COMPETENCE IN CFRP

www.dynexa.de

DYNEXA

DYNEXA

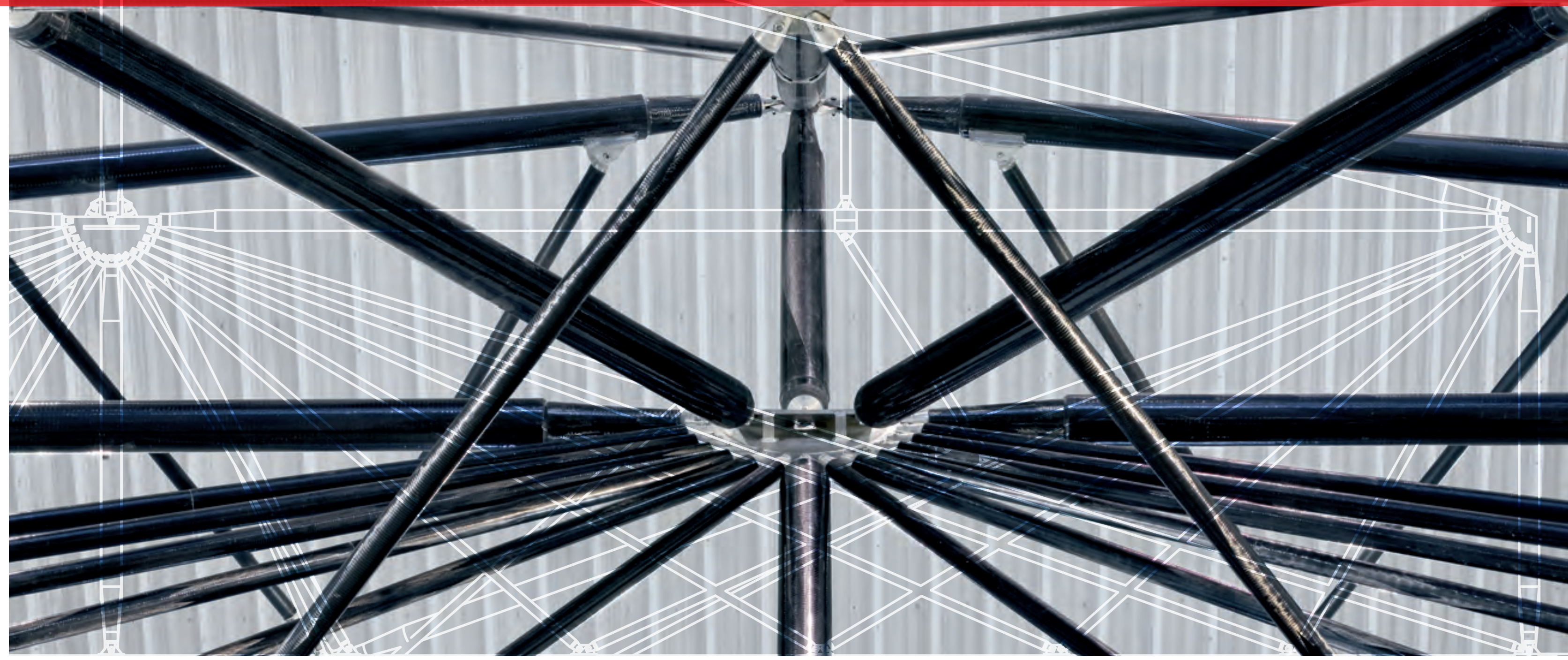
DYNEXA GmbH & Co. KG
Dr.-Werner-Freyberg-Straße 7
69514 Laudenbach, Germany

T +49 (6201) 29 086-0
F +49 (6201) 29 086-302
info@dynexa.de
www.dynexa.de

Stand: 09/2018/EN

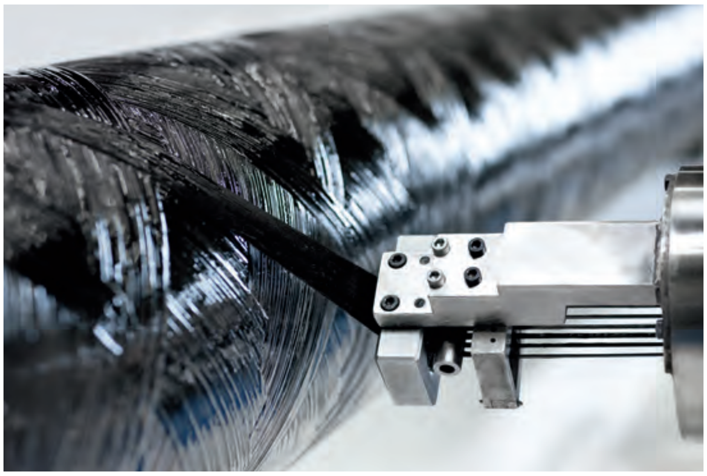
DYNEXA

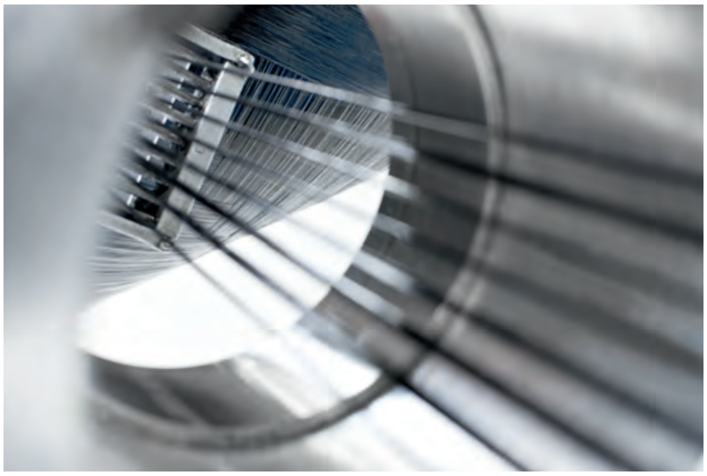
DYNEXA



THE INNOVATION MATERIAL

FASCINATION CARBON FIBER





Production of a component made of CFRP in filament winding process.

Carbon Composites

Our fiber composites are made of carbon fibers and a matrix, which consists of special resin systems or thermoplastic materials. Both components come together to give the material its specific and unusual characteristics. In doing so, fiber and matrix each have different tasks. The strength and corrosion resistance, as well as the light weight of carbon fiber is only possible as a composite material.

