# PERFORMANCE EVALUATION OF HONEYCOMB STRUCTURES USING FINITE ELEMENT ANALYSIS

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## ABSTRACT

Honeycomb structures are known for being lightweight and strong, making them essential in industries like aerospace, automotive, and construction. Despite their widespread use, significant challenges remain in optimizing these structures to balance strength, weight efficiency, and cost reduction. This study aims to evaluate the performance of honeycomb structures by analyzing variations in dimensions, geometric shape material. The investigation begins with the creation of a detailed CAD model of the honeycomb configuration, which is then converted into a finite element (FE) model. Structural steel is utilized as the standard material for the initial FE simulations. Boundary conditions and loading scenarios are applied to determine the stress distribution and deformation of the structure. The accuracy of the model is validated against established literature, and simulations are extended across different dimensions and shapes to identify the most effective configuration. The findings of this study offer valuable insights into optimizing honeycomb designs for improved mechanical performance and efficiency in engineering applications.

**Keywords:** honeycomb structures, structure performance, optimization, finite element analysis.

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## INTRODUCTION

Honeycomb structures are inspired by the natural design of bee honeycombs, which are known for their efficiency in space utilization and material strength. The unique structural design of honeycomb configurations consists of a series of hollow cells arranged in a hexagonal pattern, which provides an excellent strength-to-weight ratio. This design principle has been adopted in various industries, including aerospace, automotive, and construction, where the need for lightweight yet strong materials is paramount.

Normally, honeycomb structures minimize the amount of material needed to achieve specific weight and cost requirements while providing impressive strength. These structures consist of arrays of hollow cells, most commonly hexagonal, formed between slender vertical walls, resulting in low-density materials with high compression and shear properties [1].

The efficiency of honeycomb structures lies in their ability to maximize strength and stiffness while minimizing material usage. This is especially important in industries where reducing weight can improve performance and lower costs. Finite Element Analysis (FEA) has shown that hybrid honeycomb configurations can reduce material usage by up to 40%, compared to solid profiles, without compromising structural integrity [2]. These properties make honeycomb structures ideal for applications that demand material efficiency and lightweight design, particularly in sectors such as automotive, aerospace, and construction.

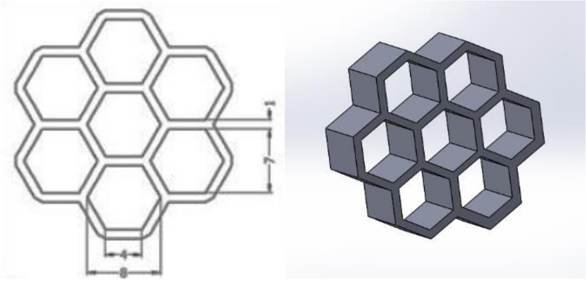
The strength-to-weight ratio of honeycomb structures is further enhanced by their geometric design, particularly the hexagonal arrangement. This geometry allows for efficient packing and exceptional load distribution, making it one of the most effective cell shapes for both static and dynamic loading scenarios. Studies have confirmed that honeycomb structures, especially hexagonal ones, offer the best strength-to-weight ratio of any cellular configuration, making them invaluable in projects requiring optimized mechanical performance under both static and impact loading conditions [3].

The application of honeycomb structures in aerospace engineering is particularly noteworthy. The aerospace industry demands materials that can withstand extreme conditions while minimizing weight to enhance fuel efficiency. Meanwhile, in the automotive sector, honeycomb structures are increasingly utilized to manufacture lightweight components. Honeycomb structures made from materials such as aluminum, titanium, and composite materials have been shown to significantly reduce weight while maintaining structural integrity [4].

Despite the advantages of honeycomb structures, challenges remain in optimizing their design for specific applications. The need to balance strength, weight, and cost is critical, particularly in industries where performance and sustainability are paramount. Traditional solid structures often require excessive amounts of material, leading to increased costs and environmental strain. Therefore, this study aims to analyse and simulate the honeycomb structure configurations to identify optimal designs that meet these criteria.

## METHODOLOGY

CAD software was used to create accurate representations of various honeycomb configurations, enabling precise control over their dimensions and geometric parameters. The models were designed to simulate real-world applications, ensuring that the analysis would produce relevant results. To establish a common baseline for comparing the stress and deformation generated by different structures during simulation, the standard dimensions of the honeycomb structure were based on previous research [2], as shown in Figure-1(a). The developed CAD model is presented in Figure-1 (b).



