Modeling Void Drainage with Thin Film Dynamics

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Introduction:

- Voids in composites can degrade structural performance
- The following is a study of voids or bubbles in uncured viscous polymer resin during composites processing
- The goal is to determine if voids can successfully migrate towards vacuum pathways, coalesce with the pathways, and escape
- Inherent to the coalescence process is the drainage and rupture of the resin thin film formed between voids and the resin free surface

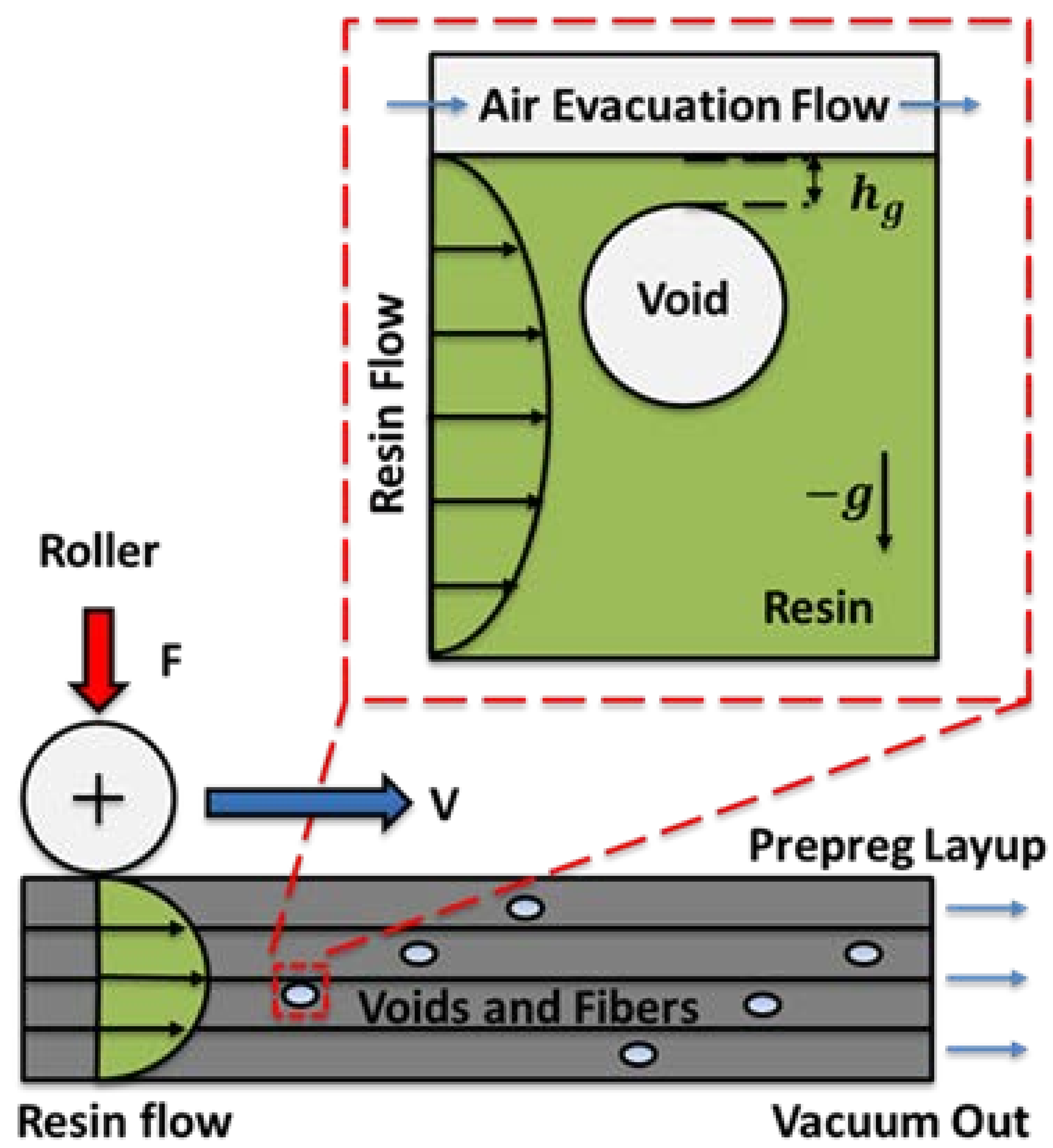

Figure 1. Void migration during composite processing. External pressure is applied to encourage void migration. A resin film of thickness h_g is formed between voids and vacuum pathway free surfaces.

