VACUUM-ASSISTED THROUGH-THICKNESS MELT IMPREGNATION OF THERMOPLASTIC COMPOSITES

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Abstract

High-performance industries are increasingly interested in transitioning from thermoset to engineering thermoplastic composites, as they offer good mechanical properties, do not require a curing cycle, and offer end-of-life re-use/recycling potential. While current techniques can produce high-quality thermoplastic composite structures utilising prepreg systems, in-situ impregnation of dry preformed woven textiles via liquid composite moulding processes (LCM) remains challenging. A significant barrier to in-situ thermoplastic impregnation stems from the high viscosity of engineering polymer melts, which can be over 10,000 times greater than their thermoset counterparts.

Efforts to enhance processibility have led to a focus on transverse impregnation of textile reinforcements, significantly reducing the infiltration length. Despite this advancement, current processing techniques yield parts with high void content, primarily concentrated within the intra-tow pore space. This void content originates from the entrapment of air bubbles due to the multi-scale flow front present during thermoplastic impregnation processes [1]. Addressing the high void content is required to improve the quality of thermoplastic composites.

In this work, control of the initial air pressure inside the dry textile during an impregnation process was investigated to reduce the final void content of manufactured composites. A dual scale, unsaturated model has been developed to investigate the influence of initial atmospheric pressure within the tool cavity. The approach couples a compressible 1D porous media model developed by Jin et al. [2] to represent the inter-tow infiltration, with multiple 2D CVFEM porous media models for the intra-tow infiltration. Gas entrapment is modelled using the ideal gas law once the tow is surrounded by polymer. Figure 1 displays example simulation results from the impregnation of a woven glass fibre textile with molten polypropylene.

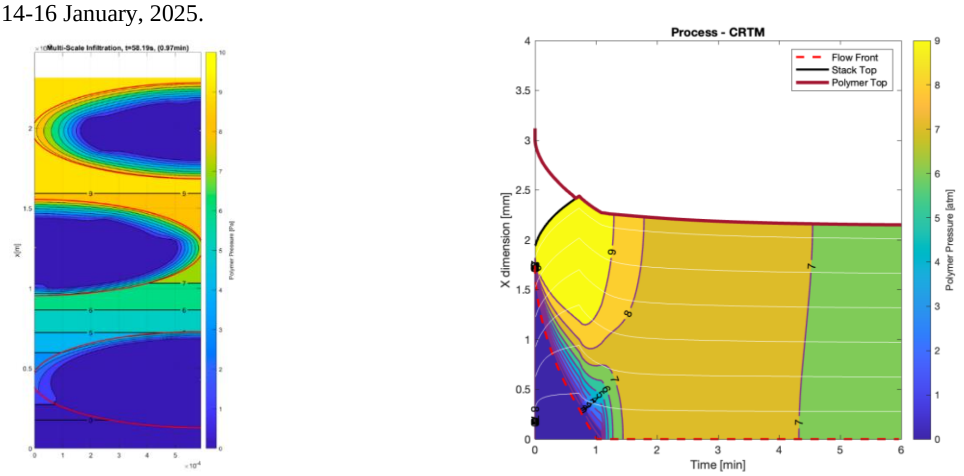

Figure 1: (a) Snapshot of infiltration cross section (b) Inter-tow polymer pressure against time.

Preliminary numerical simulations suggest that the final void content is linearly proportional to the initial ambient air pressure within the tool cavity, with a 30% void content at atmospheric pressure to <1% at 5 KPa (absolute). This indicates that vacuum assistance is a promising mechanism in reducing void content. An important note that must be made is that the vacuum assistance is only significant at the point of gas entrapment of the tow.

Furthermore, this paper will demonstrate the importance of modelling the dual scale impregnation, despite the intra-tow impregnation taking significantly longer than the inter-tow. The driving pressure of the polymer in the inter-tow region can be significantly lower than the consolidation pressure, significantly altering the intra-tow impregnation behaviour.

To validate the simulation method, a novel vacuum-assisted LCM die based on the melt thermoplastic compression resin transfer moulding (mTP-CRTM) process has been developed. The implemented design creates a gas seal inside the composite part cavity inspired by the work of Werlen et al. [3], allowing evacuation of air with a vacuum pump during impregnation. This research addresses a critical hurdle in processing high-viscosity thermoplastic composites regarding final void content and quality, expanding the potential range of engineering and high-performance polymers available for advanced applications.

References

[1] V. Werlen, R. Vocke, C. Baruner, C. Dransfeld, V. Michaud and C. Rytka, “A model for the consolidation of hybrid textiles considering air entrapment, dissolution and diffusion,” *Composites Part A: Applied Science and Manufacturing*, 2023.

[2] J. Lee, M. Duhovic, T. Allen, D. May and P. Kelly, “Computational modelling and analysis of transverse liquid composite moulding processes,” *Composites Part A: Applied Science and Manufacturing*, 2023.

[3] V. Werlen, C. Rytka, S. Wegmann, H. Philipp, Y. Khalaf, V. Michaud, C. Brauner and C. Dransfeld, “Novel tooling for direct melt impregnation of textile with variotherm injection moulding: Methodology and proof of concept,” *Journal of Composite Materials*, pp. 4245-4257, 2022.