ADVANCED FORMING OF TAILORED TEXTILES USING LOCALLY MODIFIED PROPERTIES FOR OPTIMIZED LIGHTWEIGHT STRUCTURES

J.Fial[1a], P.Böhler[1b] and P.Middendorf[1c]

[1]Institute of Aircraft Design, University of Stuttgart, Pfaffenwaldring 31, 70569 Stuttgart, Germany
[a]fial@ifb.uni-stuttgart.de, [b]boehler@ifb.uni-stuttgart.de, [c]middendorf@ifb.uni-stuttgart.de,
http://www.ifb.uni-stuttgart.de

Keywords: carbon fibre reinforced plastics, forming, tailored fibre placement, mesoscopic draping simulation, selective tow manipulation

Abstract

In order to ensure proper fibre orientations and with it effective lightweight designs, a new forming approach of tailored fibre placement preforms is investigated.

In this draping process the TFP material is rather folded than draped. This can be achieved by cuts in the base material which lie exactly on the edges of the part to be formed. Carbon fibre tows that can be selectively manipulated connect each side of a cut and close the gap during the forming process. They consequently allow the transmission of mechanical loads over the part's edges.

The forming process examined in this paper is based on a reverse mesoscopic draping simulation which deduces a two-dimensional flat sheet from a three-dimensional complex FEM based model of the part to be manufactured. The fibre paths are thereby created from information on the parts loading conditions using numerical optimization and performing a finite element draping simulation. Therefore the material behaviour is characterized through numerous tests and implemented in the mesoscopic simulation approach.

1. Introduction

In order to achieve high performing lightweight structures, carbon fibre reinforced plastics (CFRP) are used in more and more sectors of industry. One general challenge in using CFRP is their anisotropic mechanical behaviour which means that even a slight difference between the directions of loading and fibre tow leads to an intense loss of performance.

This is particularly demanding for complex structures where textiles are no longer flat but have to undergo a draping process. Forming a textile means that forming mechanisms have to occur in order to a textile to adapt to a three-dimensional geometry [1]. One important draping mechanism is shearing which inevitably leads to a change in the fibre directions. Controlling and predicting these draping mechanisms – for instance by a simulation – is the key to an adequate component design.

The challenges described are the reason for the development of what in this paper is called advanced forming of tailored textiles. The key element for this technique is the tailored fibre placement (TFP) technology. It is a perfect process to realise load path aligned fibre orientations. It is also suitable for the creation of locally varying textile topologies: Changing stitch parameters like length and width influences a reinforcement fibre's bond to the base material and can thereby be used to affect the drapability of a textile [2]. These mechanisms are also suitable to allow local selective tow slippages and manipulating single yarns can be utilized to implement draping respectively folding mechanisms.

This paper gives a brief insight in the different aspects of this kind of draping process. In this regard the main process principles, material characterisation methods and simulation approaches are presented.

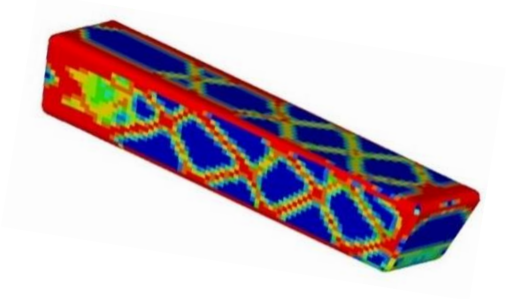
Excerpt from ISBN 978-3-00-053387-7

2. Forming Mechanism

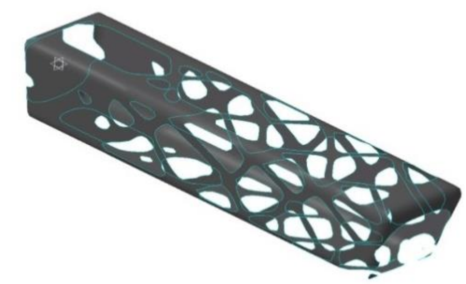
The forming mechanism presented is based on selective tow manipulation which permits closing cuts placed in the base material the fibres are stitched on. The initial textile is manufactured by the tailored fibre placement technique using a woven biaxial glass fibre base material and 12k carbon reinforcing yarns. The topology of the TFP textile is thereby determined by a reverse draping simulation which is described in detail in section 2.1 below.