Carbon Fibers

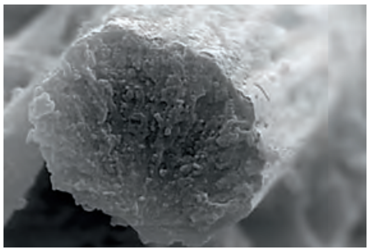
Carbon fiber, the basis of the material compound, has truly fascinating characteristics: It has several times the stiffness and tensile strength of steel while only having a fraction of the specific weight. The fibers conduct electricity, have a medium to very high thermal conductivity and a negative thermal expansion. There are different kinds of carbon fibers that we put to specific uses according to their characteristics and their price. In addition, we use glass and aramid fibers and/or hybrid mixtures of all the mentioned fibers as supplements to achieve the desired material properties.

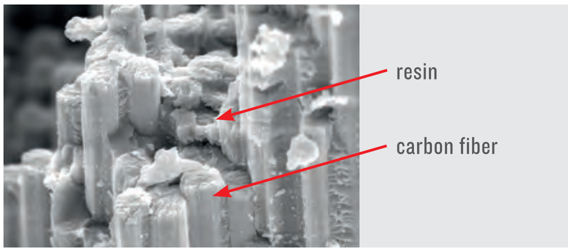
The Matrix

A bundle of carbon fibers is similar to a rope in that it is highly flexible and does not retain its shape; it is the task of the matrix to bed, support, form and protect the fiber so as to allow for load transmission between the fibers and the different fiber layers. When selecting the matrix material, we draw from a series of epoxy resins with a diverse range of characteristics. In addition, our group of companies is pioneering the development of industrial processes for the production of thermoplastic matrix materials with our CCM production.

left: individual carbon fiber filament at approximately 3,800x magnification

right: fiber/matrix composite structure at approximately 700x magnification





United We Are Strong

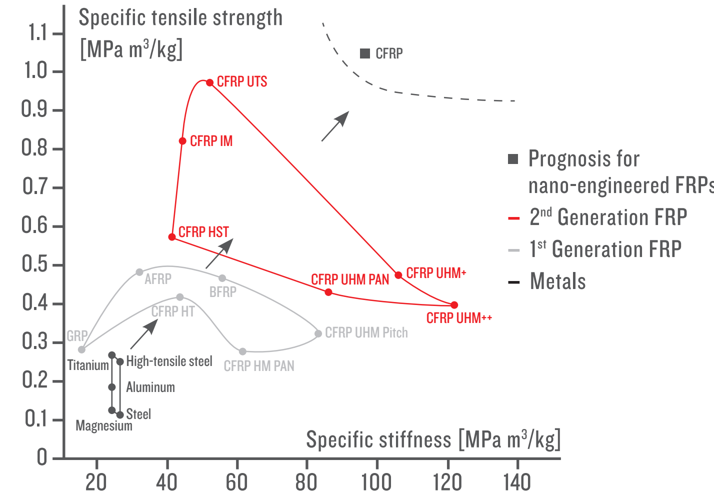
Since carbon fibers have their outstanding characteristics only in the fiber's longitudinal axis, so-called anisotropic, the fibers within the composite are arranged according to the load bearing aspects and take on the task of force transmission. When subjected to compressive loads, they are supported by the matrix material. Thus carbon fiber laminates can possess much higher stiffnesses (young's modulus) in fiber-direction than, for example, steel. The transverse direction, however, has lower values because the matrix material offers comparatively little strength. Compared with conventional materials, shear deformation and ovalization play a much larger role in the total deformation of fiber components. It is however possible to obtain a perfect ratio between modulus of elasticity and modulus of shear by layering the fibers in various directions to form a laminate structure, e. g. by using a filament winding method. In this way, we can use a specific arrangement of fibers to create tailor-made components with specific functions. This includes things such as adjustable thermal expansion or damping properties, as well as a high strength or flexibility.

When designing components with anisotropic materials, often underestimated challenges are the load transmission into the fiber-reinforced machine component or the joining of components into structures. The challenge in this case – and this is especially true by higher loading – is how to create a lasting connection to the load-bearing fibers in the composite. We have the design and production engineering know-how needed to implement various methods, such as gluing, bolting, riveting or using press-fitted assemblies.

Analogous to Nature

When designing carbon composite components, we take the lightweight design principles provided by nature as a guideline: minimum use of materials, "form follows function", establishing shape and form through constant tension and the targeted reinforcement of a component using fibers. Bamboo is a good example of what we mean when we say that we want to emulate nature's design bionics for lightweight designs using fiber composites. Bamboo stems are essentially composite structures where vascular bundles and fibers are embedded in the tissue. The shear stress at the tissue's boundary areas help dampen the movement of swinging bamboo stems and the fibers embedded in the tissue protect against buckling caused by pressure and bending loads. In addition, bamboo is hollow, making it extremely elastic and light in weight, and has inner support discs that provide strength perpendicular to the direction of growth.

SPECIFIC TENSILE STRENGTH VIA SPECIFIC RIGIDITY



MATERIAL IN THE DEVELOPMENT

Since the seventies, we have been using fiber-reinforced plastics (FRP) of the 1st generation (various generic types of fiber and matrix materials) and of the 2nd generation (new fibers and matrix materials with optimized profiles), but now we are developing a 3rd generation of FRPs, which will create new possibilities and application areas, not least through the positive effects of nanotechnology. Although it remains to be seen if the impressive forecasts will play out, we are at a phase where carbon nanotubes (CNT) are making the transition from research object to industrial use as a reinforcement material for composite materials with highly interesting properties.

Long Service Life

Correctly dimensioned components made of fiber-reinforced plastics have an incredibly long service life, even if subjected to dynamic loading. When fractures caused by material fatigue do occur, the load cycle counts are typically much higher than with comparable components made of metal materials. For the most part, this is due to the generally high strength of a material made up of thin fibers (Griffith's material strength equation) and in the high amount of inner surfaces found in fiber composites which hinder micro-cracks in a way that only allows them to grow in size once more energy is applied. In fatigue tests on CFRP components, you will often find that load transmission elements made of metal have failed due to material fatigue long before the CFRP carrier structure has been measurably, let alone visibly damaged.

