Parametric Optimization Study of Honeycomb Core Sandwich Panels using Finite Element Method

Rohit Tamrakar[1], and Aditi Kundu[1]*
[1]Department of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India

Abstract. This paper presents the finite element method (FEM) based parametric optimization of sandwich panel with a honeycomb core through ANSYS Workbench. The optimization is carried out by assigning isotropic properties to the face sheets and orthotropic properties to the honeycomb core, both made of Aluminium alloy (AL3003). Cell size and cell wall thickness of the honeycomb core are used as design variables, both individually and collectively, with the objective functions being the minimization of Von-Mises stress and overall deformation. The results indicate that cell size has a greater influence than cell wall thickness on directional deformation, overall deformation and von Mises stress distribution in sandwich structures. This research work demonstrates a complete procedure for parametric optimization through software simulation.

1 Introduction

A sandwich panel is a composite structure made up of two thin and stiff face sheets bonded to a thick and low weight core which is softer in nature [1],[3],[8],[10],[11],[12],[14]. The core is responsible for resisting transverse and shear forces, whereas the face sheets primarily sustain in-plane tensile and compressive stresses [3],[12],[14]. Since there is superiority in the strength-to-weight ratio of honeycomb core sandwich panels, so it provides excellent stiffness and strength properties [11],[12].It is popular in aerospace, transportation, pressure containment, energy absorption [4]. It has good sound absorbing characteristics, can also resist high wind pressure, maintain temperature, and retard fire and are high-performance energy-dissipation solutions for extreme impact events [7],[9],[10]. Sandwich panels exhibit remarkable mechanical efficiency at low density and their multifunctional and advanced design attributes have contributed to their broad industrial acceptance [2]. Although the aluminium face sheets exhibits isotropic behaviour, the honeycomb core displays orthotropic properties arising from its geometry and complex load-transfer mechanisms. [3]. Among various honeycomb configurations, the auxetic honeycomb featuring a re-entrant cell geometry and a negative poison's ratio exhibits unique characteristics, including enhanced

* Corresponding author: rt@med.svnit.ac.in

shear resistance and comparatively lower natural frequency than other cell designs [5]. FDM, is one of the most famous 3D printing methods, is used to manufacture parts by the usage of materials such as polylactic acid and ABS etc [6],[15]. Honeycomb cores are manufactured by different ways such as adhesive bonding, resistance welding, brazing, diffusion bonding so that these can sustain at high temperatures [8]. Parts of Honeycomb core Sandwich panels include 1.) Face sheet, for bearing bending stress of sandwich structure and 2.) Core, that reduces weight [13].

In this project, Von-Mises equivalent stress and overall deformation are set as objective functions. The aim of is to minimize both the Von-Mises equivalent stress and overall deformation to target values. The design space was parameterized in terms of cell size and cell wall thickness, which were investigated both independently and in combination to capture their individual and coupled effects. For each optimization study, a total of 200 parametric design points are evaluated.

2 FEM static structural analysis analysis

Figure 1 illustrates the three-dimensional CAD model of the honeycomb sandwich panel, developed in SOLIDWORKS. The face sheet dimensions were specified as 210 mm x 210 mm, while the honeycomb core is configured with a hexagonal cell size of 12.5 mm, a wall thickness as 0.13 mm, and a height of 0.25 mm [18]. The CAD model was exported and integrated into ANSYS Workbench for finite element pre-processing and subsequent parametric analysis. Aluminium alloy (AL3003) was assigned to the structure, with isotropic material properties applied to the face sheets (Table 1) and orthotropic properties to the honeycomb core (Table 2) to accurately capture material anisotropy. Boundary condition enforcement was implemented by fully constraining all four edges of the panel through the named selection approach. A concentrated central load of 570 N was applied to the mid-plane of the panel, as illustrated in Figure 2, to replicated service level loading conditions.

Table 1. Isotropic Properties of Al3003 Alloy [3]

Property	Value
Density(ρ)	2600 kg/m^3
Modulus of Elasticity S	69000 MPa
Poisson's Ratio(σ)	0.33

Table 2. Orthotropic Properties of Al3003 Alloy [3]

Property	Value (MPa)	Property	Value	Property	Value (MPa)
Modulus of Elasticity (X direction)	0.1 MPa	Poisson's Ratio XY	0.995	Shear Modulus XY	0.017
Modulus of Elasticity (Y direction)	0.1 MPa	Poisson's Ratio YZ	0.001	Shear Modulus YZ	79
Modulus of Elasticity (Z direction)	640 MPa	Poisson's Ratio XZ	0	Shear Modulus XZ	46

Static structural analysis was performed on the sandwich panels with a honeycomb structure, based on the dimensions mentioned in the previous section, prior to optimization. Figures 3 and 4 represents the overall deformation and Von-Mises equivalent stress of the honeycomb core sandwich panel, respectively.

