A FAST SOLUTION FOR LIQUID RESIN INFUSION PROCESS AND SIMULTANEOUS IDENTIFICATION OF DISTRIBUTION MEDIUM AND PREFORM PERMEABILITIES

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1 Introduction

LRI (Liquid Resin Infusion) process is being widely applied as a fabrication method of large composite structures in the aeronautic and aerospace industries. In LRI process, a high permeability medium is placed on top of the fiber preform in order to drive fast resin infiltration in the fabric preform as in the VARTM (Vacuum Assisted Resin Transfer Molding) process or the SCRIMP (Seeman Composite Resin Infusion Molding Process). While the use of a flexible film mounted on the of preform assemblies in those other processes may leads to a non-uniform variation of fiber volume fraction of final product, LRI process adopts the rigid tooling on both sides of the preform to ensure a uniform fiber volume fraction in the final product. For this reason, it is called DM-RTM (Distribution Medium Resin Transfer Molding) process.

During the mold filling process in LRI, a preferential flow is developed in the planar direction of distribution medium due to the big difference in the permeability between distribution medium and fiber preform. Then, flows in distribution medium and in preform arrives at equilibrium where the flow in distribution medium leads the flow in preform by a constant lag. Thus, the transverse flow from distribution medium to preform drives the fast infiltration of resin (Fig. 1).

Several analytical solutions have been suggested on the mold filling in VARTM process [1, 2]. However, they are restricted on the flow equilibrium stage between distribution medium and preform. Nowadays, the time to reach the equilibrium goes so long as the higher fiber volume fraction fabric (e.g. over 60%) with the very low transverse permeability (lower than 10^{-14}m2) is being used. On the other hand, the numerical simulation calls the adoption of even finer mesh in the thickness direction due to the small thickness of distribution medium. Consequently, the increase of mesh size in three dimensional analysis results in the high computational cost.

We present a mold filling modeling in LRI process which is faster than the numerical simulation and more flexible than the analytical solutions. This model has several advantages:

- It requires much shorter computing time than numerical simulation (e.g. CV/FEM). Thus, it is efficiently used for the optimization purpose (e.g. distribution medium design, permeability

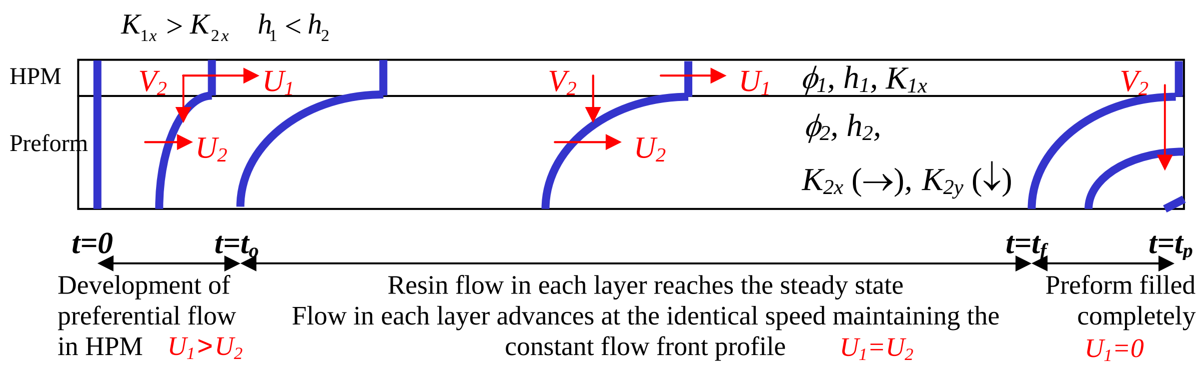

Fig. 1 Mold filling in LRI process

identification).

- Different injection conditions can de treated: injection pressure or inlet flow rate, constant or variable.
- The volume of lost resin can be estimated.

One of the main issues is the identification of transverse permeability which is usually much more difficult to be measured than the planar permeabilities. We employ this model to simultaneously identify the permeabilities of distribution medium and preform by a mold filling experiment.

2 Mold Filling Modeling

The mold filling process in LRI can be divided into 3 steps (Fig. 1). Until the flow reaches the end of distribution medium ($t=t_f$), it is assumed that the pressure distribution is linear at each layer.

