ACTIVE CONTROL OF TEXTILE FORMING PROCESSES

Thomas Gereke[1], Farbod Nosrat Nezami[2], Matthias Hübner[1], Oliver Döbrich[1] and Chokri Cherif[1]

[1]Institute of Textile Machinery and High Performance Material Technology, Technische Universität Dresden, 01062 Dresden, Germany
Email: thomas.gereke@tu-dresden.de, web page: http://tu-dresden.de/mw/itm

[2] Daimler AG, 71059 Sindelfingen, Germany

Keywords: Draping, Finite Element Modelling, Preform, Tailored process, Textile forming

ABSTRACT

The manufacturing of textile-reinforced composites requires the forming of the fabric into the desired shape. Especially in the automotive sector structural parts can have complex double-curved geometries, which makes draping of fabrics challenging. Mechanical properties of the fibres, the semi-finished reinforcements, and the resulting composite are highly anisotropic. A small misalignment of the fibre from the desired orientation leads to a significant decrease in the mechanical properties of the composite. Other defects such as wrinkles, gaps and fibre pull-out have a considerable influence on the performance of the composite part and, thus, its quality. The preforming step is very important since it is the basis for all subsequent process steps in the composites manufacturing chain. It is therefore desirable to have a forming process that can be actively controlled in order to avoid the occurrence of defects and fibre misalignments. The development of such a process can only be achieved with the help of simulation tools. Modelling of textile forming is challenging due to the specific material behaviour of high performance textiles. A user material formulation for finite shell elements that captures high tensile stiffness and low shear and bending stiffness was developed and validated. It allows the design of a tailored preforming process with blank holders and the decoupling and active control of single layers in a multilayer stack. Significant improvements in the process time and the quality of the preform were achieved. The findings can be applied to the draping of complex automotive parts.

1 INTRODUCTION

The application of fibre-reinforced composites in automotive parts with high quantities requires a complete process understanding and the knowledge of the material behaviour for high quality products. Especially in the automotive sector structural parts are highly complex, mostly design driven and with boundaries due to packaging and aerodynamics. Compared to airplane production, automotive parts are cost sensitive. For future applications material and process cost reductions play important roles for a broad breakthrough of composite materials in cars. For the important step of the forming of the 2D fabric into the 3D part a simulation driven forming process was developed. Part forming is subjected to errors and its control is thus essential for quality assurance.

Preforming strategies and simulation tools have been successfully developed, but they lack industrial relevance. Many studies were published on carbon and glass fibre fabric forming with the more academic geometries, i. e. hemisphere, double dome, tetrahedral or square box shapes [1-7]. A more realistic prediction of the drapability of a given fabric and a given geometry can be achieved with more complex, industry relevant geometries and forming processes.

A drape simulation tool can be used for the load adjusted design of the composite, the optimal exploitation of the anisotropic material properties, reproducible manufacturing processes and the prevention of defects in the preform (wrinkles, gaps, etc.). The knowledge of the interaction between geometry, material and process is essential and can satisfactory analysed only with simulation tools.

In the present study an automobile part was used to develop a tailored forming process based on simulation results. The process and the developed forming tools with hemisphere and L-geometry were presented elsewhere [8, 9]. To increase complexity a more complex automotive part was used in order to verify the developed tailored forming process. Furthermore, different modelling strategies with macro- and meso-scale models were pursued. Both have their advantages and drawbacks, which are discussed in this paper.

2 MATERIAL AND METHODS

A complex automotive geometry has been chosen for the investigations. The material used was a carbon fibre plain woven fabric T700-12K with 300 g/m^2 and 2.5 yarns/cm (Hexcel Composites GmbH, Germany). For the study two fabrics oriented at 45° to each other were formed into the geometry at the same time. For this process two forming strategies were developed: a global blank holder approach (Figure 1) and a tailored process with local control of each fabric and a separation of both fabrics with a metal sheet (Figure 2). The clamping of the individual layers was realized with an invariant force entry through pneumatic cylinders from the periphery of the press table. Additionally, vibrating piezo actors that were integrated in the metal sheets were used to reduce the interaction between the fabrics.

