Sustainability of Fibre-Reinforced Plastics
An Assessment Based on Selected Examples of Application

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Abbreviations

BMC - Bulk moulding compound
CRP - Carbon fibre reinforced plastic
FCM - Fibre composite material
FRP - Fibre Reinforced Plastic
GRP - Glassfibre ReinforcedPplastic
RTM - Processing technique (resin transfer moulding)
SMC - Sheet moulding compound
WPU - Wind power unit

1. Introduction

In the past 50 years, plastics conquered many areas of life, not only the packaging market with the classic plastic bag, but also construction, transportation, and recreation, among others.

Modern medicine would be unimaginable without plastics, which is also true of today's aviation industry or racing. Our everyday life as we know it is entirely inconceivable without plastics.

Yet today's society sometimes disdains 'plastics' materials; these have a negative image in the eyes of consumers.

'It's only plastics anyway' – all of us have heard this phrase or similar statements.

But what exactly are plastics? Are they merely disposable articles that present a hazard to the environment if thrown away thoughtlessly?

Much has been published about plastics, especially in recent months – including their disadvantages. Not all of these claims are entirely untrue since plastics, just like any other materials, do have their drawbacks.

Aside from that, however, plastics open up enormous opportunities and have a variety of advantages.

The world is never purely black and white or entirely good or bad. This is also true of plastics.

AVK - Industrievereinigung Verstärkte Kunststoffe represents a special subset - fibre reinforced plastics. Owing to their properties, these materials are used in many areas of daily life, frequently without even being recognised as such. They have exceptional characteristics, are very broad in scope, and may contribute considerably to the conservation of resources and thus to the 'sustainability' concept.

This is the essence of this report.

It should be noted at this point that the following discussion is not intended to be exhaustive but should rather be understood as basic information. If you have any questions please contact AVK.

Enjoy the world of reinforced plastics!

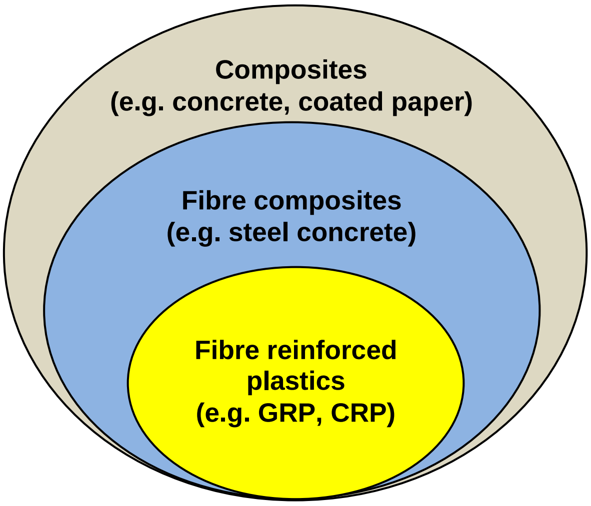
2. Background

The following chapter presents a rough outline of the fibre reinforced plastics market. It starts with a brief definition and material specification, followed by a brief overview of current areas of application as well as current production volumes. The chapter closes with a discussion of the basic advantages of fibre reinforced plastics.

For more detailed information regarding individual issues please contact us under the listed contact address.

2.1 Fibre reinforced plastics (FRP)

Fibre reinforced plastics (FRP) are generally referred to as composites; more specifically, as fibre composite materials (FCM).



In composites, two or more materials are combined in order to create a material with improved properties.

Examples include concrete, coated paper, paper, and laminate flooring.

Fibre composite materials (FCM) are specifically characterised by their fibre concent. These fibres are embedded in a matrix of any kind or are enclosed in such a matrix. Specific fibre-matrix combinations give rise to materials with certain properties that may differ considerably from one fibre composite to the next. This is also true of fibre reinforced plastics which, by definition, have a plastics matrix. Both the fibre and the matrix may be made of different materials. The resulting component part can be tailored to specification by adjusting the reinforcing fibre, the fibre content, and the fibre orientation accordingly.

Certain material combinations may be enhanced by additional parameters; fillers may be added to reduce the weight at a given component size, or chemical additives may be used to reduce the flammability of the materials respectively the fire hazard in subsequent application.

Fibre-reinforced plastics are primarily used for engineering purposes and are not usually found in short-lived consumer products. This also explains why the entire processing volume is rather low and why the public at large is less aware of them.

Yet most of us are using FRP every day. Do you drive to work or do you take the train? In this case you, too, have profited from FRP and their advantages.

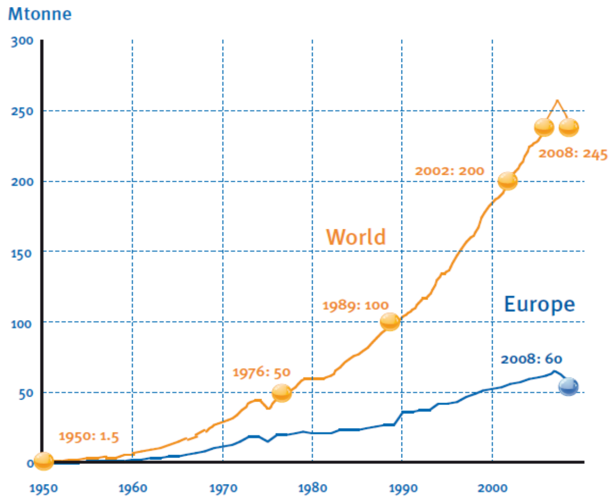
The next chapter presents some facts and figures to ascertain the production volumes and especially the economical impact of plastics.

2.2 *Facts and figures*

Reinforced plastics are part of the entire plastics industry and constitute a subset within this sector of industry.

In the introduction we have indirectly mentioned the considerable increase in plastics consumption during the past few years and decades.