Computational Methods:

- COMSOL Multiphysics 4.2 + Microfluidics module is employed for numerical solution
- The model consists of a single spherical void in a cylindrical axisymmetric two-phase domain of resin and air
- COMSOL is used to solve the transient problem with initialization of the laminar two-phase flow with the Level Set Method
- Of interest is:
  i. The interface evolution in time between resin and air
  ii. Influence of interfacial tension between resin, void and the body force (buoyancy)
  iii. Dimensionless Bond number: $Bo = \rho g a^2/3\gamma$
- Governing Equations:
  i. Navier-Stokes (incompressible): $\rho\left(\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u}\cdot\nabla\boldsymbol{u}\right) = -\nabla p + \mu\nabla^2\boldsymbol{u} + \boldsymbol{f}$
  ii. Continuity: $\nabla\cdot\boldsymbol{u} = 0$
  iii. Level-Set: $\Phi_t + \boldsymbol{u}\cdot\nabla\Phi = 0$

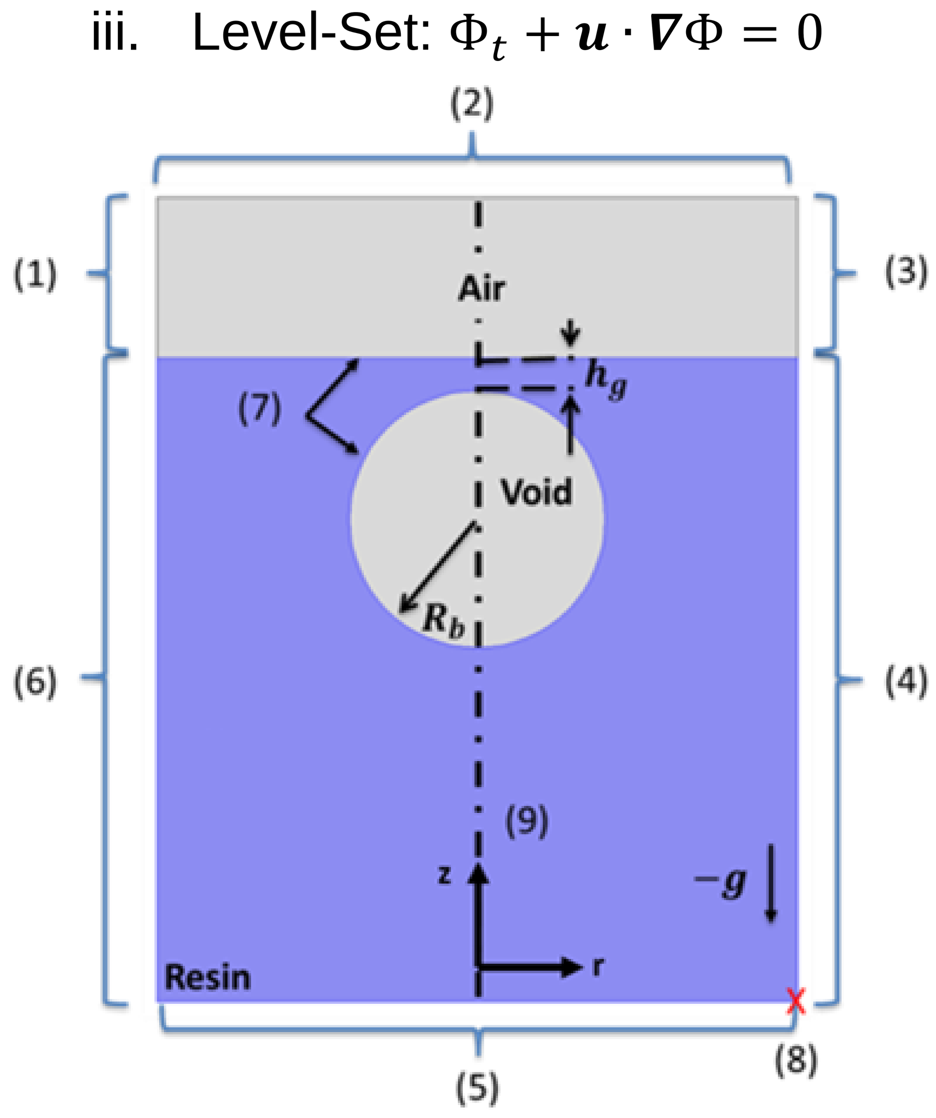

Figure 2. Axisymmertic baseline model setup with parameters defined in Table 1

Parameters	Values
Domain width	1.00 mm
Domain height	1.25 mm
Air domain thickness	0.25 mm
Void radius, R_b	0.20 mm
Thin film thickness, h_g	0.05 mm
Interfacial tension, σ	0.03 N/m
Level set reinitialization, γ	0.001 m/s

