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Segmented Compression Molding for Composite Manufacture

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Abstract

In the present study a new technique of vacuum assisted resin transfer molding (VARTM), called segmented compression molding (SCM), is proposed to improve filling process. In the method, a double-bag is placed between the upper mold and the cavity, and each bag is controlled individually. Through the vacuum pulling the double-bag upward, resin is easily infused into the loose preform. After the completion of resin infusion, the resin inlet is closed. The vacuum on the bags are sequentially released to atmospheric pressure, the inflated bags squeeze the surplus resin from the wetted preform toward dry loose preform and the filling process is thus reduced. This study is to introduce the SCM, model the filling process and explore the surface quality of the SCM parts. Results show that the SCM filling process is decreased by using a high initial cavity thickness. As compared with transfer resin transfer molding (RTM) and typical VARTM, SCM can reduce the filling process in the work. The surface roughness of SCM part approximates that of VARTM, but it is much inferior to that of RTM.

Keywords: vacuum assisted resin transfer molding, resin transfer molding, surface roughness

1. Introduction

Polymer composites have been utilized in various industries such as aerospace and automobile. Some typical processes are resin transfer molding (RTM), compression RTM (CRTM) and vacuum assisted RTM (VARTM) also known as resin infusion. For the sake of reducing filling time, various innovative methods have been developed recently. Allende et al. [1] proposed the fast remotely actuated channels (FASTRAC) system consisting of primary, secondary bags and a metal plate with machined channels placed between two bags. A vacuum applied in the channel space to pull the primary bag away from the preform and resin was easily infused into the preform. Alms and Advani [2] proposed the flow flooding chamber (FFC) method which used a rigid chamber to replace the metal plate and secondary vacuum bag in FASTRAC. Alms et al. [3] further presented the vacuum induced preform relaxation method which utilized a small vacuum chamber for guiding the liquid flow. Heider et al. [4] proposed an injection design methodology in which multiple high-permeability fabrics were integrated periodically between the thick-section and low-permeability preform. Chang [5] proposed the vacuum-assisted CRTM (VACRTM) process which was similar to FFC method. Chang and Li [6] utilized an innovative vacuum bag consisting of a film and several air cushions. The distribution channels were created between air cushions during infusion. Chang and Chen [7] proposed the progressive compression method (PCM), using a concept of the segmented compression to improve infusion time and material waste.

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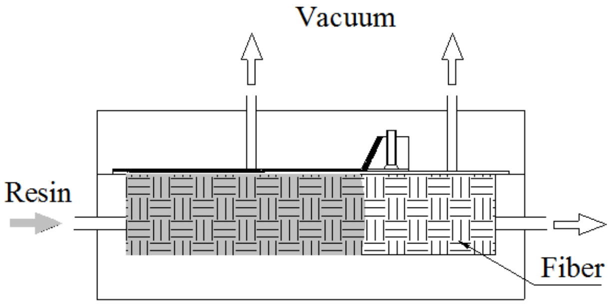
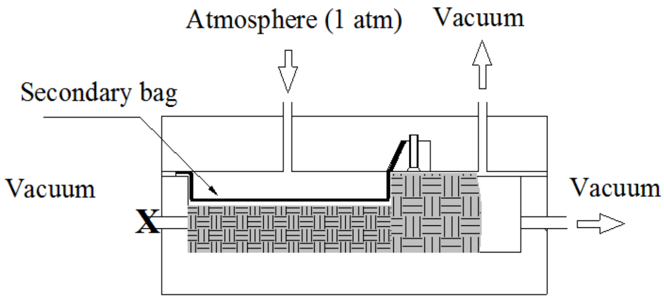
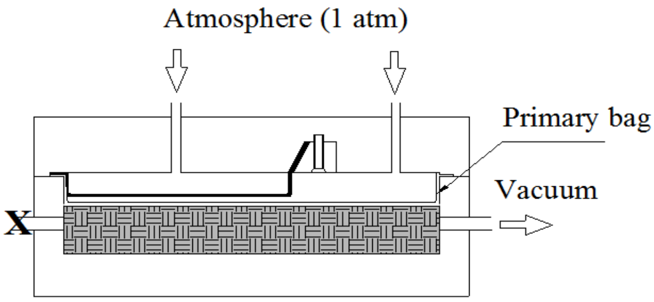
A new technique of VARTM, called segmented compression molding (SCM), is proposed to reduce the filling time. The technique shares the common concept with the double bag [1], and segmented compression [7]. Fig. 1 illustrates the schematic diagram of SCM. The technique provides the advantages in term of needless cleaning of upper mold and short filling time. The potential for low void content in the part is expected due to the cavity with vacuum assistance. In the present study, a one-dimensional filling model coupled with preform deformation is employed to investigate the filling process. The initiating timing of the primary bag compression is also discussed.