In 2008, approximately 245 million tons of plastics were being processed worldwide – as compared to 1.5 million tons in 1950. Thus, this segment of industry clearly achieved above-average growth rates in the past few decades as compared to other materials, such as steel or paper.



Source: www.plasticseurope.com

The following parameters, which pertain to the German plastics industry (plastics machine engineering, plastics processing, and plastics production), provide a better indication of the economical impact of plastics:

- In 2008, a total of 3371 companies were active in the German plastics industry
- More than 393.000 persons were employed in this sector
- The combined turnover exceeded 84 billion Euros
- Thus, the plastics industry contributed approximately 6% to the turnover of the entire industrial production in Germany at

The plastics production volume targeted for the fibre reinforced plastics segment constitutes only a minor portion of the entire plastics production, amounting to a mere 3% worldwide. This comparatively minor contribution to the entire production volume of the plastics industry may be attributed to the specific areas of application.

As mentioned above, FRP are less popular in the consumer market, such as packaging, but are utilised primarily in the industrial context. This may, for instance, include the production of parts for the automotive industry or wind power plants. Mass production respectively large series production is the exception rather than the rule. This accounts for the comparatively limited total production volume.

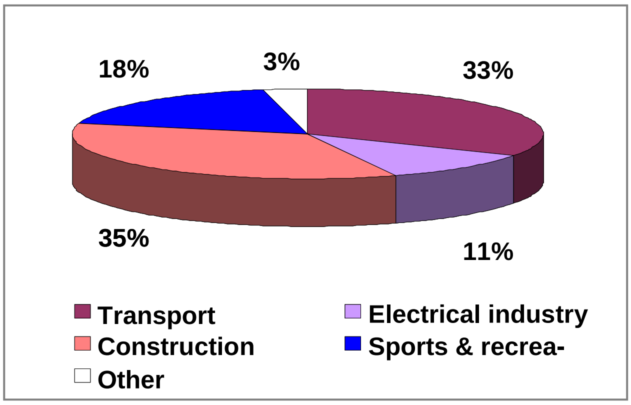
We would like to emphasise the fact that FRP are valuable materials, irrespective of the production volume; without them, certain special-purpose products could never be made and technical advancement would be inconceivable.

For detailed figures regarding production volumes and areas of application of fibre reinforced plastics please consult AVK's current market report that is available for downloading under: www.avk-tv.de

2.3 *Areas of FRP application*

The versatile combination of raw materials during the production and processing of FRP, as well as various different manufacturing techniques open up a variety of applications for fibre reinforced plastics.

The following figure shows percentage values for different application industries:

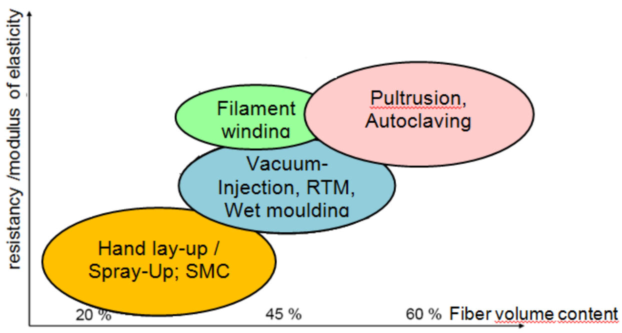


Source: AVK market report

The product variety in these fields is very high, spanning the range from large-scale manufacture in the automotive industry to large-sized components, such as hulls for ships, to tiny parts for the electronics industry.

The production process has a significant influence on subsequent areas of application and the material properties.

One may, for instance, vary the fibre content which directly affects the component properties.



Source: IMA Dresden

As shown in the previous figure, the fibre content of a given component may be used to directly influence the strength respectively the Young's modulus of the resulting component part (the fibre contents listed in this context are approximate values).

What kinds of products may be manufactured from FRP and what are the production processes that are typical of each product? Several examples based on the respective production processes are presented below:

- **Hand lay-up & spray lay-up** – These are open processes; components are manufactured manually. Thus, areas of application are small and final products are largely one-off productions, with a limited quantity being produced. The fibre content tends to be relatively low (normally between 20 and 40%).

- **Injection** (RTM, vacuum injection, pressure injection, injection moulding, transfer moulding (BMC) – Component parts produced by these partially automated techniques range from small parts to wind turbine rotors. Production volumes tend to be much higher, although they do not reach the output of a continuously operating mass production plant. However, this is not the goal with manufactured component parts. The fibre content of subsequent component parts is usually in the medium range (approx. 30-50%).

- **Compression moulding** (liquid resin press moulding, cold press moulding, hot press moulding, SMC, organic sheets, etc.) – Owing to the possible use of prepregs, these techniques make it possible to produce very large volumes that are fed into the compression moulding units as a melt, a sheet, or a preform. The automotive industry, for instance in conjunction with series production, always operates with fully automatic compression moulding units. The fibre content varies considerably but tends to be in the mid-range.

- **Filament winding / centrifugal casting** – These techniques are primarily used to make products exhibiting specific properties regarding the shape or the stress resistance. Centrifugal casting, for instance, gives rise to silos with a large diameter; while filament winding is used to create pressure vessels for the automotive industry and pipes for the chemical industry. The fibre content tends to be in the mid-range.

- **Pultrusion / autoclave procedures** – Pultrusion is a so-called continuous process used to make a variety of different profiles. Using considerable force, the fibre is pulled through a mould.
  Pultrusion and autoclaving, both of which operate at high pressure, lead to the highest fibre contents (theoretically up to more than 80%).

These techniques give rise to a very wide product range, as confirmed below.
Depending on the area of application, fibre reinforced plastics have specific advantages as compared to other materials, as shown in the next chapter.

