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Numerical parametric analysis of Triply Periodic Minimal Surfaces with deep learning

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Triply Periodic Minimal Surfaces (TPMS) have been gaining interest in recent years as structured porous medium in numerous engineering applications [1], including compact heat exchangers [2], [3], [4], heat sinks [5] and phase change materials [6]. TPMS are periodic lattices generated by the combination of sine and cosine functions in 3D, the manufacturing of which has been enabled by the deployment of Additive Manufacturing (AM) techniques. TPMS have large surface-to-volume ratio and no sharp edges, which enable high heat transfer efficiency, while simultaneously maintaining the pressure drops low. Different combinations of trigonometric functions may lead to different characteristic equations thus several diverse topologies, featuring widely disparate properties. Furthermore, TPMS performance depends heavily on their geometric parameters, such as porosity, cell size or cell orientation. Therefore, TPMS can be adapted to the different engineering problems, and optimized according to the constraints they must comply with.

Although many research studies on TPMS, both thermal and hydraulic, can be found in the literature, there is a lack of comprehensive and structured parametric analysis of the impact of their constitutive geometrical parameters, as can be achieved using deep learning. The present work aims at bridging this gap, investigating thoroughly the effects on the pressure drop of the porosity and cell orientation. In view of the very large parameter space which could be explored, to make the investigation feasible, a deep learning technique consisting in artificial neural network is adopted. Numerous CFD simulations are first performed on a single periodic lattice cell for different topologies, to calculate the flow field with Reynold number in the range 1-150, considering a wide range of porosity values and orientation angles of the lattice. Part of the numerical results, in terms of pressure drop, is used as the database for training a neural network (NN), suitably tailored for the purpose. The NN is tested on a subset of the CFD results not used for the network training, showing an excellent capability to foresee the lattice cell hydraulic characteristics. It is shown that the developed surrogate model can be used, for instance, as a selection tool for the best configuration (in terms of topology, porosity, orientation) when the minimum pressure drop is prescribed and the mass flow rate in the lattice is targeted.

[1] M. G. Gado et al., Energy Technology, May 2024
[2] T. Dixit et al., Appl Therm Eng, Jun. 2022
[3] B. W. Reynolds et al., Int J Heat Mass Transf, Sep. 2023
[4] D. Liang et al., Int J Heat Mass Transf, Feb. 2023
[5] N. Baobaid et al., Case Studies in Thermal Engineering, May 2022
[6] Z. A. Qureshi et al., International Journal of Thermal Sciences, Mar. 2022

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References

Primary authors: GAJETTI, Eleonora (Politecnico di Torino); Prof. BOCCARDO, Gianluca (Politenico di Torino); Dr MARCATO, Agnese (Los Alamos National Laboratory); Prof. MAROCCO, Luca (Politecnico di Milano); Prof. SAVOLDI, Laura (Politenico di Torino)

Presenter: Prof. BOCCARDO, Gianluca (Politenico di Torino)

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