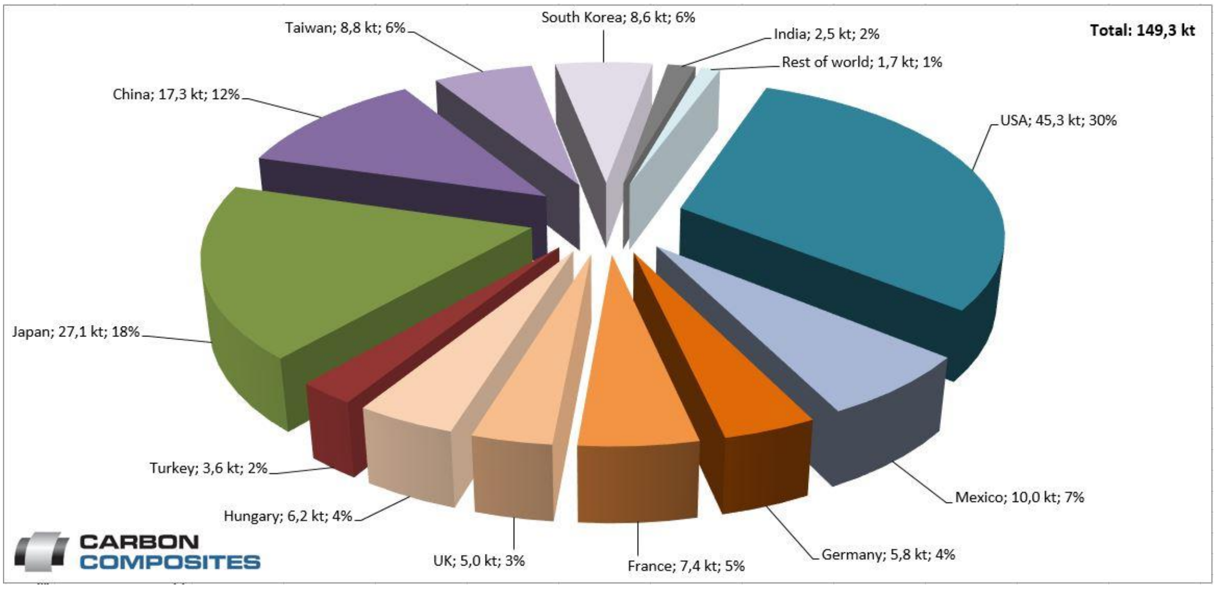


Figure 9: Global CF-Demand in Thsd. Tons by region (11/2018).

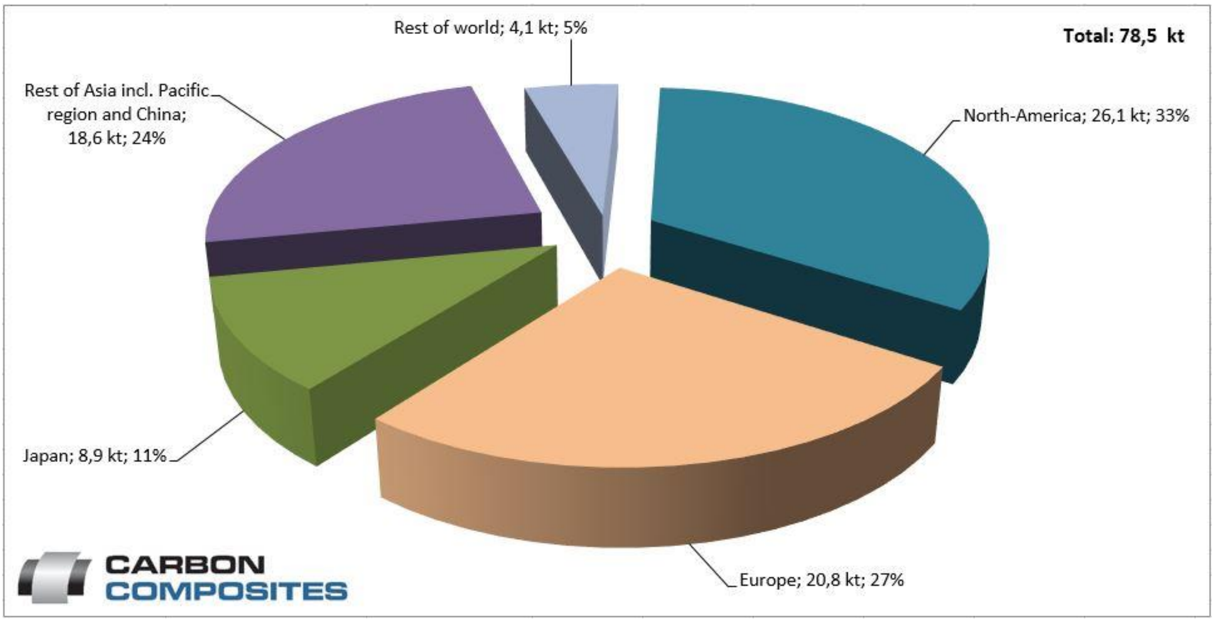


Figure 10: Theoretical, annual CF-Capacity in Thsd. Tons by region (11/2018).

These plant capacities face a global CF-Demand of 78,5kt/a (estimation for 2018). Although North-America is maintaining its leadership (33%), a detailed view shows rAPC having the strongest individual growth (+13,3%/a) compared to previous reporting period, put next to Europe (+10,4%/a), Japan (+10,9%/a) and also North-America (+11,4%/a). In summary the average overall growth (CAGR) results in approx. 11,45% since 2010.

Superordinate characteristics can be pictured even though a direct comparability can´t be established due to several reasons including such as different fiber types. Basis is taken from the percentage shares of the total market, since e.g. the absolute numbers of name plate capacities are directly linked to theoretical occupancy rates and thus the percentage shares are expected to portray the actual circumstances more accurately.

Within this framework, in the cases of North-America (33% vs. 37%) and rAPC (24% vs. 26%) a good balance between demand and capacity can be determined. Contrasting to this is Europe (27% vs. 16%) showing a market structure that is very dependent of imports. The economic region of Europe is subjected to comparatively high energy costs and environmental requirements at the same time. This may explain comparatively small establishment of CF-producers as being a very energy intensive task. The value creation is consequently pushed backwards within the overall process chain, with focus on processing and end user applications for CF. The composition of the Japanese market (11% vs. 18%) constitutes a direct contrast to European conditions as a considerable amount of excess supplies allows for extensive exports. The Japanese industry is traditionally very well represented the fields of chemistry and raw material extraction. From his position portfolios were expanded at an early stage to the carbon fiber area, while proven business models kept unchanged most often. With an extension to all of Asia (Japan + rAPC) this structure is repeated accordingly. The demand (35%) is opposed by a very high capacity with a share of approx. 44% (60,3kt/a) of the worldwide name plate capacity.

