1  Explanation of the TFP-technology
1.1  Fibre reinforced composites are "tailor-made" materials

A special characteristic of continuous fibre reinforced composites is their anisotropic properties. Only along the fibre direction exist the maximum properties. Already small differences between fibre orientation and angle of maximum stress reduce the load carrying capacity enormously (s. Fig. 1). Therefore, designers attempt to arrange the fibres in such a way that they follow the stress field in the composite component under end-user conditions. This is what is meant by the term 'tailor-made material'.

Using analytical and numerical calculation methods the stresses in components can be determined qualitatively and quantitatively. The example in Fig. 2 shows the calculated stress distribution in a torsionally loaded disc.

The FE-analysis generates a vector plot of the principal stresses. The direction and size of the vectors indicate a stress field aligned fibre orientation along the two drawn curvilinear patterns which intersect in an angle of 90°.

Such an optimal stress field aligned fibre orientation results in fibres being placed alternating under +45° and -45° over the whole disc area. In the centre area the loads are higher than at the outside so that the thickness of the disc should smoothly change from thick at the centre to thin at the outside edge. With conventional semi-finished reinforcements such as fabrics, multiaxial warp knitted fabrics and braids this is only partly possible.
1.2 Manufacturing of 2D-reinforced fibre preforms for composite components using the Tailored-Fibre-Placement technology

A number of textile reinforcements are available on the market which are made by many different manufacturing techniques. These textile reinforcements can be e.g. woven, braided or knitted. Fibres in reinforcements for advanced composite components should be arranged in the following way:

- stretched (without waves and twists),
- aligned to the stress field,
- constantly stressed (local thickness of the component corresponds to the local load).

Conventional semi-finished reinforcements can sometimes comply with these requirements. However if the component has complicated shapes and load paths then the optimum fibre orientation is not economically feasible.

That is why the Institute of Polymer Research Dresden developed the Tailored-Fibre-Placement-Technology (TFP-Technology), which allows to transfer effectively the results of a stress and strain calculation into a textile reinforcement structure. The process base on the well-known embroidery technique. By using CAD technique the desired fibre course is converted into a software pattern which, fed to an embroidery machine, takes care that reinforcement fibres, e.g. rovings, are stitched upon a base material (s. Fig. 3). Examples are presented in the collection of applications s. Point 6.

The TFP-technology has several advantageous compared to other textile technologies:

- the angle of fibre placement during the lay-up process can be varied freely between 0° and 360°,
- repeated fibre placement on the same area allows for local thickness variations in the fibre preform suited for the composite component,
- the conversion of the desired fibre orientation in a fibre placement pattern for the embroidery machine requires minor development times and costs,
- the process allows a near-net-shape production, which results in low waste and optimal fibre exploitation,
- the possibility to process a variety of fibres such as natural, glass, aramid, carbon (high strength and high modulus) and ceramic fibres.
1.3 3D-reinforced preforms

There is an increasing demand for textile reinforcements which are capable of carrying multiaxial loads in composites. The reason is that conventional textile lay-ups exhibit low mechanical out-of-plane properties. The low properties in z-direction such as tensile strength, peel strength and the interlaminar shear strength result in a poor thermal stability and an insufficient tolerance against impact.

A solution to this problem is to reinforce a two-dimensional textile structure with extra fibres in the z-direction. The character of the properties in z-direction are improved against two-dimensional reinforced composites, depends primarily on the kind and amount of reinforcement fibre as well as on the angle under which the reinforcement is brought into the composite.

The TFP-technology allows, by using upper and lower needle yarns from reinforcement fibres, to reinforce in z-direction perpendicular to the main xy-plane (s. Fig. 4).

However the in-plane mechanical properties will be reduced with increasing z-fibre content. This is caused by a reduced fibre content in the xy-direction, technology dependent material discontinuities and partial damage of the in-plane fibres.

Because of the reduction of the in-plane mechanical properties with increasing z-fibre content it is advantageous to z-reinforce only there where it is needed and with the optimal amount of fibre. In this way the in-plane properties are only partially affected by the z-reinforcement. Unnecessary z-fibres will not be placed at all. Fig. 5 shows in principle a tension-compression strut locally reinforced with 3D-reinforcement fibres.
1.4 Deep-drawable TFP-preforms

A lot of components cannot be made with 2-dimensional preforms only. This is especially true for components which are made by deep-drawing plane semi-finished products. How good conventional continuous fibre textiles can be deep-drawn depends on the sliding and shifting capability of the material. Beside this wrinkles can occur during the process of deep-drawing. TFP-preforms can be deep-drawn when at the spots where fibre reserves are necessary for the deep-draw process fibre loops are created (s. Fig. 6 and collection of applications).

1.5 Consolidation of TFP-preforms

The consolidation of TFP-Preforms to composites can be done with conventional processing techniques such as resin transfer moulding, vacuum bag moulding, pressing and autoclaving. In case of thermoplastic composites the matrix material and the reinforcement fibres can be placed simultaneously e.g. in the form of films or fibres. The base material can then be a thermoplastic foil which melts during the consolidation process and becomes part of the matrix. This type is ideally suited for deep-drawn TFP-preforms.
1.6 Advantages of tailored preforms

great variety of textile structures
• stress field aligned fibre placement
• 3D-reinforced preforms (also partially)
• deep-drawable preforms

processing of
• natural, glass, aramid, carbon and ceramic fibres

maximum exploitation of the reinforcing fibres through
• uniformly stressed fibres in the composite
• near-net-shape production (no cutting, low waste)

low production costs through
• use of rovings
• high grade of automation

good opportunities for quality management due to
• high reproducibility of the fibre placement
• recording of processing parameters for each single preform