Investigating the influence of local fiber architecture in textile composites by the help of a mapping tool

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1 Abstract

Standard approaches for the modelling and simulation of composite structures rely on the homogenisation of material properties on unidirectional plies. Doing so, simulations lose the ability to precisely describe local phenomena and complex failure mechanisms. In the research campus ARENA2036, the project DigitPro (Digital Prototype) develops a method based on a closed simulation process chain to take into account potential production effects by braided or woven composite structures. Starting from the process simulation, crucial information like fibre orientation and waviness is mapped on a target mesh for structural analysis. The resulting model is then investigated and potential needs to change the component's geometry or the manufacturing process are detected.
The mapping tool ENVYO® [1], developed at DYNAmore, offers various possibilities for the transfer of information generated from process simulation. Thus, it is necessary to investigate the impact of mapping algorithms and respective parameters on the structure simulation. The present paper details the mapping procedure for textile composites. The influence of local fibre architecture is finally investigated on a generic structure and compared to a standard approach.

2 Introduction

In the classical finite-element approach (*Fig.1*), braided composites are subdivided in unidirectional layers which are stacked to simulate the whole laminate. Doing so, the out-of-plane waviness of the layers must be considered with factors reducing the stiffness and strength in fibre direction. Furthermore, this approach assumes that the laminae do not interact with each other. These two assumptions often results in the need to oversize the structure by choosing safe reduction factors and to compensate unconsidered negative effects.

The approach developed within DigitPro uses process simulations to accurately predict the real fibre architecture in the structure. Yarn interactions within a layer or between layers, as well as weakened spots due to production effects (dry spots, out-of-plane undulated areas …) can be taken into account. The mapping of this information on a target mesh for structure simulation leads to lower reduction factors, thus increasing the potential of the structure or reducing its weight. A second benefit of process simulations is the possibility to virtually improve the real production processes and machine parameters, and consequently increase the quality of the structure by reducing the development time.

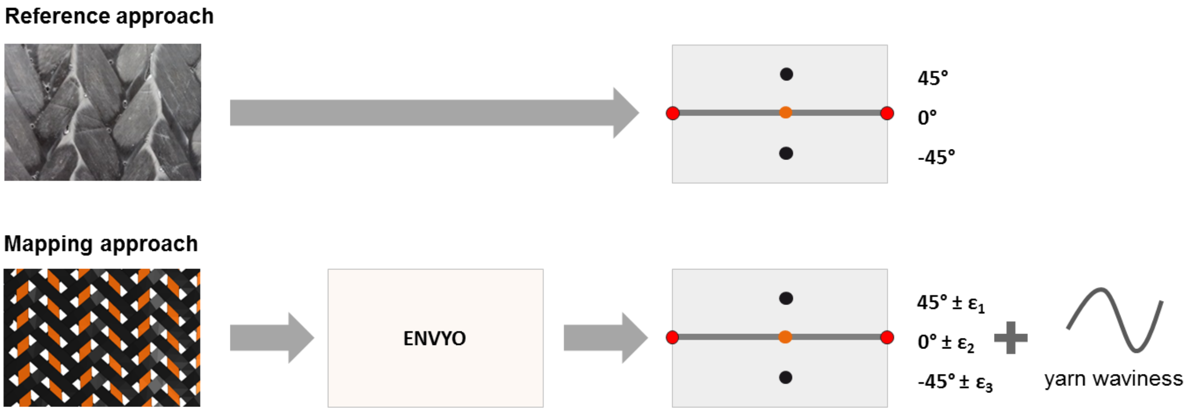


Fig.1: Graphical representation of the reference approach and the mapping approach

The mapping tool ENVYO offers various possibilities for the transfer of information between two finite-element models. To reach a reliable mapping process, it is necessary to investigate the different mapping parameters and understand their influence on the structure simulation. The present paper reports on the sensitivity analysis performed on a generic structure used as validation model for the closed process chain.

