Ceramic Components Made by Textile Technology from Inorganic Fibres

Textiles are no longer available just in their customary forms, but also with special functional properties and in combination with various other materials. This opens up a broad range of opportunities for quantum leaps in completely new products. Such technical textiles are primarily used in the automotive industry, aerospace, road construction, garden and landscaping, sports and leisure, medical, environmental, furnaces and safety technology. The trend in technical textiles is towards cost and weight reduction as well as energy-saving and sustainability. Particular interest is currently focused on fibre-reinforced composites and textile-based electronics.

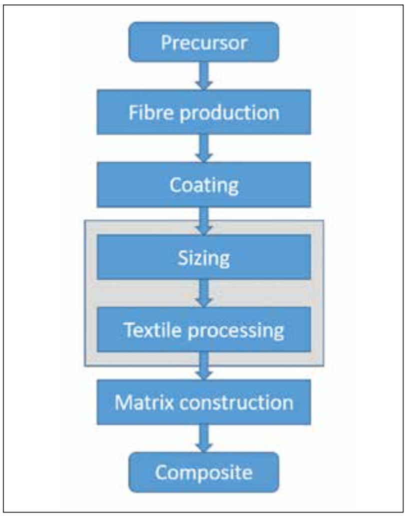

Fig. 1
Manufacturing chain for fibre composite materials

1 Introduction

High-performance fibres out of materials such as carbon, ceramics and aramid have already undergone rapid development. As the subsequent innovative step, the modification of the fibre surface has a high potential, as this is the decisive interface in the production of composites and thus also for application.

Keywords
textile reinforcement,
ceramic composites, anorganic fibres,
reinforcement of ceramics, CMC

The field of carbon and ceramic fibres is currently regarded as the most innovative area of research in technical textiles [1] due to the achievable properties of the materials, such as extreme strength, extremely low weight, high load-bearing capacity and use as lightweight materials in fibre-reinforced composites. The use of fibres for application in Ceramic Matrix Composites (CMCs) is particularly challenging due to the high temperatures, the complexity in processing the fibres and the fibre-matrix adhesion which has to be set in a defined way.

Fig. 1 shows the production chain for fibre composites with ceramic fibres. From a liquid precursor fibres are spun, which are pyrolized in a thermal treatment and provided with different coatings depending on the application. To protect the fibres and to simplify handling in the following textile processing steps, sizings are used which modify the surface properties of the fibres accordingly. Subsequently, the fibres are processed using textile processing techniques to produce two- or three-dimensional semi-finished products or preforms, depending on the intended application. The final composite workpiece is created by first removing the sizings and then filling the pore space between the fibres by a matrix, which requires further thermal processing steps.

By selecting the proper combination of fibre type and matrix material, coating the fibres and arranging the fibres, controlled composite properties can be achieved within wide limits. The Fraunhofer Center for High-Temperature Materials and Design HTL/DE with its affiliated Application Center for Textile Fiber Ceramics (TFK) is dedicated to this exciting field of research. In the following, the topics highlighted in grey (compare Fig. 1) are presented in more detail.

2 Textile fibres for use in composite materials

Some properties of important inorganic fibres are summarised in Tab. 1. Depend-

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Tab. 1
Properties of fibres

Fibre Type	Density [g/cm³]	Diameter [µm]	Tensile Strength [MPa]	E-Modulus [GPa]	Breaking Elongation [%]	Application Temperature Air/Inert [°C]	Fabric Price [EUR/m²]
Aluminium oxide	2,7–4,1	10	1700–2900	150–370	0,6–1,1	1200/1200	250–600
Silicium carbide	2,5–3,1	8–15	2600–3400	170–420	0,6–1,9	700/1800	6000–12 000
HT carbon fibres	1,8	6	3530	230	1,5	600/2000	30–50
UMS carbon fibres	1,8	6	4560	395	1,1	600/2000	30–50
Basalt fibres	2,6–2,8	9–21	3000–4840	91–110	3,5	800/800	4
Glass fibres	2,45–2,58	5–24	1800–5000	70–90	<5	600/600	1–15

ing on the requirements and the method of production, the fibres are available as filaments, staple – or short fibres.