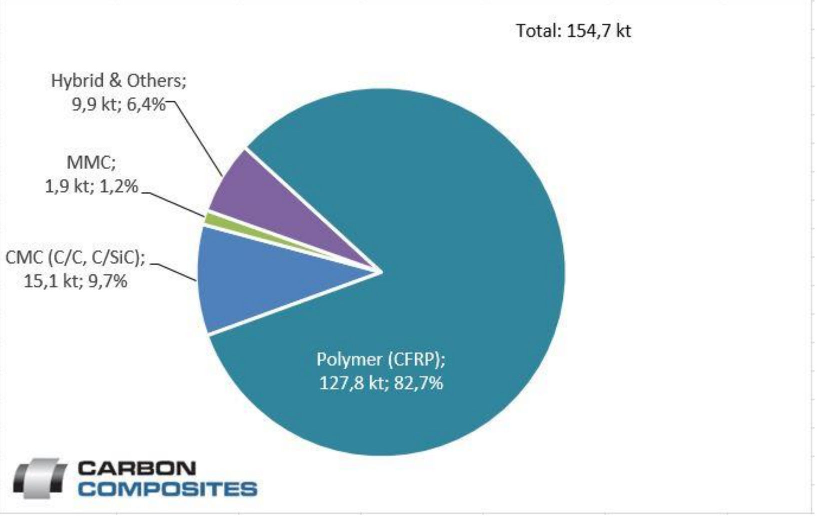
13 The global Carbon Composites Market

13.1 Distribution by matrix, global CC-Demand and global CC-Turnover

Almost the entire carbon fiber production is processed into composite materials. Thereby, the fibers are embedded into a matrix in order to combine the best properties of the different material categories to a new material. Next to a great number of further advantages, carbon composite materials (Carbon Composites; CC) have an especially high lightweight construction potential. Depending on the respective use, different metallic alloys (metal matrix composites; MMC), ceramic compounds (Ceramic-Matrix-Composites; CMC) or carbon (carbon-fiber-reinforced carbon; CFC) can be used as matrix material. The majority of composite materials however is equipped with a polymer matrix (carbon-fibre-reinforced polymer; CFRP). Figure 5 shows an itemization of carbon fibre composites (CC) broken down according to demand and achieved turnover. The major market segment CFRP (in terms of turnover) is further divided into different types of polymer matrix used, with an itemization in terms of turnover can be made more adequate on basis of given data.

This highlights the very dominant market position of CFRP amongst all carbon fiber composites, judged according to tonnage (127,8kt; 82,7%) as well as achieved turnover (16,48bn US$; 71,2%). This market position has seen a continuous consolidation over the past years. Within the CFRP-segment thermoset matrix systems are accounted for the major share of the overall turnover (69%). The share of thermoplastic matrices however is steadily increasing since 2014 (24%; 25%; 26,3%; 27,6%) to 28,8% today, which represents an average annual growth (CAGR) of about 16,8% related to overall revenue. Non-Polymer matrix systems currently account for a share of approx. 17,3% in terms of volume, but achieve 28,8% of turnovers at the same time. This is mainly caused by the contained customized solutions, e.g. within aviation and Space-applications, that allow for obtained high prices. The greatest percentage among non-polymer matrix systems is held by CMC materials, used e.g. as high performance brake discs or materials for high temperature applications.

In sum the worldwide demand for Carbon Composites (CC) amounts to approx. 140,6kt for the year 2017, with an overall turnover of approx. 21,14bn US$ being achieved. As compared to the previous year´s report this depicts a growth of 10,97% (CC-Demand) or 9,48% (CC-Turnover). This represents an average annual growth rate (CAGR) of 10.03% (CC-Demand) or 9,51% (CC-Turnover) since 2013. Based on this data, the global CC-Demand for 2018 can be estimated to 154,7kt with an achievable global CC-Turnover of 23,15bn US$.



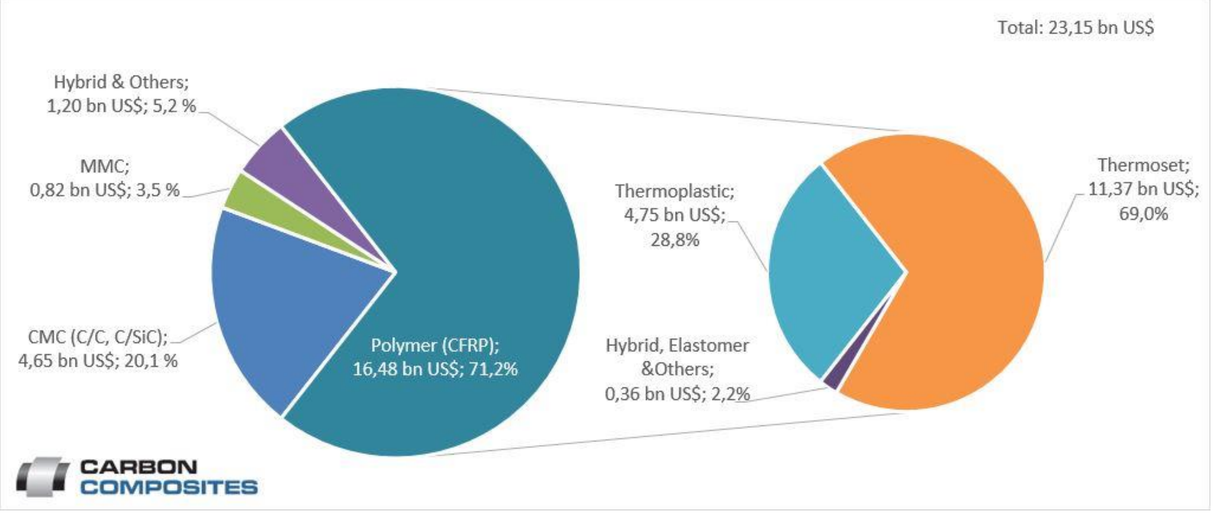


Figure 11: Distribution of the global Carbon-Composites market by matrix materials with reference to demand (above) and turnover (below; 11/2018).

13.2 Development of the global CFRP market

The material category CFRP represents the largest segment within the carbon composites market and is still considered to be the most relevant driver of growth in its branch. In 2017, the global CFRP-Demand was determined to be 114kt. As compared to the year before this represents a growth of 11,4%, exceeding the previous report´s expectations. The average annual growth rate (CAGR) therefore results in 12,8% since 2010. Based on this, the global CFRP-Demand for 2018 can be estimated to be 128kt.

The worldwide overall turnover with CFRP in 2017 amounts to approx. 14,73bn US$ and a growth of approx. 11,3% compared to the previous year was achieved. This corresponds to an average annual growth of 11,88% since 2013 (CAGR). The preliminary overall CFRP-Turnover can thus be estimated to be 16,48bn US$ for 2018.

In analogy to the CF market, CFRP shows a constantly strong growth both with regard to required quantity (demand) and achieved turnover after 2015 (91kt; 11,6bn US$) and 2016 (101kt; 13,23bn US$). For the upcoming years the expectations are accordingly positive also benefitting from the strongly increasing global economic situation.

Figure 12: Development of the global CFRP-Demand in Thsd. Tons (*Estimations; 11/2018).