From Darcy's law, we can relate the resin pressure with flow rate. Considering mass conservation of each layer, we can describe the next governing equations (Fig. 2).

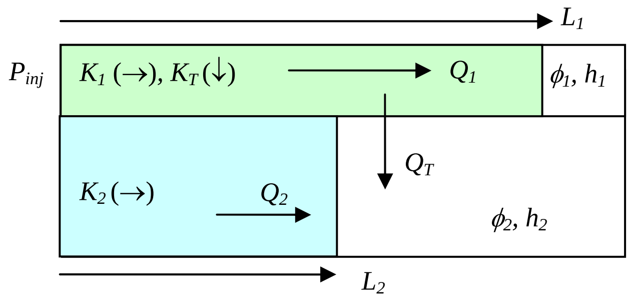

Fig. 2 Flow kinetics in LRI

$$\begin{cases} \dfrac{K_1}{\mu}\dfrac{P_{inj}}{L_1}h_1 - \dfrac{K_T}{\mu}\dfrac{P_{inj}}{h_1}\dfrac{(L_1-L_2)^2}{2L_1} = \phi_1 h_1 \dfrac{dL_1}{dt} \\ \dfrac{K_2}{\mu}\dfrac{P_{inj}}{L_2}h_2 + \dfrac{K_T}{\mu}\dfrac{P_{inj}}{h_1}\dfrac{(L_1-L_2)^2}{2L_1} = \phi_2 h_2 \dfrac{dL_2}{dt} \end{cases} \qquad (1)$$

If a line vent is placed on the right side of the preform or the distribution medium is longer than the preform, the third stage ($t_f<t<t_p$) is not considered. If we employ a flow rate imposed injection, we can calculate a new injection pressure to meet the flow rate condition at each time step. The volume of lost resin can be obtained calculating Q_1 in Fig. 2 with Darcy's law.

The model is validated by a comparison with the numerical simulation, CV/FEM (Control Volume/Finite Element Method) [3]. Even though it is not a closed form solution, the proposed model shows a much better numerical efficiency than numerical simulation. The model is also validated through the experimental measurement. The preform with high fiber volume fraction and low transverse permeability is filled under the constant flow rate condition.

3 Calculations of Permeabilities

The permeability tensor $\kappa=[K_1, K_2, K_T]$ can be determined by minimizing the deviation between the time computed by the model and the time recorded by experimental measurement. We try to minimize the following residual expression

$$S(\kappa) = \frac{1}{2}\sum_{i=1}^{N}\left[\frac{t_i(\kappa)-\bar{t}_i}{\bar{t}_i}\right]^2 \qquad (2)$$

where $t_i(\kappa)$ and $\bar{t}_i$ are the calculated and the measured times, respectively. To solve above minimization problem, we adopt Levenberg-Marquardt method. The gradient of above function is evaluated by a following expression

$$\frac{\partial S(\kappa)}{\partial \kappa_j} = \sum_{i=1}^{N}\left[\frac{t_i(\kappa)-\bar{t}_i}{\bar{t}_i}\frac{\partial t_i}{\partial \kappa_j}\right] \qquad (3)$$

4 Conclusions

We introduce a fast solution for LRI process modeling. While it adopts simple assumptions, it produces a marginal error. And it can be efficiently used for permeability estimation problem.

References

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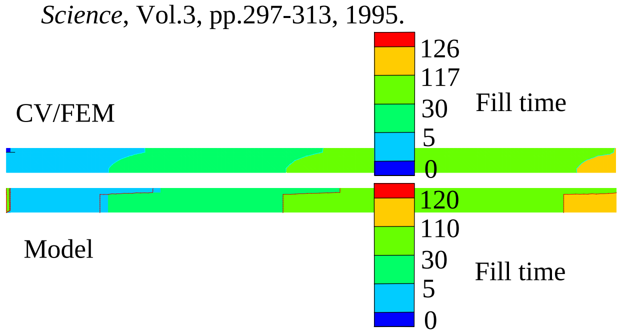

Fig. 3 Comparison of mold filling in LRI (ϕ_1=0.99, ϕ_2=0.5, $K_T=1.47\times10^{-11}m^2$, $K_2=8.8\times10^{-10}m^2$, $K_1=10K_2$, h_1=2mm, $h_2=5h_1$, μ=0.1Pa·s, L=0.3m)