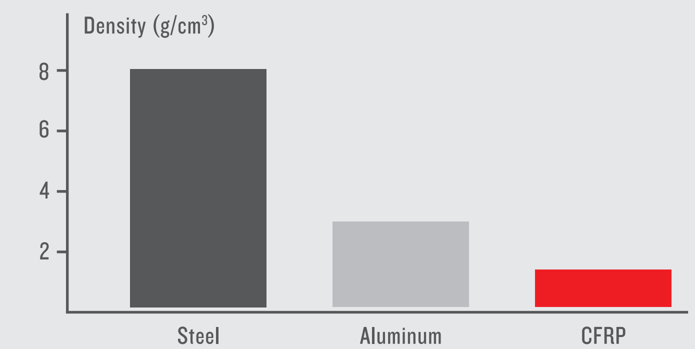
Benign Failure Behavior

A further strength of fiber-reinforced plastics is that it has a tendency to have a benign damage behavior as well as the possibility of designing a specific kind of fracture behavior into the material. This is often put to use in crash elements and energy absorbing structures, as used e. g. in Formula One racing cars or in bullet-proof vests. Today, even impact damage can be controlled by using correspondingly designed laminates and protective coating. With laminates the fiber structure helps absorb the damage, because the undamaged fibers help take up the impact load so that tears cannot spread unhindered.

Optimization of deformation behavior through the installation of support discs, following the example of bamboo.

Fatigue fracture in a metal flange of a fiber-composite driving shaft.

MORE EFFICIENCY THROUGH LIGHTWEIGHT DESIGN
The density of CFRP is approximately 20 % of the density of steel and 57 % of the density of aluminum.



TAKING THINGS LIGHTLY

A LIGHTWEIGHT FOR HEAVY DUTIES

In mechanical engineering, lightweight design is called for in many areas. The physical reason often lies in masses that need to be moved or accelerated, for example an oscillating lever, a rotating shaft or a structure that needs to be moved. Carbon fiber composite materials score with excellent lightweight design potential, thanks to low specific weight and low inertia, combined with a high degree of specific stiffness and strength.

Efficient Lightweight

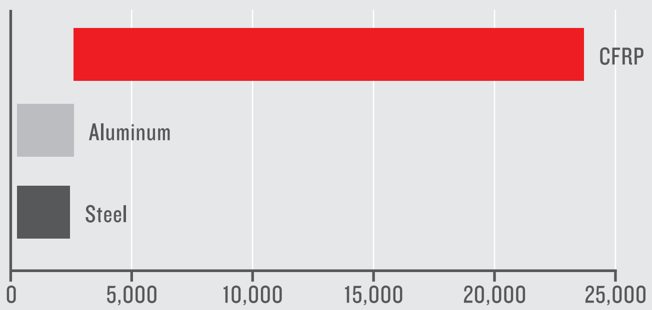
The density of CFRP is approximately 20% of the density of steel and 57% of the density of aluminum. This allows us to make light, and even very light components, which can be powered by smaller drives or in some cases no drive at all. The associated energy savings lead to significantly reduced operating costs. In addition, the deployment of CFRP components lead to reduced wear within the machine, thus driving down maintenance costs and providing additional savings. In terms of investment costs, smaller-sized drives and bearings have a cost-cutting effect.

In the mid-end segment of mechanical engineering, these advantages can be a key differentiator in the calculation of operating costs and make all the difference when dealing with competition. In the high-end segment, differentiation is created through a qualitatively and quantitatively superior machine performance, with dramatically reduced masses which allow for faster acceleration and braking times, very fast emergency stops and shorter production cycles through vibration reduction.

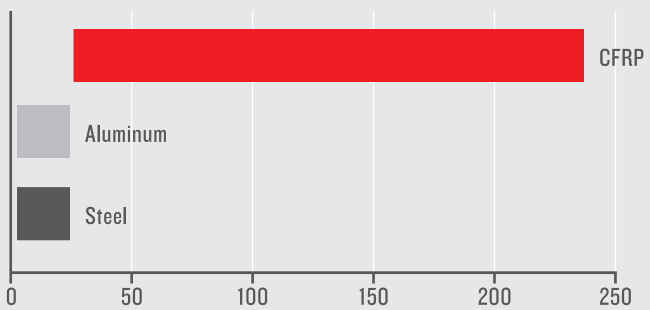
In applications where jerk, i. e. the rate of change of acceleration over time, is of essential interest to the design engineer to achieve superior machine performance, there is no substitute for carbon composite machine components.

Mechanical engineering then and now: CFRP materials allow for high-performance in precision and speed.

SPECIFIC STIFFNESS E/ρ [km]



SPECIFIC TENSILE STRENGTH R_m/ρ [km]



Specific Stiffness

The specific stiffness, i. e. the ratio of modulus of elasticity to density, is the essential ruler with which to measure the lightweight design properties of a material and is therefore often called weight-saving potential. Specific stiffness can be given as unit of length, e. g. kilometers. This value is practically the same for all metals such as steel and aluminum, but also for titanium. By contrast, we can attain a specific stiffness ten times that of metal with carbon fiber composite materials, so that we can have properties tailor-made to meet the requirements of the application.

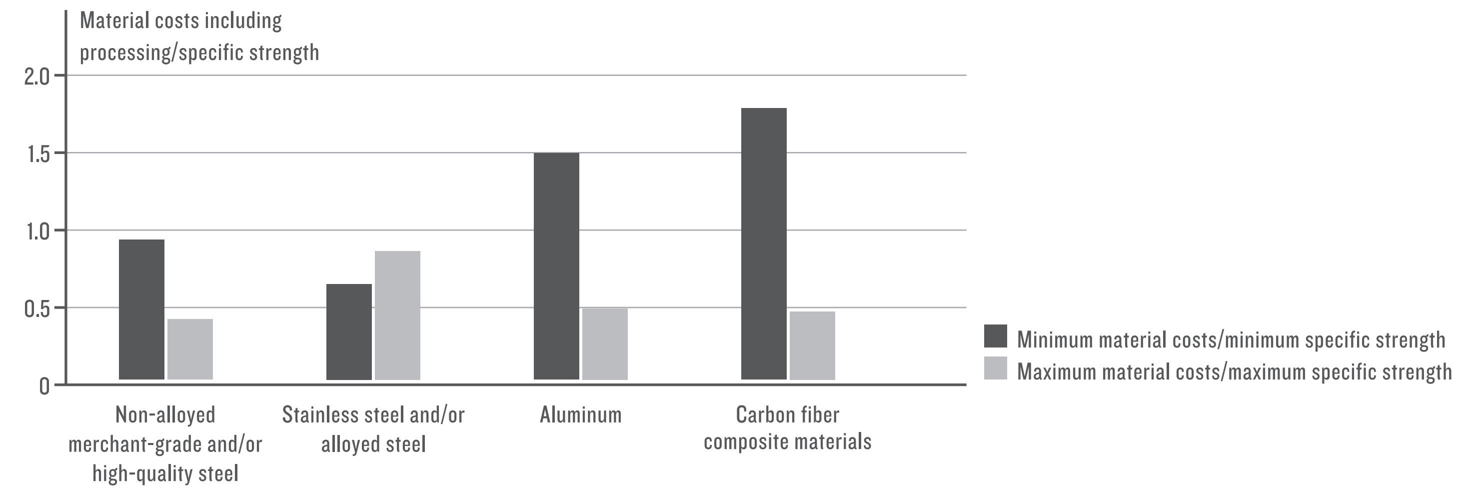
The great weight-savings of carbon composite materials can be put to use, e. g. to create smaller dimensions and/or cross-sections. This helps when tight space requirements, for example for shafts or rollers, can be fulfilled with smaller diameters. In addition, the high degree of specific stiffness means improved deformation properties and/or less distortion under load when compared with machine components made of metal structural materials. This makes it possible to design larger, unsupported lengths of equal diameter and makes the installation of intermediate bearings superfluous.

