
PRELIMINARY STUDY ON THE PREDICTION OF MECHANICAL BEHAVIOR OF HIERARCHICAL VORONOI-LIKE MECHANICAL METAMATERIALS VIA GNN-BASED APPROACH

Denis Giordana^{1,2}, Chiara Bertolin¹, Andrea Tridello², Chao Gao^{1*}

¹ Norwegian University of Science and Technology, Department of Mechanical and Industrial Engineering, Trondheim, Norway

² Politecnico di Torino, Department of Mechanical and Aerospace Engineering, Turin, Italy

*corresponding author: chao.gao@ntnu.no

Abstract

Natural cellular materials—e.g., bone, wood, and honeycomb—are known for their extraordinary mechanical performance, such as strength-to-weight and damage tolerance. One of the common geometrical features of these natural cellular materials is their Voronoi-like structure, which has been demonstrated as a critical mechanism to improve mechanical performance by studies in recent decades. Inspired by these interesting structures, scientists and engineers have developed Voronoi-like mechanical metamaterials with tunable mechanical properties for various industrial applications [1]. However, most studies focus on designing fully random or fully ordered Voronoi-like structures, which are not common in Nature. Moreover, natural materials also show hierarchy in Voronoi-like designs. Therefore, to fill this knowledge gap and develop tunable architectures, we elaborated an algorithm to control the finite randomness of Voronoi-like structures and achieve associated hierarchical design. Then, we connected these architectures to finite element (FE) simulations that were performed with the commercial FE software Abaqus to obtain the effective stiffness of the designed Voronoi-like mechanical metamaterials. After that, to understand the contributions of finite randomness and hierarchy, we exploited a data-driven approach, which recently demonstrated strong potential in mechanics-based design, by using FE results as training database. Graph neural network (GNN) [2] which is particularly well-suited to study complex geometric features, was adopted to predict effective stiffness and to understand mechanical contributions from finite randomness and hierarchy. The success of this research has deepened our understanding of hierarchical finite random Voronoi-like mechanical metamaterials, thereby paving the way for their broader adoption in structural, biomedical, and aerospace applications.

Keywords

Voronoi structure; hierarchical design; GNN; finite randomness; FEA.

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