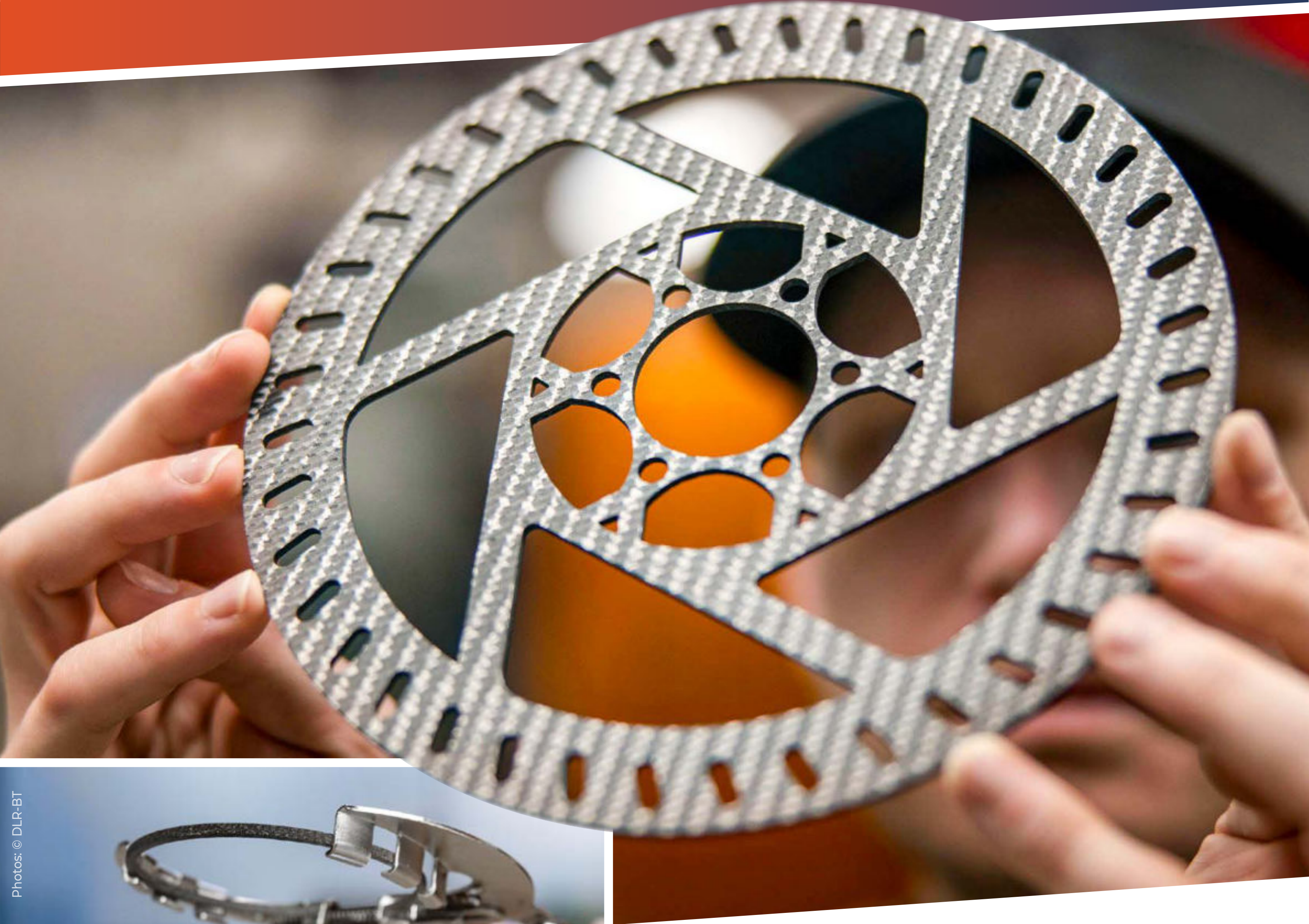
CMC
Ceramic Matrix Composites



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CERAMIC COMPOSITES

Fact Sheet on Ceramic Matrix Composites

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WHAT ARE CMC?

CMC

Ceramic matrix composites (CMC) are materials with ceramic or carbon fibers in combination with a ceramic or carbon matrix. In contrast to monolithic ceramics CMC are more damage tolerant due to toughening mechanisms (crack deflection, crack bridging) at the interface of the ceramic fibers. Depending on the property requirements of the desired application oxide or non-oxide fibers are combined with various matrices.