Unsurpassed Strength

The specific strength, i. e. the ratio of tensile strength to density, is the second ruler with which to measure the weight-saving potential of a material. The specific strength can only be varied by a factor of about two among metals such as steel, magnesium, aluminum or even titanium. By contrast, we can set the specific stiffness of CFRP within a large bandwidth to be three to ten times that of metals. In this way, the design can envisage components with the same or a higher degree of strength, e.g. tie rods or structures, pressure tanks or hydraulic cylinders. In addition, the high static and dynamic fatigue strength of the material makes durable components possible and offers enormous design advantages for highly dynamic applications, such as oscillating levers, drive shafts or flywheels.

Cost-Effective Material

Fiber composites, especially carbon fiber composite materials, are considered comparably expensive materials. And this assumption holds true when looking only at the cost per kilogram of material, but that is decidedly shortsighted, as it fails to take the low material density into account. A more meaningful comparison of the price-specific strength of various materials in an application setting shows that carbon fiber composite materials can compete with established metal construction materials. Reliable cost comparisons need to take a detailed look at the total cost of ownership (TCO) of each application, and it is here that the advantages which are typical of carbon composite materials, such as the elimination of an intermediate bearing on longer drive shafts, can be taken into account.



CFRP structures and spindle sleeve on a high-speed portal milling machine used to produce hull forms in the shipbuilding industry.

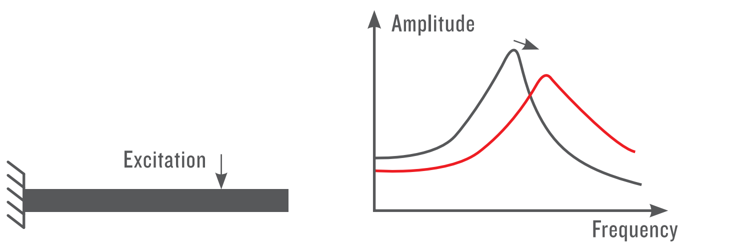
DYNAMIC MATERIAL

CONTROLLING VIBRATIONS

Vibrations will usually occur when various parts of a machine are in motion. In most cases, vibrations are not wanted, as they reduce process dynamics and precision, while increasing the wear on individual components. Reducing or even eliminating machine vibrations is a very complex design task which is rewarded with highly increased efficiency and production quality. With machine components made of fiber composites, there are several technically interesting measures at hand to minimize unwanted machine vibrations.

High, Adjustable Damping Ratio

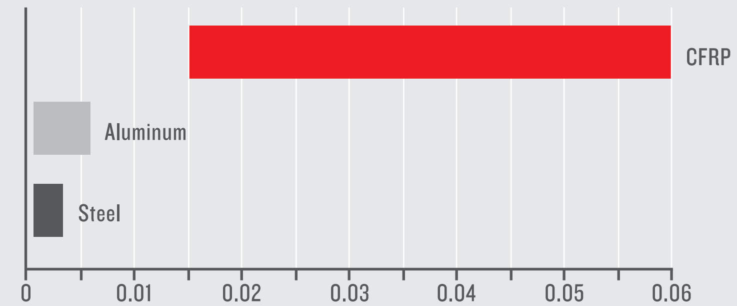
By using fiber composites as design material, we can manipulate the damping ratio or the natural frequency; a targeted pole shift can render vibrations and excitations harmless. Thanks to specific material properties, fiber composites inherently boast high damping ratios which can be further increased with the help of optimized composite layering.By converting vibrational energy into inner warmth, we can reduce the amplitude and accelerate the subsidence of induced vibrations. Measured as logarithmic decrement, these ratios have up to twenty times the values for steel which means that machine components can be adjusted to the perfect damping ratio for the required application. This allows a more abrupt positioning of components in highly dynamic applications or a better measuring signal quality.



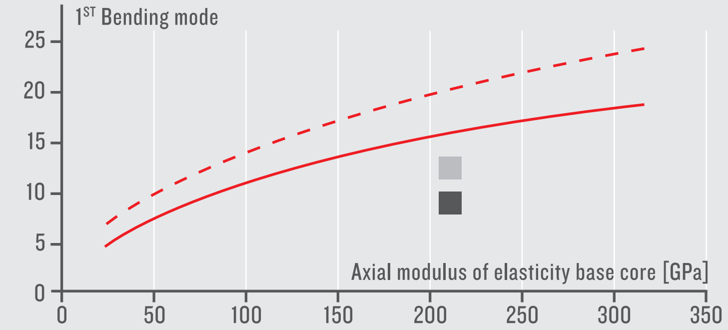
Active pole shifting of a vibration through modification of damping and natural frequency.

CFRP DAMPING RATIO

Logarithmic decrement [-]



