

Parametric Study of Honeycomb Core Geometry for Improving the Mechanical and Vibrational Performance of Copper Sandwich Panels

BABU K

babumech83@gmail.com

Karpaga Vinayaga College of Engineering and Technology

Research Article

Keywords: Copper sandwich panel, Honeycomb core, Flexural strength, Core shear Modulus, Bending properties, Stress Vs Strain, Vibrational Properties

Posted Date: October 19th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11050717/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Parametric Study of Honeycomb Core Geometry for Improving the Mechanical and Vibrational Performance of Copper Sandwich Panels

BABU K*

*Assistant Professor, Department of Robotics and Automation, Karpaga Vinayaga College of Engineering and Technology, GST Road, Chinnakolambakkam, Maduranthagam Taluk, Chengalpattu District – 603 308, Tamil Nadu, India.

*babumech83@gmail.com

Abstract

Copper Honeycomb Structures are designed, modeled, and fabricated for the analysis of flexural behavior and Vibrational properties with various loads and Boundary Conditions. The honeycomb core geometry was generated using CAD software, with a cell size of 6 mm and a node size of 3 mm. Core fabrication was carried out using a hydraulic press, employing a specially developed claw-type forming tool to ensure precise cell geometry and dimensional accuracy. The fabricated core was subsequently bonded to copper face sheets by a brazing operation, which provided strong and reliable joints. Notably, brazing joints did not fail prior to the cracking of the core material, indicating excellent interfacial strength. The mechanical behavior of the sandwich panels was investigated through flexural strength and bending stress analysis. Load–displacement responses were recorded at room temperature for panels with varying core heights, and the results were used to evaluate flexural stiffness, bending strength, and core shear behavior. The experimental findings were compared with various core heights and understand the deformation characteristics at different stages of loading. The brazed bonding in the 10 mm panel provided superior interfacial strength, enhancing load transfer between the face sheets and the core. This is not only improved structural integrity but also increased the panel's capacity for energy absorption before failure. The panels were given higher stability and lower deformation characteristics. The panel got high resistivity to deformation in 3 point bending load. The core structures and face sheets were given high stiffness to weight ratio compared to other panels. The vibration of the Panels with a 200 mm span length exhibited the lowest frequency values. Effect of Mode Number – Higher-order modes (Mode 2, Mode 3) showed progressively higher frequency values compared to the fundamental mode. Among all conditions, Mode 3 consistently recorded the maximum frequency response. The study confirmed that copper honeycomb structures exhibit superior conductivity, damping capacity, corrosion resistance, and flexural strength, making them highly suitable for aerospace, automotive, thermal management, and structural applications.

Keywords: Copper sandwich panel, Honeycomb core, Flexural strength, Core shear Modulus, Bending properties, Stress Vs Strain, Vibrational Properties

1. Introduction

Copper is a ductile, highly conductive, and corrosion-resistant material, making it suitable for advanced structural applications where both mechanical strength and functional properties (such as thermal and electrical conductivity) are required. When fabricated into honeycomb structures, copper sheets provide an excellent balance of lightweight design and structural stiffness, which are crucial for aerospace, automotive, and energy-related engineering applications. A honeycomb structure consists of thin sheets of copper formed into

hexagonal core cells, which are then sandwiched between two copper face sheets. This arrangement significantly enhances flexural stiffness, shear resistance, and the strength-to-weight ratio of the panel. The geometric efficiency of the honeycomb core allows for high-energy absorption, buckling resistance, and improved damping capacity compared to solid plates. The bonding between the copper core and the face sheets is typically achieved through brazing, a process in which a filler metal with a lower melting temperature than copper is used to form strong metallurgical joints via capillary action. Brazing ensures uniform load transfer across the interface, minimizes the risk of debonding, and provides high bonding integrity compared to adhesive or mechanical fastening methods. Compared to aluminum and polymer-based honeycomb structures, copper honeycomb panels exhibit superior thermal conductivity, high-temperature stability, and corrosion resistance, making them particularly useful in heat exchangers, vibration-damping panels, electronic shielding, and aerospace thermal management systems. Additionally, the high ductility and formability of copper sheets allow for precise fabrication of complex honeycomb geometries. Key advantages of copper honeycomb structures are High strength-to-weight ratio, Enhanced flexural rigidity and bending stiffness, Superior thermal and electrical conductivity, High damping and energy absorption capacity, Resistance to corrosion and elevated temperatures and Strong metallurgical bonding via brazing. Thus, copper sheet-based honeycomb sandwich structures offer a unique combination of structural efficiency and multi functionality, positioning them as promising candidates for next-generation lightweight, high-performance applications. Honeycomb sandwich construction has emerged as a versatile structural concept, capable of integrating a wide range of materials and design configurations. By combining thin, stiff face sheets with a lightweight honeycomb core, the sandwich structure provides excellent strength-to-weight and stiffness-to-weight ratios, which are essential for aerospace, automotive, marine, and civil engineering applications. The choice of core geometry, thickness, and face sheet material offers design flexibility to tailor the panel's performance to specific functional requirements. In the present work, the honeycomb sandwich panels consist of two copper face sheets bonded to a hexagonal copper core through brazing. The use of copper, unlike the more common aluminum or polymeric cores, offers advantages such as high damping capacity, superior corrosion resistance, and elevated temperature tolerance. Previous research has reported numerous efforts to characterize honeycomb panels fabricated with different materials. Carbon-fiber/matrix sandwich honeycomb panels have been manufactured using adhesive bonding techniques and analyzed through finite element analysis (FEA) and three-point bending tests. The maximum load capacity reported was approximately 7200 N, demonstrating high bending strength [1]. Wood-based sandwich panels have been prototyped with plywood face sheets and honeycomb cores. These designs showed improved fire resistance, higher shear modulus, and environmentally friendly characteristics [2]. A dynamic parametric model updating strategy to improve the finite element accuracy of aero engine casings. The method combined parametric modelling with experimental modal data to reduce differences between predicted and measured vibration characteristics. It effectively handled uncorrelated mode shapes and improved mode matching reliability. The updated casing model showed frequency errors below acceptable engineering limits with strong modal correlation [3]. The compressive behavior of graded honeycomb sandwich panels with varying cell density. The results showed that density gradation improved load carrying capacity and delayed local buckling. Better deformation control was observed compared with uniform core panels. Energy absorption efficiency also increased under progressive crushing [4].

Experimentally investigated vibration-damping characteristics of aluminium honeycomb sandwich composites. The panels exhibited reduced vibration amplitude due to the core's internal energy dissipation capability. Higher damping was achieved with optimized core thickness and skin bonding quality. Natural frequency values were also influenced by structural geometry [5]. The topology optimization of honeycomb sandwich plates for improved stiffness-to-weight ratio. The optimized designs redistributed material efficiently within the core structure. Numerical results indicated higher bending rigidity without significant mass increase. Stress concentration zones were also reduced through geometric refinement [6]. The necessity of integrated thermal and mechanical evaluation in the design of advanced lightweight structures, particularly for aerospace and high-temperature applications. The failure mode maps, which are graphical representations that delineate the combinations of stress and geometry that lead to distinct types of structural failure [7]. The impact damage in composite honeycomb sandwich structures using finite element simulation. The study found that impact energy caused face sheet cracking, core crushing, and interfacial delamination. Damage severity increased with higher striker velocity. Improved face sheet strength significantly reduced penetration effects [8]. The major manufacturing routes for FRP composites and relate processing choices to final mechanical performance. Material characteristics such as strength, stiffness, fatigue, and environmental resistance are discussed. Applications across aerospace, automotive, marine, and civil sectors demonstrate the versatility of these materials [9]. The performed modal analysis of aerospace sandwich panels with aluminium honeycomb cores. The investigation showed that panel stiffness and boundary conditions strongly affected natural frequencies. Optimized core geometry increased frequency separation and structural stability. Reduced vibration resonance risk was achieved through suitable design changes [10]. The fabrication of sandwich panels combining a light honeycomb core with bio-fiber reinforced thermoset skins. Mechanical testing shows competitive stiffness and strength compared with synthetic alternatives. The work supports environmentally friendly materials for lightweight structural design [11]. The infrared thermography can reveal subsurface flaws without damaging composite components. Different heating strategies and defect detectability are compared. The method is positioned as a rapid inspection tool for maintenance and quality assurance [12]. The honeycomb cell dimensions influence vibration characteristics. Analytical and numerical approaches show that equivalent stiffness changes with geometry [13]. The developed bio-inspired hierarchical honeycomb cores for enhanced crashworthiness. Multi-level cell architecture improved progressive collapse behavior under axial loading. The structures absorbed more impact energy than conventional hexagonal cores. Weight efficiency remained favorable despite higher strength. [14]. examined thermo-mechanical performance of glass fiber reinforced honeycomb sandwich panels at elevated temperatures. Increasing temperature reduced stiffness and load carrying capacity of the composite skins. Core stability was also affected during thermal exposure. However, the panels retained acceptable structural performance within moderate temperature limits [15]. The investigated additively manufactured metallic honeycomb sandwich structures and their vibration response. Additive manufacturing enabled precise control of cell geometry and customized internal layouts. Experimental results showed improved frequency tuning and lightweight efficiency. Complex shapes impossible by conventional methods were successfully produced [16]. Free vibration and buckling behavior of laminated sandwich

beams with honeycomb cores. The results indicated that stronger face sheets increased natural frequency and critical buckling load. Core thickness played a major role in structural stability. Proper laminate orientation further improved resistance to deformation [17]. Low-velocity impact resistance of carbon fiber honeycomb sandwich panels with hybrid face sheets. Hybrid surface layers reduced crack propagation and distributed impact forces more effectively. Core crushing was minimized compared with conventional laminates. Residual strength after impact remained comparatively high [18]. The crushing response of multilayer honeycomb sandwich panels under axial impact loading. The panels showed progressive deformation with stable collapse behavior during impact. Multilayer configurations absorbed more energy than single-core structures. Load fluctuations were reduced through better layer interaction [19]. Experimentally studied the flexural strength of aluminium honeycomb sandwich composites with glass fiber skins. Strong bonding between the skins and core significantly improved bending resistance. Failure mainly started with skin cracking followed by local core crushing. Increasing skin thickness enhanced stiffness and load capacity [20]. Investigated free vibration characteristics of functionally graded honeycomb sandwich plates with elastic supports. The natural frequency increased with higher edge stiffness and graded core density. Support flexibility had a noticeable influence on vibration response. Proper grading of the honeycomb core improved dynamic stability [21]. The finite element model and refined it using experimental modal data. Sensitivity studies determine which parameters most affect correlation. The procedure leads to better predictive capability for lightweight frames [22]. The software analysis of panels were taken and studied the deflection characteristics under different loads [23]. While these studies provide valuable insights, it is observed that only limited research has focused on copper honeycomb sandwich panels, particularly in the context of brazed bonding techniques and their impact on flexural bending behavior, stress-strain relationships, and core shear modulus. Therefore, the present investigation focuses on copper honeycomb sandwich panels fabricated through brazing and manufacturing of core from press type method. The systematically studying their flexural properties, shear characteristics, and load-deflection responses under three-point and four-point bending tests and vibrational characteristics under variable mode frequencies with different lengths [24].