In the future, an increased amount of fibres is expected to be obtained from the recycling of production waste and composites. These will occur as short or staple fibres. Furthermore, textile processing of various metallic fibres and wires is also possible.

The surface of textiles is the link to the environment and determines its functional properties. It can be specifically modified by physical and chemical surface treatments including coatings. By means of permanent coatings, tribological, electrical or optical properties can be adjusted. Coatings serve to protect the fibres from mechanical damage or corrosion and to improve processability.

Many fibres have a low surface tension. For coatings to adhere better, the fibre surface may have to be activated (e.g. with plasma technologies). Coatings can be applied by wet chemical or gas phase processes. Using dip coating of fibre bundles, the coating is often applied unevenly at the contact points of the fibres.

With PVD or CVD (physical respectively chemical vapour deposition) processes, shadowing effects can occur, which also cause an uneven coating. Prior to coating, fibre bundles should therefore be expanded in such a way that the contact areas between the single filaments are minimised.

Coatings can also be applied after textile processing of the fibres into preforms. However, In this case the problems caused by contact surfaces and shadowing are even greater. Ceramic fibres made of silicon carbide or carbon are often coated with layers like boron nitride having advanced sliding properties, which ensure that the fibre – matrix interface can absorb as much mechanical energy as possible.

Sizings fulfil another function. These are applied temporarily in order to be able to process fibre bundles in a better way. Sizings are usually organic polymers that can be easily removed thermally or by solvents and are applied by spraying or swapping. Both the coating and the sizing have significant effects on the textile processability of the fibres. After processing the fibre into semi-finished textile products, the size is removed, recycled if possible and returned to the production process.

3 Textile processing of the fibres

Depending on the desired end product, the fibres are further processed in various stages to produce either nonwovens, woven fabrics, scrims (so-called Non-Crimp Fabrics NCF), braids or knitted fabrics. These routes are briefly described below. Most of them are available at TFK.

If staple fibres instead of rovings are used in woven fabrics, single filaments must be spun into threads.

3.1 Nonwoven fabric production

Fibre nonwovens possess a wide variety of properties which can be specifically adapted to the desired end product and its areas of application by using different raw materials and manufacturing methods. Nonwovens are defined as: “in the widest sense flat semi-finished fabrics made from fibres or filaments, whose cohesion relies on form-fit, friction-fit, or inter-fibre bonding” [2].

Nonwovens are formed mechanically, aerodynamically, hydrodynamically and electrostatically. Fibres can be processed as nonwovens with various possibilities for bonding:

- mechanical (needling, hydroentanglement);
- thermal (thermobonding, thermofusion);
- chemical.

Fig. 2
Production of a nonwoven tube at TFK

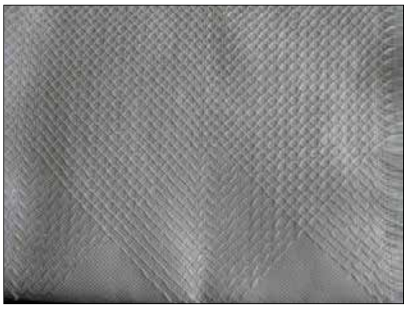

Fig. 3
Fabric with diagonal reinforcements
(Open Riet fabric)