2.1. Reverse Draping Simulation

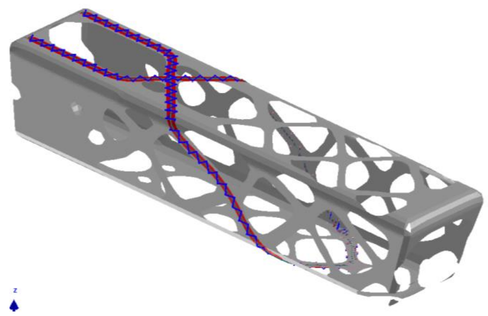
The main idea of the reverse draping approach (cf. figure 1) is based on the fact that the TFP process can only be used to create two-dimensional textiles. Most structures are not two-dimensional and a forming step is necessary to bring the TFP textile in the shape desired which will lead to a change in fibre architecture due to draping effects. In order to take into account those forming effects in the design process, the idea is not to start with the flat TFP textile but with the load path in the final three-dimensional structure (cf. figure 1 a)). From this point on, a draping model considering the physical effects of the TFP-textile is created (cf. figure 1 c)) and a reverse draping into the two-dimensional textile is performed (cf. figure 1 d)).



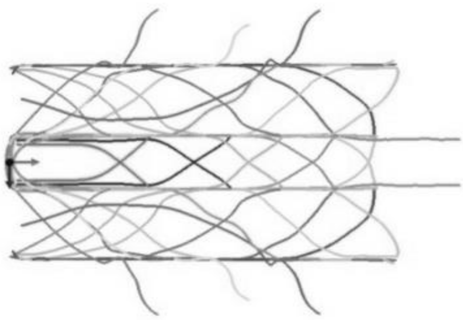
a) Load path in final structure



b) Interpretation in yarn paths



c) Mesoscopic draping model (partial)



d) Yarn paths for TFP process after draping

figure 1: reverse draping approach.

2.1.1. Definition of load paths and determination of yarn paths

The first step for the reverse draping approach is the definition of the load paths. The most common way is a topology optimization. In this context the load is applied on a homogenized structure and in several calculation steps the material distribution is determined. The result is a material distribution which reflects the loaded areas of the part (cf. figure 1 a)). As those areas consist out of oblong sections a directed loading is assumed and these sections can be interpreted as yarn paths (cf. figure 1 b)).

Another way of obtaining the yarn paths is the so called free-size calculation. In this approach the optimization is based on a stack of layers with different fibre orientations and depending on the stresses in each element the thicknesses of the different layers are calculated. That leads to a material

Excerpt from ISBN 978-3-00-053387-7

distribution for each layer. The result of this method is hard to interpret for yarn paths placed by the TFP process as non-continuous fillets can be created by the simulation.
Once the load paths are defined, the interpretation and the generation of yarn paths is a time-consuming procedure. Therefore, a tool has been created which is able to automatically build a mesoscopic model based on the previous simulation results including the base material, yarns and

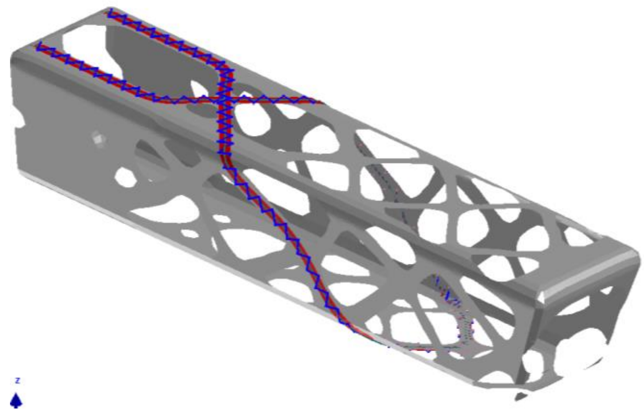


figure 2: Interpretation of optimization result in yarn paths.