The numerical model of an automotive trunk lid by matching it with measured modal data. Differences between predicted and experimental frequencies are minimized through parameter tuning. The updated model better represents stiffness and mass distribution. This improves reliability of vibration and durability assessments in vehicle design [25]. A numerically analyzed low-velocity impact behaviour of composite sandwich panels containing honeycomb cores. Impact loading caused face sheet indentation, delamination, and localized core damage. Higher core density reduced permanent deformation after impact. Energy absorption improved with stronger face materials [26]. The design of cellular architectures inspired by natural systems to enhance mechanical efficiency. Different hybrid topologies are compared for stiffness, strength, and energy absorption. Numerical analysis shows that graded layouts outperform uniform cells. The results support lightweight structures with multifunctional performance [27]. The honeycomb cores subjected to compressive loading. Response Surface Methods and neural networks are used to predict structural behaviour. The approach reduces computational effort while maintaining accuracy. It provides designers with fast tools for optimization [28]. The developed bio-inspired re-entrant honeycomb sandwich structures for better energy absorption. The negative Poisson's ratio geometry allowed controlled inward deformation during compression. These structures showed higher crushing efficiency than

conventional hexagonal cores. Improved load distribution delayed sudden failure. The design is promising for protective and transportation applications [29]. A biomimetic concept is introduced where density varies across the honeycomb to manage energy flow. The configuration enhances progressive collapse and shock absorption. Models demonstrate superior dissipation compared with conventional cores. The work opens routes for safer lightweight structures [30]. The results are further compared across panels of varying core heights to evaluate the influence of geometry on mechanical performance. The core height was increased, performance of the panels considerably increased. In vibration sector, the frequency analysis are taken place with different mode conditions and discussed. The Figure 1 shows the Natural honeycomb core structure for realising to our research.



Figure 1 Natural honey comb core

2. Experimental Investigation

The schematic configurations of the sandwich beams studied are illustrated in Figures 2.1 and 2.2. Each sandwich beam consisted of two face sheets of identical thickness t_1 & t_2 and bonded to a core of thickness h . The face sheets and core were fabricated from copper, ensuring uniformity in material properties. L and b , respectively denote the length and width of the specimens. Copper was selected as the material for both the core and face sheets due to its excellent electrical and thermal conductivity, high corrosion resistance, and superior high-temperature capability compared to aluminum. These characteristics make copper particularly suitable for structural applications where both mechanical strength and environmental durability are required.

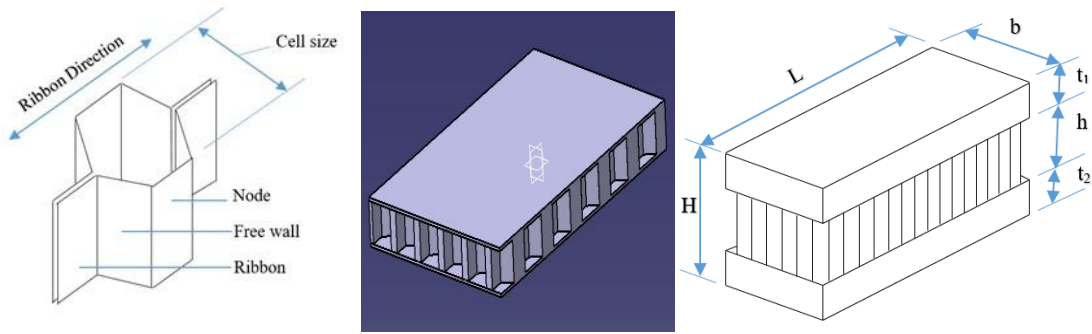


Figure 2.1 schematic representation

To evaluate the influence of geometric parameters on flexural and shear performance, sandwich panels were fabricated with different core heights and face sheet thicknesses. These variations were introduced systematically to investigate the resulting mechanical properties, including flexural stiffness, core shear modulus, and overall load-bearing capacity under three-point and four-point bending configurations.



Figure 2.2 Sandwich beams

2.1 Material Properties

Commercially available copper sheets were procured for the fabrication of the honeycomb core and face sheets. Copper was chosen owing to its excellent thermal and electrical conductivity, good formability, and superior brazing compatibility. The fundamental material properties used for analysis and fabrication are listed below. The honeycomb core was designed with a cell size of 6 mm and a cell wall thickness of 0.5 mm, ensuring a balance between structural stiffness and lightweight characteristics. To investigate the influence of core thickness on mechanical behavior, cores were fabricated with varying heights of 4 mm, 6 mm, and 8 mm.

Symbol of Element	:Cu
Atomic Number	:29
Melting Point	:1083.0°C-1356.15°K
Boiling Point	:2567.0°C-2840.15°K
Number of Protons/Electrons	:29
Modulus of Elasticity	: 120GPa

Yield Strength	: 70MPa
Ultimate Tensile strength	: 220MPa
Poisson Ratio	: 0.3
Density	: 8960Kg/m ³

For bonding the honeycomb core to the face sheets, a brazing filler rod of 6 mm diameter was employed. The brazing process was carried out at a flame temperature of approximately 600 °C, ensuring complete melting of the filler metal while maintaining the structural integrity of the copper base material. The filler metal, owing to its lower melting point compared to the parent material, flowed into the narrow joint regions by capillary action, producing continuous metallurgical bonding. The brazed joints exhibited high bonding capability, which is critical for efficient load transfer between the core and face sheets. This bonding technique not only provided superior joint strength compared to adhesive or mechanical fastening but also contributed to improved flexural stiffness, core shear resistance, and long-term reliability of the sandwich panels.

2.2 Tool Fabrication

The forming tool was fabricated using H11 die steel, selected for its high hardness, toughness, and resistance to thermal fatigue properties that make it highly suitable for press-forming operations.



Figure 2.3 Honeycomb core die

The tool was manufactured to the desired geometry by employing the wire-cut Electrical Discharge Machining (EDM) process, which enables precise cutting of complex profiles with minimal dimensional deviation. In this process, a copper alloy wire of 0.3 mm diameter was used as the electrode, while an applied voltage of 230 V facilitated controlled spark erosion between the wire and the work piece. This ensured accurate shaping of the die with smooth surface finish and minimal residual stresses. The fabricated profile-cut die is shown in Figure 2.3. The final tool dimensions were length = 250 mm, width = 50 mm, and thickness = 50 mm,

which provided sufficient strength and rigidity for repeated pressing operations during honeycomb core fabrication.

2.3 Specimen Preparation

Copper strips were cut to the required design dimensions using a precision cutting machine and subsequently formed into honeycomb cores by the hydraulic press route and the Die set up was shown in Figure 2.4. Each strip was positioned on a specially prepared die and held securely before pressing, ensuring accurate cell geometry. The pressing operation imparted micron-level compaction to the flat surfaces of the strips, thereby enhancing the microstructural density and improving the mechanical strength of the core. A small corner radius was incorporated in the die design to minimize stress concentrations and prevent core breakage during forming. The fabricated honeycomb core was shown in Figure 2.5. Following core fabrication, the copper honeycomb structure was joined with the face sheets by a brazing process.



Figure 2.4 Tool Loaded in Fixture

Brazing is a metallurgical joining technique in which two metals are bonded by melting a filler metal whose melting point is lower than that of the base materials but greater than 450 °C. The filler metal flows into the narrow gap between the adjoining surfaces by capillary action, creating a strong and continuous metallurgical bond. This method is especially suitable for copper and copper alloys, with the exception of aluminum bronzes containing more than 10% Al and alloys with lead content above 3%. The Honey comb core die was loaded in die fixture arrangements. The positioning of die fitment was in zero tolerance because of core thickness in bottom and side variation happened. The core was made in each movement of strokes of the

machines. The position of the core materials were also maintained accuracy because of arrest the angular variation during movement. The brazing process was chosen for this study because it ensures superior joint integrity, efficient load transfer between the face sheets and the honeycomb core, and excellent thermal and mechanical stability. Brazed joints are widely used in electrical manufacturing, mechanical services, and HVAC systems, which further highlights the applicability of this bonding method in multifunctional sandwich structures.



Figure 2.5 Brazed core

3. Experimental Methods

The bending behavior and flexural properties of honeycomb sandwich panels were experimentally evaluated at room temperature in accordance with ASTM C393-00 (flexural properties of sandwich constructions) three-point and four-point bending tests were conducted using a universal testing machine (UTM). For each test, the appropriate fixture was mounted on the UTM, and the specimen was positioned according to the specified span length for the given configuration. The figure 3.1 shown the 3 point bending test apparatus.

The panels were supported on roller edges, and the load was applied gradually at a constant crosshead speed of 4 mm/min until failure. The specimen dimensions and span length were maintained within a tolerance of $\pm 5\%$ in compliance with ASTM standards. During the test, the maximum load and corresponding deflection were automatically recorded by the system. From the load–deflection response, the bending stiffness of the sandwich panels was determined. Stress–strain curves were also obtained, providing insight into the flexural properties and failure characteristics of the specimens. Furthermore, the load–deformation

curves were analyzed to extract the flexural modulus, bending stiffness, and natural frequency of the sandwich panels for different core heights. This allowed for a comprehensive comparison of the influence of core thickness on the flexural behavior and dynamic response of the brazed honeycomb structures.

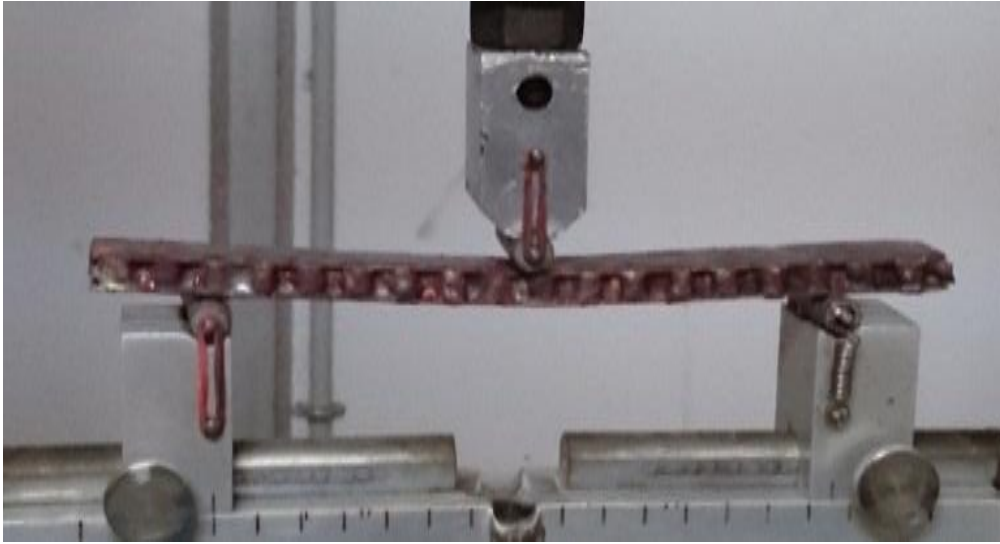


Figure. 3.1- 3 Point – Bending Test

Where,

P=Load for the corresponding deflection, L= Panel Length, H=Panel Height, h=Core height, b= Breath of the Panel, δ = Corresponding Deflection, D=Flexural stiffness & G=Shear Modulus

Flexural stiffness and core shear modulus of the sandwich specimen is given, if the deflections of the specimen are determined under Mid-span load P_1 and also under the Quarter-point load P_2 .

$$D = \frac{P_1 L^3 [1 - (11/8)]}{48 \delta_1 [1 - (2P_1 \delta_2 / P_2 \delta_1)]} \quad (1)$$

$$G = \frac{P_1 L h [(8/11) - 1]}{\delta_1 b (H + h)^2 [(16P_1 \delta_2 / 11P_2 \delta_1) - 1]} \quad (2)$$

4 Results and Discussions

The displacement curves of sandwich panels with varying core heights were obtained from both three-point and four-point bending tests. As expected, the deformation increased progressively with increasing load, leading to measurable deflections in all panels.