MATRICES

Various oxide (alumina, mullite, spinel or garnet structures) and non-oxide matrices (carbon, silicon carbide, silicon nitride) are used. The main methods for matrix development are slurry infiltration for oxide components or chemical vapor infiltration (CVI), polymer infiltration and pyrolysis (PIP) and liquid silicon infiltration (LSI) for non-oxide components.

FIBER COATING

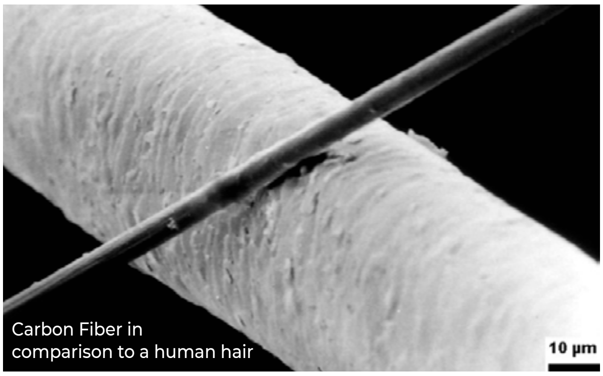
In order to ensure a damage tolerant fracture behavior a weak fiber-matrix-interface is required. This is realized by fiber coatings. Monazite for oxide CMC or pyrolithic carbon and boron nitride for non-oxide CMC are typical examples for coatings at ceramic fibers.

FIBERS

OXIDE CERAMIC FIBERS

Usually, oxide ceramic fibers are based on alumina, mullite or garnet compounds. They are fabricated by spinning process of a ceramic suspension or gel and following heat treatment. Oxide fibers exhibit covalent or ionic bonding, they are limited up to temperatures of 1,200 °C in structural applications. However, a big advantage of oxide fibers is their stability in oxidative environment. Currently, approx. 40 t per year of oxide fibers are used in CMC worldwide. The average cost is 500 €/kg - 1,500 € /kg.

NON-OXIDE CERAMIC FIBERS

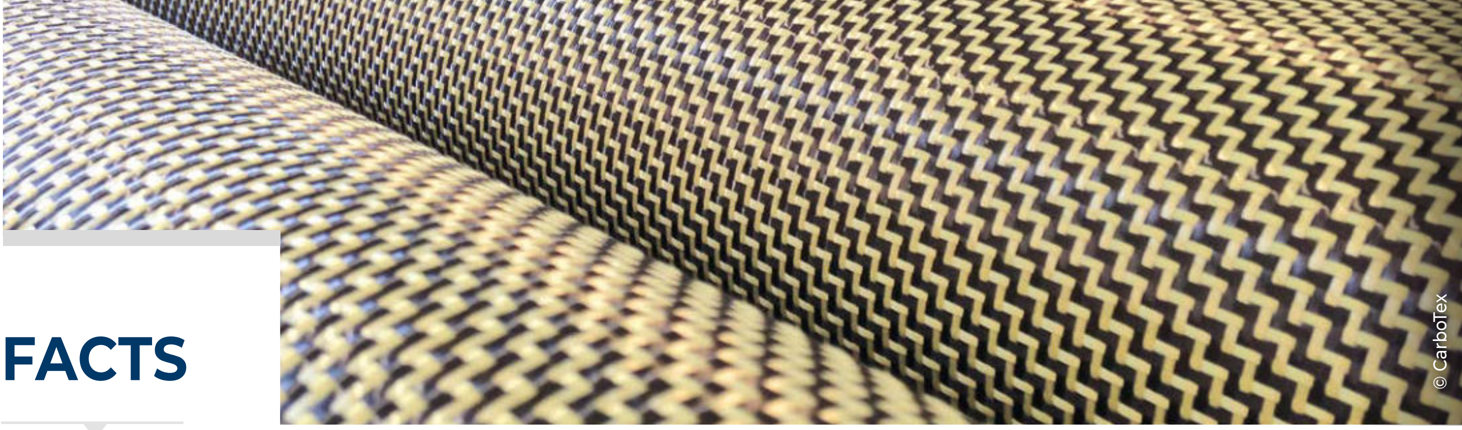


Carbon Fiber in comparison to a human hair

Carbon fibers are the most used for non-oxide CMC. The basic material of the carbon fiber is petroleum. Refining processes similar to synthetic textile technology yield to polyacrylonitrile (PAN). Through the process of stabilization (about two hours at 250 °C), almost all non-carbon material is removed from the former PAN fiber. The stabilized fiber then passes through the process of carbonization at about 1,200 °C for several minutes. Up to 50,000 of the individual carbonized fibers are wound on spools in bundles, so called tows. The carbon fiber is electrically conductive and brittle. There are carbon fibers with high tensile strengths (HT) or high moduli of elasticity (HM). Currently, approx. 8,000 t fibers per year are used in CMC and cost on average approx. 15 - 50 € / kg.

