# NUMERICAL MODELLING OF VOID BEHAVIOUR

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## Introduction

Voids remain the most prolific manufacturing defect, and while the reduction in mechanical performance due to voids is well understood, the initial size, distribution, and evolution of voids during the manufacturing process is not. In this study, a numerical method is developed to simulate void formation, compression and motion. This solves a mass-pressure system based around a Darcy-type pressure/velocity relation, where the pressure field is calculated such that mass conservation is ensured during the curing and compression process.

For validation, and to allow accurate modelling, accompanying experiments were conducted. These measurements were made using surface scanning of a 3.5mm x 3.5mm sample of prepreg backed by a glass slide, which was then subjected to a representative curing cycle. The computational method was then initialised using these surface scans of the resin, such that the fluid started at an accurate initial position, and final results of this work will illustrate how the methods are able to determine the influence of consolidation pressure and temperature profile on void content during manufacture.

## Numerical Model

The discrete representation of the fluid system is shown in figure 1. In the simplified example considered for this work, a single prepreg resin layer is compressed between two impermeable walls (the upper one of which is glass in the experiment, to permit detailed scanning of the resin surface shape).

Within every two-dimensional cell, there is a local fluid height, and as the upper wall moves, the fluid in these cells is forced laterally from the cells and towards void spaces. Simulations use periodic boundary conditions in all four compass directions on a unit cell to replicate as closely as possible an infinite domain. The model is based on conservation of mass $\nabla \cdot \boldsymbol{v} = 0$ and $\boldsymbol{v} = f(\nabla p)$. The conservation of mass equation is used to iterate the pressure field, until conservation of mass is adequately satisfied in every finite volume cell, at which point the solution procedure for pressure at that timestep is complete.

Once a timestep is complete, a second-order backward integration procedure is used to update cell heights. The compression and motion of the voids is closely linked to the motion of the compressing wall, but this is of course itself a function of the resin and void pressures. To correctly couple the motion of the upper wall to the applied pressure forces, a Newton iteration is used to solve for the wall velocity at each timestep, such that the net force acting on it at each timestep is zero. This means each individual timestep is solved repeatedly, until satisfactory force equilibrium is achieved.

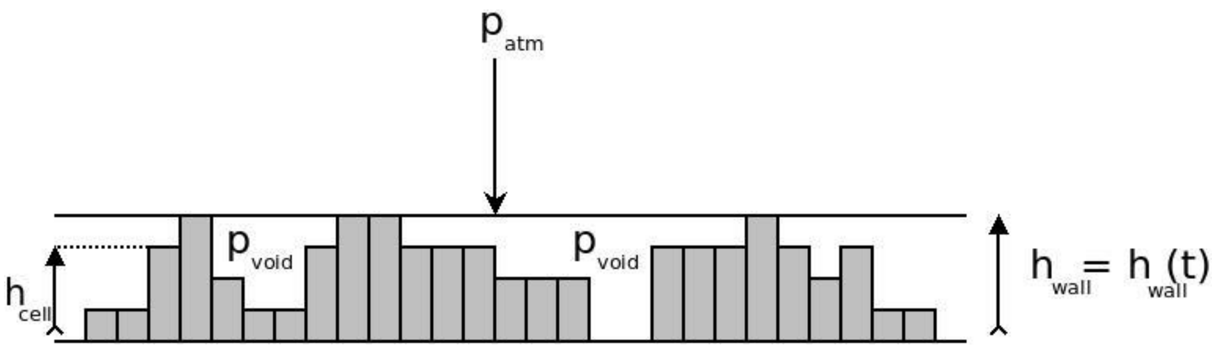


**Figure 1**: numerical model layout (sectional slice)

Gas pressure is found within voids through an ideal gas relationship, in a manner that allows gas voids to split or merge, whilst preserving total mass of entrapped gas. The motion of the resin is fully coupled to the gas pressure field, so voids can expand and force the fluid back from the void if the pressure is sufficiently high.

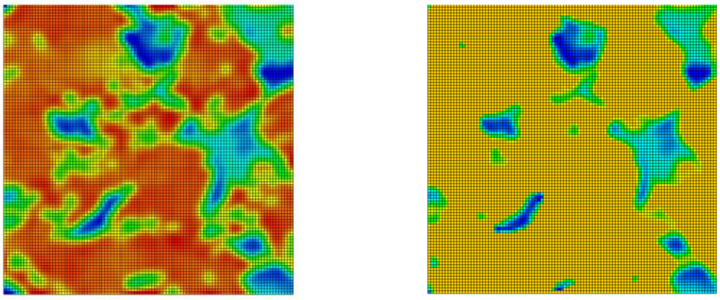

**Figure 2**: resin height distribution before (left) and after (right) compression process. Red – high fluid height, blue – low fluid height

Figure 2 illustrates how voids are compressed and move throughout the compression process for a 3.5mm square section of the test sample (in this case with 1atm of applied pressure). At the same time, the height position of the wall reduces, which alters the void content. As the temperature profile ramps up, the viscosity falls and the wall compresses the resin/void mix. Finally, the model includes a preliminary behaviour for moisture, which allows steam to form in the voids, and results in the void pressures increasing and the void volume rising.

Although the initial resin surface is accurately known, there is uncertainty surrounding the initial gas pressures, which leads to uncertainty in the final void percentages predicted by the model. The final version of this work will include comparisons with experiment and a detailed discussion of the numerical model.

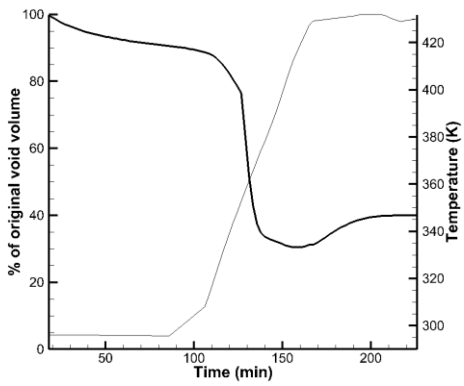


**Figure 3:** void percentage and temperature during curing. Note an initial non-physical transient for <5min has been removed.