2.4 Advantages of FRP

Many of the applications presented here rely on specific properties of FRP that are beneficial for the respective purpose. These may be influenced to a varying extent by the fibre content or the manufacturing technique. Depending on the demands, they may have enormous advantages over competing materials, such as steel, aluminium, concrete, or wood:

- **Low weight** – FRP are very lightweight compared to other materials. Thus, the weight may be significantly reduced without compromising the strength of the component part. On the other hand, component parts may be made much thicker without risking a weight increase.
- **Installation costs** (including transport) – The reduced weight facilitates the transport of large-sized component parts in particular. Other objects may, for instance, be moved manually without special facilities.
- **Favorable corrosion properties** – FRP are corrosion-resistant. This is a crucial aspect, for instance, for maritime applications, such as with gratings on drilling rigs, as well as for applications where the weather is a factor.
- **Good chemical resistance** – FRP, due to their resistance with respect to a variety of chemicals, lend themselves excellently to pipeline construction throughout the chemical industry.
- **Heat resistance** – Reinforced plastics and thermosets in particular form a tight lattice structure during manufacture that cannot be destroyed or dissolved even at high temperatures. They do not lose stability at extremely high temperatures, either. Apart from these characteristics one may, for instance, add flame retardants (additives) to FRP.
- **Durability / longevity / maintenance** – FRP are used, for instance, in conjunction with bridge and structural engineering. After all, these materials are weather-resistant and also (at least largely) impervious to road salt. This eliminates the need for the kind of demanding maintenance that is required, for instance, with steel.
- **Freedom of design** – Corresponding processing techniques make it possible to produce component parts with a complex geometry or a relatively large size (such as underbody elements in automotive construction or frames) 'in one shot' respectively in one piece.
- **Specific mechanical properties** – Depending on the type or amount of fibres added, the specific properties of finished products (such as rigidity or strength) may be adjusted in accordance with the demands of specific applicational purposes.

There are many more benefits besides the positive properties mentioned in this context. A full detailed list, however, exceeds the scope of this text.

In general we may conclude that FRP may, in some cases, have certain advantages over other materials such as steel or aluminium, but that many companies have yet failed to acknowledge or fully utilise these advantages.

This may often be attributed to the lack of necessary knowledge regarding the materials, or to the fact that the corresponding machines at the factories are designed for metals only.

Even though FRP are not generally 'better' materials, companies would do well to familiarise themselves with this topic; especially if they wish to cut down on production and manufacturing costs, too.

3. Sustainability

The terms 'sustainability' and 'sustainable development' have been buzz words in professional circles for a long time. It was only in recent years, however, that they were catapulted into the spotlight and became the subject of political discussions about climatic changes.

In conjunction with the public debate, various terms, definitions, and designations were introduced and have taken root. Sometimes, however, this creates more confusion than clarity.

In order to take up position at this juncture and to avoid potential misconceptions, we will explain our own interpretation of the term 'sustainability'.

The German Council for Sustainable Development that was appointed by the Federal Government summarises the basic principle of sustainable development as follows***:***

„Sustainable development means that environmental aspects are to be considered equally and on the same level as social and economic factors. Thus, 'fit for the future' means that we should leave behind an intact ecological, social, and economic system for our children and grandchildren. One is inconceivable without the other.“

Sustainability according to this definition touches interdependent spheres of activity which, however, require a practical content. We generally agree with this view, which also considers other factors besides ecological ones.

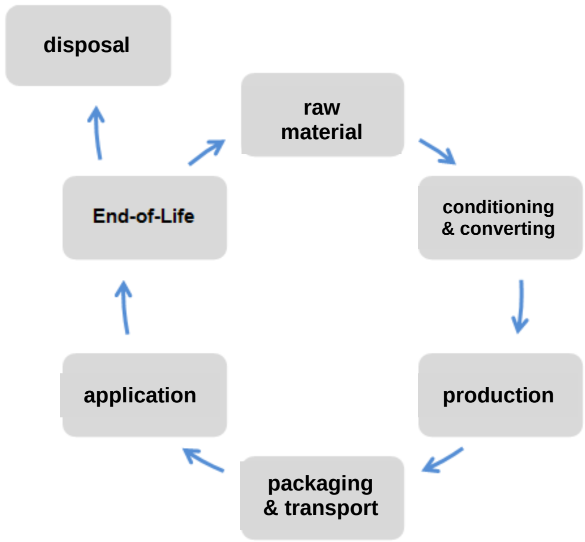
But how can the mentioned basic requirements be met with an industrial product?

In this context we have listed a number of requirements that bear consideration in conjunction with manufacturing processes and specificially with regard to FRP parts.

- Products should be manufactured as effectively and efficiently as possible. This involves using materials that are best positioned to meet the respective product requirements (i.e., properties). Secondly, the aspects of business economics and national economics are to be factored in at all times.
- All raw materials to be used are to be obtained respectively produced in an ecologically friendly manner, making allowances for human rights.
- During production, personal injury or material damage caused by emissions or by the manufacturing procedures are to be avoided at all cost; respectively the risk ought to be minimised.
- The manufacting process is to be as resource-efficient as possible. This means that all resources are to be utilised with caution.
- Ideally, a product should, in the course of its entire life cycle, generate as much energy was was used to create it. If this is impossible, then the alternative with the lowest energy balance should be chosen.
- If a product is no longer used for its original purpose or if it cannot be used anymore for its original purpose, then corresponding alternative utilisation concepts, reuse, or recycling methods are to be presented.
- During the entire life cycle, ecologically harmful emissions during the production process must be reduced to a minimum.

According to this concept, any product rating focusing on isolated aspects alone - for instance on disposal - would thus be inadequate. AVK and its members show their commitment to this maxim by actively developing corresponding strategies for the FRP sector.

