Modeling and Simulation of Liquid Compression Molding Using LIMS

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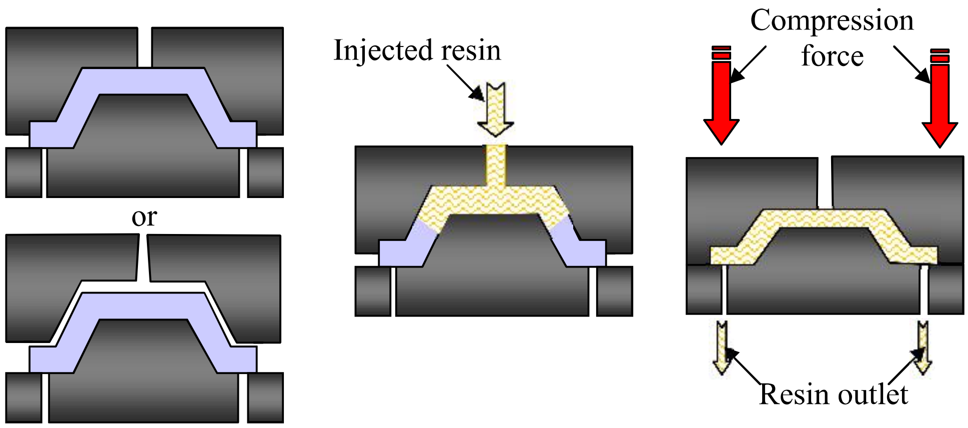
SUMMARY: Injection Compression Molding is a fast Liquid Composite Molding (LCM) process in which resin is injected in a mold which is not completely closed. Once the desired amount of resin is injected, the mold is slowly closed and the resin is forced to impregnate the remaining dry fibrous medium until the desired fiber volume fraction or preform thickness is reached. The main advantage of this process as compared to Resin Transfer Molding (RTM), where the mold is fully closed before injecting, is the reduction of the mold filling time. The topic of this paper is to model the compression stage, that is the flow of resin through the preform while the preform is being deformed. The model consists in changing the geometry of the part between each calculation step and updating the fibrous material properties according to experimental data.

KEYWORDS: Simulation, Injection/Compression (I/CM, CRTM), Forced deformations

INTRODUCTION

Injection/Compression (I/CM) or Compression RTM (CRTM) process is a good alternative to Resin Transfer Molding (RTM) as it allows to reduce cycle time while ensuring good part quality. In both processes, fabric layers are previously laid up in the mold. Once the mold is closed, resin is injected. The part is de-molded at the end of the curing stage. The difference between the two processes lays in the closure position of the mold, as presented in Fig. 1. In RTM the mold is fully clamped during the injection, whereas in I/CM resin is injected before clamping the mold, either leaving a gap between the mold wall and the fabric, or injecting while the preform is not fully compacted. When the desired amount of resin is injected, a compression stage forces the resin to impregnate the whole preform. The simulation of compression based processes was addressed first on the material deformation side. For instance, Pillai et al. addressed this problem by characterizing a multi layered preform deformation and change in physical properties using a nonlinear elastic model [1-3] and by presenting a 3D-mesh generation method that keeps the preform layers integrity dKqBu e. Nevertheless, the topic of the compression driven flow during compression was not approached. Bickerton and Abdullah [4] developed an analytical model to predict the clamping force necessary during a I/CM process, using an elastic model and showed limitation via experimental results, proving the need to use a viscoelastic model to consider small deformations. The simulation of compression driven flow was previously addressed by Pham et. al. They modeled Compression Resin Transfer Molding (CRTM) for a 2D flow created by a 1D-compressive load using RTMFlot a computer-based program developed at the University of Montreal [5].



Mold pre-closing **Injection stage** **Compression stage**

Fig. 1 : Injection/Compression process main stages

In this paper, we demonstrate the possibility of implementing the I/CM process in a simulation code called LIMS. This code developed at the Center for Composite Materials, University of Delaware, USA, is based on a control volume approach and is dedicated to the simulation of Liquid Composite Molding Technologies [6]. The advantage of LIMS is that one can access and modify any data as well as geometric features (nodes location for instance) between each calculation step, get information and take control actions without interrupting the simulation. The complexity of the I/CM process can thus be addressed using LIMS through dedicated algorithm and routine as one can change the geometry and update material properties at any time.