4.1 Bending Properties - Experimental

The maximum ultimate loads for both three-point and four-point bending are presented in Table 1. A clear trend was observed in which the strength of the panels increased with greater core thickness, owing to the higher bending stiffness provided by the larger core height. During testing, the core itself remained largely unaffected by the applied load; however, failure was initiated in the face sheets. In the case of three-point bending, localized buckling and fracture were observed at the interface between the face sheets and the core. This behavior can be attributed to the higher localized stresses and shorter effective span length under three-point loading. In contrast, under four-point bending, the load distribution was more uniform, and no fracture occurred at the brazed interface for a prolonged period of loading. Instead, the panels exhibited a curved deflection shape, with fracture primarily localized at the mid-span region. Gradual deformation was also observed near the junction of the face sheets and the core, indicating progressive damage accumulation rather than sudden failure. Importantly, no fracture was detected in other regions of the panel, confirming the structural reliability of the brazed joints. Deflection responses of the 8 mm and 6 mm sandwich panels exhibited only slight variations, with both showing a steady incremental trend under applied loading. As illustrated in Figure 4.1, the load–deflection curve revealed that during the initial stage, deformation increased gradually within the elastic region.

Table. 1 Bending Property - Experimental

Panel Height (H) (mm)	Load (P) (3-point) (kN)	Deflection Max δ_1 (mm)	Load (P) (4-Point) (kN)	Deflection Max δ_2 (mm)
6	0.88	38.0	0.88	36.0
8	0.91	36.0	0.91	34.0
10	0.94	32.0	0.94	31.0

Beyond this region, once the applied load surpassed the elastic limit, the panels experienced a rapid increase in deflection, indicating nonlinear deformation behavior. This transition highlights the reduction in bending stiffness as the flexural rigidity of thinner cores provides lower resistance to apply moments. The 10mm panels was given higher stability and lower deformation characteristics. The panel got high resistivity to deformation in 3 point bending load. The core structures and face sheets were given high stiffness to weight ratio compared to other panels. Due to the core thickness, the panels got the high value of deflection under different loading conditions without crack, peeling or shear failures.

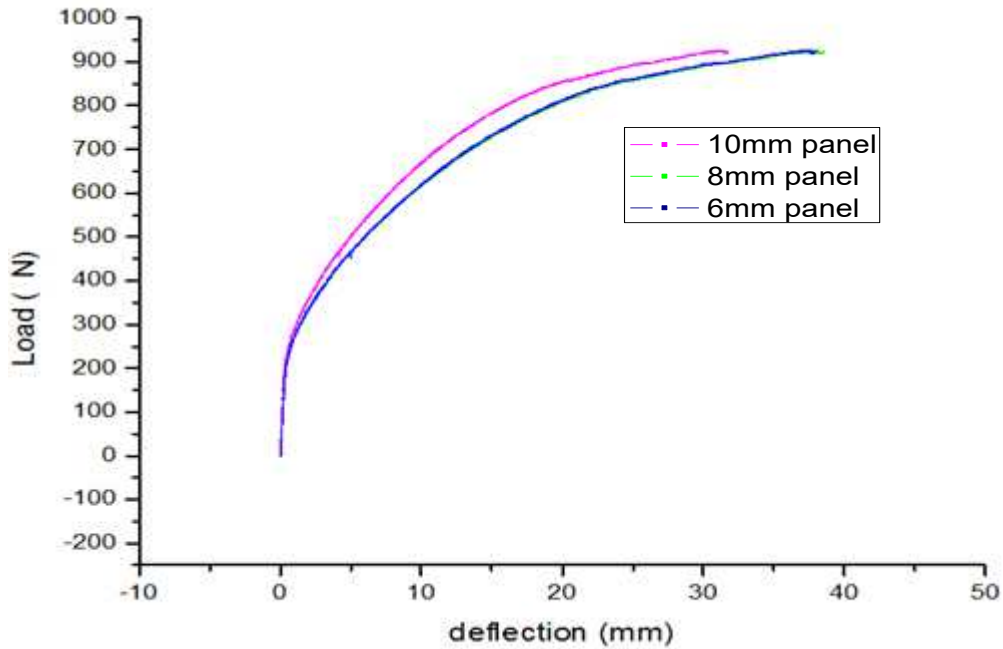


Figure. 4.1 Load Vs Deformation (3 Point)

In contrast, the 10 mm panel under four-point bending exhibited a noticeably different deflection profile compared to the 6 mm and 8 mm panels, as shown in Figure 4.2. The enhanced core thickness contributed to higher bending stiffness, thereby reducing curvature and delaying the onset of large deflections. Moreover, the thicker core minimized shear deformation by distributing the applied load more effectively across the sandwich structure, which is consistent with classical sandwich beam theory. Additionally, the brazed bonding in the 10 mm panel provided superior interfacial strength, enhancing load transfer between the face sheets and the core. This not only improved structural integrity but also increased the panel's capacity for energy absorption before failure. The combination of higher bending stiffness, reduced shear deformation, and efficient load distribution explains the deviation of the 10 mm panel's deflection curve from that of the thinner panels.

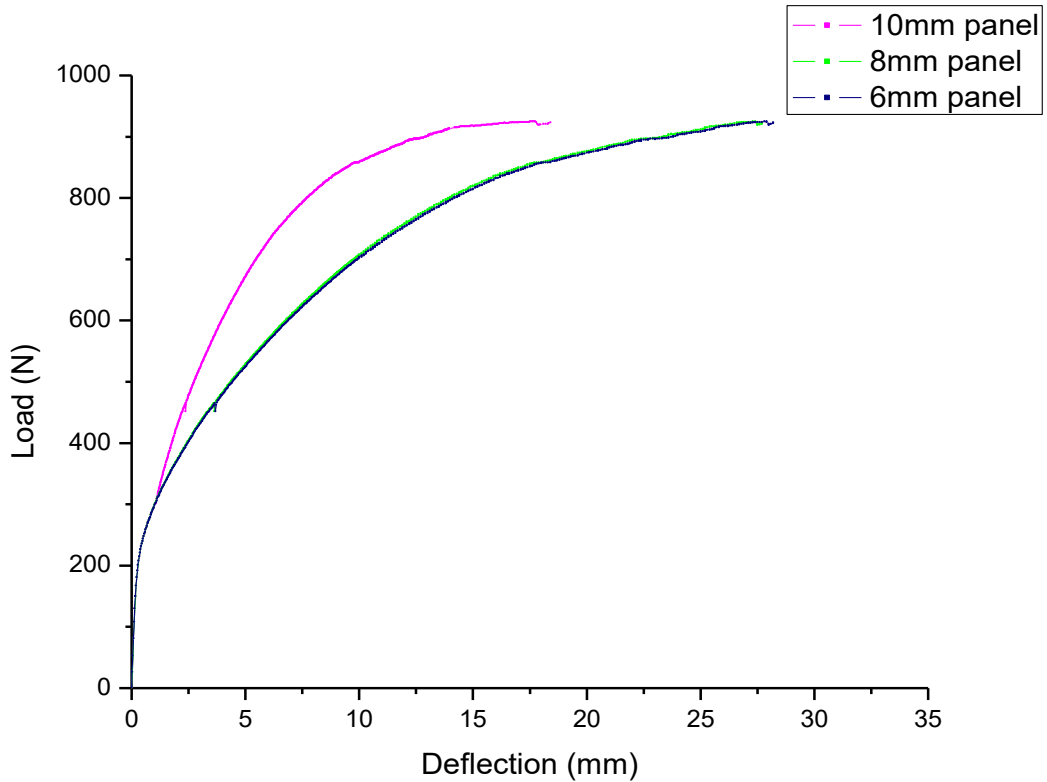


Figure 4.2 Load Vs deflection (4-point)

4.2 Flexural Properties - Software

4.2.1 Meshed Model of Sandwich Panel

ANSYS V18 was used in this work as the primary simulation software for designing, modeling, and analyzing the product under various structural conditions and configurations. The initial model file was converted into the IEGS format to enable seamless importing into ANSYS. After import, the product was meshed using different combinations of face-sheet materials and honeycomb core structures, each with varying dimensional parameters. The corresponding deflection values for each configuration were then computed and tabulated for comparison. Figure 4.3 shows the meshed model of the 6 mm panel. During the meshing process, multiple mesh controls—such as coarse, medium, and fine mesh densities—were applied to evaluate their influence on the accuracy of the results. Additional mesh parameters were also adjusted as needed. For fine meshing, triangular elements (tri-node elements) were selected to achieve better resolution along the curved and complex geometrical features of the model, ensuring improved accuracy in the subsequent analysis.

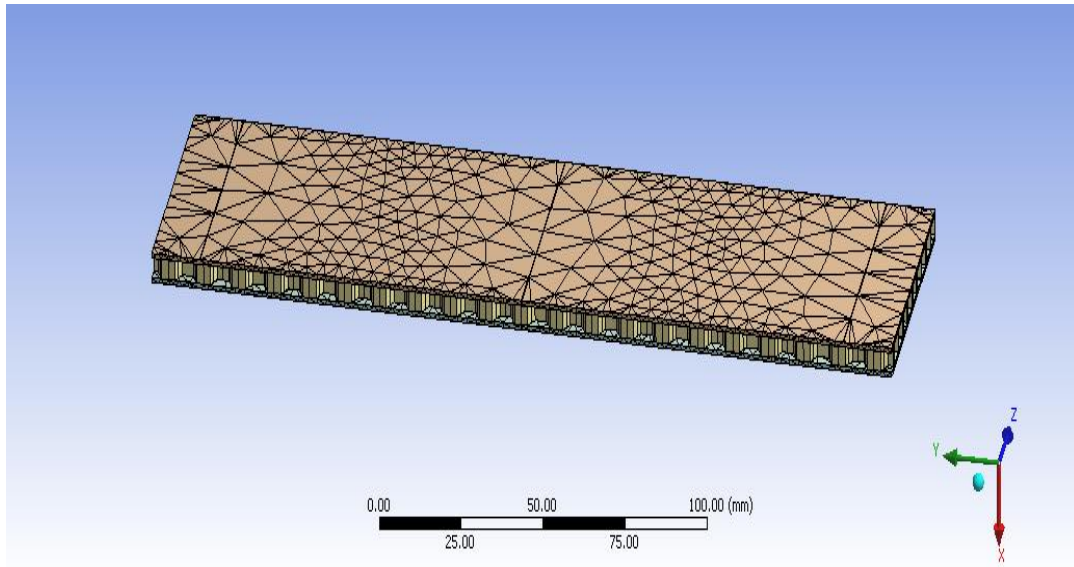


Figure 4.3 Meshed Model of Sandwich panel

4.2.2 Structure analysis of honey comb panels – 3-Point Bending

The structural analysis of the copper honeycomb panel was carried out under a simply supported boundary condition with a central point load, as illustrated in Figures 4.4, 4.5&4.6. These analyses allowed for the observation of different failure modes that occurred in the panels when subjected to varying load conditions and core heights. As the core height changed, the mechanical response of the structure such as stiffness, deformation pattern, and failure behavior—also varied significantly. The resulting deflection values obtained from each simulation were measured, compared, and systematically presented in Table 2 for further evaluation and interpretation.