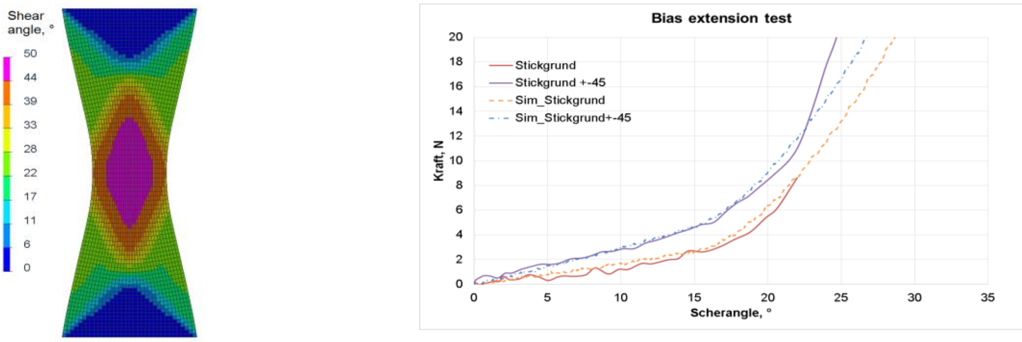
stitching threads. To achieve a good yarn sliding during the forming different stitching types can be used and are implemented in the pre-processor-tool.

2.1.2. Finite Element Simulation

The draping simulation is performed using ESI Visual PamCrash. The yarns and the base material are modelled by shell-elements whereas the stitching threads are described by bar elements. For the textile behaviour of the yarns and the base material a specific material model is used (MAT140). Several material tests are performed (cf. section 2.2) which are later used to calibrate the material models by comparing them with equivalent simulations.

For the description of the shearing behaviour of the base material the bias extension test [3] is used (cf.

figure **3**).

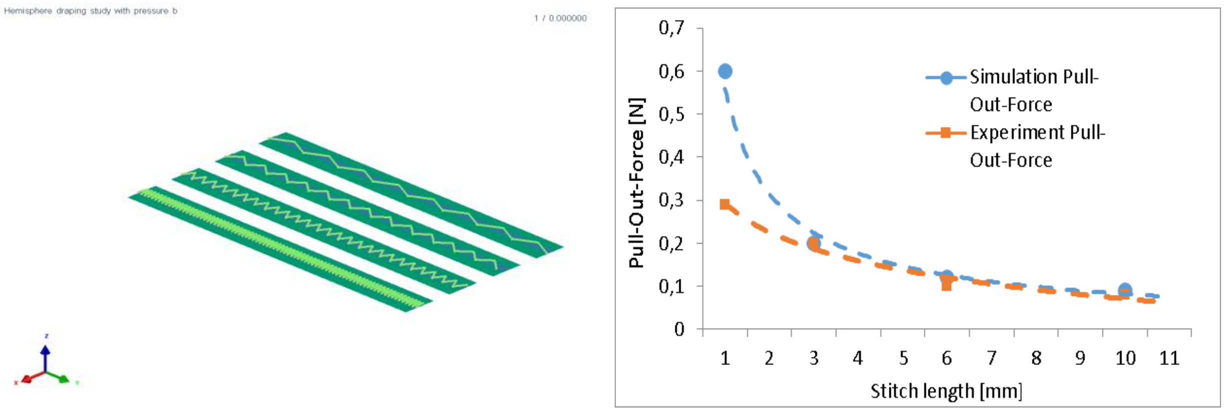


a) Numerical bias extension test b) Force-displacement - simulation and experiment

figure 3: Bias Extension test for base material.

In order to determine the influence of the stitching on the draping process and to investigate the friction behavior between base material, yarns and stitching threads different pull-out tests [3] are performed and simulated (cf. figure 4).

Excerpt from ISBN 978-3-00-053387-7



a) Pull-out tests for different stitch-types b) Pull-out force vs. stitch-length -sim and exp

figure 4: Pull-out force.

The diagram above illustrates that the simulation model is capable of expressing the general influence of the stitching. However, for a very strong fixation of the yarns a mismatch between the simulation and the test results can be observed.