(a) (b)

**Figure-1.** (a) Referred dimension (in mm), and (b) CAD model of standard honeycomb structure.

The CAD model was then discretized into several elements as shown in Figure-2. This finite element model consists of 59,202 nodes and 10,560 elements. It is followed by the definition of material properties, loading conditions, and constraints. The standard FE model used structural steel, with its mechanical properties depicted in Table 1. A uniform pressure of 10 MPa was applied to the top face of the honeycomb structure, while the opposite face was fixed.

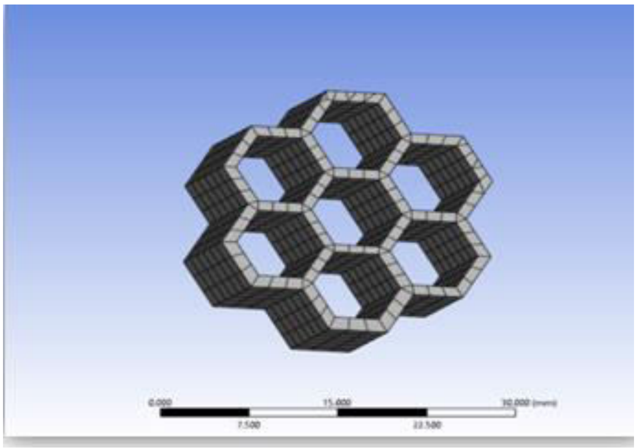


**Figure-2.** Meshed finite element model.

**Table-1.** Mechanical properties of structural steel.

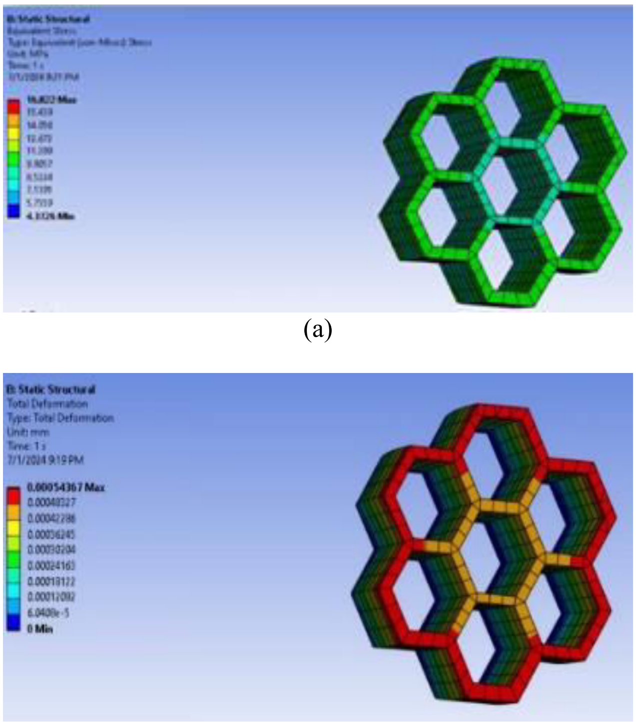
| Properties | Value |
|---|---|
| Density (tonne/mm$^3$) | 7.85 x 10$^{-9}$ |
| Elastic modulus (GPa) | 200 GPa |
| Poisson ratio | 0.3 |
| Yield strength (MPa) | 250 MPa |
| Ultimate strength (MPa) | 460 MPa |

The validation of an FE model involves comparing simulation results, such as stress and deformation, with experimental data or established research to confirm accuracy and reliability. In this study, the von Mises stress and deformation results of the standard FE model were compared with findings from the previous research done by Chandrashekhar *et al.* [2]. This process ensures the model's predictions are consistent with real-world behaviors, thereby bolstering confidence in its use for further analysis. A validated model enhances the credibility of simulation outcomes and supports sound conclusions.

Subsequently, simulations were carried out using different materials and varying dimensions of the honeycomb structure to identify the optimal configuration. This approach ensures a comprehensive comparison of structural performance, facilitating the selection of the most efficient design for practical applications. The results from these simulations will provide insights into the mechanical behavior of the honeycomb configurations under different conditions.

