고분자 수지 이송 성형에서 브레이드 프리폼의 투과율 계수 측정

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Permeability Measurement of the Braided Preform in Resin Transfer Molding

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Key Words : permeability measurement, braided preform, Resin transfer molding(RTM)

ABSTRACT

Resin Transfer Molding(RTM) is increasignly used for producing fiber reinforced polymer composites, the resin has to flow a long distance to impregnate the dry fibers. The measure for the resistance of the fiber proform to the resin flow is the permeability of the fiber preform. Permeability is a key issue in the design of molds and processes and in flow modeling. In this study, permeability measurement for braided preform is presented and compared with the permeability calculated numerically. Experimental techniques being used to measure the permeability are also discussed. Measurement is conducted in radial flow test under constant pressure.

1. INTRODUCTION

In modern production processes, The advantages of the resin transfer molding(RTM) are a good surface finish on both sides of the part, low volatile emission, the possibility to mold highly complex shapes, relatively low tooling costs and excellent dimensional tolerances. In RTM, a fiber preform is placed in the mold cavity. The mold is then closed, and resin is injected into the cavity to impregnate the preform. After the mold is filled with the resin, the inlets are closed. Finally, the resin cures to form the final composite part.

Accurate permeability data are essential for the flow simulation programs, which can predict the resin flow in an RTM mold and aid mold design. In this paper, because braided perform is anisotropy, the shape of flow front is ellipse. permeability values for braided preform are obtained through the saturated and unsaturated radial flow experiments. And principal permeability is obtained by following equation, is compared with simulation results. In both cases, the measurement of the permeability can be performed with constant injection pressure

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2. THEORETICAL BACKGROUND

The generally accepted equation to describe the radial flow through a porous medium is obtained by combining the continuity equations and Darcy's law

$$\frac{\partial^2 p}{\partial x^2} + \alpha \frac{\partial^2 p}{\partial y^2} = 0 \qquad (1)$$

where p is pressure, $\alpha = k_2 / k_1$, the ratio of the two principal in-plane permeabilities k_1 and k_2 (m^2)

2.1 Unsaturated permeability measurement

It is possible to obtain an analytical solution in this case. This can be achieved by transforming the physical domain into a quasi-isotropic system by applying the following transformation :

$$x' = x\alpha^{1/4} \quad y' = y\alpha^{-1/4} \qquad (2)$$

The quasi-isotropic permeability is defined as

$$K' = \sqrt{k_1 k_2} \qquad (3)$$

while the radius in the quasi-isotropic system is

$$\bar{r} = \sqrt{x'^2 + y'^2} \qquad (4)$$

In the past literature, an expression for quasi-isotropic permeability can be obtained by following Eq. (1)

$$K' = \left\{\bar{r}_f^2\left[2\ln(\bar{r}_f/\bar{r}_0) - 1\right] + \bar{r}_0^2\right\}\frac{1}{t}\frac{\mu\varepsilon}{4\Delta P} \qquad (5)$$

where ε is the porosity, μ is the dynamic viscosity of the fluid, t is the time from the start of the injection to when a specified point in the cavity is reached and $\bar{r}$ is related to the x and y coordinates by

$$\bar{r} = \sqrt{\left(\frac{k_2}{k_1}\right)^{1/2} x^2 + \left(\frac{k_1}{k_2}\right)^{1/2} y^2} \qquad (6)$$

The expression for K' has become quite complex. However there are two preferred orientations where Eq. (5) simplifies significantly.

$$k_1 = \left\{x_f^2\left[2\ln(x_f/x_0) - 1\right] x_0^2\right\}\frac{1}{t}\frac{\mu\varepsilon}{4\Delta P} \qquad (7)$$

A closed form solution for k_2 is obtained in a simillar manner

$$k_2 = \left\{y_f^2\left[2\ln(y_f/y_0) - 1\right] y_0^2\right\}\frac{1}{t}\frac{\mu\varepsilon}{4\Delta P} \qquad (8)$$

where x_f and y_f are the coordinates of the flow front radius and x_0 and y_0 are the coordinates of the inlet radius

2.2 Saturated permeability measurement

Eq. (1) can be transformed to

$$\frac{\partial^2 p'}{\partial x'^2} + \alpha\frac{\partial^2 p'}{\partial y'^2} = 0 \qquad (9)$$

by introducing, $x' = x\alpha^{1/4}$ $y' = y\alpha^{-1/4}$ and $p' = (p - p_r)/(p_0 - p_r)$ where p_0 is the inlet pressure and p_r is the pressure at some reference point.