CFRP NATURAL FREQUENCY



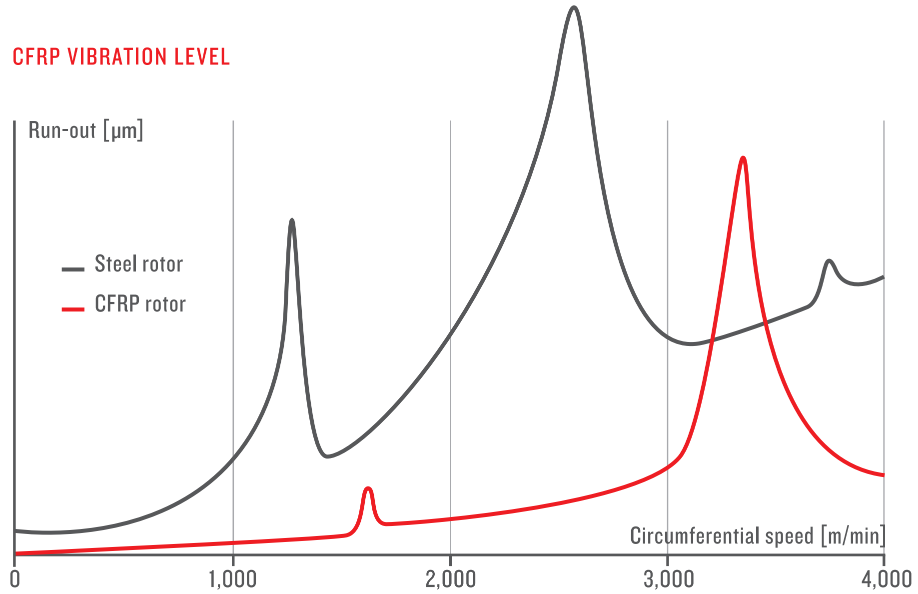
Adjustable Natural Frequency Spectrums

Thanks to the many design characteristics of fiber composites, it is also possible to adjust the natural frequency of a machine component to perfectly match the requirements of an application. By varying the component rigidity, the frequency can be moved into a range where the component can no longer be excited by its surroundings. In contrast, the natural frequency of machine components made of metals are permanently defined by their geometry. Here too, fiber composites allow for intelligent solutions and products that overcome the restrictions of conventional materials.

- Steel, flexible axis
- Steel, stiff axis
- CFRP, flexible axis
- CFRP, stiff axis

Example of possible natural frequencies for a CFRP beam with a rectangular cross-section of approximately 250 mm and a length of 8,000 mm.

CFRP VIBRATION LEVEL



Low Vibration Levels

An overall low vibration level is achieved through a combination of characteristic material properties that include low amount of excitable component mass, a high degree of damping as well as high, in some cases "adjustable" natural frequency spectrums. As an example, the imbalance of shafts or rollers made of CFRP is very low.

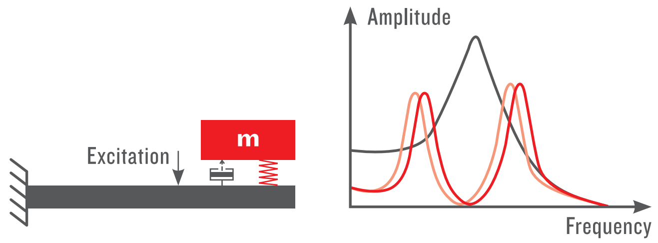
As a consequence, if the vibration displacement is the same as it would be for metal components, much higher production speeds can be achieved or, if the dynamics are the same, more smoothness can be achieved which in turn allows for things such as more precise measurement results or better production results.

Adaptronic Absorption of Vibrations

Low- and high-frequency vibrations in machines can be further reduced by using tuned mass dampers or vibration absorbers. The design of tuned mass dampers is based on a spring mass system that counteracts unwanted vibrations and thus suppresses them. To do so, the mass of the tuned mass dampers and the mass of the system that needs to be protected against vibration need to correspond to one another. If additional damping elements are used, these are referred to as vibration absorbers. We have developed adjustable tuned mass dampers that make it possible to move the location of the damping point without time-consuming calculations, so as to counter unwanted vibration or to stay away from problems caused by natural frequencies without much fuss.

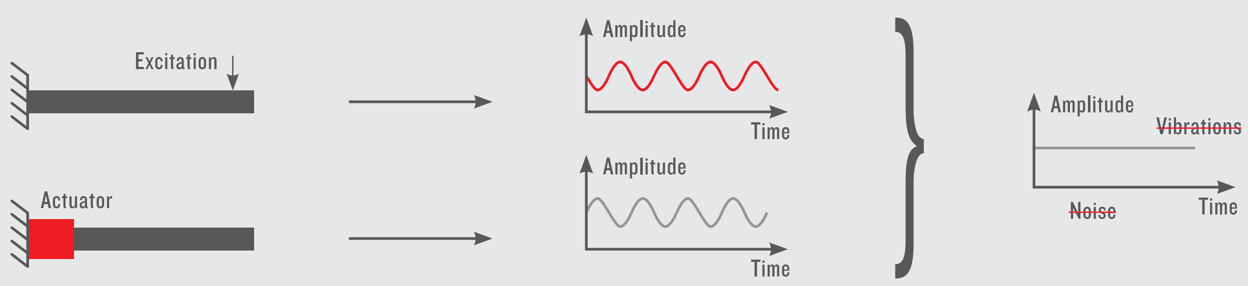
VIBRATION ABSORPTION

Deployment of adaptive tuned mass dampers to displace the damping point.



COUNTER VIBRATION

Operating principle behind the cancellation of vibrational excitation through targeted artificial counter-vibrations.



The Fine Art of Adaptronic Technology

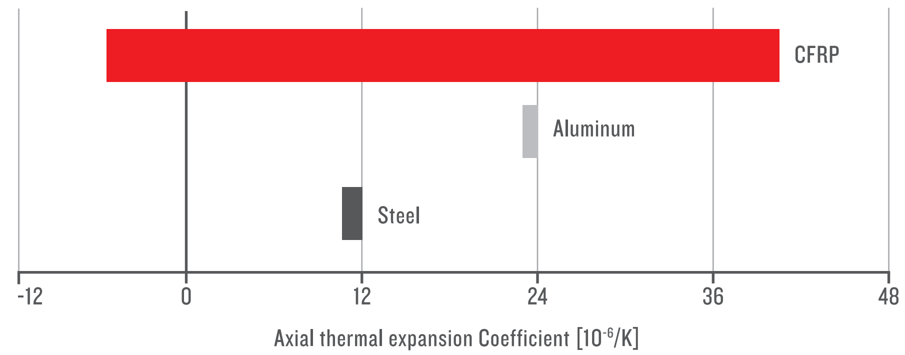
With the help of actuators that induce artificial counter vibrations with controlled phase and amplitude, structure-borne interference noises can be created that cancel out the vibrations. We offer these more sophisticated solutions in cooperation with experienced specialists from our network. To us, adaptronic technology and composites are partners that create great solutions for higher complex problems.

GETTING THE RIGHT SETTING

THERMAL EXPANSION AS DESIGN VARIABLE

Besides their numerous other advantages, fiber composites have the advantage of offering variable thermal expansion. More than anything else, the so-called thermostability, which means adjusting a material to a thermal expansion rate of zero, is of special technical and industrial interest.

THERMAL EXPANSION

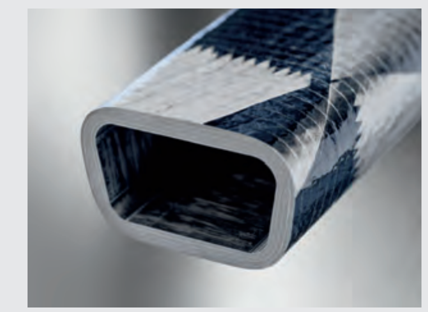


The graphic gives an example of expansion coefficients for the axial direction of a fiber wound structural composite.

