PROGRAMMABLE DESIGN OF THE CONTOUR SHAPE OF SOFT CYLINDRICAL HONEYCOMB UNDER DEFORMATION

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Background

Rapid advances in additive manufacturing, computational design and conceptual breakthroughs have made material design as a catalyst for unveiling novel material functionalities. Cellular metamaterials offer an ideal platform for the development of novel smart and multi-functional materials, thanks to their high-dimensional design space determined by a variety of geometric parameters and bulk material properties.

In this work, we focus on the design of soft cylindrical structures formed by a combination of auxetic and conventional honeycomb unit cells (i.e., star-shaped and octagonal honeycomb unit cells, SOH), and manage to achieve their programmable mechanical response driven by external deformation.

Star-shaped and octagonal honeycomb (SOH) unit cells

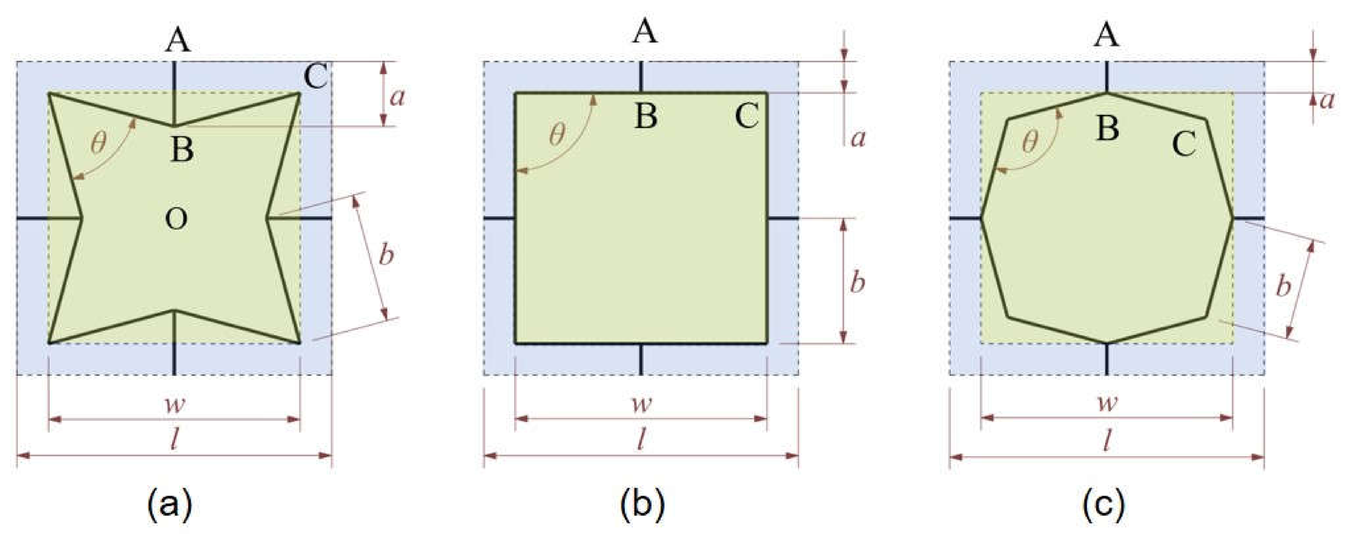

Figure 1: unit cells: (a) a star-shaped unit cell with auxetic properties, (b) a transitional unit cell (c) an octagonal unit cell with conventional properties.

$$E_x = E_y = \frac{2E_s t^3}{b^3(5-3\cos\theta)}, \qquad \nu_{xy} = \nu_{yx} = \frac{3-5\cos\theta}{5-3\cos\theta}$$