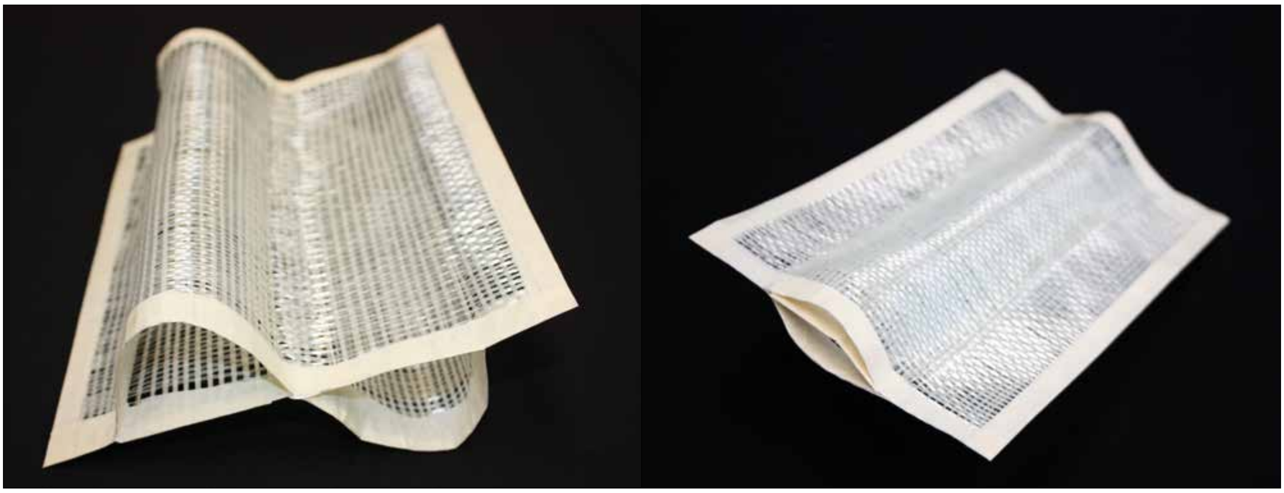

Fig. 4
Two-layer fabric with sinusoidally convex layers of oxide ceramic fibres (l.); and planar structure with counter-rotating tubular half-shells on top and bottom of fabric made of oxide ceramic fibres (r.)

With regard to near-net-shape production, tubes can be produced with different diameters and thicknesses (Fig. 2). By specially manufactured 3D-shaped tools other geometries are produced by fibre deposition using airlay processes.

3.2 Fabrics and weaving techniques

Woven fabrics are formed from at least two systems of yarns (warp and weft) that usually cross at right angles [3]. With special weaving technologies additional treads in diagonal direction are possible (Fig. 3). Characteristic features of woven fabrics are high stiffness and dimensional stability on the one hand, and requirement-specific controllable elongation and drapability on the other hand [4].

A distinction is made between dobby, jacquard, leno and multiaxial techniques which are used to achieve different fabric properties. At TFK, numerous experiments were carried out on the weaving of ceramic fibres. Especially in the field of oxide ceramic fibres, single-layer, as well as multi-layer fabric structures, could be developed.

Fig. 4 shows a concept study, in which curved structures with layers of varying lengths were produced. The production of three-dimensional fabrics is already possible with conventional weaving machines. In terms of weaving technique, simple “tunnels” can be worked in at right angles to the direction of production and then be raised, or individual warp threads can be inserted but not tied in.

With a double-rapiermachine designed for technical fabrics (Fig. 5), which is just installed at TFK, spacer fabrics can be produced in which the warp threads are repeatedly and alternately integrated into the respective cover layers. The separate thread groups for the cover layers and the web thread group provide a considerably higher stiffness and dimensional stability even without impregnation with matrix, as the web density can be specifically adapted to the requirements. Shuttle weaving had a renaissance because the possibilities of a turn back of the weft could be used for a lot of interesting products (e.g. tubes). The drapability of fabrics is lower than that of ply structures consolidated by stitches. An advantage of woven fabrics, however, is that the drapability can be easily partially changed via the weave.