3 Use of the numerical process chain for the simulation of braided composites

The numerical process chain (*Fig.2*) virtually predicts each stage of the product development and manufacturing, from the preliminary design up to the structure simulation. In a first step, the textile-based composites are numerically investigated on the mesoscale with the help of Representative Volume Elements (RVE). The calculated mechanical properties are stored in a database and further used all along the process chain in various simulations (pre-sizing, structure simulation…). The second step uses process simulations on the mesoscale (braiding simulation, draping simulation…) to predict the influence of the manufacturing on the textile architecture in the structure, and so, on the structural properties. The transfer of these data on the macroscopic scale with the mapping tool allows considering production effects in the structure simulation. The post-processing of the results leads to an optimization of the machine parameters, which are finally transferred to the real production line in order to improve the quality of the structure.

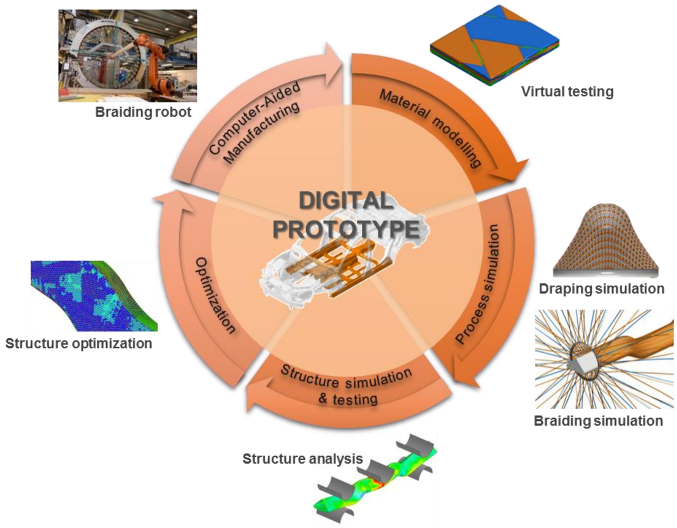


Fig.2: Numerical process chain developed in the project DigitPro

3.1 Braiding simulation

A numerical braiding simulation is developed for the prediction of complex fibre architectures within braided composite parts (*Fig.3*). In the simulation, real machine parameters and boundary conditions are considered (e.g. mandrel speed or translation of the robot arm). Two modelling approaches for the yarns are implemented: the beam approach offers a good computing efficiency whereas the shell approach increases the level of details by higher computing time. In each approach, the yarns mechanical properties (in tension or bending) and the tension in the yarns can be modified to represent the real manufacturing conditions. *Fig. 3* shows the result of the braiding simulation on the example of a generic component using shell elements. Several manufacturing effects are simulated, such as fibre tensioning in the S-shaped section, gaps or changes in the braid angle along the component length.

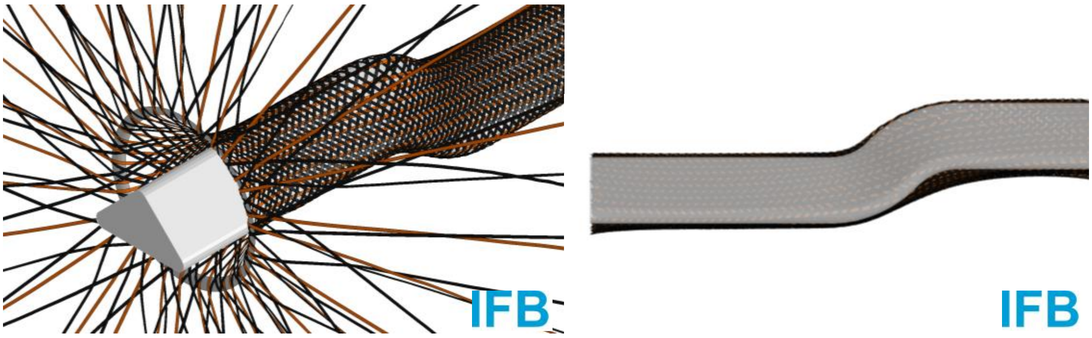


Fig.3: Braiding simulation (left) and view of the predicted fibre architecture (right) on the example of a generic component