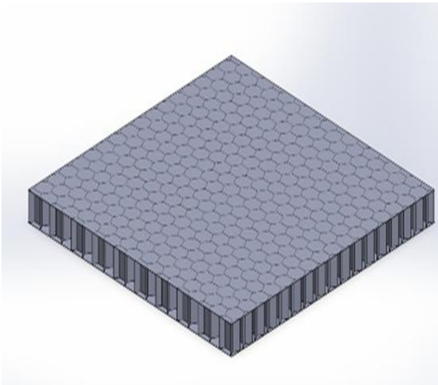

Fig. 1. 3D model of honeycomb core sandwich panel

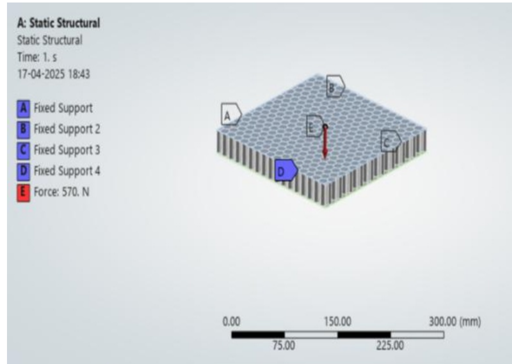

Fig. 2. Boundary conditions and Loading condition

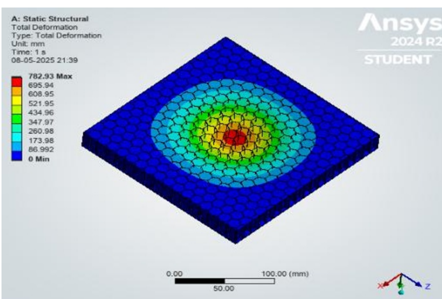

Fig. 3. Overall deformation of Honeycomb Core Sandwich Panel

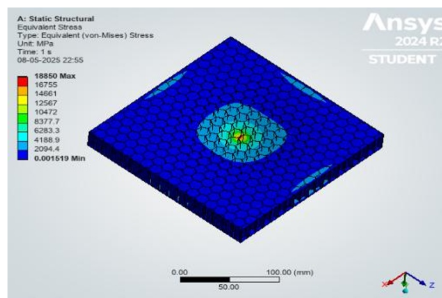

Fig. 4. Von-Mises stress of Honeycomb Core Sandwich Panel

3 Parametric Optimization

The ANSYS workbench software package was utilized through the direct optimization module to obtain accurate results. The optimization study was conducted with cell size and cell wall thickness as design variables, aiming to minimize von Mises stress and overall deformation as the objective functions. The output parameters considered include overall deformation, deformation measured along specific direction, Von-Mises equivalent stress, geometric mass and geometric volume. The study is carried out in three stages: in first stage, only cell size is considered as the design variable; in the second stage, only cell wall thickness is taken as the design variable; and in the final stage, both parameters were used as simultaneously to minimize the von Mises stress and overall deformation.

3.1 Stage I - Taking cell size as design variable

This study is performed by considering only the cell size only as the design variable, with Von-Mises equivalent stress and overall deformation as the objective functions to be minimized. The target values are set to 18,849 MPa and 782.81 mm respectively, as these represent the highest values in the raw optimization data. In the optimization study, the cell size is specified as the P2 point, and a total of 200 parametric points for cell size variation are considered, as shown in Figure 5.

