SIMULATION OF COMPOSITE PROPERTIES
REINFORCED BY 3D SHAPED WOVEN FABRICS

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ABSTRACT

In opposite to 2D-woven fabrics the use of 3D-woven fabrics provides important advantages. The production process is less time-consuming and the fabric offers a high-quality surface. Within two research projects, staff of the Niederrhein University of Applied Sciences in Mönchengladbach is working on the acceleration of the production process and the optimization of 3D-fabrics by using a CAD-Simulation.

1. INTRODUCTION

Until now the production of textile fabrics, adapted to a three-dimensional form, were achieved by methods like transforming, manufacturing and fibre spraying.

Fig. 1: Transforming

- deep drawing of a two-dimensional textile
- **limit**: drape ability of the 2D-textile

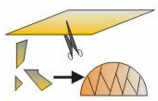

Fig. 2: Manufacturing

- cutting/punching out and assembly (through sewing, sticking together etc.)
- **limit**: quality and costs

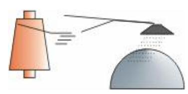

Fig. 3: Fibre spraying

- application of cut fibres through the spraying method
- **limit**: mechanical load-bearing capacity

By now there is a possibility to adjust textile fabrics already to a certain shape during the weaving process. These fabrics are called 3D-textiles. Their characteristic is the volume making expanse of the textile body without the impact of pre-and post-transforming actions.

The process to produce these 3D-textiles is called *Shape Weaving* process and was developed by the company Shape 3 Innovative Textiltechnik GmbH. The integration of different long warp and weft yarns during the weaving process is the principle of this process. Through these surplus yarn lengths the textile expands into the third dimension.

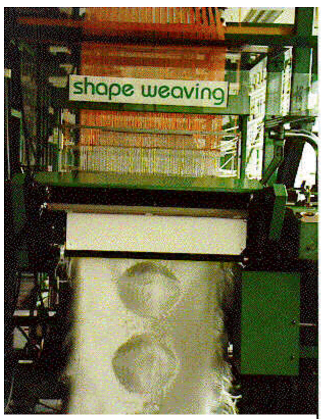

Fig. 4: 3D-loom

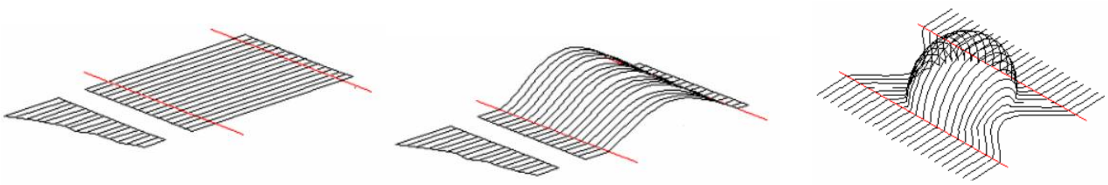

Fig. 5: Principal 3D-weaving

The *Shape Weaving* process provides several advantages:

- The later ready-made is not necessary.
- Disturbing and eventually quality reducing joins will be avoided.
- High strength and form stability of the textile can be guaranteed.
- Final product has a lower weight and a more homogeneous surface.
- Lower number of personnel and the clear reduction of cutting waste save costs.

Typical applications of 3D-woven fabrics are half-finished products in composites, for example hard hats, car interior linings or monocoques.

