Process modeling of liquid composite molding processes

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The polymer matrix composites (PMCs) are carving out a niche amid the keen market competition to replace the other material counterparts, e.g., metals. Due to the low weight and the corrosion resistance, the PMCs are wildly utilized from aerospace to automobile industries, both in the sectors of civilian and defense. To obtain high-quality products at low cost, the composites industry continues seeking for numerical simulation tools to predict the manufacturing processes instead of prototype testing and trials. Regarding the attractive liquid composite molding (LCM) process, it provides the possibility to produce net shape parts from composites. The challenges are how to identify the primary physics of LCM processes and develop mathematical models to represent them. Models need to be both accurate and efficient, which is not easy to achieve.

To model LCM processes, we have one option that describes all physics at the macroscopic scale. The fundamental continuum mechanics principles, e.g., mass balance, momentum balance, energy balance, and entropy inequality, help us developing models. In this regard, the theory of porous media (TPM), which relies on the concept of volume fractions, can explain the problems of the saturated/unsaturated multi-phase materials. Darcy's law describes the relation between the flow velocity and the pressure gradient, without accounting for the dual-scale flow. The air and resin compose the homogenized flow at the infusion stage. The existence of the capillary pressure influences the flow front, which has been revealed in this thesis. The finite element method is employed to solve for the homogenized flow pressure, and the degree of saturation with the staggered approach, especially the Streamline-Upwind/Petrov-Galerkin (SUPG) method is implemented to eradicate the stability problem.

As to the fiber preform response, an assumption of shell kinematics is made to reduce the model from a full 3-D problem to a shell-like problem. Given this, an explicit formulation is obtained to express the normal directional stretch as a function of homogenized flow pressure. This model has been verified and validated by a resin infusion experiment. The model mimics the preform relaxation and lubrication mechanisms successfully and efficiently.

So far, the works mentioned above aimed at the isothermal infusion stage. However, resin flow development, heat transfer, and resin curing are strongly interrelated during the whole LCM process. The holistic simulation of both the infusion stage and the curing stage is carried out in this thesis. Finally, we propose a system of coupled models to help process engineers to design and control process parameters by using virtual numerical experiments instead of the traditional trial-and-error approach.