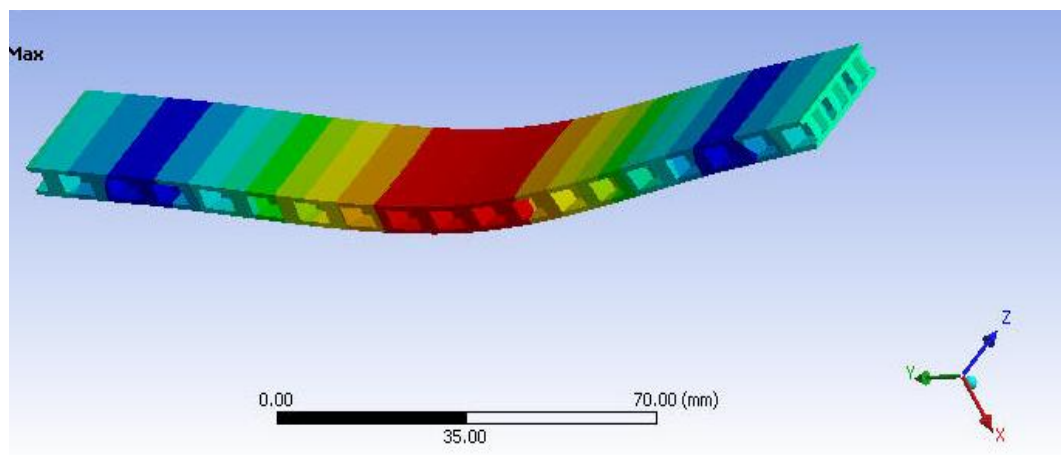


Figure 4.4 Panel deflection of 6mm

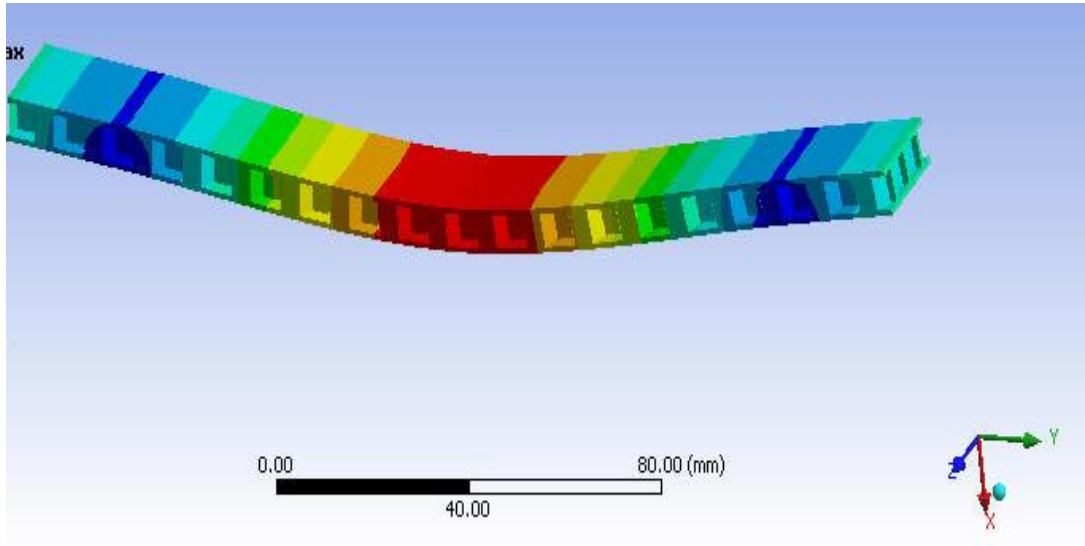


Figure 4.5 Panel deflection of 8mm

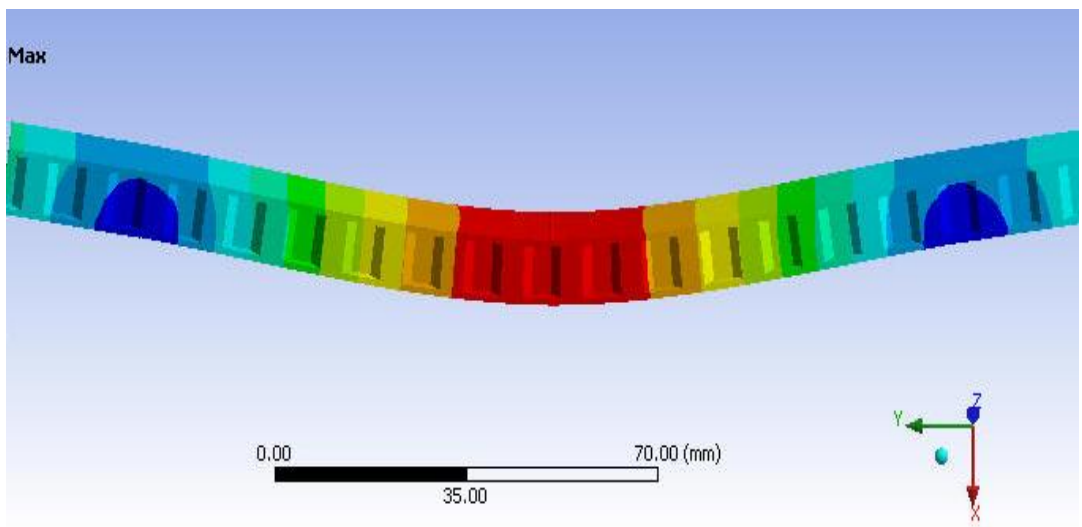


Figure 4.6 Panel deflection of 10mm

4.2.2 Structure analysis of honey comb panels – 4-Point Bending

The structural analysis of the copper honeycomb panel was performed under a simply supported boundary condition with a quarter-point load, as illustrated in Figures 4.7, 4.8 & 4.9. This loading configuration allowed for the assessment of the panel's deformation behavior and stress distribution when the load is applied away from the center, providing insights into how the honeycomb structure responds to asymmetric loading conditions.

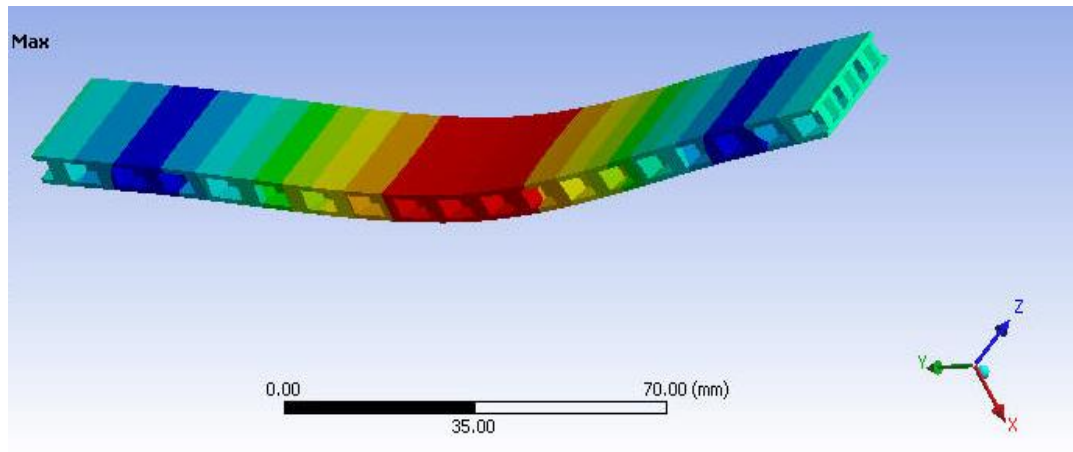


Figure 4.7 Panel deflection of 6mm

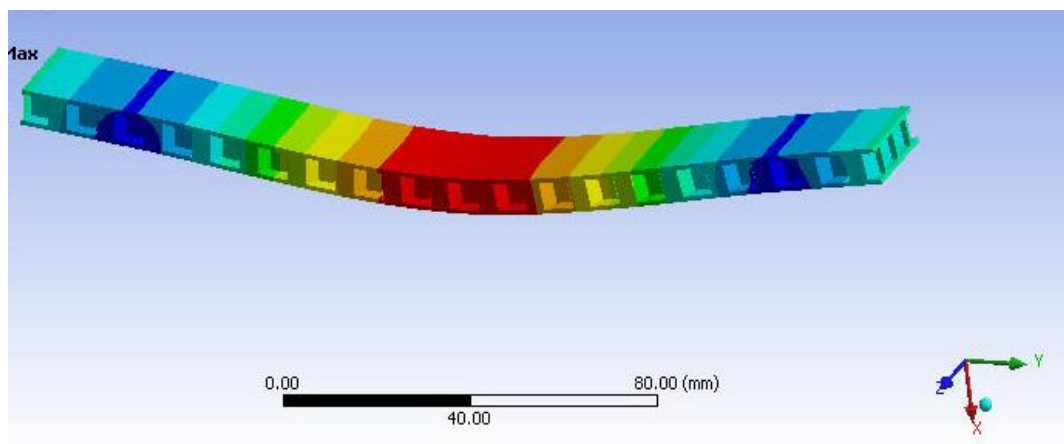


Figure 4.8 Panel deflection of 8mm

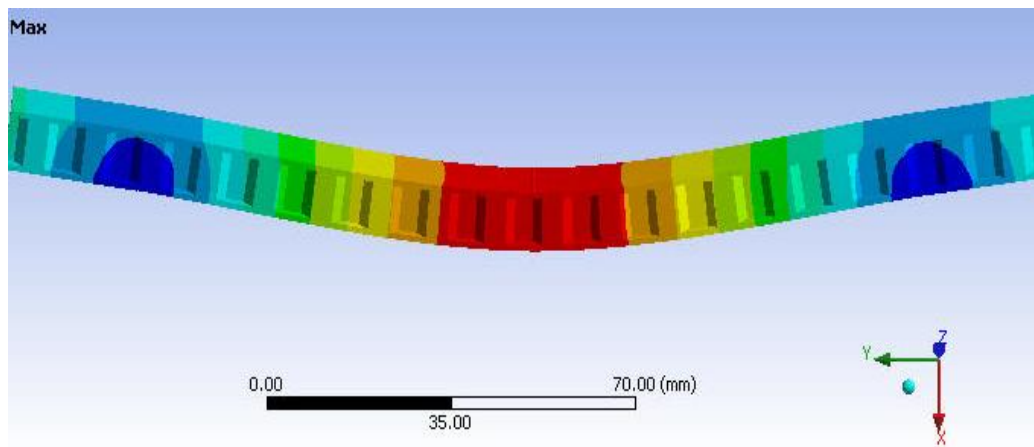


Figure 4.9 Panel deflection of 10mm

Table. 2 Bending Property – Software Analysis

Panel Height (H) (mm)	Load (P ₁) (3-point) (kN)	Deflection Max δ_1 (mm)	Load (P ₂) (4-Point) (kN)	Deflection Max δ_2 (mm)
6	0.88	35.0	0.88	32.0
8	0.91	33.0	0.91	30.0
10	0.94	30.0	0.94	28.0

4.3 Flexural Properties

Furthermore, the flexural modulus and core shear modulus were significantly enhanced with increasing core thickness, while the associated shear stress and face-sheet bending stress decreased. This inverse relationship underscores the role of core height in improving load-carrying capacity and energy absorption, while simultaneously reducing stress concentrations in the face sheets. A comparative summary of these properties for different core heights is presented in Table 3.