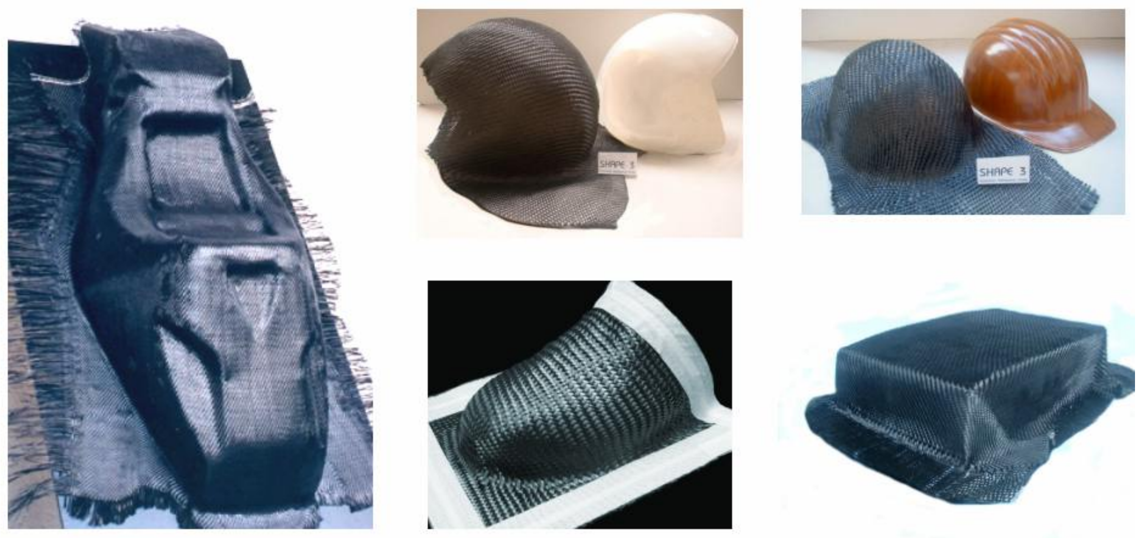

Fig. 6: Examples for application area of 3D-textiles

<u>Problems</u>

The writing of a database for the 3D weaving was very expensive.

First, it had to be determined which length is needed for every warp yarn. This was done by manual measuring of the prototypes regarding warp and weft yarn lengths. Hence, the quality of a 3D-textile depends largely upon the accuracy of this measurement. In a second step the weave constructions – adjusted to the 3D shape - had to be defined. These were defined on the basis of experience values. Only by weaving of the whole product the problem areas was apparent. To control any made changes the complete product had to be rewoven. Until now, only after extensive single trials you got a sufficient result. There was also the fact, that the determined data was not reproducible and the database had to be completely redone by the use of minimal changes (yarn strength, fabric weight etc.)

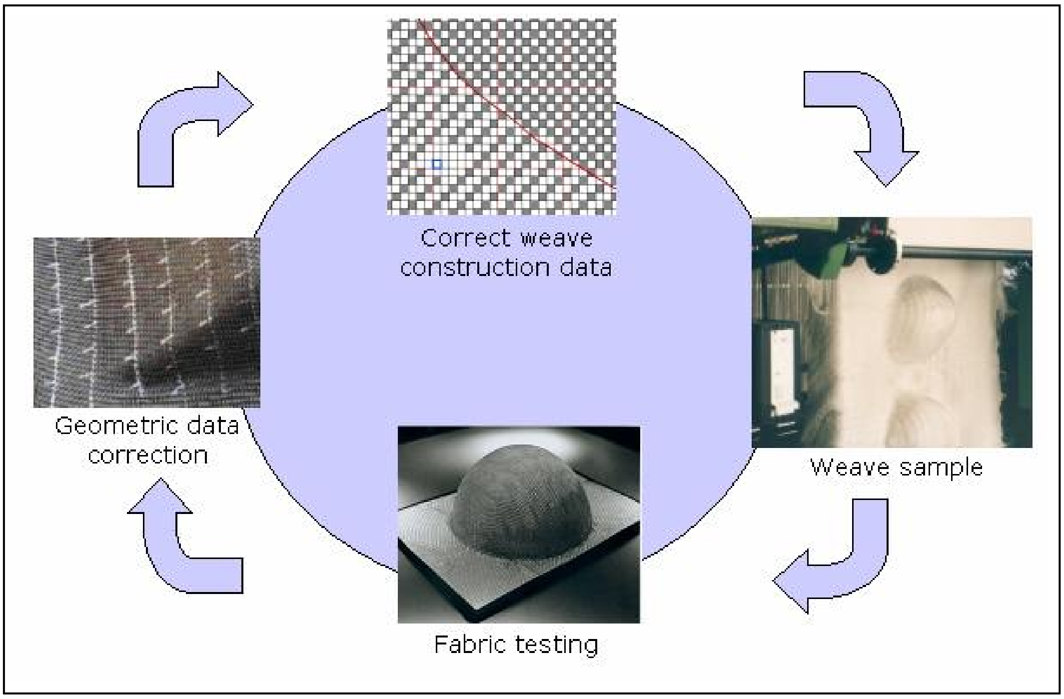

Fig. 7: Previous procedure, optimisation weaving trials

To reduce this expenditure, a CAD-appendix-module to the Mechanical Desktop program was created. It is used before the weaving process to check the feasibility of a geometry as a 3D-fabric and to predict fabric construction defects.