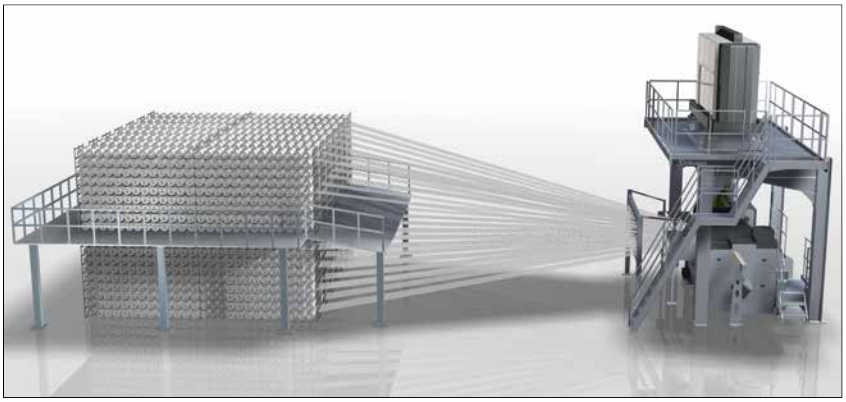

Fig. 5
Stäubli weaving system for the production of multilayer fabrics made of composite fibres (Source: Stäubli International AG)

3.3 Knitting techniques

Another technique for the production of textiles is the knitting technology, divided into weft knitting and warp knitting. This division is based on the needle movement during the stitch forming process at the machines. In weft knitting, the needles are moving individually and in warp knitting, they are moving together.

In there basic structure knitted goods are characterised by high elasticity and stretchability. The advantage of a flat weft knitting machine (Fig. 6) is that a shaped textile can be produced close to the final contour even in several layers – connected if desired. Warp knitting produces very flexible fabrics in a high productivity (Fig. 7).

However, with modified knitting machines it is also possible to produce knitted fab-

Fig. 6
Knitting machine at TFK

Fig. 7
Flexible wire mesh

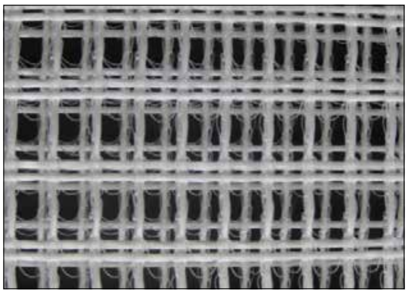

Fig. 8
Knitted spacer fabric

rics with high stiffness, like the so-called non-crimp-fabrics, used e.g. for composites. NCFs can be draped well.

A modified drapability can be achieved e.g. by changing the stitch type and density as well as by changing the inlay angle of the reinforcing threads during the production process. Besides weaving spacer fabrics can also be manufactured by the knitting technology (Fig. 8). Fabrics based on this technology have outer layers connected by web threads. They ensure that the spacer fabric maintains its spacing and hence provides high rigidity and dimensional stability.

3.4 Braiding

During braiding at least three yarns are crossed with each other and traditionally form a narrow textile. Whereas in weaving, the thread systems run in the direction of production and crosswise, in braiding the threads cross each other diagonally. Thanks to big braiding machines (Fig. 9), products in greater dimensions are also possible.

Braiding is predestined for manufacture of 3D-structures due to its very high flexibility with regard to the realisable geometry. This technology is particularly suitable for the production of tubes and hoses. How-

Fig. 9
Radial braider for manufacture of textile preforms with a diameter up to 57,5 cm installed at TFK

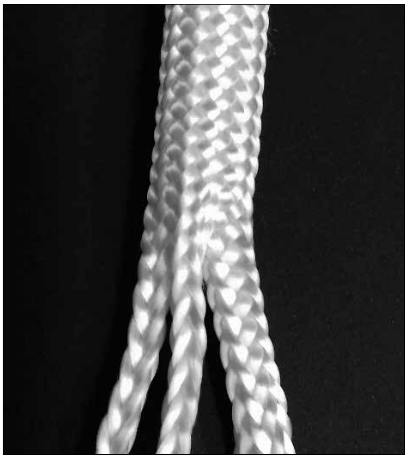

Fig. 10
Braiding with different branches

ever, with appropriate machines complex three-dimensional structures can be produced. Other textiles can be braided around or later inserted into the preform. Relatively new is the braiding of different kinds of branches (Fig. 10), which is possible by the variation braiding technology. It enables various designs beyond flat braids, cords or ropes.

The Institute for Materials Science ifm/DE at Hof University of Applied Sciences and the Application Center Textile Fiber Ceramics TFK have been able to produce novel, lightweight and multifunctional braided structures via a variation braider (Herzog GmbH/DE).