CFRP is the dominant segment within the carbon composites industry, regarding both turnover and required quantities. According to this, different characteristics overlap in terms of the market structure. Just like for CF, in the case of CFRP the available data supports the cautious forecast that the balanced zone of the growth rates can be slightly elevated compared to the previous assumption. It still remains to be seen at which exact point the annual growth rates start to level off. In direct comparison it is a striking factor that the growth rates for CFRP always have been slightly stronger than those for CF over the past years. Meanwhile the values approach each other more and more, which also becomes apparent when regarding the CAGR for demand (CF: 11,45%; CFRP: 12,28%) and turnover (CF:11,10%; CFRP: 11,88%). The difference that had been present for a long period, may have been caused by the significantly less concentrated market concentration of the CFRP segment compared to the CF market. The great number of active participants generates a natural competitive pressure, accelerating the overall development. In addition to that, the CFRP segment allows for more options of influence within the value chain, so that a variety of following process steps can be optimized in parallel, whereas prices and profit margins in the preceding CF production remained constant over longer periods of time.

This fundamentally different market structure is the most relevant characteristic when explaining the respective growth figures. It should be pointed out that meanwhile in a lot of corporations there is explicit activity oriented towards a vertical market integration. Thereby it is attempted to depict larger shares of the value chain within the own company or at least to offer holistic solutions via strategic cooperations. This approach is predominantely promoted by CF manufacturers who hold the necessary resources as well as a network with potential customers due to high market shares in their segment.

13.3 CC-Demand und CC-Turnover by region

The worldwide demand for carbon composites of approx. 154,7kt, along with the associated turnover of 23,15 bn US$ (estimations for 2018) are depicted by region in Figure 7 and Figure 8.

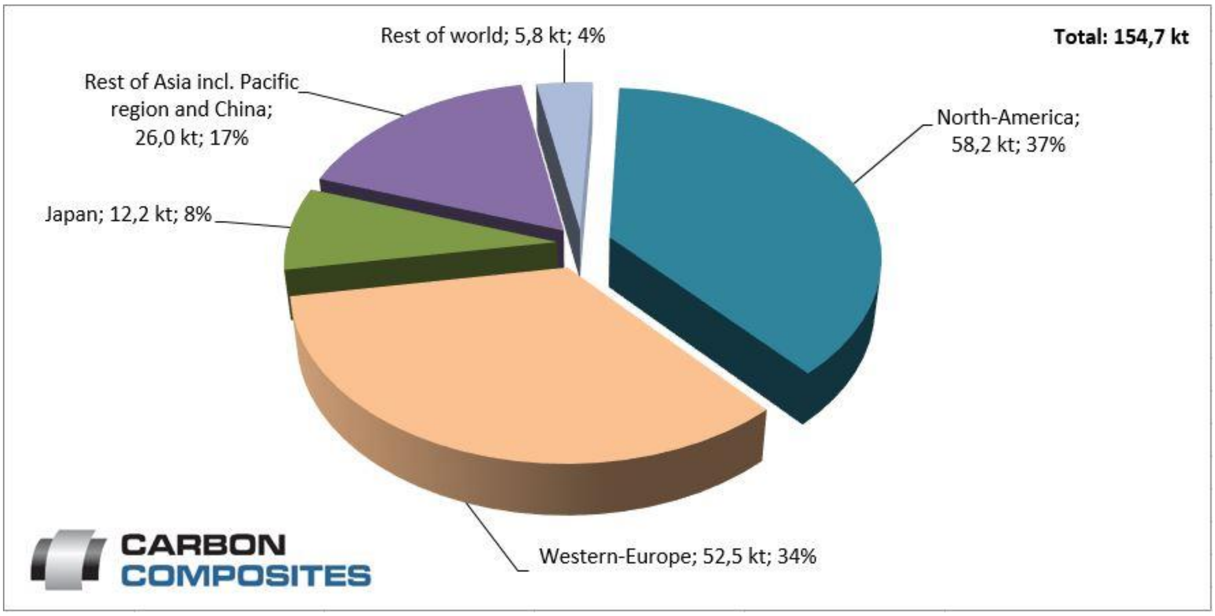


Figure 13: Global CC-Demand in Thsd. Tons by region (11/2018).

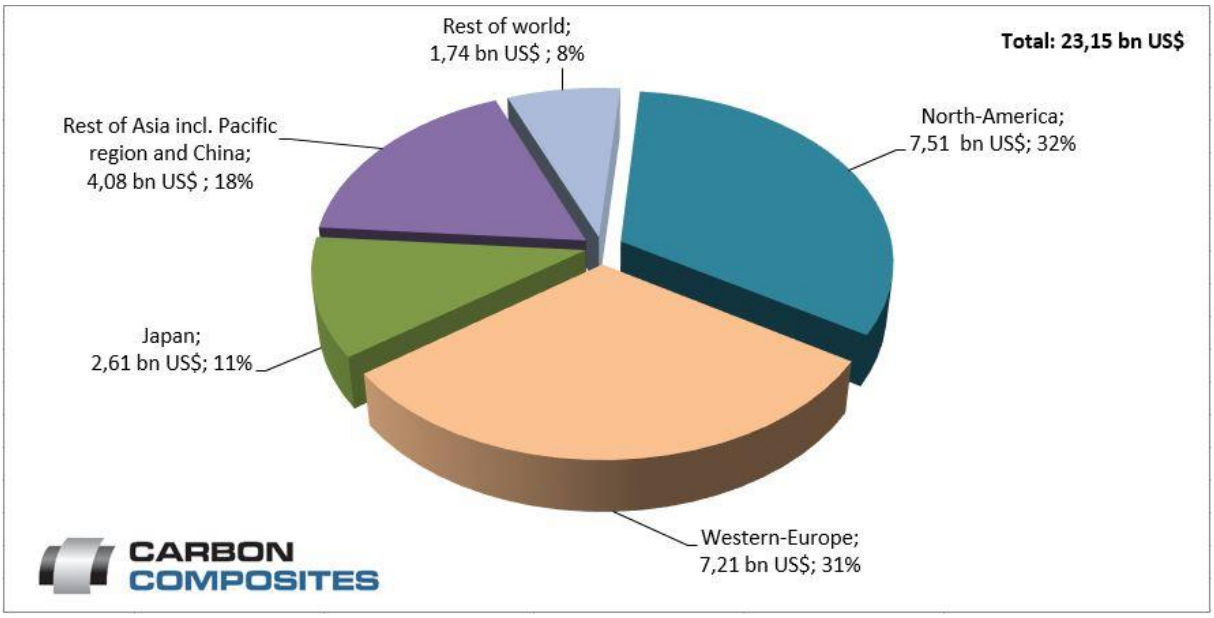


Figure 14: Global CC-Turnover in billion US$ by region (11/2018).

An interesting correlation shows up with the help of the explanation from Figure 3 since the regional distribution of the required CF-Demand is very similar to the CC-Turnover distribution. This may be explained as nearly the complete CF production is used for CC production and thus requested CF quantities directly result in local CC-Turnover.

The assessments resulting from the Interpretation of Figure 3 and Figure 4 about superordinate market structures can furthermore be extended as follows when taking into account Figure 7 and Figure 8. At first, the presented estimate shows the required CC-Demand for the Asian region (including Japan and China) to be smaller than those in North America (37%) and Europe (34%) being at approx. 25% in 2018. This can be explained with the majority of final assembly plants of CC processors being located in Europe or North America still today. The CC material flows, usually in the form of finished parts, are therefore required in those regions. Over the last years the Asian region has however shown a significant growth of CC-Demand. With regard to the absolute required quantity a CAGR of 12,09% can be estimated (since 2014) which is disctinctly above the growth in demand of the overall CC market (10,03% CAGR since 2013).