Sustainability as understood in the context of this brochure accounts for all of the above-mentioned aspects and is closely related to the so-called life cycle assessment of products.
This is a systematic analysis of the environmental effects of products or services performed using such products along their whole life cycle. It includes environmental effects during production, service life, and disposal of the products.
The different ‘phases of life’ of a product may be illustrated as follows.



This diagram involving various steps corresponds to a so-called LCA (life cycle analysis); i.e., the assessment of the potential environmental effects of a given product, a process, or an activity during its entire lifetime (life cycle). In this context certain resources are quantified.

This means that both the 'input', such as energy, raw materials and water, and the emissions into the environment ('output' released into the air, the water, and the ground that is in contact with the investigated system) are evaluated.

"A conciliation between the economy and the ecology is reached when the chimney is smoking instead of fuming."

(Peter Gillies (*1939), former Editor in Chief of 'Die Welt' up until 1995)

At this point we would like to invite all interested companies to participate. The plastics sector in general as well as the FRP segment discussed in this context have to face the obligation to develop suitable concepts.

Your company's participation, too, may help quite a bit (www.avk.tv.de)

The next chapter discusses a number of practical applications with regard to their sustainability in accordance with the concepts mentioned above.

4. Practical examples

This chapter presents four selected fields respectively areas of application in order to demonstrate the practical benefits and the advantages of GRP with regard to their use and especially their sustainability.

This is not an arbitrary selection; it was guided by a number of parameters:

According to one criterium, the public at large had to be familiar with these applications and the use of FRP ought to be well-documented. Besides, sufficient studies and records had to be available in these cases so as to provide conclusive evidence.

The statements in the respective chapters are complementary. In order to make for an easy read, redundancies were deliberately eliminated; although this was not always feasible.

Once more it should be noted that this text makes no claims of being complete.

If you have any further queries regarding individual applications, please do not hesitate to contact us under the above address; we will be happy to help you.

4.1 *FRP in wind power plants*

Wind energy plants are probably among the best known areas of application for large-sized GRP parts, although they may not always be perceived as such. They are conspicuous because of their size and have in recent years been catapulted into public scrutiny in conjunction with the debate regarding renewable energies.

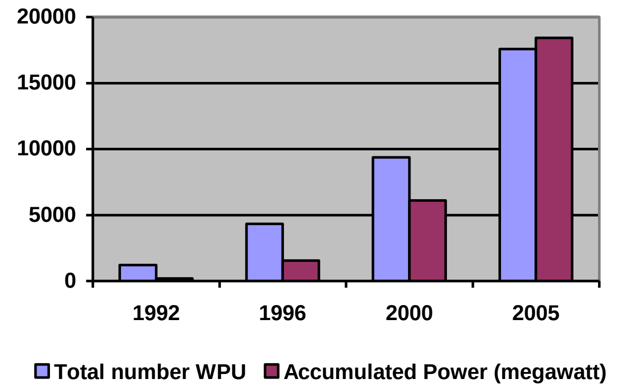
The nacelles as well as the rotor blades of today's wind turbines tend to be made (at least largely) of GRP or CRP.

Source: AVK course material

Applications in this area clearly demonstrate the enormous growth potential of the FRP sector.

While about 400 plants were installed in Germany in 1990, this number rose to more than 21,000 plants in 2009.

Besides, the total capacity installed with these plants, too, showed a noticeable increase, as illustrated by the following figure.



Source: www.wind-energie.de

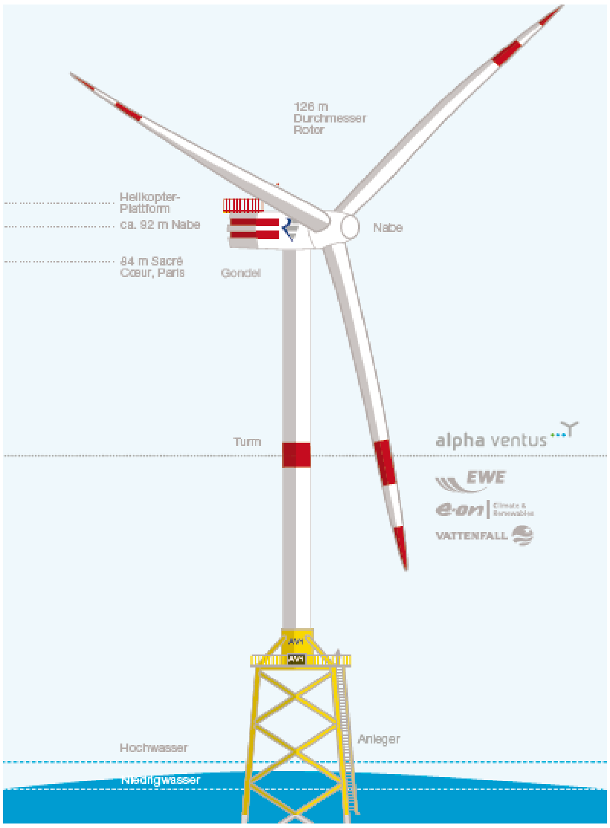
This was only possible by enlarging the size of wind turbines, which have grown spectacularly in recent years.

Around 1980, an average wind turbine, for instance, had a hub height of 30 metres and a rotor diameter of 15 metres. These wind power units had an annual power output of approximately 35,000 kWh.

Benchmark figures for 1995 show a hub height of 78 metres and a rotor diameter of 46 metres. Such a wind turbine had a power output of about 3,500,000 kWh (3,5 MW).

Modern plants have a much higher power output. In the spring of 2010, the first large-sized offshore wind farm named 'alpha ventus' off the German coast was commissioned.

Those wind turbines have a hub height of about 92 metres and a rotor diameter of 126 metres.



Source: www.alpha-ventus.de

All in all, these wind turbines, with a rotor blade height of 155 metres, are almost as high as Cologne Cathedral (157 metres). Each unit has a power output of approximately 5 MW.

