6 months Internship Offer 2025: Modeling of Gas Bubbles in a UD Carbon/Epoxy Laminate for Aerospace Applications Using OpenFOAM

Location: Institut Clément Ader – IMT Mines Albi, France

Context: In the aerospace field, carbon/epoxy laminated composite materials are widely used for their high specific mechanical properties. However, manufacturing these materials presents challenges related to the formation of internal defects, such as gas bubbles [1]. These bubbles can form during the epoxy resin curing process, affecting the final mechanical properties of the composite. The causes and mechanisms behind the formation and evolution of these pores within the laminate are still not fully understood. Therefore, modeling pores at the scale of a unidirectional (UD) ply during composite compaction and curing would help to better predict these complex phenomena. The use of computational fluid dynamics (CFD) offers the advantage of modeling the complex flow of fluids (resin, gas) while accounting for the rheological and thermodynamic behavior of the resin. The *open-source* CFD software OpenFOAM is particularly suited for this work, as access to the source code allows both the use of solvers developed by the scientific community and the implementation of new solvers tailored to the case study.

Internship objectives: This internship offers the opportunity to work on modeling, using the open-source CFD software OpenFOAM, the nucleation and growth of gas bubbles in an epoxy matrix within a unidirectional carbon/epoxy ply used in aerospace applications, as well as their interaction with carbon fibers and bubble coalescence. For this internship, the solvers *interFoam* (multiphase modeling), *bubbleFoam* (bubble growth and coalescence in a liquid phase), and *reactingTwoPhaseEulerFoam* (chemical reaction and mass transfer between two phases) will likely be used. Additionally, the micro-continuum approach and associated solvers [2,3,4] may be utilized. The micro-continuum approach allows the resin and gas bubbles to be treated as continuous media while accounting for microscopic-scale interactions. This approach introduces an intermediate modeling framework between a purely macroscopic description and a discrete approach, suitable for the complex interactions between the liquid phase, gas bubbles, and fibers in a composite material.
The work will first focus on improving an existing bubble growth model developed in OpenFOAM, specifically using various solvers implemented in OpenFOAM. In the second phase, this model should include a bubble nucleation model. The results will then need to be validated against experimental data or findings from scientific literature.

Profile: Final-year engineering student or Master's student specializing in fluid mechanics, materials engineering, numerical simulation, or related fields.

- Proficiency in the principles of computational fluid dynamics (CFD).
- Practical experience with OpenFOAM (or other CFD simulation software) preferred.
- Knowledge of composite materials, particularly carbon/epoxy laminates, and polymer rheology.
- Programming skills (C++, Python, or similar) for implementing models in OpenFOAM would be an asset.

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Duration: 6 months **Level:** Engineering school, last year **Start:** February 2025

References:

[1] Plessix, B. P. du. (2016). Analyses et modélisation du développement de porosités lors de la cuisson de pièces composites thermodurcissables hautes performance. *Http://Www.Theses.Fr*. http://www.theses.fr/2016NANT2132
[2] Soulaine, C., & Tchelepi, H. A. (2016). Micro-continuum Approach for Pore-Scale Simulation of Subsurface Processes. *Transport in Porous Media*, *113*(3), 431–456.
[3] Carrillo, F. J., Bourg, I. C., & Soulaine, C. (2020). Multiphase flow modeling in multiscale porous media: An open-source micro-continuum approach. *Journal of Computational Physics: X*, *8*, 100073.
[4] Carrillo, F. J., & Bourg, I. C. (2019). A Darcy-Brinkman-Biot Approach to Modeling the Hydrology and Mechanics of Porous Media Containing Macropores and Deformable Microporous Regions. *Water Resources Research*, *55*(10), 8096–8121.