Highly reactive flows in LCM processes

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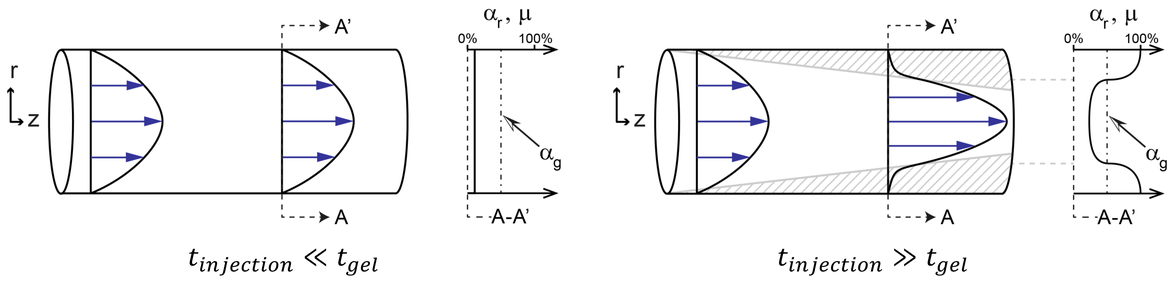
Motivation

In Liquid Composite Molding processes (LCM) a reactive resin system is injected into a dry textile, cured, and demolded.

As the curing can take a large amount of the processing time, initiating the reaction of the resin during the impregnation can drastically reduce the cycle time. Understanding of reactive flows is necessary to exploit the full potential of cycle time reduction.

Approach and Modeling

Due to the parabolic velocity distribution within the flow channels of a textile, a mixture of old and new resin creates an inhomogeneous distribution of degree of cure in the cross-section of the flow.



Resin gelation will start in the low velocity areas adjacent to the contact surfaces, while the faster layers mainly introduce new resin. The progression of the curing reaction will continuously decrease the channel's cross-section, therefore its available flow space, until the inlet mass flow is completely stopped. This continuous decrease in the cross-section depends on the curing reaction and the injection velocity, and can be modeled as a variation in the permeability of the textile during the reactive flow.

State of the art

The flow in textiles can be described by Darcy's Law, which states a relationship of flux, pressure gradient, viscosity and permeability:

$$\mathbf{v} = -\frac{\mathbf{K}}{\mu}\nabla\mathbf{p}$$

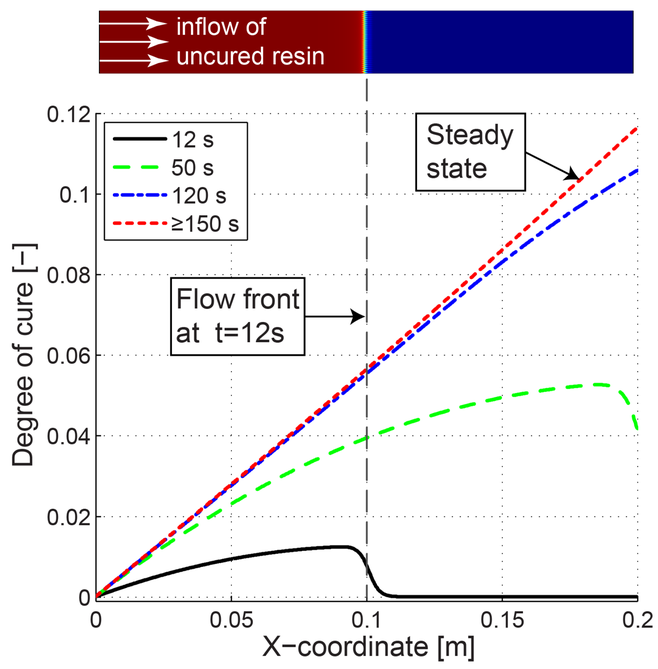
For LCM processes, the permeability is assumed to be solely dependent on fiber architecture and fiber volume content.

While a thermoset resin is flowing through the dry textile, its hardening is characterized by a cure kinetics equation, which defines a degree of cure between 0 (uncured) and 1 (fully cured).

Current methods average the cure kinetics at a part-scale, assuming a uniform distribution of degree of cure within the cross-section orthogonal to the flow direction.

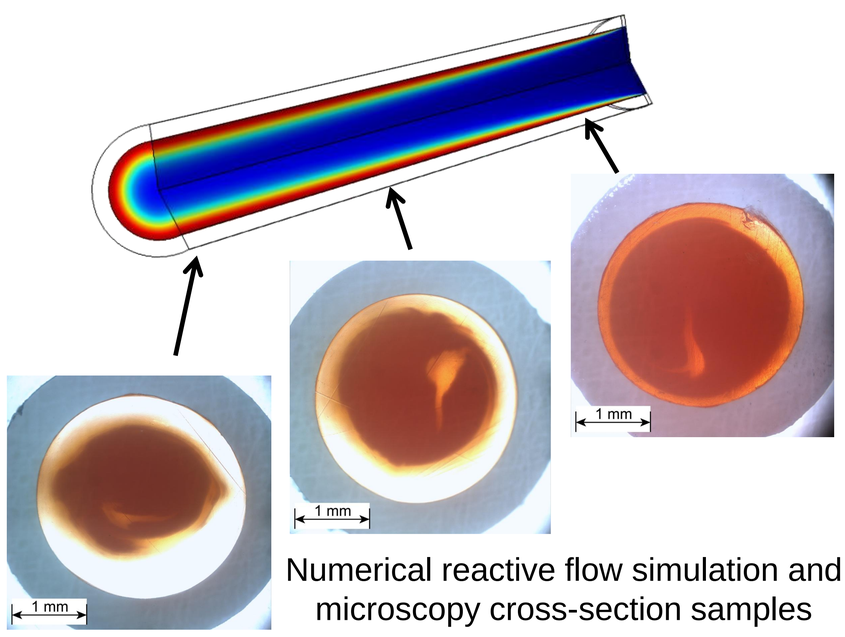
By this method, if the impregnation time is shorter than the gelation time, the resin flows indefinitely.

