Development of near-net-shape woven, curved profile preforms

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At the ITM, the simulation-supported development and weaving implementation of integrally manufactured curved profile preforms with requirement-oriented cross-sectional changes along the profile length for the reinforcement of shell-shaped FRP components was carried out in the IGF project 20903 BR (Curved Profile Preforms).

Introduction

Fibre-reinforced plastic composites (FRP) offer enormous lightweight construction potential due to their excellent ratio between achievable stiffness and at the same time low weight. As a result, moving masses can be reduced in all areas of machine, aircraft and plant construction, thus saving resources. Consistent lightweight construction requires the combination of lightweight material construction with constructive lightweight engineering [1, 2]. This is realised, for example, in shell-shaped components by stiffening with corresponding profile-shaped ribs, frames or stringer reinforcements [3]. The stiffening significantly increases the bending, buckling and torsional stiffness of the components [4, 5]. The numerous applications result in different requirements for the profiles. For example, curvatures and cross-sectional dimensions of the profiles must be designed according to the resulting loads and the given installation space. However, the production of the necessary reinforcement profile preforms, often from fabrics, is usually done in sequential preforming, which is still characterised by a low degree of automation [6]. The necessary process steps of cutting, layer build-up, forming as well as compaction and pre-fixing cause up to 30 % of the total component costs. In addition, due to the use of several individual partial pre-cuts, the fibres are not arranged continuously and in a load-adjusted position in the component, which is why the lightweight construction potential of the high-performance fibres cannot be fully achieved [7]. The prevention of notch stresses in gusset areas also usually requires the complex insertion of a separately manufactured keder into the preform.

Objective and solution

In this IGF project, a solution for the direct near-net-shape weaving of curved 3D profile preforms was developed using 3D weaving. The production of near-net-shape 3D weaves is defined as the direct production of 2.5D fabric semi-finished products by combining multi-layer fabrics with adapted weaves and followed by forming for one-piece 3D preforming. Forming involves changing the geometry in the forming process, leaving the structure of the fabric unchanged. Draping changes the structure and geometry of the fabric.

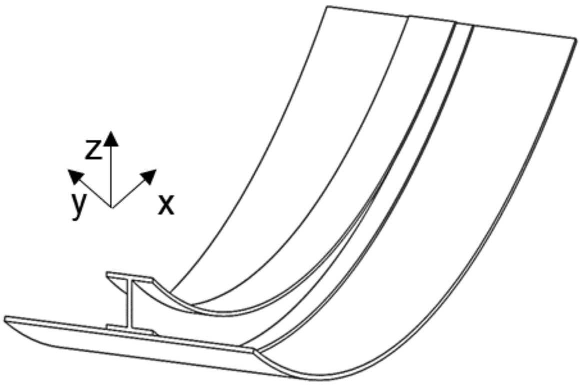

Figure 1: Example profile geometry

The research approach is based on arranging the profile semi-finished products obliquely to the manufacturing direction and thus arranging the reinforcement threads in ±45° direction to the profile axis. The ±45° layers in FRP profiles, in comparison to 0°/90° layers, enable the high shear stability required for shell-shaped components [8, 9] and a better draping of the woven 2.5D profile semi-finished products to 3D profile preforms. The focus of the research project was the development of profile semi-finished products with adapted curvature around the Y-axis (cf. Figure 1), which had not been implemented in weaving technology so far. The possibilities and limits for adapting the curvature as well as the cross-section along the profile length were also researched. In addition, a specific weave development was carried out such that the additional insertion of keder tapes to minimise the notch stresses in the gusset area can be omitted. The development of the fabric profile preforms was carried out on a Jacquard rapier weaving machine with 2400 tex glass filament yarn.

Results

Fabric and simulation model development:

For the development of the curved semi-finished profiles, the profile geometry was first determined. Profiles with T and I cross-sections were selected due to their common use and high complexity. For the fabric development of the semi-finished profiles , the starting point for the development of the profile geometry in the weaving plane was determined in the first step. In this process, the area of the flanges is to be designed as two separate fabric layers and merged into one fabric layer in the area of the bar. To shape the profiles, the outer contours are cut after weaving and the two-layer flange areas are folded up. The joint between the flange and the web area forms the gusset. To enable subsequent forming of the woven semi-finished profiles, the profiles must be manufactured with threads oriented diagonally at about 45° to the longitudinal axis of the profile (cf. figure 2). For this purpose, the corresponding weaves of the partial sections must be adjusted to each other in such a way that their rapports merge in the direction of the weft and warp threads. Special multi-ply weaves were developed and analysed for the flange, bar and gusset areas. The investigations in the gusset show that the amount of fibre to be arranged can be controlled to a large extend by the weaves (Figure 3). To map the required curvature of the semi-finished profile, a program routine was developed that generates the required arrangement of the weave areas with software support based on equations describing the curvature. The calculation of the required weave for the semi-finished profile by means of a program routine has the decisive advantage that the individual weave areas are coordinated with each other and thus there is no undesired warp or weft lifting. The curvature of the semi-finished profile can be specified as a circle equation, polynomial equation or trigonometric equation, depending on the radius. As an output of the program routine, the weave is directly created as an image and is thus available for the creation of the control file of the Jacquard machine by means of corresponding software solutions.

