EFFICIENT NUMERICAL SIMULATIUON METHOD FOR THREE-DIMENSIONAL RESIN FLOW IN LAMINATED PREFORM FOR LIQUID COMPOSITE MOLDING PROCESSES

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Introduction

We propose an efficient simulation method for the 3D resin flow in a laminated preform composed of multiple layers with different properties at each layer. During LCM processes, the resin flow in such a preform takes places in the thickness direction as well as in the planar directions. Usually, the thickness of each layer is very small, about 100 µm and a great number of nodes, about 10 million, are needed if 3D mesh is adopted. Hence, transient flow simulation by 3D mesh is extremely heavy. Instead of 3D mesh, we propose multi-layered shell elements to perform 3D flow simulation within a short computing time. We describe the numerical formulation of multi-layered shell elements to consider both the through-thickness and planar flows. The accuracy and efficiency are evaluated by comparison with the simulation by 3D mesh. New parameters to estimate the accuracy and efficiency are defined in terms of preform permeability ratio (planar to transverse) and the ratio of shell element size to the distance between the adjacent layers. We also compare simulation results and experimental results of resin infusion into preform made by automated dry fiber placement of thin carbon fiber tape.

Numerical formulation

The 3D mass conservation equation can be reorganized by putting the in-plane mass flux terms in the left hand side and the out-of-plane mass flux term in the right hand side. Each velocity component can be represented in terms of pressure gradient according to Darcy's law. To obtain pressure values, control volume finite element method is employed by integrating the governing equation over the control volume to obtain a weak formulation.

$$\iiint \frac{\partial}{\partial x}\left(\frac{Kx}{\boldsymbol{\mu}}\frac{\partial P}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{Ky}{\boldsymbol{\mu}}\frac{\partial P}{\partial y}\right)dV=\iiint -\frac{\partial}{\partial z}\left(\frac{Kz}{\boldsymbol{\mu}}\frac{\partial P}{\partial z}\right)dV \qquad (1)$$

where Kx, Ky and Kz are the preform permeabilities in x, y and z directions. P is the resin pressure and μ is the resin viscosity. To solve this governing equation, the pressure field in the planar directions (LHS of equation 1 and $C_1P_1+C_2P_2+C_3P_3$ in Figure 1) is represented by finite element method using a linear shape function in the three node triangular elements whereas the pressure field along the thickness direction (RHS of equation 1 and $C_0P_{up1}+C'_1P_1+C_4P_{down1}$) is expressed by finite difference scheme using the pressure values at upper and bottom nodes. Subsequently, there are five nodal pressure values in an elementary matrix in the current formulation, whereas there are three nodal pressure values in the conventional shell element formulation (see Figure 1). Because different 3D permeabilitiy tensors are assigned at each layer, averaged planar permeabilities are not required and a real stacking sequence of preform stack including distribution medium can be exactly represented.

To validate the accuracy of the multi-layered shell element method, its simulation results are compared with the 2D simulation results in x-z plane while ignoring the flow in y direction and with the 3D simulation results by tetrahedral elements, for different ratios of through-thickness permeability to planar permeability and different sizes of shell elements. The accuracy of the current method is decreased as the ratio of through-thickness permeability to planar permeability is increased as the ratio of the shell element size to the distance between adjacent shell elements layers is increased. The most important advantage of the current method is the reduced number of nodes and computational cost because elements with large planar dimensions can be adopted, whereas the size of 3D volumetric elements is limited to the small thickness of a single layer in a preform [1]. Therefore, the size of shell elements should be carefully selected to find out optimal compromise between the accuracy and the efficiency.