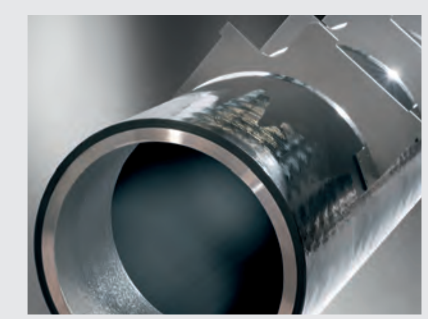
In combination with other advantages of the material, being able to manipulate the thermal expansion properties of CFRP allows for economically attractive solutions. A thermostable machine component is insensitive against periodic changes of temperature or locally inhomogeneous temperature distribution and can thus be perfectly adapted for high-precision measurement tasks, such as probes in precision measuring instruments.

Machine components designed this way are also highly effective when it comes to achieving the highest possible accuracy in metal working machines or in dynamic applications such as metering and dosing when exposed to changes in temperature.

In addition, the thermal expansion of the CFRP machine component can be set to match the value of any other material used in the machine to ensure congruent component behavior. This is possible for many technically relevant materials such as glass, ceramics, tantalum, iridium and graphite, to give some examples, and this is also useful for high-precision processing of these materials.



Construction profiles made of fiber composites with zero thermal expansion allow for innovative modular solutions for complex and high-precision design tasks.



Support beam for a dynamic, high-precision dosing task in the paper industry. The defined, near-zero thermal expansion alleviates the need for component distortion measurement and the corresponding hydraulic correction apparatus which was needed with the steel version.

COMBINED STRENGTH

PROPERTIES OF COMPOSITE MATERIALS

In general, fiber-reinforced plastics are well-protected against environmental influences. However, as the material is not homogeneous at the micro-mechanical level, these environmental influences have different effects on fiber and matrix, so that, in addition to the impact on the individual components, the resulting consequences must always be considered for the composite material.

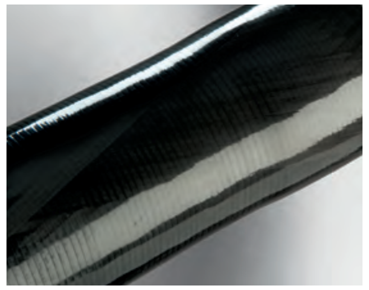
Chemical Resistance Properties

The chemical resistance of fiber composites depends foremost on the matrix materials used. For this reason, the design department has many different resin systems and thermoplastic materials at their disposal to adapt the chemical and thermal resistance of a component to various environments. It is in this context that duroplastic fiber composites with special, highly resistant matrix materials have become very popular in process technology and plant engineering.

The dense resin matrix on the component surface works as a protective layer against chemicals and other aggressive substances. Of course even fiber-reinforced plastics are not completely immune to the material's natural aging process. Because of time and concentration dependent diffusion processes of the surrounding substances, the fiber composite material will absorb moisture and thus lost some of its mechanical properties. However, these processes are very slow and need to be measured in years, even when dealing with highly aggressive substances. Due to their corrosion resistance, specially created composite materials are very well suited to replace stainless steel or other metals.

Thermal Resistance Properties

The thermal resistance fiber composites is dependent upon the characteristics of the applied matrix, especially the glass transition temperature. The duroplastic matrix materials we routinely use have glass transition temperatures between 145 °C and 200 °C. A deployment limit of up to 350 °C is possible using special materials. Subjecting the component to higher ambient temperatures will decrease the modulus of elasticity of the matrix material and thus the compression strength parallel to fiber axis. With regard to low temperatures, the strength of composite materials is usually very good. Metal load-transmission elements or the glue used in the joining processes could prove to be a weak link within the component, however, this is taken into account during the design phase.



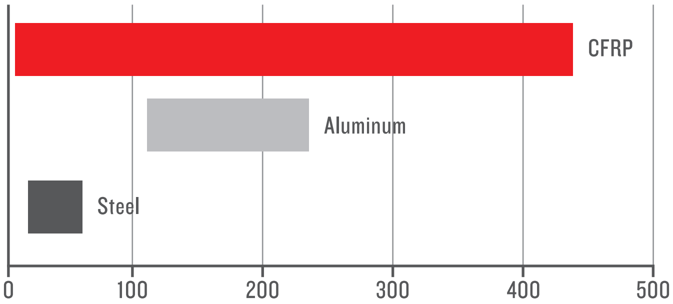
The closed resin matrix acts as protective layer against chemicals.

CHEMICAL RESISTANCE PROPERTIES

Chemical/Concentration/Conditions	Resistant	Partially resistant	Non-resistant
sulfuric acid (10 % /+60 °C)	–	•	–
sulfuric acid (70 % / +60 °C)	–	•	–
toluene (100 % / +40 °C)	–	–	•
ethyl alcohol (100 % / +23 °C)	–	•	–
ethyl glycol acetate (100 % / +40 °C)	–	–	–
ammonium hydroxide (100 % / +23 °C)	–	•	–
ammonium hydroxide (100 % / +60 °C)	–	–	–
aniline (100 % / +40 °C)	•	•	–
benzyl alcohol (100 % / +40 °C)	–	–	•
butyl acetate (100 % / +40 °C)	–	–	•
chlorobenzene (100 % / +40 °C)	–	–	•
cyclohexane (100 % / +40 °C)	•	–	–
decalin (100 % / +40 °C)	•	–	–
dibutyl phthalate (100 % / +40 °C)	•	–	–
diisobutyl ketone (100 % / +40 °C)	•	–	–
diisopropyl ketone (100 % / +40 °C)	•	–	–
dimethylformamide (100 % / +40 °C)	–	–	•
dioxane (100 % / +40 °C)	–	–	•
dichlorobenzene (100 % / +40 °C)	–	•	–
glacial acetic acid (100 % / +40 °C)	–	–	•
ethanol (100 % / +23 °C)	–	•	–
lauryl alcohol (100 % / +40 °C)	•	–	–
methyl glycol acetate (100 % / +40 °C)	–	–	•
methyl isobutyl ketone (100 % / +40 °C)	•	–	–
n-methylpyrrolidone (100 % / +40 °C)	–	–	•
sodium hydroxide (10 % / +23 °C)	–	•	–
sodium hydroxide (10 % / +60 °C)	–	•	–
sodium hydroxide (10 % / +80 °C)	–	•	–
petroleum (100 % / +60 °C)	•	–	–
piperidine (100 % / +40 °C)	•	–	–
hydrochloric acid(20 % / +23 °C)	•	–	–
hydrochloric acid (20 % / +40 °C)	–	•	–
hydrochloric acid (20 % / +60 °C)	–	–	•
hydrochloric acid (20 % / +95 °C)	–	–	•
Disinfectant			
sodium hypochlorite up to 50 g/m³	•	–	–
peracetic acid up to 50 ppm	•	–	–
quaternary ammonium compounds	•	–	–
biguanide	•	–	–
phosphoric acid up to 1 %	•	–	–
acetic acid up to 1 %	•	–	–
formic acid up to 1 %	•	–	–
citric acid up to 1 %	•	–	–

The values provided in the table above refer to a standard epoxy resin for mechanical engineering applications.

