

A Multiscale Modelling Framework for Additively Manufactured Heat Exchangers

L. Cibrario⁺, I. Cozza^{*†}, C. Delprete⁺, A. Ferrero⁺, C. Gastaldi⁺, W. Cherkaoui⁺

⁺Department of Mechanical and Aerospace Engineering
Politecnico di Torino – Corso Duca degli Abruzzi 24, 10129 Torino, Italy

[†] Dumarey Automotive Italia S.p.A.
Corso Castelfidardo, 36, 10129 Torino, Italy

ABSTRACT

Additive manufacturing (AM) enables the realization of compact heat exchangers (HX) with highly complex internal architectures that cannot be achieved through conventional methods. In this context, Triply Periodic Minimal Surface lattice (TPMS) structures have emerged as particularly attractive solutions for aerospace and motorsport applications, where strict constraints on weight, volume, and efficiency apply. However, the numerical characterization of such devices remains challenging, since direct CFD simulations resolving the full lattice geometry are computationally unfeasible at component scale. This work presents a dedicated multiscale CFD framework for the thermal–fluid dynamic characterization of additively manufactured heat exchangers based on TPMS. The approach relies on a two-levels modelling strategy that links microscale lattice behaviour to macroscale component performance. At the microscale, an innovative conjugate heat transfer homogenization scheme is developed for representative volume elements composed of three coupled domains: two fluid streams and the solid lattice. Periodic boundary conditions are imposed on all representative volume element (RVE) boundaries, while a prescribed mean inlet temperature is enforced, avoiding the introduction of artificial volumetric heat sources and ensuring energetic consistency. This formulation represents an evolution of existing homogenization approaches and enables the robust extraction of effective properties [1]. The microscale response is condensed into surrogate models as functions of the operating conditions. Flow resistance is represented through a Darcy–Forchheimer law, while convective heat transfer is described via Nusselt-based correlations, capturing transitions between conduction- and convection-dominated regimes. These homogenized models are then embedded into a full-scale porous-medium representation of the heat exchanger core. Component-level simulations are carried out in OpenFOAM using a dedicated conjugate heat transfer solver [2]. The framework is validated against literature experiments on a full-scale liquid–liquid heat exchanger [3]. Predicted heat transfer and pressure losses from the homogenized approach are compared with both high-fidelity full-geometry CFD and experimental data.

REFERENCES

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