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23.11.2018

Project title: Multi-Scale Modelling of Thermoplastic Fibre Reinforced Composites during Thermoforming

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Duration: 04/2017 – 03/2020

Funding: DFG (Normalverfahren)

Mission Statement

Rising energy costs and growing concerns over the environment are causing a strong demand for lightweight materials in vehicle construction to increase fuel efficiency. One of the strongest contenders for these lightweight parts is fibre reinforced polymers (FRPs), which exhibit high strength to weight ratios and the ability to be tailored to local load directions. Most high-performance FRPs contain a *thermoset* polymer matrix, where the polymer is cured irreversibly through a chemical reaction. *Thermoplastic* composites, on the other hand, can undergo repeated heating and cooling. Thermoset composites typically have superior mechanical and thermal properties, but thermoplastic composites are becoming more popular because of the potential for shorter part cycle times, ease of storage and handling, increased toughness, and recyclability.

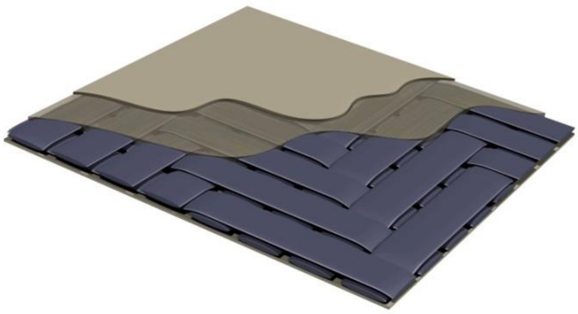

Figure 1: Meso-scale schematic of TPFRC with one layer of 4x4 twill weave textile. The translucent layer represents the matrix infiltrating the textile. The opaque layer represents the outer neat TP matrix layer.

Thermoplastic fibre reinforced composites (TPFRCs) most often come in the form of blanks which are produced by stacking several plies of thermoplastic (TP) foil in between carbon fibre or glass textile layers (Figure 1) and consolidating them using heat and pressure. These blanks can be handled and transported easily and stored over extended periods of time without cooling. The final part producer only needs to heat up the blank above the melting temperature of the polymer and form it into the final part shape as shown in Figure 2. This can be done with short cycle times (~1 min. or less). Existing metal-forming machinery and methods can be utilised. Furthermore, the thermoplastic matrix allows the potential for scrap and eventually part recycling, which is becoming a regulatory demand in most vehicle markets.

Despite the advantages of TPFRCs, only a few specialised companies use them in their products. Process stability is a major problem which is difficult to keep under control. Residual stresses due to thermal gradients and coefficient of thermal expansion (CTE) mismatches between fibre and matrix might lead to shape distortions of the final part – commonly referred to as the "spring-in" effect. To counteract this effect, process parameters such as heating/cooling rates, tool shape, and part positioning must be carefully determined. This is typically done by trial and error, making development time-consuming and cost-intensive. To eliminate trial and error, computational models of the thermoforming process are needed which can predict residual stresses and spring-in for TPFRC parts. To achieve this, several innovations are required. The build-up of residual stresses must be considered at multiple scales (see Figure 3), since there is a CTE mismatch between individual fibres and their surrounding matrix (micro-scale) as well as between tows and matrix (meso-scale). Thermal gradients occur at all scales.

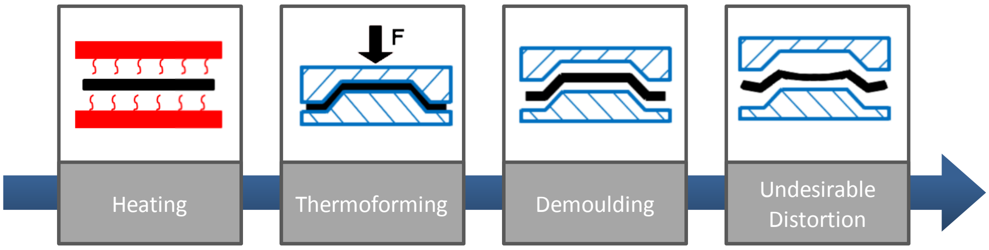

Figure 2: Steps in forming of a TPFRC sheet with frequently occurring shape distortions after deforming.

The entire process temperature range of the polymer must be considered, from room temperature to above the melting temperature and back. Finally, the melting and solidifying of the polymer in the presence of fibres must be fully characterised and considered.

This project will result in a scale-bridging thermoforming simulation of TPFRCs with three major innovations. First, a matrix material model for the entire temperature range of thermoforming will be developed for TPs. It will find application in the project at micro- and meso-scale. Second, a meso-scale tow model based on a micro-scale representative volume element (RVE) and the previously developed matrix material model will be created for both solid and liquid matrix phases. Third, both models, matrix and tow will be fully characterised experimentally over the entire temperature range. The target materials will be a glass fibre weave with a polyamide 6 (PA6) matrix. All of this will be combined in a meso-scale model of the thermoforming process with a new level of fidelity.

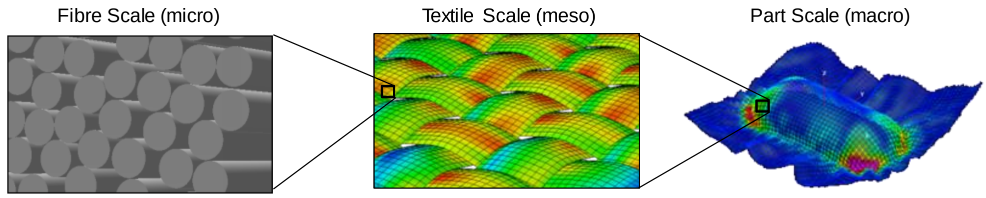

Figure 3: Three scales typical of a TPFRC: (left) micro, (middle) meso, and (right) macro.

Acknowledgement

We would like to thank Deutsche Forschungsgemeinschaft e.V. (DFG), Bonn, for the financial support of the research project.

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