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Optimization of Design Parameters in Auxetic Lattice Structure for Relieving Surface Stress Concentrations

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Abstract

An auxetic lattice structure with a negative Poisson’s ratio has excellent energy absorption and high fracture toughness. Unlike conventional metamaterials with Poisson’s ratio, the auxetic lattice structure has been used in various fields from biomechanics to industrial structural applications to improve mechanical properties. We aim to optimize the design parameters of the auxetic unit cell to minimize the stress concentrations on the surface of the metamaterial based on the analysis of the compressive mechanical behavior of the auxetic lattice structure. After parametrizing the design variables for three types of re-entrant structures, the maximum stress on the structure surface and the Poisson's ratio of the structure was measured through a finite element (FE) parametric study. The results of the FE parametric study were used as training and prediction data to construct an artificial neural network (ANN)-based FE surrogate model. Using the design optimization with a deep neural network (DNN)-based surrogate model, we proposed insights into the design parameters of the auxetic unit cell that minimize the surface stress concentrations.

Keywords: auxetic metamaterial, design optimization, deep neural network

1 Introduction

Poisson's ratio is the ratio of the transverse strain to the longitudinal strain under the axial loading condition. Typical isotropic materials have a positive Poisson's ratio because of the different longitudinal and transverse strains. However, metamaterials can be designed to have a negative Poisson’s ratio when specific lattices, such as the auxetic unit cell, are constructed macroscopically. Re-entrant, Chiral, and Pre-buckled unit cells are included in the types of the auxetic lattice [1]. For the effective mechanical properties, auxetics were efficiently used in various fields, from biomechanics to industrial structural applications [2]. Previous studies have been mainly conducted to analyze the effects of design variables of the auxetic unit cells for mechanical behavior [3]. Also, studies have been mainly conducted to optimize the design parameters of the auxetic structure to maximize the energy absorption capacity [4]. However, studies on optimizing the design parameters of the auxetic structure to relieve surface stress concentrations were lacking.

This study aims to optimize the design parameters of the auxetic lattices to minimize the stress concentrations generated on the structure surface under the concentrated loading on the rigid body using the metaheuristic algorithm based on a DNN-FE surrogate model. The maximum stress of plates attached to the top and bottom of a cube composed of auxetic lattice was evaluated.

2 Methods

The procedure for design optimization of auxetic structure is: 1) Setting the design parameters of auxetic lattice and FE cases, 2) Performing the FE parametric study and analyzing the FE results, 3) Constructing an artificial neural network using training data, 4) Derivation of the optimal design parameters of auxetic structure using metaheuristic algorithm based on the FE surrogate model.

As for the design structure, the auxetic unit cells included three types of re-entrant structures. The main design variables were the side length of the unit cell (S), the angle between the vertical and inclined struts of re-entrant (θ), and the ratio of thickness to side length (t/S).

The FE parametric study was performed to obtain the training and prediction data to construct an artificial neural network (ANN)-based FE surrogate model. The FE analysis was performed to simulate the situation in which the concentrated loading was applied to the metamaterial formed with re-entrant unit cells. The overall dimensions of the 3D re-entrant structure were 20 mm × 20 mm × 22 mm (X × Y × Z). As the FE results, the maximum von Mises stress on the structure surface, the reaction force, and Poisson’s ratio of the structure were measured.

The FE surrogate model based on DNN to accelerate the FE analysis was constructed using the obtained FE results. The output (the maximum stress, Poisson’s ratio) for the input (design parameters) was predicted by the FE surrogate model.

A metaheuristic algorithm based on the DNN-FE surrogate model was used to optimize the main design parameters of auxetic lattices for minimizing the stress concentrations. The optimization problem was to find the main design parameters for each unit cell that minimizes the maximum stress of the metamaterial. Each trial solution was evaluated by the FE surrogate model based on DNN. The derived optimal case is verified by performing FE analysis.

3 Results

A comprehensive parametric study was performed to investigate the effect of design parameters of auxetic unit cell lattices on surface stress concentration. As the FE results, the maximum von Mises stress on the structure surface, the reaction force, and Poisson's ratio of the structure for each case were measured. As a result of the simulation, as the unit cell length (S) increased, the magnitude of the negative Poisson's ratio increased. As the inclination angle θ increased, the magnitude of the negative Poisson's ratio increased, and the force required for compression was not affected.

Training and prediction data were used to construct an artificial neural network (ANN)-based FE surrogate model. The coefficient determination values (R^2) between the FE results and predicted results by the FE surrogate model were evaluated. The coefficient of determination is a measure of goodness of fit for a model based on the proportion.

This study found the optimized design parameters of each re-entrant unit cell for reducing the stress concentrations using the design optimization with a DNN-based surrogate model. We obtained optimal designs and proposed insights into the design parameters of the auxetic unit cell that minimize the surface stress concentrations.

4 Conclusions and Contributions

In this study, the optimization framework using the metaheuristic algorithm based on the DNN-FE surrogate model as an optimization strategy was suggested to optimize the design parameters of auxetic lattices for reducing the stress concentrations. The results of the FE parametric study were used as training data to construct an artificial neural network-based FE surrogate model. The design parameters of the optimized auxetic lattice that minimize the surface stress concentration were found through the metaheuristic algorithm using the ANN-based FE surrogate model.

Acknowledgements

References

[1] H. Xiaonan, V.V. Silberschmidt, "Metamaterials with negative poisson's ratio: A review of mechanical properties and deformation mechanisms", Mechanics of advanced materials, 155-179, 2015.

[2] M. Mir, M.N. Ali, J. Sami, U. Ansari, "Review of mechanics and applications of auxetic structures." Advances in Materials Science and Engineering", 2014.

[3] Y. Xue, P. Gao, L. Zhou, F. Han, "An Enhanced Three-Dimensional Auxetic Lattice Structure with Improved Property", Materials, 13, 4, 1008, 2020.

[4] Z. Chen, Z. Wang, S. Zhou, J. Shao, X. Wu, "Novel Negative Poisson's Ratio Lattice Structures with Enhanced Stiffness and Energy Absorption Capacity Materials", Materials, 11, 7, 1095, 2018.