Furthermore 3D-fabrics worked up in composites have to bear heavy loads. Hence, the calculation of the mechanical properties is necessary to determine weak points and to eliminate them. A special module, which considers the characteristics of 3D-woven fabrics, such as permanently changing thread densities, cross-over points and changing weaves is needed.

2. RESULTS

2.1 Simulation for the development of 3D-fabrics

Within the bounds of the research project “Construction of 3D-fabrics with the aid of a standard CAD-system”, financed by the Innovationsfond, a simulation was developed which is able to simulate 3-dimensional fabrics regarding geometry and fabric construction. Different thread orientations can be shown and compared directly on the screen. Limits depending on the machine or fabric and geometry, as for example decreased thread orientations or too high thread distances, can be tested and if applicable changed at the “virtual fabric”. Furthermore weaves can be added and changed in some parts. Examples of the weave simulation are shown in Fig. 4-6.
The most important results are data records to control the loom.

1) Parallel warp and weft threads
Result:
- too high deflections of warp and weft threads especially in the 2D-area
- too high compaction of warp and weft threads especially in the 2D-area

⇨ pleat formation in the fabric

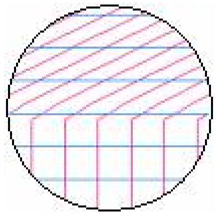

Fig. 1: Disorientation and compaction

- Nearly parallel thread orientations lead to missing intersection points of warp and weft ends at the upright edges

⇨ fragmentary fabric in the edges

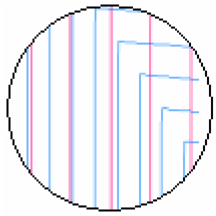

Fig. 2: Missing points of intersection

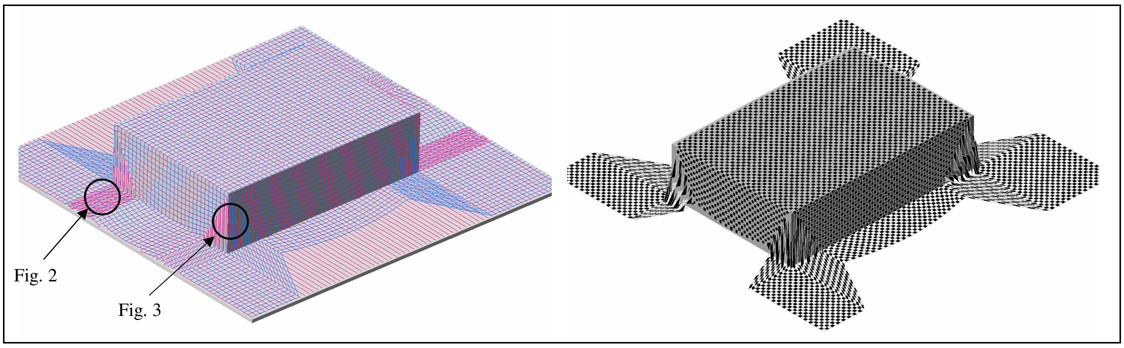

Fig. 3: Parallel warp and weft threads, simulation of threads (left) and plain weave (right)

2) Parallel warp and spread weft threads
Result:
- too high deflection of warp in the edges
- too high compaction of warp in the edges

⇨ pleat formation in the fabric

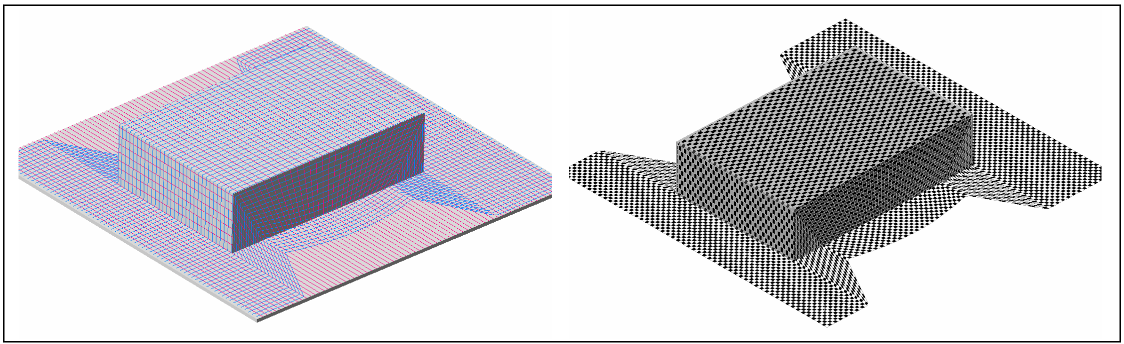

Fig. 4: Parallel warp and spread weft threads simulation of threads (left) and plain weave (right)