3.2 The mapping tool ENVYO

During the mapping procedure, information from the braiding simulation is transferred to a target mesh to be used in the structure simulation. Within ENVYO, meshes out of beam, shell or solid elements can be mapped on a shell or solid target mesh with either the layered-shell approach or the stacked-shell approach. The mapping procedure is displayed in *Fig. 4*. In case of a target mesh made of shell elements, each yarn of the braiding simulation is mapped on one integration point in the shell element. Using *ELEMENT_SHELL_COMPOSITE, the orientation and thickness of the yarns can be assigned to the shell elements. The matrix-rich zones in the braided structure are mapped on one integration point as well and assigned the material properties of pure matrix.

In this paper, the braiding simulation with beam elements is investigated. In order to consider the real yarn geometry, it is necessary to implement a scaling factor for the yarn size in the mapping approach. The search radius can be varied as well for the consideration of area which are not covered with braid yarns (resin-rich domains). As a consequence, the target mesh realistically reproduces the wavy surface of the braid due to the in-plane and out-of-plane compaction of axial and bias yarns (Fig.5). In the next section, some of the parameters used during the mapping procedure are investigated.

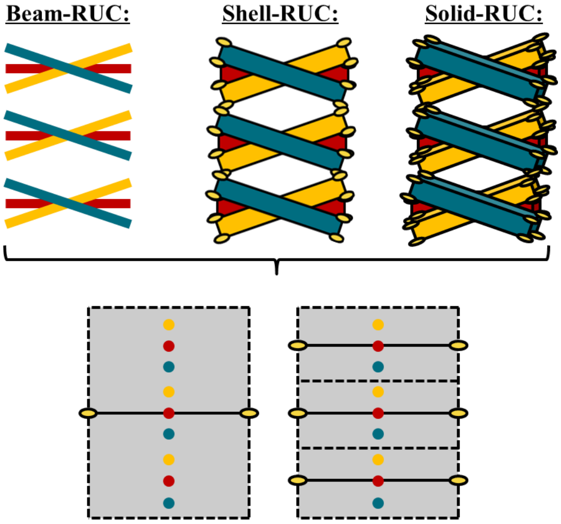


Fig.4: Mapping procedure within ENVYO for different input and target meshes

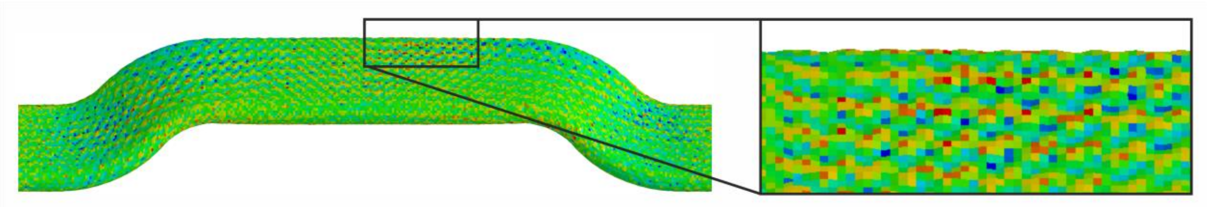


Fig.5: Variable thickness and resulting surface waviness in the generic component after the mapping of the braiding simulation

4 Numerical investigation of the mapping tool on a generic component

In this section, the results of the mapping investigation are reported. The generic structure is simulated with the reference approach with UD-plies and the mapping approach presented in chapter 3.2. The mapping parameters are varied to determine their influence on the numerical result. Aim of the present study is to define general rules for the mapping of the braiding simulation on a mesh structural analysis.

