Hierarchical Honeycombs with Enhanced Mechanical Properties

Amin Ajdari[*], Babak Haghpanah Jahromi[*], Hamid Nayeb-Hashemi[*], Ashkan Vaziri[*,a]

[*] *Department of Mechanical and Industrial Engineering, Northeastern University, Boston, MA USA 02115*
[a] *corresponding author. E-mail: vaziri@coe.neu.edu*

Summary In this work, we have presented a systematic way to incorporate hierarchy in honeycomb structures. The hierarchical organization is made by replacing the edges of a regular honeycomb structure with smaller regular honeycomb. This will be shown able to exhibit a Young's modulus superior to that of its regular hexagonal counterpart of equal relative density.

Hierarchical Honeycombs

Hierarchical structures are found in many natural and man-made materials [1]. This structural hierarchy play an important role in determining the overall mechanical behavior of the structure. It has been suggested that increasing the hierarchical level of a structure will result in a better performing structure [2]. Besides, honeycombs are well known structures for lightweight and high strength applications [3]. In this work, we have presented a systematic way to incorporate hierarchy in honeycomb structures. The hierarchical organization is made by replacing the edges of a regular honeycomb structure with smaller regular honeycomb. This will be shown able to exhibit a Young's modulus superior to that of its regular hexagonal counterpart of equal relative density. This replacement procedure for three-edge vertices can be repeated at smaller scales to achieve fractal-appearing honeycombs with higher orders of structural hierarchy. Figure 1A shows the evolution of a hexagonal honeycomb cell as structural hierarchy is increased. The structural organization of the honeycomb at each level of hierarchy can be defined by the ratio of the introduced hexagonal edge length (b for 1st order hierarchy and c for 2nd order hierarchy), to the original hexagon's edge length, a, as described in Figure 1A (i.e., $\gamma_1 = b/a$ and $\gamma_2 = c/a$). We studied the mechanical properties of honeycombs with hierarchical organization using theoretical, numerical, and experimental methods. The hierarchical honeycomb samples were fabricated using 3D printing, as shown in Figure 1B. Our results showed that honeycombs with structural hierarchy have superior properties compared to regular honeycombs. The results show that a relatively broad range of elastic properties, and thus behavior, can be achieved by tailoring the structural organization of hierarchical honeycombs, and more specifically the two dimension ratios. Increasing the level of hierarchy provides a wider range of achievable properties. Further optimization should be possible by also varying the thickness of the hierarchically introduced cell walls, and thus the relative distribution of the mass, between different hierarchy levels. These hierarchical honeycombs can be used in development of novel lightweight multifunctional structures, for example as the cores of sandwich panels.

Acknowledgment

This work was supported in part by the U.S. Air Force Office of Scientific Research under AFOSR YIP grant award, #FA 9550-10-1-0145 under the technical supervision of Dr. Joycelyn Harrison and in part by the U.S. Department of Homeland Security under Award Number 2008-ST-061-ED0001. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.