3) Spread warp and weft threads
   - regular surface of fabric without too heavy thread deflections
   - possibly too high thread distances on the top of the suitcase shell

   ⇨ possibly additional threads are necessary

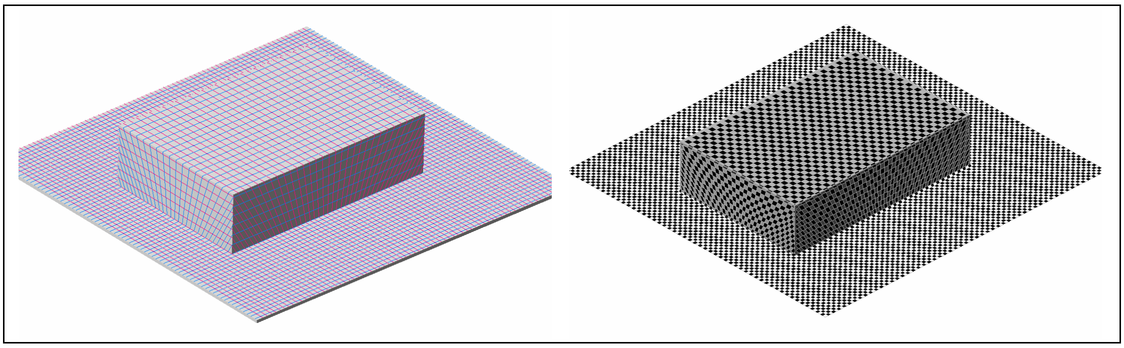

Fig. 5: Spread warp and weft threads, simulation of threads (left) and plain weave (right)

2.2 Mechanical properties of composites

A TRAFO-project, financed by the AiF (Arbeitsgemeinschaft industrieller Forschungs-vereinigung), continues the before mentioned simulation. In this course a simulation to calculate and depict the mechanical properties of 3D-reinforced fabric composites will be developed. Input data are yarn and resin parameter, as well as information about the intersection points of warp and weft threads. The former simulation provides these points. The central point of this project is less the exact failure analysis by means of FEM, rather stiffness calculation, through which weak points in the fabric can be shown. They can be repaired by the use of additional threads or changed proportional spread threads.
At the beginning a base cell was developed, which considers the special features of 3D-fabrics (changing thread distances, intersection angels of warp and weft threads and changing weaves). The basis cell includes one intersection point of one warp and weft thread. Two different ways of creating this cell are possible. This is first shown considering as an example the plain weave and after that brought forward to other weaves.

1. Possibility:
Central points of intersection are calculated in warp and weft direction.
By connecting these points we span the base cell, see dashed lines.

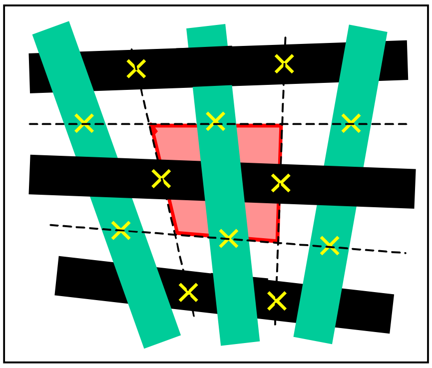

Fig. 6: Area-wide base-cell

Advantages:
Area-wide; dependent on the next and next but one neighbor

Disadvantages:
Instead of four eight intersection points have to be; difficult to calculate area; several angles respectively vectors per base cell

2. Possibility:
The second possibility is the used method to create the base cell.
In warp and weft direction central points of intersection of threads are calculated
Parallels to the regarded warp or weft threads are drawn through these points. Theses parallels build up the base cell.