## RESULTS AND DISCUSSIONS

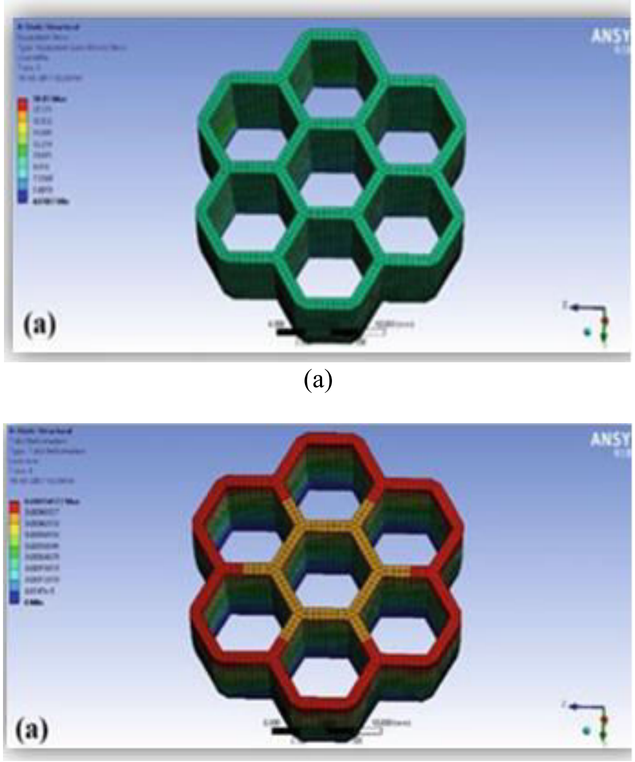
Validating an FE model is essential to establishing its predictive accuracy and ensuring that simulation outcomes are scientifically robust. This process not only enhances the model's credibility but also supports the reliability of its applications in complex engineering analyses. Figure-3 illustrates the stress and deformation distribution of the standard FE model developed in this study. The results indicate a maximum von Mises stress of 16.8 MPa and a maximum deformation of $54.2\times10^{-3}$ mm. In comparison, Figure-4 presents the stress and strain distribution obtained from literature [2], showing a maximum von Mises stress of 18.6 MPa and an identical maximum deformation of $54.2\times10^{-3}$mm.



(a)

(b)

**Figure-3.** (a) Stress and (b) deformation distribution obtained from the standard FE model.



(a)

(b)

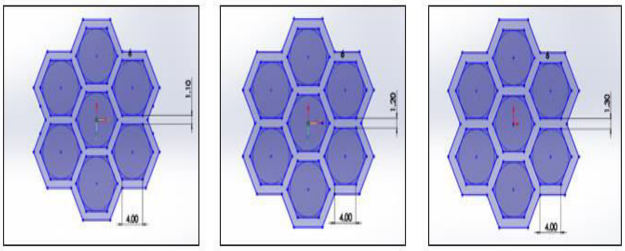
**Figure-4.** (a) Stress and (b) deformation distribution obtained from literature [2].

The results are summarized in Table-2, which compares the stress and deformation values obtained from the standard FE model in this study with those reported in the literature [2]. The differences in stress and deformation values are less than 10%, demonstrating close agreement with the reference data and falling within an acceptable range. This high level of consistency supports the accuracy of the developed FE model, confirming its capability to reliably replicate expected mechanical responses. Consequently, these findings validate the FE model and affirm its robustness for further analysis in similar applications.

**Table-2.** Comparison of the maximum von Mises stress and maximum deformation values obtained from the standard FE model and literature [2].

