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Programmable Multistable 3D Printed Perforated Shellular

J.Shi[1], H.Mofatteh[2], A.Mirabolghasemi[1], B.Shahryari[1], G. Desharnais[2], A.H.Akbarzadeh[1,3*]
[1]*Department of Bioresource Engineering, McGill University, Montreal, QC, H9X 3V9, Canada*
[2]*Axis Prototypes, Montreal, QC, H1P 3C1, Canada*
[3]*Department of Mechanical Engineering, McGill University, Montreal, QC, H9X 3V9, Canada*
[*]*Email: hamid.akbarzadeh@mcgill.ca*

ABSTRACT

A shell-based cellular solid or *Shellular* (as a portmanteau word blending of *Shell* and *Cellular*), is composed of a periodic 3D unit cell of continuously smooth and non-self-intersecting shells. Shellulars offer less sensitivity to stress concentration and architectural defects than truss/plate-like cellular solids, and therefore are promising candidates for realizing ultralight architected materials with enhanced stiffness, strength, and resilience. They are commonly developed based on triply periodic minimal surfaces (TPMS) (for example, Schwarz P (Primitive), Schwarz D (Diamond), and Gyroid) with zero mean curvature, in which *triply periodic* refers to three-dimensional periodicity and *minimal surface* represents a locally minimum surface area for a given boundary. The *pre-fabricated* topological features of TMPS hold great promise for creating shell-like metamaterials with unparalleled multifunctional properties for applications in bionic scaffold, catalytic converters, heat exchanger, ultrafiltration, and microbatteries. However, the geometry of shell surfaces can be tailored in the *post-fabrication* state by harnessing structural instability similar to the instability-driven rapid snapping and fast closure of Venus flytrap in the nature. In this study, we present a novel design route for 3D printing of programmable and previously inaccessible deployable multistable shellular metamaterials by introducing delicate perforations on the surface of Schwarz's P shellulars. Two perforation design strategies, i.e. a bistable shellular motif containing elliptical holes and a multistable shellular motif containing multilayer staggered perforations, are introduced and the mechanical properties and structural stability characteristics of the perforated shellular metamaterials are analyzed by simplified theoretical mechanics models, finite element simulations, and mechanical testing on SLS 3D printed samples. While the bistability in the first design strategy arises from the balance between compression-induced buckling and bending of flexible parts, bending-torsional hinges imparted by staggered perforations in the second design strategy contribute to the multistability of multilayer perforated shellulars. Exploiting snap-through and snap-back structural instabilities and self-contact behavior, the introduced perforated shellulars demonstrate controllable rigidity in loading and unloading, enhanced energy dissipation, and a plethora of stable configurations.