TOWARDS A COMPLETE SIMULATION PROCESS CHAIN FOR THE MANUFACTURING OF BRAIDED COMPOSITE PARTS

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Introduction

Textiles braided over hollow cores, and subsequently infused with a thermoset resin via Resin Transfer Moulding (RTM), provide an increasingly viable industrial solution. In the automotive field, BMW applies Braided-RTM technology in both Project i, and the latest BMW 7-Series. Geometries can be complex, resulting in textile architecture with spatially varying yarn spacing and angles. Process simulations have been developed at the Technical University of Munich (TUM) to simulate the complex braiding process. These produce a map of tow spacing and angles over the surface of a braided preform. In a preliminary collaborative project with the University of Auckland (UoA), output from these simulations have been used to develop geometric models of braided textiles unit cells. These have been used to predict the compressed geometry of these textiles within a mould, and subsequently predict flow properties. This paper presents a complete simulation process chain through to RTM filling simulations, providing an approach which may be used to optimise the manufacturing process of braided parts.

Braiding Simulations

The over-braiding process is simulated, predicting the resulting textile architecture at different locations on a mandrel (local definition of braiding angle and tow spacing) [1]. The simulation is carried out in Abaqus (Dassault Systèmes Simulia) using the explicit FE solver. The mandrel and the guide ring are modelled by their surfaces, and each single yarn is modelled using truss elements. An example of this is shown in Figure 1, illustrating a braiding simulation partially completed.

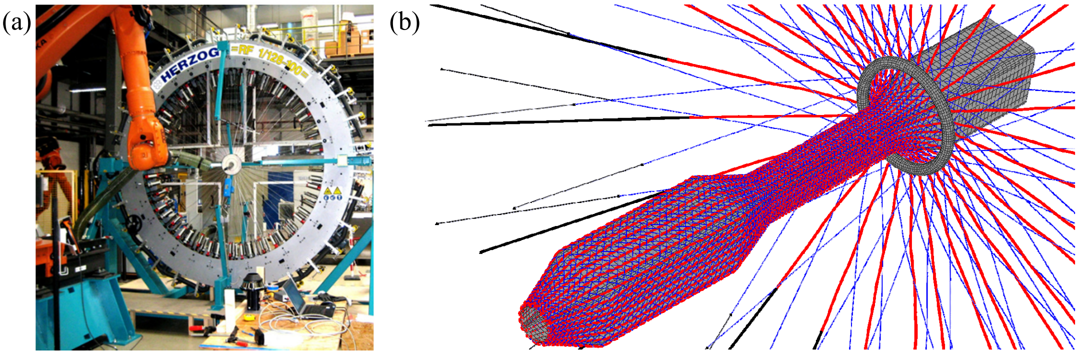

Figure 1: *(a) Over-braiding machine. (b) Example of Abaqus based braiding process simulation.*

Once the braiding simulations are completed, an additional post-processing step is performed in order to determine the resulting braiding angle and yarn spacing for each finite yarn element [1]. Each node is allocated to a single cell (finite element) of the mandrel, for which the braiding angle and yarn spacing are derived. The resulting braided textile is then visualised in Catia V5, the yarns being represented by their finite elements and coloured depending on the local braiding angle to generate a contour plot. An example is provided in Figure 2 for a square mandrel with side length 45 mm, for which the mandrel take-up velocity has been varied. Braiding angle and tow spacing are dependent on part geometry, and the parameters of the braiding process, and are very influential on the textile compaction and flow properties.