The technical equipment makes it possible to develop several new structures, such as the twisting of multiple threads during the braiding process or bobbin lace patterns. This enables the fabrication of novel braided structures with tailored tensile strength and flexibility.

Interlocking structures comparable to chain links can also be produced by variation braiding. Variation braiding technology allows a highly automated production of textile chains. If the chain-like connections are omitted, rings are obtained, which can be produced with a significantly lower process complexity compared to conventionally available spliced rings.

Furthermore, the development of so called interlock nets, which are nets without knots, has been realised. Interlock nets are highly flexible and drapable and can therefore be fitted around any shape. Every element of the net is freely movable and can be shaped individually. The production of nets with flexible and inflexible parts is also possible. This special kind of production technique is new and shows high potential in the fabrication of protection, securing and packaging nets due to high drapability, high strength and low weight of the product.

4 Production of 3D-reinforced preform structures

3D-preforms are created either by directly three-dimensionally manufactured textile products (described in 3) or by sub-preforms that are subsequently assembled. The advantages of the first process are the possibly higher strength of the component and the higher degree of automation, while the second variant allows a simplified design of complex components.

In the future, textile semi-finished products and Z-reinforced preforms will play an increasingly substantial role in the production of high-performance CMCs (Ceramic Matrix Composites) in order to meet the increased requirements of automotive, energy and aircraft sectors.

As part of the Federal Ministry of Education and Research's initiative "Technical Textiles for Innovative Applications and Products – NanoMatTextil", textile carbon fibre preforms with a defined Z-reinforcement have been developed by needling. The semi-finished products used were unidirectionally and biaxially reinforced non-crimp fabrics, highly drapable fabric structures, radial fabrics with load-compliant fibre orientation, carding nonwovens and nonwovens made of chopped fibres. The developed preforms serve as a basis for the production CMCs.

The results of the research work prove that high-strength fibre composites can be produced based on Z-reinforced textile preforms. At the same time, it has been shown that Z-reinforced preforms for the production of high-performance composite ceramics must have a high degree of structural adaptability – such as handling capability, a specifically adjustable pore size distribution and fibre density as well as a preferred fibre orientation.

By selecting the right type of needle preform design and needling parameters, a variation of infiltration behaviour, density and inner material structure is achieved. In particular, the sandwich structures developed for the CVI (Chemical Vapour Infiltration) process favour gas transport due to the hollow structures introduced via the needling process, thereby allowing economical infiltration with shorter process times compared to structures available on the market.

5 Summary

The future of high-quality textile ceramics lies in the application-specific adaptation and optimisation of fibre manufacture, textile and ceramic processing. Various textile production processes offer a broad range of possibilities that can be used at TFK.

The author and his team are looking forward to working together for new and challenging products.

References

[1] Ceramic Matrix Composites Market Size Analysis Report by Product (Oxide, Silicon Carbide, Carbon), by Application (Aerospace, Defense, Energy & Power, Electrical & Electronics), and Segment Forecasts 2019–2025. Report ID: GVR-1-68038-254-9, April 2019, https://www.grandviewresearch.com/industry-analysis/global-ceramic-matrix-composites-market

[2] Pietsch, K.; Fuchs, H.: Ch. 9: Nonwoven Semi-finished Products and Nonwoven Production Technology. In: Ed. Ch. Chokri: Textile Materials for Lightweight Constructions. Springer Verlag, Berlin, Heidelberg, 2016, 307–345. DOI: 10.1007/978-3-662-46341-3_2

[3] Sennewald, C.; et al.: Ch. 5: Woven Semi-finished Products and Weaving Techniques. In: Ed. Ch. Chokri, Textile Materials for Lightweight Constructions. Springer Verlag, Berlin, Heidelberg, 2016, 159–211. DOI: 10.1007/978-3-662-46341-3_5

[4] Meyer zu Capellen, Th.: Lexikon der Gewebe. 5th ed., ISBN-13: 978-3866412583, Deutscher Fachverlag Frankfurt/Main, 2015