Considering the whole Asian region, the existing value chains are now extended, after completing large CF production capacities. Presented amounts for CC-Turnover, being evenly distributed over all regions, underline this trend. This suggests that the CC processing industry, hence part manufacturers, are already very active in the Asian region and generate those turnovers. For the upcoming years it is thus to be expected that local end users at the end of the value chain will follow accordingly, just delayed to the establishment of large CF production capacities or already launched expansion projects, and after respective processors have settled. China, South Korea and Japan are in individual key positions, however the framework conditions are regionally different. It remains to be seen whether the rather protectionist structures focused on building national value creation streams, or globally acting networks using international synergy potentials, will prevail.

13.4 CC-Demand und CC-Turnover by application

The global annual required quantity for carbon composites of approx. 154,7 kt and the respective turnover of 23,15 bn US$ (estimation for 2018) are depicted by application in Figure 9 and Figure 10. It should be pointed out that the information base in this section has been significantly enhanced compared to the previous year's report, which enabled the use of new calculation methods. Since with this approach a direct comparability cannot be ensured, growth forecasts have been renounced in this section for this year´s report.

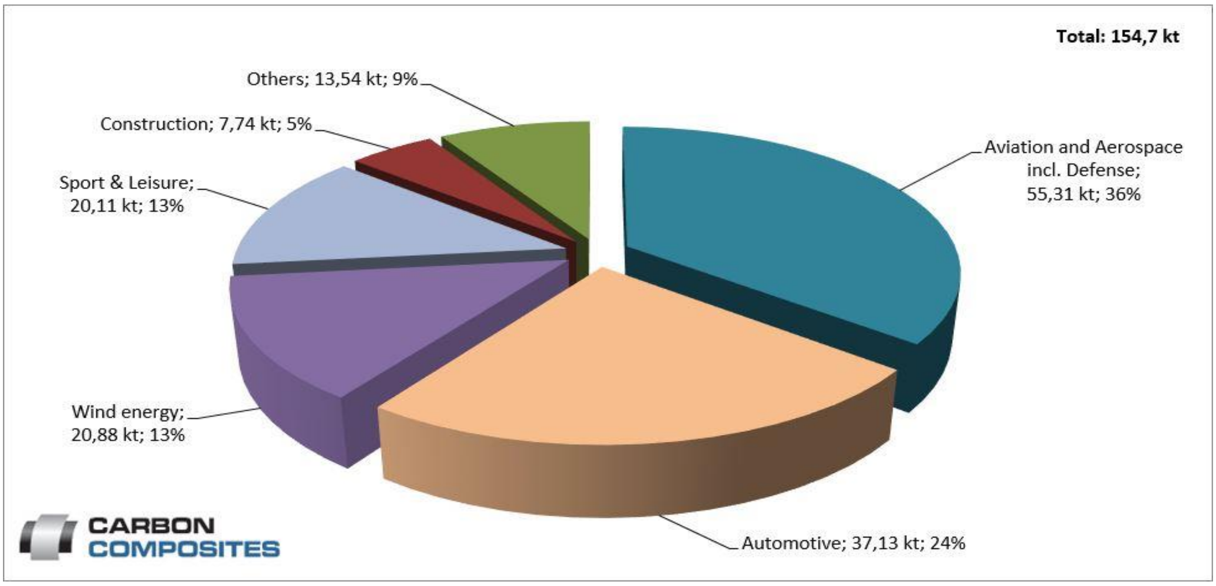


Figure 15: Global CC-Demand in Thsd. Tons by application (11/2018).

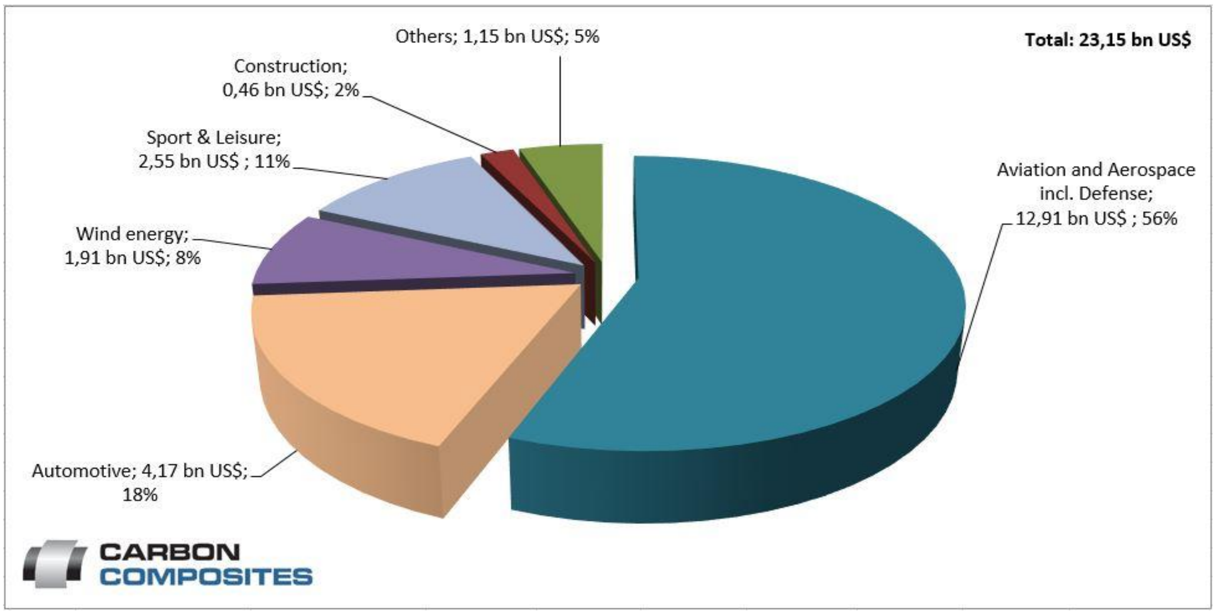


Figure 16: Global CC-Turnover in Thsd. Tons by application (11/2018).

The segment of aviation and aerospace (incl. defense) has established as a strongly dominant turnover segment and entails approx. 56% (12,91 bn US$) of the overall CC-Turnover, but only approx. 36% (55,31 kt) of the worldwide CC-Demand were requested from this area. High quality and safety requirements and the thereto related costs for certifications and qualifications in this field of application lead to elevated prices per kilogram. In an era of constantly low airfares, commercial aviation can be stated as the most important growth driver. Current flagship models Boeing B787 and Airbus A350XWB use CC in large proportions. Both models are currently still in their production ramp up in order to respond to the increasing demand by airlines. In addition to that, new models such as the Boeing 777X or the Chinese COMAC C919 will also incorporate a great number of CC parts into their structures. But also such aircraft types being produced in high quantities, like the Airbus A319/20/21neo series and the Boeing 737 MAX 7/8/9 series, also use CC in several modules such as the engine cowling (CFM LEAP).