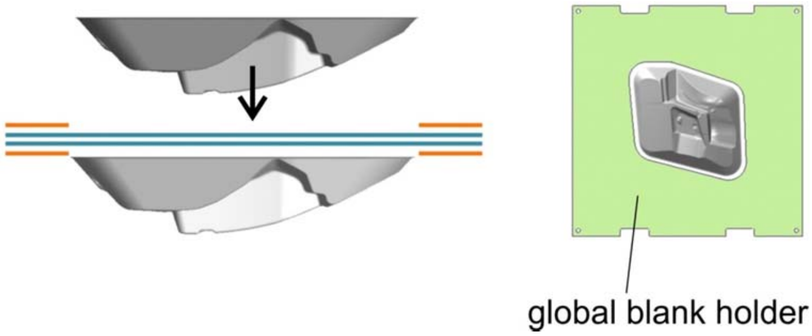

Figure 1: Forming process with global blank holder

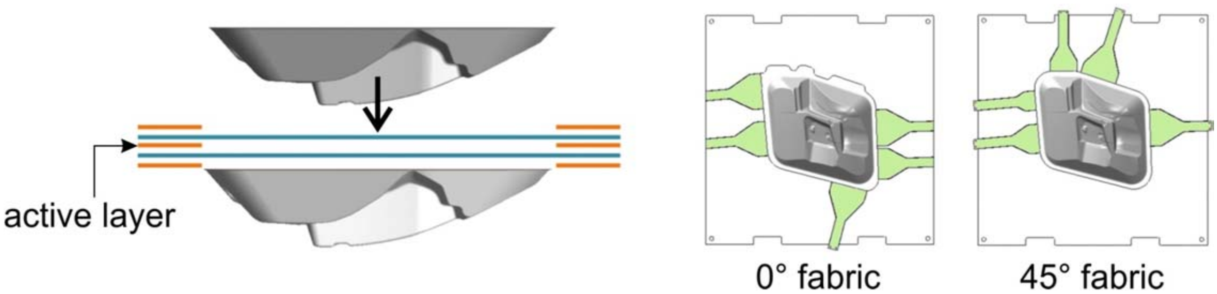

Figure 2: Forming process with local clamping of individual layers and active middle layer (green colour: local clamping)

The draping process was simulated with a previously introduced textile material model [10]. This model used macroscopic properties of the fabric (shear, tension, bending) in a shell element formulation in LS-Dyna. The mentioned material properties were determind with standard testing procedures and implemented into the user material formulation. The bending formulation is decoupled from the tensile properties in order to account for the low bending stiffness of fibre-based materials. Furthermore, a model of the fabric on the meso-scale was developed and applied to the forming process. The unit cell of the woven fabric was generated with a previously developed simulation method [11]. The fabric model was generated with shell elements for the yarns. The element thickness was adapted in order to achieve a realistic representation of the yarn geometry.

3 RESULTS

The formed part and the simulation results using the macroscopic approach are presented in Figures 3 and 4. Due to the tailored process the wrinkles and other defects could be reduced significantly compared to a global blank holder approach. However, some wrinkles still occur in the formed part with the chosen woven fabric material used for draping. Wrinkle amplitude was reduced from 11 mm to 3 mm compared between both draping strategies.

The clamping has influenced the shearing of the fabrics. Being used only in small areas the shear angles were influenced locally. The decoupling of the layers by metal sheets reduced the interaction between the different fabric layers and, thus, the damage in the fabrics. The advanced approach with high frequent vibrations is further beneficial especially for woven fabrics where yarns get caught when sliding over each other. The result was less damage compared to the standard process.

The application of active intermediate plates has proved effective particularly in combination with specifically positioned cuts outside visual and functional areas. Single layer specific membrane tensions, reduced friction through high frequent vibrations and reduced compression zones through cut ins represent a sufficient combination of measures for the manufacturing of the segment.

