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LOAD-ADAPTED 3D-REINFORCEMENT BY MEANS OF FUNCTION-ADJUSTED READY-MAKING PROCESS

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SUMMARY:

The empirical examinations together with the experiments carried out on the textile and plastic composites, which are joined by sewing, impressively showed that the sewing technology is an excellent means to noticeably increase the interlaminary strength for the application of load-adapted z-reinforcement arrangement. The textile assembly of complex textile preforms and their further plastics processing is possible. The research work will be carried on, which will open new markets for new products to the textile and clothing industry. These textile-reinforced synthetic materials will make vehicles and machines lighter, more resistant, safer and, as a result, more economic in the future.

KEYWORDS:

3D-Reinforcement, thermoplastic composites, textile Preform, Ready-made clothing process

INTRODUCTION

Complex material requirements for high-technology applications increasingly demand the use of hybrid material structures with properties tailored to the lines of loading. Textile-reinforced multi-layer composite structures are particularly suitable for the production of component structures in an optimized lightweight construction. In the loading case, however, delamination phenomena occur between the individual layers due to the low interlaminar shear strength.
The appropriate techniques and machines of the ready-made-clothing technology allow the specific sewing-up of the semi-finished textile products into a three-dimensionally reinforced multilayer composite structure, the setting of a load-adapted and failure-tolerant characteristic of properties being possible in the z-direction through a versatile variation of sewing parameters. Moreover, the sewing technology makes possible a ready-made-clothing-technological pre-assembly of components of semi-finished products and thus can perform position-fixing functions in the consolidation of the composites.

Within the framework of a research group „Textile reinforcement for High-Performance Rotors in Complex Applications“ promoted by the German Research Society (DFG), rotationally symmetric reinforcement structures in the shape of rotors were assembled by means of optimal sewing process parameters and further processed plastics-technologically. Eight subprojects focus on the following issues:

- carbon and thermoplastic hybrid yarn
- spinning of very thin PEEK filament yarn
- textile fabrics with variable axes for rotational loads

- application of procedures and machines used in the textile industry to manufacture and assemble textile preforms
- computations on the basis of material parameters
- experimental testing of the prototypes on the rotor test stand
- integration of sensor components in the rotors
- application of kinematic molding tools

It is interesting to note that a thermoplastic matrix is applied, which is introduced into the composite via the textile form by consistently using hybrid yarns. The plastics process is realized by applying the autoclaving technique for the manufacture of complex components.

Autoclave technique, i.e. curing the laminate in the vacuum under pressure and heat, still requires a certain degree of manual work.
Form tools adapted to the component are necessary to stabilize the made-up textile preform. In the autoclave, the component geometry should be subjected to a homogenous pressure. Therefore, the form tools should ideally be tensible inside the component.

PRODUCTION OF PREFORMS WITHIN THE READY-MADE PROCESS

The tests are carried out on high-performance rotors of a diameter of 500 mm containing blades that are arranged between two disks. Potential applications of these rotors may be centrifugal substance separators for the process, chemical, and laboratory technology or also flywheels running at extreme speeds.

The disks of the model rotor 1 (Fig. 1) are still flat, while one of the disks of model rotor 2 has already been hyperbolically shaped.

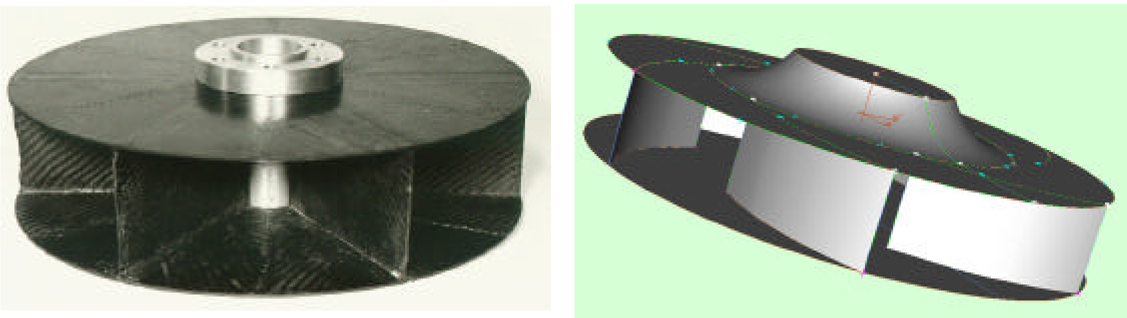


Fig. 1   Model rotor 1 and Model rotor 2

The following steps are necessary to make a textile preform with the component design being very complex:
- pattern design in accordance with material behavior
- cutting
- stacking
- prefabrication and placing of the z reinforcement
- assembly of the 3D preform

The technical procedures and machines applied are chosen from economic aspects. Beside the large number of pieces extreme thickness of the textile products of up to 20 mm and the required sewing precision demand precise and reproducible manufacturing processes.

