EFFECT OF DISTRIBUTION MEDIUM ON RESIN FLOW BEHAVIOR IN VACUUM INFUSION MOLDING PROCESS

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Abstract: The permeability of the distribution medium (DM), the fiber preform and the assembly were measured to study their relations. And the effects of DM on resin flow behavior were studied through a series of visualization flow experiments. The results showed the average permeability of DM was 10~100 times as that of the glass fiber preforms. The DM when as a surface layer or a middle layer can greatly speed up the resin flow and reduce the mold filling time. Distance difference of the flow front position between the top and bottom increased linearly with the thickness of the fiber preform, so did the difference of filling time. The mold filling time changed linearly with the scale of the DM in VIMP.

Keywords: *vacuum infusion molding process, distribution medium, resin flow behavior, permeability*

1 Introduction

Vacuum infusion molding process (VIMP) is widely used to make large-scale polymer-matrix composites such as wind turbine blades, boats, bridge decks and so on. But under the vacuum condition, which injection pressure fewer than 0.10MPa, the molding filling is too slow to make large-scale composites. It is necessary to use resin distribution system. VIMP based on the distribution medium (DM) is one of most often used to manufacture large-scale composite products.

DM incorporates with the preform as a surface layer to speed up the in-plane flow. A peel ply laid between on the fiber preform and DM makes easy disposal. During the infusion, the resin prefers to flow across the preform surface and simultaneously through the thickness.

Permeability describes the ease of flow through porous materials. The higher permeability of the DM makes the flowing easier and reduces the infusion time. However, because of the significant differences between the DM and the fiber preform in permeability, the use of DM reduces the through-thickness flow in the reinforcement, then forming a three-dimensional flow front.

The fiber preform permeability, a role of the fiber perform microstructure, often shows large variations, which create local areas of high or low flow resistance. As a result, the resin flow often deviates from the desired pattern during infusion, thus creating areas where the resin does not permeate the fibers. These regions of unfilled preform are termed voids. Voids result in the manufacture of defective parts which is a primary concern in VIMP.

Several models have been proposed [1,2] to predict permeability based on the preform architecture and the fiber volume fraction. The Kozeny-Carman model has the simplest form. But this model only suits the simple architecture reinforcement and the related constants are always difficult to fix without many complicated experiments, so do the other predicting models.

The primary object of this research is to study the resin flow behavior during VIMP based on DM. Also, a series of one-dimensional flow experiments were employed to determine the DM permeability (K_d), the fiber preform permeability (K_f) and the apparent permeability of assembly (K_a) in this paper.

2 Experimental description

2.1 Materials

The resin used in this research was unsaturated polyester (Palatal1777-G-4), provided by DSM Composite Resins. And the curing agent was methyl ethyl ketone peroxide supplied by Guangdong Baling Chemical Co. Ltd. The DM (GreenFow 7541), peel ply (Econo Ply) and vacuum bag were obtained from Airtech Co. Ltd. Glass fiber fabric from Changzhou Hongfa Geogrid Fabric Co. Ltd were used.

2.2 Permeability testing

The One-dimensional flow experiments were employed to determine K_d, K_f and K_a in this paper. The schematic of experimental setup is show as Fig.1. Resin filling distance is 0.7m and the width is 0.24m. In these experiments, the flow front progress as a function of time was recorded to determine the permeability by using the one-dimensional flow Darcy's equation[3].

$$K = \frac{\mu \cdot \phi}{2 \cdot t_f \cdot \Delta P} x_f^2 \qquad (1)$$

where ϕ is the porosity of reinforcement, x_f is the flow front position, t_f is the corresponding time; ΔP is gradient pressure. In actual experiment the permeability can be deduced from a least-square fit of the experiment data according to Eq. (1).

In K_d measuring experiments, DM configurations are 5, 10 and 15 layers of DM, respectively. In K_f measuring experiments, fabric configurations are 10, 20 and 30 layers of glass-fiber fabric, respectively. K_a is the integral permeability of the fabric preform with one layer of DM on the surface. In K_a measuring experiments, one layer of DM is laid over the fabric preform, and fabric configurations are 10, 20 and 30 layers of glass-fiber fabric, respectively.

2.3 Flow experiments

The setup of flow experiments is same as that of the permeability testing. In the flow experiments, the flow front positions and the corresponding filling time were recorded to study the effects of the DM laid pattern, the preform thickness and the DM scale on resin flow behavior in VIMP.