The relationship between the elliptical coordinates (ξ, η) and the rectangular coordinates (x', y') can be written as

$$x' = L\cosh\xi\cos\eta \qquad (10)$$

and

$$y' = L\sinh\xi\sin\eta \qquad (11)$$

where $L = r_0(\alpha^{-1/2} - \alpha^{1/2})^{1/2}$, one half the focal length of the inlet ellipse.

Knowing the liquid-flow rate and the pressures at four locations, p_0, p_1, p_2 and p_3 as shown in Fig.1, one can determine by the following analysis the permeabilities in the two principal directions, k_1, k_2, and the angle, β, between the principal direction of the fiber preform and the global coordinates.

$$\ln\left[\sqrt{\left(\frac{x_1}{x_0}\frac{1}{\sqrt{1-\alpha}}\right)^2 - 1} + \frac{x_1}{x_0}\frac{1}{\sqrt{1-\alpha}}\right] - \ln\left[\frac{1+\alpha^{1/2}}{(1-\alpha)^{1/2}}\right] - \frac{2\pi h(p_0 - p_1)}{q\mu}\bar{k} = 0 \qquad (12)$$

$$\ln\left[\sqrt{\left(\frac{y_1}{y_0}\frac{\sqrt{\alpha}}{\sqrt{1-\alpha}}\right)^2 + 1} + \frac{y_1}{y_0}\frac{\sqrt{\alpha}}{\sqrt{1-\alpha}}\right] - \ln\left[\frac{1+\alpha^{1/2}}{(1-\alpha)^{1/2}}\right] - \frac{2\pi h(p_0 - p_2)}{q\mu}\bar{k} = 0 \qquad (13)$$

where $\alpha = k_2/k_1$ and $\bar{k} = \sqrt{k_1 k_2}$. Solving this set of two nonlinear equations for α and $\bar{k}$ yields the in-plane permeabilities k_1 and k_2.

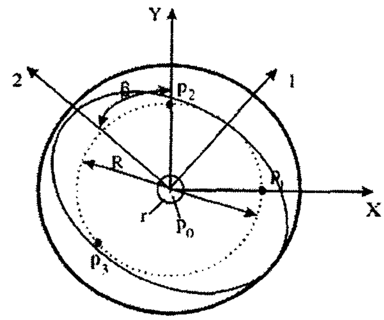

Fig. 1. Pressure transducer locations

3. EXPERIMENTS

3.1 Preparation of braided preform

Multi-axial braided performs were produced using a 3-D circular braiding machine, fitted with 48 carriers and with provision for 12 axial tows. In this study, braided preform is made by 48×12(Fig.2). The carrier of braiding machine was moved by piston using compressed air mode. Braided performs were produced using E-glass roving.

3.1 Permeability measurements

Permeability measurements were carried out using a saturated and unsaturated test of radial flow under constant pressure. Flat braided reinforcements were cut from cylindrical mandrels(80mm diameter) and placed into RTM, which consisted of a closed steel plate mold(500×500mm) with a controllable thickness of cavity. Radial in-plane flow is achieved by injecting the fluid through a central 5mm diameter gate into a 420×420mm region between two parallel plates containing the reinforcement(Fig.3). Silicone oil(DC 200F) was used as injecting fluid and viscosity is 100cs($9,7\times10^{-2}$Pa·s). A 20mm-thick upper flexiglass which is drawn circle for comparison with ellipse shape permits recording the progress of the flow front with digital camcorder. And pressures at four locations in the flow field are measured and used for determining the permeabilities.

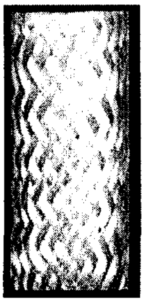

Fig. 2. Braided preform

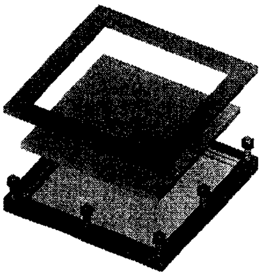

Fig.3. Mold set up

ACKNOWLEDGEMENTS

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.

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