



Mechanical properties of 3D printed polymeric cellular materials with triply periodic minimal surface architectures

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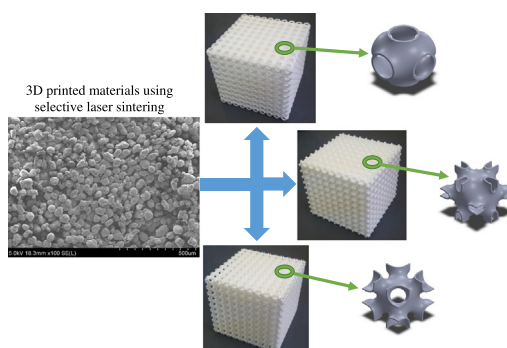
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HIGHLIGHTS

- Triply periodic minimal surfaces (TPMS) are utilized to create new cellular materials (CMs).
- The modulus and strength of three types of TPMS-CMs are found experimentally and computationally.
- Post-yielding behavior of the three TPMS-CMs is reported and discussed.
- Failure (buckling vs. yielding) maps are reported.

GRAPHICAL ABSTRACT



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ABSTRACT

In this paper, three types of triply periodic minimal surfaces (TPMS) are utilized to create novel polymeric cellular materials (CM). The TPMS architectures considered are Schwarz Primitive, Schoen IWP, and Neovius. This work investigates experimentally and computationally mechanical properties of these three TPMS-CMs. 3D printing is used to fabricate these polymeric cellular materials and their base material. Their properties are tested to provide inputs and serve as validation for finite element modeling. Two finite deformation elastic/hyperelastic-viscoplastic constitutive models calibrated based on the mechanical response of the base material are used in the computational study of the TPMS-CMs. It is shown that the specimen size of the TPMS-CMs affect their mechanical properties. Moreover, the finite element results agree with the results obtained experimentally. The Neovius-CM and IWP-CM have a similar mechanical response, and it is found that they have higher stiffness and strength than the Primitive-CM.

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1. Introduction

Discovery of new lightweight yet strong materials is of high scientific and technological interest as they can be utilized in numerous engineering applications (e.g. automotive and aerospace industry) [1–4]. Researchers investigated the effects of base materials, density, and

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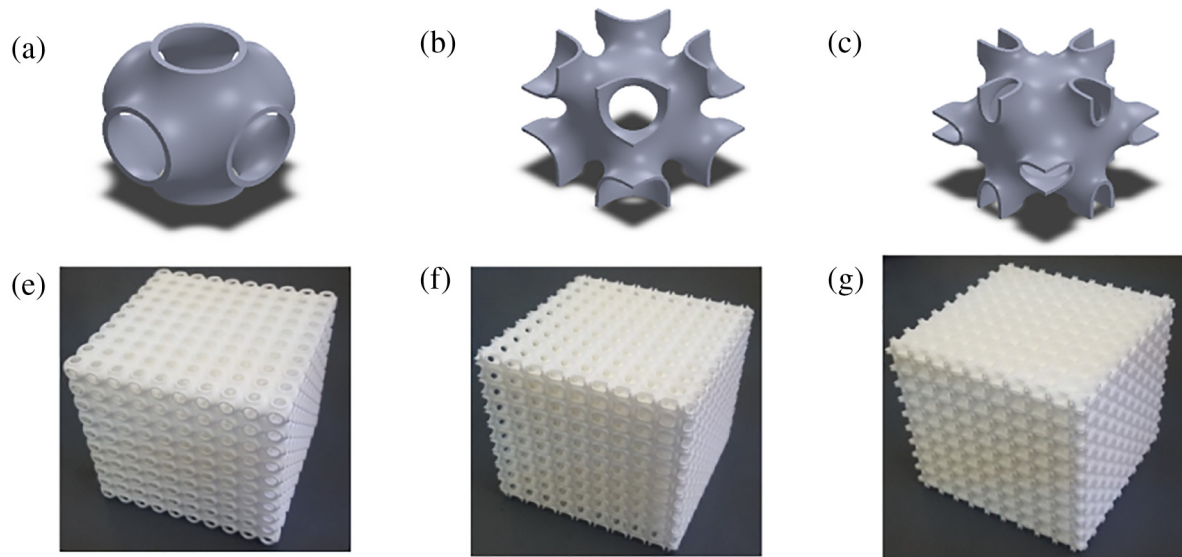