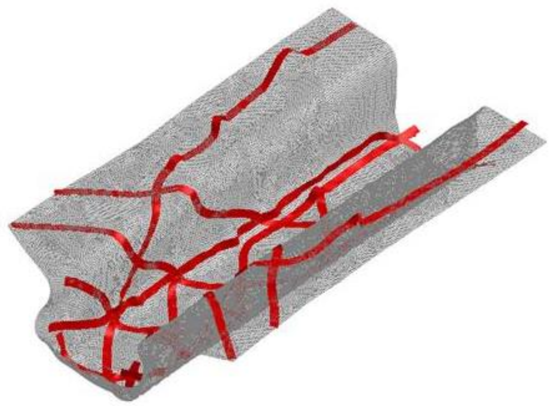


figure 5: Reverse draping simulation of base material and reinforcing yarns.

With that information the reverse draping process of a TFP-textile can be simulated considering the physical behavior of the yarns (cf. figure 5). The numerically determined yarn paths for the two-dimensional textile can then be used for the manufacturing of the actual preform.

2.2. Material Characterisation

The characterisation of the material to be formed is the basis for the simulation described in the previous passage. Characterisation methods used in this context are the already mentioned bias-extension [3] and fibre pull-out [2] as well as the cantilever test [4]. Those tests are performed using the ZSD and Cantilever test rigs at the Institute of Aircraft Design [5], [6], [7]. More information on the realisation of these tests can be found in [2].

2.3. Forming Process

The intended forming process is much like a classical punch and die process. There is a negative mould of the part to be built and a positive stamping tool. These parts can be handled by the draping

Excerpt from ISBN 978-3-00-053387-7

device that has been developed and built at the IFB [8]. A correspondent draping configuration can be seen in figure 6 below.

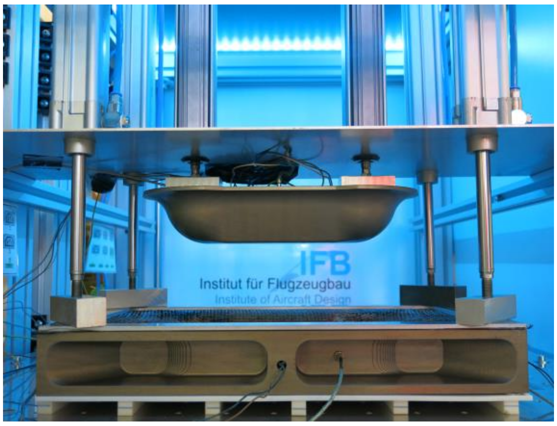


figure 6: IFB draping device [8].

In order to point out the feasibility of this new forming process, a simple trapezoidal block geometry is chosen. For the forming process it is crucial that the TFP preform is well designed and adapted to the forming tool. The creation of this kind of preform and its constraints are pointed out in section 2.3.1. This is followed by a detailed describtion of the key elements of the forming strategy – the single yarn slippage and manipulation (section 2.3.2).

2.3.1. Preform Creation

As mentioned before, for the creation of the preforms the tailored fibre placement technology is used. This gives advantages concerning load path orientated design of the reinforcing carbon fibre structure and a higher lightweight level can be accomplished.
As a base material for the TFP process a woven glass fibre textile is used. In connection with the forming process presented this base material is purely there to carry the reinforcing fibres and does not need to fulfil any mechanical or draping-related requirements.

Before starting stitching the carbon fibres onto the glass fabric the folding lines and the coherent cuts have to be taken into consideration. This is illustrated followingly in figure 7:

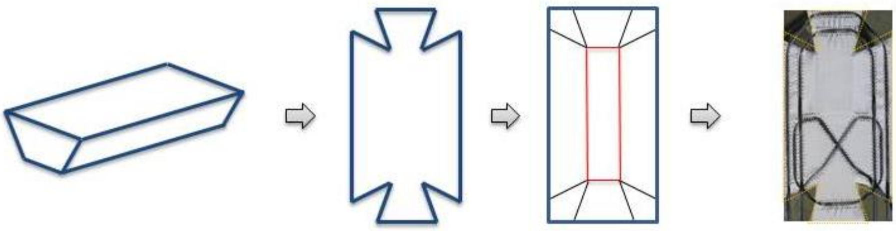


figure 7: Deduction of the base material geometry. From left to right: part geometry, unfolded contour plot, plot with folding and cutting lines, realisation of base material.

