International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

Comparison of Mechanical Properties Between Aperiodic Structures and Conventional Honeycombs

Lawrence Tyler[1] Brandon Farnum[1] Heng Li[1] Carl Bonner[2] Natalia Noginova[2]

1. Department of Applied Engineering Technology
Virginia State University
1 Hayden St, Petersburg, VA 23806 USA
2. Center for Materials Research
Norfolk State University
700 Park Ave, Norfolk, VA 23504 USA

***Abstract* - Aperiodic cellular structures have recently attracted significant attention due to their unique geometric configurations and potential advantages over traditional periodic designs. In this study, the mechanical properties of an aperiodic cellular structure based on the Einstein tile geometry are experimentally compared with those of a conventional honeycomb structure. Both structures were fabricated using polylactic acid (PLA) via 3D printing. Mechanical characterization was conducted through tensile and compression testing. Results indicate that the aperiodic structure exhibits lower stiffness but higher toughness compared to the conventional honeycomb. Distinct fracture behaviors were also observed, with brittle failure dominating in aperiodic samples and progressive deformation occurring in honeycomb structures. These findings highlight the trade-offs between stiffness and energy absorption in different cellular architectures.**

Keywords – Mechanical properties; Aperiodic structures; Mechanical metamaterials.

I. INTRODUCTION

Aperiodic cellular structures have recently emerged as a promising alternative to conventional honeycomb cores due to their unique geometric characteristics and potentially enhanced mechanical performance. Unlike periodic honeycomb structures, aperiodic geometries do not exhibit translational symmetry, which can lead to different load distribution mechanisms and mechanical responses. Several research efforts have investigated these structures, demonstrating their potential in advanced materials and structural design. Recent studies have explored the use of such structures in lightweight engineering applications, where mechanical efficiency and structural performance are critical.

Conventional honeycomb structures are widely applied in aerospace, transportation, and lightweight engineering because of their excellent stiffness-to-weight ratio and efficient load-bearing capability; however, their periodic topology often leads to pronounced anisotropy and susceptibility to progressive buckling or localized failure under non-uniform loading conditions [1,2]. In contrast, aperiodic structures—such as quasi-random, gradient, or non-repeating cellular architectures—can introduce structural heterogeneity that improves stress distribution, delays crack propagation, and enhances energy absorption capacity compared with traditional periodic designs [3–5]. With the advancement of modern manufacturing technologies, particularly additive manufacturing, it has become feasible to fabricate complex aperiodic geometries with high precision, enabling researchers to explore mechanical behaviors that were previously unattainable using conventional fabrication methods [6]. Nevertheless, direct comparative studies between aperiodic structures and conventional honeycomb structures remain relatively scarce, especially regarding their stiffness, strength, deformation mechanisms, and energy absorption performance under similar boundary conditions [7]. Therefore, this study focuses on a systematic comparison of the mechanical properties of an aperiodic cellular structure and a conventional honeycomb structure, aiming to provide deeper insight into their structural advantages and potential engineering applications.

In this work, we focus on comparing the mechanical behavior of an aperiodic structure based on the Einstein tiling with a conventional honeycomb structure under tensile and compressive loading conditions.

II. DESIGN AND MODELING OF THE STRUCTURES

The aperiodic structure used in this study is based on the Einstein tile geometry, a recently discovered aperiodic tiling that fills space without repeating patterns. This geometry was selected due to its non-periodic characteristics and potential mechanical advantages.

Both the aperiodic and conventional honeycomb structures were designed using Autodesk Fusion 360 and further processed using MATLAB for geometric parameter control and pattern generation.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

The models were designed with comparable overall dimensions and relative densities to ensure a fair mechanical comparison. The honeycomb structure followed a standard hexagonal periodic configuration, while the aperiodic structure exhibited irregular cell topology.

Fig.1 is shown the building block of conventional honeycomb structure and building block of aperiodic structure with the unit mm. The building block of aperiodic structure is “Einstein Hat” geometry [8]. Using Autodesk Fusion 360 and further processed using MATLAB, two types of structures, a conventional honeycomb and as aperiodic structure, were modeled, as shown in Fig.2.