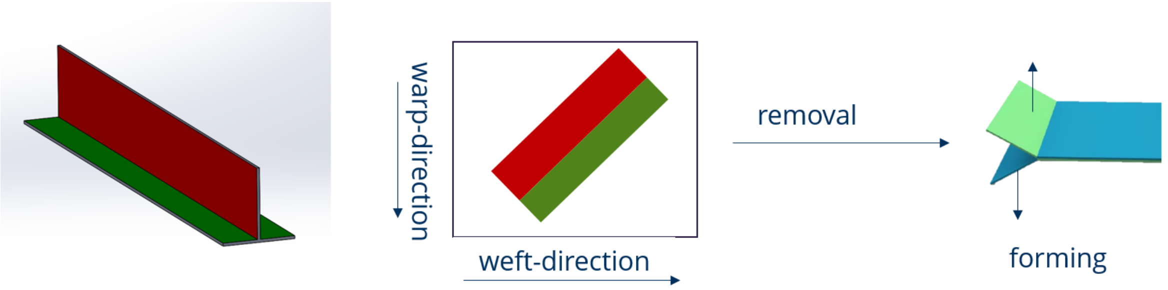

Figure 2: Weaving concept of profile preforms

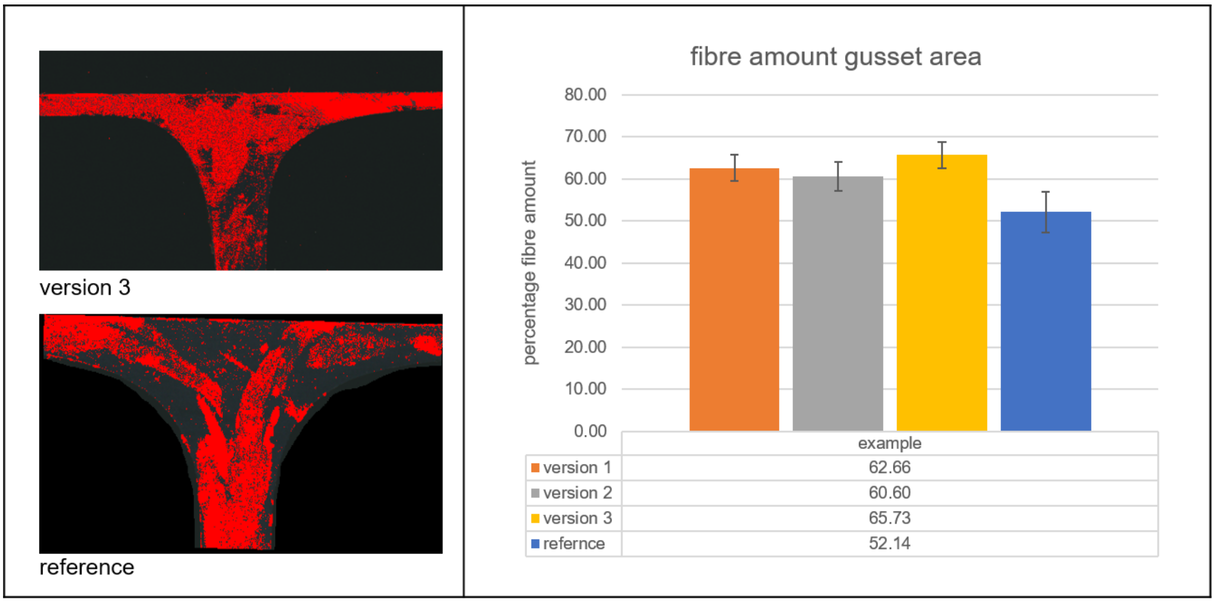

Figure 3: Results weave pattern analysis gusset area

Simulation model development:

For the manufacture of curved semi-finished profiles, a part of the curvature is woven in and then draped by shaping according to the required curvature. For a precise fitting implementation of the weave according to the required curvature, the flattening of the 2.5D semi-finished profile and the draping of the partial weave areas are simulated together. To calculate the shaping, the textile-physical properties of the developed fabric structures were first simulated in an FE model and implemented in the LS-DYNA software solution. As a result of the simulation, the shaping of the woven structure can now be calculated in advance and compared with the required curvature.

