Effect of inter-tow spacing on dual-scale flow patterns in LCM preforms

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Abstract

Liquid Composite Molding (LCM) processes rely on the infiltration of a viscous resin into a dry textile preform that contains a complex pore network spanning several length scales. Controlling infiltration is key to reducing air entrapment and voids, since the resin–fiber interaction dictates the fluid front progression and thus the efficiency and speed of the process [1]. Advancing these processes require a deeper understanding of the flow behaviour inherent to textile reinforcements, where the interplay between fabrics geometry and fluid dynamics becomes central [2].

The fabrics are typically composed of tows made of thousands of filaments, arranged through weaving or stitching to create a bimodal pore structure with micro-porosity inside the bundles and macro-porosity between them. This geometry leads to a dual-scale flow: capillary wicking governs impregnation inside the tows, while viscous flow dominates in the inter-tow channels. At low flow velocities, capillary forces drive the resin into the intra-tow spaces, which can trap air between bundles; at higher velocities, viscous forces prevail and the resin progresses mainly through the macropores. A general consensus in the literature points to the existence of an optimal flow velocity, often expressed through the capillary number, at which viscous and capillary forces balance and void content is minimized[1]. Yet this optimal range is usually too low to meet industrial production targets, and the geometry of the textile therefore remains a decisive factor in governing these flow interactions.

In this work, we investigate the influence of textile geometry by fabricating unidirectional carbon fabrics with varied inter-tow distances. These preforms are produced using a tailored fiber placement approach, an embroidery-based technique that enables precise control over roving spacing [3]. In order to span a wide range of capillary numbers, model fluids with different viscosities and surface tensions are used for the flow experiments. Saturated and transient permeability measurements are first performed for each sample, with at least three repetitions per sample to ensure reproducibility[4], [5].

A microscopic analysis is carried out in parallel to document the fiber arrangement and local porosity; a cross-section of a high V_f composite made from such fabric, impregnated with epoxy, is shown in Fig. 1, where the carbon rovings, resin-rich zones, and stitching yarns are clearly visible, and form a repetitive pattern. In parallel, flow-pattern visualization is conducted using in-situ X-ray–based imaging techniques developed in our previous work, employing a closed mold made of COC (cyclic olefin copolymer) sheets[6]. This configuration enables us to capture the progression of the fluid front at different imposed flow rates within these custom-designed preforms. Results on the flow front patterns, as a function of inter-tow distances, will then be presented, and their influence on the transition from capillary to hydrodynamic driven effects.

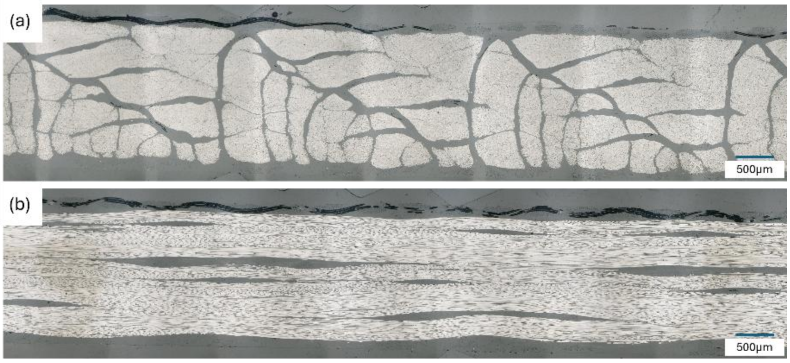

Fig. 1. Cross-sections of the UD carbon specimen: (a) cut perpendicular and (b) parallel to the UD direction

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