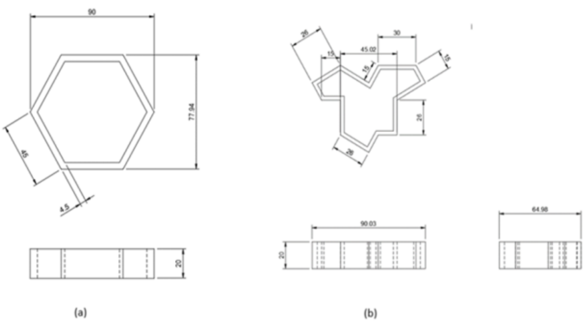

Fig.1 (a) The building block of conventional honeycomb structure,(b)The building block of aperiodic structure (mm).

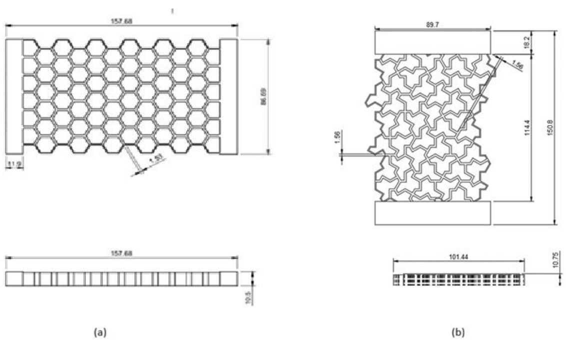

Fig.2 (a) Conventional hexagonal model and its size (mm), (b) Aperiodic structure model based on Einstein tile geometry (mm).

III. MATERIALS AND METHODS

A. *Material Preparation*

All samples were fabricated using polylactic acid (PLA) filament through fused deposition modeling (FDM) 3D printing. Printing parameters such as layer height, infill density, and printing speed were kept consistent across all specimens to minimize variability. The fabricated specimens are shown in Fig.3. Specimen in (a) represents the conventional hexagonal honeycomb structure, while specimen in (b) represents the aperiodic structure.

B. *Compression test and Tension tests*

The fabricated specimens were used for compression and tensile testing. The corresponding stress-strain response and mechanical properties obtained from these experiments are presented in Fig.4. Stress–strain curves were obtained for all samples. During the elastic deformation stage, both specimens were subjected to compression and tensile tests to characterize their mechanical responses. After testing, the specimens were further compressed until fracture occurred, and the resulting fracture patterns were observed and analyzed.

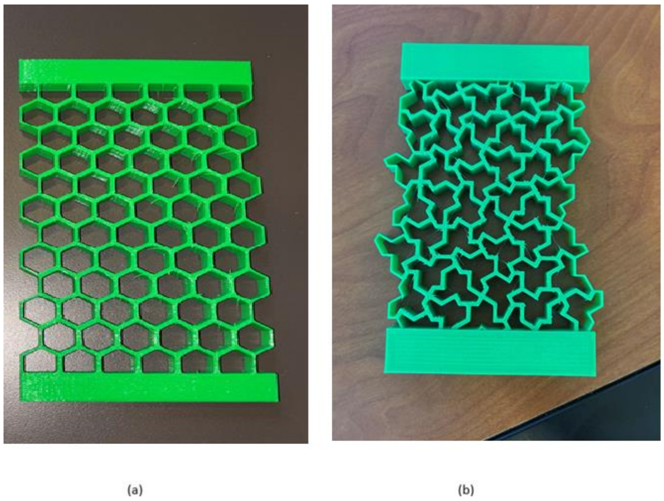

Fig.3 (a) The specimen of conventional hexagonal honeycomb structure printed-out by 3D printer, made of PLA (b) The specimen of aperiodic structure printed-out by 3D printer, made of PLA.

IV. RESULTS AND DISCUSSIONS

The experimental results show clear differences between the two structures, as shown in Fig.4. The honeycomb structure exhibits higher stiffness, as indicated by a steeper initial slope in the stress–strain curve in Fig.4. The aperiodic structure shows lower stiffness but greater deformation capability. This indicates that honeycomb structures are more suitable for applications requiring energy absorption.

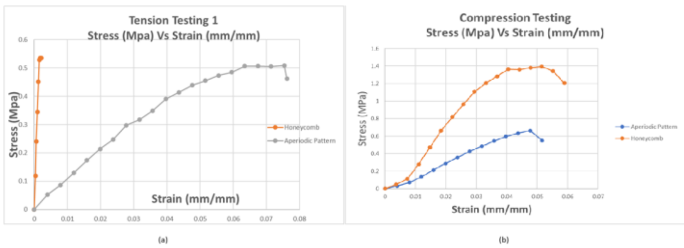

Fig.4 (a) The tension test results of honeycomb sample and aperiodic sample, (b) The compression test results of honeycomb sample and aperiodic sample.

