CAPILLARY PRESSURE CHARACTERIZATION AND MODELING FOR FLOW PROCESSING OF COMPOSITES

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Introduction

The most important factor of LCM is controlling the resin flow throughout the fiber reinforcement during infusion, as incomplete filling of fibers is a major quality issue as it results in dry spots or voids. Void formation occurs at the resin flow front due to competition between viscous forces and capillary pressure. The purpose of this work is to characterize capillary pressure in vacuum infusion, so as to better be able to account for its effects in flow simulation and void modeling.

Two types of fabric reinforcements were evaluated: a fiberglass unbalanced weave (JB Martin TG-15-N (518 g/m2) with PPG rovings) and a carbon +45/-45 biaxial non-crimped fabric (NCF) (VectorPly C-BX 1800 (580 g/m2)). Dip tests were performed by lowering a perpendicularly oriented reinforcement sample towards a bath of canola oil until just barely touching the fluid, and then the length versus time data is recorded for the capillary-driven flow-front. Results from dip tests using non-compressed samples were presented previously including the test methodology and subsequent image analysis [1]. A better model accounting for the effects of gravity, provided by Amico [2], was applied in this study to that uncompressed test data as well as new compressed sample data. In this model, the change in height (h) with time (t) is fit to a linear function of the inverse of h, and the fitted slope (M) and intercept (B) are then used to evaluate the capillary pressure (P_{cap}) in regards to the permeability, porosity, and viscosity. A simplification of the Amico model was made in this study, by solving for the permeability in the equations for both M and B, combining them, and then solving for P_{cap}:

$$\frac{dh}{dt} = M\frac{1}{h} + B\,, \qquad P_{cap} = \frac{-M\rho g}{B} \tag{1}$$

Note that this allows evaluation of P_{cap} in simple terms of M, B, the fluid density (ρ) and gravity (g) and is independent of the other usual Darcy Law terms. Capillary pressure is then proportional to the ratio M/B. Example fits of dh/dt vs $1/h$ for the uncompressed carbon tests are shown in Figure 1, where more linearity is seen in the three warp direction tests than the three weft tests.

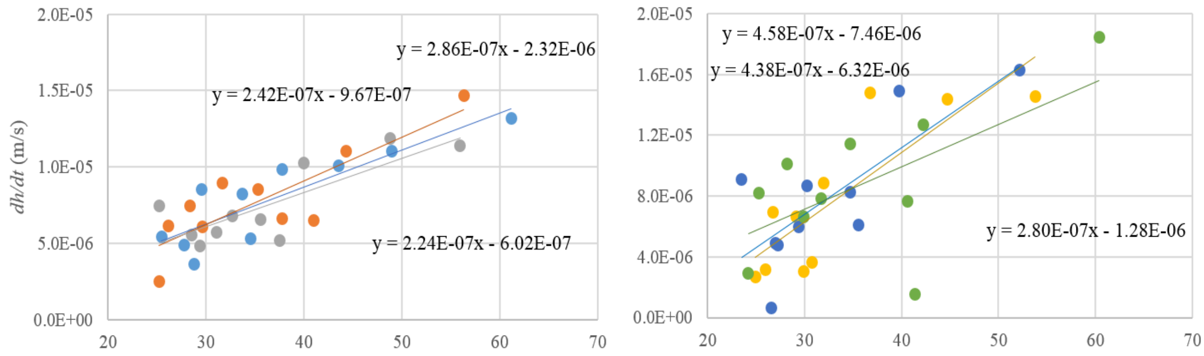

Figure 1: *Example linear fits of Equation 1, for uncompressed carbon warp (left) and weft (right) flow directions.*

Results

Each compressed test sample consisted of four plies of fabric, held between 13 mm thick acrylic sheets clamped together at the corners to thicknesses determined by metal strips. Sealing putty was applied along the edges of the samples. Three samples were tests at each v_F, flow orientation, and fabric type. Example fits of Equation 1 are shown in Figure 1 for both fiberglass-weft.