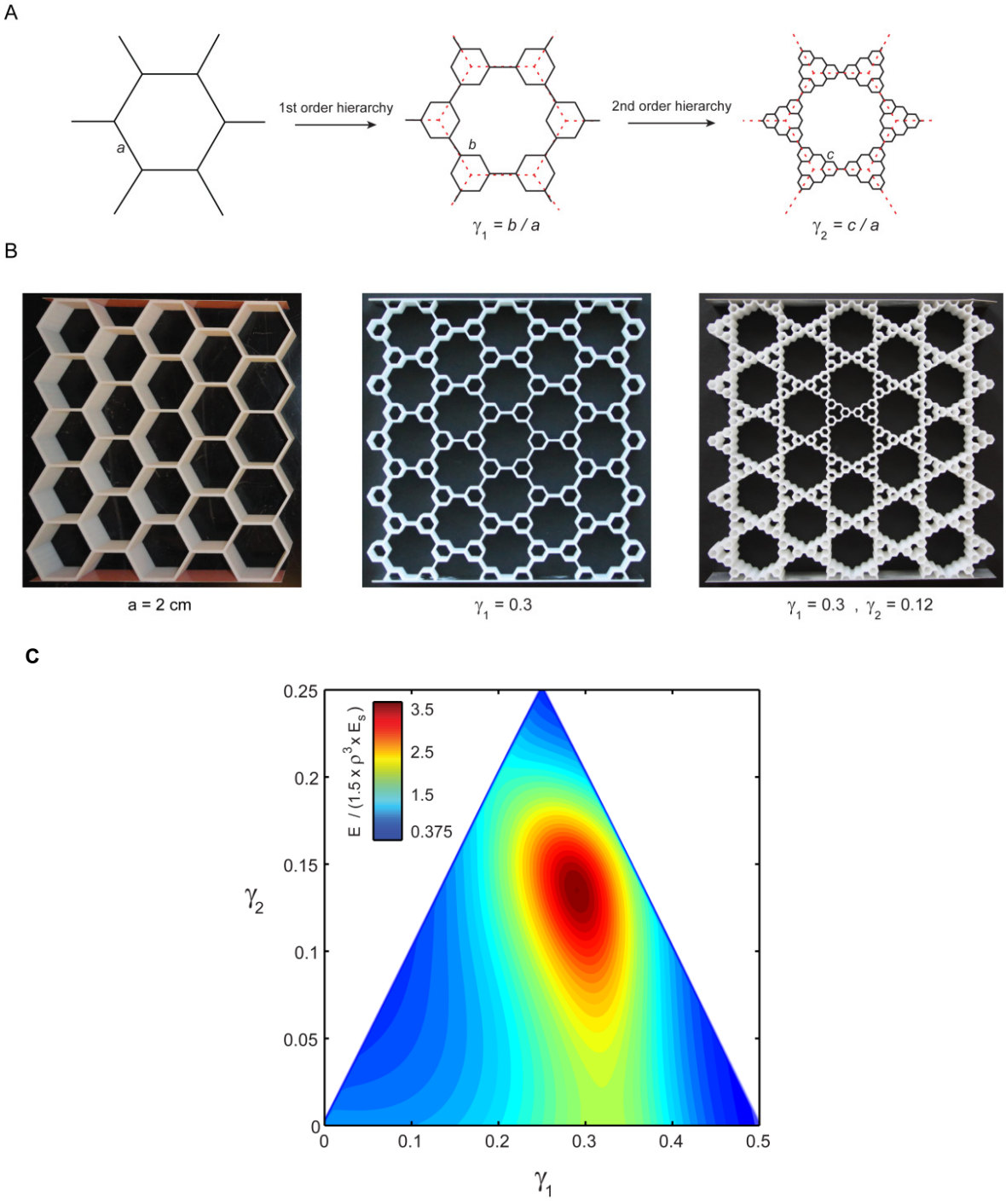

Figure 1 – Hierarchical Honeycombs. (A) Unit cell of the hierarchical honeycombs with regular structure and with 1st and 2nd order hierarchy. (B) Images of honeycombs with a = 2 cm fabricated using three-dimensional printing. (C) Contour maps of the effective elastic modulus of hierarchical honeycombs with 2nd order hierarchy for all possible geometries (i.e., admissible range of $\boldsymbol{\gamma_1}$ and $\boldsymbol{\gamma_2}$).

References

[1] R. Lakes: Materials with Structural Hierarchy. *Nature*, 361(1993), 511-515.
[2] C.M.,Taylor, C.W., Smith, W., Miller, K.E., Evans: The effects of hierarchy on the in-plane elastic properties of honeycombs. *International Journal of Solids and Structures*, 48(2011), 1330-1339.
[3] L.J. Gibson, M.F. Ashby: Cellular Solids: Structure and Properties, 2nd Ed. Cambridge University Press, 1997.