FIBER-PARALLEL THERMAL CONDUCTIVITY λ_{II} [W/mK]



High-Energy Radiation

Short-term exposure to small doses of ultraviolet, infrared, X-ray, and even cosmic and radioactive rays improve the mechanical properties of epoxy resins. However, long-term exposure and/or large doses can degrade their original strength.

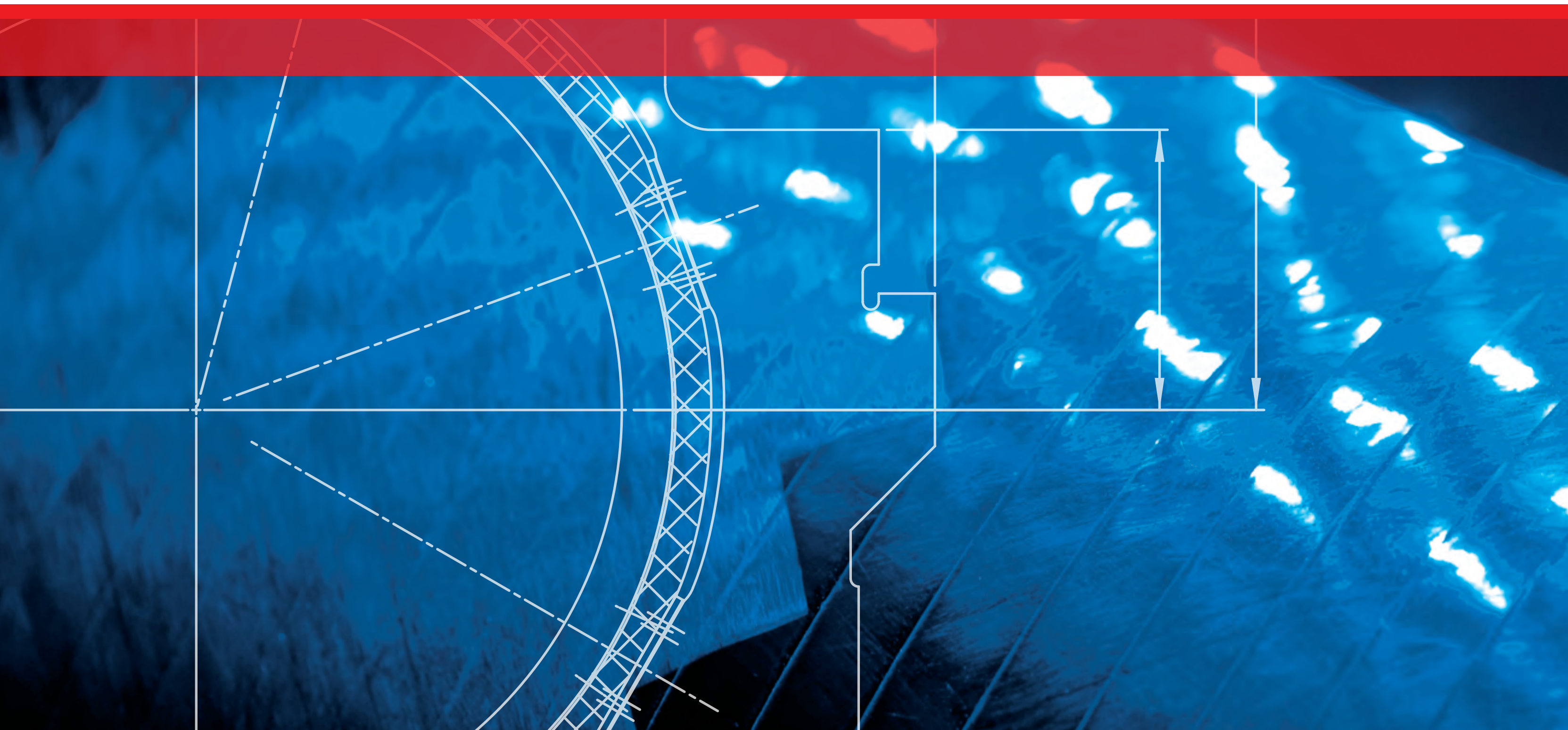
Exposure to wind and precipitation normally have little adverse effect on fiber composites with epoxy resin matrix, it is only when used under extreme exposure conditions such as for example in the desert or at sea that additional protective coatings with special materials are recommended.