(a) Resin infusion



(b) The secondary bag compression



(c) The primary bag compression

Fig. 1 Schematic diagram of SCM

2. Theory

In the filling process of SCM, the resin flow through a fiber preform is modeled as flow through a deformable porous media. The governing equations of resin flow are written as follows.

$$\frac{\partial(h\phi)}{\partial t}+\frac{\partial}{\partial x}(h\phi v)=0 \tag{1}$$

$$v=-\frac{K}{\mu}\frac{\partial P}{\partial x} \tag{2}$$

where v , P, μ are resin velocity, pressure and viscosity; φ, h, K are the preform porosity, thickness and permeability, respectively. Note that K varies with the preform deformation and the Kozeny-Carman model is employed to relate K with the preform porosity.

During preform compaction, the resin pressure obeys the Terzaghi's law. An empirical power model is utilized to provide the relationship between φ and compression pressure exerted on the preform (P_{com}).

$$V_f=V_{f0}\times P_{com}^{B} \tag{3}$$

where V_f=1-φ; V_{f0} and B are the material constants.

In the present numerical analysis, a finite difference method is utilized to solve the governing equations of resin flow. The process parameters are used: ambient pressure of 101.3 kPa, infusion pressure of 95 kPa, vent pressure of 1.3 kPa, mold cavity length of 1 m and resin viscosity of 0.2 Pa-s. The properties of the preform are listed: Kozeny-Carman constant of 71.8× 10^{-12} m^2, filament density of 2540 kg/m^3, V_{f0} of 0.11 and B of 0.126.

3. Results and Discussion

Three SCM cases are used to investigate the SCM filling process as listed in Table 1. Fig. 2 shows the filling time for various cases. Evidently, a high initial cavity height can reduce the filling process by comparing case 1 with case 2. In SCM, the premature initiation of the primary bag compression is necessary since the late compression of secondary bag is relatively slow. A comparison between case 2 and case 3 give an explanation that the appropriately premature initiation of the primary bag compression is preferable. As compared with RTM and typical VARTM, case 3 can reduce the filling process by 13.4% and 50.1% respectively in the present study.

Table 1 Process parameter of three SCM cases, RTM and VARTM

	Initial cavity height	Final cavity height	Initiating timing of primary bag compression
SCM case 1	1.3×10^{-3} m	0.838×10^{-3} m	Preform at the inlet is compacted to 0.95×10^{-3} m
SCM case 2	1.5×10^{-3} m	0.838×10^{-3} m	Preform at the inlet is compacted to 0.95×10^{-3} m
SCM case 3	1.5×10^{-3} m	0.838×10^{-3} m	Preform at the inlet is compacted to 1.3×10^{-3} m
RTM	0.838×10^{-3} m	0.838×10^{-3} m	– – – – – – –
VARTM	– – – – – – – –	0.838×10^{-3} m	– – – – – – –

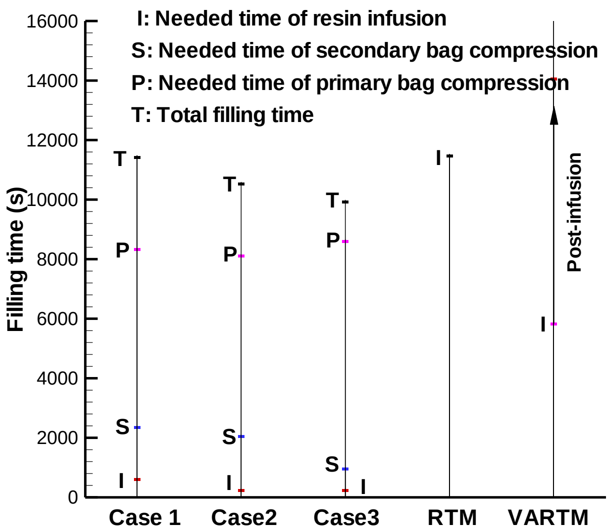


Fig. 2 Filling time for various cases

(a) SCM part

(b) VARTM part

Fig. 3 Surface quality of SCM and VARTM.

The surface quality of the SCM part made from four layers of bi-directional mats (TGFW-600) and unsaturated polyester resin (2597PT-6) is evaluated. As expected, the surface flatness of the SCM part is improved relative to PCM due to the primary bag flattening entire preform. Fig. 3 shows the surface roughness of SCM part supplied by mold. Through the visual observation, it is found that the surface finish of SCM supplied by the bag is not as good as the mold side surface due to the flexible bag. The phenomenon of the “print through” is obvious and needed to be improved for both surfaces. Through the measurement of the surface roughness tester, the surface roughness of SCM part approximates that of VARTM but is much inferior to that of RTM.

Acknowledgements

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