From left to right this figure shows the deduction of the two-dimensional base material geometry from the three-dimensional trapezoidal body. In red folding lines are represented right of the centre of the figure. In the same part cutting lines are pictured as black lines. These cuts are to be sliced into the base material before the stitching is performed. The realisation of this approach can be seen at the very right part of figure 7.

Excerpt from ISBN 978-3-00-053387-7

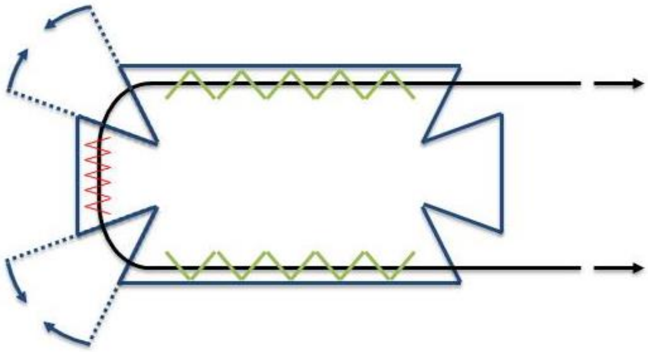


figure 8: Closing base material cuts by selective tow manipulation using different TFP stitching parameters.

Another important aspect is the selective use of different stitching parameters (cf. figure 8). This simple example illustrates how the two left-hand cuts in the base material (blue) can be closed by pulling a carbon fibre tow (black) on its right-hand ends towards the right side. In a real process it has also to be ensured that the preform is well fixed so the pulling forces don't draw it out of the draping tool.
It is crucial to notice that in the example above the carbon fibre tow is strongly be fixed on the left-hand side by a tight stitching pattern of the TFP sewing thread (red) which disables its relative movement to the base material.
In contrast, a lose tow fixation is realized in the horizontal fixation areas (green) which allows local fibre slippages and therewith the carbon fibres to be pulled out of the preform.

2.3.2. Selective Tow Slippage and Manipulation

This section examines the technique that is used to selectively manipulate individual or several carbon fibre tows in order to pull them out of a preform allowing the closing of cuts.
As mentioned above, the goal is to realise a simple punch and die process with as few sub process steps as possible and with a simple tool. The challenging part in this is the manipulation of few or even one single carbon fibre tow using only the lateral movement of the stamp-like draping tool.

figure 9 shows on its left-hand side a scheme of how this is realised whereas on its right-hand side a simple application of that technique is shown:

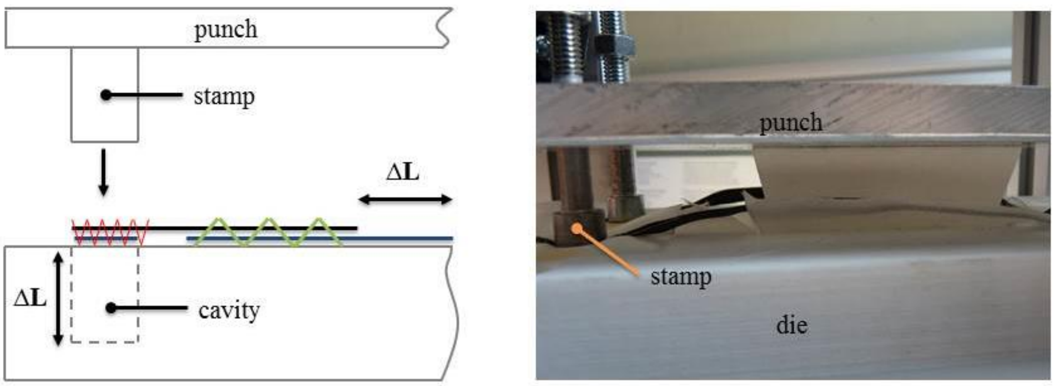


figure 9: Selective tow manipulation. Left: schematic illustration, right: real application.