PATTERN CONSTRUCTION WITH DUE REGARD TO MATERIAL BEHAVIOR

If curved element contours of lightweight textile structures are covered with an undefined shape of the reinforcing textile, the mechanical component properties may deteriorate. The patterns should be developed directly on the object to apply the reinforcing structures to the desired 3D shape according to the required load and thus avoiding rework.
Three-dimensional CAD programs are mainly applied to design complex components (AUTOCAD 2000, Pro Engineer, Thinkdesign 4.0, CATIA...). The data obtained by the above programmes may be transferred to the simulation programs via suitable interfaces (IGES- Initial Graphics Exchange Specification, VDAFS – interface suited for the exchange of free forms and curves). The component outline and/or the form tools, respectively may quite as well be generated in the simulation programs 3D Concept directly, which is however not very comfortable in terms of handling (Fig. 2).

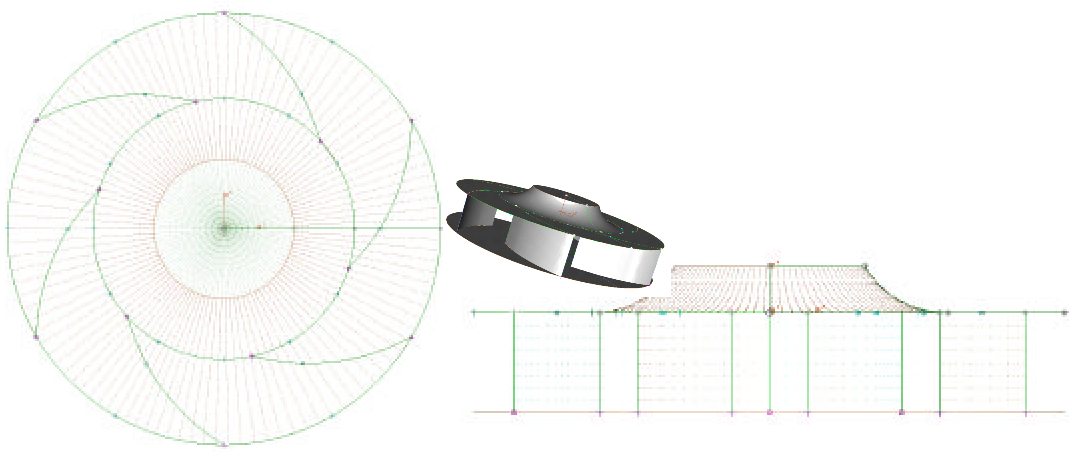


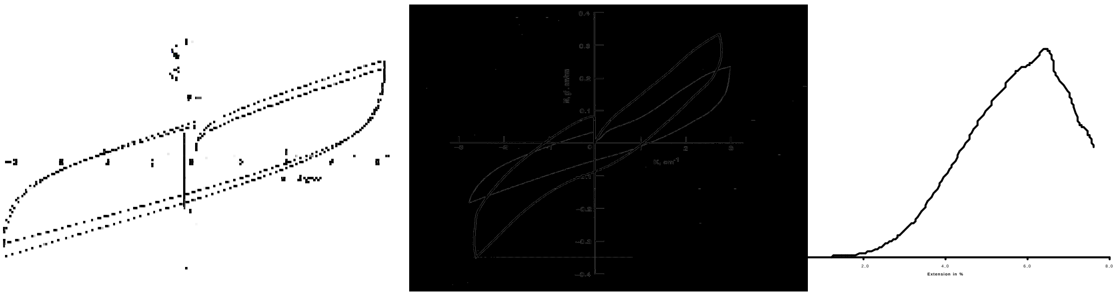
Fig. 2 3D component geometry of the simulation program

The textile and bendable (with low bending stiffness) preform should be in most exact accordance with the component geometry desired in the end. In particular for the realization of free-form surfaces it is necessary to cut the fabric or non-stitched-fabric thus that it may be shaped later without irregular folds.

In the garment industry this is called working in the close-to-body range close-fitting garments, where the essential factors that influence the shaping behavior are the tension and stretching behavior together with the shearing behavior of the material used.