3 Results and discussion

3.1 K_d, K_f, K_a and their relationship

The testing results of K_d are shown in Table 1. The averaged porosity of DM is 0.85, the averaged K_d is 1.31×10^{-8}m^2 under the same vacuum condition. Relative errors of experimental results are approximate to zero. Under the same vacuum condition, K_d and porosity of DM can be considered as constants.

The testing results of K_f and K_a are shown in Table 2 and Table 3. The magnitude of K_f is 10^{-11}, and that of K_a is 10^{-10}. The average permeability of DM is 10~100 times as that of the glass-fiber preform. Compared with the same fabric without one layer DM on the surface, K_a increased 10, 6 and 4 times, respectively. It shows the effect of DM on K_a decrease with the layers of fabric under the same vacuum condition.

Theoretical values of K_a in Table 3 are calculated by the rule of mixtures. The magnitude of theoretical values is 10^{-9}, but the magnitude of experimental values is 10^{-10}. It indicates that K_a is not the simple mixture of K_d and K_f, that is, their relationship does not obeyed on the rule of mixtures.

3.2 Resin flow behavior in VIMP based on DM

3.2.1 Molding filling with DM

For the VIMP based on DM, it is necessary to use a low-porous, low-permeable peel-ply to separate the composite part from DM and vacuum bag and leave a smooth finish. The ply was laid on between DM and fiber preform. The presence of peel-ply may affect molding filling in several ways. First, it increases the flow resistance in the thickness direction, which may prolong the mold filling time. On the other hand, the peel-ply decreases the nestling effect of the fiber preform on DM and therefore increases its permeability. The overall effect depends on these two competing factors [4]. The results of molding filling experiments show the existence of peel-ply can slightly speed the velocity of resin flow. This indicates the nestling effect is more significant than the addition of flow resistance in the thickness direction.

Resin flow through two distinct porous medium (fiber preform and DM) at the same time in VIMP based on DM. The flow in DM can be considered as a 2D in-plane flow with a leakage flow in the direction of thickness to the fiber preform. The fiber preform and peel-ply are treated as sinks that receive the resin leaking from DM. Resin flow mode for VIMP based on DM is show as Fig. 2. The existence of DM affects the mold filling process and the velocity of resin flow.

3.2.2 Effect of DM laid pattern

Experiments were carried out to investigate the effect of DM laid pattern on mold filling process. The results are shown in Table 4. The filling times are 75s, 82s and 2842s with the DM as a surface layer, a middle layer and without DM, respectively. The filling time of the preform without DM is almost 30 times as that of the preform with DM. It indicates the DM is essential for VIMP to reduce the mold filling time. And as a surface layer or a middle layer, the existence of DM can greatly accelerate resin flow and reduce the mold filling time.

3.2.3 Distance difference between the top flow front position and the bottom flow front position

To investigate the distance difference between the top flow front position and the bottom flow front position in VIMP based on DM, flow experiments have been carried out under the same condition (same vacuum degree, filling distance and setup system). Keeping resin viscosity and changing layers of fabric in experimental filling process, the results are shown in Table 5.

In the experiment, it can be found the distance difference (DD) between the top flow front position and the bottom flow front position was nearly a fixed value. As shown in Table 5, the DD increases with the layers of fabric. Regression analysis shows the DD increases linearly with the layers of fabric under the same vacuum condition as shown in Fig. 3. It can be deduced the DD increases linearly with the thickness of the fiber preform.

Difference of filling time (DF) in experimental process also increases with the layers of fabric, as shown in Table 5. According to Darcy's law, we can also deduce the DF increases linearly with the thickness of fiber preform under the same vacuum and viscosity condition.

3.2.4 Effect of DM scale

It is very difficult to control the mold filling process in VIMP, especially the velocity of the resin flow. One of effective solution is to adjust DM scale to control the velocity of the mold filling in VIMP based on DM. Flow experiments were carried out to investigate the effect of DM scale on mold filling process. The width of DM is 0.24 m and the length is 0.10 m, 0.20 m and 0.30 m respectively in the three experiments. Process parameters and other material parameters are same, including vacuum degree, resin viscosity, layers of fabric and system of setup and so on.

Fig. 4 shows the filling time as a function of DM scale. The filling time decreases with DM scale in VIMP mold filling process, and the relationship between the filling time and the DM area is linear.

4 Conclusions

In this study, mold filling experiments were carried out to study the effects of DM on resin flow behavior in VIMP. The results show the relationship of K_d, K_f, K_a do not complied with the rule of mixtures and their contribution to resin flow changes with the thickness of fiber preform. Resin flow behavior in VIMP is significantly different with DM. This work could be as a reference for process control in large scale composite part manufacturing. Future work on this topic should be done on the system of controlling and monitoring in VIMP.

