Multiscale Shape and Topology Optimization of Porous Composites Based on Biological Microstructures for 3D Printing with Connectivity Constraints

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Abstract:

In recent years, advancements in measurement and additive manufacturing (AM) technologies have made it possible to apply complex biological structures to products, which was previously considered challenging. This progress has led to biomimetics, a method that applies the superior structures, functions, and motions found in biological organisms to engineering, being widely recognized as a promising approach for innovative product development. In particular, research on biological microstructures has gained significant attention. Numerous researchers revealed that biological microstructures possess superior mechanical properties. This demonstrated that applying biological microstructures to macrostructures is effective for designing high-strength structures.

In this study, we propose a multiscale shape and topology optimization method which uses biological microstructures as the initial shapes, inspired by the diverse and complex shapes found in nature. In this method, initial shapes for each subdomain are selected from a database constructed from biological microstructures obtained via X-ray CT. The database includes various biological microstructures, such as the reticulate structure of the vascular bundles in loofah, with shape information for each unit cell, including density, anisotropy index, and homogenized elastic matrix.

The concurrent shape and topology optimization problem is formulated to minimize the compliance of the macrostructure under a volume constraint. The SIMP method is employed for topology optimization. Furthermore, the connectivity between neighboring subdomains is considered to ensure continuity of the microstructures across interfaces, which enhances the 3D printability of the optimized structures by AM.

The sensitivities of both the shape and density are derived using the Lagrange multiplier and adjoint methods, and then applied to the H^1 gradient method to iteratively update the shape and topology of the structure. Several numerical results using biological microstructures are presented to demonstrate the effectiveness of the proposed method.

Biography of Presenter:

The presenter is a graduate student in the Laboratory of Solid Mechanics, Department of Advanced Science and Technology, Graduate School of Engineering at Toyota Technological Institute (TTI), Japan. He earned his bachelor's degree from TTI in 2024 and is currently conducting research on multiscale topology optimization and biomimetic structure design. He has experience presenting his research at both domestic and international conferences. Notably, he gave a presentation titled "Multiscale Shape Optimization of Porous Composites Based on Biological Microstructures" in the "Novel Approaches of Shape Optimization" session at the 16th World Congress of Structural and Multidisciplinary Optimization (WCSMO-16), one of the most prestigious international conferences in the field of structural optimization.

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Presenter image