After the patterns have been developed with due regard to functional requirements using a three-dimensional model, surface generation and the development of the two-dimensional patterns in the two-dimensional level are made feasible by an efficient software tool (3D Concept by CDI, recently belonging to Lectra Systemes, France). The software 3D Concept is based on the polygone computation of NURBS (Non-Uniform-Rational-B-Splines). It is considered the state-of-the-art computation method to design complex polygon surfaces.

Shearing occurring in the pattern as well as material tension stresses and stretching may be analyzed to provide the designer with information that enable him to produce suitable patterns of the reinforcing textile material. For this purpose, detailed knowledge about the mechanical properties of the reinforcement structures that are to be processed is inevitable. The instrument system developed by KAWABATA may be used to investigate the mechanical parameters of textile fabrics, such as measurements of compression, surfaces, bending, shearing and strain/tension (Fig. 3). In some cases, the common standardized test procedures may be applied, too.



Shear Bending Tensile

Fig. 3 Investigation of the mechanical parameters of textile fabric

The thermoplastic matrix materials used are polypropylene (PP), polyamides (PA) and polyethylene terephthalate (PET) and even such high-performance plastics as polyetheretherketone (PEEK). Thanks to the use of commingling yarns in the form of thermoplastic hybrid yarns for the production of the intermediate textile stuff in the form of fabrics and/or non-crimp fabrics an additional matrix component that changes the shaping behavior of the textile surface is not necessary.

The material data obtained for the shearing, the material tension stress and also the stretching behavior may be implemented by scanning the measurement curves and subsequent scaling or by loading a file in the ASCII format. This investigation starts from an orthotropic structure for the majority of fabrics tested so far. When high modulus carbon yarns are processed (E modulus > 650.00 N/mm^2), we may start from the fact that the potential deformation between the two-dimensional cutting and the multiply curved component surface results from the shearing deformation.

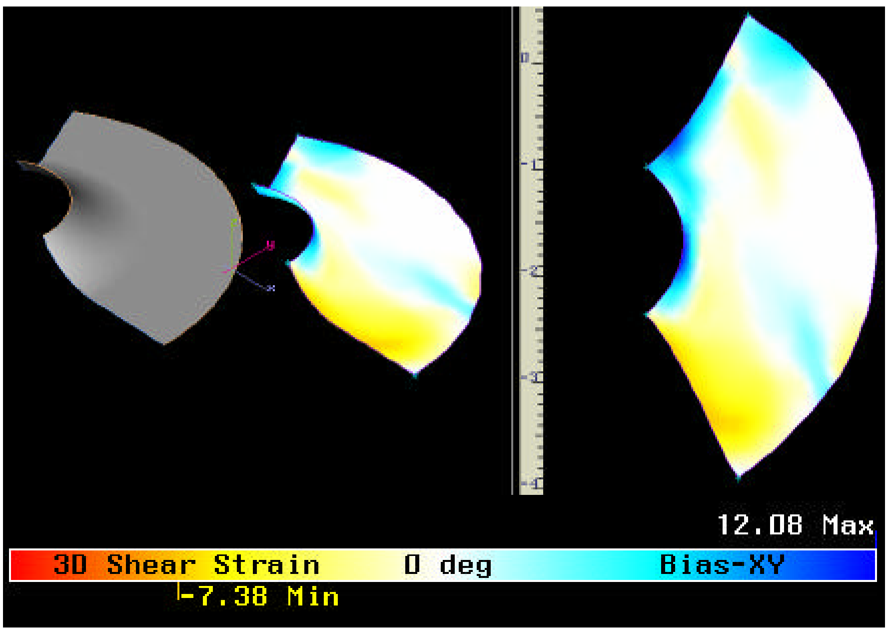


Fig 4. Sample Rotor with conical shell, wrap flat simulation 3D to 2D

Problems characterized by large deformations may be described by incremental formulations to determine the state of deformation and tension stress. For this purpose, a network is generated on the component surface to be shaped. The network may be generated automatically or interactively. The accuracy of computation depends on the triangle size. Material behavior is attributed to the network to simulate the development in the two-dimensional level depending on the material type. After the computation has been completed, the shearing occurring in the shaped patterns may be read. A comparison with the critical shearing angle, which indicates how far the share of threads can be twisted/compressed without crease formation (folds), helps the designer decide whether the cut-up pattern is suited for the component surface (Fig. 4).

