Deflection and Vibration Analysis of Different Types of Honeycomb Structures using ANSYS

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Abstract: ***This study employs ANSYS to conduct a comprehensive analysis of various honeycomb structures, focusing on deflection and vibration characteristics. Through meticulous examination, we explore the unique mechanical behaviors exhibited by different types of honeycomb configurations. The research delves into the dynamic aspects of these structures, providing insights into deflection patterns and vibrational responses. The findings contribute to an enhanced understanding of honeycomb structural dynamics, offering valuable information for applications in engineering and structural design.***

Keywords: Equivalent elastic stress, Equivalent elastic strain, First order shear deformation (FSDT), Hexagonal sandwich plate, Natural vibration, Total deformation, Triangular sandwich plate.

1. Introduction

"In recent years, there has been a growing interest in studying the deflection and vibration characteristics of various honeycomb structures, particularly those composed of lightweight metal sandwich designs. These structures feature a central porous core sandwiched between two thin face sheets, offering superior mechanical properties such as high specific strength, low density, excellent thermal conductivity, and effective sound insulation. They find extensive applications in aerospace, automotive, maritime, and other engineering fields [1–7].

Research highlights the significant influence of face sheet distribution on structural integrity and performance. Traditional symmetrical configurations, where face sheets are identical, may not always optimize dynamic failure behavior, energy absorption, and overall mechanical properties [3, 8]. Previous studies primarily focused on symmetric sandwich structures under low - velocity impact conditions. For instance, Foo et al. [9] developed a modified energy - balance model based on momentum conservation to analyze low - velocity impact responses of honeycomb core sandwich plates, providing insights into load–displacement characteristics. Similarly, Fard et al. [10] analytically investigated the dynamic response of sandwich plates subjected to impacts from rigid blunted cylinders.

However, there remains a need to further investigate how variations in face sheet distribution influence the overall deflection and vibration behavior of honeycomb structures. This research aims to fill these gaps using advanced computational techniques, such as finite element analysis (FEA) with ANSYS, to simulate and analyze dynamic behaviors across diverse honeycomb configurations. By doing so, this study aims to enhance our understanding of how design modifications can optimize structural performance and functionality of these lightweight composite materials in practical engineering applications. "

This covers techniques such as the analogous single - layer theory, which encompasses the shear deformation laminated plate theories as well as the classical laminate theory [11–12]. There has also been used of the three - dimensional elastic theory, which includes layerwise theory, unified formulation, generalized unified formulation, and conventional 3 - D elastic formulations [13–17]. In this setting a variety of model approaches have been applied [18, 19].

Furthermore, the response of composite sandwich constructions is greatly impacted by the influence of transverse shear deformation, which results from the high core thickness and the wide variation in material characteristics along the thickness direction of the composite laminated face sheets. The analogous single - layer theories fall short in addressing these phenomenon. As a result, layer - wise or three - dimensional elastic theories may be required for the analysis of composite sandwich constructions. In light of the small number of accurate solutions for 3D elasticity and the possible processing load related to 3D finite element analysis, layer - wise theory is the better choice when compared to comparable single - layer theory and 3D elasticity theory.

In an assessment of computational models, Hu [20, 21] evaluated Zig - Zag and shear deformation theories to forecast how sandwich plates would bend under static stress and dynamic circumstances. The evaluation showed that Zig - Zag models are more accurate than shear deformation theories and traditional laminate theory. Ferreira [22, 23] looked into motionless in light of the small number of accurate solutions for 3D elasticity and the possible processing load related to 3D finite element analysis, layer - wise theory is the better choice when compared to comparable single - layer theory and 3D elasticity theory.

By discretizing the core separately using brick elements and still using the layer - wise theory to simulate the composite laminated face sheets, the substantial influence of transverse shear deformation caused by the large core thickness can be lessened. Fortunately, based on compatibility conditions at the interface between face sheets and core, the governing equations of the face sheets established by the layer wise theory can be seamlessly integrated with the governing equations of the core established by brick elements, unlike equivalent single - layer theories. The displacement variables of the upper and lower surfaces of face sheets exist in the governing equations, and the degree of freedoms (DOFs) of the layer - wise theory equals that of the brick element, which facilitates this integration.

2. Methodology

The First Order Shear Deformation Theory (FSDT) is an advanced structural engineering concept that extends traditional beam theories, such as the Euler - Bernoulli beam theory, to account for shear deformation effects. Unlike classical beam theories, which neglect shear deformation, FSDT considers both bending and shear deformations in beam - like structures.