In the defense segment, it is predominantly the aircraft programs F-35, Boeing KC-46, Airbus A400M and Embraer KC-390, as well as the helicopter programs V-22 Osprey, Black Hawk, Sikorsky CH-53K and Airbus H160 that lead to a stable demand [9] [20] [26]. The very positive overall environment was recently affirmed during the „Farnborough International Airshow“ as one of the most important sales events in the industry. Within this framework the International Air Transport Association (IATA) published their assessment of growth of 7,6% for 2017 for the important characteristic „revenue passenger mile“. At the same time, ever increasing environmental- and noise-restrictions as well as the development of more efficient propulsion systems lead to a higher exchange rate for older aircraft models and also to upgrade programs (helicopter rotor blades, aircraft engines) which also increases the demand for CC [20]. The current activities in the space industry already have a positive impact on the composites market too. For the years to come, an accelerated growth is expected due to the increasing privatization and rising competitive pressure. Innovative companies like SpaceX or Blue Origin even yet provide a vision of future aerospace technology and rely increasingly on composite materials, e.g. for boosters, panels and cargo doors [9] [27] [28]. A very positive outlook for this sector can be sketched accordingly.

The automotive sector is the second largest segment, both regarding turnover (4,17 bn US$; 18%) and required quantity (37,13 kt; 24%). In standard automotive engineering a significantly increased price sensitivity, especially regarding large series compatible process technology, defines the material choice. The lightweight design aspect, respectively the resulting weight savings, provide a significantly lower added value at this point compared to the aviation sector. In order to benefit from the advantages of anisotropic fiber structures, new part designs including adapted manufacturing technologies are necessary in many cases. Thereby manufacturers have to overcome high investment and development expenses. The increasing interest in those technologies on the part of Tier1 suppliers, with the objective of extended portfolios, is noticeable. Alongside small and medium sized businesses with a high degree of innovation, nearly all globally operating suppliers take part in respective research and development projects. The OEMs themselves are active as well, usually via strategic cooperation with selected CF and CC producers. An example which is very remarkable for the period under review are the CFRP-components for the Audi A8, R8 Coupé, R8 Spyder and R8 e-tron series, developed in collaboration between i.a. Voith Composites and Audi [13]. The applied combination of fiber placement technology and high pressure RTM has been developed to a continuous process chain until the required large series readiness level. The high flexibility leads to the assumption that a transfer to further parts will happen in the near future. For a long period of time, the Sheet-Molding-Compound (SMC) technology has also been studied extensively in the automotive sector. The focus is on highly integrative structures that have been implemented in prototype scenarios but also in series applications. The complex-shaped rear door frame of the new Toyota Prius PHV (Release: February 2017) for example is manufactured using SMC materials from producer MCCFC, reaching cycle times of 2-5 min [15]. All things considered, in the very complex market structure of the automotive sector, it is not yet possible to estimate the scope of how extensively CC materials will penetrate the market. Because of extremely high mass flow rates in the automotive industry as a whole, and because of the constant growth, even smallest application quantities per vehicle have a significant effect in the comparatively young overall CC market. Superordinate restructurings due to the shift towards E-mobility or towards the fuel cell, furthermore open up completely new opportunities for considering new materials in the material choice of future vehicles. Possible multi-material concepts convincingly suggest a positive perspective for the future.

With the comprehensive implementation of climate targets in focus, the wind energy sector as well is benefitting from restructuring measures. The efforts to implement the transformation of the energy system in Europe increase, for example in the backdrop of the currently discussed withdrawal from brown coal as an energy source in Germany. Renewable energy sources have equally gained in importance in Asia over the last years. At the same time it remains to be seen which effect the resignation of the USA from the Paris climate convention will have on their national wind industry in the upcoming years. On a technical level however, there is a high application potential respectively a great utilization necessity for increasingly large wind rotor blades, especially in offshore applications. Meanwhile, smaller blades are often replaced by larger ones (repowering). Nearly all wind turbine models of newer generations, laid out for large dimensions, rely on high volume usage of CC for tension and compression chords. To name an example: In October 2017 already, the worldwide largest wind turbine manufacturer Vestas Wind Systems has, in the framework of a perennial supply contract with Hexcel, started the transition to the „next generation“ wind rotor blade series [29]. According to information provided by the WWEA (World Wind Energy Association) in 2017 the worldwide installed overall capacity (539,6 GW) has increased by 10,6%. According to a GWEC (Global Wind Energy Council) report, the amount of new installations did however not meet the expectations. The reason put forward are auction processes for awarding new projects that are applied more and more often and lead to a bidding war and minimal margins [14]. At short notice, through this the growth of the segment, such as the application of CC, is slowed down. Over the medium and long term, climate targets move into focus so there still is a stable growth market. At the moment, approx. 85% of the overall wind turbine capacity are allocated to the Top 10 in a country-specific manner, led by China, the USA and Germany [14]. This means that there also is a high potential in previously untapped regions.

The sector of sports and leisure obtains the second highest prices per kilogram in comparison of required quantities and achieved turnover for the given estimations. CC show an already high market penetration in this segment and are established standard for many uses. This includes high volume areas of application such as commercial sporting goods production (golf, bicycles, hockey, tennis, winter sports) but also high-priced individual solutions, e.g. in boat building or competitive sports. In these areas, technical requirements and marketing aspects override price restrictions. Especially CFRP prevailed due to its excellent performance spectrum and also not least its image as a high performance material. With the focus being on the limits of technical feasibility a lot of innovations arise in this sector that could spread out to other areas of application, also in the field of CC materials. With increasingly short development cycles, exciting innovations can be expected in the future.

In civil engineering CC applications are sparsely established. At the same time, the intended purposes that are looked at promise a high mass flow rate. Even individual solutions would have significant impact on the overall CC market. Current extensive research activities focus, amongst others, on fiber reinforced depositors for concrete constructions (e.g. rebars, structural mats/ grids) that could substitute steel reinforcements. Since CC are corrosion resistant, great amounts of concrete could be economized because the minimum standards for wall thickness preventing moisture ingress could be lowered. This would have an important influence on the CO_2 - Emissions of the construction sector. Apart from this, solutions for certifications are also being discussed extensively (e.g. flame protection). The results to date promise far-reaching innovations in this segment. Over the mid and long term, this could make the presented conservative estimate obsolete.

Based on the available data, not all application areas can be broken down in detail, therefore the segments „medical technology“ (prostheses, X-ray coaches etc.), „marine“, „machinery and plant engineering“ and „energy storage“ (hydrogen tanks, industrial gas transport) are summarized within “Others”.

14 Trends and Outlook

14.1 Horizontal and vertical market integration

Parallel to the superordinate market movements, there currently is a lot of internal activities within the corporations. These split up into horizontal build-up processes aiming at expanding their portfolios on a defined product level and vertical expansion processes in order to exploit shares of the up- or downstream value chains. The objective is the buildup of holistic process chains within the own company or group being able to offer efficient one sourced solutions as well as performing as a supplier on all levels of the value chain. The following explanations are examples focused on CF manufacturers who play a key role [30].

