FIBRE SURFACE MODIFICATION FOR FLOW ENHANCEMENT IN LIQUID COMPOSITE MOLDING

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Introduction

In Liquid Composite Moulding (LCM) processes, a stack of dry fabrics is placed in a mould and impregnated with a resin. To achieve the full potential of these processes, the part should be manufactured with short cycle times and minimal void content to ensure cost-effectiveness without compromising quality.

Void formation in LCM processes is linked to the dual scale porosity of textile fabrics (small intra-tow spaces and large inter-tow spaces) and to the flow kinetics [1–3]. During resin injection into the mould, viscous forces (due to the applied pressure) tend to dominate the flow in the inter-tow spaces whereas flow in the narrow inter-tow spaces is driven by capillary forces, if the resin wets the fibers. For an ideal range of fluid velocity (which differs for each liquid-solid system), these two forces equilibrate, resulting in minimal micro-voids (within the fibre tows) and macro-voids (between the fibre tows) [2–5].

By increasing the injection pressure, P_{inj}, higher fluid velocities enable for faster processing thus shorter cycle times. However, the dominance of viscous forces results in formation of micro-voids within the inter-tow regions and ultimately reduces the mechanical properties. In this study, we investigate the potential of fibre surface modification for improving the influence of capillary forces, which in turn can be used for reaching higher infiltration velocities without compromising part quality.

Materials and Methods

We used a 2x2 twill weave E-glass fabric (Suter Kunststoffe AG) with a superficial density, ρ_{sup}, of 390 g/m^2 per layer and a bulk fiber density, ρ_{bulk}, of 2.60 g/cm^3. Fabric dipping tests and one-dimensional permeability tests were performed on pristine fabrics and on air plasma treated fabrics (applied manually using a corona pen (BD-20AC, Electro-Technic Products Inc.)). In all the tests, fluid flow was induced in the warp direction and at least three tests were performed.

Fabric dipping tests were performed on a single layer of fabric cut to dimensions of 150 mm x 40 mm. Non-compressed fabric layers were used with no additional weight since the fabric was well aligned with the liquid surface without any additional weight. A video was recorded during each test and was subsequently analysed to determine the increase in fluid height. The results were further analysed to calculate the capillary pressure as $P_{cap} = h^2(t)\phi\mu/2Kt$ where h, t, ϕ, and K denote fluid height, time, porosity, and permeability. Tests were performed using distilled water with a small fraction of a water-based food dye for contrast enhancement.

One-dimensional permeability measurements were performed using different number of layers (ranging from 7 to 11 layers) placed in a 3 mm cavity height to characterize the unsaturated permeability (K_{unsat}) and saturated permeability (K_{sat}) as well as their ratio ($R_s = K_{unsat}/K_{sat}$) using the mould and the methodology summarized in our previous work [6,7]. Test fluid was an aqueous solution of polyethylene glycol (PEG, Sigma Aldrich, 35 kDa) at different concentrations to reach viscosity, μ, varying between 2.73 and 69.91 mPa.s at 20°C.

Results

Figure 1 shows the square of the fluid height with respect to time, in a fabric dipping test. The resulting capillary pressure was 1.39 kPa and 12.31 kPa for pristine and air plasma treated fabrics, respectively. It should be noted that this method does not take into account the gravity, thus P_{cap} values might differ with a different approach. Yet, the ratio of the capillary pressures of pristine fabrics and air plasma treated fabrics indicate that fluid rise is significantly faster in air plasma treated fabrics due to improved surface wettability by incorporation of oxygen functional groups.

Figure 2a shows the results of permeability measurements. As expected, K_{sat} values are very close to each other for all types of fluids and injection pressures, P_{inj}, with a slightly larger scatter at low volume fractions. Figure 2b reports R_s for the same sets of experiments. R_s (correspondingly K_{unsat}) increases with increasing v_f in all sets of measurements, indicating that the influence of the capillary effects increases when the flow rate is lower. Still, for most cases, R_s is lower than one; hydrodynamic forces tend to dominate in this flow regime. For plasma treated fabrics, in particular at low P_{inj} and low μ, R_s is larger as expected from the fabric dipping tests, and increases above unity.

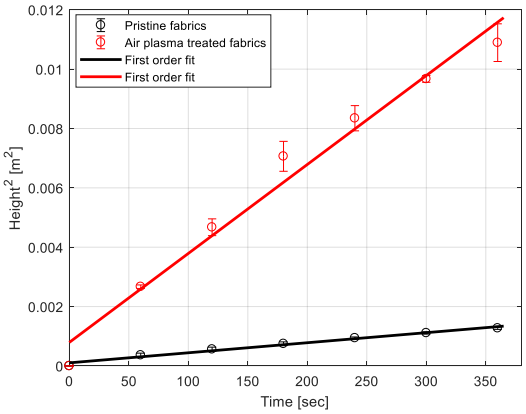

Figure 1. *Results of fabric dipping tests*

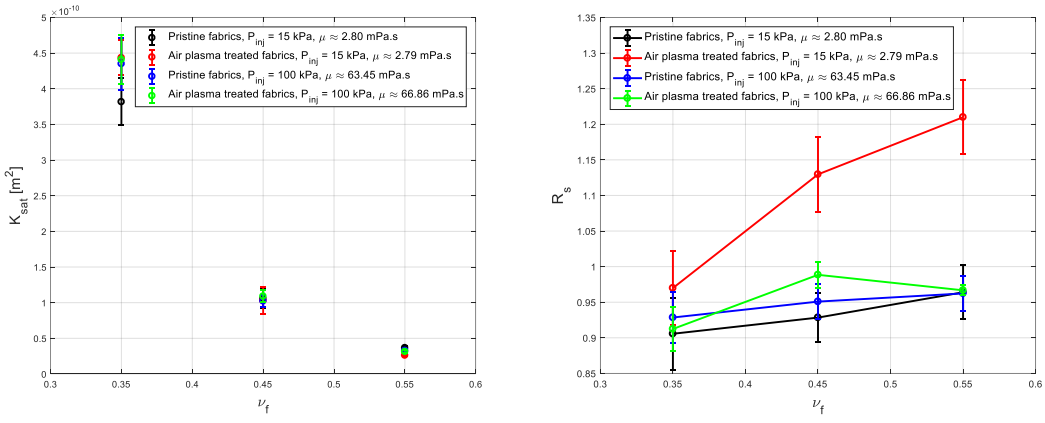

Figure 2. *(a) Saturated permeability, K_{sat}, (b) Permeability ratio, R_s, in permeability measurements with different test fluids and pressure differentials.*

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