Outside carbon fibers: Most non-oxide fibers are based on silicon carbide, sometimes they contain silicon nitride. The fabrication process comprises the spinning of a pre-ceramic precursor, a curing process and the final thermal treatment. As the consequence of the high reactivity of the precursor and the intermediate products in oxidative and humid environment the whole process must be performed in inert environment. Non-oxide fibers are featured a superior high temperature stability up to 1,500 °C as the consequence of their covalent bonding conditions. The current market volume of SiC fibers is approx. 22 t per year, with one kilogram costing approx. 5,000 - 10,000 €.

	Carbon Fiber	Oxide Fiber	SiC-Fiber
Diameter	6 µm – 9 µm	8 µm – 12 µm	7 µm – 14 µm
Tensile strength	3.0 GPa – 3.5 GPa	2.1 GPa – 3.1 GPa	2.6 GPa – 3.5 GPa
E-Modulus	230 GPa – 400 GPa	260 GPa – 380 GPa	170 GPa – 420GPa
Density	1.8 g/cm^3	3.4 g/cm^3 – 3.9 g/cm^3	2.5 g/cm^3 – 3.1 g/cm^3
Price	10 €/kg – 50 €/kg	500 €/kg – 1,500 €/kg	5,000 €/kg – 10,000 €/kg



FACTS

MECHANICAL PROPERTIES

CMC are featured by a superior high temperature potential up to temperatures above 1,000 °C, a region where metallic materials cannot be used. They exhibit a high specific tensile strength with damage tolerant fracture behavior at elevated temperatures and high specific stiffness.

CHEMICAL PROPERTIES

CMC are resistant in various high corrosive liquid and gaseous environments. In combination with their superior elevated temperature stability, they are promising candidates for applications in high temperature processes in various industries.

RECYCLING

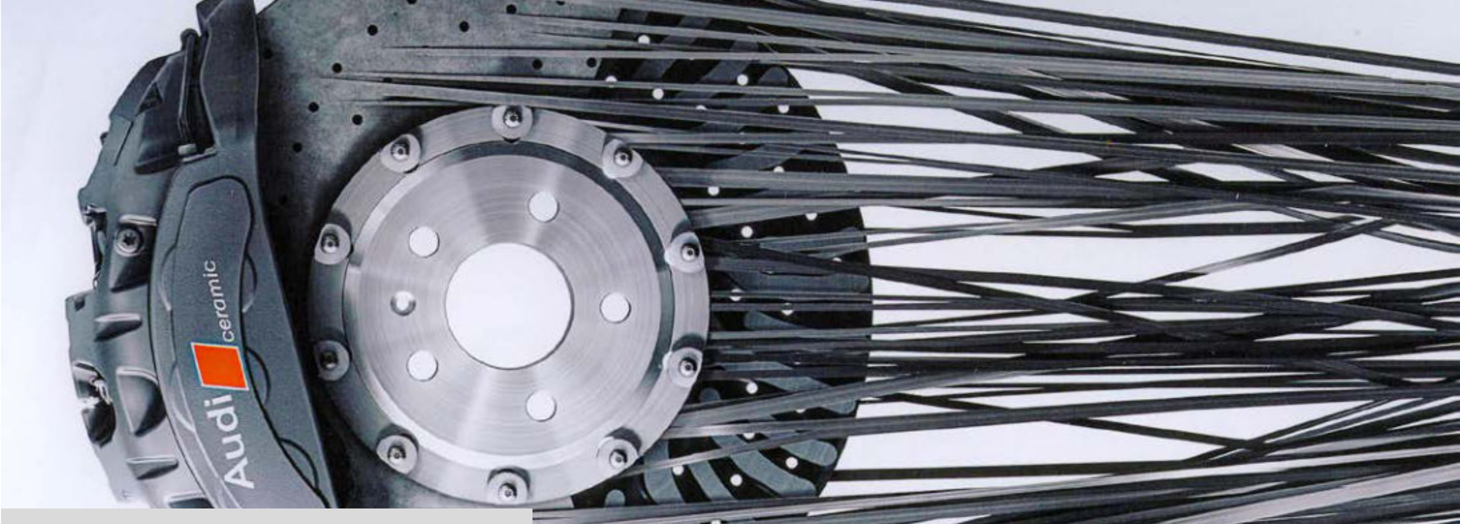
Currently various projects are performed dealing with the recycling of oxide and non-oxide CMC. In this way the basics of a sustainable industrial fabrication of CMC will be established.

