Additional solid phases in textile preforms for Liquid Composite Molding: influence on permeability and capillary effects

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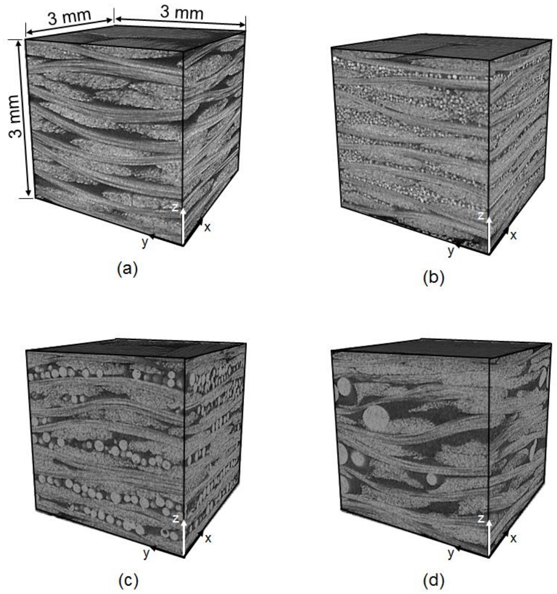
During composite processing by Liquid Composite Molding (LCM), a fluid precursor of the matrix phase (an uncured thermoset resin, a thermoplastic polymer or a pre-polymer) is made to infiltrate the open pore space within a reinforcement preform. Understanding the flow kinetics governing the part production cycle time, and the final part quality in terms of void content and reinforcement homogeneity has been a main area of research in the past 20 years, enabling these processes to reach many industrial applications, in particular for medium volume applications. As most reinforcements are based on textile fabrics, the pore size distribution in the textile tend to show a binary profile, with small intra-tow spaces and larger inter-tow areas; the geometry of the textile fabric was thus shown to be a crucial parameter, characterized by its permeability tensor, and by its influence on the flow front morphology, driven by the interplay between capillary and hydrodynamic effects [1, 2].

In some cases, in addition to the reinforcing fibers, another solid phase, that could have the form of granular particles, or of polymer fibers may be introduced. Reactive or non-reactive binders or tackifiers are often introduced at the preforming stage to ease the handling of multiple layers of reinforcement and improve the efficiency of processing. In addition, for composite functionalization, self-healing capsules may be sieved between the layers of reinforcement, hollow microspheres are introduced to improve the buoyancy or to produce lightweight parts. Regarding the introduction of fibers, various forms of polymer (or inorganic) stitches are used to modify the preform channel sizes, to improve translaminar composite properties or to ease handling operations; non-woven nanofibers are also sometimes introduced to alter the composite toughness, and network of fugitive fibers have been proposed to ensure flow of fluids for repair or thermal management. In cases where fast flow kinetics are required, or when highly viscous matrices are used, distribution media or flow channels are also introduced.



(a) (b) (c) (d)

Figure 1: 3D images (304 × 304 × 304 voxels) showing the structure of (a) a plain fabric sample (*i.e.*, with no beads), and samples with embedded beads with diameters of (b) 40-70 µm, (c) 100-200 µm, and (d) 400-800 µm. Sample thickness, in *z* direction is the same in all samples in (a) – (d); and volume fraction of beads is 10% in all samples in (b) – (d).

The effect of the presence of a second solid phase on the resulting mechanical or other functional properties of FRPCs has been extensively investigated and reported in the literature. Their effect on flow kinetics and final part quality is less often reported, and is in many cases considered as a specific issue to solve with no systematic approach.

Recently, we investigated in our laboratory the role of model spherical inclusions under the form of glass beads, of various diameters and volume fraction, introduced onto woven glass reinforcement [3]. Figure 1 shows examples of the microstructure of a plain fabric stack, compared to those of glass beads filled fabrics, as measured by X-Ray tomography. By combining microstructural analysis, flow modeling as well as experimental measurement of saturated and unsaturated permeability, we could highlight the relation between the inclusion size and volume fraction and the intrinsic features of the fabric. We showed that the in-plane permeability was a function of two competing mechanisms, one corresponding to the filling of pore space in the case of lower sized particles and the other corresponding to new pore formation and/or pore opening due to fabric distortion (mostly in the case of large beads). We will show that a simple analysis of the plain fabric mesostructure is sufficient to construct first estimates of the influence of a given volume fraction and size of inclusions on permeability.

We also observed a different type of flow front behavior, leading to variations in the magnitude of the ratio of relative to saturated permeability, attributed to a change in the capillary forces acting at the flow front. It should thus also be possible to alter the capillary forces by inserting second phases that have enhanced or reduced wetting through altering the binary profile of pore size distribution and through adequate surface treatment.

In parallel, work focused on the improvement of flow kinetics for infiltration with rather high viscosity fluids, around 15 to 30 Pa.s. To this end, several fabric producers have focused on the development of high permeability textiles, which contain stitched tows creating large channels. In plane permeability in the order of 10^{-9}m^2, for fiber volume fraction in the order of 45%, can be reached. However, in these fabrics with a large dual-scale morphology, the usual flow front behavior, for which capillary forces lead flow in the tows in the case of low Capillary number (Ca, ratio of fluid velocity over the product of fluid viscosity and surface tension), and hydrodynamic forces lead flow in the case of high capillary numbers, is not found anymore. Instead, flow channels dominate, and fingering of the flow front is observed even at low Ca. In turn, progressive filling of the tows must be ensured by bleeding or by inserting a dam reducing the flow speed at the exit of the mold.

The presentation will thus highlight these recent results and discuss the role of second phases on flow kinetics and final part quality.

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V. Michaud Short Bio

Véronique Michaud is currently Associate Professor and head of the Laboratory for Processing of Advanced Composites, and director of the Materials Science and Engineering Section of the Ecole Polytechnique Fédérale de Lausanne, in Switzerland. She graduated in 1987 from Ecole des Mines in Paris with an engineering degree, in 1991 from MIT with a PhD in Materials Engineering, and obtained a Research Habilitation from INPG in France in 1994. After a post-doctoral research stay at MIT, she spent 3 years at Ecole Centrale in Paris for teaching and research in the Laboratory for Materials, Structures and Soils Mechanics, before joining EPFL in 1997. Her fields of research are fundamentals of composite materials processing, as well as smart materials and structures including self-healing, shape and vibration control and tailored damping.