The advantages of reinforced plastics are evident precisely in view of this enormous size and the stringent requirements pertaining to it.

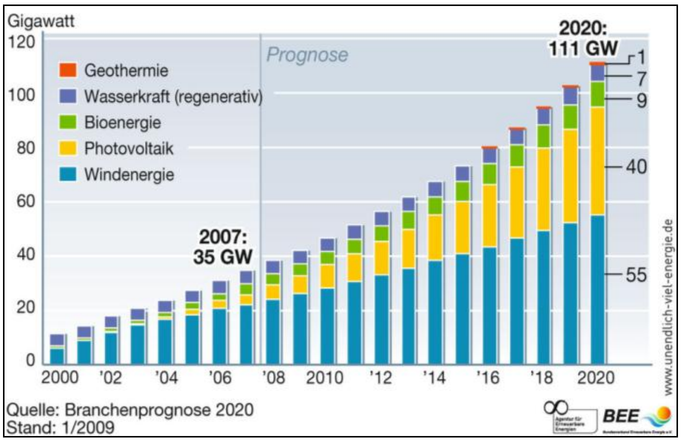
The corresponding processing methods and the possibility of creating individual designs allow an aerodynamically optimum design, eliminating the need for demanding rework.

The weight, too, plays a major role in this context. Rotor blades made of steel, for instance, would carry an incredible weight and not only considerably complicate transport and assembly, but also create additional problems, especially due to the continuous stress they are exposed to during operation.

Besides, lightning protectors and heating systems preventing ice formation may be directly integrated into rotor blades made of GRP/CRP.

Stress inside the component parts is easy to control and can be perfectly diverted by corresponding fibre orientation.

The specific growth trend for wind power units as suppliers of renewable energy is expected to continue, as shown by the following image.



Source: http://www.wind-energie.de/de/materialien/folien-sammlung/

In the future, growth of wind power units will primarily be offshore. Together with this trend, the turbine size is expected to increase even more. Units with a capacity between 8 and 10 MW and more are to be expected.

The installation of wind turbines at sea, of course, means that construction materials are exposed to continually changing weather and corresponding stress.

This reveals another enormous advantage of FRP as compared to other materials. Owing to the excellent corrosion properties of these materials, there is much less demanding maintenance to be done.

In view of the German Federal Government's target to increase the share of renewable energies in electricity generation to 25 or 30 percent by 2020, wind energy will be an enormously important factor.

Aside from political and ideological aspects, however, wind energy also plays a major economical role, too (Bundesverband Windenergie e. V.):

- In 2007, more than 84,000 persons were directly or indirectly employed in the wind energy sector. By 2020, employment is expected to increase to 112,000
- The entire sector has generated a total turnover of more than 9 billion Euros. Thus, the benefits of this young industry for the entire economy are equally undisputed

The primary remaining question regards the benefits of wind energy respectively wind power units and, in this context, the large-scale use of GRP parts – in economical and ecological terms - and thus with regard to the energy balance.

Most importantly, wind turbines require no fossil resources for operation and therefore fail to cause emissions that may be harmful to the climate.

Pertinent benchmark figures prove that wind turbines save enormous amounts of CO_2 during operation as compared to electricity coming from fossil fuels.

According to the economic report ("Wirtschaftsreport") 2009, published by VDMA, an installed capacity of more than 120,000 megawatts worldwide avoided the release of a total of 158 million tons of CO_2 in 2008.

The energy balance for building a wind power unit (WPU), too, is highly positive.

"Wind turbines generate as much energy as was used to build them within merely three to six months."

(The wind industry in Germany)

Source: http://www.deutsche-windindustrie.de/fakten/klimaschutz/

The enormous potentials of wind energy arise from an average plant lifetime of about 20 years. Thus, during its lifetime, a wind turbine may generate 40 to 80 times as much energy as was used to build it.

The reuse of worn-out rotor blades remained a complex challenge for a long time.

But this problem, too, was solved. Today there are sustainable solutions for the reuse of rotor blades having reached the end of their service life. A procedure developed by the cement industry makes it possible to completely recycle not only the energy content of the resins, but also the mineral components of worn-out rotor blades, such as SiO_2 or CaO. For more information regarding this topic please see below or under www.compocycle.com

Another area of application already conquered by FRP – even though generally unknown to the lay public - is infrastructure.

In this sector, too, we expect demand for FRP to increase. The next chapter is to illustrate this by a corresponding example.

4.2 FRP in infrastructure

Construction respectively infrastructure is a less well-known area of application for GRP.

In this context, too, FRP have many advantages, especially as far as sustainability is concerned. This particular example focuses on bridge engineering.

The photo below shows a footbridge in Moscow that is subject to very stringent requirements due to the particular weather conditions in this location.

Source: www.fiberline.com

GRP, as mentioned above, generally have certain typical properties that are advantageous especially in construction. These benefits are to be mentioned again in this context.

The list includes, among others:

- High mechanical strength combined with low weight
- Corrosion resistance and fatigue resistance
- A wide variety of design options
- Versatile combination of material components

GRP parts or even complete GRP constructions that exhibit some of these properties are positively predestined for use in bridge engineering.

During their entire lifetime, bridge constructions are continuously exposed to the weather and additional stress, such as road salt in the wintertime. Since GRP are resistant to frost and road salt (which do not not significantly influence their mechanical properties), they have an enormous advantage over steel or concrete as common construction materials for bridges.

The lower weight of GRP is another advantage over conventional constructions. Plastic bridges only weigh about fourty percent of composite steel bridges and less than thirty percent of prestressed concrete bridges, allowing pre-fabrication in much greater lengths and making it possible to lift the parts into position with a crane.

Besides, the superstructure (including the road surface) may be pre-assembled, thus noticeably reducing the construction periods and the frequent holdup times for new constructions or restorations.