I/CM PROCESS MODELING

Two types of problems, presented in Fig. 2, are addressed:

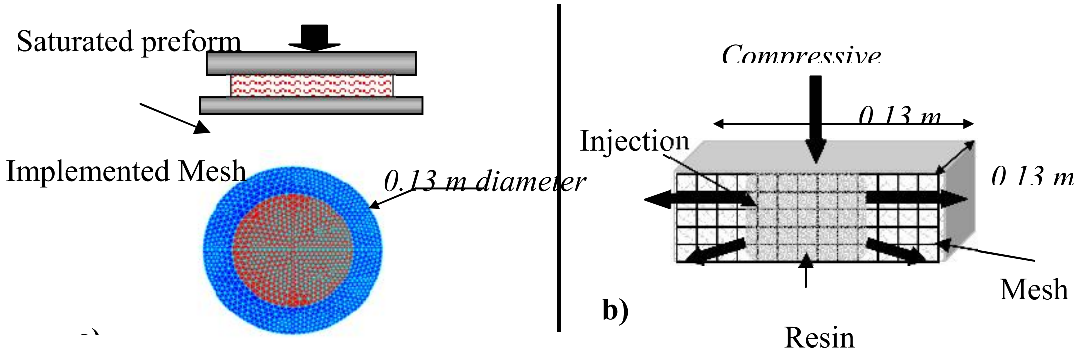


Fig. 2 : Consolidation (a) and Injection/Compression (b) processes and mesh presentation

- The consolidation step: a fully saturated fibrous preform is compressed to evacuate the excess of resin. The input geometry is a 2D shell mesh representing a plane perpendicular to the applied compressive load. A circular mesh shape is used as the resin flows radially (Fig. 2a).
- Injection followed by a compression stage (I/CM): resin is injected through the preform, then the preform is compressed and the resin flows towards the dried areas. In this case, the unidirectional compressive load creates a 2D in-plane flow. A rectangular mesh constituted of 50x20 rectangular elements is used as the representation of a slice of the part (Fig. 2b).

Assumptions

Although not required, the preform considered here is isotropic. A 1D-compression is set in the thickness direction with a constant deformation speed. Deformations in the in-plane directions are assumed negligible. The permeability is calculated from the fiber volume fraction according to experimental data obtained from the permeability tests performed for different fiber volume fractions on a balanced woven fabric (Lyvertex, Hexcel of 0.41 Kg/m^2) preform (Fig. 3).

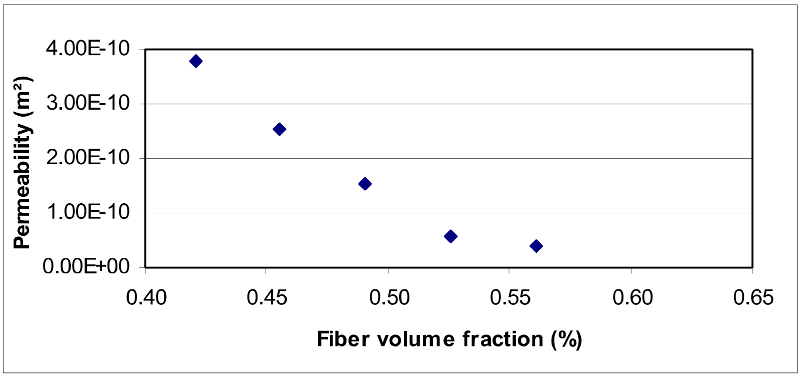


Fig .3 : Experimental permeability values for the studied preform

Algorithm

The principle of the simulation is to convert the vertical pressure load applied during the compression into progression of the resin flow front. The program is based on control of the amount of resin displaced. The algorithm is decomposed into the following steps :

- Set element properties (initial permeability K and volume fraction V_f, resin viscosity μ, elements thickness, …)
- Set injection gates (I/CM case) and vents
- Set nodes as filled nodes (consolidation case) or perform the injection until the desired amount of resin is injected (I/CM case)

- Compression loop
    - Set each filled node as an injection gate
    - Update the flow rate Q from the volume of resin moved out of the part

$$Q = V_{comp}(1 - Vf)\frac{filled\ area}{Number\ of\ nodes\ filled}$$

where V_{comp} is the compression velocity and V_f is the preform fiber volume fraction

    - Calculate the new part thickness

$$h_n = h_{n-1} - V_{comp}(t_n - t_{n-1})$$

where h and t represent the part thickness and time, respectively, the subscripts n and $n-1$ represent the current and previous calculation steps, respectively

    - Calculate the new perform volume fraction and permeability
    - Update material properties and mesh geometry
- Solve until the desired final thickness is reached

Results

The simulations are validated by controlling the injected volume with respect to time. The outputs are the resin pressure profile in the mold and the resin pressure at the center of the mold, presented in Fig. 4 and 5 respectively. Parameters used for the simulation for both cases are reported in Table 1.