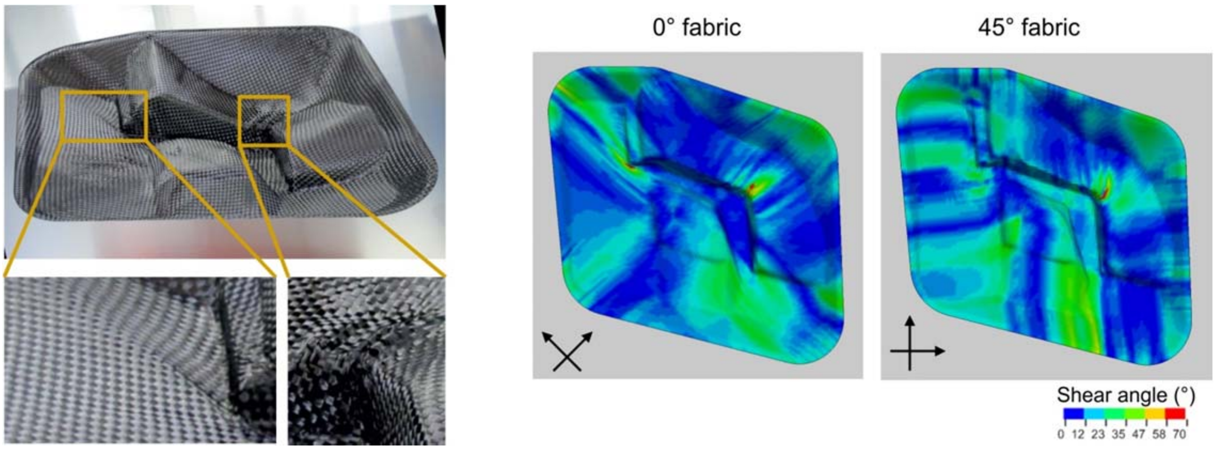

Figure 3: Experimental and theoretical results of the draping process with global blank holders (simulation results showing macro model)

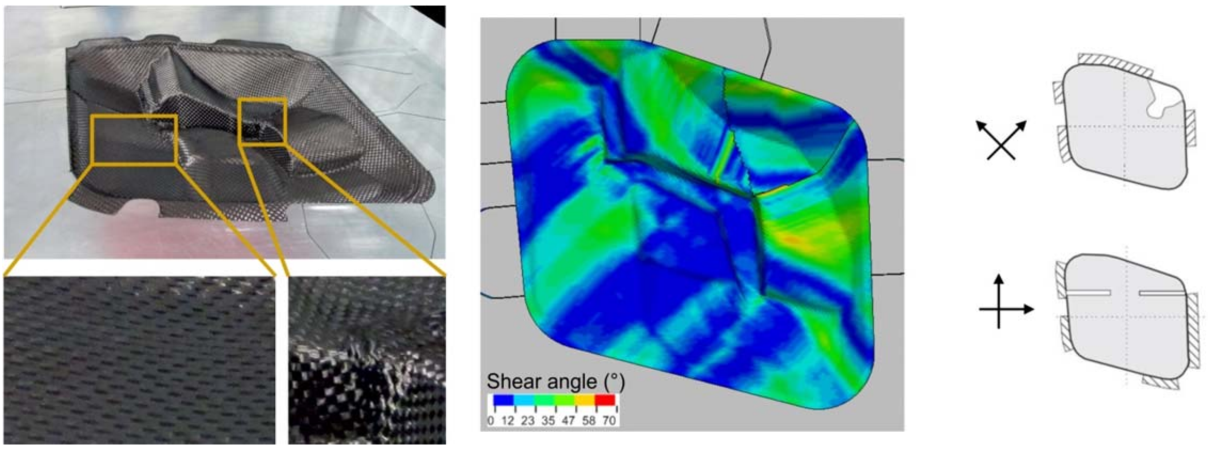

Figure 4: Experimental and theoretical results of the tailored draping process (simulation results showing macro model), right-hand side: cut ins

