수지이송성형에서 다층예비성형체로의 수지유동에 대한 연구

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A Study on Resin Flow through a Multi-layered Preform in Resin Transfer Molding

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1. Introduction

In resin transfer molding, mold filling is governed by the flow of resin through a preform which is considered as an anisotropic porous media. The resin flow is usually described by Darcy's law and the permeability tensor must be obtained for filling analysis. When the preform is composed of more than two layers with different in-plane permeability, effective averaged permeability should be determined for the flow analysis in the mold. The most frequently used averaging scheme is the weighted averaging scheme, but it does not account for the transverse flow between adjacent layers. A new averaging scheme is suggested predicting the effective permeability of the multi-layered preform, which accounts for the transverse flow effect. The new scheme is verified by measuring the effective permeability of the multi-layered preforms which consist of glass fiber random mats, carbon fiber woven fabrics, aramid fiber woven fabrics. Fluid flow through the preform composed of more than two layers with different in-plane permeability shows different flow fronts between layers. The difference in the flow front advancement is observed with a digital camcorder. The predicted flow front is compared with the experimental results.

2. Theory

Darcy's law is used in calculating permeability. In order to evaluate the averaged permeability of multi-layered preform, the weighted average scheme and the effective average scheme proposed in this paper are used. The new scheme accounts for the effects of the difference of flow fronts and transverse flow between adjacent layers. When the flow in the mold is unsaturated, the effective averaged permeability is predicted by using pre-predicted mold filling time and transverse permeability.

3. Experiments

2.13×10^{-11} (glass/aramid), $1.69\times10^{-11}m^2$ (aramid/ carbon). These values are lower than the in-plane permeabilities by about two orders. Especially, when the difference of in-plane permeabilities between two layers is large, the transverse flow plays a more important role in determining an effective permeability. Therefore, the weighted average scheme ignoring the transverse flow effect produces a large error when the difference of in-plane permeabilities between two layers is large.

Using this effective average scheme, the advancement of flow front in glass/carbon preform is represented in Fig. 4. The calculated flow front length of carbon layer in glass/carbon preform was compared with the experimental results within 16.55 ~ 23.45 cm from the gate as shown in Fig. 5. And images processed by ***Image Pro 4.1*** is also shown in Fig. 6. As shown in these results, the flow pattern observed in the experiment was less stable than the predicted flow pattern.

5. Conclusions

Permeabilities of three kinds of single layered preform are measured in the saturated flow. And permeabilities of three kinds of multi-layered preform are also measured in the same way.

A new effective averaged permeability considering transverse flow between two different layers is proposed and compared with the weighted averaged permeability and the experimentally measured result. The effective averaged permeability is much closer to the experimentally measured permeability than the weighted averaged permeability that does not consider the transverse flow.

The progress of flow front in multi-layered preform is investigated theoretically and visualized by a digital camcorder. A commercial image analysis software is used for determining the exact position of flow front. The calculated length of flow front represents a reasonable flow pattern. However, the experimental flow front pattern shows a little unstable tendency with respect to the calculated result. It is expected that the effective averaged permeability can be used for modeling the resin flow through the multi-layered preform in resin transfer molding.

6. Acknowledgement

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7. References

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2. Veronica M. A. Calado and Suresh G. Advani, "Effective Average Permeability of Multi-Layer Preforms in Resin Transfer Molding", *Composites Science and Technology*, **Vol. 56**, 519-531 (1996).

3.1. Single layered preform

The in-plane permeabilities of three kinds of fiber preforms, glass fiber random mats, carbon fiber woven fabrics, and aramid fiber woven fabrics, were measured. Volume fraction of each preform was specified experimentally. Each experiment was performed under the constant inlet pressure. Pressure applied by compressed nitrogen was in the range from 0.25 MPa to 0.26Mpa. Pressure gradient was calculated from two values of two different pressure transducers. Volumetric flow rate was calculated from measuring both volume of fluid and time. From these data, the in-plane permeability of single layered fiber preform could be calculated by Darcy' law. And the progression of flow front was also observed by using a digital camcorder.

3.2. Multi-layered preform

3.2.1. Effective permeability of multi-layered preform

Multi-layered preforms were made by combining the two preforms out of three kinds of the fiber performs. They were glass (4 plies) / carbon (7 plies), glass (4 plies) / aramid (4 plies), aramid (4 plies) / carbon (7 plies). Experiments were performed at constant inlet pressure. Applied pressure in each experiment by compressed nitrogen was in the range from 0.19 MPa to 0.28 MPa.