Looking at the horizontal diversification, historically established business models have significantly softened over the past years. Over long periods of time, portfolios and target applications have been comparatively clearly defined, but now these lines blur increasingly fast. The acquisition of Zoltek by Toray end of 2013 has certainly been a milestone of this evolution, entailing the extension of the portfolio, so far specialized on aeronautics, by large-tow products for wind power and automotive industry. At this point at the latest, nearly all large CF manufacturers started to broaden their product palette. Having gone through the respective development cycles, certifications are now pushed forward. Most CF producers already are (or will be in the near future) able to offer their own fibers in a broad range of qualities, tailored to the specific applications. Toray, for example, underlines their ambitions by the two currently running investment programs in Mexico and Hungary as a consequence of the higher demand from the automotive sector (Cadillac ATS/ CTS or Audi A8/ R8-series amongst other) [9] [10] [13]. However, Hexcel as well is extending its product range by the fibers HexTow IM5 and HexTow HM63 and is now covering a large cost-benefit spectrum [20] [31].

The latest development by SGL is combining automotive and aeronautics-specific requirement profiles in their “Advanced Modulus” fiber SIGRAFIL® C T50-4.8/280 (50K). Despite a high number of filaments (large-tow) this fiber achieves a very high

Young's modulus as well as it maintains high strength and is supposed to be available for both areas of use [32].

MCCFC is heading in the same direction, but has not yet been able to bring their development to product maturity. Interestingly, it is planned to use the production line in Evanston (USA) for this purpose., that has recently been taken over from SGL [15] [33].

Apart from defined product levels, CF manufacturers strongly promote a vertical market integration. By now, the producers could significantly enlarge their influence on the overall value chain, mostly through direct acquisitions or in the framework of strategic cooperation (e.g. joint ventures). Initially, the raw materials for CF in the form of basic chemicals and precursor fibers, were paramount. The downstream textile processing to fabrics, non-woven fabrics and finally also to binder-coated semi-finished products and prepregs followed as the next step. Nearly all considerable CF manufacturers hold extensive capacities in these areas by now. At the same time, manufacturers keep investing, which is proven by the finished PAN line in Decatur (USA), a NCF line in Leicester (UK) as well as a large plant in Casablanca (Morocco) for the manufacturing of honeycomb core materials on the part of Hexcel [20]. Hexcel also acquires the French corporation Structil, a former joint venture between Safran Ceramics and Mitsubishi Chemical Corp. as a manufacturer for prepregs and pultrusion profiles for engine cowlings and interior components [20]. Toho also is investing i.a. in their joint venture INITZ (with SK Chemicals Korea) for the mass production of matrix materials, especially PPS [18]. By the end of 2017, their competitor Solvay (Cytec) has taken over the PAN producer European Carbon Fiber GmbH (ECF) for the production of a 50K large-tow variant [34]. Solvay has furthermore founded a joint venture with Strata (Mubadala) in Al Ain (United Arab Emirates) in order to produce prepregs for the primary structure for the Boeing 777X program [35]. The takeover of the „composites materials division“ TCAC (Netherlands) of TenCate by Toray mid-2018 is probably the largest acquisition during the reported period as well as the respective corporate history [36]. Hereby Toray secures extensive additional capacity for prepreg production, including thermoplastic tapes [9] [37].

By constant integration of further processing steps, the current focus of this vertical expansion is now on the level of part production. This is where CF producers find a significantly less dense market environment with many small and medium sized participants. Contracted companies that already act as suppliers more and more become attractive targets for acquisitions. Against this background, Toho acquires Continental Structural Plastics Holding Corporation as one of the largest automotive SMC suppliers worldwide [38]. This strategic decision is accompanied by a more pronounced orientation towards the automotive sector. The CFRTP Sereebo-Process showing cycle times < 1,5 min [39], sensitively kept under lock and still being under development in cooperation with General Motors, probably also plays a role here being a "thermoplastic SMC-Process". Competitor MCCFC is also investing in the SMC technology, acquiring Gemini Composites (USA) and by having built up SMC capacities in Vilshofen (Germany) [40]. Hexcel implements a forward-thinking takeover with Oxford Performance Materials (OPM), a leading OEM for orthopedic and neurologic implants, manufactured by 3D printing according to medical-technical standards. The applied OXFAB®-technology is already being used for high performance thermoplastic parts (e.g. PEKK) in aeronautics as well as the energy and electronics sectors [20]. CF manufacturer SGL currently puts an extensive re-orientation into practice. In the course of this, by the end of 2017, the external holdings of the former joint ventures SGL-ACF (formerly with BMW) and Benteler-SGL (formerly with Benteler) were completely taken over. Parallel to this, their own holdings of SGL-Kümpers were sold to their joint venture partner [14], which then sold the whole business to Kangde Group. Kangde is very active in this field as well, e.g. also using several Memorandum of Understandings (MoU), i.a. with Hexion [41] [42] [43].

A rising number of acquisitions and a thereto increasing market concentration is now facing a very high number of startups, which enter the market very often with a focus on product level. For larger business groups it is thus getting more difficult to identify appropriate acquisition targets. It remains to be seen whether a market composition similar to the CF-Production-Sector will build up or whether the currently very diversified environment, accelerated in its evolution by competitive pressure, will prevail on the long term.

14.2 Restructuring as an entry opportunity

The growth of the global automotive industry amounts to approx. 2,4% for 2017, according to a study conducted by IHS Markit. The German "Verband der Automobilindustrie" (VDA) counts the growth to be approx. 2%, based on a different analysis model [14]. In the background of the ongoing diesel crisis, involving customers to have lost trust and high additional costs for manufacturers, those growth rates are to be considered to be quite positive and they underline the strength of the overall market. Even though country-specific regulations can be very different from each other, overall a trend towards more serious environmental restrictions is to be expected. For the automotive industry in the European Union, taking a leading position in the global competition, allowed emission limits are consistently lowered. Since 2009, passenger cars and small utility vehicles are subject to a CO2 regulation, whereas the defined target of 130 g CO2/km for 2015 was lowered to 95 g CO2/km for 2020 (new vehicles). At the moment, details of a further reduction until 2030 are defined, as well as an extension of the regulations to heavy trucks is discussed [44]. The value is assessed for the comprehensive fleet by manufacturer overall, but already induces a necessity for solutions in terms of low emission technologies or alternative propulsion concepts. The VDA believes the respective investments to amount to 40 bn € until 2020 for german manufacturers alone. The technical progress in E-mobility and the according battery technology have risen the interest of nearly all considerable automotive manufacturers. Until 2025, electrical vehicles are said to account for 25% of all new cars registered in Germany [14].

As seen by the authors of this report, the extensive restructuration of the automotive sector holds great potential for the application of CC materials. The given lightweight design potential can contribute to a direct economization of emissions, especially in very defined areas of application. Resulting from the current upheaval, unique entry opportunities for new material categories arise. Historically, only comparatively small adaptions were possible in order to maintain established, adjacent processing steps. In the course of new drive concepts, in many cases large areas of the overall vehicle need to be redesigned, including the respective material and process selection. This significantly lowers market entry barriers which in consequence are easier to overcome by CC materials and connected manufacturing processes.

The very high extend of restructuring measures and the numerous electrified models spread out over a broad area, from middle class to luxury models to electrically driven sports cars. At the same time this opens up entry opportunities for a great number of start-ups and international joint ventures who so far would not have been able to compete with established OEMs. This implies a new competitive pressure around the innovation field of E-mobility, speeding up the overall development cycle. A higher number of varieties allows for the use of synergy potentials and finally results in improved technical solutions. On the basis of these parallel evolutions, CC materials are very likely to successfully establish themselves in several points within multi-material concepts of future models.