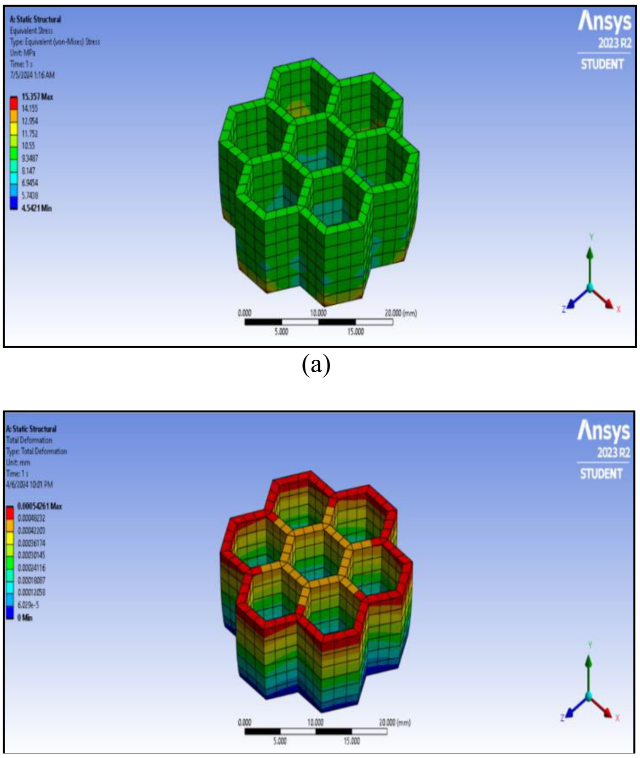
| Result | Stress (MPa) | Deformation (mm) |
|---|---|---|
| FE Model | 16.8 | $54.2 \times 10^{-3}$ |
| Literature | 18.6 | $54.2 \times 10^{-3}$ |
| Different | 9.6 % | 0 |

In this study, three different thicknesses of honeycomb structures were modeled using FEA to investigate their stress and deformation behavior under compressive loading. The honeycomb wall thicknesses used were 1.1 mm, 1.2 mm, and 1.3 mm, as shown in Figure-5. The stress and deformation distributions are presented in Figure 6. Meanwhile, Table 3 provides a summary of the results.



(a) (b) (c)

**Figure-5.** Three differences in wall thickness (a) 1.1 mm, (b) 1.2 mm, and (c) 1.3 mm.



(a)

(b)

**Figure-6.** (a) Stress and (b) deformation distribution for 1.1 mm honeycomb wall thickness.

**Table-3.** Comparison of the maximum von Mises stress and average deformation values for different honeycomb wall thicknesses.

| Wall thickness | Stress (MPa) | Deformation (mm) |
|---|---|---|
| 1.1 mm | 15.36 | 251.9 x $10^{-6}$ |
| 1.2 mm | 15.31 | 251.5 x $10^{-6}$ |
| 1.3 mm | 15.27 | 251.1 x $10^{-6}$ |