Thus far, complete GRP bridges are primarily found among footbridges with small radii, since GRP have a lower deformation resistance than steel. Yet this area opens up considerable opportunities for future application. [1]

Apart from purely technical benefits, however, this field also profits from sustainability.

[1] Fibre composite materials in architecture and construction – Stuttgart University (Faserverbundwerkstoffe in Architektur und Bauwesen – Universität Stuttgart)

A study performed on behalf of the Rotterdam city government has determined the benefits of FRP bridges in Rotterdam as compared to 'conventionally' built bridges, especially with regard to the added energy value. This study was based on various indicators for comparison, such as:

- The 'cumulative energy requirement respectively energy content' - calculation of the energy requirement of a given product during its entire life cycle (including production of the basic materials and the raw materials, production process, transport as well as utilisation and disposal)
- The carbon footprint (CO_2 comparison)

Calculations were performed regarding the data for a bridge with a clear span of 11,85 metres and a hypothetical 'lifespan' of 100 years. Besides, this bridge is to span water and should be suitable for transport / heavy traffic.
The analysis included various 'phases of life':

- Construction, including raw materials (building the bridge, transport, substructures, etc.)
- Maintenance / repair
- Reconstruction and/or displacement of the bridge after 50 years (experience shows that bridges, after this period, normally have to be either displaced or completely restored)
- Dismantling (effect on the environment by recycling; energy requirement for shredding)

Apart from confirming the significant weight differences as mentioned above, this study arrives at the following results:

- The **maintenance respectively repair** of a CRP or GRP bridge would use up no additional resources – in contrast to a concrete or steel bridge. Owing to ageing as well as wear and tear of the latter materials, about 5% of the used concrete / the construction would have to be replaced after 50 years
- The situation with regard to **longevity and ageing** is even more obvious. It is assumed that the two plastic bridges may easily be displaced after 50 years. Steel and concrete constructions, on the other hand, would have to be completely disassembled, recycled, and rebuilt at a different location after 50 years.

The above-mentioned **index regarding the cumulative energy requirement** yielded the following results. This value indicates the energy content of a given product / part. In this context, the production of raw materials, the manufacturing process itself, transport and recycling (positive and negative) are all taken into account.

- The 'energy content' of a concrete bridge, measured in gigajoules (GJ), equals 1978 GJ over a 100-year life cycle
- About 2210 GJ are needed to build a carbon fibre bridge
- Steel bridges consume much more additional energy; i.e., 3380 GJ
- The lowest energy consumption (about 652 GJ) is achieved by the GRP bridge

The next indicator according to this study was the so-called **carbon footprint** which was calculated for four alternatives.

This footprint assesses and balances the total set of greenhouse gas emissions during the course of a life cycle. To facilitate this comparison, the greenhouse potentials of a given gas are converted to CO_2 equivalents. This calculation yielded the following results:

- Building a GRP bridge gives rise to 75 tons of CO_2 during its entire life cycle.
- The second plastics alternative, carbon, clearly exceeds this value with 108 tons of CO_2
- The concrete bridge, on the other hand, is already associated with 145 tons of emissions; while the steel bridge is heading the list with 178 tons of CO_2.

This calculation, too, points to the clear advantage of the glass fibre bridge.

We may conclude that the GRP bridge 'did better' with regard to all indicators investigated in this context. However, there are still some open questions remaining apart from the design-related constraint.

GRP is a relatively recent material and there are no empirical values available for time periods of 100 years. Exact calculations therefore remain theoretical.

Besides, recycling concepts for steel and concrete are significantly more advanced than those for GRP and CRP. This demonstrates the need to develop corresponding concepts.

But how sustainable really are GRP in everyday objects like automobiles? The next chapter discusses this question.

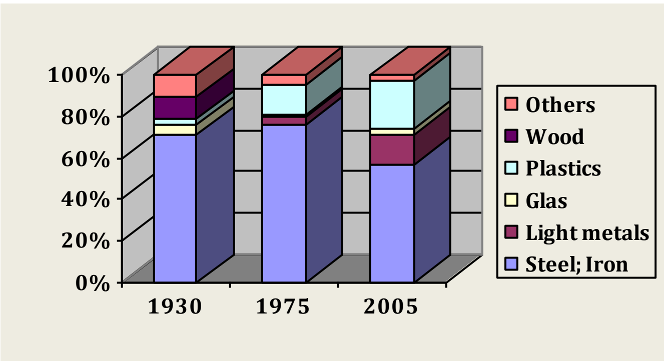
4.3 FRP in the automotive industry

In the automotive industry, FRP materials are broad in scope. The probably best-known examples are found in racing or tuning where a multitude of carbon parts and single elements are being used.

GRP parts have become very popular in this field. Because of their nature, they are less conspicuous than carbon elements but have gained a considerable market share and are now providing a high percentage of construction materials.

The following image shows the difference between materials used by the automotive industry during the past 80 years or so, exemplified by various different BMW models:

- For the 'Dixi' BMW model, a 1930s model, India rubber was used, which is a subset of plastics. FRP were not available at the time. Other materials, such as wood and metals, were preferred.
- This clearly changed with subsequent production series (the 3 series BMW 1975 and the 3 series BMW 2005), where a lot more plastics were utilised.



Sources: Stauber http://www.bayern-innovativ.de/stauber_Vortrag; Richter: http://www.gdch.de/strukturen/fg/wirtschaft/vcw_va/richter.pdf ; http://www.iff.tu-bs.de/alt/docs/studium/Werkstoffe_im_Automobilbau.pdf

Now what is the reason for FRP to be used specifically as construction materials for recent automobiles?