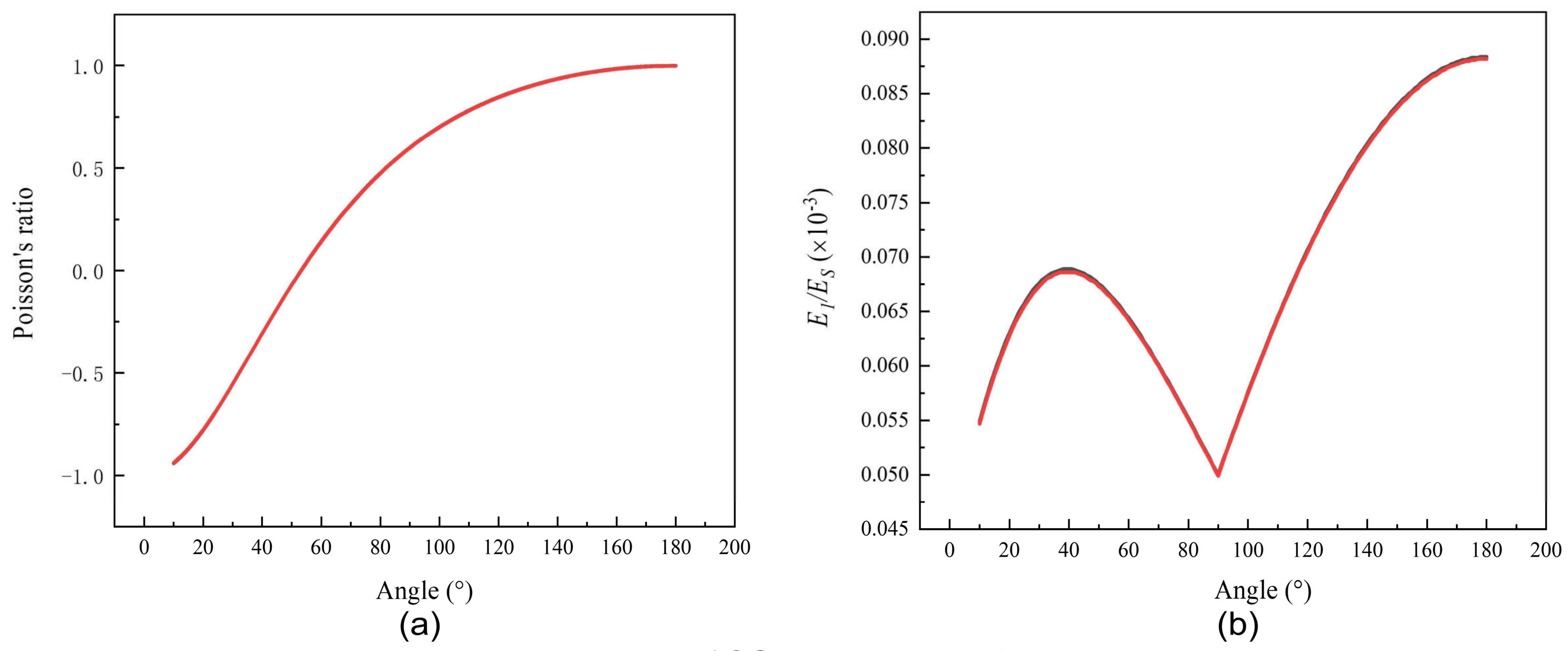

Figure 2: Basic mechanical properties of SOH unit cells as the internal angle increases: (a) Poisson's ratios, (b) relative stiffness.

Programmable Design of SOH Structures

- The control variable is internal angle, θ
- The equivalent design factor k of transverse strain is

$$k = -\frac{\nu}{E/E_s} = \frac{b^3}{2t^3}(5\cos\theta - 3)$$

where

$$b = \begin{cases} \dfrac{w}{2}\dfrac{1}{\cos\left(\dfrac{\pi}{4}-\dfrac{\theta}{2}\right)}, & 10^\circ < \theta \le 90^\circ \\ \dfrac{w}{2}\dfrac{1}{\sqrt{2}\sin\dfrac{\theta}{2}}, & 90^\circ < \theta \le 180^\circ \end{cases}$$

- The design factor k is normalized to [0,1], to be used in the programmable design.