In First Order Shear Deformation Theory (FSDT), the displacement field of the beam is described by considering displacements in both the transverse and longitudinal directions. This includes horizontal and vertical displacements, as well as rotations along the directions. The theory's primary equations consist of equilibrium and compatibility equations, which govern the behavior of the beam under loading conditions.

The equilibrium equation incorporates the effect of shear deformation and is expressed as:

$$D\frac{\partial^4 \omega}{\partial \xi^2 \partial \eta^2} + q(\xi,\eta) = 0$$

Where D represents the elastic modulus and q denotes the distributed load acting on the beam.

The compatibility equation ensures that the displacement field satisfies the condition of continuity and smoothness. It is given by:

$$\frac{\partial^2}{\partial \xi^2}\left(\frac{\partial^2 \omega}{\partial \eta^2}\right) + 2\frac{\partial^2}{\partial \xi \partial \eta}\left(\frac{\partial^2 \omega}{\partial \omega \partial \eta}\right) + \frac{\partial^2}{\partial \eta^2}\left(\frac{\partial^2 \omega}{\partial \xi^2}\right) = 0$$

2.1 Material Section

These materials exhibit distinct properties suitable for various applications, with titanium being favored for its high strength and lightweight properties, while silicon carbide is valued for its exceptional hardness and wear resistance. The middle layer of the plate is referred to as the core layer, and it is made of silicon carbide, while the top and bottom layers are face layers made of titanium. Property as soon in table I.

Table I: Material properties

Property	Titanium	Silicon Carbide
ρ^* Density (kg/m³)	4.5	3.2
E^* Modulus of Elasticity (GPa)	100	400
μ^* Poisson's Ratio	0.32	0.22

ρ^* = Density (kg/m³), E^* = Young's modulus (Gpa), μ^* = Poisson's ratio. All the material properties are taken in the material data book. (1 and 2 are used for the face layer and core layer of the sandwich plate).

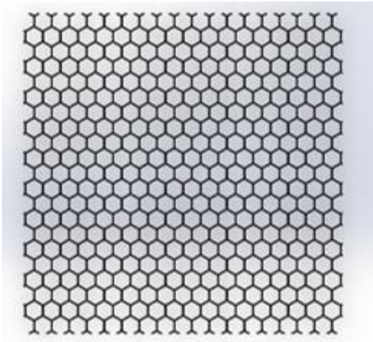

Image 1

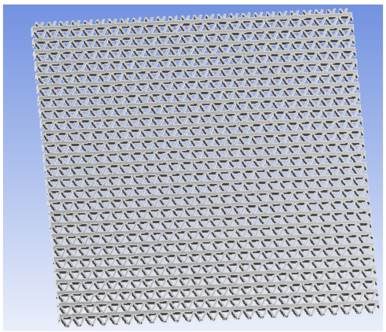

Image 2

3. Result and Discussion

In this study, sandwich plates with three layers were fabricated, utilizing different core structures. Initially, a hexagonal core was employed, followed by a triangular core. Both configurations maintained consistent face material layers throughout the experimental process. The sandwich plate is divided into three layers: the top and bottom layers are the face layers, and the middle layer is the core layer. The total height of the plate is (H), which is divided into three thicknesses. The face layer thickness is (t_f), and the core layer thickness is (t_c). The overall thickness is calculated by the formula ($H=t_c/t_f$).

3.1 Convergence

Firstly, different mesh sizes were selected for the convergence test to calculate the optimum value of frequency. As the mesh size increased, the frequency reached a stable condition. In the study of convergence and validation, the selected size of the plate was 0.3048 m x 0.3480 m. The total thickness of the plate is 0.726 mm, with the upper and lower layer thickness being 0.762 mm and the middle layer thickness being 0.254 mm. The properties of the material of the plate are given in Table II. These material properties were taken from the reference. Published paper by Conor D. Johnson* and David A. Kienholz (reference 25). As soon in figure 1

Table II: Material properties for validation.

Face plate		Core layer	
E^*	6.86×10^4	G^*	0.896
ρ^*	2.74	ρ^*	0.999
μ^*	0.30	μ^*	0.49

In the given table material properties are E^*=Young modulus (MPa), G^*= Shear modulus (Mpa), ρ^*=Density (kg/m^3), μ^*=Poison ratio.

Using these material properties calculate the natural frequency of the sandwich plate with simply supported boundary conditions. All results are plotted on the graph and seen the results calculated by the process are match approximately.

