BIO-INSPIRED HONEYCOMB STRUCTURE

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College : Dayananda Sagar College of Engineering, Bengaluru
Branch : Aeronautical Engineering
Guide : Dr. Manu Hegde
Student(S): Mr. Puneeth S
Mr. Darshan S
Mr. Farhan Minhaj Kasim
Mr. M Satya Sai Srinivas

Keywords:

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Introduction:

Honeycomb structures are known for their excellent strength-to-weight ratio and energy absorption capabilities, making them valuable in aerospace, automotive, and defense industries. Traditionally, honeycomb cores use hexagonal patterns for structural efficiency. However, recent bio-inspired studies reveal that nature's designs such as the trabeculae structures found in beetle exoskeletons offer superior mechanical properties like multi-directional stress handling and enhanced energy absorption.

Figure1: Natural hexagonal honeycomb structure by bees.

This project explores the potential of a trabeculae honeycomb structure, inspired by the *A. dichotoma* beetle, comparing it against conventional honeycomb cores. The structures were modeled in CAD, fabricated using 3D printing with PLA material, and tested through Finite Element Analysis (FEA) and Universal Testing Machine (UTM) experiments. The objective is to evaluate the mechanical efficiency of the bio-inspired structure and assess its applicability for future aerospace components.

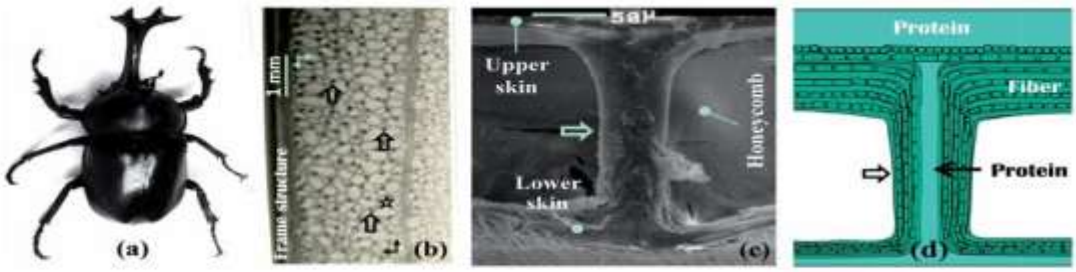


Figure 2: Beetle and microstructure. (a) Adult Allomyrina dichotoma (A.dichotoma) beetle.(b) Topview, location distribution of trabeculae in the fresh elytron of A. dichotoma. The region is between the two right-angled arrows. (c) Cross-sectional view, trabecular shape in the elytron of an adult A. dichotoma beetle.(d) Cross-sectional view, simple model of a trabecula. Trabeculae are indicated by the broad arrows; honeycomb walls are indicated by a star.

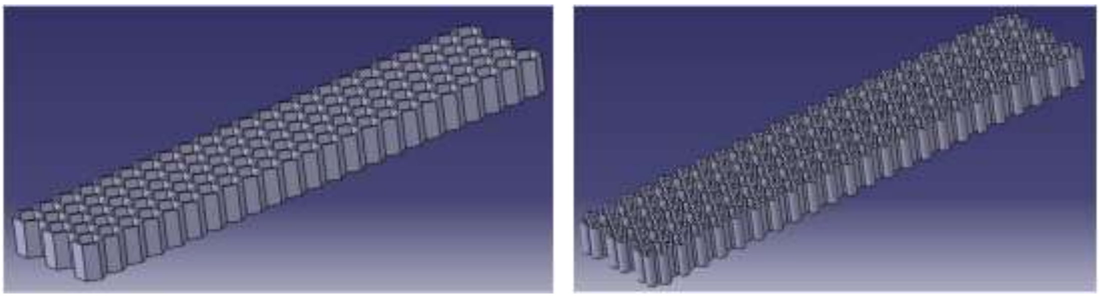
Objectives:

- To design and analyze existing conventional honeycomb structures.
- To develop a bio-inspired trabeculae honeycomb model mimicking beetle skeletal structure.
- To compare mechanical performance parameters like energy absorption and stress distribution via simulation and experimental validation.
- To assess the real-world applicability of bio-inspired structures in aerospace environments.

Methodology:

The project methodology is structured into five stages to evaluate honeycomb structures comprehensively:

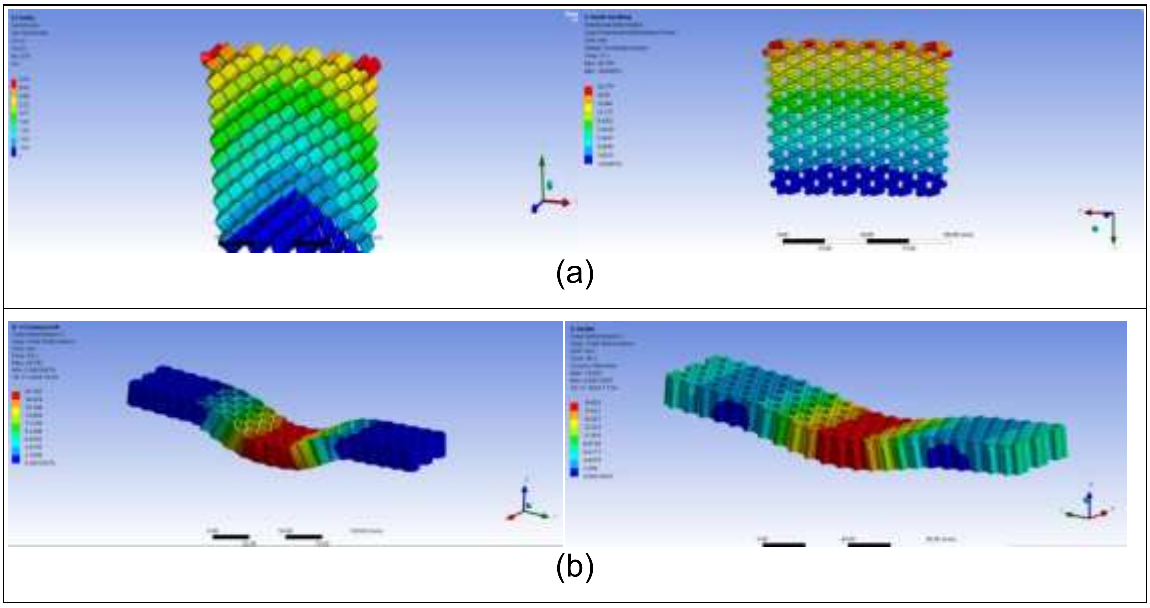
1. CAD Modelling: Both conventional and bio-inspired honeycombs were modelled using Catia with precise dimensions.



(a) (b)

Figure 1: CAD model of (a) conventional honeycomb, (b) bio-inspired honeycomb structure

2. FEA Analysis: ANSYS was employed to simulate compression, bending, and buckling tests, analyzing parameters like stress distribution, deformation, and strain energy.



(a)

(b)

Figure 3: FEA simulation results illustrating deformation behavior in conventional and trabeculae-inspired honeycomb structures under compressive and bending loads. (a) Compressive load distribution in conventional and bio-inspired honeycomb structures, (b) Bending load-induced deformation in conventional and bio-inspired honeycomb structures.

3. 3D Printing: Prototypes were fabricated using PLA material via 3D printing for accurate physical representation.
4. Experimental Testing: UTM was used for compression, bending, and buckling tests on prototypes.

Figure 4: Experimental setup for mechanical testing of 3D-printed honeycomb structures under (a) compressive load and (b) three-point bending load using a Universal Testing Machine (UTM).

5. Comparative Analysis: Results from FEA and experiments were compared for load-bearing capacity, deformation behavior, and energy absorption. Metrics such as stress distribution and strain energy were evaluated to confirm performance improvements in the bio-inspired design.

Result and Conclusion:

In conclusion, The bio-inspired trabeculae honeycomb outperformed the conventional hexagonal design in both simulations and physical tests. The trabeculae model showed:

- Higher stress resistance and energy absorption capacity.
- Improved deformation control under compressive, bending, and buckling loads.

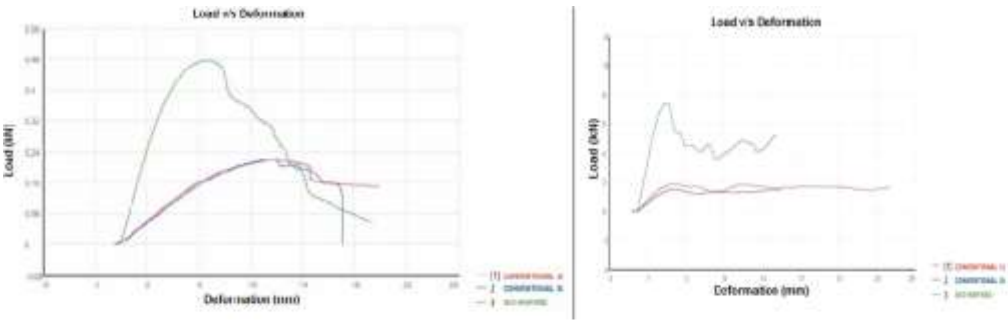


Figure 5:Experimental Load vs. Deformation curves for conventional and bio-inspired honeycomb structures under (a) Compressive, (b) Buckling.

- The trabeculae-inspired honeycomb structure showed uniform stress distribution, delayed buckling, and higher load absorption with lower deformation, confirming its suitability for aerospace structural applications.

Project Outcome, Industry Relevance & Learnings:

The project successfully confirmed the superior mechanical performance of trabeculae-inspired honeycomb structures, demonstrating enhanced energy absorption and impact resistance without compromising weight efficiency. This innovation presents significant potential for industries requiring lightweight, crash-resistant materials, including aircraft fuselage and wing structures, UAV frameworks, satellite panels, and automotive crash components. Through this work, the team acquired valuable hands-on experience in CAD modeling, FEA simulation, 3D printing, and mechanical testing. Additionally, important skills were developed in correlating experimental results with simulation data and analyzing material behavior under various loading conditions. The successful validation of the bio-inspired design underscores its immediate feasibility for prototyping and future integration into aerospace and defense applications, contributing meaningfully to advancements in lightweight structural optimization.

Future Scope:

The future scope of this project includes:

1. Investigating the use of **advanced composite materials** for enhanced performance.
2. Extending testing to dynamic, fatigue, and multi-axial load conditions.
3. Exploring **multi-material honeycomb cores** for specialized aerospace and marine applications.
4. Integrating trabeculae honeycomb panels into **full-scale aircraft wing prototypes**.
5. Evaluating potential in automotive crash-box designs, protective equipment, and construction panels.
6. Exploring sustainable, biodegradable 3D printing materials to align with green manufacturing initiatives