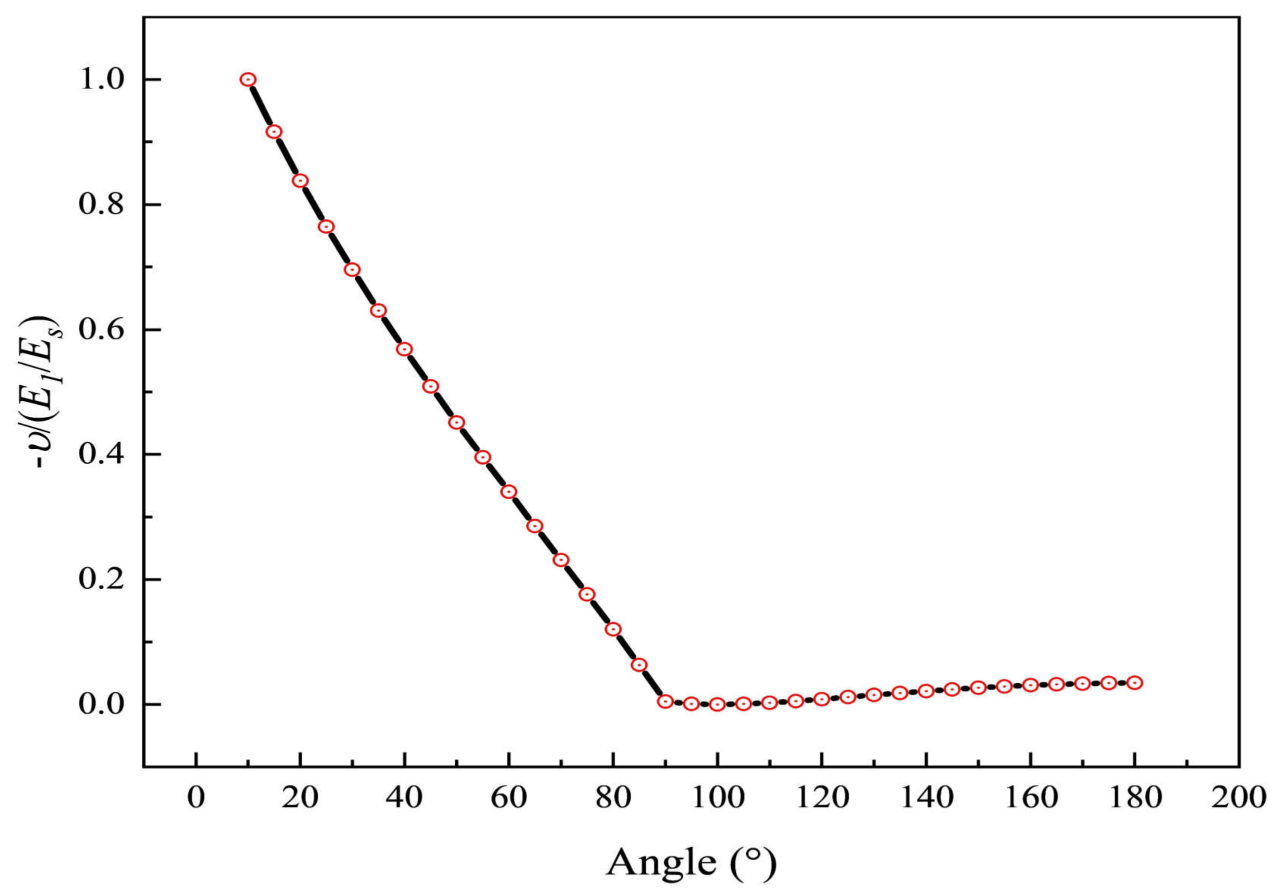

Figure 3: The relationship between the normalized k value and the internal angle θ of SOH unit cell.

