다층 프리폼에서의 방사형 유동진행

신국승 · 송영석 · 윤재륜*

Radial Flow Advance in Multi-layered Preforms

K.S. Shin, Y.S. Song and J.R. Youn.

Abstract

In resin transfer molding, the preform similar to product shape is placed into a mold cavity. Rapid flow front without void formation is important for the composites processing. Multi-layered preform of sandwich is selected. Experiments is carried out using redial flow. An analytical modeling is performed and compared with experimental results. Accurate prediction of flow advance in the preform is of use for reducing the time consumption in the process and enhancing product properties of the final part.

Key Words: resin transfer molding, permeability, multi-layered preform

기호설명

Q :Volume flow rate(m^3/s)
K :One-directional permeability
R :Flow front
ε : Porosity of preform

1. Introduction

Resin Transfer Molding is one of polymer composites processings. This is an effective and versatile way of producing complicated composite parts. In the RTM, a prefabricated preform composed of a lot of layers is placed into mold cavity. Total permeability of the multi-layered preform is usually governed by a high in-plane permeable layer.

In this study, a sandwich preform of three layers is adopted for experiment and analytical modeling. Adams et al. studied the multi-layered preform for the first time. Through a new suggested analytic procedure, advancement of flow front and effective permeability are predicted according to time. More realistic height based on compaction test is employed for the analytic solution.

2. Theory

2.1 Permeability measurement

To calculate out-of-plane permeability, one-dimensional form of Darcy's law and series model are used as the following forms.

$$Q = \frac{KA}{\mu} \Delta P \qquad (1)$$

$$Q_t = Q_p = Q_w \qquad (2)$$

* School of Materials Science and Engineering Seoul National University, Seoul, Korea

For measuring radial flow permeability, an equation for quasi-isotropic permeability was expressed as follows

$$K = \left\{ r_f^{\,2}\left[2\ln(r_f/r_0)-1\right]+r_0^{\,2}\right\}\frac{1}{t}\frac{\mu\varepsilon}{4\Delta P} \quad (3)$$

where ε is the porosity, μ is the dynamic viscosity of the fluid, t is the time elapsed from the start of the injection to reaching at a specific point in the cavity.

2.2 Analytic solution

2.2.1 Flow front difference

Multi-layered preform stacked in the mold is composed of three layers. Upper and lower layers are same preforms. Schematic diagram of the preform was shown in Fig.1. Bruschke et al. proposed an analytical solution in the case of two layers but didn't measure out-of-plane permeability. It was found that mass balance was exaggerated to calculate permeability because heterogeneous multi-layer preform has non-linear flow front. In this study, radial flow front difference considered the results of transverse permeability obtained by experiment is calculated from Darcy's law. Pressure profile is derived from Darcy's law and continuity equation.

$$Q_1 = 2\pi R_1 h_1 \cdot u_{r1} = 2\pi R_1 h_1\left(\frac{K_{r1}}{\mu}\frac{\partial P}{\partial r}\Big|_{R_1}\right) \quad (4)$$

$$Q_2 = 2\pi R_2 h_2 \cdot u_{r2} = 2\pi R_2 h_2\left(\frac{K_{r2}}{\mu}\frac{\partial P}{\partial r}\Big|_{R_2}\right) \quad (5)$$

$$\frac{\partial P}{\partial r} = \frac{P_i}{r\ln\left(\frac{r_0}{R}\right)} \quad (6)$$

$$R_1 = \frac{t}{\varepsilon_1}\left(\frac{Q_1+Q_t}{h_1}\right) \quad (7)$$

$$R_2 = \frac{t}{\varepsilon_2}\left(\frac{Q_2-2Q_t}{h_2}\right) \quad (8)$$

Flow front difference is calculated by equations (7) and (8). The equations are solved by using Matlab 6.5.