4.1 Modelling methodology

4.1.1 Geometry of the generic component

The generic component has a triangular cross-section and an S-curved shape (*Fig. 6*). This curvature leads to potential deviation between the ideal and the real fibre architecture (changes in the yarn angle, dry spots…) and was used to investigate the potential of the braiding simulation. The composite consists in three triaxially braided layers with a nominal braid angle of 45° for a total thickness of about 3 mm. The length of the component is 540 mm.

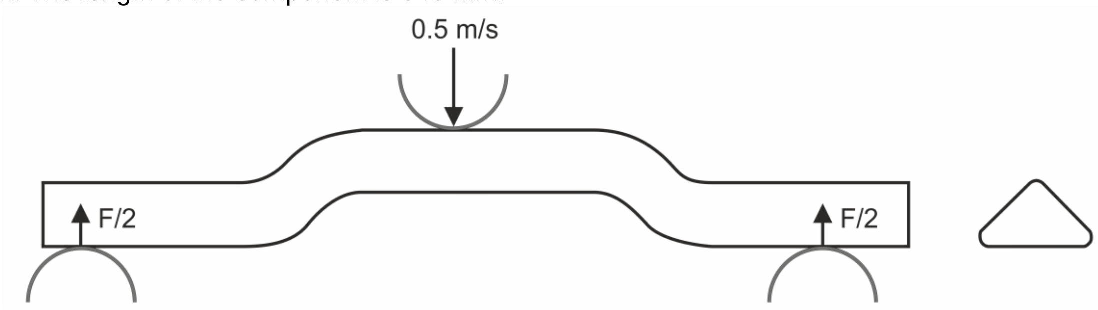


Fig.6: Testing conditions for the generic component under three-point bending

4.1.2 Testing use-case

The selected generic component is numerically investigated under three-point bending. The speed of the cylindrical steel impactor is kept by a constant value of 0.5 m/s during the whole simulation and the component is simply supported on two cylindrical steel bearings (*Fig. 6*).

4.1.3 Modelling of the braided composite

In the reference simulation, the braid is modelled following the layered-shell approach, with one shell element for the three braid layers. Full-integrated shell elements (**`ELFORM`** 16) with a length of 2 mm are chosen to avoid hourglass deformations during the simulation. In the mapped model, it is necessary to separate the material models for the yarns and for the matrix-rich areas. The element with yarns properties and with pure matrix properties are assigned the material models **`*MAT_262`** and **`*MAT_124`** respectively. The material cards and mechanical properties have been previously investigated and validated with simulations on the mesoscopic scale.

The reaction force of the component on the support cylinders and the displacement of the impactor are measured with **`*DATABASE_RCFORC`** and **`*DATABASE_HISTORY_NODE`**. The results are finally filtered with a 1 kHz SAE filter.

4.2 Investigation range

Two parameters are investigated in this paper: the scaling factor for the beam radius and the element length of the target mesh. The variation chosen for this investigation is detailed in *Table 1*.

Table 1: Summary of the parameters investigated in this study

Parameter	Investigation range
Beam scaling factor	0.25 to 2.0
Element length	1.0 mm – 2.0 mm – 4.0 mm

4.3 Numerical results

4.3.1 Qualitative analysis

A qualitative analysis of the mapping results is first performed by considering the repartition of axial and bias yarns in the mapped models (*Fig.7* and *Fig.8*). By scaling factors under 0.50 or above 1.0, the proportion of axial yarns is either underestimated or overestimated. Under 0.75, the braid yarns do not cover the whole component as they do in the real component. It firstly appears that a good prediction of the fibre architecture is reached with values between 0.5 and 1.0. In these models, some resin-rich zones are visible (in grey in *Fig.7* and *Fig.8*), particularly in the bottom part of the S-shaped section.
The mesh refinement (*Fig.9*) increases the model accuracy: at an element length of 1 mm (about one half of the yarn width), the axial yarns are continuous and clearly separated from each other in the mapped model. Though, it appears that refining the mesh requires to increase the scaling factor in order to limit the number of pure matrix elements in the model.