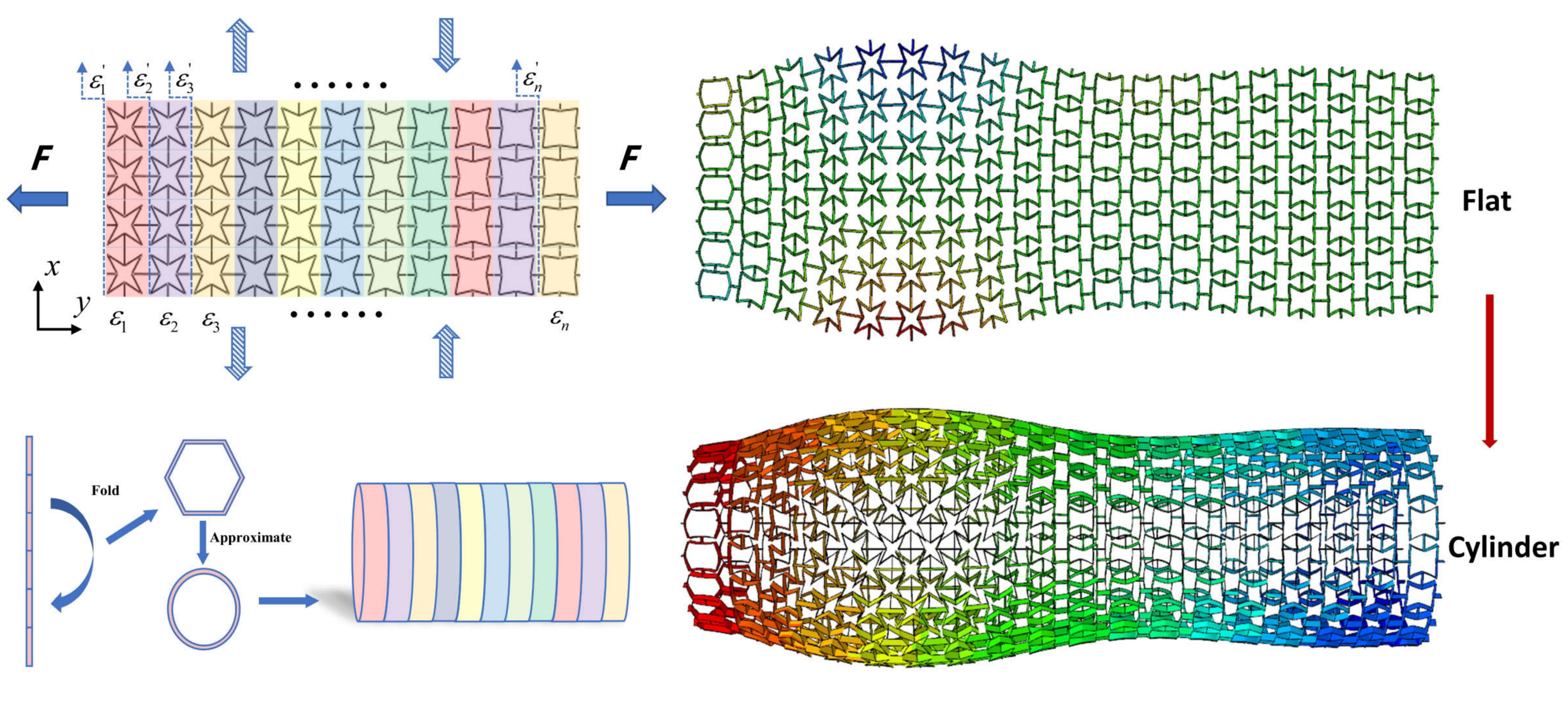

Figure 4: The schematic of SOH cylinder contour design: firstly, calculate the internal angle distribution of 2D SOH structure; then fold the flat structure to be a cylinder.