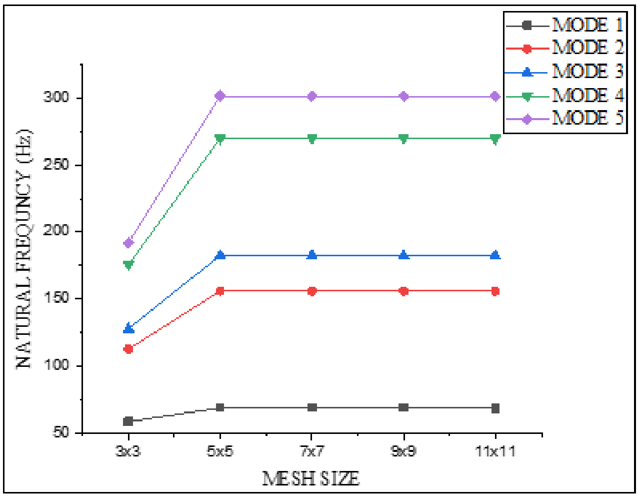

Figure 1: Natural Frequency and mesh size

3.2 Validation

The validation of calculating results of the paper and present results as seen on the graph. The graph is plotted in between modes and natural frequency. (reference 25) shows the values of natural frequency which is validated by this study.

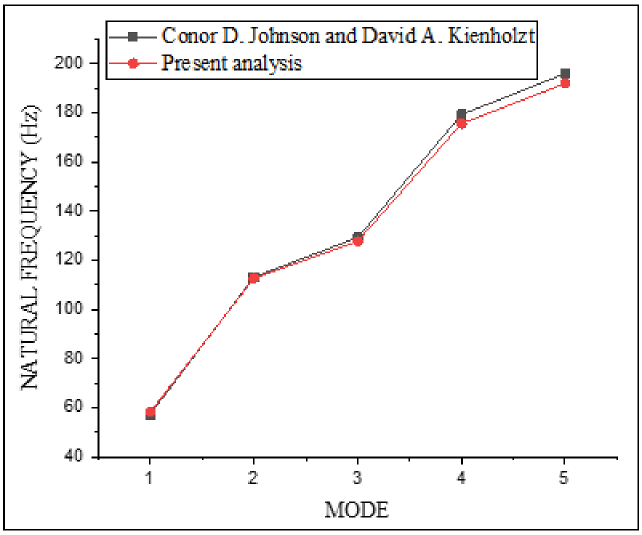

Figure 2: Mode and natural frequency

3.3 Frequency Analysis:

We have initially created a model plate in SolidWorks software, which consists of three layers. The top and bottom layers are made of titanium, while the middle plate (core) is made of silicon carbide. Within the core plate, various types of structures have been incorporated, such as hexagonal and triangular shapes. The plate dimensions are set at 100*100 Millimete, with each side of the hexagonal and triangular shapes measuring 3mm, following the similar triangle's dimensions. Now, we have kept the size of the plate constant, where a represents the length and b represents the width, and we have varied the height H to create different types of plates. For instance, H values have been set to 5, 10 and 15. We have also adjusted the thickness of the core t_c and the thickness of the face plate t_f to different sizes and calculated the frequencies. Using the different cores (hexagonal and triangular) to compare the natural frequency of the plate the results were calculated using Ansys.

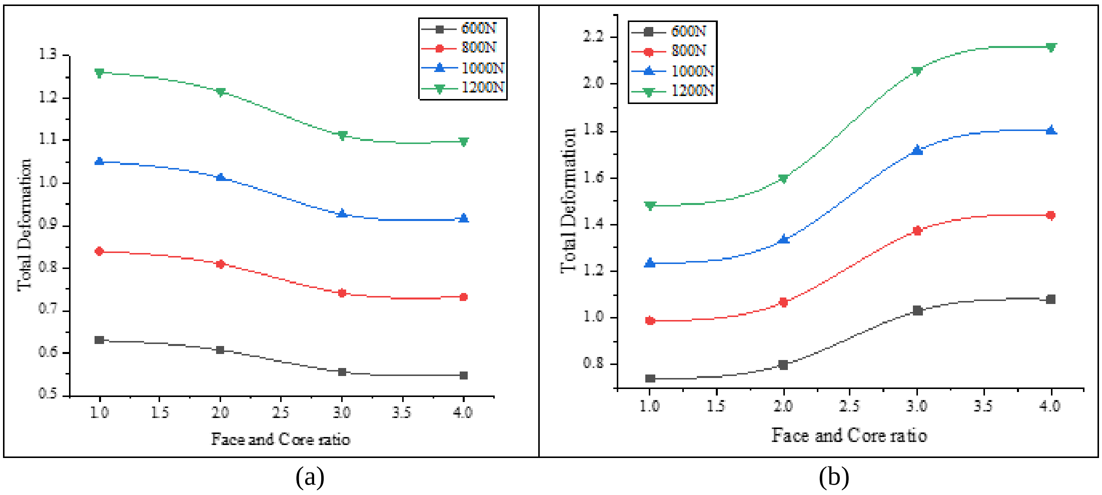

Figure 3: Core and face ratio about the x - axis and deformation shown in the y - axis. CCCC (All side clamp) condition, Height (H).