Under compression, the aperiodic structure exhibited progressive fracture, with cracks forming and propagating as

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

the load increased. In contrast, the honeycomb structure mainly experienced cell deformation, where the hexagonal cells changed shape rather than fracturing immediately. Therefore, the two structures exhibit distinct failure mechanisms: fracture-dominated failure in the aperiodic structure and deformation-dominated failure in the honeycomb structure.

The aperiodic structure is nearly isotropic, with similar properties in all directions. However, its acute angles create stress concentrations that promote crack initiation and progressive fracture during compression. In contrast, the honeycomb structure is anisotropic, with properties that depend on loading direction. Because it lacks sharp stress-concentrating features, the honeycomb structure mainly deforms through cell-wall bending and buckling rather than fracturing immediately. This difference in geometry results in different failure mechanisms for the two structures.

V. CONCLUSIONS

This study investigated the mechanical behavior of a conventional hexagonal honeycomb structure and an aperiodic structure through tensile and compression testing.

The tensile test results showed that the honeycomb structure exhibited higher stiffness, whereas the aperiodic structure demonstrated lower stiffness but greater toughness, indicating an enhanced capacity for energy absorption. The compression test results similarly revealed that the honeycomb structure possessed higher stiffness and greater ultimate strength than the aperiodic structure.

Failure analysis showed that the aperiodic specimens fractured shortly after the elastic deformation stage, at lower strain levels than the honeycomb specimens. These results indicate that, in the loading direction considered in this study, the honeycomb structure provides superior stiffness and strength.

However, the aperiodic structure theoretically offers a more uniform geometric arrangement and is expected to exhibit more isotropic mechanical behavior, with properties that are less dependent on loading direction. In contrast, the honeycomb structure is inherently anisotropic, and its mechanical performance varies with orientation.

Future work will include testing honeycomb structures under different loading directions to provide a more comprehensive comparison with the aperiodic structure. In addition, metallic versions of both structures will be fabricated and evaluated to investigate their mechanical performance and potential engineering applications.

Overall, the results demonstrate that the honeycomb structure provides higher stiffness and strength, while the aperiodic structure offers improved toughness and energy-absorption capability, highlighting the trade-offs between these two structural designs.

ACKNOWLEDGMENT

The authors would like to thank the U.S. Department of Energy (DOE) and the National Nuclear Security Administration (NNSA) for their financial support of this project.

REFERENCES

[1] [1] L. J. Gibson, and M. F. Ashby, Cellular Solids: Structure and Properties, 2nd ed., Cambridge University Press, Cambridge, UK, 1997.

[2] [2] T. Bitzer, Honeycomb Technology: Materials, Design, Manufacturing, Applications and Testing, Springer, Dordrecht, Netherlands, 1997.

[3] [3] X. Zheng, W. Smith, J. Jackson, et al., “Multiscale metallic metamaterials,” Nature Materials, vol. 15, pp. 1100–1106, 2016.

[4] [4] J. Bauer, A. Schroer, R. Schwaiger, and O. Kraft, “Approaching theoretical strength in glassy carbon nanolattices,” Nature Materials, vol. 15, pp. 438–443, 2016.

[5] [5] L. R. Meza, S. Das, and J. R. Greer, “Strong, lightweight, and recoverable three-dimensional ceramic nanolattices,” Science, vol. 345, no. 6202, pp. 1322–1326, 2014.

[6] [6] I. Gibson, D. Rosen, and B. Stucker, Additive Manufacturing Technologies, 2nd ed., Springer, New York, USA, 2015.

[7] [7] A. Ajdari, H. Nayeb-Hashemi, A. Vaziri, “Dynamic crushing and energy absorption of regular, irregular and functionally graded cellular structures,” International Journal of Solids and Structures, vol. 48, pp. 506–516, 2011.

[8] [8] David Smith, Joseph Samuel Myers, Craig S. Kaplan, and chaim Goodman-Strauss, “An aperiodic monotile”, Combinatorial theory 4 (1) (2024), #6.