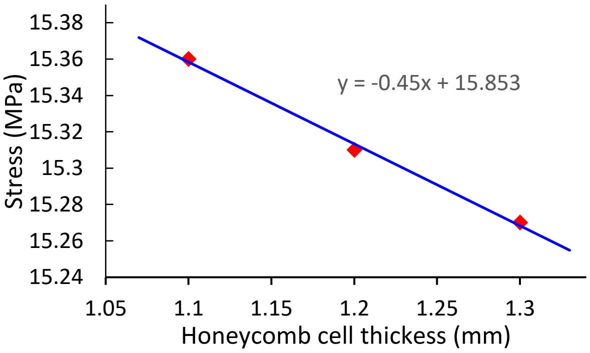


**Figure-7.** The relationship between maximum von Mises stress and honeycomb wall thickness.

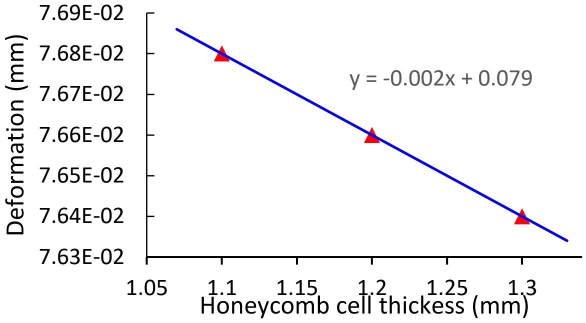


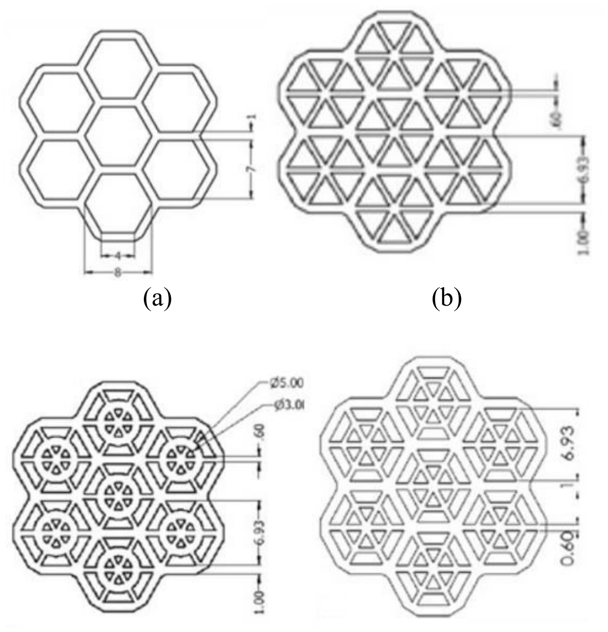
**Figure-8.** The relationship between average deformation and honeycomb wall thickness.

Results indicate that increasing the honeycomb wall thickness from 1.1 mm to 1.3 mm leads to a slight reduction in von Mises stress and deformation, as shown in Figure-7 and Figure-8, respectively. This trend is expected, as thicker walls provide greater resistance to deformation, enhancing the overall stiffness of the structure.

The reduction in deformation can be attributed to the increased material volume, which distributes the applied load more effectively, reducing localized strain and stress. This behavior is consistent with the findings of Thomas & Tiwari [5], which state that thicker honeycomb walls exhibit improved load-bearing capacity due to their higher moment of inertia and resistance to bending. Additionally, the observed decrease in von Mises stress suggests that the honeycomb structure with thicker walls experiences lower internal stress under compressive loading, reducing the likelihood of structural failure.

However, despite the overall reduction in stress and average deformation, it is important to consider the impact of overall structure weight. While increasing wall thickness improves structural integrity, it also results in added weight, which may not be ideal for applications requiring lightweight materials, such as aerospace and automotive components. Therefore, the selection of an optimal wall thickness must balance mechanical performance with material efficiency, ensuring that the honeycomb structure maintains its strength while minimizing unnecessary weight.

The geometric configuration of a honeycomb structure plays a crucial role in determining its mechanical performance, particularly in terms of stress distribution and deformation behavior. Variations in cell shape can significantly influence the load-bearing capacity, stiffness, and energy absorption characteristics of the structure. In this study, four different honeycomb shapes, as shown in Figure-9 were analyzed to evaluate their effects on von Mises stress and deformation under applied loads. Meanwhile, their results comparison was shown in Figure-10 and Figure-11.



(a) (b)

(c) (d)

**Figure-9.** Four configurations of honeycomb structures (a) Original (shape-1), (b) cross-ribbed (shape-2), round-supported (shape-3), and hexagonal-supported (shape-4).