Table 1. Simulation parameters

Parameter	**Representation / unit**	**Value**	**Parameter**	**Representation / unit**	**Value**
Injection flow rate	Q / $m^3.s^{-1}$	$1.67\ 10^{-5}$	**Preform initial porosity**	ϕ / %	70
Compression velocity	V_{comp} / $mm.min^{-1}$	0.5	**Initial preform thickness**	H_{init} / m	0.02
Resin viscosity	μ / Pa.s	0.2	**Final preform thickness**	H_{fin} / m	0.01

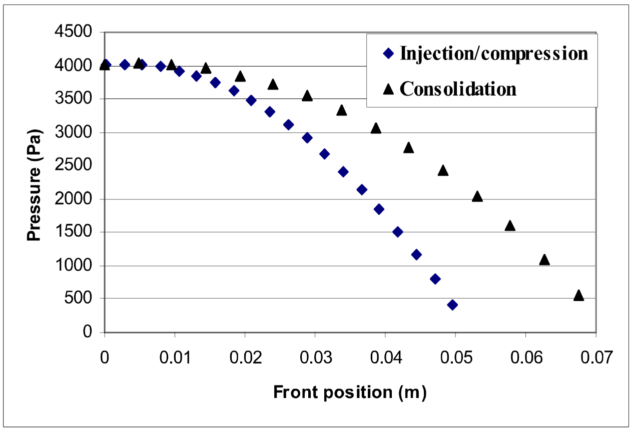


Fig. 4 : Resin pressure profile along the bold at the end of the process

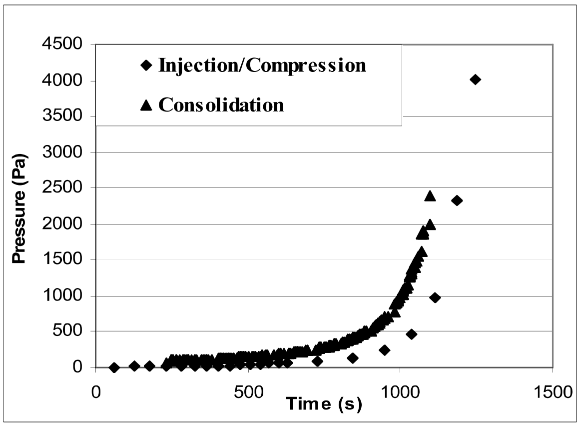


Fig. 5 : Resin pressure profile at the center of the mold during the injection

Even though the mesh geometry is different, the mold dimensions are of the same range for the two presented configurations. The pressure profiles obtained in both cases have the same trend and the pressure levels reached are of the same order of magnitude. As confirmed by Pham et. al., the resin pressure profile along the mold is parabolic [5]. Knowing the pressure inside the mold would help dimensioning the production in terms of press requirements, and maximum compression velocity.

CONCLUSION AND FUTURE DEVELOPMENTS

The present paper shows the possibility to model forced deformation and the compression driven resin flow induced in the I/CM process. Further extension of the code towards other LCM technologies is possible, involving other class of materials such as a gap filled with resin or a sandwich core, provided that the materials behavior (dry and wetted preform, resin, foam core in the case of sandwich materials…) is characterized under a compressive load. Constant pressure compression in Resin Film Infusion (RFI) could then be modeled successfully. The consolidation process simulation can be used to model the mechanical behavior of an impregnated perform and thus determine the contribution of the fluid pressure during the compression. Moreover, the flow induced deformations that occur in some processes such as in sandwich composites molding or in Vacuum Assisted RTM (VARTM) could be simulated [7]. As LIMS can also solves for 3D structures, further developments are currently in progress in order to mel a,,

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