IN-PLANE AND TRANSVERSE-PLANE MEASUREMENTS TO DETERMINE COMBINATIVE PERMEABILITY OF LAMINATES IN VARTM PROCESS

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Introduction

VARTM (Vacuum Assisted Resin Transfer Molding) is a good technique to manufacture large laminate structure, such as wind turbine blades or yachts [1]. However for the reason of diversity models and various kinds of raw materials including matrix, fiber or core, how to apply this method correctly becomes an important issue between manufacturers and research organizations. Most important factor which affects manufacturing process is permeability of laminates.

Therefore, this research was to establish the measurements to detect fiber's permeability of in-plane and transverse-plane and then utilize the mold flow analysis software RTM-Worx to obtain the combinative permeability with various fiber components on the database of experiments.

Theory and experimental configurations

To simulate the resin flowing pattern, in-plane permeability is the most important parameter which should be provided to analysis tool. Therefore the main idea of this research is to integrate the in-plane and transverse-plane permeability measurements and then use the software RTM-Worx to simulate its thickness-direction flowing profile. Consequently, the combinative materials' in-plane permeability can be transferred from the simulative profile.

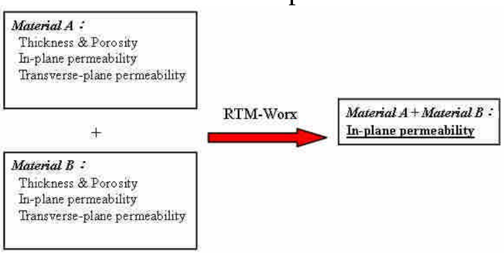

Fig.1 The idea of the combinative permeability

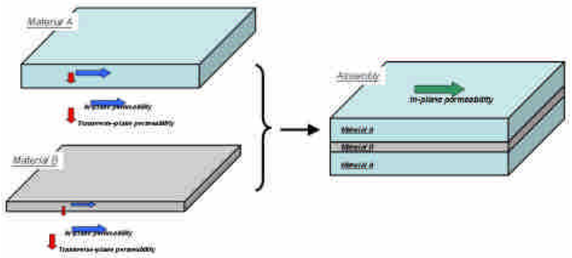

Fig. 2 The scheme of the combinative permeability

I. *In-Plane permeability experiment*

The resin flow during the VARTM process can be described by Darcy's Law [2]. Otherwise consider the fluid's viscosity, the difference of seepage and Darcian velocity and with proper experimental arrangement, the governing equation can be transferred and expressed as follows.

$$Q=-\frac{K}{\mu}\frac{dP}{dx}A \rightarrow V=\frac{K}{\mu}\frac{\Delta P}{\Delta L} \rightarrow \frac{K}{\phi}=\frac{\mu}{2\Delta P}\frac{L^2}{t} \qquad (1)$$

Where K is the in-plane permeability (m^2), ϕ is the assembly's porosity, μ is the viscosity of resin (cps), ΔP is the pressure gradient (Pa), L is the position of the flow front and t is the consuming time. Hence the in-plane permeability, K, can be detected by recording the relationship of L^2/t. The experimental equipments are indicated as Fig. 3.

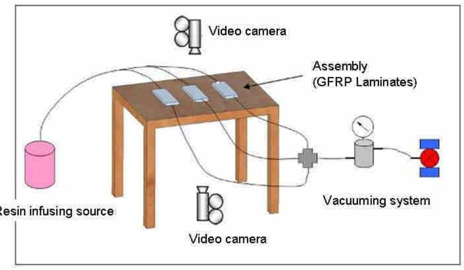

Fig. 3 In-plane permeability experimental scheme

II. *Transverse-Plane permeability experiment*

The fluid's permeability in the thickness direction (transverse-plane) also could be transferred from the Dacy's Law by obsering the velocity which fluid passes through the assembly (in its thickness direction) and its pressure gradient. Furthermore, the goving equation of this experiment can be derived after intergrating the equation through the assembly's thickness.

$$u_z=\frac{Q}{A}=-\frac{K_z}{\mu}\frac{dp}{dz} \rightarrow K_z=\frac{Q\mu t}{AP_{in}} \qquad (2)$$

Where k_z is the transverse-plane permeability (m^2), Q is the flow rate across the assembly, t is assembly's thickness (m), A is the cross-section which fluid pass through (m^2) and P_{in} is the pressure gradient (Pa). These parameters could be detected from the instruments and sensors as shown in Fig. 4 and 5.

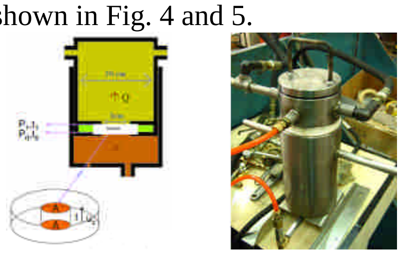

Fig.4 The clamping apparatus

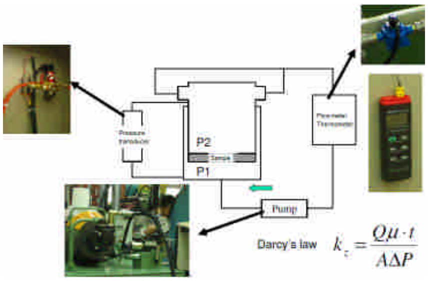

Fig.5 Transverse-plane permeability instruments

Results and Discussion

The assembly's materials used in this research are two types of glass fiber, Mat-300 and DBLT-1900. Their permeability in two directions was measured using the procedures mentioned before. Otherwise, permeability of the distribution media and peel ply which are utilized in the VARTM process was detected as well.