The process design based on simulation results has advantages compared to a trial and error experimental approach. If compared to the real formed fabrics, the macroscopic simulation models gives excellent results in terms of fibre orientation and wrinkling. The meso model further reveals effects that are not visible when simulating with the macroscopic model. Since the yarns are modelled individually, in- and out-of-plane yarn movements can be simulated. Details of the draped complex geometry are presented in Figures 5 and 6. The resulting wrinkles were similar to the prediction of the macroscopic model and to the real forming process.

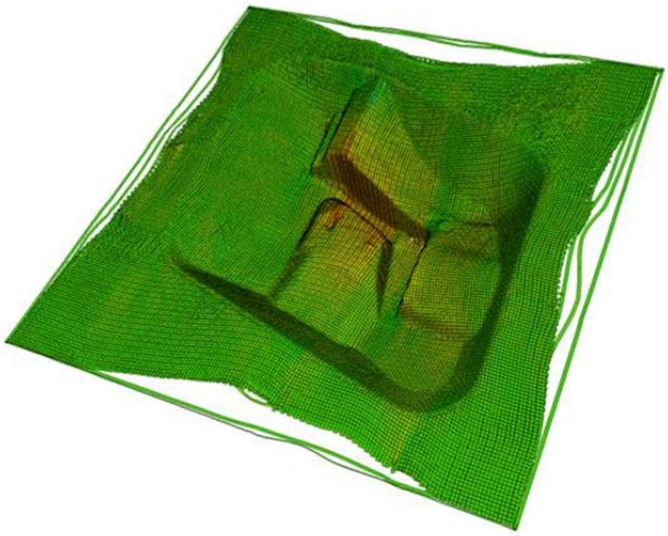

Figure 3: Results of forming simulation on the meso-scale

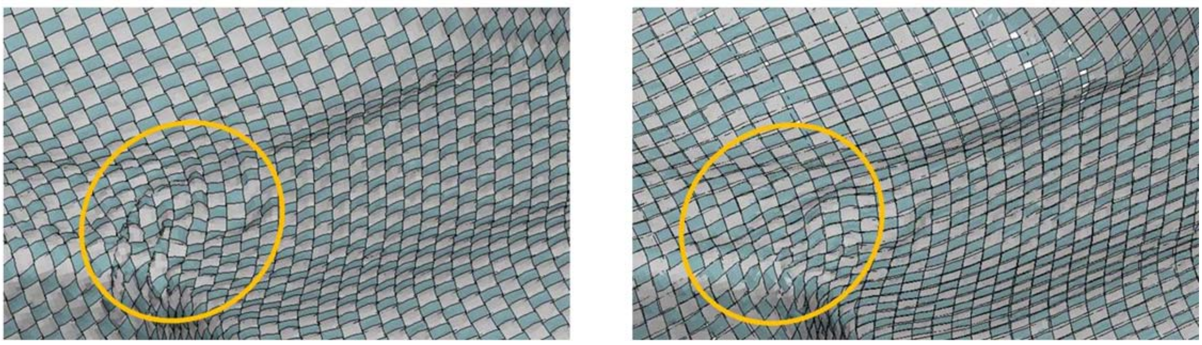

Figure 4: Wrinkling simulated with the meso model, left-hand side: global blank holder, right-hand side: tailored process

4 CONCLUSIONS

The active control of the fabrics in a forming process was shown with the chosen example. Single layer-specific local material guidance, single layer decoupling and friction reduction by high-frequency vibrations reduce damaging and result in an improved preform compared to a global blank holder approach. Supported by simulations the process could be designed for the specific material and geometry. Macroscopic models are applicable to all kinds of fabrics and provide excellent results for checking the formability of a fabric. Wrinkling and fibre orientation can be reproduced and calculation time is short. The modelling complexity increases when using meso-models. However, effects on the yarn scale could be described. But modelling and simulation costs increase depending on the fabric construction. In the future the interactions between geometry, material and process could be adjusted together with the presented methods in order to provide defect free preforms in a reasonable time for industrial production.