3.2.2. Difference of flow front positions

Because the permeability of each layer in multi-layered preform was different, the flow front position of each layer was different. The difference of flow front position was observed through the side of the mold by a digital camcorder. The variation of flow front difference respect to time was observed.

4. Results and Discussion

4.1. Single layered preform

Volume of fluid was measured with the exact elapsed time. Two pressure values were measured at two pressure transducers located in the mold. Permeabilities of each fiber preform are calculated through Darcy's law.

Mold filling patterns of a glass preform was shown in Fig. 1. Edge effects were observed, which are caused by the poor fitting of the preform in the cavity. Vents might be necessary at proper locations in the mold to prevent the formation of dry spots.

4.2. Multi-layered preform

The effective permeabilities of multi-layered preforms are measured. And the weighted averaged permeability and effective averaged permeability are compared with this measured permeability in Fig. 2 and Fig. 3. It is shown that the effective averaged permeability is closer to experimental result than the weighted averaged permeability. This is due to the fact that the effective averaged permeability considers transverse flow between two adjacent layers. The calculated time averaged transverse permeabilities are 1.26×10^{-11} (glass/carbon),

3. Jeffery Mogovero, Suresh G. Advani, "Experimental Investigation of Flow Through Multi-Layered Preforms", *Polymer Composites,* **Vol. 18**, 649-655 (1997).

4. K. L. Adams and L. Rebenfeld, "Permeability Characteristics of Multilayer Fiber Reinforcements: Ⅱ. Theoretical Model", *Polymer Composites*, **Vol. 12**, 186-190 (1991).

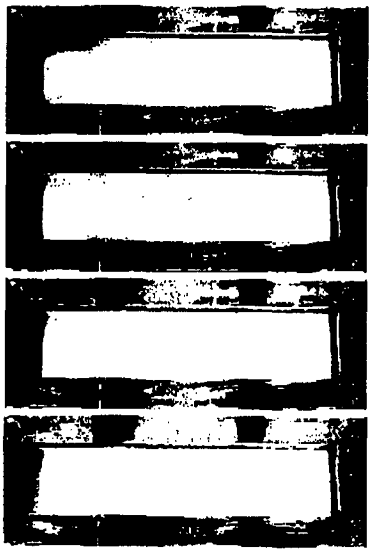

Fig.1. Advancement of the resin flow front in glass preform.

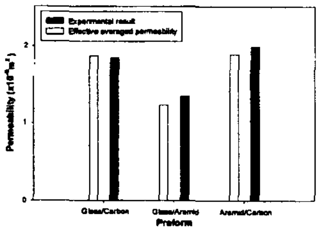

Fig. 2. Predicted values of the effective averaged permeability in comparison with the experimental result.

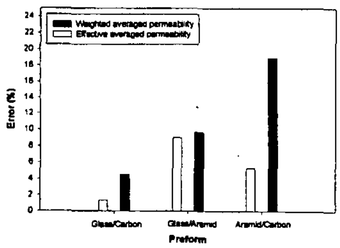

Fig. 3. Errors of the two averaged permeabilities in comparison with from the experimental results.

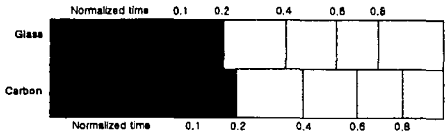

Fig. 4. Advancement of the flow front in glass/carbon preform.

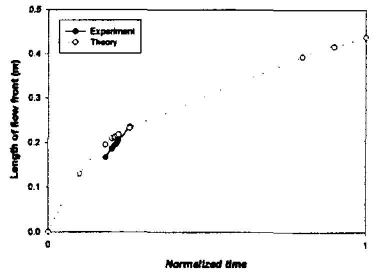

Fig. 5. Comparison of the calculated flow front length with the experimental result in glass/carbon preform.

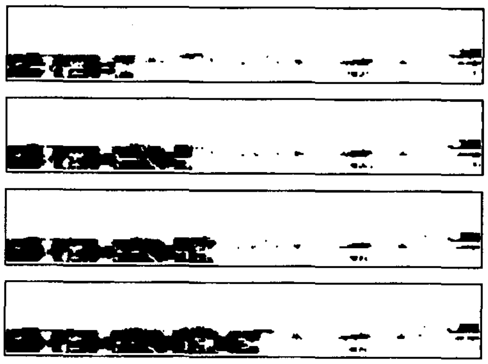

Fig. 6. Advancement of the resin flow front in glass/carbon preform (images processed by Image Pro 4.1).