Connecting Multi-Material Topology Optimization and Additive Manufacturing to Achieve Structures with Unique Properties

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Topology optimization is a computational design tool used to find the layout of structures so that they efficiently meet performance objectives and satisfy relevant constraints, (e.g., lightweight structures, stiff structures, structures meeting stress limits). With recent developments in additive manufacturing that have enabled fabrication of the complex geometries obtained from topology optimization, the field is being widely embraced for many engineering applications (e.g., lightweight aerospace components [1], customized medical implants [2,3]). In both topology optimization and additive manufacturing, the use of multiple materials has been recognized to significantly open the design space and enable novel functionalities (e.g., negative thermal expansion [4], tuned elastic response [5]); however, advances in both fields are needed to make multi-material design and manufacturing a realistic possibility. In this project, we aim to design, manufacture, and experimentally validate the behavior of multi-material and multi-microstructure parts designed via topology optimization and printed via stereolithography (SLA). For the design, we adopt a novel multi-material topology optimization formulation for compliance minimization, recently proposed by the PI, that efficiently handles many candidates materials and many global or local volume constraints [6,7,8]. In an effort to expand the design space, we tailor the formulation to accommodate a wider range of candidate materials (i.e., porous microstructures with anisotropic material behavior) and demonstrate, in 2D, the ability to obtain designs in which the anisotropic, porous candidate materials distribute themselves according to the expected mechanical response (Fig 1). The 3D implementation is currently in progress, but in parallel, we have developed an approach to prepare such 3D multi-material/multi-microstructure designs for SLA 3D printing. Our approach is tailored to account for and take advantage of the features and characteristics of multi-material topology optimized parts. Using a 2-material cantilever beam designed considering two isotropic materials [7], we demonstrate the ability to print structures with varying stiffness using a grayscale Digital Light Processing (g-DLP) technique [9,10] (Fig. 2b), and varying embedded microstructures using masked SLA (m-SLA) from Prusa (Fig. 2c). We demonstrate that our approach leads to smooth parts that are well-connected at material interfaces, that can have functional grading over the material interfaces, and that do not require large STL files even when "microstructures" are embedded. Perfecting print quality for both processes is ongoing work.

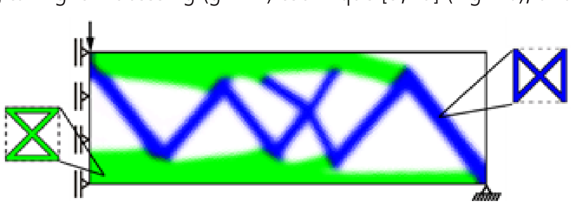

Figure 1: Multi-material MBB design considering a single global volume constraint that controls two porous, anisotropic candidate materials.

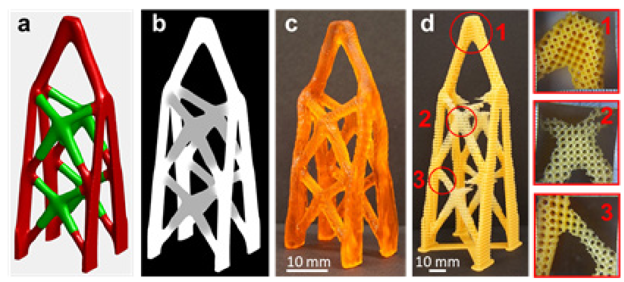

Figure 2: Two-material topology optimized cantilever beam: (a) post-processed numerical result where the red and green regions represent different materials; (b) grayscale representation; (c) g-DLP 3D printed part with two elastic moduli from a single resin [9]; (d) Prusa's m-SLA 3D printed part with two microstructures embedded and graded interfaces between them.

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