ACKNOWLEDGEMENTS

The IGF project 18063BR of the Research Association Forschungskuratorium Textil e.V. was sponsored by the AiF under the program to promote joint industrial research by the Federal Ministry for Economic Affairs and Energy, following a decision of the German Bundestag.

REFERENCES

[1] T. Gereke, O. Döbrich, M. Hübner and C. Cherif, Experimental and computational composite textile reinforcement forming: A review, Composites Part A: Applied Science and Manufacturing, 46, 2013, pp. 1-10 (doi: 10.1016/j.compositesa.2012.10.004)

[2] X.K. Li and S.L. Bai, Sheet forming of the multi-layered biaxial weft knitted fabric reinforcement. Part I: On hemispherical surfaces, *Composites Part A: Applied Science and Manufacturing*, **40**, 2009, pp. 766-777 (doi: 10.1016/j.compositesa.2009.03.007)

[3] X. Peng and F. Ding, Validation of a non-orthogonal constitutive model for woven composite fabrics via hemispherical stamping simulation. *Composites Part A: Applied Science and Manufacturing*, **42**, 2011, pp. 400-407 (doi: 10.1016/j.compositesa.2010.12.014)

[4] C. Dufour, P. Wang, F. Boussu and D. Soulat, Experimental investigation about stamping behaviour of 3D warp interlock composite preforms, *Applied Composite Materials*, **21**, 2014, pp. 725-738 (doi: 10.1007/s10443-013-9369-9)

[5] M.A. Khan, T. Mabrouke, E. Vidal-Salle and P. Boisse, Numerical and experimental analyses of woven composite reinforcement forming using a hypoelastic behaviour. Application to the double dome benchmark. *Journal of Materials Processing Technology*, **210**, 2010, pp: 378-388 (doi: 10.1016/j.jmatprotec.2009.09.027)

[6] S. Allaoui, P. Boisse, S. Chatel, N. Hamila, G. Hivet, D. Soulat and E. Vidal-Salle, Experimental and numerical analyses of textile reinforcement forming of a tetrahedral shape. *Composites Part A: Applied Science and Manufacturing*, **42**, 2009, pp. 612-622 (doi: 10.1016/j.compositesa.2011.02.001)

[7] P. Wang, X. Legrand, P. Boisse, N. Hamila and D. Soulat, Experimental and numerical analyses of manufacturing process of a composite square box part: Comparison between textile reinforcement forming and surface 3D weaving. *Composites Part B: Engineering*, **78**, 2015, pp: 26-34 (doi:10.1016/j.compositesb.2015.03.072)

[8] F. Nosrat Nezami, T. Gereke and C. Cherif, Automated Preforming of complex shaped geometries with active forming manipulation "Tailored Drape". *Proceedings of the Fachtagung Carbon Composites*, Augsburg, Germany, November 18-19, 2014

[9] F. Nosrat Nezami, T. Gereke and C. Cherif C, Automatisiertes Preforming komplexer Geometrien mit aktiven Materialführungssystemen „Tailored Drape“, *Proceedings of the 8th Aachen-Dresden International Textile Conference*, Dresden, Germany, November 27-28, 2014

[10] O. Döbrich, T. Gereke, O. Diestel, S. Krzywinski and C. Cherif, Decoupling the bending behavior and the membrane properties of finite shell elements for a correct description of the mechanical behavior of textiles with a laminate formulation, *Journal of Industrial Textiles*, **44**, 2014, pp. 70-84 (doi: 10.1177/1528083713477442)

[11] O. Döbrich, T. Gereke and C. Cherif, Modeling of textile composite reinforcements on the micro-scale, *Autex Research Journal*, **14**, 2014, pp. 28-33 (doi: 10.2478/v10304-012-0047-z)