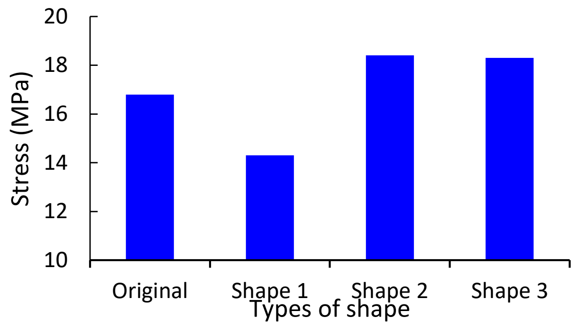


**Figure-10.** The comparison of maximum von Mises stress among different honeycomb shapes.

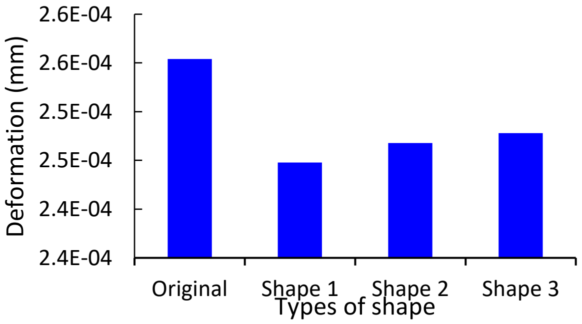


**Figure-11.** The comparison of average deformation among different honeycomb shapes.

Figure-10 presents a comparative analysis of four different honeycomb shapes: the original shape (shape 1), cross-ribbed (shape 2), round-supported (shape 3), and hexagonal-supported (shape 4) designs. The results demonstrate that the original honeycomb shape exhibited a von Mises stress of 16.8 MPa, whereas the cross-ribbed shape had the lowest stress at 14.3 MPa, indicating superior load distribution properties. Conversely, round-supported and hexagonal-supported experienced higher stresses of 18.4 MPa and 18.3 MPa, respectively. The differences in stress distribution suggest that the cross-ribbed shape provides the most efficient load-bearing capacity by minimizing localized stress concentrations, potentially due to its optimized geometry and load dispersion properties.

The deformation response of honeycomb structures is also significantly influenced by their geometric configuration, as shown in Figure-11. The results indicate that the cross-ribbed honeycomb exhibits the lowest deformation among all configurations, demonstrating superior structural stiffness. This trend aligns with findings from Jiang *et al.* [6], who reported that additional reinforcement ribs in honeycomb cores enhance load-bearing capacity and reduce deformation levels. The presence of these reinforcing ribs increases structural rigidity by improving the internal load distribution, thereby mitigating localized bending and minimizing material deflection under applied loads.

Furthermore, while reinforced honeycomb structures exhibit reduced deformation, they come at the cost of increased mass. As observed in Figure-9, the original honeycomb shape is approximately 40% lighter than the cross-ribbed and other reinforced configurations. Despite the additional stiffness provided by the ribs, the variation in deformation remains relatively small, suggesting that the original shape may offer a more weight-efficient design without a significant compromise in structural integrity. The inherently hollow profiles of honeycomb structures further contribute to material savings, making them an attractive option for lightweight engineering applications. These findings emphasize the importance of optimizing honeycomb geometry to balance deformation resistance, weight efficiency, and material utilization in structural design.

The mechanical performance of honeycomb structures is also highly dependent on the properties of the materials used, as different materials exhibit varying strength and deformation characteristics. Titanium, aluminum, and magnesium alloys each provide unique mechanical responses that influence the overall structural integrity and load-bearing capacity of honeycomb configurations, as shown in the Figure-12 and Figure-13.

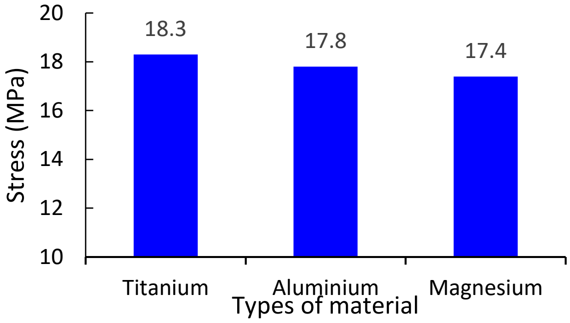


**Figure-12.** The comparison of maximum von Mises stress among different types of materials.

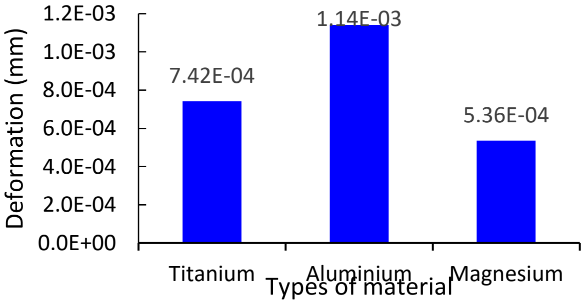


**Figure-13.** The comparison of average deformation among different types of materials.

The choice of material significantly affects the honeycomb structure's stress and deformation responses. As shown in Figure-12, titanium exhibited the highest von Mises stress at 18.3 MPa, followed by aluminum at 17.8 MPa and magnesium at 17.4 MPa. These results indicate that titanium, due to its superior mechanical properties, can sustain higher stress levels before failure.

Furthermore, the variation in von Mises stress across the materials (Ti > Mg > Al) can be explained by differences in their crystal structures and associated deformation mechanisms. Titanium and magnesium both possess a hexagonal close-packed (HCP) crystal structure, which typically results in limited slip systems and increased susceptibility to stress concentrations. However, titanium's higher intrinsic strength leads to a higher von Mises stress than magnesium in finite element simulations.