Table. 3 Flexural Strength – Experimental & Software

Panel Height (H) (mm)	Flexural Stiffness - Experimental (kN-mm ²)	Flexural Stiffness - Software (kN-mm ²)
6	0.53	0.7
8	0.65	0.9
10	0.95	1.1

Figure 4.10 illustrates the variation in flexural properties and core shear modulus of the honeycomb sandwich panels. It is evident that with increasing core thickness, the overall flexural rigidity of the panel improved, while thinner cores exhibited lower stiffness and higher deflection responses. This gradual change in flexural performance can be attributed to the direct dependence of bending stiffness and shear resistance on the geometric parameters of the core and face sheets. Consequently, core thickness plays a decisive role in governing the load-carrying capacity and deformation characteristics of the sandwich structure.

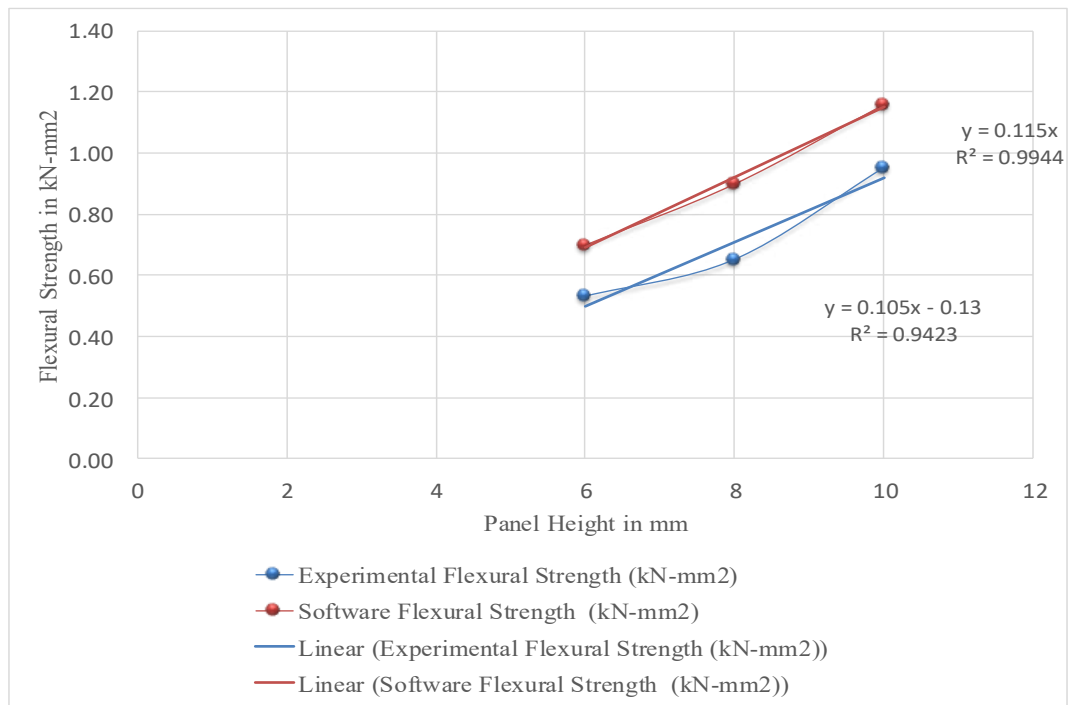


Figure. 4.10 Flexural Strength – Experimental & Software

The shear modulus is a material property that describes the material's resistance to shear deformation, sliding along a plane under tangential stress. In a honeycomb sandwich panel, the core carries most of the shear load. The faces skins carry bending and tensile/compressive loads. Therefore, the core shear modulus is critical for determining panel stiffness and deflection under transverse loads.

Honeycomb cores are anisotropic: their properties vary with direction because of the hexagonal geometry. The shear modulus differs along the two in-plane directions: (in plane) and through-thickness.

Table. 4 Core Shear Modulus – Experimental & Software

Panel Height (H) (mm)	Core Shear Modulus - Experimental (Gpa)	Core Shear Modulus - Software (Gpa)
6	1.10	1.50
8	1.0	1.30
10	0.98	1.28

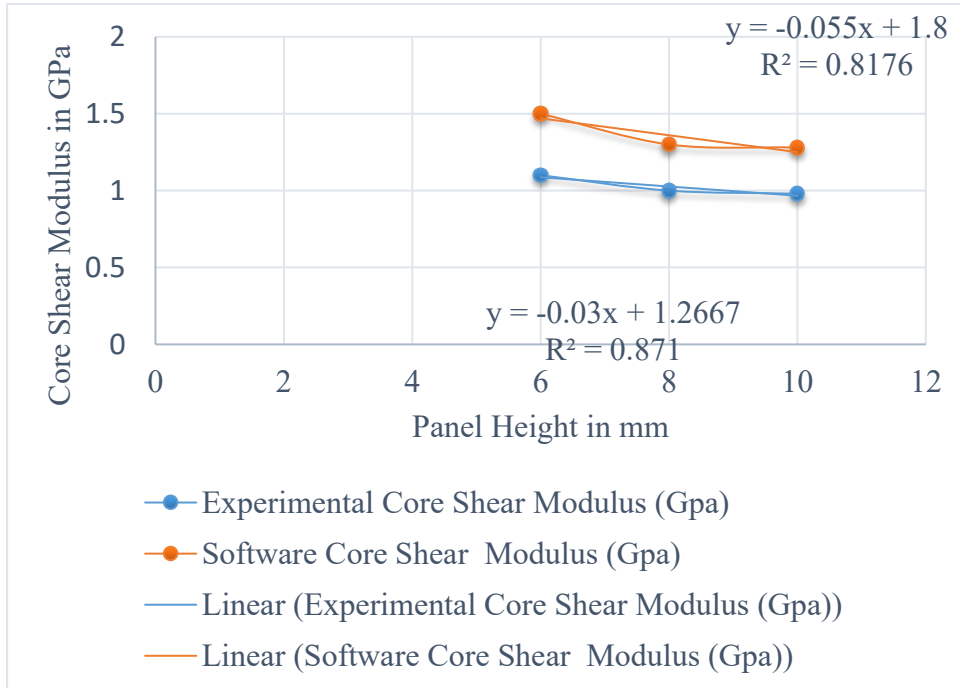


Figure. 4.11 Flexural Strength – Experimental & Software

4.4 Stress Vs Strain

The stress–strain variation of the sandwich panels exhibited a gradual increase with increasing load. The curve corresponding to the 10 mm panels showed only slight deviations, remaining closely aligned with the behavior of the 8 mm panels, as illustrated in Figure 4.12. In contrast, the face bending stress and core shear stress values demonstrated a decreasing trend with increasing core thickness, indicating that as the core height increased from lower to higher values, the overall stresses in both the face sheets and the core were progressively reduced. This behavior can be attributed to the improved load distribution and enhanced stiffness associated with larger core thicknesses, which effectively minimized localized stresses within the sandwich structure. The stress–strain behavior obtained from the four-point bending tests exhibited a distinct trend when compared to the three-point bending results. In the case of four-point bending, the stress values demonstrated a noticeable increase even with relatively small increments in strain, which can be attributed to the enhanced load transfer efficiency provided by the brazed bonding of the sandwich panels. Furthermore, the variation in performance was more pronounced when comparing panels of different core thicknesses.

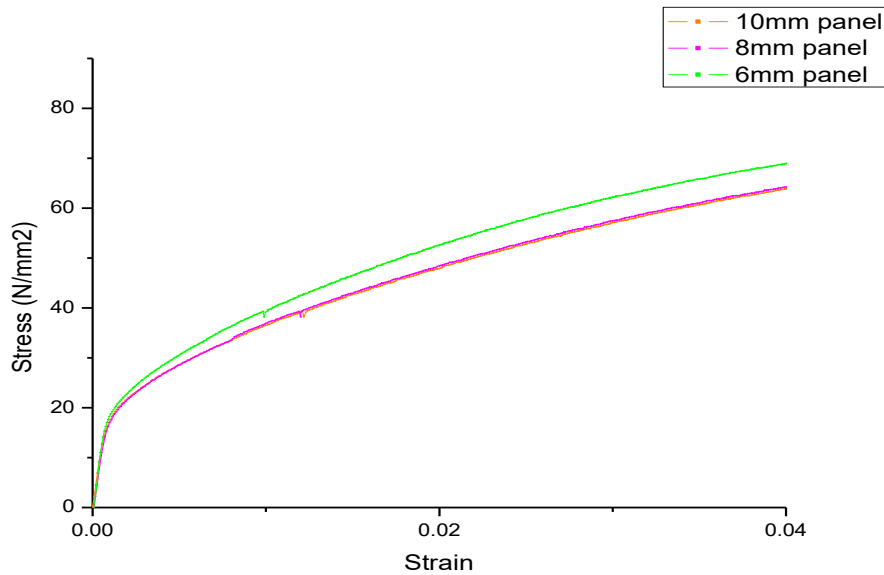


Figure 4.12 Stress Vs Strain (3-Point)

Specifically, the 10 mm and 8 mm thick panels exhibited consistent stress–strain responses, whereas the 6 mm panels showed significant deviation from this trend. These differences in mechanical response, as illustrated in Figure 4.13. The strain rate is gradually increased all the panels and also got steady responses.

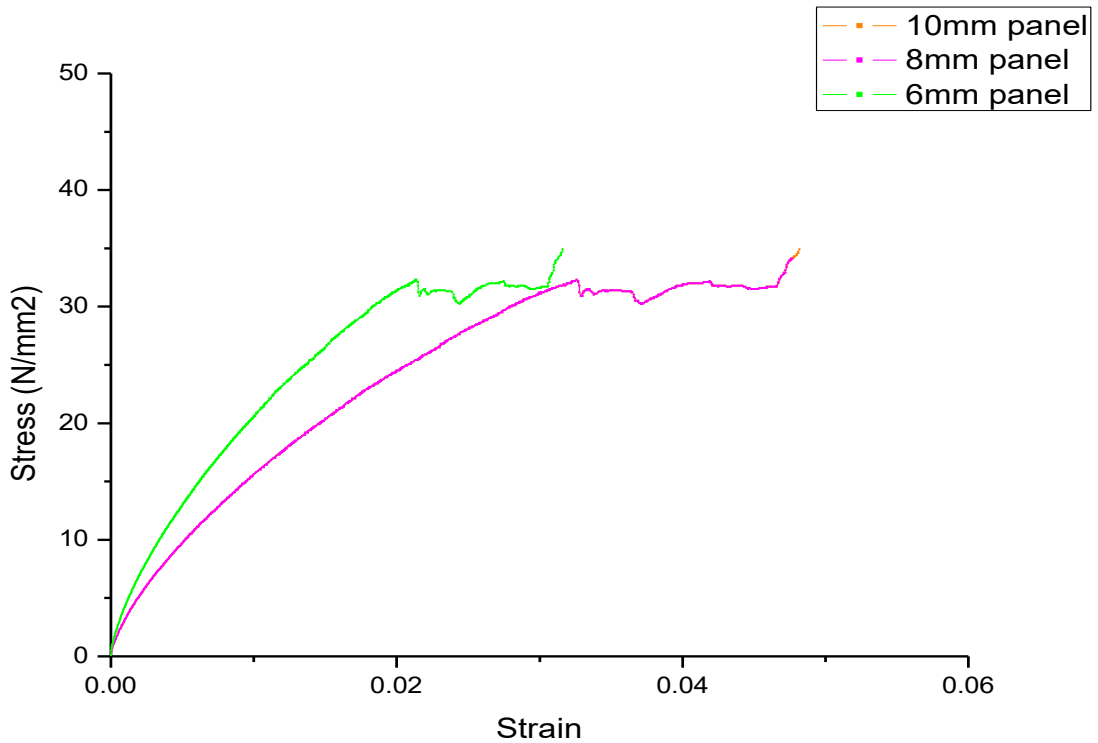


Figure 4.13 Stress Vs Strain (4-Point)