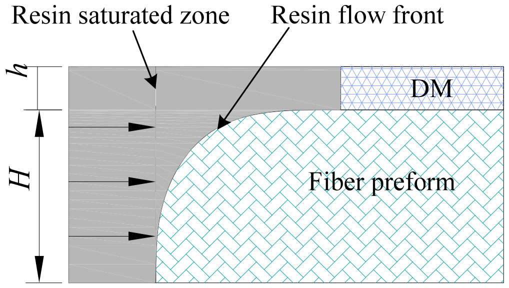

Fig.2. Schematics of resin flow modes for traditional RTM process and VIMP based on DM.

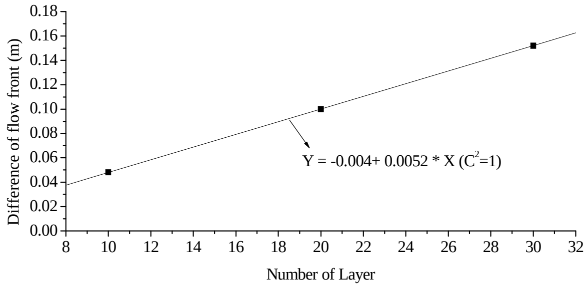

Fig. 3 Distance difference of flow front position between mat's top and bottom.

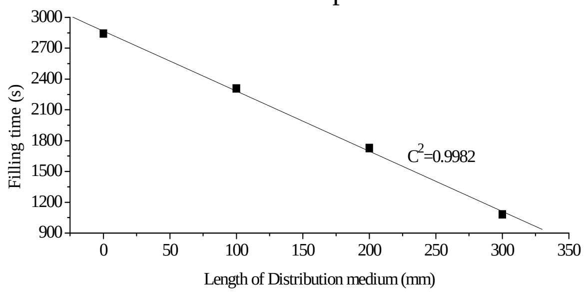

Fig. 4 Filling time as a function of DM scale.

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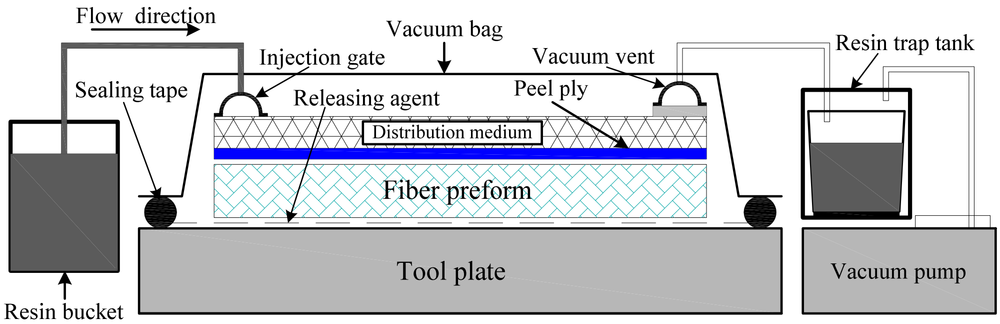

Fig.1. Schematic of the VIMP setup with DM.

Tables

Table 1. Permeability for the distribution medium

Exp. no.	Layers	Porosity	$K_d/\times10^{-8}m^2$	Filling time/s
1	5	0.848	1.31	47.5
2	10	0.848	1.30	47.7
3	15	0.850	1.32	47.8

Table 2. Permeability for the fiber preform

Exp. no.	Fabric Layers	Porosity	$K_f/\times10^{-11}m^2$
1	10	0.242	3.78
2	20	0.201	3.14
3	30	0.154	2.41

Table 3. Apparent permeability for the assembly

Exp. no.	Layers		K_a/m^2	
	DM	Fabric	Experimental values	Theoretic values
1	1	10	3.93×10^{-10}	2.64×10^{-9}
2	1	20	1.87×10^{-10}	1.55×10^{-9}
3	1	30	1.04×10^{-10}	1.13×10^{-9}

Table 4. Influence of DM laid pattern on mold filling

Exp. no.	Layers		Laid pattern of DM	Filling time/s
	DM	fabric		
1	1	6	laid on the top of fiber preform	75
2	1	6	laid in the middle of fiber preform	82
3	0	6	no DM	2842

Table 5. Difference of flow front position between mats' top and bottom

Exp. no.	Layers		Distance difference/m	Filling time/s		
	DM	Fabric		Top	Bottom	Difference
1	1	10	0.048	538	582	44
2	1	20	0.100	865	1038	173
3	1	30	0.152	1362	1697	335