SIMULATION OF 3D RTM PROCESS USING SOLID SHELL ELEMENT

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Introduction
In the era of process modeling of composite materials, 3D simulation of manufacturing processes is desirable considering the manufacturing trend where parts became more complex leading to complex 3D stress-strain states. Moreover, coupling of sub-processes that are happening simultaneously such as macro-scale preform processes, flow advancement and solid and fluid interaction requires full 3D description of the problem.
The development is exemplified considering RTM process where the main focus of the modeling will be on the flow advancement into fiber preform and flow front capturing. To this end, the theory of two phase porous media is used along with assuming hyper-elastic material response for the fiber bed to formulate the problem. A finite element formulation and implementation of the two-phase problem is developed for incompressible constituents.

Homogenized theory of porous media
Theory of compressible porous media is the back-bone of the simulation framework which is used in this contribution. The aim is to simulate RTM process and visualize it in 3D considering the flow motion, flow front and preform deformation using the solid shell element. Different infusion methods such as line infusion and point infusion were practiced.

Physical assumptions
In the development of the model, from the continuum mechanics perspective, the assumed medias are needed to be distinguished and assumptions with respect to time and scale are necessary to be made. In that sense the fiber bed during any process is being considered as a porous material with a solid fiber network with pores. The fluid motion through the preform is also important event during any composite manufacturing process. In this sense the preform deformation is considered coupled to the fluid motion [1]–[3].

Governing equations
The respective mass and momentum balance for the problem are formulated as below

$$\nabla \cdot \boldsymbol{v}^s - n^f \dot{\varepsilon}^f = -\frac{1}{\rho^f} \nabla \cdot (\frac{\rho^f}{\xi^f} \boldsymbol{v}^d), \qquad \bar{\boldsymbol{\sigma}} \cdot \nabla + \hat{\rho} \boldsymbol{g} = \boldsymbol{0} \;\; \forall \boldsymbol{x} \in B. \tag{1}$$

where we solve them using FE method. The governing equation to calculate the saturation degree, equation (3), will lead to distinguish the liquid and gas constituents through the relevant processes.

$$n^f \dot{\xi}^f + \frac{\dot{J}}{J} \xi^f + \nabla \cdot \boldsymbol{v}^d = 0 \qquad \forall \boldsymbol{x} \in D \qquad with \qquad \boldsymbol{v}^d = -\frac{1}{\nu} \boldsymbol{K}_{mac} \nabla p \tag{2}$$

Solid Shell Element

Normally such a problem is treated using solid elements; however, those are not practical for industrial purposes due to computational costs. In this context, shell elements are very efficient and robust in capturing mechanics of structures with thickness span much smaller than other two directions. However, standard shell elements are incapable of capturing out of plane responses, which are ever more important in composite manufacturing. Therefore, in this work the focus is on implementation of the solid shell element, illustrated in figure (1) [4], which is capable of handling out of plane responses and full porous media theory as well as small thickness to in-plane length ratio.

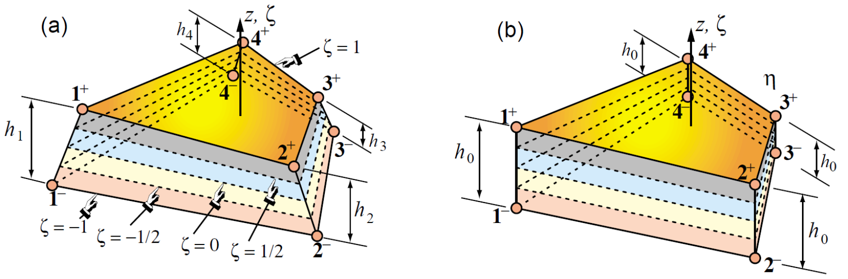

Figure 1: *Wall fabrication assumption for solid shell element. (a) constant thickness, (b) variable thickness. [4]*

Results

In order to demonstrate the results, a model example consisting of point infusion is considered. In particular the model is able to distinguish four different processing zones: i) fully saturated area, ii) partially saturated area, iii) flow front and iv) dry area consisting of compressible gas, as seen in figure (2).

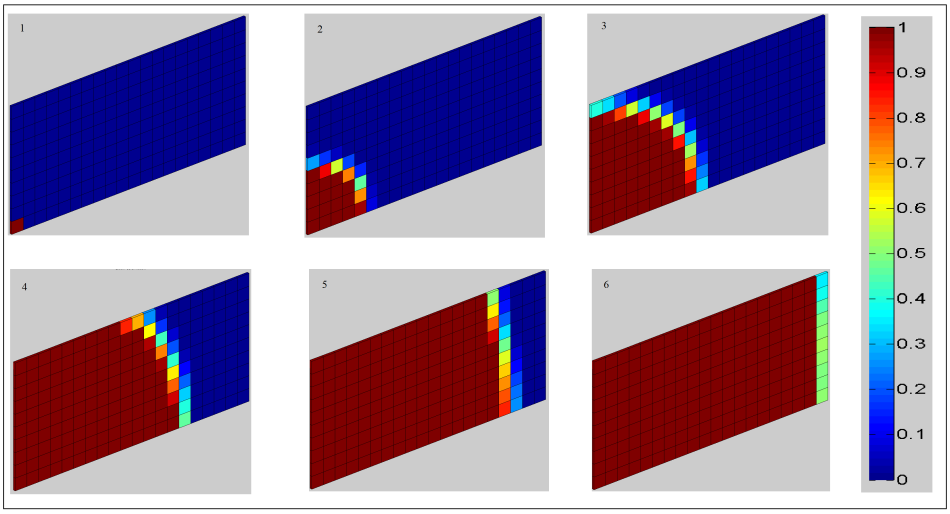

Figure 2: *The degree of saturation.*

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