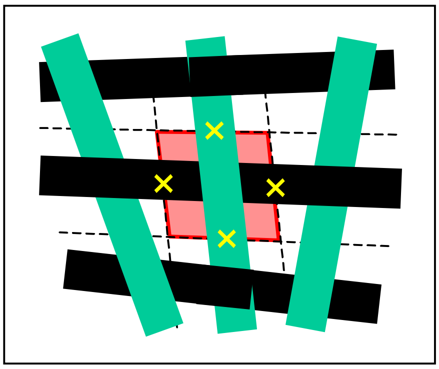

Fig. 7: Parallelogram-base cell

Advantages:
Calculation is much easier than in the 1st possibility.

Disadvantages:
Overlapping base cells, influence of next but one neighbor unconsidered.

Whereas plain weave can be calculated with only one base cell, other weaves consist of the same number of base cells, as the pattern repeat possesses intersection points.
Thus the surface accordingly the volume of the pattern repeat increases by a factor of n^2, if the weave has a period length of n threads. At the same time the number of considered pieces of threads in warp as well as in weft direction are increased by the factor of n. With these weaves an averaging about all occurred thread pieces (different numbers of gradients, curves and horizontals)

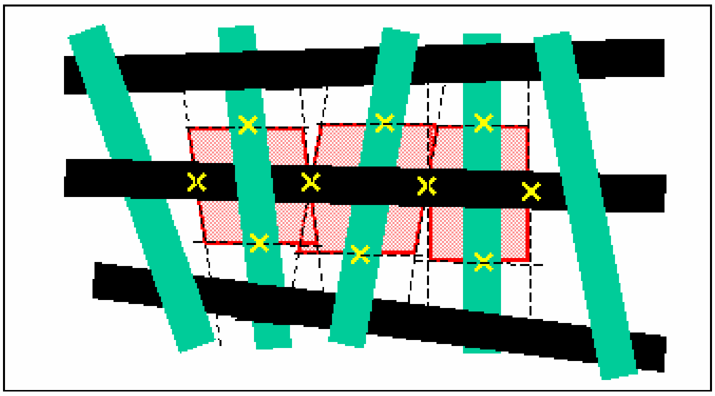

Fig. 8: Base cell of a twill 1/2-weave

In other calculation models the smallest decomposable unit is called unit cell. Because of the fact that in our case not every cell looks the same, but they are created in the same way and their appearance depends on the weave and the position of the neighboring threads, we call it base cell.

The base cell can include three different segments, caused by thread orientations depending on the weave. Referring to Shang [1] the wavelike thread orientations is not described by a sinus curve, but with gradients, curves and horizontals.

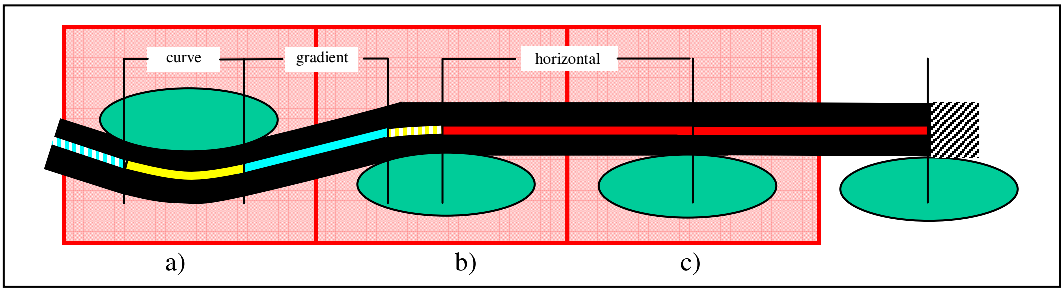

Fig. 9: Different segments of a weave and base cell

Different contents of a base cell:

a) ½ gradient, 1 curve, ½ gradient

b) ½ gradient, ½ curve, ½ horizontal

c) 1 horizontal (in the strict sense consisting of two half horizontals)

Dependent on the continuing thread orientation following c) one complete horizontal or - if a decline of threads is desired - the mirrored case b) is possible

Additional to the base cell, which regards different angles between warp and weft and not only 90° angles, one more difference to the model of Shang exists. The rotation matrix M refers in Shang's paper to a fixed coordinate system, while 3D-fabrics are referring to a local coordinate system on the area of the current point of intersection.

The implementation of the developed calculation model was first done in Microsoft ® Excel. Soon it turned out, that Excel cannot afford this calculation efforts. Especially in future components, which can provide nearly 400.000 points of intersection, Excel is not an adequate software with its limitation to only 256 columns. Furthermore Excel only offers limited mathematic functions and also mistakes in calculation are possible when using bigger data records.

