# Modeling Void Drainage with Thin Film Dynamics

J.J. Gangloff Jr. [1], W.R. Hwang[2], S.G. Advani[1]

[1]Center for Composite Materials, Department of Mechanical Engineering, University of Delaware, Newark, DE, USA

[2]School of Mechanical Engineering, Gyeongsang National University, Jinju, Gyeongsangnam-do, Korea

## Abstract

Voids in polymer matrix composite materials can lead to degraded structural performance. The following is a study of voids or bubbles in uncured viscous polymer resin during processing. The goal is to determine if voids can successfully migrate through fibrous porous media towards vacuum pathways, coalesce with the pathways, and escape under processing conditions. Precursor to the coalescence process is the drainage and rupture of the resin thin film formed between voids within the resin in the proximity of the resin free surface. Figure 1 describes a simplified model schematically. Note the presence of air evacuation and flow due to applied vacuum and resin flow near the embedded void. It will be important to establish how these flows induce the movement of the void which in turn needs to rupture through the resin interface before it merges with the air being evacuated by the applied vacuum. The ability of the void to break through the resin surface will be a function of the resin thin film dynamics as the void approaches the air-resin interface. For this work, the scope is focused on the establishment of resin thin film dynamics under the influence of body forces and surface tension effects only with no fibers and is modeled using COMSOL. COMSOL Multiphysics 4.2 Microfluidics Module is employed for modeling. The model consists of a single spherical void in a cylindrical axisymmetric two-phase domain of resin and air. Figure 2 and Table 1 displays the simplified model schematically with baseline parameters. COMSOL was used to solve the transient problem with initialization of the laminar two-phase flow with the Level Set Method. Of interest are the interface evolution between resin and air in time, in which the influence of interfacial tension between resin and void and the body force (buoyancy) is accounted for. The air domain is modeled as a fictitious fluid with the viscosity and density being 100 times smaller than those of the resin to avoid large difference in magnitude in the final assembled stiffness matrix, but at the same time to address the differences in the physical behavior of the air from that of the resin. The key results of this work are the change in resin thin film thickness h_g versus time. Figure 3 displays a plot of log scale non-dimensional film thickness versus linear scale non-dimensional drainage time as a function of the Bond number (Bo). Note that Bo = 0.0 represents the analytical solution of a void of either very small size or very high surface tension. In general, increasing Bo leads to longer thin film drainage time between Bo = 0.0 to Bo = 1.0. The linear trend on the log-linear scaled plot implies an exponentially decaying thin film thickness. This trend was observed experimentally in [1] for gas bubbles in a viscous fluid. Void dynamics were found to be strongly dependent on void body force and surface tension effects as characterized by Bo. Results suggest that resin thin film drainage can be successfully modeled as an exponential decay, though

thin film rupture modeling is limited due to mesh dependency issues attributed to the fact that results are suspect once the film becomes thinner than the film element size. Knowledge of thin film drainage information can provide valuable insight into void removal efficiency. Implications of this work can be applied to many fields where gas bubble migration through viscous fluids is of interest (i.e. oil & gas industry, biomedical engineering, MEMS, etc.).

## Reference

1. G. Debrégeas, The Life and Death of “Bare” Viscous Bubbles, Science. 279 (1998) 1704-1707.
2. P. Howell, The draining of a two-dimensional bubble, Journal of Engineering Mathematics. 35 (1999) 251–272.
3. F. Pigeonneau, A. Sellier, Low-Reynolds-number gravity-driven migration and deformation of bubbles near a free surface, Physics of Fluids. 23 (2011) 092102.
4. P.J. A. Janssen, P.D. Anderson, Modeling Film Drainage and Coalescence of Drops in a Viscous Fluid, Macromolecular Materials and Engineering. 296 (2011) 238-248.
5. E. Olsson, G. Kreiss, A conservative level set method for two phase flow, Journal of Computational Physics. 210 (2005) 225-246.

