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**TITLE:** Multi-scale two-phase flow modelling of bubble migration during resin transfer moulding in fibre-reinforced composites

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**ABSTRACT:**

In mould-filling processes for fibre-reinforced composites (e.g., resin transfer moulding, vacuum infusion), the formation and migration of air bubbles critically impact the quality of the final part, leading to voids, poor impregnation, and mechanical weakness. To better understand and predict this phenomenon, we develop a multi-scale homogenization model for two-phase (air-resin) Darcy flow. This model ensures two-way coupling of pore-scale physics with the mesoscopic scale. At the microscale (fibre scale), we solve the two-phase Stokes equations with surface tension effects. Our framework relies on a finite-element level-set method to track the evolving resin/air interface via a continuum surface force model for surface tension. The resulting microscale velocity fields and interfacial dynamics feed into a homogenized mesoscopic model derived by multi-scale virtual power principles, which captures the influence of microstructure (fibre geometry, porosity) on the effective transport behaviour.

We implement a strongly coupled resolution between scales: the mesoscopic flow predicts pressure and saturation distributions, while the microscale solver refines the interface position and computes effective properties. The model is validated against benchmark test cases (e.g., static bubble, square bubble), and then applied to simulate bubble migration in fibre tows. Our results show that the multi-scale approach can significantly reduce computational cost compared to full pore-scale simulations, while preserving predictive capacity for bubble migration velocities. We also analyse how fibre volume fraction and processing parameters (injection rate) influence migration velocity.

This modelling framework provides a powerful tool for process optimization, enabling designers to predict void risk and adjust process parameters (e.g., injection strategy, fibre architecture) to minimize bubble entrapment and improve part quality.

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