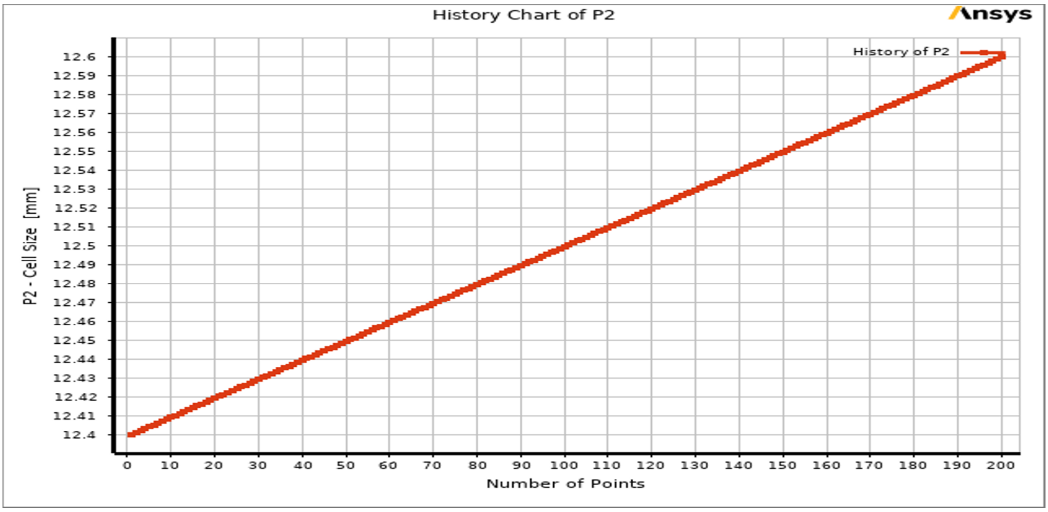

Fig. 5. Cell size variation with parametric points

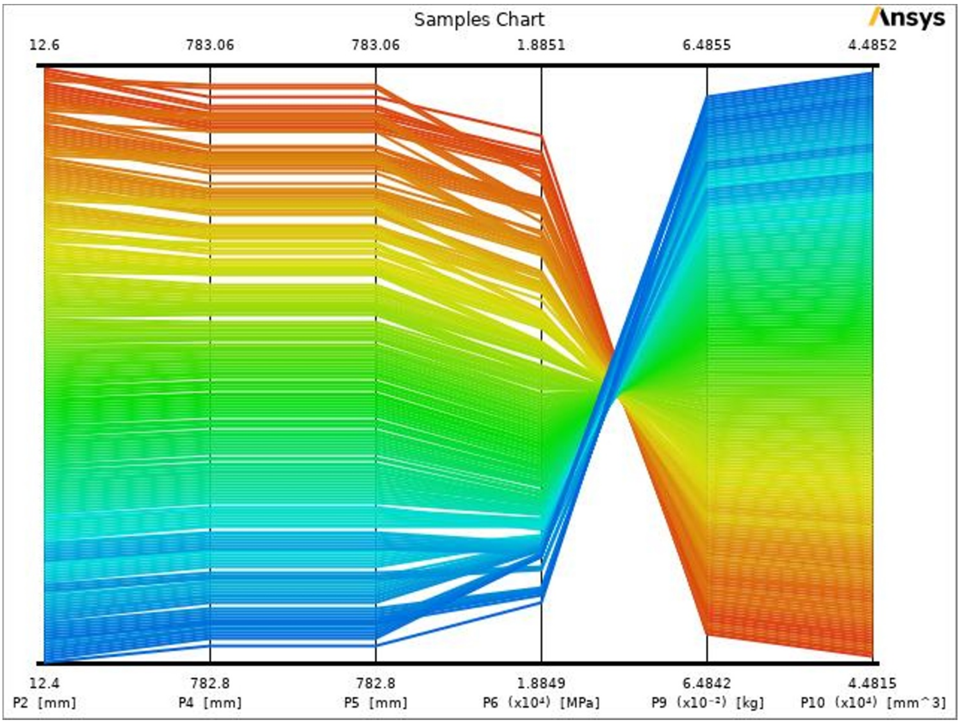

Fig. 6. Samples chart with parametric points

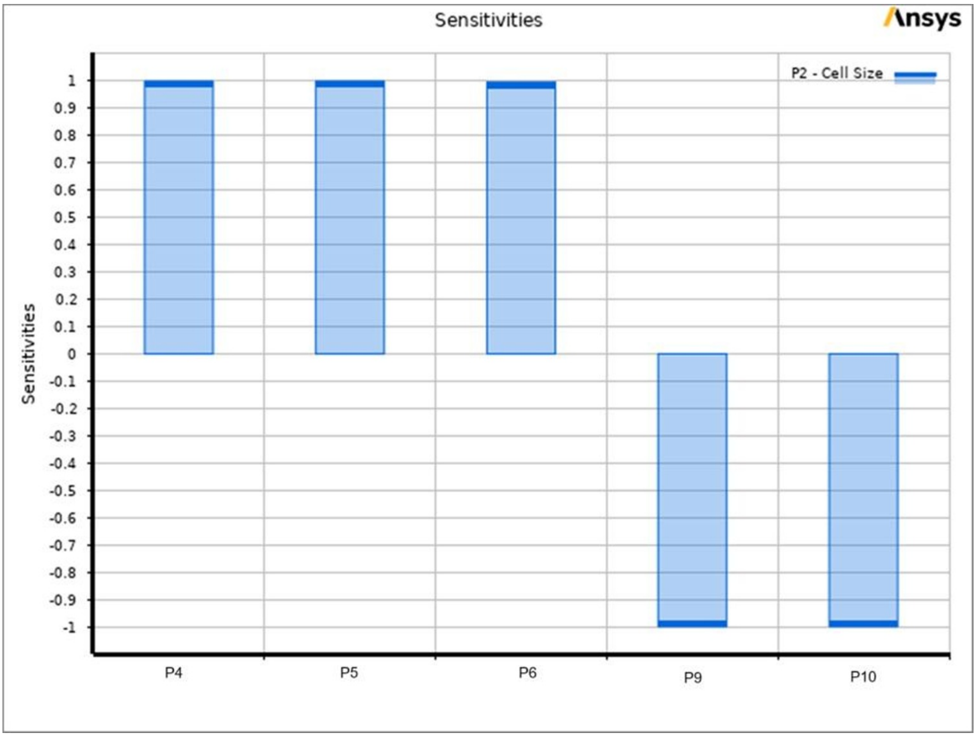

Fig. 7. Sensitiveness chart with parametric points

Figure 6 and Figure 7 respectively shows Sample Chart and Sensitiveness Chart of 200 parametric points and their output parameters, which include overall deformation (P4), deformation measured along specific direction (P5), Von-Mises equivalent stress (P6), geometric mass (P9) and geometric volume (P10) to cell size (P2). The sensitiveness chart indicates that cell size has an almost negligible effect on the geometric mass and volume of the sandwich structures. Table 3 presents the best three candidate points obtained after the optimization study, with a cell size of 12.401 mm resulting in the lowest equivalent von misses stress and overall deformation.

