17th International Conference on
Flow Processes in Composites Materials (FPCM17)
Sheffield, United Kingdom, 30 June to 02 July 2026.

TITLE: Development of a Multiphysics Two-Phase Solver for Porosity Prediction in Prepregs Laminates

AUTHOR(S): Anne-Lise Briard[1,2,a*], Raffaele D'Elia[1], Florentin Berthet[1], Anthony Cheruet[2] and Fabrice Schmidt[1]

AFFILIATION(S): [1]Institut Clément Ader (ICA), Université de Toulouse, CNRS, IMT Mines Albi, INSA Toulouse, ISAE SUPAERO, UT3, 31400 Toulouse, France

[2]Airbus Operations SAS, 316 route de Bayonne, 31300 Toulouse, France

[a]anne-lise.briard@mines-albi.fr (*corresponding author)

ABSTRACT:

Keywords: Porosity, Thermoset Prepreg, Flow Simulation, Porous Medium.

I. Introduction

While porosity in traditional thermoset prepreg composites is well-controlled during autoclave processing, new manufacturing challenges are emerging in the aeronautics sector. The demand for accelerated manufacturing processes to increase productivity (e.g., rapid curing cycles or out-of-autoclave processes) is growing. At the same time, the development of advanced materials such as thermoplastic-toughened prepregs, introduces new process parameters that can generate void content [1]. Porosity is a defect known to significantly degrade the mechanical properties and durability of the final composite parts [2].

Numerical modelling is required to better understand and predict defect formation and evolution. While macro-scale models are useful for process optimization, they are based on homogenized properties and cannot capture the local physics governing bubble nucleation, growth, and transport at the fibre level. This work aims to overcome these limitations by developing a micro-scale model. The primary objective is to create a predictive tool capable of simulating how local fibre architecture and process parameters interact to control void formation and evolution.

II. Methodology

The research is conducted using the open-source CFD software OpenFOAM, based on the Finite Volume Method (FVM). A custom, multi-physics, two-phase compressible solver has been developed to capture the complex phenomena occurring during the curing process. The Volume of Fluid (VoF) method is employed to track the evolution of the resin-gas interfaces. This new solver fully couples several key physics:

- the resin's cure kinetics (polymerization);
- the evolution of resin viscosity as a function of both temperature and degree of cure;
- the exothermic heat of reaction generated by the polymerization.

This new solver developed is used to simulate the evolution of bubble populations within representative volumes of a prepreg ply, created to match a specified fibre volume fraction. These geometries feature a random distribution of fibres to represent the realistic microstructure of the material, as shown in Figure 1.

Industrial processing conditions are replicated by imposing autoclave-like temperature and pressure cycles as boundary conditions to the representative volumes. This allows for the direct simulation of how processing parameters influence void dynamics (growth and transport) at the micro-scale. The solver is designed to simulate the entire manufacturing process, which is broadly divided into two main phases:

- Compaction phase: an external pressure is applied to mimic the consolidation of the laminate stack. This phase captures the corresponding resin redistribution within the spaces between fibres. The model resolves the evolution of the flow field within the porous network, thereby enabling a detailed assessment of the initial void content generated during compaction.
- Curing phase: following compaction, the model applies industrial autoclave-like temperature and pressure cycles as boundary conditions. The solver tracks the void dynamics (growth, shrinkage, and transport) as the resin's properties evolve. A key focus is the variation of resin viscosity, which is affected by the local temperature field.

Preliminary results indicate that both the applied compaction pressure and the viscosity profile strongly influence the porosity and bubble radius, according to literature review [2].

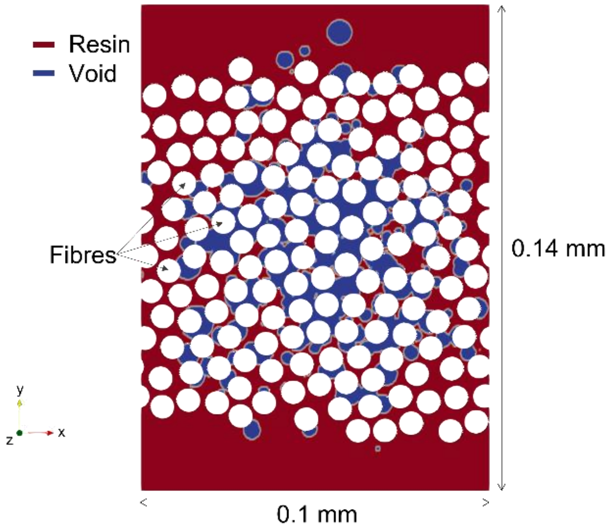

Figure 1 – Example of an RVE of a prepreg ply with porosity used in the simulation.

III. Current capabilities and future work

The primary achievement of this work is the development of a robust, custom multi-physics solver. This framework provides the capability to simulate bubble nucleation and evolution within realistic, fibre-scale representative volumes subjected to industrial manufacturing cycles.

Ongoing developments aim to improve the solver through the integration of moisture diffusion, which plays a key role in the formation and evolution of porosity in prepregs [3]. Future work will extend the model to incorporate additional factors such as layer stacking sequence, and the homogenisation from microscale in OpenFOAM to macroscale in the finite element software Abaqus, using a reduced-order modelling approach. This scale-bridging will enable part-scale manufacturing process simulation with higher fidelity compared to the semi-analytical models currently in use.

Furthermore, an experimental validation campaign is planned to support and validate the numerical model. This campaign will track the evolution of pore morphology during the compaction and curing process. Initial tests will be conducted using X-ray tomography, followed by in-situ 4D monitoring on a synchrotron beamline to capture the void dynamics in real-time during compaction and polymerisation.

References

[1] Kermani, N. N., Simacek, P., Advani, S. G., Porosity predictions during co-cure of honeycomb core prepreg sandwich structures, Composites Part A: Applied Science and Manufacturing, 132, 105824 (2020). https://doi.org/https://doi.org/10.1016/j.compositesa.2020.105824
[2] Mehdikhani, M., Voids in fiber-reinforced polymer composites: A review on their formation, characteristics, and effects on mechanical performance. *Journal of Composite Materials*, *53*(12), 1579–1669 (2018).
[3] Grunenfelder, L. K., Nutt, S. R, Void formation in composite prepregs-Effect of dissolved moisture, (2010). https://doi.org/10.1016/j.compscitech.2010.09.009