Fig. 1. CAD drawings of TPMS-CMs with a relative density of 10%: (a) Primitive-CM, (b) IWP-CM, (c) Neovius-CM. 3D printed specimens: (e) Primitive-CM (relative density is 23.5%), (f) IWP-CM (relative density is 25.6%), (g) Neovius-CM (relative density is 23.7%).

foam's architecture on the overall performance of cellular materials. The geometry of architected materials can be designed, based on engineering optimization process, or inspired. In architected materials, the morphology of their structures yields properties that are not available in bulk, continuous media. Moreover, researchers have designed and created materials with architectures that are inspired by nature. Natural and biological materials possess characteristics such as hierarchical, optimized periodic and multifunctional structuring, size effect strengthening, and high interconnectivity [2,5–8].

Furthermore, the architectures of cellular materials control the way the materials get deformed: in a bending-dominated mode or a stretching-dominated mode [9]. Structures that are statically and kinematically determinate are stretching-dominated and support external loads by only compressive and tensile loadings [10,11]. Therefore, materials deforming in a stretching-dominated mode have higher stiffness and strength than the ones deforming in a bending-dominated mode. Cellular materials with stochastic porosity usually deform through bending of walls and trusses [12]. Also, stochastic structuring usually introduces imperfections which reduce the overall mechanical properties. Thus, periodic structures are more desirable than the stochastic ones [5,7,13]. Several researchers have used experimental, computational, and analytical approaches to study linear and nonlinear mechanical responses of cellular materials including elastic

properties, yielding, buckling, and effects of imperfections [1,14,15]. They showed that the wall thickness (or relative density) of the cellular materials governs the failure mechanisms and that imperfections in cellular materials such as octet-truss might lead to dramatic deterioration in strength. In addition to the effect of the architecture of the microstructure and relative density of the cellular materials, the mechanical behavior of cellular materials is directly affected by the scale at which they are made and base materials they are fabricated from [16]. The architecture of cellular materials can be designed and optimized to create materials with multifunctional properties including high stiffness, strength, energy absorption, and damage-tolerance, among others [4,7,17]. One of the most common cellular materials is a honeycomb which is anisotropic material. One of the main reasons that honeycomb structures are attractive is that their microstructures allow large deformations which in turn lead to high specific energy dissipation capacity [18]. Restrepo et al. [19] fabricated periodic cellular materials (two types of honeycombs) using a shape memory polymer as a base material. They introduced a new class of programmable materials whose mechanical performance is modified after manufacturing. Further, cellular materials can be used to create materials with unconventional properties such as negative Poisson's ratio [18,20–23]. Bertoldi et al. [24] utilized elastic instabilities of periodic cellular materials to create 2D materials with negative Poisson's

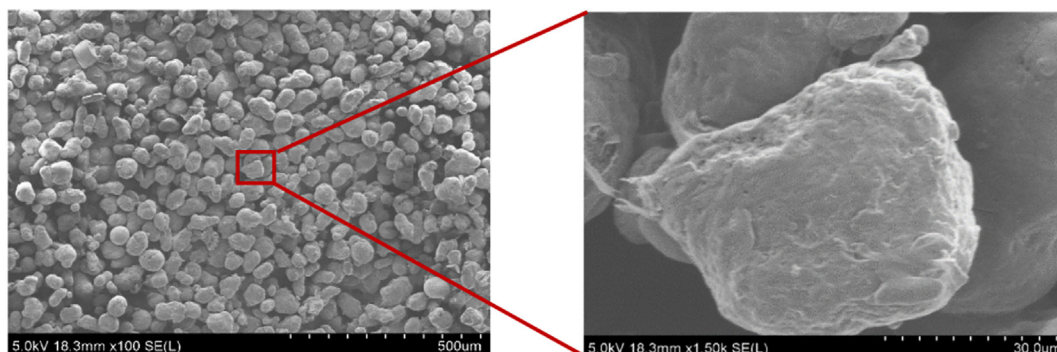


Fig. 2. SEM images of PA 2200 fabricated using the 3D printer Formiga 100.

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