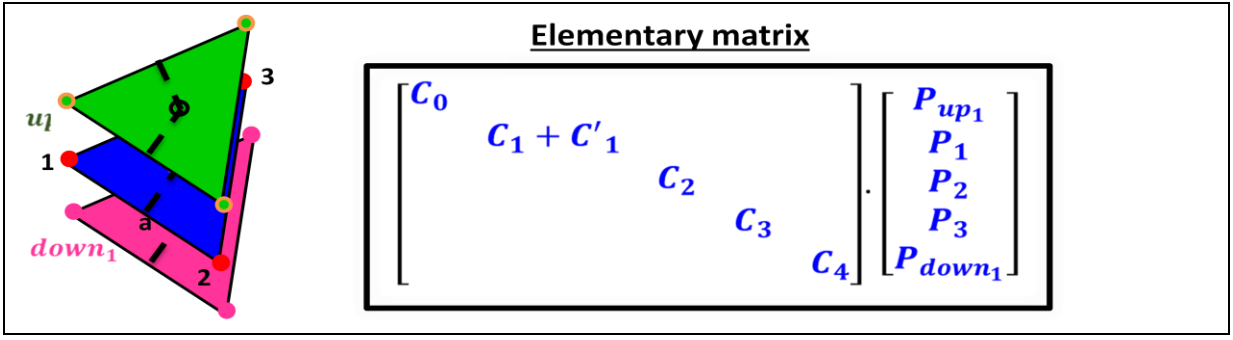

Figure 1: *Elementary matrix for node 1 in the control volume finite element formulation*

Numerical applications and experimental validation

We present three representative examples of numerical simulation, viz. resin infusion of multi-layered preform obtained by automated dry fiber placement, vacuum assisted resin transfer molding (VARTM) of boat structure and impregnation of quasi-isotropic non-crimp fabrics. It should be noted that full 3D transient flow simulation of such structures by the conventional volumetric elements is not possible due to the great number of nodes, such as 10^7-10^8. Conversely, 3D flow simulation can be performed by the multi-layered shell elements method with a reasonable computational time such as less than 10 hours using a single personal computer (see Figure 2).

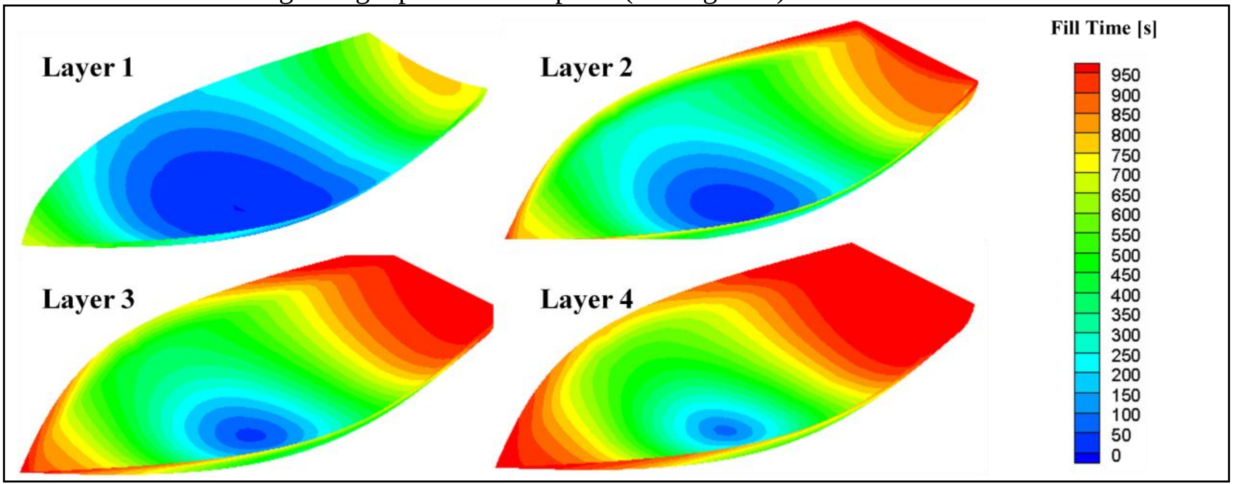

Figure 2: *Mold filling pattern in the VARTM of boat structure (Layer 1: distribution medium, Layers 2-4: preform).*

In particular, the experimental data for the resin infusion of multi-layered preform obtained by automated dry fiber placement was compared with the numerical simulation result to demonstrate the validity of the current method [2].

References

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