# Figures used in the abstract

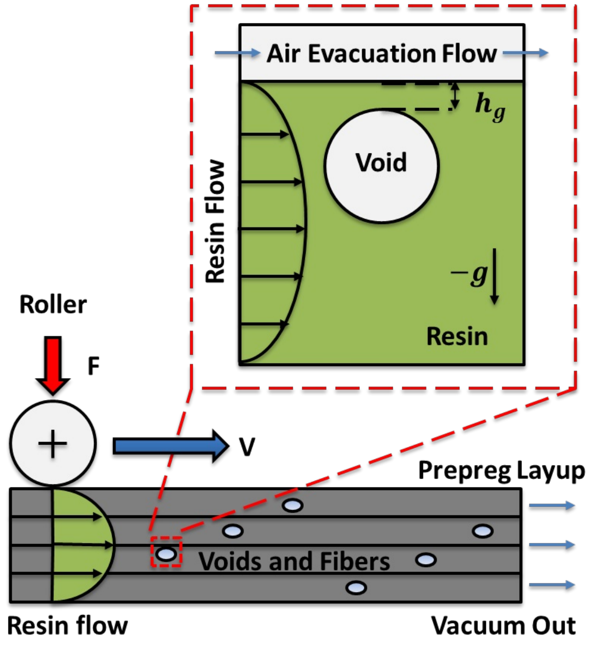
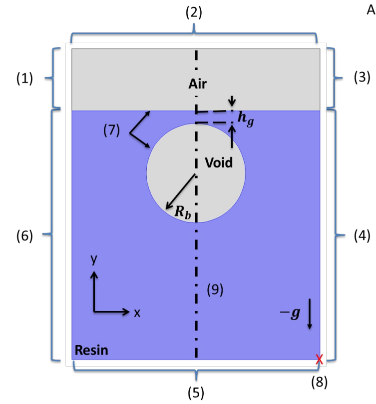


**Figure 1**: Void migration during composite processing. External pressure is applied to encourage void migration. Note the resin thin film at thickness h_gformed between voids and vacuum pathway free surfaces.



Axisymmetric 2D Baseline Model Setup

| Parameters | Values |
|---|---|
| Domain width | 1.00 mm |
| Domain height | 1.25 mm |
| Void radius, $R_b$ | 0.20 mm |
| Thin film thickness, $h_g$ | 0.05 mm |
| Interfacial tension, $\sigma$ | 0.03 N/m |
| Level set reinitialization, $\gamma$ | 0.001 m/s |

| Phase | Density, $\rho$ [kg/m$^3$] | Viscosity, $\eta$ [Pa-s] |
|---|---|---|
| Resin | 1000 | 10 |
| Air | 10 | 0.1 |

| Edge ID | Boundary Condition |
|---|---|
| (1)-(6) | No slip wall |
| (7) | Initial air-resin interface |
| (8) | Pressure point constraint |
| (9) | Axis of Symmetry |

**Figure 2**: The figure displays the axisymmetric 2D baseline model setup with parameters as shown.

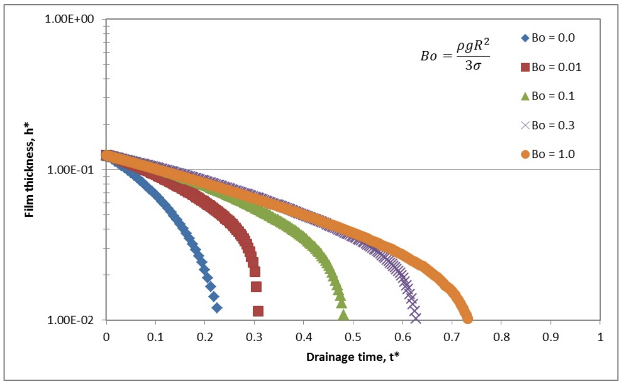


**Figure 3**: Resin thin film thickness versus drainage time.