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Optimal Designs of Body-Centered Truss Structures using Machine Learning and Additive Manufacturing

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ABSTRACT

Designing lightweight and strong materials has been a long sought goal in mechanical/materials engineering for decades. The truss structure, inspired by the lattice structure of single-crystalline materials in nature, is one of the lightweight structures compared to conventional engineering materials. Many previous works aim to improve mechanical properties of the trusses by tuning the microstructure. However, most studies have been conducted using beam elements with simple geometries because it is difficult to control the relative density of trusses composed of beam elements with complex architectures. Hence, limited design space has been explored for optimizing mechanical properties of trusses. In this study, we suggest the optimal shape of beam elements in body-centered(BC) truss structure having both high elastic stiffness and strength by employing an artificial intelligence-based neural network(NN) to overcome the previous limitation. We create 20,000 beam elements modeled by a high order Bézier curve and predict the elastic modulus of the truss using the finite element analysis(FEA) and the homogenization method. Two NNs are trained to learn the relationship between the properties (density and modulus) of the truss structure and the geometry of the beam element. By leveraging the fast inference of the trained NNs, we conduct genetic optimization(GO) to generate new beam elements having high modulus compared to initial data sets. Using the active learning-based optimization approach, we are able to gradually enhance the modulus of the BC truss structure and the final design shows an improvement of over 75% in elastic stiffness compared to the cylindrical beam case. Through our machine learning-based design results, we find a mechanism for increasing the stiffness and strength of the truss structure. We then fabricate the optimal lattice structure along with other benchmark designs using additive manufacturing and conduct compression tests to validate our design and computational approaches.

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