Phase	Density, ρ [kg/m^3]	Viscosity, η [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

Table 1: Axisymmetric 2D baseline parameters

Results:

- Figure 3 displays a plot on the log scale of non-dimensional film thickness versus non-dimensional drainage time as a function of the Bond number (Bo)
- The resin film thickness is non-dimensionalized with respect to the initial void radius (i.e. $h^* = h/2a$)
- The drainage time scales (i.e. $t^* = tga/6\nu$) with ν the kinematic viscosity of the resin

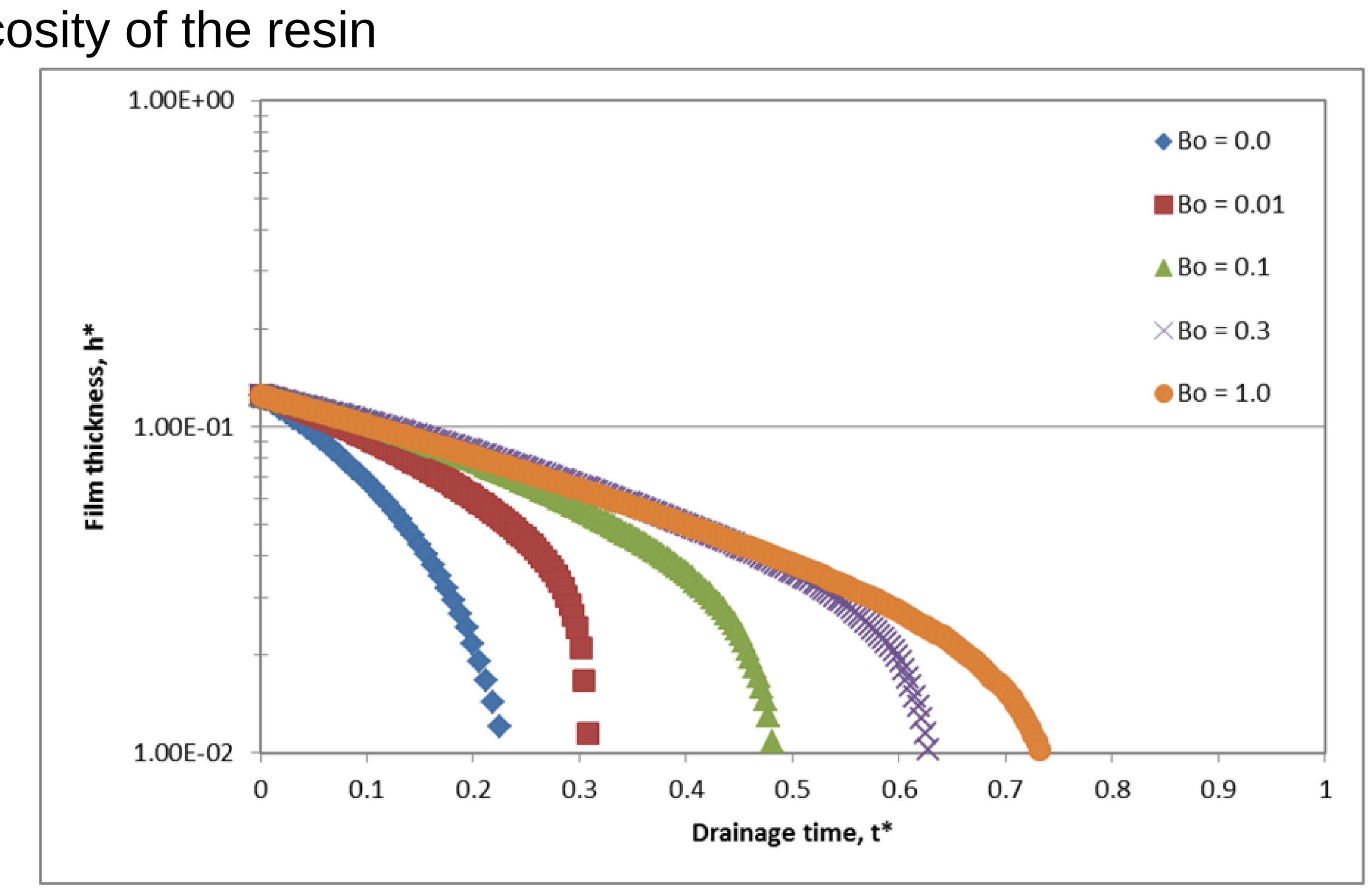

Figure 3. Reduction in interface film thickness as a function of time

- In Figure 4, the drainage curves are generated with two different mesh sizes called M1 and M2
- The linear region representing the exponential drainage of the interface film is formed
  - The rupture times (i.e. x-axis intercept) are different
- The Level Set Method breaks down in accuracy, leading to instability and artificial bubble rupture during drainage
  - The film becomes thinner than the thickness of the film elements
- The exponential drainage constant can be extracted
  - One can predict a general time scale for void rupture