I. Results of In-Plane experiments

The experiments were completed with same kind of fiber weave but various layers, such as Mat-300×10, ×12, ×16 and DBLT-1900×2, ×4, ×6. For the reason of no distribution media existing, the results indicate the permeability value was extremely small and would almost be relative with sort of weave but few related to numbers of layers. Accordingly, these permeability values could be regarded as constant here. Otherwise, the different kind of fiber layer which distribution media contacts with was also considered.

Table 1 Results of in-plane permeability

Sort of assembly	Permeability K_x (m^2)
Mat-300	5.90×10^{-11}
DBLT-1900	5.25×10^{-11}
Distribution media / Mat	1.89×10^{-11}
Distribution media / DBLT	2.00×10^{-11}

II. Results of Transverse-Plane experiments

The experiments were done with Mat-300×12~16 and DBLT-1900×2~6, as Fig. 6 shows. For the same fiber weave, the permeability would vary with diverse porosity which was caused due to the specimens under different pressure conditions, but still little related to numbers of laminates.

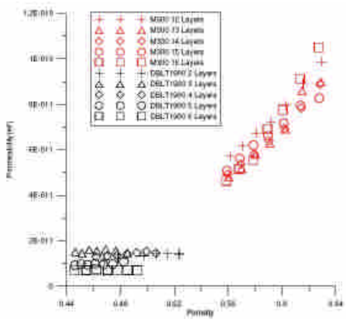

Fig. 6 Permeability under various porosities

Besides, VARTM process is proceed under atmospheric pressure and therefore the permeability can be considered as constant in this study.

Table 2 Results of transverse-plane permeability

Sort of assembly	Permeability K_z (m^2)
Mat-300	5.50×10^{-11}
DBLT-1900	1.16×10^{-11}
Distribution media	2.54×10^{-11}

Simulation and Application

I. Simulation of combinative materials

As Fig. 1 & 2 indicates that when individual materials' properties are prepared, the combinative laminate's permeability could be simulated by RTM-Worx and transfer to the assembly's in-plane permeability. Fig. 7 displays the model in the RTM-Worx and the simulation process in the thickness-direction.

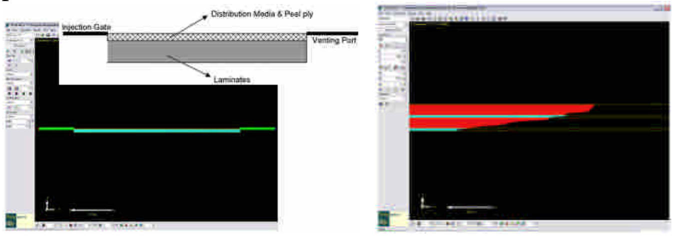

Fig.7 Model in RTM-Worx and flowing profile in the thickness-direction

The experiments were concluded with two combinations, MDM and M(DM)×3. Results contain about 15% error because of un-considering fiber compressive effect accurately.

II. Application to turbine blade's manufacturing

The way to define in-plane permeability established in this study was applied to manufacturing one-third length of wind turbine blade (13 meters). The blade contains large area with combinative fiber weaves, however it still got fine simulation pattern against the experiment.

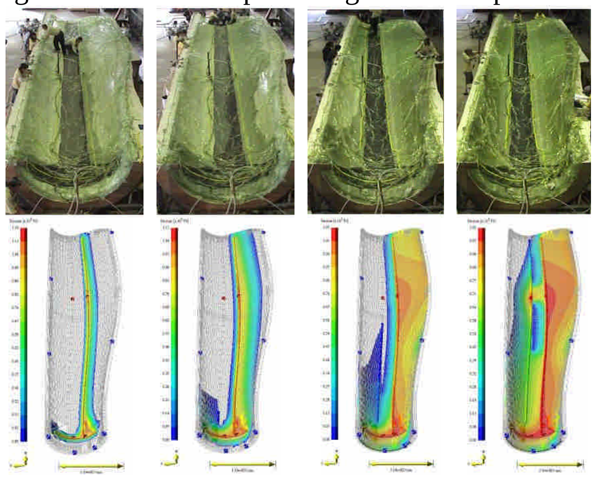

Fig.8 Application of manufacturing wind turbine blade

Conclusion

Through this study, two conclusions are drawn as:

1. Assembly's in-plane permeability could be derived by integrating two directions permeability experiments and still be proved by combinative laminates experiments.
2. In- and transverse-plane permeability of simplex one type glass fiber lamina could be regarded as constant in VARTM process.

References

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2. P. Simacek, S. G. Advani, "*Use of Resin Transfer Molding Simulation to Predict Flow, Saturation, and Compaction in the VARTM Process*", J. Fluids Eng., 126, 210, (2004).