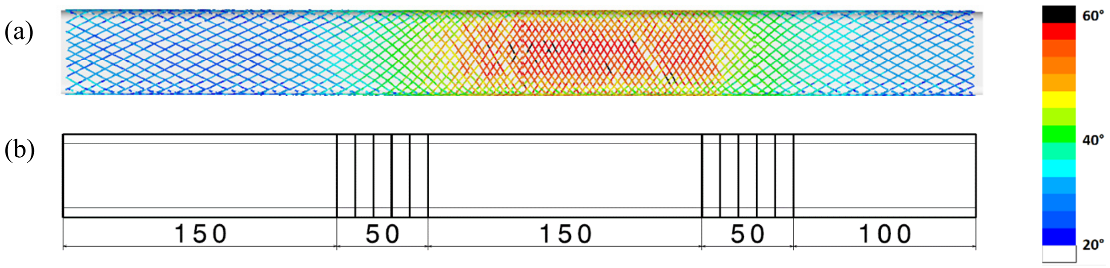

Figure 2: *Example braiding simulation result. (a) Braiding angle contour plot and (b) definition of mandrel sections.*

Permeability Predictions and Filling Simulations

The predicted braid architecture is used to generate a range of textile models of the reinforcement, which cover variations in textile architecture of the target part as determined by the braiding simulations. These models are stacked so as to create four-layer preform structures with both no, and maximum, in-plane ply shift. Compaction simulations are applied to these models, reflecting the compaction that happens to the preform during the manufacturing process and the resulting models are then used to predict the in-plane permeability tensor.

Unit cell geometries are generated in TexGen, software developed by the University of Nottingham. An automated simulation chain has been presented previously, which models compaction of multi-layer textile models using Abaqus, and subsequently predicts permeability components using ANSYS CFX [2]. Example pre-compaction textile models are provide in Figure 3, for the extreme cases of non-nesting and maximum nesting. Predicted fluid velocity streams are also shown for the compacted textile model, highlighting the influence of nesting on axial permeability. Look-up tables are used to generate axial and lateral permeability maps for filling models, which are subsequently solved using SimLCM [3].

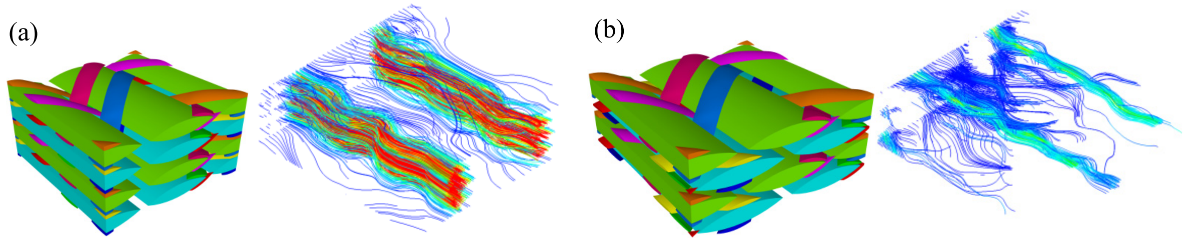

Figure 3: *Uncompressed textile unit cells, and fluid velocity streamlines. (a) Non-nested, and (b) maximum nesting.*

Highlighting the importance of layer nesting as a demonstration of the virtual process chain, the square mandrel shown in Figure 2a was numerically braided with a constant take-up velocity. Filling models using the two nesting extremes were assembled, and simple end injection simulated (constant injection pressure of 10 bar, viscosity of 0.1 Pa.s). The large open flow channels in the non-nested case results in a short fill time of 2.3 s, while maximum nesting increases fill time significantly to 41.5 s. The nesting format also alters the ratio of in-plane permeabilities, leading to a significant flow front lag along the corners of the non-nested case, as demonstrated in Figure 4.

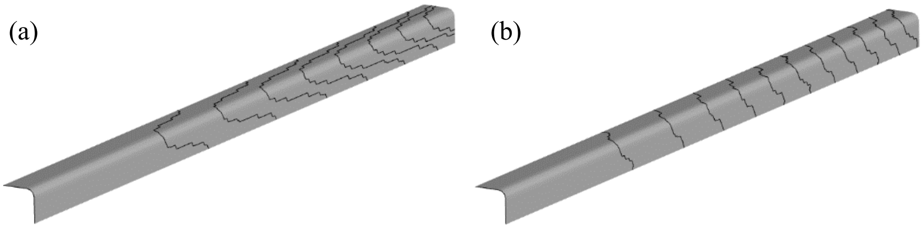

Figure 4: *Predicted flow front progression. (a) No nesting, and (b) maximum nesting.*

References

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