FLOW MODELNG OF VARTM INFUSION IN PRESENCE OF HPM USING LEVEL SET APPROACH

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Keywords: *Compaction pressure, Permeability, VARTM, HPM, Level set, Depth averaging.*

Introduction:

Vacuum assisted resin transfer molding (VARTM) is an open mold process, extensively used for composite manufacturing. In this process, the rigid top mold of resin transfer molding (RTM) is replaced by a flexible vacuum bag. During vacuum infusion, as the flow-front advances towards the vacuum outlet, a transient spatially varying pressure gradient develops in the entire porous preform resulting in a complex moving boundary problem [1, 2]. Due to the significantly lower pressure gradient as compared to RTM and other process, complete saturation of the porous preform is a challenge. In addition fill times tend to be very high. Thus a high permeability medium (HPM) is used as a top layer placed over the fabric preform to reduce fill time, Figure 1(a) [3]. Therefore, the entire infusion process becomes a 3-D flow problem with a combination of seepage flow through the thickness, a faster planar flow in the HPM and a relatively slower flow outside HPM in the fiber preform.

In the past, a 1-D flow model has been developed for the flow through HPM coupled with transverse seepage flow through thickness [3, 4, 5]. During infusion, the thickness of fiber preform will increase until the saturation has established. Therefore, the seepage velocity in thickness direction will experience an extra drag due to upward movement of the interface between HPM and fiber preform. These phenomena are not modeled in literature for the vacuum infusion with HPM on top of the preform.

Theoretical Modeling:

In the present work, a 2-D planar transient flow model with HPM has been introduced incorporating a varying preform thickness. In addition, planar flow front position has been predicted with the help of level set advection model. A cross sectional view of XZ-plane is shown in Figure 1(a). Layer-1 denotes the HPM layer of constant thickness h_1 with constant pore volume fraction φ_1, and in-plane permeability $K_{1_{xx}}$, $K_{1_{yy}}$. Layer-2 represents the fabric layer with varying pore volume fraction $\varphi_2 = (1 - v_f)$ and permeability in all three principal directions as $K_{2_{xx}}$, $K_{2_{yy}}$ and $K_{2_{zz}}$. The permeability of the fabric layer varies with the compaction pressure whereas it is constant for HPM of Layer-1. Thickness of fiber preform $h_2(P, x, y, t)$ varies up to saturation in the wetted and partially saturated region of the fiber preform.

Darcy's superficial flow velocity and depth averaged flow velocity in the HPM is assumed to be $(u_1, v_1, -w_1)$ and $(\bar{u}_1, \bar{v}_1, -\bar{w}_1)$ respectively. As there is no time rate of mass change in a control volume of HPM, the depth average continuity equation of Layer-1 becomes

$$\frac{\partial(\bar{u}_1 h_1)}{\partial x} + \frac{\partial(\bar{v}_1 h_1)}{\partial y} - \left(w_1|_{h_1+h_2} - w_1|_{h_1}\right) = 0 \tag{1}$$

Similarly, Darcy's superficial flow velocity and depth averaged flow velocity for the bottom of fabric layer is assumed to be $(u_2, v_2, -w_2)$ and $(\bar{u}_2, \bar{v}_2, -\bar{w}_2)$ respectively. Here, time rate of mass change in a control volume of fiber preform is function of time and space, the depth average continuity equation of Layer-2 becomes