Production materials today are subject to a number of requirements. These may differ considerably, depending on the component part / group of components; although they do sometimes match. Here are some of the pertinent requirements so as to exemplify this:

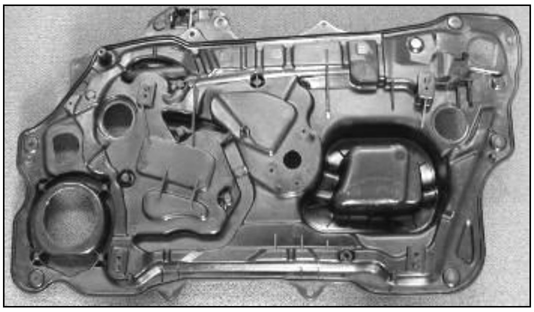
- Car body shell: strength and rigidity, crash behaviour (safety), torsion resistance, low weight
- Attachments (visible): high surface quality, good mouldability, forming properties, paintability, good buckling resistance, low weight
- Interior: pleasing appearance, high recyclability, good feel, high passive safety, low weight
- Axles/chassis: high crash safety, high rigidity, high dynamic strength, good corrosion resistance, low cost

These numerous automotive requirements, some of which are superficially contradictory (such as strength versus weight) increasingly necessitate customised material solutions. In this respect, FRP offer solutions already mentioned in the previous chapters. Owing to the wide variety of possible fibre-matrix combinations and manufacturing techniques with a varying fibre content, fibre composite technology has considerable potential with regard to tailoring materials in accordance with certain specifications.

Certain requirements in automotive construction have recently come into focus and are more or less generally accepted. The list includes lightweight construction, safety, environmental compatibility, comfort, and customer benefit.

Some of these requirements will be discussed in greater detail in conjunction with FRP use, emphasising once more the sustainability aspect respectively the environmental compatibility, both of which are closely related to all the other aspects as well.

The automotive industry relies on FRP parts for a variety of reasons. One of the major factors favouring FRP might be the opportunity to make complex component parts with large surfaces in one piece that are used, for instance, for underbody coatings or door panels.



Source: AVK work group – EATC

The lightweight potential of FRP, too, is relevant in this context. Attachments for utility vehicles such as bumpers or windshields, for instance, as well as radiator cores are made of GRP.

FRP, due to its lightweight construction potential, offers even more opportunities for the automotive industry, specifically in terms of sustainability. At this point in time, the debate regarding reduction of CO_2 emissions is one of the primary criteria for almost all automobile manufacturers.

It seems that the defined reduction targets regarding the emissions of new vehicles that are to be achieved by 2020 cannot be attained with conventional concepts. Automotive manufacturers would be risking high penalties.

Owing to the lower weight realised with lightweight construction, one may either reduce the total weight of a vehicle and thus cut down on fuel consumption, or rely on engines with less capacity without compromising the road behaviour. Another option is to compensate for heavy components, such as electromotors.

Based on this discussion and several publications, for instance by Volkswagen and Toyota, individual aspects in conjunction with lightweight construction are discussed below and some corresponding studies on the future are cited. Besides, opportunities offered by FRP/GRP in this segment are described.

In October 2009, Christoph Koffler and Klaus Rohde-Brandenburger, Volkswagen Group employees, published a detailed article titled “On calculating fuel savings through lightweight design in automotive life cycle assessments”. This report presents a calculation method to determine the savings potential of fuel based on weight reductions.

While a thorough discussion of the authors‘ calculations is beyond the scope of this text, Koffler and Rohde-Brandenburger conclude that a specific amount of petrol is needed to move a mass of 100 kilograms and that – in accordance with a physical principle - reducing the vehicle weight obviously makes it possible to cut down on fuel consumption. Without wishing to comment on these calculations and on the validity of the calculated fuel volumes in all detail, we may safely state that the cruising range may be enlarged by reducing fuel consumption. Reversely, this means that the fuel needed for one and the same cruising range is reduced.

Thus, lightweight construction – apart from other approaches, for instance by improving engine technology – is one of the leading factors influencing fuel savings as well as CO_2 emissions. Koffler and Rohde-Brandenburger are summarising that “accordingly, lightweight design has been recognised as one of the key strategies to reduce vehicle fuel consumption, along with power train efficiency, aerodynamics, and electrical power management.“

A VW press report published in September 2009 phrases it differently: ”What should a passenger car look like and how should it be designed in order to use up as little energy as possible? The logical answer is that it should be extremly aerodynamic and low-weight without compromising the indispensable requirement of maximum safety.“ This quotation is from a presentation of the “most fuel-thrifty automobile in the world“, the L1 – according to the manfuacturer. This vehicle was presented on the IAA 2009 and is doubtlessly a benchmarking car with regard to environmental compatibility without disregarding other crucial factors.

The L1 study combines major lightweight construction elements with additional features to cut down on fuel consumption. It is a full hybrid car with a complete plastic car body, reinforced with carbon fibres, which reduces the total vehicle weight to a mere 380 kilograms with an average fuel consumption of only 1.38 litres diesel/100km.

The L1, at a top speed of 160 km/h, has CO_2 emissions of 36 g/km. The excellent freedom of design – enabled by the conception and the lightweight car body parts made of fibre-reinforced plastics – reduces the cd value of this vehicle to 0.195. In this case, too, low fuel consumption is based on another factor apart from the reduced weight.

Source: Volkswagen

Other vehicle manufacturers, too, have recognised lightweight construction opportunities that may be realised by combining fuel-thrifty engines with detailed design concepts.

Toyota, for instance, recently introduced the 1/X concept vehicle. This lightweight four-seater features a fuel consumption of 2.17 litres per 100 kilometres.

Increasingly stringent legal requirements along with the pressure to reduce CO_2 emissions may therefore increase the acceptance of lightweight constructions among final customers as well.

FRP in particular offer an enormous potential in this respect as compared to steel with its greater weight. Although there are other materials with a similarly low weight, such as aluminium, these alternatives are less pliable, have limited moulding properties, and the energy balance with regard to their manufacture is not always as favourable as with FRP.