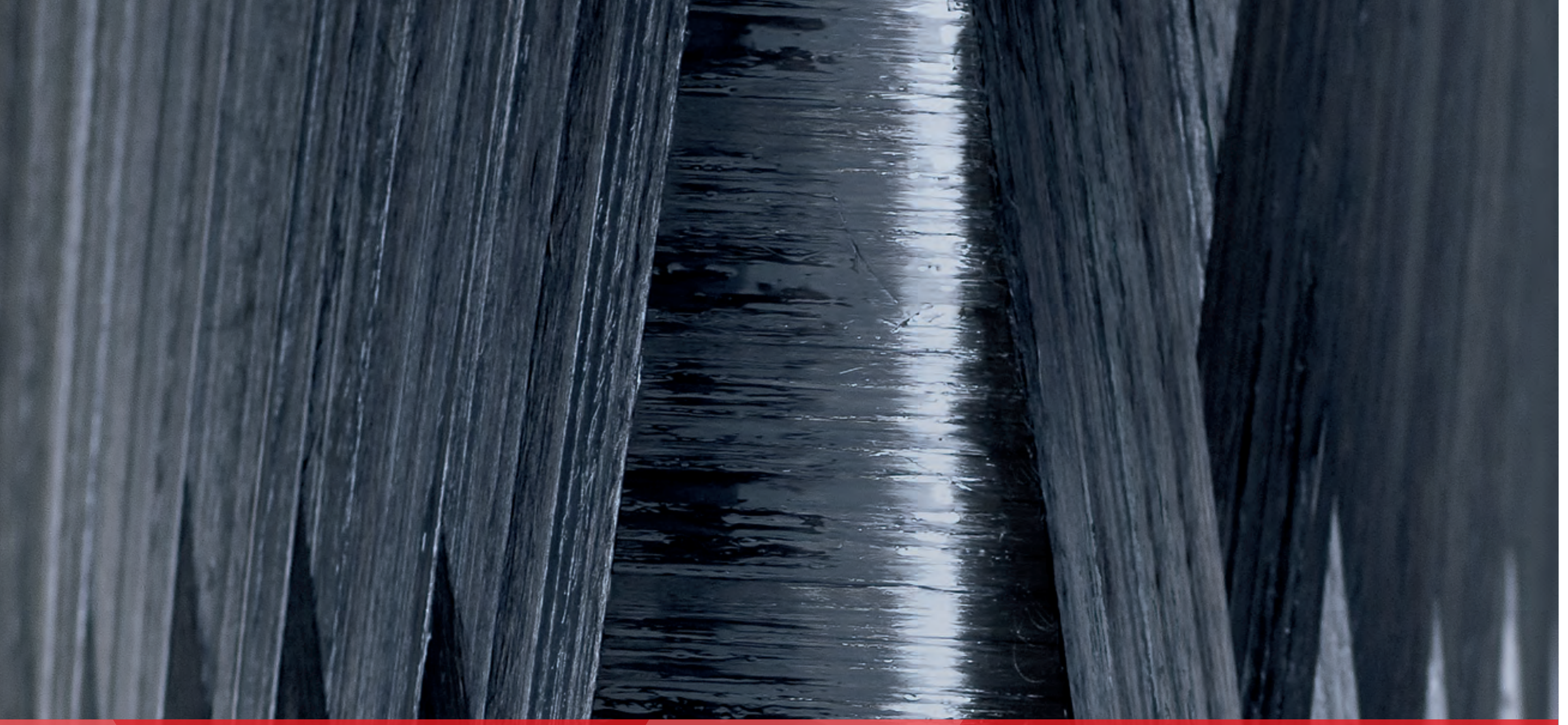
X-Ray Transparency

Carbon fiber composite materials are x-ray transparent, i. e. they do not absorb x-rays and are not recognizable on x-ray images. This special property allows for various ways of using CFRP products within medical technology.

Electrical Conductivity

Carbon fibers have very good electrical conductivity properties which is why they are often used when manufacturing things like resistance heating elements. In contrast, composite materials based on glass fibers are excellent electrical insulators and therefore offer many interesting technical applications.





THE MATERIAL OF EXCELLENCE

FOLLOWING NATURE'S EXAMPLE

Why do carbon composites make for such perfect mechanical engineering materials? Why are they better suited for certain applications than conventional materials such as steel or aluminum? Why do fiber composites have such outstanding characteristics? We want to answer all these questions on the following pages to prove that there is currently no more exciting or more diverse material on the market.

Transverse Strain

An often neglected and thus seldom utilized possibility of fiber-reinforced plastics is that their poisson's ratio can be precisely adjusted. Traditional materials have a constant poisson's value of approximately 0.3 which means, for example, that a sheet metal strip which is elongated under load by approx. 1 percent will lose approx. 0.3 percent in width. In contrast, being able to select the fiber orientation makes possible CFRP transverse strain values of more than 1.0 or even slightly negative values. This makes it possible to design components which will e. g. maintain their width or diameter when subjected to tension or compression loads. Other laminate designs can expand or contract.

Heat Conduction

As a result of the way they are manufactured, the thermal conductivity of composite materials is extremely direction-dependent. Perpendicular to the fiber direction, the thermal conductivity of composite materials is dominated by the matrix, and in fiber direction it is dominated by the fiber. There are carbon fibers with a thermal conductivity which is four times as high as that of aluminum.

FIBER AND MATRIX PROPERTIES

In composite materials, fiber and matrix each have specific characteristics and have different tasks to perform. Depending on the laminate design, components can be adapted to a large extent to meet individual application requirements. Which tasks are assigned more to the fiber and more to the matrix can be seen in the characteristic profiles above.

EXEMPLARY SUSTAINABILITY

CFRP: SUSTAINABLE AND ENVIRONMENTALLY EFFICIENT

Taking the ecological, economical and social effects of their production into account, e. g. with the help of a study on life cycle assessment (LCA), it is fair to say that fiber composites are environmentally efficient and sustainable. Compared with traditional materials such as steel or aluminum, fiber composites have less environmental impact, require less energy and emit fewer greenhouse gases, which in turn means less impact on the environment and a better carbon footprint.

Exemplary studies conducted by the aerospace sector show that the production of carbon fiber products requires significantly less energy than comparable aluminum structures, and that far less harmful emissions and waste products are created in the process.

In mechanical engineering, the main purpose of lightweight design is its potential for energy savings, and in turn cost reductions. Strength and stiffness are the cards that allow CFRP to trump over their metal competitors, which are neither corrosion-resistant, nor can they compete when it comes to comparing the amount of load cycles under dynamic loading. In addition, these last two aspects point towards the fact that composite products have a much longer service life than metals and are thus more economical. These aspects by themselves make fiber-reinforced plastics the better and more sustainable material when designing mechanical engineering components.

At the end of their service life, parts made of fiber composites can be recycled without any difficulty. They are no threat to health, air or water, quite the contrary, they are very suited for eco-friendly recycling. In the meantime, a diversified recycling landscape has come to life that can recycle products made of fiber composites in a way individually adapted to the FRP-type, including the recycling of long fibers.

The green potential is even more appealing when you take into account that some fiber-reinforced plastics are made using biological resins and ecologically sound natural fibers. Ecologically sound fiber composites are being used in many interesting applications already.

We are committed to protecting the environment, especially when it comes to our very own manufacturing processes. It almost goes without saying that we keep in mind all environmental laws as well as every essential health and safety regulation. In addition, we are relentless when it comes to optimizing our machines and processes to conserve as many valuable resources as possible.

We are developing recycling measures which allow us to use carbon fibers, our most valuable raw material, at a utilization ratio of 100 percent in a direct, internal process without down-cycling effects. Further efforts are being made to replace our raw materials and additives with more eco-friendly alternatives.

The high interest in the material and the intense activities of all market participants, especially with regard to R&D, will further increase the leading position of fiber composites as a preferred green material for demanding engineering tasks. Carbon composite materials offer a reduced carbon footprint, longer service life and better sustainability. In addition, they have much more as yet untapped optimization potential when compared with metal materials.