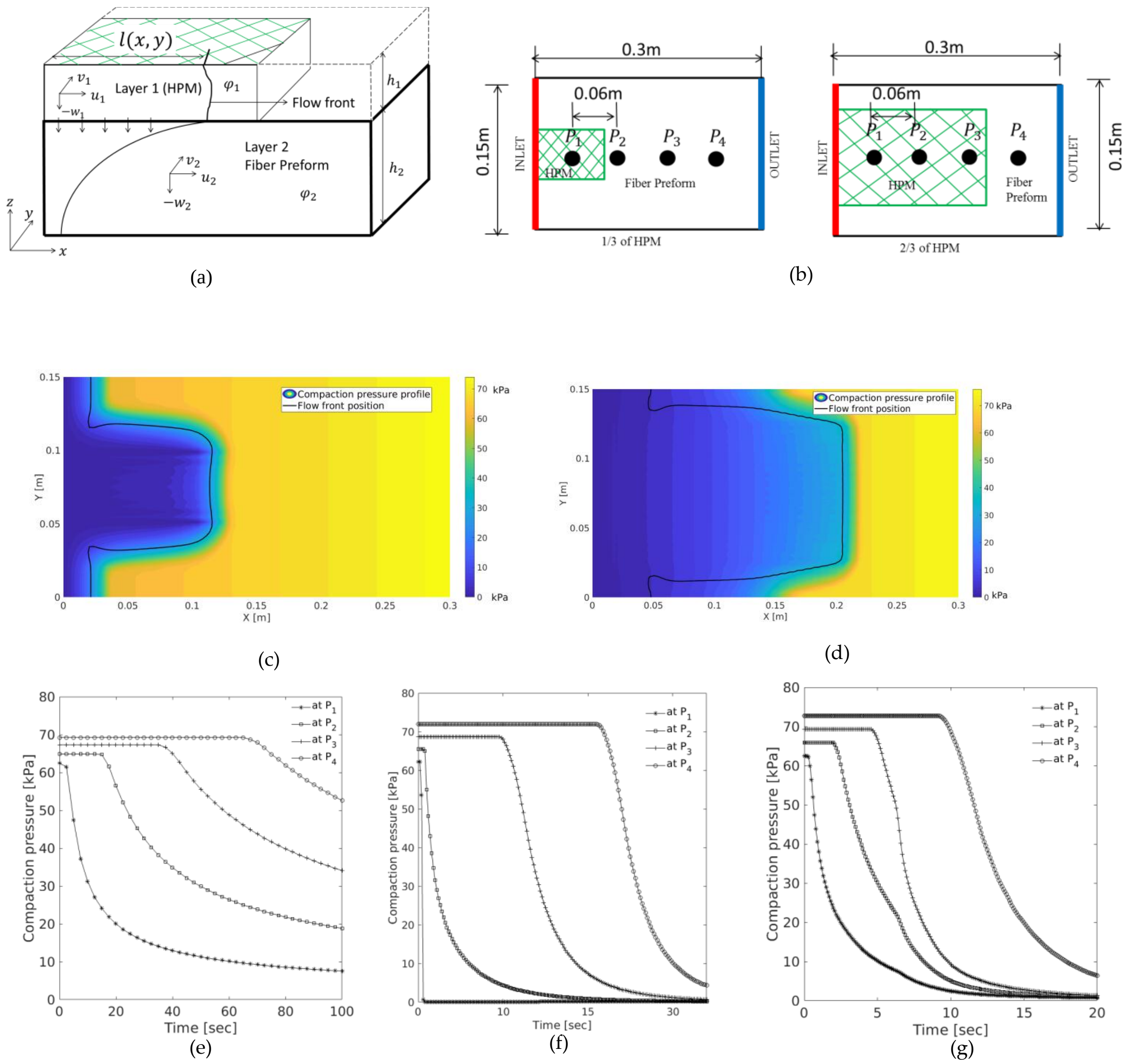
$$\frac{\partial(\bar{\varphi}_2 h_2)}{\partial t} + \frac{\partial(\bar{u}_2 h_2)}{\partial x} + \frac{\partial(\bar{v}_2 h_2)}{\partial y} - \varphi_2|_{h_2}\frac{\partial(h_2)}{\partial t} - u_2|_{h_2}\frac{\partial(h_2)}{\partial x} - v_2|_{h_2}\frac{\partial(h_2)}{\partial y} - w_2|_{h_2} = 0 \tag{2}$$

Assuming a pillbox shape domain around the interface of HPM and fiber preform, a matching velocity condition is derived through the thickness as $w_1|_{h_2} = w_2|_{h_2}$. Velocity at the free surface of HPM is also derived assuming a similar approach of pillbox at the top layer of HPM. Later, the entire two layer model of HPM and fiber is advected with flow front $\emptyset$ using level set front tracking method Eq-3 of a fluid velocity $V = (u, v)$, (different velocity component at the interface of preform and HPM, and the bottom of the preform) as

$$\frac{\partial\emptyset}{\partial t} + V.\nabla\emptyset = 0 \tag{3}$$

Results and discussion:

Methods of lines have been used to solve the numerical problem. The model has been validated with the existing results from the literature [5]. Figure 1(b) shows the schematic for HPM area 1/3 and 2/3 of fiber preform. Permeability of HPM layer is taken to be 10 times higher than the fabric layer of YC-N200 (*Fibertech Co. Ltd.*), 0.88 as the porosity volume fraction, and 0.00025m as the height of HPM is taken from the literature [3].



(a) (b)

(c) (d)

(e) (f) (g)

Figure 1: *(a) Schematic of flow model along XZ-plane. (b) Schematic of 2 different configuration of HPM layer. (c) and (d) are the compaction pressure profile along with flow front at the end of 1/3 and 2/3 HPM of fabric layer respectively. (e),(f),(g)Pressure profile at location of* P_1, P_2, P_3, P_4 *without and with 1/3 and 2/3 HPM of fiber preform respectively.*

As the permeability is higher in the HPM region Figure 1(c), (d) shows the rapid advancement of flow front near the HPM region for both the 1/3 and 2/3 HPM of fabric. Therefore, due to the sudden increase of fluid velocity, compaction pressure near HPM decreases rapidly. Comparison of pressure profiles with and without HPM is shown in Figure 1(f), (g) and (e). Fill time at the location of P_4 for without and with HPM of 1/3, 2/3 is 78 sec, 17 sec and 12 sec, respectively. The present work can capture the fill time and transient behaviour of pressure profile along with the flow front.

References

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