Thus, to calculate the mechanical properties/stiffness the software MathCAD version 13.0 (from MathSoft) is in use. The graphical depictions are done with the Mechanical Desktop ® 2005, the original software for the fabric simulation.

The following pictures of the simulation indicate the influence of the thread orientations on the stiffness of the fabric.

The first example shows the stiffness in case of parallel warp and weft threads, leading to a fabric with regular thread distances. As seen before in the simulation of threads and weave, extreme thread compactions depending on the geometry occur in some areas (here blue).

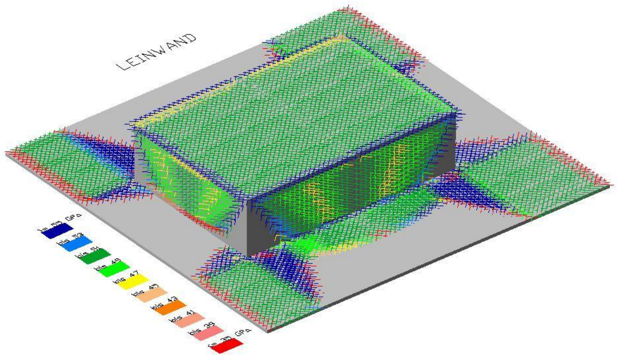

Fig. 10: Stiffness of parallel warp and weft threads, plain weave

The second example shows the stiffness of a fabric with parallel warp and spread weft threads. Areas with a too high thread compaction are reduced. However, at the sidewalls there are areas where the fabric becomes too loose (here beige).

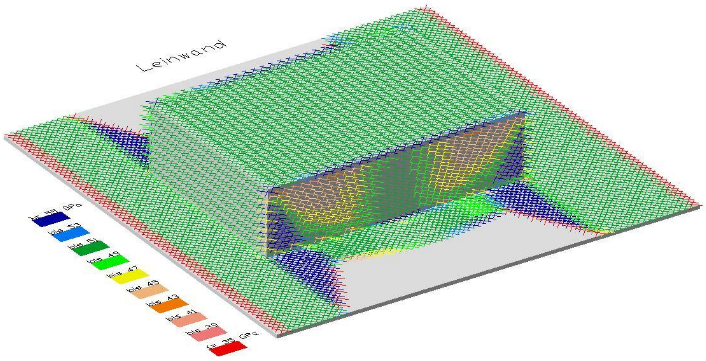

Fig. 11: Stiffness of parallel warp and spread weft threads, plain weave

The third fabric offers significantly less stability in the 3D-area. This could already be guessed in the simulation of thread orientations and the weave. For components that have to endure heavy loads these fabric construction is not advisable.

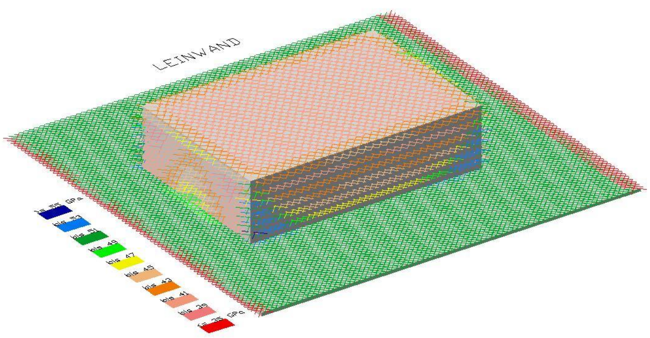

Fig. 12: Stiffness of spread warp and weft threads, plain weave

3. FUTURE PROSPECTS

The previous results are intermediate steps, which have to be improved in the following month. For example currently a maximum crimp angle of 90° is assumed. In practice this is not possible, because the thread thickness, which mostly does not allow such a big thread deflection, has to be considered. The maximum crimp angle could therefore be determined due to the stiffness of the filaments.

Acknowledgements
We thank the AiF (Arbeitsgemeinschaft industrieller Forschungsvereinigungen) for the financial support of this research project within the scope of the program TRAFO (Transferorientierte Forschung an Fachhochschulen).

References:

1. **SHANG, S. Z.; VAN HOA, S.**: „Three Dimensional Micro-Mechanical Modelling of Woven Fabric Composites", in: Journal of composite materials Band 35, Heft 19, S. 1701-1729, London, 2001