Scaling factor	Axial yarns repartition

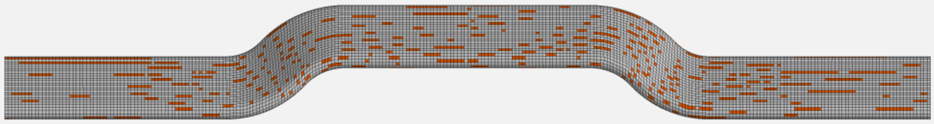
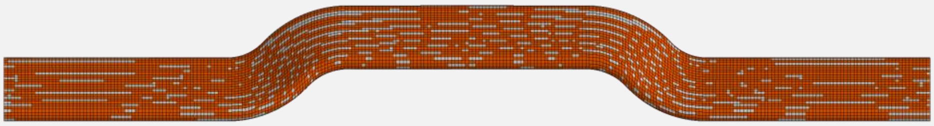
0.25	
0.50	
0.75	
1.00	
1.25	

Fig.7: Repartition of the axial yarns (in orange) after mapping depending on the scaling factor

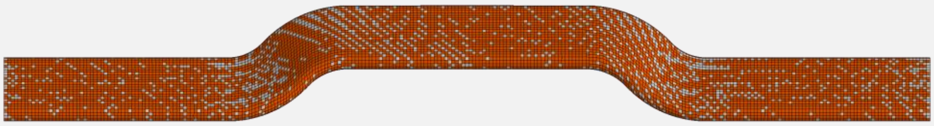
Scaling factor	Bias yarns repartition
0.50	
0.75	
1.00	

Fig.8: Repartition of the braid yarns (in orange) after mapping depending on the scaling factor

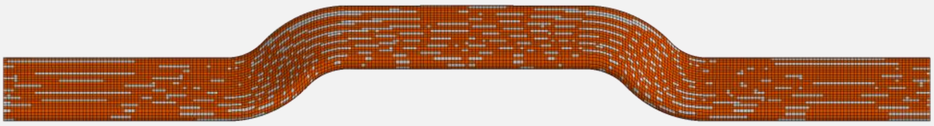
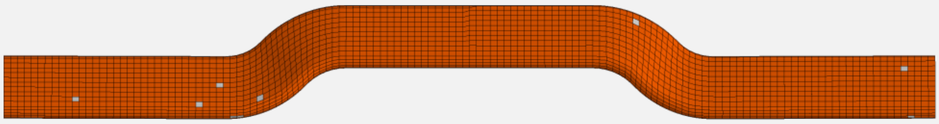
Element size	Axial yarns repartition (scaling factor = 1.0)
1 mm	
2 mm	
4 mm	

Fig.9: Repartition of the braid yarns (in orange) after mapping depending on the element length

4.3.2 Quantitative analysis

It results of the sensitivity analysis that the scaling factor considerably influences the structure behaviour of the generic component (*Fig. 10* and *Table 2*). Low scaling factors tend to strongly decrease the component stiffness and strength due to the predominance of element with pure matrix properties. At scaling factors higher than 1.0, the elements with axial yarns properties are predominant and the component fails in a very brittle way. It is to notice that increasing the scaling factor further than 1.25 does not change the simulation result.

The mapped generic component with standard scaling factor presents a lower stiffness as in the reference model. This can be explained by the consideration of matrix-rich areas and a better approximation of the real axial yarn content in the component. In the mapped model, the axial yarns reinforce locally the component in the impact zone, thus delaying the first failure and increasing the strength (*Fig.11*).