15 Further market development & concluding observations

The worldwide overall market for carbon fibers and carbon composites shows a stable growth in the current report period. The average growth numbers vary between 10 – 12% for the demand, and 9,5 – 12% for the achieved turnover (see chapter 3.1, 4.1 and 4.2). The absolute numbers globally amount to currently approx. 78,5 kt (CF), 128 kt (CFRP) and 154,7 kt (CC) (estimations for 2018), whereas an overall turnover of 2,88bn US$ (CF), 16,48bn US$ (CFRP) and 23,15bn US$ (CC) is expected to be achieved (estimations for 2018).

The positive outlooks are supported by strong individual indicators for the market:

- Continuing significant investments, especially on the part of CF producers increasing their plant capacities and extending their product portfolios
- Increased understanding of the materials and process know-how
- Increased acquisition activities, often initiated by CF manufacturers, and a high number of newly founded start-ups and joint ventures
- Willingness to collaborate and established supplier relationships

CF manufacturers in particular take a key position in the current market composition. Their horizontal diversification is very advanced so the individual producers have application-specific, optimized products at their portfolios. The well balanced cost-effectiveness ratios allow for a great number of innovative applications. With regard to the vertical integration as well extensive value creation chains have been build up. Hexcel for example is now producing PAN precursor exclusively for their own CF production. In processing as well, approx. 80% is covered by their own CF (textile semi-finished products and prepregs) [20]. Due to the high market concentration and the accompanying high shares in the CF market, as well as respective supplying structures, they hold necessary resources to effectively extend their network. The extended value chains result in transferred business models, also increasingly incorporating the sales channels from their acquired subsidiary companies. Elaborate certification processes, especially in the aeronautics industry, are currently considered to be the major barrier for vertical expansions. This already leads to complicated cross-linked sales between CF manufacturers and associated processors.

The manufacturers' consistent expansion strategy not only shows the continuously strong trust in the growing sector, but also underlines the high profitability of the agglomerated business groups as their balance sheets show. This is one of the reasons why CF expansions are deeply embedded in the corporate strategy, usually in the form of discrete management projects. The continuously high target expectations are further supported by long-term supplier contracts, especially in the aeronautics and space sector, proven for example by Toray collaborating with Boeing and SpaceX [9] or Hexcel and UTC Aerospace Systems [27].

Parallel to this, manufacturers signal a strongly increasing demand for large-tow varieties (50K), especially from the wind energy and automotive sectors. Against this background, Vestas Wind Systems for example, one of the major manufacturers worldwide, is currently transforming their production to the next generation of wind rotor blades with a higher percentage of CF and has prolonged the sub-contracting arrangements with Hexcel and Dow-Aksa [29]. The agreement with Dow-Aksa alone amounts to a volume of approx. 300 Mio. US$ over the course of four years for supplying pultruded CF reinforcing elements (spar caps) [45]. On top of this, as a consequence of current political discussions (diesel crisis, more restrictive environmental and noise regulations, progressing energy system transformation) as well as the upheaval in the automotive industry towards E-mobility, a positive stimulation of the CC market is expected [44]. Toray is already signaling a starting but noticeable supply shortage, especially in the Asian region (notably China and India) [9]. In view of the currently announced local capacity expansions of Kangde Group, as well as Hyosung (Economic hub of northeast asia), this is of special interest, but the exact scope remains to be seen.

To sum up, numerous strong stimuli result in a positive forecast for the carbon composites market. The composition comprises stable fields of application that are established on the long term as well as a variety of innovative applications that are just at the outset of their market penetration. Contrary to a classic market inertia, respective material varieties increasingly qualify for multi-material applications.

16 Literature

[1] Lucintel LLC, "Assessment of Global Carbon Fiber and Carbon Composites Market," 2015.

[2] Lucintel LLC, Growth Opportunities in Global Carbon Fibre Market: 2014-2019, Irving, USA, 2014.

[3] Acmite Market Intelligence e.K., Market Report: Global Carbon Fiber Composite Market, Ratingen, 2014.

[4] Acmite Market Intelligence e.K., Market Report: Global Carbon Fiber Composite Market, Ratingen, 2016.

[5] I. E. Inc., "Carbon fibers & carbon fibre reinforced plastics (CFRP) - A global market overview," USA, 2013.

[6] Industry Experts, "Carbon Fibers & Carbon Fiber Reinforced Plastics (CFRP) - A Global Market Overview," Industry Experts, India, 2018.

[7] V. G. Ltd., "Carbon Fibre Reinforced Plastic (CFRP) - Composites Market Report 2016-2026," UK, 2017.

[8] G. V. Research, "Composites - Market Analysis 2017," Advanced Materials - Grand View Research Inc., USA, 2018.

[9] Toray, "Annual Report 2017," Toray Group, Japan, 2018.

[10] Toray, "Production Capacity," 3 2018. [Online]. Available: https://www.toray.com/ir/management/man_010.html. [Accessed 15 8 2018].

[11] TechnicalTextile.net, "Zoltek - CF-Production in Hungary," 12 4 2018. [Online]. Available: https://www.technicaltextile.net/news/zoltek-to-increase-carbon-fibre-production-in-hungary-241635.html. [Accessed 28 10 2018].

[12] Plastics Insight, "Toray expands Zoltek capacities," 17 4 2018. [Online]. Available: https://www.plasticsinsight.com/toray-expands-production-capacity-of-large-tow-carbon-fiber-in-its-subsidiary-zoltek-companies/. [Accessed 28 10 2018].

[13] Composites World, "Rear wall reboot: One-stop, tow to tape to CFRP part," *Composites World Vol.4 No.6,* p. 48, June 2018.

[14] SGL Group, "Annual Report 2017," SGL Carbon SE, Germany, 2018.

[15] Mitsubishi Chemical Carbon Fiber and Composites, "KAITEKI Report 2017," Mitsubishi Chemical Holdings Corporation, Japan, 2018.

[16] Teijin Ltd., "CF Facility in South Carolina," 4 6 2018. [Online]. Available: https://www.teijin.com/news/2018/ebd180604_28.html. [Accessed 28 10 2018].

[17] Teijin Ltd., "New U.S. Subsidiary," 30 11 2017. [Online]. Available: https://www.teijin.com/news/2017/ebd171130_02.html. [Accessed 28 10 2018].

[18] Teijin, "Integrated Report 2017," Teijin Group, Japan, 2018.

[19] Hexcel Corp., "France Plant Roussillon," 2 10 2018. [Online]. Available: https://www.hexcel.com/News/News-Releases/2682/hexcel-officially-opens-new-plant-in-france-to-meet-growing-demand-for-advanced-c. [Accessed 28 10 2018].

[20] Hexcel, "Annual Report 2017," Hexcel Corporation, USA, 2018.

[21] Hexcel, "Hexcel Homepage - Locations," 2017. [Online]. Available: http://www.hexcel.com/About/Site-Locations/1454/hexcel-roussillon. [Accessed 06. 09. 2017].