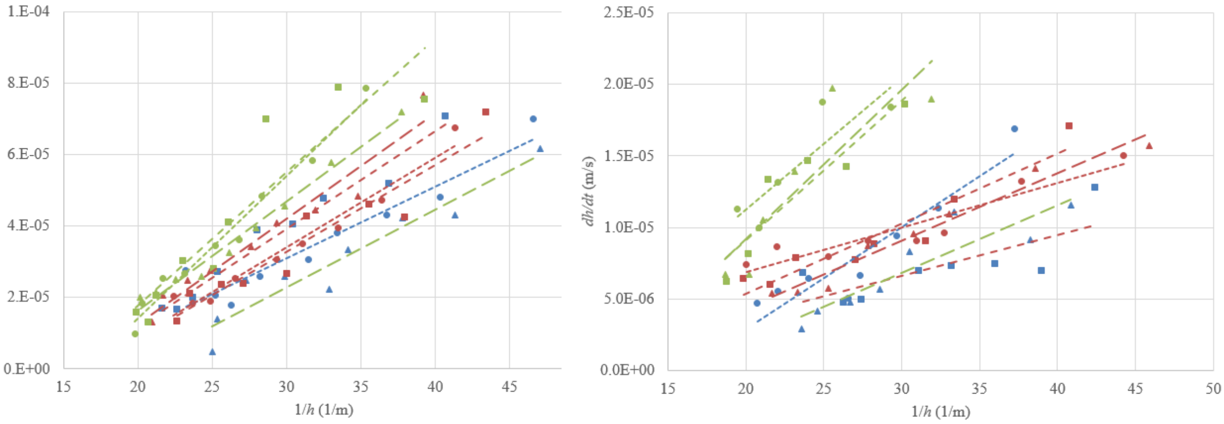

Figure 2: *Example linear fits of Equation 1, for compressed glass weft (left) and carbon warp (right); blue = 41/50% fiber (glass/carbon), red = 45/55%, green = 51/60%*

The average of the calculated values of P_{cap} (Equation 1) are presented in Figure 3 along with the standard deviation across the results from the three samples for each configuration. The left-most columns represent the uncompressed samples. In all tests P_{cap} for the carbon samples was roughly twice that of the fiberglass samples. This is assumed to be due to the increased fiber packing associated with the carbon fabric, and this ratio is approximated by Ahn's model [3]. The high P_{cap} in the uncompressed samples is thought to be due to the lower degree of sample control in that test, where the fiber content may change along the flow direction, and fluid may flow off the edges of the sample.

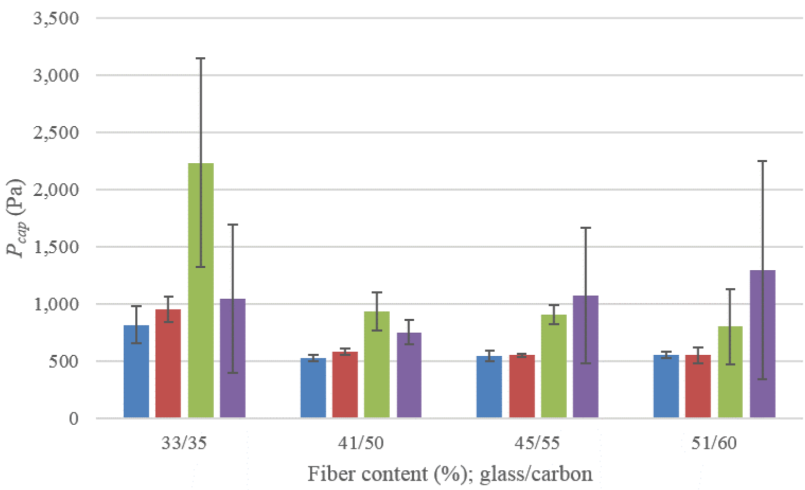

Figure 3: *Average P_{cap} with increasing fiber content. From left to right for each fiber content: glass warp, glass weft, carbon warp, carbon weft.*

The measured values seen in Figure 3 are small compared to the usual maximum pressure gradient applied during infusion, but may become significant in flow modelling under certain slow flow conditions in composite processing, such as far from the inlet or through-thickness flow. Methods to apply this capillary force to flow simulation will be presented at the conference.

References

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