Demonstrator:

In order to validate the solutions developed in the project for the production of curved, woven semi-finished profiles, a complete process chain was set up and checked using the production of a demonstrator. A curved profile with an I cross-section was selected as the demonstrator geometry (bar height 140 mm, inner radius of the curvature 500 mm). The process chain begins with the creation of the CAD model according to the required target geometry and the resulting assignment of the partial surfaces. Shaping and forming simulation follow. The curvature to be woven in is calculated and the structural distortion due to the occurring forming forces is analysed. By means of the simulation, the curvature gradients to be woven into the fabric structure were calculated and used for the weave development. The resulting curvature equations were transferred into the developed program routine and the weave file for the fabrics was generated. The output of the weave generation was read into the EAT-Design Scope software tool and the control file of the Jacquard machine was created. The structure was then woven, removed from the weaving plane and finally formed to the target curvature.

In order to validate the achieved curvature, the fabric preform was scanned and compared with the original CAD model. The result is a deviation between the required and actual geometry of 2.4 % for the inner radius and 2.2 % for the outer radius.

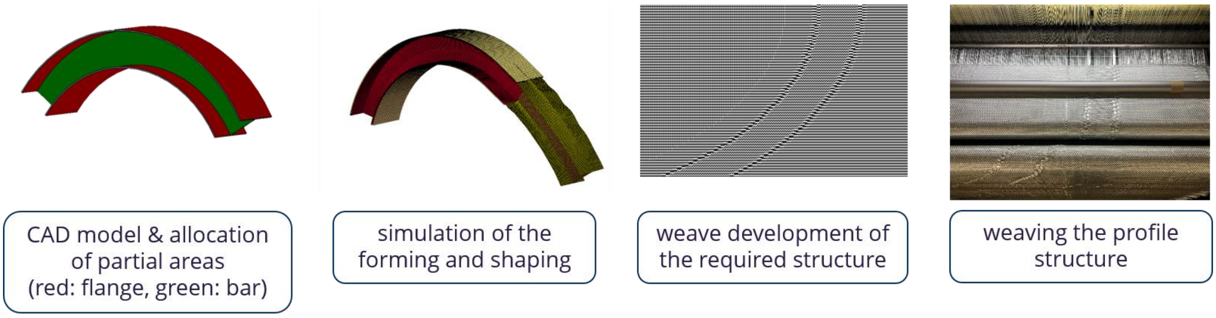

Figure 4: Process chain of producing curved woven profile preforms

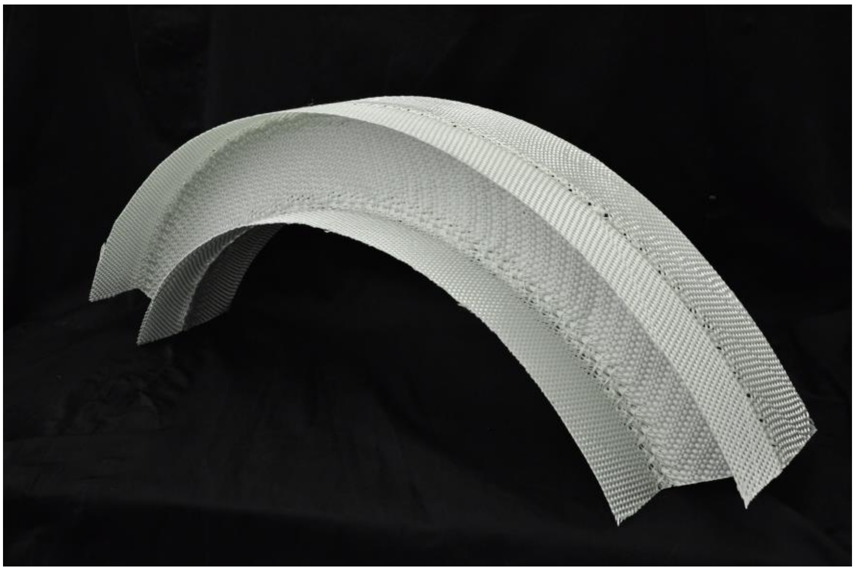

Figure 5: Demonstrator component

Conclusion and outlook

Based on the results obtained in this project, curved profile semi-finished products for FRP applications can be produced seamlessly and close to the final contour on industrially available Jacquard weaving machines. These semi-finished products can be used in particular for reinforcing shell-shaped components [10]. The process chain developed in the project enables the direct transfer of the CAD model into a fabric, depending on the required curvature.

In order to realise the project objective, special multilayer fabric structures and their reproduction in a simulation environment were developed. The development of a program routine enables a direct weave creation, which can reproduce the correspondingly required curvature to be woven in. The entire results were validated by manufacturing a demonstrator in the design of a curved I-profile and the proof of performance of the technology of near-net-shape weaving for the production of seamless fabric profile preforms was provided.

Industrially available machine periphery and common software solutions were used for the development of the process steps. This allows an easy transfer of the project results to the SME-oriented weaving companies. Industrial application of the project results is to be expected in particular in automotive, aircraft and ship building (e.g. hull reinforcements) or in machine and plant construction (e.g. frame systems).

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