[22] China Composite Group Corporation Ltd., "Zhongfu Shenying," [Online]. Available: http://www.ccgc.com.cn/en/news.php?show=detail&c_id=73&news_id=2528. [Accessed 28 10 2018].

[23] Plasteurope.com, "Hengshen Bombardier Supply Agreement," 10 10 2017. [Online]. Available: https://www.plasteurope.com/news/detail.asp?id=238040. [Accessed 28 10 2018].

[24] CompositesWorld, "Supply and demand: Advanced fibers (2016)," 17. 03. 2016. [Online]. Available: http://www.compositesworld.com/articles/supply-and-demand-advanced-fibers-2016. [Accessed 06. 09. 2017].

[25] Reliance Industries Ltd., "Integrated Annual Report 2017-18," Reliance Industries Limited, India, 2018.

[26] Hexcel Corp., "Airbus Helicopter H160 Supply Agreement," 22 6 2017. [Online]. Available: https://www.hexcel.com/News/News-Releases/2544/airbus-helicopters-selects-hexcel-as-supplier-of-advanced-composite-materials-for. [Accessed 28 10 2018].

[27] Hexcel Corp., "UTC Aerospace Systems Supply Agreement," 30 10 2017. [Online]. Available: https://www.hexcel.com/News/News-Releases/2577/hexcel-and-utc-aerospace-systems-extend-existing-contract-through-2030. [Accessed 28 10 2018].

[28] The Institute for Advanced Composites Manufacturing Innovation - IACMI, "Space X," 12 2 2018. [Online]. Available: https://iacmi.org/2018/02/12/spacex-falcon-heavy-launch-holds-promise-for-carbon-fiber-composites/. [Accessed 28 10 2018].

[29] Hexcel Corp. , "Vestas Supply Agreement," 16 10 2017. [Online]. Available: https://www.hexcel.com/News/News-Releases/2573/hexcel-and-vestas-expand-composite-materials-supply-agreement-for-wind-blades. [Accessed 28 10 2018].

[30] Composites World, "Composites Market M&A," 26 1 2018. [Online]. Available: https://www.compositesworld.com/columns/composites-bucking-the-market-trend-in-ma. [Accessed 28 10 2018].

[31] Hexcel Corp., "Mubea Carbo Tech Supply Agreement," 4 4 2017. [Online]. Available: https://www.hexcel.com/News/News-Releases/2467/hexcel-wins-contract-to-supply-carbon-ncf-to-mubea-carbo-tech-for-new-supercar. [Accessed 28 10 2018].

[32] SGL Group SE, "SGL Materialportfolio," 23 02 2018. [Online]. Available: http://www.sglnewsroom.com/de/meldungen/meldungen-detailseite.22657.php. [Accessed 28 10 2018].

[33] Mitsubishi Chemical Carbon Fiber and Composites Inc., "Acquisition SGL Plant," 2017. [Online]. Available: http://mccfc.com/acquisition-u-s-based-sgl-carbon-fiber-manufacturing-site/. [Accessed 28 10 2018].

[34] Solvay, "Annual Integrated Report 2017," Solvay SA, Belgium, 2018.

[35] Solvay AG, "Strata Joint Venture," 12 11 2017. [Online]. Available: https://www.solvay.com/en/press-release/solvay-and-strata-sign-final-agreement-united-arab-emirates-first-aerospace-materials. [Accessed 28 10 2018].

[36] Toray Industries Inc., "Acquistion TenCate Advanced Composites," 15 03 2018. [Online]. Available: https://www.toray.com/news/pdf/nr180315.pdf. [Accessed 28 10 2018].

[37] Koninklijke Ten Cate B.V., "Toray Acquisition TenCate Advanced Composites," 14 03 2018. [Online]. Available: https://www.tencate.com/en/News/2018/3/14/Toray-to-acquire-TenCate-Advanced-Composites. [Accessed 28 10 2018].

[38] Teijin Ltd., "Acquistion of Continental Structural Plastics," 5 1 2017. [Online]. Available: https://www.teijin.com/news/2017/ebd170105_00.html. [Accessed 28 10 2018].

[39] Composites World, "Teijin Sereebo Process," 14 3 2016. [Online]. Available: https://www.compositesworld.com/news/teijin-sheds-more-light-on-sereebo-manufacturing-process. [Accessed 28 10 2018].

[40] American Fiber Manufacturers Assoc. Inc. , "Aquisitiin Gemini Composites," 9 3 2017. [Online]. Available: http://www.fibersource.com/mitsubishi-rayon-purchases-composites-design-engineering-prototyping-firm-gemini-composites/. [Accessed 28 10 2018].

[41] Titan FRP, "KDC "1+N" ecological model," 4 7 2018. [Online]. Available: https://frptitan.com/china-composites-exhibition-organizing-committee/. [Accessed 28 10 2018].

[42] Business Wire Inc. , "Hexion Kangde MoU," 6 3 2018. [Online]. Available: https://www.businesswire.com/news/home/20180305006042/en/Hexion-Signs-Memorandum-Understanding-Kangde-Composites-Ltd.. [Accessed 28 10 2018].

[43] Zhejiang Jonggong power technology co., LTD, "CF automotive applications," 12 4 2017. [Online]. Available: http://www.jgtec.com.cn/home.php/en/news/details/id/849. [Accessed 28 10 2018].

[44] Verband der Automobilindustrie e.V. VDA, "CO2-Regulierung bei Pkw und leichten Nutzfahrzeugen," 2018. [Online]. Available: https://www.vda.de/de/themen/umwelt-und-klima/co2-regulierung-bei-pkw-und-leichten-nfz/co2-regulierung-bei-pkw-und-leichten-nutzfahrzeugen.html. [Accessed 28 10 2018].

[45] Dow Aksa Advanced Composites Holdings BV, "Vestas Supply Agreement," 7 6 2017. [Online]. Available: http://www.dowaksa.com/vestas-selects-dowaksa-to-support-rapid-global-growth-of-wind-energy/. [Accessed 28 10 2018].

[46] Jeffrey J. Cook, Samuel Booth; National Renewable Energy Laboratory, "Carbon Fiber Manufacturing Facility Siting and Policy Condiderations: International Comparison," CEMAC - Clean Energy Manufacturing Analysis Center, USA, 2017.

[47] Sujit Das, Josh Warren, Devin West: Energy and Transportation Science Division - Oak Ridge National Laboratory; Susan M Schexnayder, The University of Tennessee, Knoxville, "Global Carbon Fiber Composites Supply Chain Comptetitiveness Analysis," CEMAC - Clean Energy Manufacturing Analysis Center, USA, 2016.

[48] Formosa Plastics, "EHS Annual Report 2017," Formosa Plastics Corporation, USA, 2018.

[49] Formosa Plastics Group, "Annual Report & Shareholder Services," [Online]. Available: http://www2.fpg.com.tw/html/eng/annu.asp. [Accessed 28 10 2018].

[50] Formosa Plastics Corp., "Formosa Plastics Corporations and Subsuduaries - Consolidated Financial Statements," 7 8 2018. [Online]. Available: http://www.fpc.com.tw/fpcwuploads/files/2018Q2-Financial%20Statement.pdf. [Accessed 28 10 2018].