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Experimental Study of Progressive Compression Method of Resin Delivery in Liquid Composite Molding

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Abstract

A new technique of resin delivery, which we refer to as the progressive compression method (PCM), has been invented to reduce filling time associated with the vacuum assisted resin transfer molding (VARTM) process. In the method, the bag is divided into several segments. During infusion, all segmented bags are pulled away from the preform by the vacuum. Hence, resin is easily infused into the loose preform. Once enough volume of resin is infused, the vacuum within the segmented bags is released in a step-wise manner. The atmospheric pressure of the heated air is progressively applied on the segmented bag that is inflated to compact the wetted preform and drive the resin through the remaining dry preform. The resin flow is enhanced since the dry preform remains loose during the filling process. The research aims to investigate the effect of seven process parameters on the PCM complete filling process by applying Taguchi's method. All chosen factors are designed with two levels. Experimental results show that the predicted optimum settings are higher vacuum pressure, more compression segment, later initiation of the next compression segment, higher air temperature, later introduction of the heated air, lower initial height of the cavity and less excess infused resin for reducing the filling time. Compared with typical VARTM without flow enhancement, PCM at the optimum settings reduces the filling time by 72.85%.

Keywords: filling process, Taguchi's method, vacuum assisted resin transfer molding

1. Introduction

Vacuum assisted resin transfer molding (VARTM) process is a popular method for the manufacture of composite components. In a typical VARTM, the dry preform is placed on the rigid mold and sealed with an elastic bag to create an airtight mold cavity. The inlet line is opened and the resin is driven by atmospheric pressure through the infusion line after the vacuum is applied within the mold cavity. Once the preform is completely saturated, the removal of the unnecessary resin from the wetted preform is performed to achieve the uniform thickness of the part.

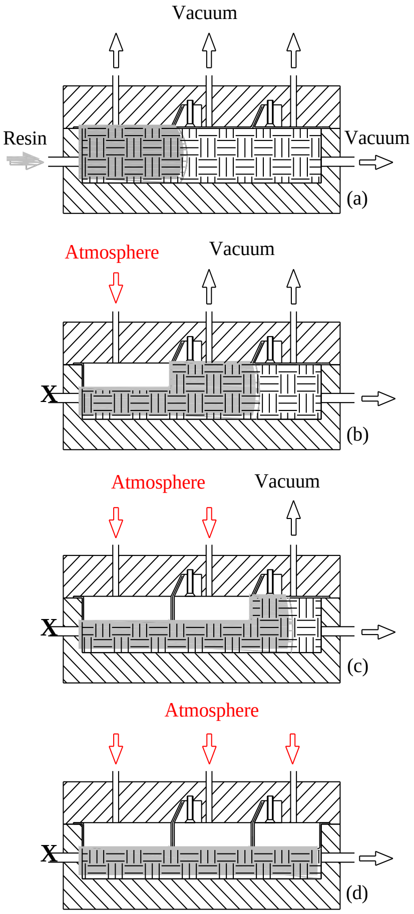

Fig. 1 Schematic diagram for PCM

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A key disadvantage of VARTM is a long infusion time because the driving pressure is low and the flow resistance offered by the compacted preform is high. Recent methods of flow enhancement have been devised. In the present study, the progressive compression method (PCM), sharing the common characteristic with the articulated resin transfer molding [1] and the vacuum assisted compression resin transfer molding [2], is proposed to improve infusion time as shown in Fig. 1. In the process, the sequential inflation motion of the segmented bag is designed to squeeze out the resin within the wetted preform and drive the resin through the remaining dry and loose preform. The resin flow is thus enhanced.

In the present study, the effect of seven process parameters, including vacuum pressure in the mold cavity (factor A), number of the compression segment (factor B), compression timing of the next segment (factor C), temperature of the heated air (factor D), initiating segment of the heated air (factor E), initial height of the cavity (factor F) and volume of the infused resin (factor G), on the PCM complete filling process is investigated by applying Taguchi's method. The typical VARTM filling process is also performed for comparison purpose.