(a) And (b) Comparison hexagonal and triangular sandwich plate height H=5,

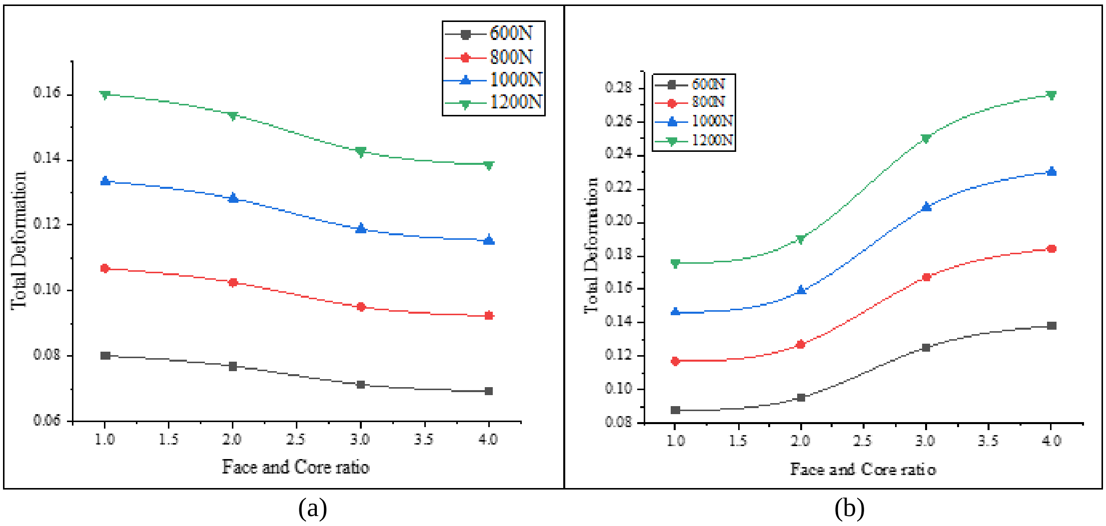

Figure 4: Core and face ratio about the x - axis and deformation shown in the y - axis. CCCC (All side clamp) condition, Height (H) (a) And (b) Comparison hexagonal and triangular sandwich plate height H=10

The model of the plate in hexagonal and triangular shape honeycomb structures has done with boundary condition under the application of 600N, 800N, 1000N, 1200N force. Here in the section in Ansys 18.0. The value of total deformation, about the x and y axis, and natural frequency in different modes in fig3 and fig4. the compression of deflection of the plate of the structural of the cross - section 3 (a and b), 4 (a and b) was compared graphically.

The comparison of honeycomb sandwich plates with heights h=5 mm and h = 10 mm shows that the Honeycomb Triangular Plate consistently performs better than the Hexagonal Plate. For both heights, the triangular plate exhibits lower deformation and higher stiffness across all face - to - core ratios and load conditions. Increasing the core height to h = 10 mm further reduces deformation for both plates, but the triangular design shows greater improvement. While the hexagonal plate may be suitable for lightweight or low - stress applications, the triangular plate is the optimal choice for high - stress environments due to its superior load - bearing capacity and structural integrity.

