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Prediction of Linear Elastic Properties for Hybrid Cellular Structures Using Artificial Neural Networks

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Additive manufacturing offers an exceptional opportunity to create complex geometries, enabling the production of lightweight components through cellular solids, which are not feasible with traditional manufacturing methods. Among these cellular solids, triply periodic minimal surfaces (TPMS) have garnered significant attention due to their unique properties. TPMS are intricate, three-dimensional structures that repeat periodically in all directions and possess zero mean curvature, meaning they locally minimize surface area. These structures effectively distribute stress and exhibit excellent mechanical properties. Their periodic nature reduces stress concentrations, thereby enhancing strength-to-weight ratios and improving energy absorption and resilience under load. This leads to controlled deformation, which boosts performance and material efficiency. This research aims to develop a comprehensive framework for predicting the elastic properties of Triply Periodic Minimal Surface (TPMS) structures using homogenization techniques and Artificial Neural Networks (ANN).

The study begins with the construction of various cells starting from four fundamental TPMS structures, namely Primitive, Gyroid, Diamond, and I-WP. The new cells are generated as linear combinations of the mathematical equations defining the four fundamental TPMS.

Each cell is then subjected to Finite Element Analysis (FEA) to determine its elastic properties. This involves creating detailed models of the cells and simulating their behavior under different loading conditions to calculate the equivalent compliance matrix. A Python script dialoguing with NTop software is developed to automate the data collection process. This script runs multiple simulations, varying parameters such as cell size and material properties, to generate a comprehensive dataset. The collected data is then used to train a linear Artificial Neural Network (ANN). The ANN is designed to predict the coefficients of the compliance matrix of TPMS structures based on the equation parameters. The network is trained using a portion of the dataset and validated using the remaining data to ensure accuracy and reliability.

The results demonstrate that the ANN can accurately predict the elastic properties of TPMS structures with high precision. The trained network shows excellent agreement with the FEA results, indicating that the proposed method is both efficient and reliable. Key findings include high accuracy, with the ANN predictions closely matching the FEA results, minimal error margins, and significant reduction in computational time required for predicting elastic properties compared to traditional FEA methods. The framework is applicable to various TPMS structures, demonstrating its potential for widespread use in engineering applications.

The study successfully develops a robust framework for predicting the elastic properties of TPMS structures using homogenization and ANN. The proposed method offers significant advantages in terms of accuracy, efficiency, and versatility. By automating the data collection and prediction processes, the framework enhances the design and optimization of TPMS structures, making them more accessible for practical applications. Future work will focus on expanding the dataset to include a wider range of TPMS geometries and exploring the application of the framework to other material properties. Also, the fatigue properties of these structures will be investigated.

This research highlights the potential of combining homogenization techniques with machine learning to advance the field of material science and engineering. The developed framework not only improves the understanding of TPMS structures but also provides a valuable tool for engineers and designers seeking to optimize materials for specific applications.

Autori principali: Prof. CROCCOLO, Dario (University of Bologna); DE AGOSTINIS, Massimiliano (Univer-

sity of Bologna); Dr. FINI, Stefano (University of Bologna); MELE, Mattia (University of Bologna); Dr. MILAN, Gianmarco (University of Bologna); Prof. OLMI, Giorgio (University of Bologna); Dr. PAFFETTI, Andrea (University of Bologna)

Relatore: MELE, Mattia (University of Bologna)

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