Multiphysical Process Modeling Approach for Vacuum Bag Only Prepregs: Integration of Resin Flow, Consolidation and Heat Transfer

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Abstract

Vacuum Bag Only (VBO) prepreg processing holds significant potential for addressing the challenges of traditional manufacturing processes, particularly in terms of robustness and cost-effectiveness. The success of the VBO process relies heavily on precise process design, which must encompass the physics of the process along with accurate material data. In the VBO process, dry fibrous regions are impregnated by resin flow through porous media under a controlled temperature profile. In addition to resin flow and heat transfer phenomena, the prepreg stack is consolidated by the applied pressure gradient, leading to preform compaction. Therefore, process design requires a multiphysical approach that integrates: (i) resin flow, (ii) consolidation, and (iii) heat transfer.

In this study, we systematically integrate the material models of a thermoset prepreg system for fiber architecture (porosity and permeability), thermal properties (specific heat capacity and thermal conductivity), and the resin system (glass transition temperature, cure kinetics, and viscosity) (Figure 1.a) [1]. We then develop a multiphysical process modeling tool that couples these material models (Figure 1.b). This tool is subsequently combined with a multi-objective optimization platform to achieve an optimal two-stage temperature profile to minimize void content and ensure a uniform and successful degree of cure (Figure 1.c). The platform is tested for the effects of two-stage temperature profile parameters on 1-, 2-, and 4-layer prepreg laminates using process modeling simulations, as depicted by the resin impregnation model findings at different time instants in Figure 2. The findings of the optimization platform for each number of layers are validated through microscopic void content analysis. Significant improvement in void contents is reported with the implementation of optimal temperature profiles, highlighting the success of our multiphysical process modeling approach coupled with systematic material characterization [1]. Thus, these advancements demonstrate the potential for improved performance and cost-efficiency in prepreg processing, specifically tailored for thermoset prepreg systems and varying numbers of layers, paving the way for more effective manufacturing solutions in composite materials.

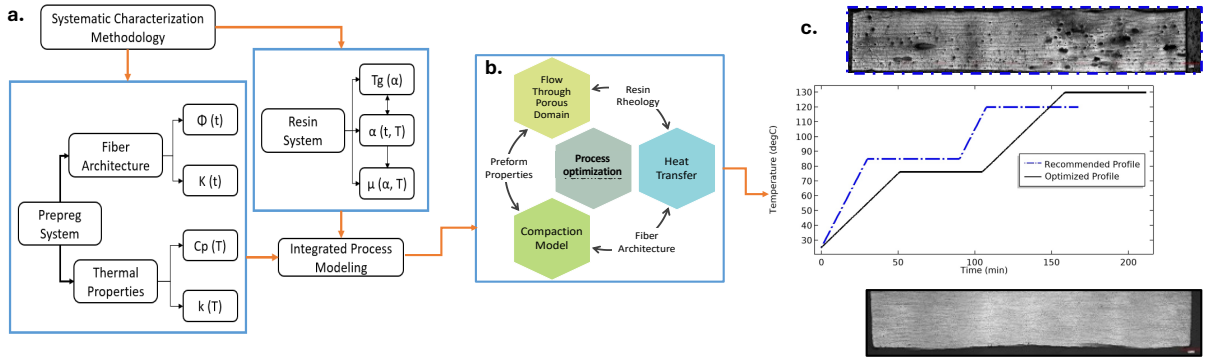

Figure 1. VBO optimization roadmap: **a.** systematic characterization of the thermoset prepreg system, **b.** multiphysical process modeling, optimized two-stage temperature profile, and **c.** the resulting microscopy images showing significant improvement in void content using the optimized profile.

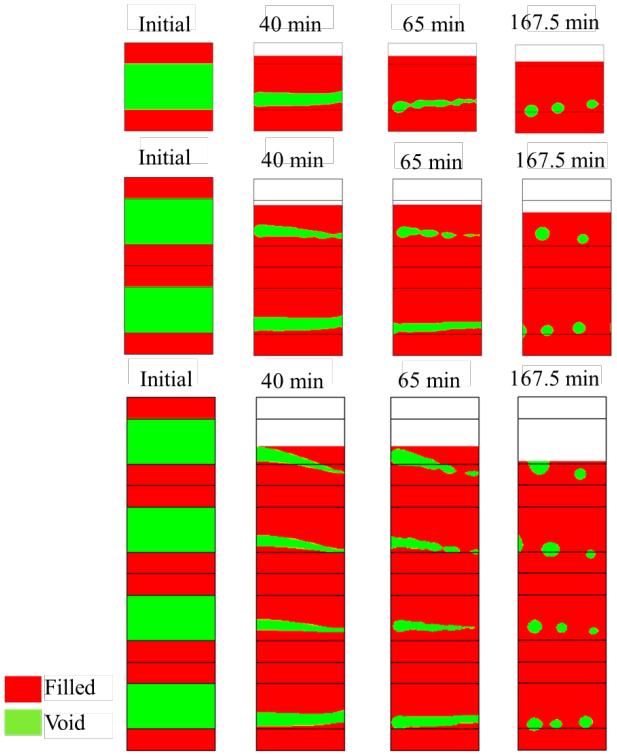

Figure 2. Time-varying change of resin impregnation for 1-, 2- and 4-layers of VBO prepregs after 0, 40, 80, and 167.5 minutes.

References

[1] Arikan, Muhammed H., et al. "A systematic characterization approach for vacuum bag only prepregs towards an accurate process design." Materials 15.2 (2022): 451.