2. Method

2.1. Materials

In the experiments, four layers of bi-directional fiber mat (TGFW-600) were stacked together to form a preform. The used resin was commercial unsaturated polyester resin system (Eternal Chemical, 2597PT-6) including 0.5% of the catalyst. Before resin infusion, resin and hardener (MEKPO) were mixed well in a weight ratio 100: 1. The dimensions of the rectangular cavity were 280 mm × 150 mm × 10 mm. The cavity thickness could be adjusted by placing an extra plate in the cavity.

2.2. Taguchi's Method

The chosen factors are designed with two levels as shown in Table 1. Thus, the $L_8(2^7)$ standard matrix can be applicable. Eight experiments are performed and the factors corresponding to each column are varied among the levels within the matrix.

Table 1 Chosen factors

Factor	Level 1	Level 2
A. vacuum pressure (kPa)	100	80
B. number of compression segment	2	3
C. compression timing of the next segment (sec)	5	10
D. temperature of the heated air (℃)	20	40
E. initiating segment of the heated air	1st segment	3rd segment
F. initial cavity height (mm)	7	10
G. volume of infused resin (ml)	100	130

For factor B, the position of the compression segment is shown as Fig. 2.

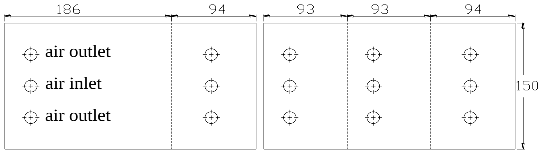

Fig. 2 Position of the compression segment

The minimization of filling process is the goal of optimization. A signal-to-noise (S/N) ratio depicting the 'small the better' characteristic can be calculated using the formula.

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \tag{1}$$

where y_i is the measured property and n corresponds to the number of samples in each test trial. The measured property is compiled in decibel (dB) in the matrix experiment. The S/N ratio is also denoted by η.

3. Results and Discussion

Performing the technique of the analysis of variance (ANOVA) investigates the relative effect of different factors on the filling time as shown in Table 2. The variance ratio, denoted by R, is the ratio of the mean square (MS) due to a factor and the error mean square. That is to say, the larger the value of R, the more important that factor is in influencing the process response η. Therefore, the process variables are ranked in order of importance of vacuum pressure, volume of infused resin, initial cavity height, temperature of the heated air, compression timing of the next segment, number of compression segment and initiating segment of the heated air. Referring to the sum of squares (SS) column, notice that factor A (vacuum pressure) makes the largest contribution to the total sum of squares, namely, (40.93/57.67) × 100 = 70.97%. Factors

G (volume of infused resin), F (initial cavity height) and D (temperature of the heated air) make a 20.12%, 6.09% and 2.26% contribution to the total, respectively. Factor E (initiating segment of the heated air) makes the least contribution to the total, only 0.09%. This is because the temperature of the heated air at the outlet is found to be roughly 24℃. Analyses of the experimental η show that the predicted optimum settings are $A_1B_2C_2D_2E_2F_1G_1$.

Table 2 ANOVA

Factor	Average η by factor level		DF	SS	MS	R
	1	2				
A.	-53.8	-58.3	1	40.93	40.93	669.8
B.	-56.2	-56.0	1	0.07*	0.07*	1.1
C.	-56.2	-55.9	1	0.20	0.20	3.2
D.	-56.5	-55.7	1	1.30	1.30	21.4
E.	-56.1	-56.0	1	0.05*	0.05*	0.9
F.	-55.4	-56.7	1	3.51	3.51	57.5
G.	-54.9	-57.3	1	11.60	11.60	189.9
Error			0	0	-	
Total			6	57.67		
(Error)			(2)	(0.12)	(0.06)	

* indicates the sum of squares added to estimate the error sum of squares indicated by parentheses.

4. Conclusions

A new VARTM process, called progressive compression method, is successfully developed to reduce the filling time. In the present study, the effects of seven process parameters on the filling time are investigated by Taguchi's method. Experimental results show that the vacuum pressure, the volume of infused resin and the temperature of the heated air are significant variables for reducing the filling time, while the initiating timing of the heated air appears to be trivial.

References

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