Finally it should be pointed out that FRP, in the automotive industry, are by no means 'better' or 'worse' than established materials and will never replace them entirely. In this case, too, it is the specific properties that are decisive. There will always be applications where high-strength steels or aluminium have clear advantages over FRP.

In order to ensure sustainable development and resource efficiency, however, a suitable material ought to be selected for each specific purpose. FRP will play a decisive role in this respect.

FRP are particularly significant, for instance, in conjunction with the discussion about electromobility. Since batteries used to operate such vehicles are still quite heavy, the weight of conventional vehicles increases considerably by corresponding equipment which, in turn, increases fuel consumption.

In the future we will therefore have to find ways to reduce vehicle weights in general. FRP will be able to contribute significantly in this respect, too.

One of the largest areas of application for FRP is the aviation industry. The next chapter discusses why this is so and in how far composites contribute to the sustainability in this field.

4.4 FRP in aviation

In the aviation industry, lightweight FRP construction has already penetrated the market quite effectively.

Modern aircraft are made for a large part of fibre composites.

Thus, a variety of different FRP were used for the Airbus 380, as illustrated by the following image.

More familiar materials such as CRP and GRP are supplemented by less well-known materials like QRP (quartz-reinforced plastics) or glare.

Aircraft with the currently highest share of composites are the Airbus A 350 XWB and the Boeing 787 Dreamliner.

The A 350 XWB contains 53% composites and about 19% aluminium. In terms of volume, titanium (14%) and steel (6%) are third and fourth in line.

The 787 Dreamliner shows similar material values; it contains 50% composites and 20% aluminium. Titanium (10%) and steel, at 5%, are used, too (sources: Wikipedia; BBC; Boeing).

Boeing, on their website, argue in favor of fibre composites:

„[…] They will bring the economics of large jet transports to the middle of the market, using 20 percent less fuel than any other airplanes of their size.[…]"

In this context, weight reduction allowing fuel savings is not meant to be an ecological statement; airlines, on the contrary, are primarily trying to save jet fuel by reducing the weight and to minimise expenses by reduced consumption.

This raises another argument for lightweight FRP construction. In view of our initial definition, the economical balance of sustainable development is quite positive, too. After all, endurance depends on using a material profitably as well. The field of aviation is already on the way, and successfully at that.

At the same time, reduction of jet fuel consumption reduces CO_2 emissions, too.

Airbus, in a press report about the A 380, says that 1.5 tons of weight may be saved by using CRP for the wings. The SKF Group explains that a weight reduction of 10 kilograms per flying hour will reduce jet fuel consumption by 3 litres. Even though these claims are not substantiated and the savings potential is rather low in view of the total consumption of a modern long-range aircraft, this serves to demonstrate the opportunities offered by even minor weight reductions.

5. Summary / outlook

This text paints a highly positive image of reinforced plastics; which is entirely justified in view of the numerous benefits offered by them. It should be noted, however, that a number of questions with regard to FRP remain to be answered and these answers should not be left to chance.

In contrast to the enormous sustainability potential, for instance by CO_2 reduction in the automotive industry, and the favourable energetic values yielded by life cycle assessments, there are only very few promising recycling and processing techniques to end the FRP product life cycle. Thermosets in particular are problematic in this respect. Production methods turn them into a strong lattice structure that is very difficult to break up.

Separating fibres and matrix after shredding, too, presents a considerable challenge. It is for this reason that the shredded pieces are suitable only for a very few production processes; alternatively, they may be used as fillers. Another option involves thermal processing. The residues are disposed of in a refuse incineration plant and their energy content is recovered. Often, however, the only alternative for the remaining incineration ashes is to deposit them at a waste disposal site or to subject them to demanding further processing. Biological degradation, for instance by composting, is currently as elusive as is separate material or raw material recycling.

A promising new approach is offered by the cement industry. While introducing a new label named 'CompoCycle' (www.compocycle.com) and a corresponding process chain for FRP disposal to the market, a procedure was developed to reprocess FRP waste and then to use it as a raw material and fuel to produce cement. Owing to complete material and thermal recycling during the course of this process, natural resources are saved and this is another contribution to the sustainability concept.

One of the challenges that AVK and the industry generally are facing (and we are happy to do so) is to develop sustainable recovery and recycling methods in collaboration with participating corporations.

In this context, however, we should not forget that fibre reinforced plastics are a 'comparatively recent' invention. In relation to other materials, such as steel or wood, we are still in the early stages of utilisation and development. Much remains to be done. We are confident, however, that FRP, also considering the stringent ecological requirements we are facing, will turn into a leading material of the 21rst century that will be indispensable in most if not all branches of industry.

What remains to be done?

We are convinced of the benefits of our materials for a variety of purposes, also with regard to optimum utilisation of the available finite resources.

It is unfortunate that not all decision-makers are familiar with our materials.

Universities and colleges, too, where future designers, product developers, and engineers are being trained, frequently neglect FRP in favor of ‘conventional’ materials. This is one of our most important future tasks within this sector of industry. We should unfailingly demonstrate the benefits without neglecting potential problems.
To the best of our knowledge there are tremendous opportunities in combining various materials. We would therefore like to get away from pure material assessments based on the question of “What can the material do?“ Instead we would prefer a product-oriented approach, in which case the question is: “What should the resulting product be able to do respectively what are its desired characteristics?” This leads to the next question regarding the material or combination of materials that is best suited to meet the pertinent requirements.

Thank you very much for your interest!
Would you like to join or do you have any comments or questions?
In this case please feel free to contact:

Arbeitskreis Nachhaltigkeit
AVK – Industrievereinigung Verstärkte Kunststoffe e. V.
Am Hauptbahnhof 10
D - 60329 Frankfurt am Main
info@avk-tv.de

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