Table 1 Software

Function	**3D-Concept**
3D design	✓ not very comfortable
3D digitiser	✓ devices may be connected for contact digitization
shape models	✓ may be implemented
material data	✓ data points or data graphs may be read in from the KAWABATA measurement system or other test instruments for tension stresses and stretching and shearing
wrap flat 1. mesh generation a. automatical b. interactive 2. wrap flat a. geometry b. with material data	development of two-dimensional patterns from the parts constructed three-dimensionally on the shape models ✓ ✓ ✓ ✓
data exchange	✓ e.g., DXF, IGES, ...

Cutting

The pattern design is followed by the cutting process. Very often multiple-layer cutting of geometrically identical pattern is not feasible due to the load-specific arrangement of the threads in the fabric. In addition to conventional cutting techniques (knife cutter – drawing knife, oscillating knife), unconventional cutting media (hydrocutter, laser cutter) are particularly suited (Fig. 5).

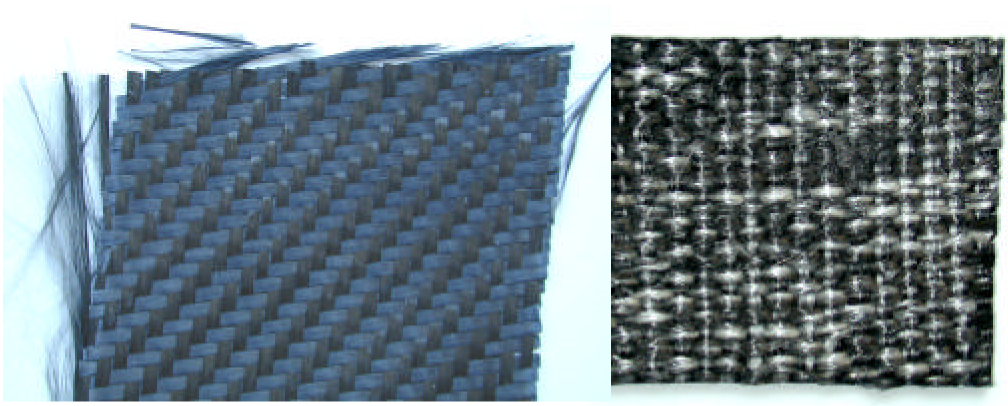


Fig. 5 Conventional cutting technique (left) and Lasercutter (right)

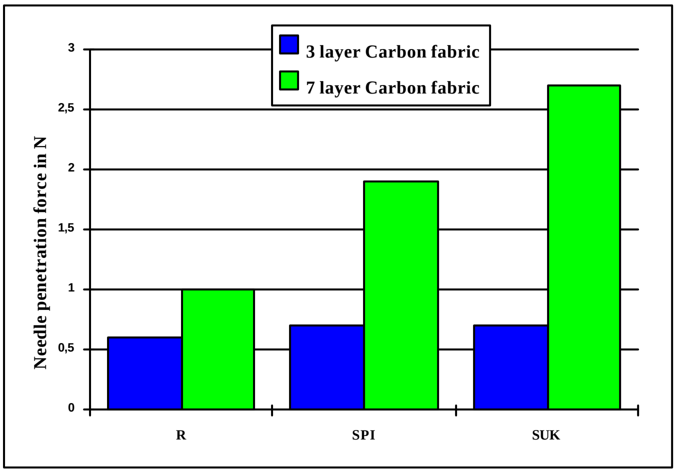
If the fabric to be cut is made of 100 % glass fiber or carbon fiber, the obtainable quality of the cutting edges is not satisfactory. There will be slipping of the edge fibers or falling out of the fabric during successive stacking and ready-made processes. When thermoplastic hybrid yarns are used by cutting cut with a laser cutter (1,000 W) a consolidated cut edge will be obtained, which positively influences the exact further ready-made processing on the one hand, but which does not influence the shaping behavior of the fabric. The thermoplastic fixation is effective 1...2 mm into the fabric.

INVESTIGATION OF SEWING PROCESSES

Shaping and joining requires the use of sewing-machine technology. The extremely high number of layers, the geometry of the blank parts and preforms, along with the rows of stitching required for reinforcement, all currently point to a thrust to develop further the sewing technology involved. CNC system control of the stitching processes (see also page xx) is a prerequisite for the reproducible fabrication precision required for mechanical engineering and automotive sector applications. There are additional processing problems in this area in the form of the normally very delicate fibrous materials used as sewing thread. Multiple parameter variations with respect to type of stitch, sewing needle geometry, type of sewing thread, sewing thread precision, stitch length and seam clearance and direction can be used to establish the load-bearing characteristics of textile seams.