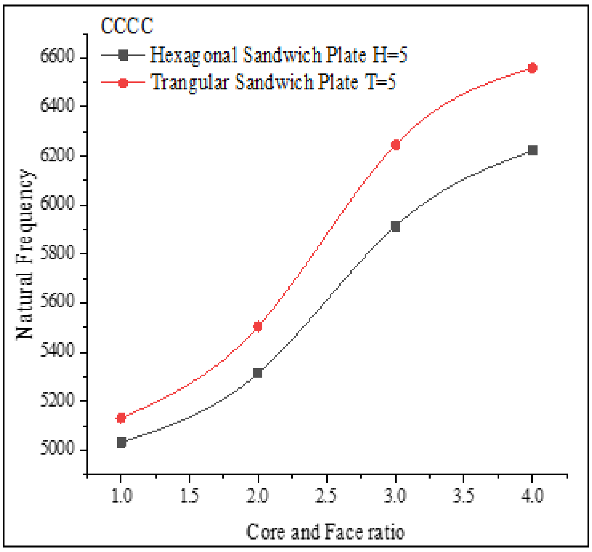

Figure 5: Natural Frequency of hexagonal and Triangular sandwich plate

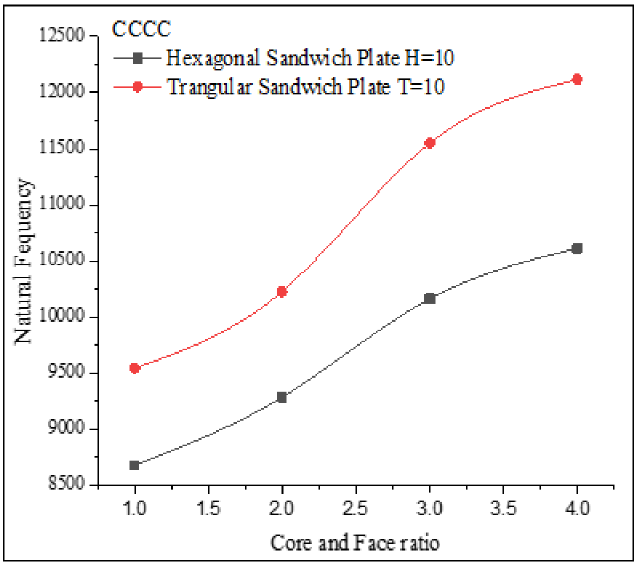

Figure 6: Natural Frequency of hexagonal and Triangular sandwich plate

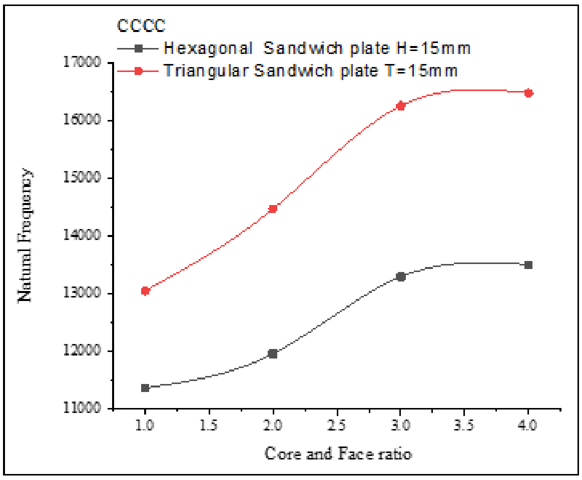

Figure 7: Natural Frequency of hexagonal and Triangular sandwich plate

Natural Frequency of hexagonal and Triangular sandwich plate: - The graph in Figures 5, 6, and 7 illustrate the variation in natural frequency for hexagonal and triangular sandwich plates with total heights H=5mm, H=10mm, and

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15mm, respectively, under CCCC boundary conditions. In all cases, the natural frequency increases with the core - to - face thickness ratio (t_c/t_f), as a thicker core enhances the stiffness of the plate. The triangular sandwich plates consistently demonstrate higher natural frequencies compared to hexagonal plates, indicating superior stiffness and dynamic performance. This trend is more pronounced at larger ratios t_c/t_f and greater total height, highlighting the effectiveness of the triangular configuration in improving dynamic stability.

4. Conclusion

In conclusion, this study analyzed the deflection and vibration characteristics of honeycomb structures with hexagonal and triangular cores using ANSYS. The results demonstrated that triangular core structures generally perform better in terms of lower deformation, reduced stress levels, and higher natural frequencies compared to hexagonal cores. Additionally, the boundary conditions All side clamped and All side simply supported (CCCC and SSSS) significantly influenced the mechanical behavior of these structures, with the All side clamped (CCCC) condition providing better stability and lower deformation. The findings suggest that triangular cores are more suitable for applications requiring high structural integrity and dynamic stability.

Furthermore, the choice of materials, titanium for the face layers and silicon carbide for the core, was effective in achieving the desired balance of strength and weight. These insights are valuable for optimizing the design of honeycomb sandwich structures in various engineering fields. Future research could explore different core geometries, materials, and loading conditions to further improve the performance and applicability of these structures. Experimental validation of the computational results would also enhance confidence in the findings

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Author Contribution

Author 1: Conceptualization, investigation, data analysis, writing and original draft.

Author 2: Reviewing and editing.

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