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The acoustic band structures, sound attenuation, and uniaxial elastic modulus of cellular materials (CMs) based on triply periodic minimal surfaces (TPMS) (see Figure 1) are presented. TPMS are defined as infinitely extending, smooth, and continuous surfaces that are attributed by local area minimizing [1, 2]. In addition, the sum of principal curvatures vanishes at each point on the TPMS; hence, the mean curvature of TPMS is zero. Moreover, TPMS divide the space into two congruent intertwined regions where each region is three-dimensionally (3D) periodic and possesses a volume fraction of 50%. TPMS cellular materials have an advantage over other cellular materials available in the literature as they overcome the common drawbacks of truss/strut-based structures. Specifically, truss structures induce stress concentrations and usually have imperfections in their joints induced during manufacturing process which in turn cause them to collapse at lower applied loads [3].

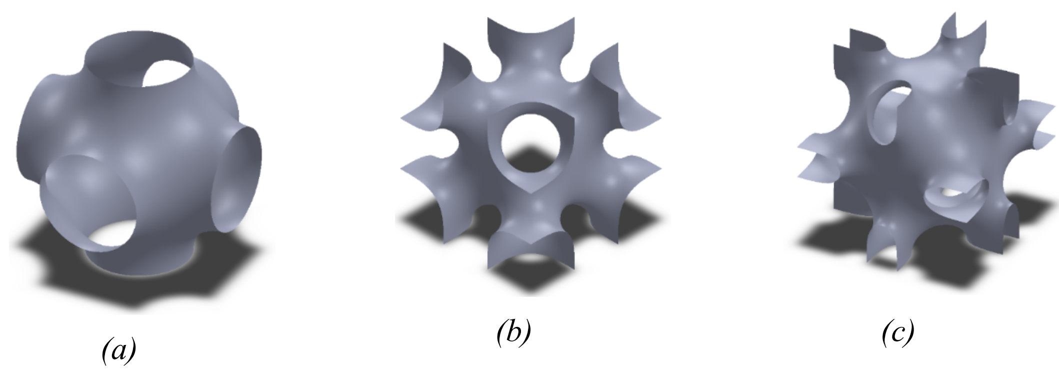

Figure 1: TPMS surfaces: (a) Schwarz Primitive surface, (b) Schoen IWP surface, and (c) Neovius surface.

In this paper, we investigate computationally responses of three polymeric cellular materials that are based on TPMS. These TPMS include Schwarz Primitive, Schoen IWP, and Neovius surfaces. The studied cellular materials are basically uniformly thickened TPMS where different wall thicknesses lead to different porosities/volume fractions. The finite element method (FEM) is adopted to calculate the acoustic band gaps (their width and location), sound attenuation, and elastic stiffness of these three types of cellular materials. Moreover, the dependence of the band gaps and elastic stiffness on the porosity of the three TPMS cellular materials are investigated where the structures are assumed to be infinite (periodic boundary conditions are applied as shown in the equation below).

$$
\begin{aligned}
p(x_1 + a, x_2, x_3) &= p(x_1, x_2, x_3)\, e^{ik_1 a} \\
p(x_1, x_2 + a, x_3) &= p(x_1, x_2, x_3)\, e^{ik_2 a} \\
p(x_1, x_2, x_3 + a) &= p(x_1, x_2, x_3)\, e^{ik_3 a},
\end{aligned} \tag{1}
$$

where (k_1, k_2, k_3) a are the components of Bloch wave vector, and p is the pressure. The eigenfrequencies and eigenmodes are attained through scanning the wave vector in the first irreducible Brillouin zone. The porosities considered in this study range from 28 to 92%. Since the elastic impedance of the cellular solids is higher than that of the air, it is expected that acoustic waves propagating in the air are reflected by the cellular solids and propagation takes place mainly in the air. Complete band gaps are obtained in these structure at low frequencies and low relative densities compared to the cellular structures available in the literature. Cellular material based on Neovius surface shows the highest robustness regarding the acoustic response. Furthermore, sound attenuation for the three TPMS-CMs is calculated along desired directions to verify the band gap analyses. We stack seven unit cells in the desired direction, and then we send an incident wave with a known power. The power at the outlet of the wave guide is calculated to find the transmitted power and sound attenuation.

TPMS-CSs promote complete band gaps, and the width of the band gap increases with the increase of the relative density. The humps appearing in the sound attenuation analysis are in a good agreement with the band gap analysis. The band gaps of TPMS-CSs are wider than the band gaps obtained for other structures mentioned in the literature. Also, all the band gaps obtained for TPMS-CSs lie in the audible range of frequencies. Thus, TPMS-CSs show very promising acoustic response for use in many engineering applications including noise control.

Furthermore, we discuss the variation of the elastic moduli of the three TPMS-CMs with their relative densities. In this paper, we study the elastic moduli for a wide range of relative density where periodic boundary conditions are applied to obtain the effective elastic moduli. Also, cellular materials based on TPMS have a mechanical behavior that is between stretching- and bending-dominated modes for the relative densities considered in this study.

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