4.5 Vibrational Properties

Copper honeycomb sandwich panels exhibit excellent vibrational characteristics due to their unique lightweight core–face sheet configuration. The periodic honeycomb geometry provides high specific stiffness, which increases the natural frequency and reduces susceptibility to resonance under dynamic loading. The damping capability of copper enhances the vibration attenuation, minimizing transmission of oscillations through the structure. Furthermore, the stiffness-to-weight ratio and energy absorption capacity of the honeycomb core play a vital role in suppressing structural vibrations, thereby improving fatigue resistance and dynamic stability. Compared to conventional solid panels, copper honeycomb structures demonstrate superior modal behavior, including higher mode separation and lower amplitude response under harmonic excitation. These properties make copper honeycomb sandwich panels highly suitable for applications requiring **noise** reduction, shock absorption, and vibrational isolation in aerospace, automotive, and defense sectors. Based on the design and performance requirements, the dimensions and material properties of the honeycomb sandwich panel were carefully selected. The developed panel is thin, lightweight, and exhibits a symmetric configuration, consisting of two identical face sheets bonded to a uniformly distributed honeycomb core. Such symmetry ensures uniform stress distribution under bending loads, minimizes warpage, and enhances both flexural stiffness and shear resistance, making the structure highly efficient for load-bearing applications. The elastic modulus (Young's modulus) of copper face sheet depends slightly on purity, processing, and whether it is annealed or cold-worked.

Table. 5 Sandwich Beam Properties

Sl. No	Properties & Testing specification of the Sandwich Beam	
1	Face-sheet material	- Copper
2	Core Material	- Copper
3	Elastic Modulus E_f	- 120 Gpa
4	Density of Face sheet ρ	- 8960 kg/m ³
5	Density of Core ρ_c	- 1720 kg/m ³
6	Poisson's ratio	- 0.3
7	Core heights t_c	- 4, 6, 8mm
8	Specimen span L	- 100,150 & 200mm
9	Specimen width b	- 25mm
10	BC – Boundary condition	
11	SS- Simply supported, CC – Clamped – Clamped, CL - Cantilever	

In general the Euler–Bernoulli beam theory, also known as the classical beam theory, is one of the most widely used models for analyzing the bending and vibrational behavior of slender

structural members. The theory is based on the fundamental assumption that a beam subjected to bending will deform in such a way that plane cross-sections of the beam, which are initially perpendicular to the neutral axis, remain plane and perpendicular to the neutral axis even after deformation. This implies that shear deformation and rotational inertia effects are neglected, making the theory most accurate for slender beams with relatively small depth-to-length ratios. In its mathematical formulation, the equation 9 has Euler–Bernoulli theory relates the bending moment $M(x)$ along the beam to the curvature of the deflected shape as:

$$M(x) = EI \frac{d^2w(x)}{dx^2} \dots\dots\dots (9)$$

Where E is the modulus of elasticity of the material, I is the second moment of area of the cross-section, and $w(x)$ is the transverse displacement of the beam. For free vibration analysis, the equation 10 has the governing differential equation of motion can be expressed as:

$$EI \frac{d^4w(x,t)}{dx^4} + \rho A \frac{\partial^2w(x,t)}{\partial t^2} \dots\dots\dots(10)$$

Where ρ is the density of the material, A is the cross-sectional area and the solution of this equation, subject to appropriate boundary conditions, yields the natural frequencies and corresponding mode shapes of the beam. The Euler–Bernoulli beam theory provides a simplified yet powerful tool for understanding the vibrational and flexural characteristics of structural elements such as sandwich beams. Although it does not account for shear deformation or rotary inertia (which are considered in Timoshenko beam theory), it is sufficiently accurate for long and slender beams, making it a practical choice for initial analytical investigations. The natural frequency of copper honeycomb sandwich beams was estimated using the Euler–Bernoulli beam theory. Table 5 presents the material properties of the sandwich beams along with their span lengths and widths considered in the study. Table 6 shown the sample calculation formulas for simply supported boundary condition.

Table 6 Sample Formulas & Testing Norms

1	Core height $t_c = h$	4mm
2	t_f (face thickness) t_1, t_2	1mm
3	b (width)	25mm
4	d	$t_c/2 + t_f/2$
5	I faces	$2*(b*t_f*d^2 + b*t_f^3/12)$
6	EI	$E_f * I \text{ faces}$
7	m (mass per length)	$b*(2*t_f*\rho_f + t_c*\rho_{core})$
8	f_1 (SS)	$(\pi^2/(2\pi)) * \text{sqrt}(EI/(m*L^4))$

The vibrational response behavior of the beams were analyzed under different boundary conditions and for a range of core heights. The results revealed a clear dependency of frequency on geometric parameters and support conditions. Specifically, it was observed that an increase in the span length of the panel led to a corresponding variation in the natural frequency across different vibrational modes.

Table. 7 Vibrational Properties of Sandwich Beam

Core Height (mm)	L = 100mm BC=SS			L = 150mm BC=SS			L = 200mm BC=SS		
	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)
4	1229.75	4918.99	11067.72	546.55	2186.22	4918.99	307.44	1229.75	2766.93
6	1608.18	6432.7	14473.58	714.74	2858.98	6432.7	402.04	1608.18	3618.39
8	1949.56	7798.25	17546.06	866.47	3465.89	7798.25	487.39	1949.56	4386.52
Core Height (mm)	L = 100mm BC=CC			L = 150mm BC=CC			L = 200mm BC=CC		
	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)
4	2787.7	7684.39	15064.5	1238.98	3415.28	6695.33	696.92	1921.1	3766.13
6	3645.55	10049.1	19700.28	1620.25	4466.26	8755.68	911.39	2512.27	4925.07
8	4419.44	12182.34	23882.3	1964.19	5414.37	10614.35	1104.86	3045.59	5970.57
Core Height (mm)	L = 100mm BC=CL			L = 150mm BC=CL			L = 200mm BC=CL		
	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)
4	438.09	2745.48	7687.44	194.71	1220.22	3416.64	109.52	686.37	1921.86
6	572.9	3590.35	10053.09	254.62	1595.71	4468.04	143.23	897.59	2513.27
8	694.52	4352.52	12187.18	308.68	1934.45	5416.53	173.63	1088.13	3046.8

Furthermore, three distinct boundary conditions were examined in combination with multiple core heights to provide a comprehensive understanding of the structural response. The comparative results, summarized in Table 7, highlight the influence of core geometry and support conditions on the free vibration characteristics of the copper honeycomb sandwich beams. The standard values of the boundary conditions were SS-3.142, CC – 4.73 & CL – 1.875. In **Figure 4.6** presents the frequency response curves of the copper honeycomb sandwich panels with simply supported boundary conditions under various modal conditions. The results clearly show that the natural frequency decreases with an increase in the panel span length. This behavior is in accordance with the Euler–Bernoulli beam theory. The frequency is inversely proportional to the span length. Hence, as the panel length increases, the structural stiffness per unit length reduces, resulting in a lower natural frequency. The governing frequency equation 11 is

$$f_n = \frac{n^2 \pi^2}{2L^2} \sqrt{EI} / \rho A \dots\dots\dots (11)$$

where n is the mode number, E is the effective modulus of elasticity of the sandwich panel, I is the second moment of area, ρ is the density, A is the cross-sectional area, and L is the span length. The frequency response curves also indicate a gradual increase in frequency with higher-order modes, which aligns well with the theoretical model, since $f_n \propto n^2$. Among the analyzed panels, the configuration with a span length of 200 mm exhibited the lowest frequency values across all modes, emphasizing the dominant role of geometric dimensions in dynamic performance. This demonstrates that for simply supported sandwich panels, reducing span length significantly enhances stiffness and raises the resonant frequencies, improving resistance against vibrational effects.

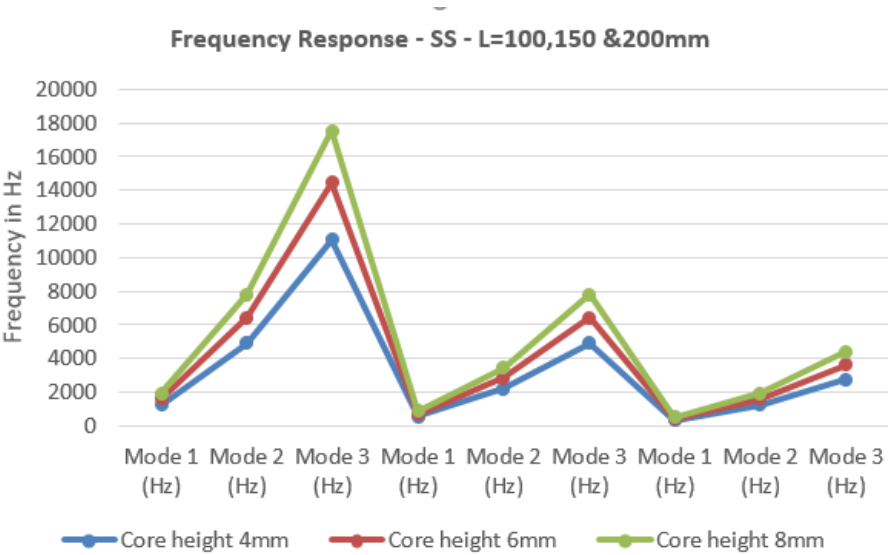


Figure 4.6 Frequency response curve - SS

Figure 4.7 illustrates the frequency response curves of the copper honeycomb sandwich panels subjected to clamped–clamped boundary conditions across different modal responses. The results demonstrate that the natural frequencies obtained under clamped–clamped support are significantly higher compared to those observed in the simply supported configuration. This is primarily due to the higher degree of structural constraint, which restricts both translational and rotational displacements at the panel ends, thereby enhancing the global stiffness of the system. Among the various modes investigated, Mode 3 consistently exhibited the highest frequency values for all span lengths. This trend aligns with the theoretical formulation of beam vibration, where higher-order modes are associated with greater numbers of half-wavelengths along the span, resulting in elevated natural frequencies. The governing relation for the natural frequency of a clamped–clamped beam, based on Euler–Bernoulli beam theory, can be expressed as equation 12 is

$$f_n = \frac{\beta_n^2}{2\pi L^2} \sqrt{EI} / \rho A \quad \dots\dots\dots(12)$$

where E is the elastic modulus, I is the moment of inertia, ρ is the density, A is the cross-sectional area, L is the span length, and β_n represents the frequency parameter depending on the boundary condition (for clamped–clamped, β₁=4.73, β₂=7.85, β₃=11.0, etc.). In comparison with the simply supported condition, the clamped–clamped configuration yielded considerably higher frequency levels for all modes. This confirms that boundary conditions have a critical influence on the dynamic characteristics of sandwich structures.