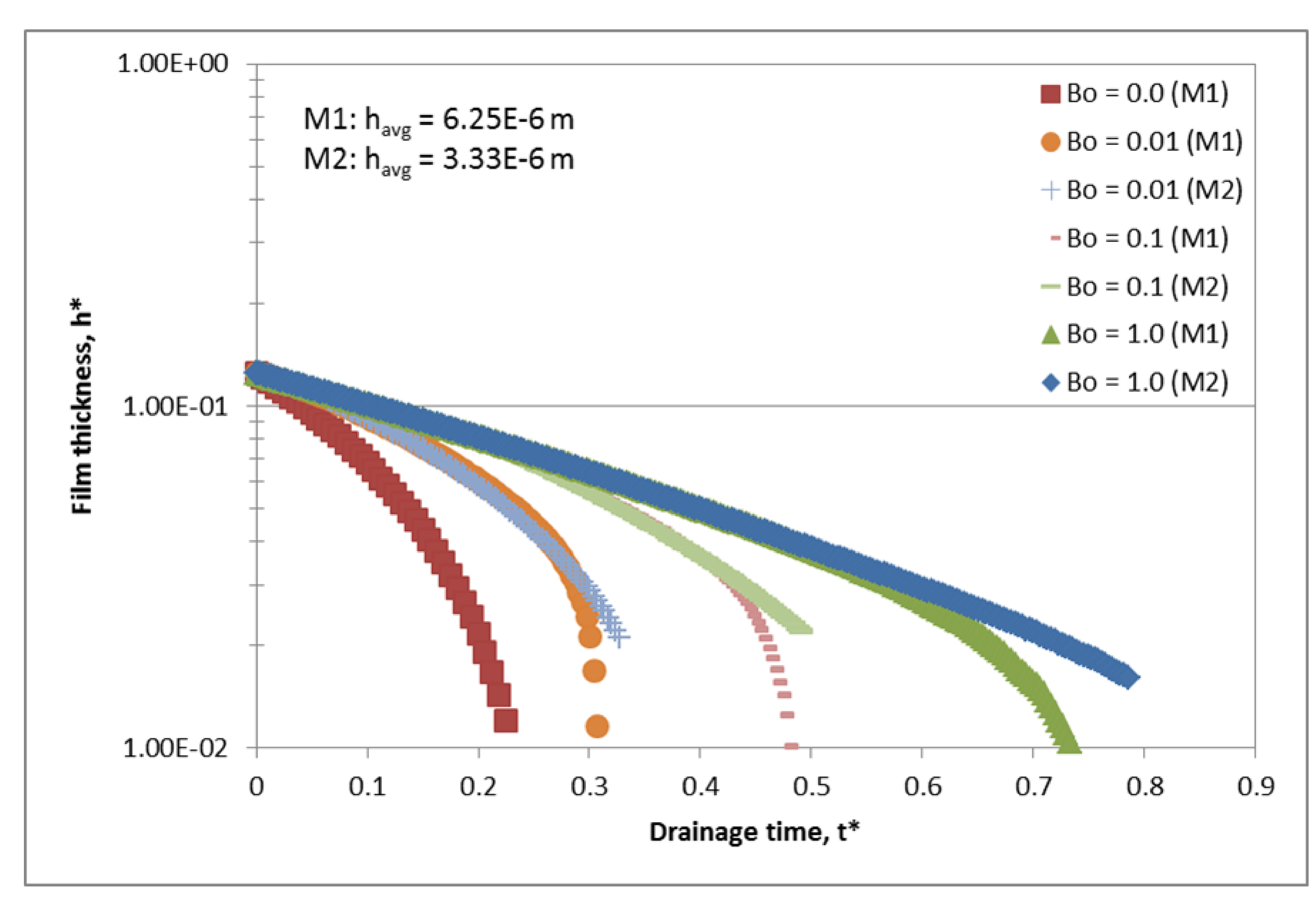

Figure 4. Resin thin film thickness mesh dependence

Conclusions:

- Void dynamics were found to be strongly dependent on void body force and surface tension effects as characterized by Bo
- Results suggest that resin film drainage at the interface with the bubble can be successfully modeled as an exponential decay
- Results are suspect once the film becomes thinner than the film element size
- Knowledge of film drainage information can provide valuable insight into void removal efficiency

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