Establishing needle penetration force

The needle penetration force is one of the factors selected with respect to research into sewing techniques for application to multiple-layer, textile-reinforced semi-finished components with a total thickness of up to 20 mm. It is assumed that dimensions should be easy to handle with measuring instruments, thus permitting evaluation of the efficiency of the sewing needle precision, the design of the needle point (Fig. 6), and the turning speed of the main shaft required for the needle to penetrate the material being sewn. The dynamic process is carried out with reference to the angle of rotation of the main shaft of the sewing machine.



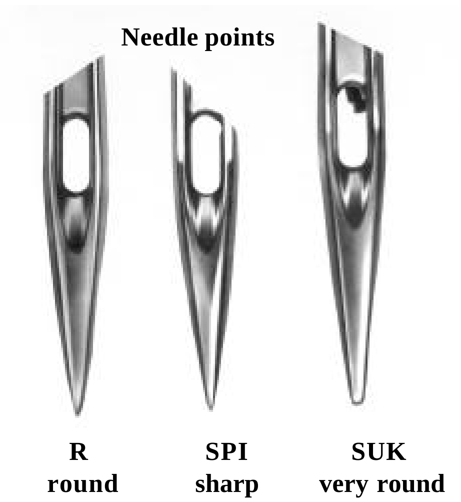


Fig. 6 Needle penetration force relative to needle fineness and geometry

Perforation effects

The penetration of the needle into the laminated, reinforced textile material is inevitably associated with a certain perforation effect. An important influencing factor, apart from the geometry of the sewing needle, is the length and density of the stitching. The degree of weakening attributable to the perforation effect is determined by the carrying out of tensile-strength testing on the reinforcement textile layers that are partially-perforated by the stitching action and which lie crossways to the direction of strain.

Reduction in seam strength

The stitching process is related in particular to paired elements regarding the effects on sewing threads of larger correlated dynamic loads and the results of rubbing and friction.

Stronger (and thus thicker) sewing threads made of the same fibre material can in fact increase seam strength and the reliability of the stitching process, but they require the use of larger-diameter sewing needles and greater-sized perforations in the surface of the textile material. Evaluation of the loss of strength so caused is extremely difficult to carry out, although a comparison of the maximum tensile strengths of stitched and non-stitched threads, using appropriate testing apparatus, can produce results of the desired accuracy if a sufficient number of tests are carried out.

Selection of stitch type

Double lock stitching is particularly suitable for sewing textile-reinforced semi-finished items. However, the principle behind this technique produces stitches where the loop in the thread normally lies in the center of the article being sewn, which has a significant weakening effect on delicate sewing threads made of materials such as glass or carbon-fiber. In the case of bend-stressed textile-plastic composites, the maximum interlaminate shear stresses likewise arise in the center of the composite, while -- in the case of compound textile-reinforced structural items such as overlapping joins -- it is the maximum z-standard tensions that occur at this point.
By varying the tension in the upper and lower thread, it is possible to displace the kink in the stitch towards the outer or inner surface of the material being sewn. This stretches the thread in the breakdown-critical area, thus allowing this weak point to be avoided.

Thread tension

Thread tension also influences the alignment of the seam in a consolidated textile-plastic composite. The multiple-layer, stitched textile-reinforcement material is compressed, during the composite material consolidation process, to a fraction of its original thickness, thus converting a loose set of textile layers into a compact composite structure. An increase in the tension of the upper and lower thread, and the effect of high sewing foot pressure, can lead to a tendency of the thickness of the multiple-layer reinforcement textile material to be compressed down to the thickness produced by consolidation. Using the available technological knowledge regarding possible processing parameters, and textile-fabrication techniques and machines, it has now been possible to manufacture complex textile preforms for high-performance rotors.

PRE-FABRICATION OF THE ROTOR DISK

The disk consists of several reinforcement textile cuttings which can yet be supplemented by especially shaped parts. The sewing unit must guarantee the defined multi-layering of the reinforcement textile cuttings with positioning seams. Taking under consideration the concrete loads situation, defined reinforcement seams are to be applied. The problems of multi-directional sewing known from the x-y-cross-table are to be avoided for the most part as the carbon multi-filaments, or carbon/thermoplastic multi-filaments and/or stable fiber yarn that might be used as sewing thread are extremely difficult to work with on account of the high brittleness of carbon fibers.

