EXPERIMENTAL ANALYSIS OF FLOW BEHAVIOR IN THE FLAX FIBER REINFORCEMENT WITH DOUBLE SCALE POROSITY

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Keywords: *Flax fiber, Resin transfer molding, Fiber swell, Liquid sorption, Permeability.*

Introduction

Recently, natural fibers are attracting great interest from automotive industry by virtue of their environmental friendliness as well as high specific stiffness. Liquid composite molding (LCM) processes have a high potential as a manufacturing process of natural fiber reinforced composite structures by dint of high fiber volume fraction to enhance mechanical performances and low processing temperature to minimize fiber degradation. Due to the inherent variation of the material properties during the manufacturing process, however, it is a difficult task to analyze the resin impregnation process in the natural fiber reinforcement. In this work, we investigate the influence of liquid sorption and fiber swell on the resin impregnation into the flax fiber reinforcement during the resin transfer molding.

Resin flow model and experimental measurement

It has been well reported in the literature that the permeability measurement value of a same natural reinforcement can be different for different test liquids [1]. The liquid sorption into the natural fiber and the corresponding increase of fiber diameter has been suggested as a main reason for the inconsistency of permeability measurement [2, 3].

To characterize the fiber swell, a single filament of flax fiber was immersed in a test liquid and the change of fiber diameter with time was observed by an optical microscope. The mass of the test liquid absorbed into the flax fiber was obtained by comparing the mass of the fiber that had been immersed into the test liquid for a certain period and the mass of the dried fiber by removing the liquid with a centrifuge. For both the tests of fiber swell and of liquid sorption, two different test liquids were used, namely, distilled water and engine oil.

The permeability of the flax fabric was measured with the same test liquids as used in the fiber swell and liquid sorption tests. As reported in the literature, the permeability values of the same flax fabric obtained with the two different liquids exhibited a significant difference (see Figure 1). The change of flax fiber diameter and the corresponding porosity of flax fabric in the two test liquids was assumed as the main reason for this discrepancy. We suggest a permeability model to consider the fiber swelling effect.

$$K = \frac{1}{A}\frac{\left(1 - f_{sw}^2 V_f\right)^{n+1}}{\left(f_{sw}^2 V_f\right)^n} \tag{1}$$

where K is the permeability, V_f is the fiber volume fraction, f_{sw} is the fiber swelling ratio which the ratio of the wet fiber diameter to the dry fiber diameter, and A and n are the model constants to be decided by experimentally. We can see in Figure 1 that the permeability data obtained using two different test liquids can be represented by the same model equation (1).

Moreover, the fiber swell and the liquid sorption can influence the resin flow by changing the mass conservation condition as well as the permeability. The resin flow advancement may be delayed if the resin is absorbed into the fiber behind the flow front. On the other hand, the fiber swell may have a favorable effect on the flow front advancement. Hence, these two controversial effects should be taken into account in the mass conservation equation as the mass source and sink terms.

$$\nabla \cdot \vec{u} = \nabla \cdot \left(-\frac{K}{\mu} \nabla P \right) = S_{swell} - S_{sorption} \tag{2}$$

where S_{swell} and $S_{sorption}$ are the rates of volumetric change due to the fiber swell and the liquid sorption into the fiber, respectively.

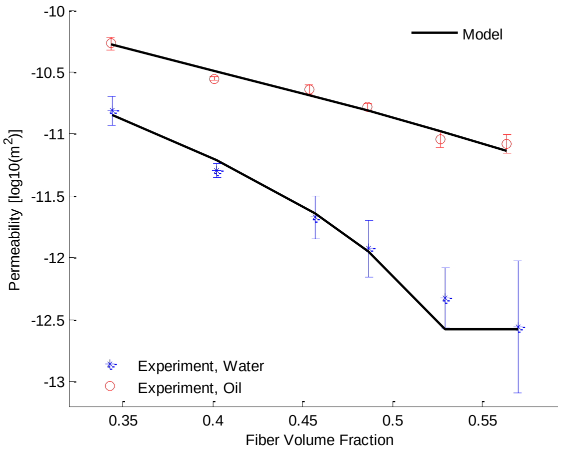

Figure 1: *Permeability of flax fabric.*

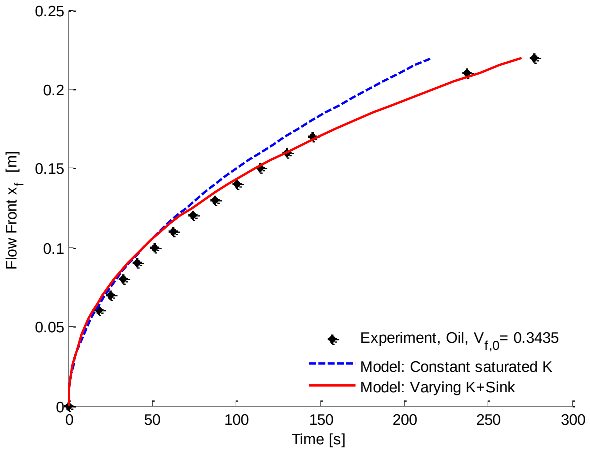

Figure 2: *Flow front advancement in a rectilinear flow*

In Figure 2, the model prediction results are compared with the experimental measurement data of the flow front advancement in a rectilinear flow under a constant inlet pressure. For the model predictions, two different modeling approaches were adopted. In the first case, constant permeability value obtained in Figure 1, was used. And, no sink or source term was considered in the mass conservation equation. In the second modeling approach, the permeability value was varied with time and position in the preform according to the time immersed in the test liquid. The source and sink terms in equation (2) were considered in the mass conservation equation. We can see in Figure 2, the model prediction with varying permeability and mass source/sink shows a better agreement with the experimental measurement than the constant permeability model without mass source/sink. As the fiber volume increases, the influence from the mass sink becomes greater.

Conclusions

Natural fibers used in LCM processes have time dependent varying properties such as liquid sorption and fiber swell when immersed in the liquid. Consequently, the conventional models for the resin flow in the natural fiber reinforcement should be modified considering these time dependent phenomena. The permeability model and the governing equation for the resin flow in the RTM process with natural fiber reinforcement have been proposed and validated by the comparison with the experimental measurement.

References

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