RESIN AND POROSITY REDISTRIBUTION DURING CONSOLIDATION

P.Šimáček[1*], S.G. Advani[1]

[1] *University of Delaware, Department of Mechanical Engineering and Center for Composite Materials, 202 Composites Manufacturing Science Laboratory, Newark, DE 19716, United States.*
*Corresponding author (psimacek@udel.edu)

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Introduction

In several prepreg-based manufacturing techniques such as Autoclave, Out of Autoclave processing and Automated Tape or Tow Placement, the stacked prepreg material is placed on the tool surface and consolidated by the application of temperature and pressure. The prepreg consists of resin, fibers and non-trivial volume of porosity. The consolidation should reduce the thickness, increase the fiber volume fraction and reduce the porosity to desired limits. The goal of modeling such processes is to estimate the development of thickness and porosity during the consolidation process.

Multiphase Consolidation Physics

The present modeling approaches falls short of providing accurate estimates, particularly in corners and bends of non-planar parts. This is because the current models tend to describe the consolidated material as a continuum with some "effective viscosity" and elastic properties of the material as inputs to a FEM package to determine the global deformation based on the assumption that that the material is a single viscous continuum. This is far from observed behavior that happens during the consolidation process as schematically shown in Figure 1.

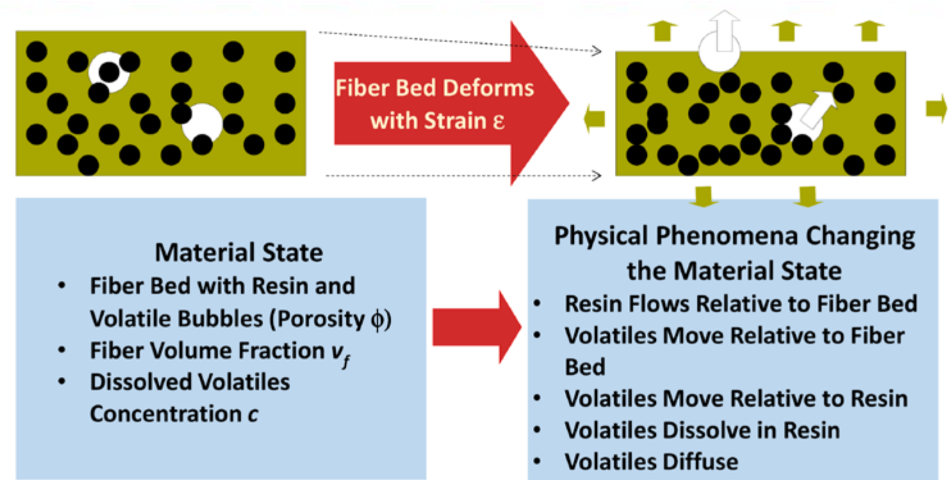

Figure 1: *The physical phenomena changing the material state during the consolidation process*

It is clear that the reinforcement behaves as a porous medium with not insignificant elastic or, visco-elasto-plastic deformation. In addition due to applied or induced pressure gradients, the resin flows through the fibrous medium to fill available porous space or bleed out. The flow is driven by the pressure field within the resin and this pressure field has to be added to stress exhibited by the fibrous bed. At the same time, the resin convects volatiles at different velocity relative to the reinforcement. The diffusion and dissolution of volatiles adds to the transport of volatiles. Thus, the presence of porosity will greatly affect the deformation characteristics as the fluid can no longer be considered as incompressible.

The most significant challenge is to describe the relative motion of the individual components: Solid fibrous reinforcement, liquid resin and gaseous porosity. While some components of this system can be successfully modelled by existing numerical packages, the underlying coupling between these components calls for a new approach which will be described in this presentation.

Modeling Approach

To study the process mechanics, we present a simplified one-dimensional through-the thickness model of consolidation in radial (or flat) geometry. The geometric simplification allows one to capture much of the physics described above and study the system behaviour based mainly on material, not geometric parameters. In this system we describe the behaviour in a single (through the thickness) dimension and time. The in-plane behavior is assumed to provide only the membrane stress in the reinforcement which tends to have a significant impact on consolidation away from flat regions.

The simplification is limiting, but a number of important cases can be described in such a way as shown in Figure 2, namely consolidation of flat and corner geometry of prepreg or tape material placed over rigid tool and consolidation supported only by edges and normal pressure as encountered in sandwich panels and whenever material bridges in corners of the tool.

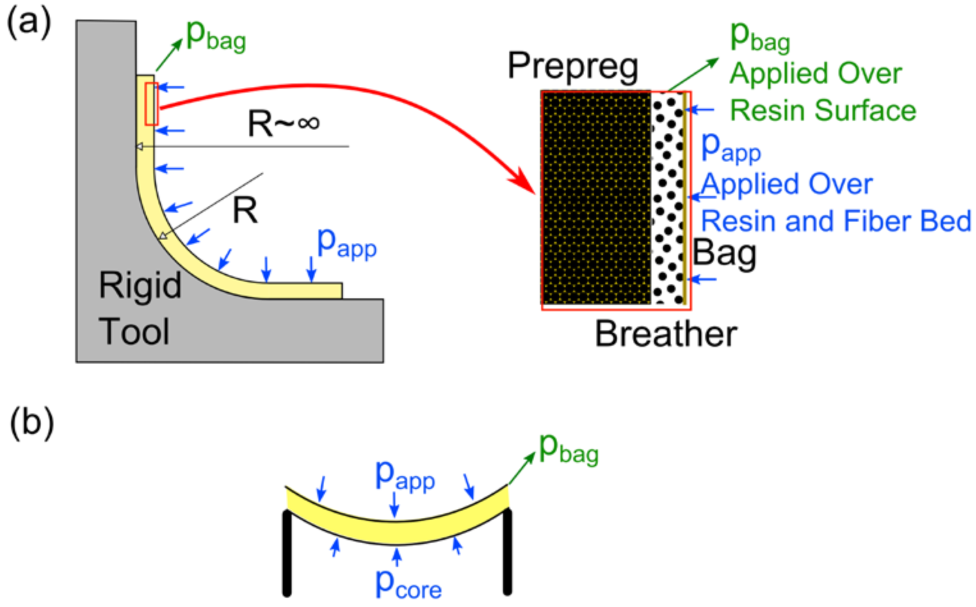

Figure 2: *Consolidation cases that can be modeled with simple geometric approach (a) Flat and corner consolidation on a rigid tool and (b) Unsupported consolidation over sandwich core or bridged corner. Note that the arrangement of vacuum bag and breather may allow independent control of resin pressure and total stress on bag surface.*

The model governing equations are formulated to describe conservation of momentum and mass of resin and volatiles. Within the coordinate reference given by the solid reinforcement we couple the relative flow of resin to the deformation of porous reinforcement and evaluate the resin transport through the reinforcement thickness. We extend this description to account for the transport of volatiles (dissolution, convection and diffusion) to determine the development of porosity in the system. Thus, the evolution of fiber volume fraction, porosity and resin bleeding is predicted. The time-frame at which individual physical phenomena influence the consolidation behavior is analyzed. The impact of independent pressure and vacuum control will also be demonstrated.