MULTI-SCALE MODELING IN LIQUID COMPOSITE MOLDING

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ABSTRACT:

In Liquid Composite Molding (LCM), fibrous preform is placed within a mold and injected with liquid resin. Once the preform is saturated, the resin cures and the finished component is de-molded. There are many variations of the process, most important being Resin Transfer Molding (RTM) in which the two-sided mold is rigid and resin is injected under positive pressure. Second widely used variation is the Vacuum Assisted Resin Transfer Molding (VARTM) in which the mold is one sided, preform is covered with a flexible bag and vacuum is drawn. The resin is drawn into the preform due to the pressure gradient. In this case, highly permeable distribution media is placed on one face of the perform to speed the injection. In all these processes, it is imperative that the preform is sufficiently saturated during the resin injection. Otherwise, the resulting part will contain inadmissible void content. To ensure successful filling, numerical analysis of the flow process has been widely applied.

The complication arises from the internal structure of textile reinforcement generally used in LCM. Preforms usually consist of woven or braided fiber tows. Under this "macrostructure" there is the underlying "microstructure" of fiber tows, consisting of aligned fibers. On both levels of its structure the reinforcement acts as porous medium. As the scale of the pores between the fiber tows (macro-pores) is several orders of magnitude larger than that of pores within the fiber tows (micro-pores) it creates a dual scale porous medium. The result of dual-scale structure is that the resin flow progresses at different rates within the macro- and micro-pores. The flow-front advances through the macro-pores but micro-pores remain unsaturated in the region behind this "macro" or "unsaturated" flow-front up to the "saturated" flowfront.

Usual numerical modeling of the flow cannot capture this effect as it utilizes the concept of homogenous porous media and, therefore, a single flow-front. Depending on the structure of the reinforcement, this approach might prove sufficient, but it cannot capture some effects observed experimentally, and, most importantly, predict the fiber tow saturation whenever there is a significant lag between the saturated and unsaturated flow-fronts.

The dual scale flow can be modeled by using Darcy's law to describe flow through porous medium and mass conservation for the flow within the larger pores and representing the smaller pores can be included within these equations as a sink term. Alternatively, in this paper, we present the standard finite element/control volume approach and model the "internal" sink term by appending extra one-dimensional elements to control volumes associated with the control volumes of discretized part geometry to represent the resin sink. This approach allows one to solve the problem efficiently using existing simulation package for RTM filling simulation.

To model the single scale flow through porous medium one requires only limited description of the porous medium: its porosity and its permeability. The mutil scale model is more accurate, but it requires additional material parameters to characterize not just the “macro” properties but also the effective “micro” properties of the fiber tows. In this paper, we analyze the material properties necessary to characterize the dual-scale flow and we present the approach to determine these values from simple 1-D, constant flow-rate injection experiment and show examples of experimental characterization.

The dual-scale model can be used to provide more accurate information about the resin flow in macro-pores, but most importantly it allows one to predict the degree of saturation of micro-pores within fiber tows. For example, this allows one to determine the necessary “bleeding” time after the macro-flow reaches the vent to saturate the fiber tows. In this paper we present optimization of the bleeding time and application of flow resistance at the vent location to achieve satisfactory fiber tow saturation and compare the numerical results with the experimental data. Finally, we demonstrate how to model the saturation of fiber tows in VARTM process with distribution media, where the resin flow from collapsing distribution media continues to saturate fiber tows even after the injection is terminated.