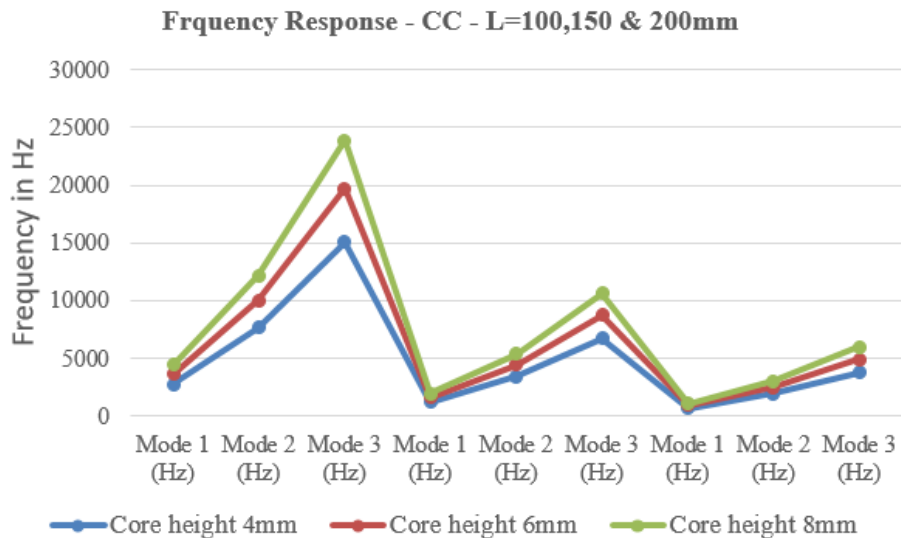


Figure 4.7 Frequency response curve - CC

The higher frequency response under clamped–clamped support makes the panels more resistant to resonance under dynamic loading, which is a desirable property in structural and aerospace applications where vibration suppression is critical. **Figure 4.8** presents the

frequency response curves of the copper honeycomb sandwich panels under cantilever boundary conditions for different modal responses. The results reveal that the natural frequencies in the cantilever configuration are considerably lower than those observed in the simply supported and clamped–clamped conditions. This reduction in frequency arises from the lower degree of end constraint in a cantilever system, where one end is fixed while the other end remains free. Such a boundary condition allows larger deflections and rotations at the free end, thereby reducing the effective stiffness of the structure and leading to lower resonant frequencies. The theoretical natural frequency for a cantilever beam, based on Euler–Bernoulli beam theory, is given by equation 12. Here the β values are varied when substituting in the equation 12. β_n are mode constants specific to cantilever supports ($\beta_1=1.875$, $\beta_2=4.694$, and $\beta_3=7.855$, etc.).

The frequency response curves further show that, despite the overall lower magnitude of frequencies, higher-order modes (e.g., Mode 2 and Mode 3) exhibit an expected progressive increase in values. This agrees with the theoretical prediction that natural frequency increases with mode number due to shorter half-wavelengths along the beam.

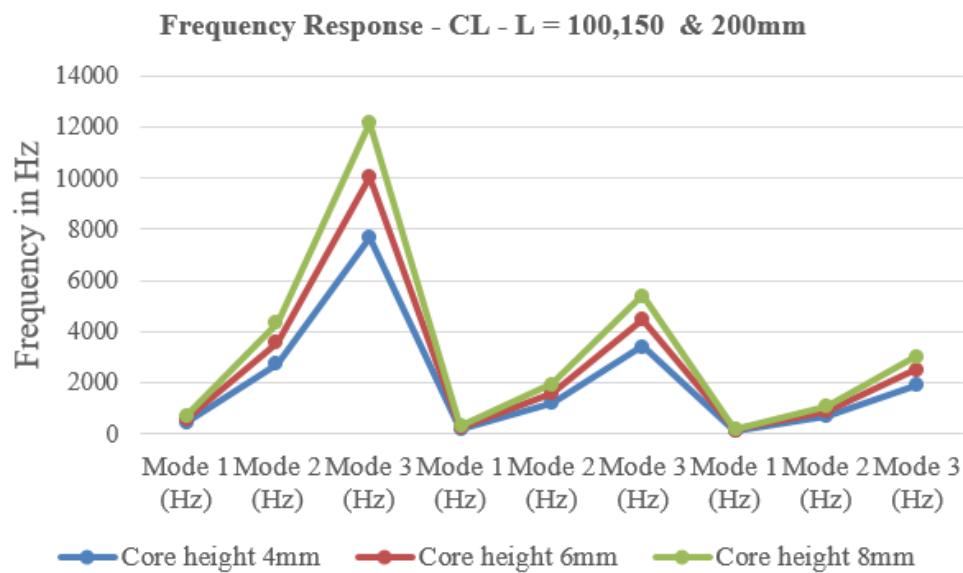


Figure 4.8 Frequency response curve - CL

When compared across all three boundary conditions—clamped–clamped, simply supported, and cantilever—the cantilever configuration consistently demonstrates the lowest natural frequency levels. This highlights the critical influence of boundary support conditions on the vibrational performance of honeycomb sandwich structures. From a design perspective, cantilever-supported panels are more prone to resonance at lower excitation frequencies, and thus require careful consideration in structural and aerospace applications where vibration control is essential.

5 Conclusion

This study presented the fabrication method of honeycomb core sandwich panels, emphasizing the brazing technique employed to join the core strips with the face sheets. The brazed bonding approach demonstrated excellent bonding capability, which directly enhanced the flexural stiffness and reduced core shear stresses across panels of varying core heights. Compared to other bonding methods, brazing provided superior interfacial strength and reliability, making it a highly effective technique for sandwich panel construction. Experimental investigations were carried out using both three-point and four-point bending tests to evaluate the deformation characteristics and core shear modulus of the panels. The results revealed that the ultimate strength obtained under three-point bending was slightly higher than that under four-point bending, owing to the localized stress concentration at the mid-span in three-point loading. In contrast, four-point bending provided a more uniform stress distribution and delayed fracture initiation, highlighting the influence of the loading configuration on structural response. Furthermore, the bending properties improved significantly with increasing core height. Panels with higher core thickness exhibited superior flexural stiffness and core shear modulus compared to panels with smaller core thicknesses. The deflection curves confirmed that the slope (gradient) was steeper for lower core panels, reflecting reduced bending rigidity. Additionally, both core shear stress and face-sheet bending stress decreased with increasing panel height, confirming the beneficial effect of a thicker core on stress distribution and load transfer within the sandwich structure. The vibrational analysis of copper honeycomb sandwich panels under different boundary conditions reveals a clear dependence of natural frequency on the span length, mode number, and boundary constraints. Across all conditions, the following key observations were made. Effect of Span Length – Increasing the span length consistently resulted in lower natural frequencies, confirming the inverse-square relationship between frequency and length predicted by Euler–Bernoulli beam theory. Panels with a 200 mm span length exhibited the lowest frequency values. Effect of Mode Number – Higher-order modes (Mode 2, Mode 3) showed progressively higher frequency values compared to the fundamental mode. Among all conditions, Mode 3 consistently recorded the maximum frequency response. Effect of Boundary Conditions Clamped–Clamped panels (Figure 4.7) produced the highest natural frequencies due to maximum end restraint and enhanced stiffness. Simply Supported panels (Figure 4.6) exhibited intermediate frequency values, with rotational freedom at the supports reducing stiffness compared to the clamped condition. Cantilever panels (Figure 4.8) recorded the lowest frequency values, as the free end allowed greater deflection and reduced structural rigidity. Comparative Performance – The order of frequency levels across boundary conditions can be expressed as:

$$f_{\text{Clamped–Clamped}} > f_{\text{Simply Supported}} > f_{\text{Cantilever}}$$

This hierarchy validates theoretical expectations and emphasizes the critical role of support conditions in dynamic performance. Overall, the study establishes that boundary conditions are the dominant factor controlling the frequency spectrum of copper honeycomb sandwich panels, followed by span length and mode number. These findings are particularly relevant for structural and aerospace applications, where optimizing support configurations can significantly improve vibration resistance and dynamic stability. Overall, the results demonstrate that brazed honeycomb sandwich panels with higher core heights provide superior

flexural performance, reduced stress concentrations, and improved structural integrity and vibrational responses, making them highly suitable for lightweight, high-strength structural applications. In summary, vibration analysis of brazed bonding structures not only validates the mechanical integrity of the brazed joints but also establishes a foundation for performance-driven design improvements, ultimately contributing to the development of high-performance sandwich panels suitable for demanding engineering applications.

References

A. JOURNAL ARTICLES

- [1] C. Lua, M. Zhaoa, L. Jie, J. Wang, Y. Gao, X. Cuia, P. Chen, Stress distribution on sandwich honeycomb sandwich structure suffered from bending load, *Procedia Eng.* 99 (2015) 405–411. <https://doi.org/10.1016/j.proeng.2014.12.540>.
- [2] E. L., K. Z., K. K., Structural performance of wood based sandwich panels in four point bending, *Procedia Eng.* 172 (2017) 628–633. <https://doi.org/10.1016/j.proeng.2017.02.074>.
- [3] F. Chen, H. Liu, S. Li, H. Liu, L. An, C. Lu, Dynamic parametric modelling-based model updating strategy of aero engine casings, *Chin. J. Aeronaut.* (2021). <https://doi.org/10.1016/j.cja.2020.10.019>.
- [4] X. Zhang, Y. Wang, H. Li, Z. Chen, Mechanical response and energy absorption characteristics of graded honeycomb sandwich panels under compressive loading, *Compos. Struct.* 336 (2024) 118021. <https://doi.org/10.1016/j.compstruct.2024.118021>.
- [5] R. Kumar, P. Singh, A. Sharma, S. Verma, Experimental investigation on vibration damping behaviour of aluminium honeycomb sandwich composites, *Mater. Today Proc.* 72 (2023) 1456–1462. <https://doi.org/10.1016/j.matpr.2022.11.214>.
- [6] J. Li, M. Zhao, Q. Sun, T. Xu, Topology optimization of lightweight honeycomb core sandwich plates for enhanced stiffness performance, *Thin Wall. Struct.* 199 (2025) 111622. <https://doi.org/10.1016/j.tws.2024.111622>.
- [7] A. Petras, M.P.F. Sutcliffe, Failure mode maps for honeycomb sandwich panels, *Compos. Struct.* 44 (1999) 237–252. [https://doi.org/10.1016/S0263-8223\(98\)00123-8](https://doi.org/10.1016/S0263-8223(98)00123-8).
- [8] S. Ahmed, M. Rahman, N. Karim, Finite element analysis of impact damage on composite honeycomb sandwich structures, *J. Compos. Mater.* 56 (18) (2022) 2785–2798. <https://doi.org/10.1177/00219983211065421>.
- [9] D.K. Rajak, D.D. Pagar, P.L. Menezes, E. Linul, Fiber-reinforced polymer composites: Manufacturing, properties, and applications, *Polymers* 11 (10) (2019) 1667. <https://doi.org/10.3390/polym11101667>.