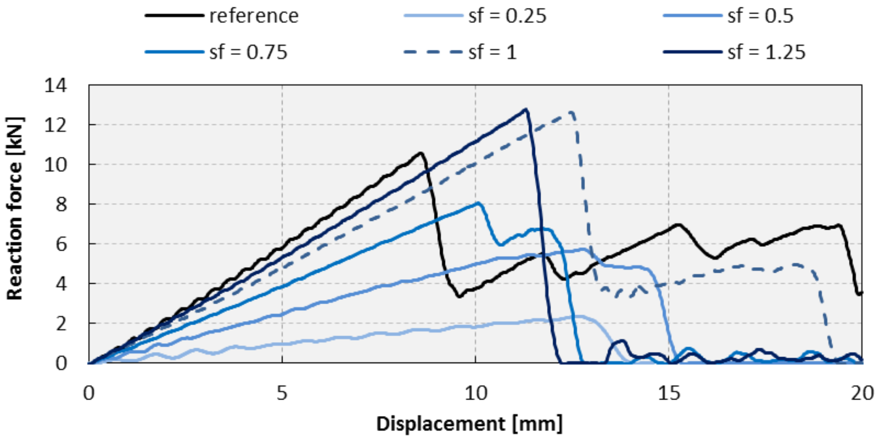


Fig.10: Force-displacement diagrams for different scaling factor values in comparison with the reference approach

Table 2: Comparison of the component stiffness and failure force between the reference approach and the mapping approach

Model	Stiffness [kN/mm]	Failure force [kN]
reference	1.24	10.3
sf = 0.25	0.19 (-84%)	2.4 (-76%)
sf = 0.50	0.50 (-59%)	5.8 (-43%)
sf = 0.75	0.81 (-35%)	8.0 (-22%)
sf = 1.00	1.01 (-18%)	12.6 (+22%)
sf = 1.25	1.12 (-10%)	12.7 (+23%)
e = 1 mm	0.93 (-25%)	4.0 (-61%)
e = 4 mm	1.07 (-14%)	12.6 (+22%)

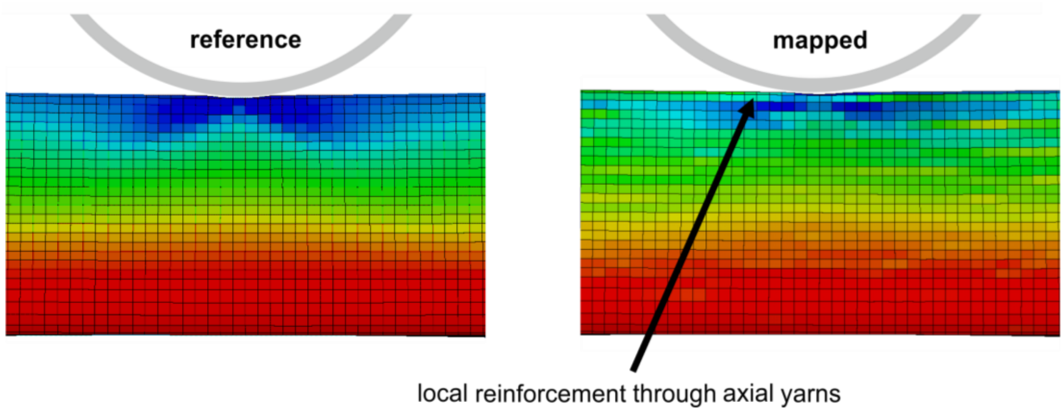


Fig.11: Local influence of the axial yarns on the axial stress field (fibre compression)

5 Summary and outlook

The benefits of the numerical process chain developed in DigitPro are shown in the present paper. Information about the fibre architecture in the braid is obtained via braiding simulations and is mapped on a target mesh for structure simulation. With this approach, the local influence of bias and axial yarns on the stress distribution and structure behaviour can be taken into account. Mapping parameters, such as scaling factors or element length of the target mesh, substantially change the structure behaviour. In the simulation of braided composites, special care must be taken to chose the correct set of parameters in order to simulate the right fibre volume content and axial yarn content.
In future works, the performed sensitivity analysis will be validated with an experimental test on the generic component. Aim is the definition of a reliable methodic for the mapping of braided composites.

6 Literature

[1] C. Liebold and A. Haufe, "Closing the Simulation Process Chain using a Solver Independent Data Exchange Platform: The Digital Prototype," in *14. Deutsches LS-DYNA Forum*, Bamberg, 2016.

Acknowledgement

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