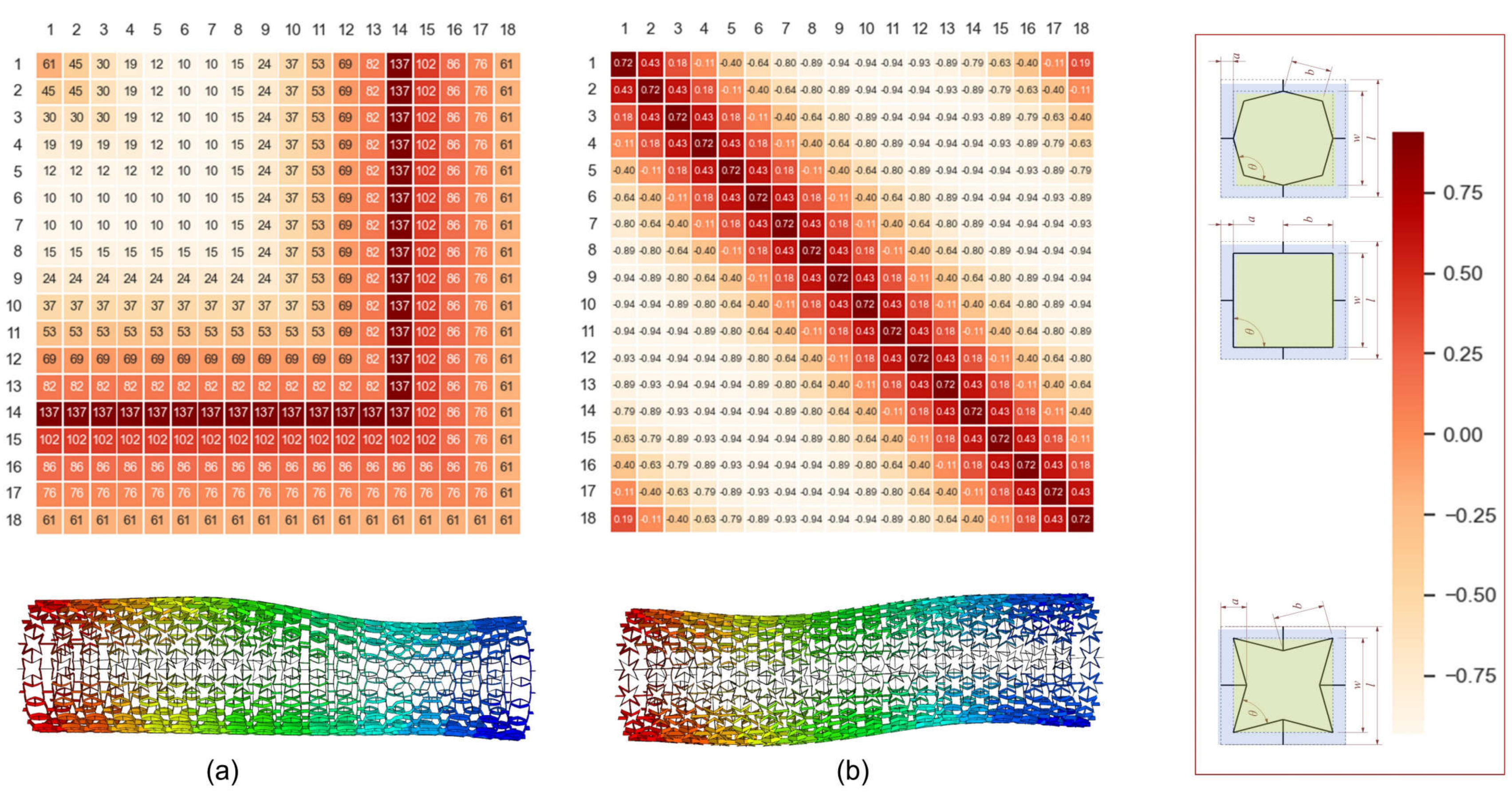

Figure 5: The deformation form of 2D arrangement SOH structures: (a) 2D symmetric arrangement (the numbers in the heatmap are the internal angles of the unit cells), (b) 2D diagonal arrangement (the numbers in the heatmap are the corresponding Poisson's ratios of the unit cells).