- [10] D. Patel, M. Joshi, K. Desai, Modal analysis and frequency optimization of aerospace sandwich panels with aluminium honeycomb core, *Aerosp. Sci. Technol.* 139 (2023) 108445. <https://doi.org/10.1016/j.ast.2023.108445>.
- [11] N. Du, N. Yan, et al., Light-weight honeycomb core sandwich panels containing bio fiber-reinforced thermoset polymer composite skins: Fabrication and evaluation, *Compos. Part B Eng.* 43 (7) (2012) 2875–2880. <https://doi.org/10.1016/j.compositesb.2012.04.015>.
- [13] G. Dai, W. Zhang, Cell size effects for vibration analysis and design of sandwich beams, *J. Sound Vib.* 325 (3) (2009) 353–365. <https://doi.org/10.1016/j.jsv.2008.06.033>.
- [14] L. Chen, P. Wu, Y. Tang, F. Liu, Bio-inspired hierarchical honeycomb cores for superior crashworthiness and energy dissipation, *Eng. Struct.* 306 (2024) 117726. <https://doi.org/10.1016/j.engstruct.2024.117726>.
- [15] M. Ramesh, S. Kumar, R. Balaji, Thermo-mechanical behaviour of glass fiber reinforced honeycomb sandwich panels under elevated temperature, *J. Reinf. Plast. Compos.* 40 (15–16) (2021) 593–607. <https://doi.org/10.1177/07316844211008456>.
- [16] H. Yang, X. Zhou, D. Li, Additive manufacturing of metallic honeycomb sandwich structures: Design and vibration performance, *Addit. Manuf.* 89 (2025) 104321. <https://doi.org/10.1016/j.addma.2025.104321>.
- [17] P. Suresh, R. Kannan, V. Hariharan, Free vibration and buckling analysis of laminated sandwich beams with honeycomb core, *Structures* 42 (2022) 912–923. <https://doi.org/10.1016/j.istruc.2022.06.048>.
- [18] C. Dong, Y. Xu, J. Wang, Z. Shen, Low-velocity impact resistance of carbon fiber honeycomb sandwich panels with hybrid face sheets, *Compos. Part B Eng.* 281 (2024) 111552. <https://doi.org/10.1016/j.compositesb.2024.111552>.
- [19] K. Rajesh, V. Hariharan, S. Murugan, Thermal stability and mechanical characterization of natural fiber reinforced honeycomb sandwich laminates, *J. Reinf. Plast. Compos.* 40 (21–22) (2021) 845–858. <https://doi.org/10.1177/07316844211029871>.
- [20] Y. Chen, D. Wu, F. Li, Additively manufactured lattice-honeycomb hybrid sandwich panels for aerospace vibration control, *Addit. Manuf.* 92 (2025) 104689. <https://doi.org/10.1016/j.addma.2025.104689>.
- [21] R. Prakash, M. Suresh, S. Balaji, Buckling and modal behaviour of laminated composite beams with aluminium honeycomb core, *Structures* 45 (2022) 1152–1164. <https://doi.org/10.1016/j.istruc.2022.09.071>.

[22] M.S.M. Fouzi, K.M. Jelani, N.A. Nazri, M.S.M. Sani, Finite element modelling and updating of welded thin-walled beam, *Int. J. Automot. Mech. Eng.* 15 (4) (2018) 5874–5889. <https://doi.org/10.15282/ijame.15.4.2018.7.0443>.

[23] N.A.Z. Abdullah, M.S.M. Fouzi, M.S.M. Sani, Computational modal analysis on finite element model of body-in-white structure and its correlation with experimental data, *Int. J. Automot. Mech. Eng.* 17 (2) (2020) 7915–7926. <https://doi.org/10.15282/ijame.17.2.2020.05.0594>.

[24] C. Sultan, et al., Designing structures for dynamical properties via natural frequencies separation: Application to tensegrity structures design, *Mech. Syst. Signal Process.* 23 (4) (2009) 1112–1122. <https://doi.org/10.1016/j.ymssp.2008.06.007>.

[26] H. Dong, L. Xu, P. Wang, Y. Shen, Impact resistance enhancement of carbon-epoxy honeycomb sandwich panels using hybrid nano filler face sheets, *Compos. Part B Eng.* 286 (2024) 111901. <https://doi.org/10.1016/j.compositesb.2024.111901>.

[27] Y. Sun, F. Guo, Y. Liu, Bio-inspired design of mechanical properties of hybrid topological cellular honeycomb structures, *Biomimetics* 10 (8) (2025) 528. <https://doi.org/10.3390/biomimetics10080528>.

[28] P. Li, F. Xing, Structural design analysis of substrate with honeycomb core under normal pressure using RSM and ANN, *Processes* 13 (1) (2025) 189. <https://doi.org/10.3390/pr13010189>.

[29] N. Singh, R. Patel, V. Kumar, Optimization of honeycomb core parameters for lightweight sandwich panels under bending loads, *Mater. Des.* 232 (2023) 112145. <https://doi.org/10.1016/j.matdes.2023.112145>.

[30] Y. Dong, J. He, D. Wang, D. Luo, Y. Zeng, H. Feng, X. You, L. Shen, Advanced modular honeycombs with biomimetic density gradients for superior energy dissipation, *Biomimetics* 10 (4) (2025) 221. <https://doi.org/10.3390/biomimetics10040221>.

B. BOOK CHAPTERS

[12] O. Ley, V. Godinez, Non-destructive evaluation (NDE) of aerospace composites: Application of infrared (IR) thermography, in: *Non-Destructive Evaluation of Polymer Matrix Composites*, Woodhead Publishing, 2013, pp. 309–334. <https://doi.org/10.1533/9780857093554.309>

C. CONFERENCE PAPERS

[25] M.S.M. Zin, M.N.A. Rani, M.A. Yunus, M.A. Ayyub, M.S.M. Sani, et al., Modal based updating for the dynamic behaviour of a car trunk lid, in: *AIP Conf. Proc.* 2059 (2019). <https://doi.org/10.1063/1.5085959>

Model Calculations

Experimental Method (L=200mm, H=6mm)

Flexural Strength:

$$D = P_1 L^3 [1 - (11/8)] / 48 \delta_1 [1 - (2P_1 \delta_2 / P_2 \delta_1)]$$

$$D = 0.88 * 200 * 200 * 200 * [1 - (11/8)] / 48 * 38 * [1 - (2 * 0.88 * 36) / (0.88 * 38)]$$

$$D = 0.53 \text{ kN mm}^2$$

Core Shear stress:

$$G = P_1 L h [(8/11) - 1] / \delta_1 b (H + h)^2 [(16P_1 \delta_2 / 11P_2 \delta_1) - 1]$$

$$G = 0.88 * 200 * 4 * [(8/11) - 1] / 38 * 30 * (6 + 4)^2 * [(16 * 0.88 * 36) / (11 * 0.88 * 38) - 1]$$

$$G = 1.1 \text{ Gpa}$$

Software Method (L=200mm, H=6mm)

Flexural Strength:

$$D = P_1 L^3 [1 - (11/8)] / 48 \delta_1 [1 - (2P_1 \delta_2 / P_2 \delta_1)]$$

$$D = 0.88 * 200 * 200 * 200 * [1 - (11/8)] / 48 * 35 * [1 - (2 * 0.88 * 32) / (0.88 * 35)]$$

$$D = 0.70 \text{ kN mm}^2$$

Core Shear stress:

$$G = P_1 L h [(8/11) - 1] / \delta_1 b (H + h)^2 [(16P_1 \delta_2 / 11P_2 \delta_1) - 1]$$

$$G = 0.88 * 200 * 4 * [(8/11) - 1] / 35 * 30 * (6 + 4)^2 * [(16 * 0.88 * 32) / (11 * 0.88 * 35) - 1]$$

$$G = 1.5 \text{ Gpa}$$

Declarations

Competing interests policy

“The author declare that they have no competing interests.”

Declaration of Interest Statement

- The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
- The author is an Editorial Board Member/Editor-in-Chief/Associate Editor/Guest Editor for this journal and was not involved in the editorial review or the decision to publish this article.
- The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Funding Declaration

This work did not receive any specific grant from funding agencies in the public, commercial, or not for-profit sectors. All expenses related to this work were borne personally by the author.

Data availability statement

The data sets generated and/or analyzed during the current study are available from the corresponding author on reasonable request

Consent to Registration

I hereby provide my consent to complete the registration process on my behalf. I understand that I am currently not registered, and by granting this consent, I authorize the concerned authority to use my provided details for completing the necessary registration.

I confirm that the information I will provide is true and accurate to the best of my knowledge, and I agree to abide by the terms and conditions of the registration process.

Consent to Publish Declaration

I, BABU K, hereby grant my consent to Journal of **Discover Robotics** to publish the work titled “**Parametric Study of Honeycomb Core Geometry for Improving the Mechanical and Vibrational Performance of Copper Sandwich Panels**” in any of its publications, whether in print or digital form, and to distribute it through any media channels, including but not limited to websites, social media platforms, and promotional materials.

I affirm that:

- The submitted work is original and does not infringe upon any copyright, trademark, or other intellectual property rights.
- I have the full authority to grant this consent and no other party’s permission is required.
- I understand that this consent is granted without expectation of monetary compensation unless otherwise agreed in writing.
- The publisher may edit or adapt the work for clarity, formatting, and length while preserving its intended meaning.

By signing below, I acknowledge that I have read and understood the terms of this declaration and agree to them.

Consent to Participate Declaration

I, Babu K, hereby declare that I voluntarily agree to participate in Publishing Program organized by Journal of Discover Robotics

I confirm that:

- I have been informed about the purpose, nature, and details of the work.
- I understand that my participation is voluntary, and I have the right to withdraw at any time without any penalty.
- I agree to abide by the rules and guidelines set by the organizers during the publishing.
- I understand that the organizers will not be held responsible for any personal injury, loss, or damage to my belongings during the event.
- I consent to the use of my participation details, photographs, or videos taken during the event for documentation and promotional purposes, if applicable.

I declare that the information provided by me is true and correct to the best of my knowledge.

Ethics Declaration

I, Babu K, hereby declare that I will uphold the highest standards of ethical conduct in all activities related to research work.

I confirm that:

- I will act with honesty, integrity, and fairness in all my dealings and decisions.
- I will respect the rights, dignity, and confidentiality of all individuals involved.

- I will ensure that no activity I undertake will cause harm to individuals, society, or the environment.
- I will comply with all applicable laws, organizational policies, and ethical guidelines relevant to the work
- I will avoid any form of misconduct, including plagiarism, fabrication, falsification, or misrepresentation of information.
- I will declare any conflict of interest that may influence my actions or decisions.

I acknowledge that failure to adhere to these principles may result in disciplinary action or termination of my participation in the project/event.

Author Contribution Statement

Authors have made significant contributions to the work reported in this manuscript as follows:

BABU K- Conceptualization, Methodology, Investigation, Data Curation, Writing – Original Draft,

Formal Analysis, Validation, Visualization, Writing – Review & Editing, Resources, Supervision, Project Administration, Funding Acquisition, Software, Data Interpretation, Writing – Review & Editing.

Author have read and approved the final manuscript and agree to be accountable for all aspects of the work.

Acknowledgements

The author would like to acknowledge individuals and organizations who contributed to this work but do not meet the criteria for authorship.

The authors also thank institute for providing facilities and support during the course of this research.

Author's Name: Babu K

Signature: 

Clinical Trail Nos:

6mm panels:

177131, 1717132, 1717133, 1717134 – 4 Trails

8mm panels:

1717151, 1717152, 1717153, 1717154– 4 Trails

10mm panels:

1717181, 1717182, 1717183, 1717184– 4 Trails