The velocity is so fast that the resin never has time to reach gelation: due to the stagnant layers, this is evidently not realistic.



Results: numerical and experimental

Numerical and experimental investigations are carried out for a saturated tube with flowing resin.



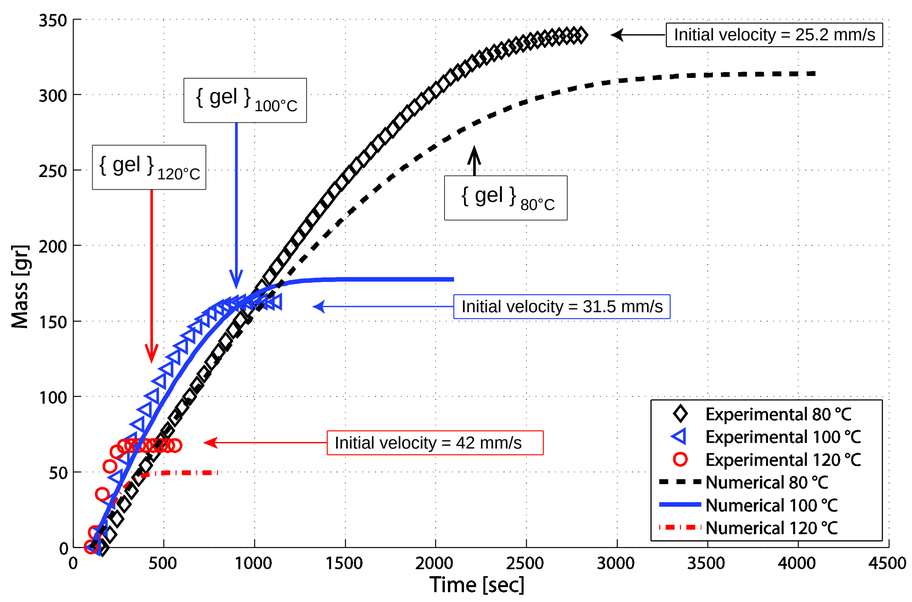
Numerical reactive flow simulation and microscopy cross-section samples

Velocity and reactivity are analyzed in the experiments.

For mass flow comparisons, the output mass is recorded with a balance.

For sampling and visualization of old and new resin, a transparent resin is infused, and followed by a red resin.

The results show that flow could be continued beyond the gelation time of the initially injected resin. The total mass transferred depends on the reactivity of the resin and the inlet velocity.



Comparison between experimental and numerical results at different temperature. Experimental settings: Length: 7.5m, Vacuum: 25 kPa, Resin: LY564+XB3486, saturated tube.

Conclusions

In reactive flows, slow laminar layers will become solid layers after their gelation point, creating a wall build-up.

This constriction bears a direct effect on the permeability, proving the need for a model that considers the reactivity of the resin and the flow velocity. Moreover, the degree of cure should be redefined to account for stagnant layers and for lower degree of cure at the flow front due to newer resin coming from the central streamlines.

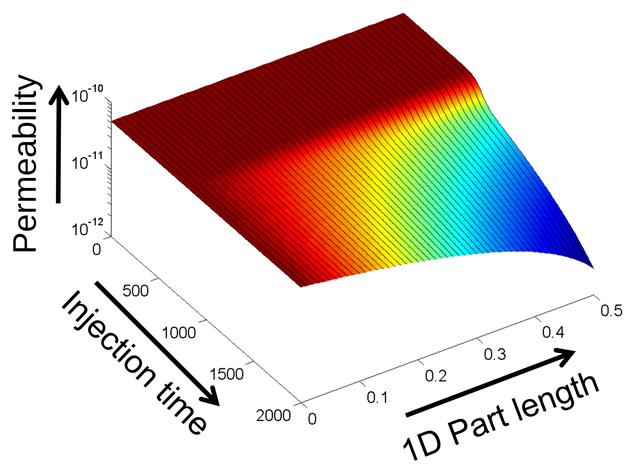
$$\frac{d\alpha}{dt} + \mathbf{u}\cdot\nabla\alpha = f_{reaction}(\alpha, T) + f_{sink}(\alpha, \phi)$$

Therefore, effective permeability and porosity are a function of velocity, temperature, porous medium architecture and resin reactivity.

$$\frac{dK}{dt} = f_1(v, T, geometry, \alpha)$$

$$\frac{d\phi}{dt} = f_2(v, T, geometry, \alpha)$$

The effect is evident and should be addressed in the future for the simulations of reactive flows. The final result is a processing map that provides this effective permeability with regard to reactivity, time and component coordinates.



Effective permeability in reactive flow for a given temperature

Publication

J. Maldonado, B. Louis, F. Klunker, and P. Ermanni, "Reactive flow of thermosetting resins - Implications to LCM Processing," presented at the FPCM 12, Auckland, New Zealand, 2012.