On the left-hand side it can be seen that a stamp which is attached to the punch tool pushes down into a cavity which's depth is described by ΔL. This enables the carbon fibre tow (black) to be pulled out

Excerpt from ISBN 978-3-00-053387-7

of the loose stitching (green) of the base material (blue). Consequently the pull-out length is also equal to ΔL which can be used to close gaps in the base material.
The implementation of this mechanism can be seen on the right-hand side of figure 9. Note that the part of the base material which is pushed into the cavity has to be separated from the rest of the preform.

The following figure 10 shows the final result of the whole forming process using the trapezoidal geometry:

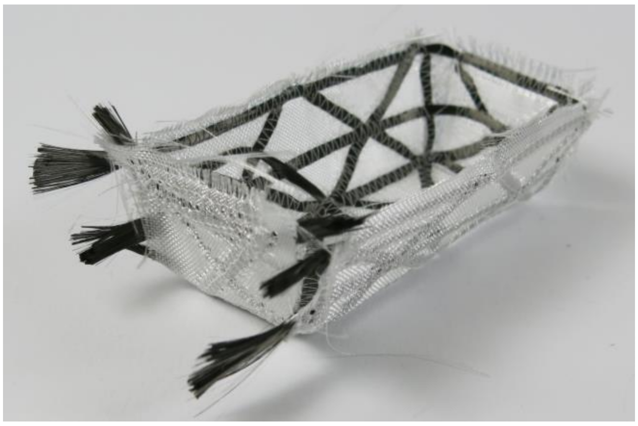


figure 10: Three-dimensional preform resulting from the forming process using selevtive fibre manipulation.

3. Discussion and Conclusion

The tests performed have shown that this new draping approach is feasible and works the way it is supposed to. With the help of the material characterisation tests it has been possible to build up a material model that is able to predict the draping result in a mesoscopic simulation.
It is consequently an appropriate way to realise effective lightweight constructions and could also be a way of bypassing classical draping issues. Even three-dimensional, “free” carbon fibre reinforcement structures have been proved to be possible.
In the future this technique will have to prove its additional value in an application of a real aerospace structure. For an industrial scale the development of an end-effector like advice needs to be done. The realisation of this task is a challenging step as the design of the end-effector needs to combine many different tasks and is therefore rather complex. Once these points are achieved, this forming technique has the potential of being applied on a larger industrial scale.

Excerpt from ISBN 978-3-00-053387-7

References

[1] F. Härtel, Entwicklung eines Vorentwurfansatzes für die automatisierte Drapierung von Faserhalbzeugen. Dissertation, Stuttgart, 2015.
[2] P. Böhler, S. Carosella, C. Götz, P. Middendorf, Path definition for tailored fiber placement structures using numerical rerverse draping approach, in: Key Engineering Materials, pp. 446–457, 2015.
[3] P. Xiongqi, C. Jian, BIAS EXTENSION TEST STANDARD, Northwestern University, Evanston, IL, 2003.
[4] DIN Deutsches Institut für Normung e.V., Bestimmung der Biegesteifigkeit, Verfahren nach Cantilever 59.080.40, 53362, Beuth Verlag GmbH, Berlin, 2003.
[5] F. Härtel, P. Middendorf, Process Parameter Studies and Comparison of different Preform Processes with NCF Materials, in: ICCM19, Montreal, 2014.
[6] F. Härtel, P. Böhler, P. Middendorf, An integral mesoscopic Material Characterization Approach, in: ESAFORM, Helsinki. 2014
[7] S. Küppers, F. Härtel, L. Müller, P53940 DE , 2014
[8] M. Tartler, D. Hägele, J.Fial, M. Engelfried, I.Karb, P. Middendorf, Investigation and Simulation of Forming Behavior of Preforms made by Direct Fibre Placement, ECCM München, 2016.

Excerpt from ISBN 978-3-00-053387-7