2.2.2 Effective permeability

Calado et al. derived the effective average permeability in the unidirectional multi-layered preform. In this study, the equation to find the overall effective permeability is derived in the radial flow direction. First, the equation of total volumetric flow rate is cast by using Darcy's law as follows.

$$Q_t = \frac{2\pi H P_i K}{\mu \ln\left(\frac{r_o}{R}\right)} \quad (9)$$

Total volumetric flow rate in the three layers is also known from mass valance of each layer.

$$Q_t = Q_1 + Q_2 + Q_3 = 2Q_1 + Q_2 \quad (10)$$

Eqation (9) is equal to Equation (10). As a result, the effective permeability is represented as follows.

$$K_{eff} = \frac{\ln\left(\frac{r_o}{R}\right)}{H}\left(\frac{2h_1K_{r1}}{\ln\left(\frac{r_0}{R_1}\right)} + \frac{h_2K_{r2}}{\ln\left(\frac{r_0}{R_1}\right)}\right) \quad (11)$$

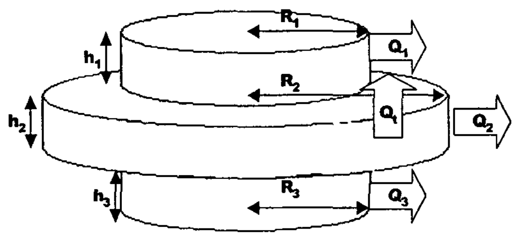

Fig.1 Schematic diagram of radial flow advance in multi-layered preform

3. Experiments

3.1 Materials

A number of fiber mats were used in this study. Some were plain woven fabrics such as glass fiber woven fabric aramid fiber woven fabric and hybrid fiber woven fabric. The other was glass random mat.

3.2 Permeability measurement

3.2.1 Out-of-plane Permeability

The experiment was performed using a one-directional channel flow under constant pressure. A circular fiber preform with 6cm diameter was placed into between two permeable walls of which function was to contain resin flow uniformly. Concentric cylinders were used for controling thickness of the preform. A pressure was measured at the inlet and outlet. The transverse flow was achieved by injecting the fluid through a central 5mm diameter gate. The fluid was silicone oil(DC 200F) which viscosity was about 0.97 poise(9.7×10^{-2} Pa·s).

3.2.2 Radial flow Permeability

Radial flow was carried out by injecting fluid into a 450 x 450 mm size of preform between two parallel plates through a central 5mm gate. The fluid was the same as that of out-of-plane measurement. PMMA flexible glass with 20 mm thickness was drawn circle lines for monitoring the exact flow front recorded with camcorder. Pressure was measured at the inlet.

3.2.3 Multi-layered Preforms

The preform was constituted in three layers. Upper and lower layers were the same kinds of preforms. A middle layer had the highest permeability preform of three layers. So, this seemed like sandwich structure. The reason is that the total permeability was improved when the high permeability preform was set in the middle of three layers. Top and bottom layers were aramid fiber plain woven fabric and the middle layer was glass fiber plain woven fabric. In order to fit height of each layer similarly, aramid woven fabrics of 2 layers and glass woven fabric of 1 layer were employed.

3.2.4 Compaction test

During permeability measurement, the preform was compressed due to the pressure imposed on upside plate. In order to find volume fraction for the individual layers of multi-layered preform, compaction test needs to be performed. The compaction test was achieved by measuring the compressed thickness of each preform. Test machine was MTS(Material Test System). The preforms were located between flat plates attached at the bottom of the crosshead and at the top of the load cell.

4.Results

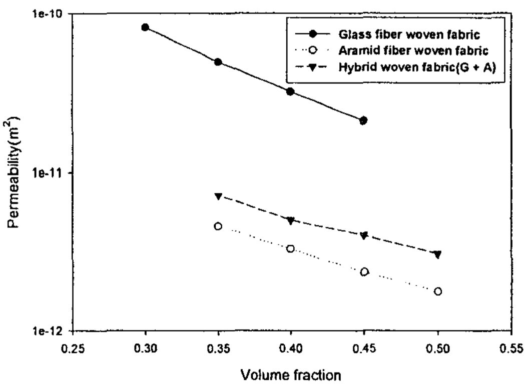

Fig 2. out-of-plane Permeability of 20 layers preform

experimental value.