The sewing unit (Fig. 7) allows for the most part a normal drawing-off of the thread from the sewing needle to the seam in the material. As basic seam forms concentric circles and spirals were chosen which, by a variation of the diameter, the number of rotations, the stitch length, as well as the beginning angle in a polar coordinate system, are changeable and make possible the arrangement of the positioning and the reinforcement seam far-reachingly in favour of the composite properties.

Fig. 7 Sewing unit for pre-fabrication of the rotor disc

The sewing unit has of using a commercial sewing head. The material-leading equipment is a especially constructed whereby steering and driving are moved by means of the CNC-technology of the SIEMNENS AG. The construction of the material-loading equipment was established by contract with the CETEX Chemnitzer Textilmaschinenentwicklung gGmbH Chemnitz.

ASSEMBLY OF THE 3D PREFORM

Complex component geometries can often not be made up in a single step. Only following the assembly of individual textile components in two or more sub-steps is the complex preform created. The stitching used here is known as assembly stitching and it fulfills its function primarily in the textile preform. Depending on component geometry, it may also fulfill a reinforcement function in the consolidated component.

The use of assembly stitching is conceivable not only normal to the surface; using special sewing technology, it may also make good sense to employ a variable angle to the surface in order to lend shape or effect reinforcement.

The component geometry determines the shape and the dimensions of the textile cut parts, whose contours are developed using industrially applied CAD systems. The cut parts are arranged on the flat structures in a way that is tailored to the yarn lines and then cut using for this purpose state-of-the-art CNC automatic cutting systems.

The sewing technology is especially suited for shaping and connecting. The extreme number of layers, the geometry of the cut parts and of the preforms as well as the arrangement of the sewing yarns in the component due to reinforcement requirements are just giving a strong impetus to the sewing technology (Figure 8). The CNC control of the sewing processes is a precondition for the reproducible production precision. Another aspect is the problematic processing of these normally very brittle fibers when they are used as sewing yarns. Packaging and shipping of the textile preforms from the garment industry to the plastics enterprise should be handled in a careful and clean manner.

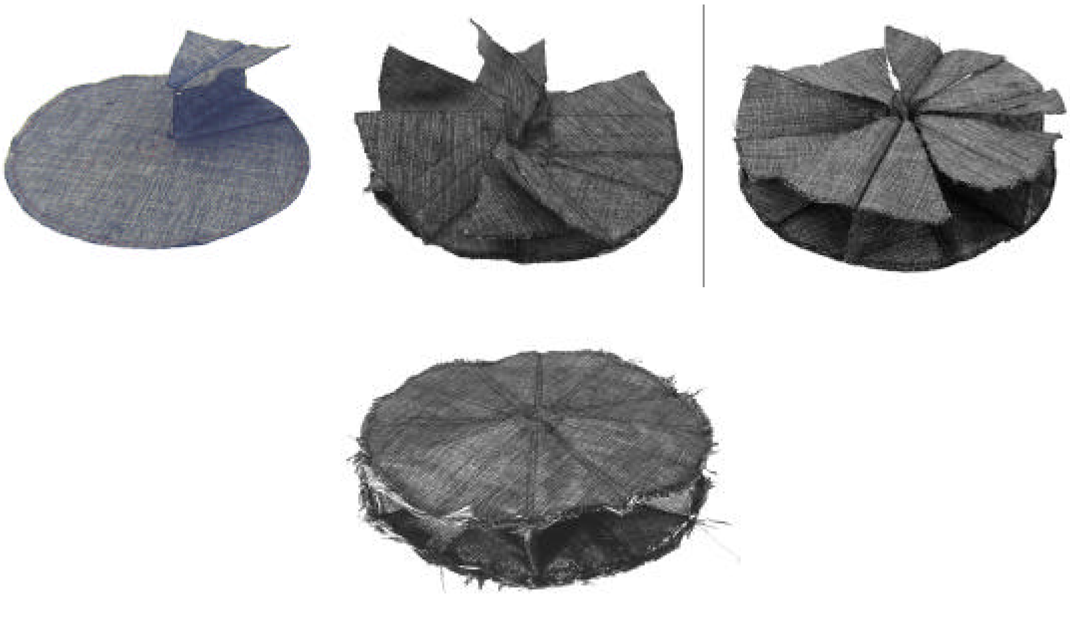


Fig. 8: Stages of the rotor production

Component-integrated sensors are necessary to be able to measure the extension field that occurs as a result of operational and extreme extraordinary loads. Ready-made clothing technologies are used to integrate these sensors into the textile preform.
A vacuum high-speed rotor test stand verifies the data.

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