PRODUCTION

In comparison to metals the fabrication costs are still high caused by the currently expensive ceramic fiber fabrication and thermal processing. High efforts are performed in the development of ceramic fibers in industrial scale by various companies such as BJS Ceramics or Rath. CMC are mainly produced via liquid silicone infiltration (LSI), chemical vapor infiltration (CVI), polymer infiltration and pyrolysis (PIP) and slurry infiltration.

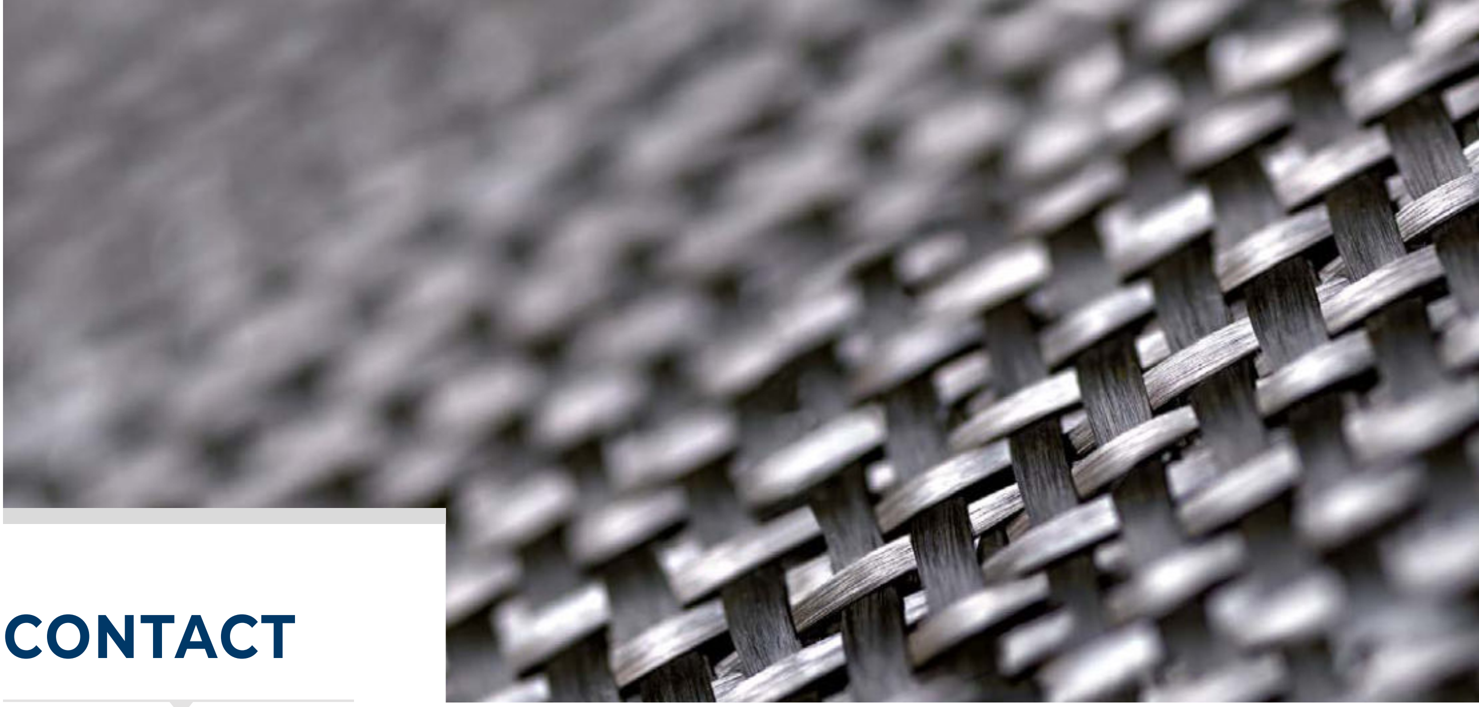
PRODUCTION COSTS

- Carbon/Carbon: 80 €/kg - 200 €/kg for parts in industrial applications and aerospace
- Carbon/Silicon Carbide: 150 €/kg (ceramic brakes) to 6,000 €/kg (space)
- Oxide/Oxide: 800 €/kg (industrial application); 2,500 €/kg (defense)
- Silicon Carbide/Silicon Carbide: 5,000 €/kg (Industrial application); > 10,000 €/kg (defense)



APPLICATIONS

Applications of ceramic composites can be found in many industries: automotive, aviation, defense, mechanical engineering, heat treatment and many more.



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