PLANAR INFUSION FLOW MODELLING OF THIN-WALLED COMPONENTS WITH DEFORMABLE PREFORM

Da Wu*, Ragnar Larsson

Chalmers University of Technology, SE 412 96, Göteborg, Sweden.
*Corresponding author (dawu@chalmers.se)

Keywords: *process modeling; free surface flow; liquid composite molding*

Introduction

The vacuum assisted resin transfer modeling is one of the essential processes to produce large-scale thin-walled FRP components. To simulate the resin flow moving inside the preform, we provide a model to predict preform deformation together with the in-plain resin flow. Instead of a full 3-D model, the process is simplified as 2-D resin flow pass through the 3-D deformable preform ignoring the through-thickness flow. The model dramatically reduces the corresponding 3-D problem and increases the computational efficiency.

The model of pressure loaded preform

To represent a thin-walled preform deforming under the external atmospheric pressure (p^a) and the internal fluid pressure (p), we advocate a shell type formulation. We also assume that the top of the preform (B_0) can be only extended or compressed along the top surface (Ω_0) normal direction ($\boldsymbol{N}$). Also, the preform bottom is assumed fixed to the mold. The 2-D Darcy fluid can flow in between the preform top and bottom surfaces (in Figure 1).

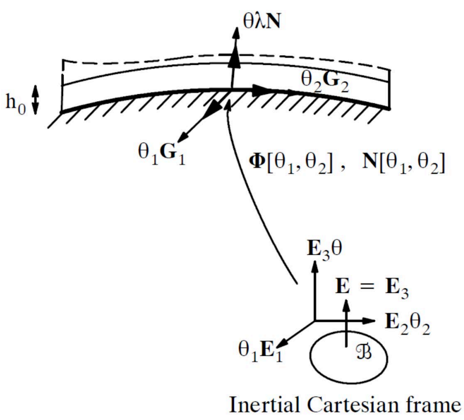

Figure 1: *The definition of (un)deformed configurations of the thin-walled preform and the mapping relating to the inertial Cartesian frame.*

The bottom of the preform position can be represented regarding the local curvilinear coordinates as $\boldsymbol{\Phi}[\theta_1,\theta_2]$, and the position of the top preform surface turns out to be $\boldsymbol{\Phi}+h_0\lambda\boldsymbol{N}$. The notation λ stands for the normal stretch that measures the preform thickness changes. For instance, when $\lambda=1$, the preform is unreformed; if $\lambda>1$, the preform thickness increases or $\lambda<1$ implies the preform is under compression. By using differential geometry tools, we can compute out the covariant base vectors ($\boldsymbol{G}_1,\boldsymbol{G}_2$ and $\boldsymbol{N}$), the differential line elements ($d\boldsymbol{X}$ and $d\boldsymbol{x}$), the surface area element ($d\Omega_0$) and the volume element (dB_0). By combining all inputs, we can derive the deformation tensor $\boldsymbol{F}$ and the right Cauchy Green strain tensor $\boldsymbol{C}$ in terms of stretch λ and normal $\boldsymbol{N}$. Once we insert $\boldsymbol{F}$ and $\boldsymbol{C}$ into the weak form of the linear momentum balance equation, and given the variables p, p^a and the stored free energy function based on the fiber packing law by Toll [1], we can explicitly solve out the stretch from,

$$\lambda = \left(1 + \frac{p^a - p}{k^s E (n_0^s)^m}\right)^{-1/m} \tag{1}$$

where m, $k^s E$ are parameters in the packing law and n_0^s is the initial fiber volume fraction.

Planar 2-D Darcy flow

We introduce an in-plane gradient operator ($\bar{\nabla}$) to transfer the volume integration in dB_0 to a surface area integration $d\Omega_0$, e.g., $\int_{B_0} \nabla \cdot \boldsymbol{v} \; dB = h_0 \int_{\Omega_0} \bar{\nabla} \cdot \bar{\boldsymbol{v}} \; d\Omega$. The corresponding variables, e.g., Darcy velocity, can be projected to the plane by using the projection tensor ($\bar{\mathbf{1}} = \mathbf{1} - \boldsymbol{N} \otimes \boldsymbol{N}$) as $\bar{\boldsymbol{v}} = \bar{\mathbf{1}} \cdot \boldsymbol{v}$. Implementing the in-plane operator and projection tensor in the model by Wu and Larsson [2], we obtain a set of mass balance equations for the planar Darcy flow on the preform surface.

The numerical example and result

The model developments are illustrated through the resin infusion of a double-curvature rectangular 1×1 m plate with a hole in the center. The resin inlet valve is placed in the middle of the bottom edge, and the outlet locates along the top side, cf. Figure 2. The plate is discretized to 882 quad elements. Figure 2 shows the top preform surface deformation and the embedded in-plane resin flow. As the resin migrates, it raises the pressure up and consequently increases the preform thickness. After full saturation, the top surface edges will move upwards and inwards. The in-plane resin flow patterns are also similar as observed in [2], which is a pure 2-D simulation.

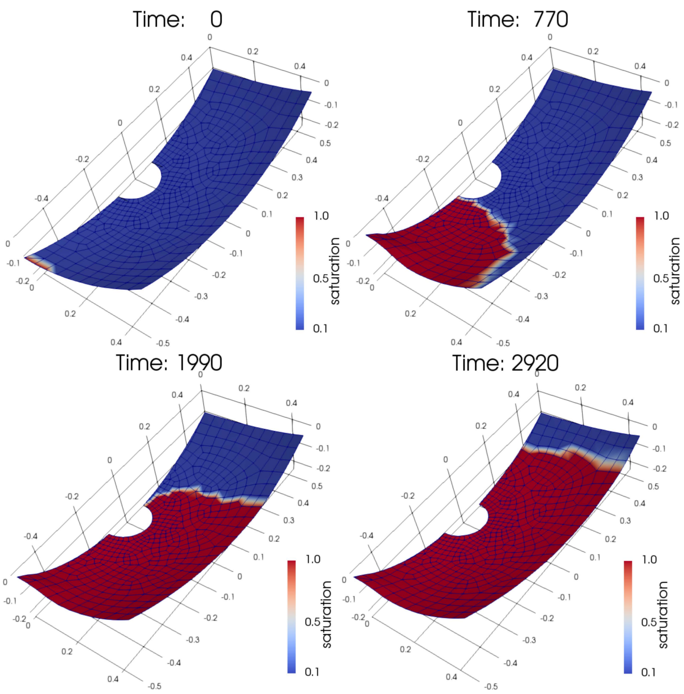

Figure 2: *Preform top surface deformation and resin flow patterns at different time steps.*

References

[1] Toll S. Packing mechanics of fiber reinforcements. *Polym Eng Sci*, 56(8):133-150, 1998
[2] Wu D, Larsson R. Homogenized free surface flow in porous media for wet-out processing. *International Journal for Numerical Methods in Engineering* 1(17), 2018. doi:10.1002/nme.5812.