In contrast, aluminium, with its face-centered cubic (FCC) structure, offers more slip systems and better plastic deformation capabilities, which help distribute stress more uniformly, thereby resulting in lower von Mises stress. These distinctions emphasize the critical influence of microstructural characteristics on the mechanical response of materials, particularly in complex geometries such as honeycomb structures.

In terms of deformation, magnesium exhibited the lowest deformation at 5.36E-04 mm, indicating its superior stiffness relative to the other materials. Titanium showed a moderate deformation of 7.42E-04 mm, while aluminum exhibited the highest deformation at 1.14E-03 mm, as shown in Figure-13.

The results show that the titanium alloy exhibits the lowest values of deformation and strain, yet it records the highest von Mises stress among the three. This can be attributed to titanium's inherently high stiffness and Young's modulus, and supported by Hayat *et al.* [7]. These findings are consistent with the well-established properties of titanium alloys, particularly their superior strength-to-weight ratio and limited elastic deformation under load [8]. The reduced strain and deformation observed in titanium-based structures make them highly desirable in applications requiring dimensional stability and high load-bearing capacity, despite the penalty of elevated internal stress.

## CONCLUSIONS

This study validated the FE model by comparing it with existing literature, confirming its reliability with less than 10% variation in stress and identical deformation values. The model was then used to investigate the effects of wall thickness, geometry, and material type on the mechanical performance of honeycomb structures under compressive loading. Increasing wall thickness from 1.1 mm to 1.3 mm led to slight reductions in stress and deformation, enhancing stiffness but increasing overall weight. This highlights the need for a balance between structural integrity and material efficiency.

Geometric analysis showed that the cross-ribbed configuration offered the lowest stress and deformation, indicating better load distribution and stiffness. However, the original honeycomb shape remained more weight-efficient, making it suitable for lightweight applications with minimal compromise in strength. Material selection also had a significant impact: titanium alloy showed the highest von Mises stress but lowest deformation due to its high stiffness and strength-to-weight ratio, while magnesium and aluminium offered different balances between stress and deformation. These findings underscore the importance of optimizing geometry, thickness, and material properties to achieve efficient, lightweight, and high-performing structural designs for engineering applications.

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## REFERENCES

[1] Miranda A., Leite M., Reis L., and Copin E. 2021. Evaluation of the influence of design on the mechanical properties of honeycomb cores used in composite panels, Journal of Materials: Design and Applications. 235(6): 1325-1340.

[2] Chandrashekhar A., Shaik H. S., Ranjan Mishra S., Srivastava T., and Pavan Kishore M. L. 2021. Static

Structural Analysis of Hybrid Honeycomb Structures Using FEA. In: Narasimham, G. S. V. L., Babu, A. V., Reddy, S. S., Dhanasekaran, R. (eds) Recent Trends in Mechanical Engineering, Lecture Notes in Mechanical Engineering, Springer, Singapore.

[3] Sanchaniya J. V., Kanukuntla S. P., Dutta A., and Jevstignejevs V. 2022. Analysis of the honeycomb structure evaluated in static and impact loading. Engineering for Rural Development. 21: 745-753.

[4] Mohammadi H., Ahmad Z., Petrů M., Mazlan S. A., Johari M. A. F., Hatami H., and Koloo S. S. R. 2023. An insight from nature: honeycomb pattern in advanced structural design for impact energy absorption, Journal of Materials Research and Technology. 22: 2862-2887.

[5] Thomas T. and Tiwari G. 2019. Energy absorption and in-plane crushing behavior of aluminium reinforced honeycomb Vacuum. 166: 364-369.

[6] Jiang D., Fei Q., Wu S. and Zhang D. 2016. Experimental and numerical investigation on indentation and energy absorption of a honeycomb sandwich panel under low-velocity impact, Finite Elements in Analysis and Design. 117-118: 21-30.

[7] Hayat M. D., Singh H., He Z., and Cao P. 2019. Titanium metal matrix composites: An overview, Composites Part A: Applied Science and Manufacturing. 121: 418-438.

[8] Sha W. and Malinov S. 2009. Titanium Alloys: Modelling of Microstructure, Properties and Applications, Woodhead Publishing, United Kingdom.