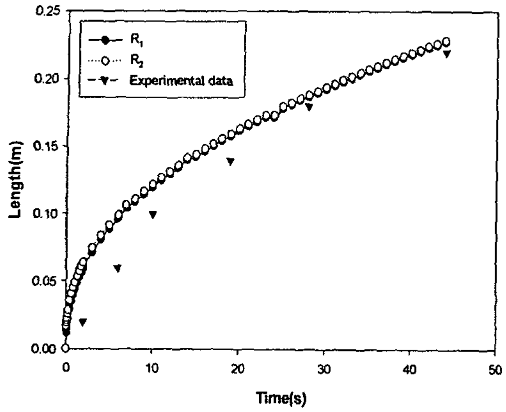

Fig3. Comparison between advancements of the radial flow front and experimental results according to time

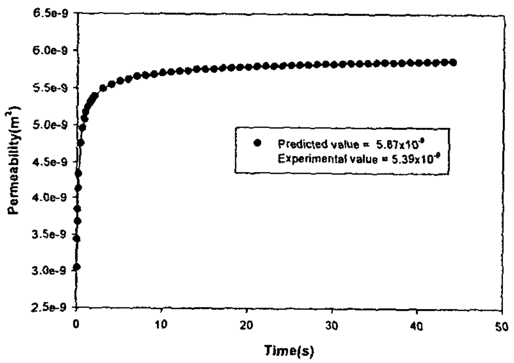

Fig4. Predicted effective permeability

5. Discussion

Out-of-plane permeability is a function of the fiber volume fraction. The reason is that the higher fiber volume fraction is, the more compressed the preform is. In Fig 3, the difference of the predicted flow front and the experimental results arises from filling of injected resin within intratow region near the gate. In Fig 4, after the preform is saturated, the flow front reaches the steady-state. As a results, the predicted permeability has a good agreement with the experimental value.

6. Conclusions

A new analytic model for flow advance is suggested. There is a agreement of the flow front between experimental results and analytical predictions based on Darcy's law. The effective permeability equation is able to forecast the total permeability in the two dimensional flow.

Acknowledgement

This study was partially supported by the Korea Science and Engineering Foundation through the Applied Rheology Center(ARC) and by the Ministry of Science and Technology through the National Research Laboratory. The authors are grateful for the support.

References

(1) Veronica M.A.Caalado, Suresh G.Advani, "Effective average permeability of multi-layer preforms in resin trasfer molding", Comp.Scie.and Tech, 56, pp.519-531(1996)

(2) M.V.Brusche, T.L.Luce, S.G.Advani, Proc.7th Tech.Conf. on Comp. Mat, pp 103-112(1992)

(3) K.L.Adams, L.Rebenfeld, Poly. Comp, 12, pp 179-190(1991)

(4) M.L.Diallo, R.Gauvin, F.Trochu, Poly. Comp.19 pp 246-256(1998)

(5) D.G.Seong, K.Chung, T.J.Kang, J.R.Youn, Poly. and Poly. Comp. 10 pp 493-509(2002)

(6) Y.D.Parseval, K.M.Pillai, S.G.Advani, Trans.in Por.Med, 27, pp 243-264(1997)

(7) Y.Luo, I.Verpoest, Poly.Comp, 20, pp 179-191(1999)

(8) J.Dai, D.Pellaton, H.T.Hahn, Poly.Comp, 24, pp 672-685(2003)

(9) J.R.Weitzenböck, R.A.Shenoi, P.A.Wilson, Comp.Part A, 30, pp 781-796(1999)