Table 3. Candidate points for cell size as only variable

Candidate points	Cell Size(D) (mm)	Deformation measured along specific direction (mm)	Von -misses equivalent Stress (MPa)
1.	12.401	782.8100853	18849.2043
2.	12.425	782.838894	18849.31714
3.	12.449	782.8680079	18849.45307

3.2 Stage II - Taking cell wall thickness as design variable

In this study cell wall thickness is considered as sole design variable along with Von-Mises equivalent stress and overall deformation as the objective function to be minimized. The target values are set to 18850 MPa and 782.92 mm respectively, as these represent the highest values in the raw optimization data. In the optimization study, cell wall thickness is specified as P8 point and a total of 200 parametric points for cell wall thickness are considered, as shown in Figure 8.

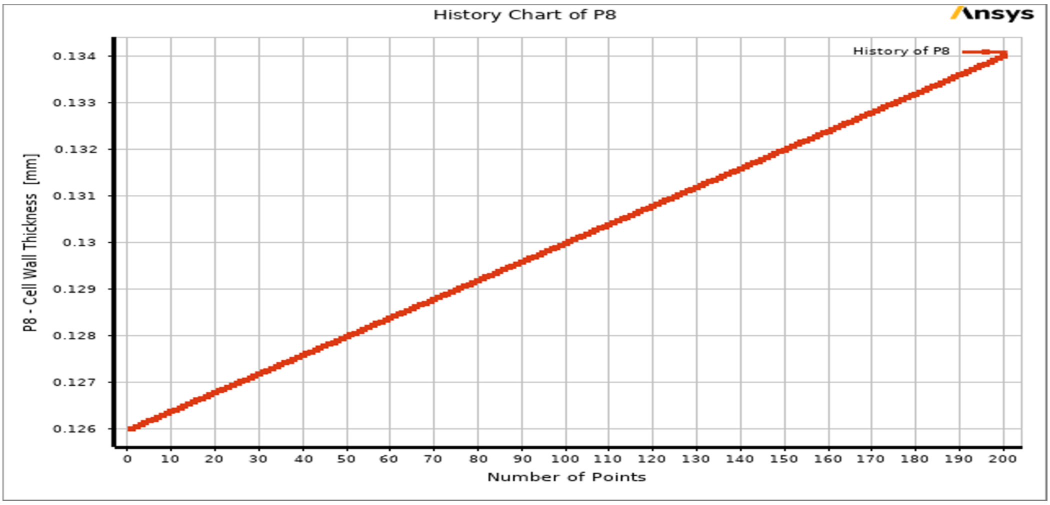

Fig. 8. Cell wall thickness variation with parametric points

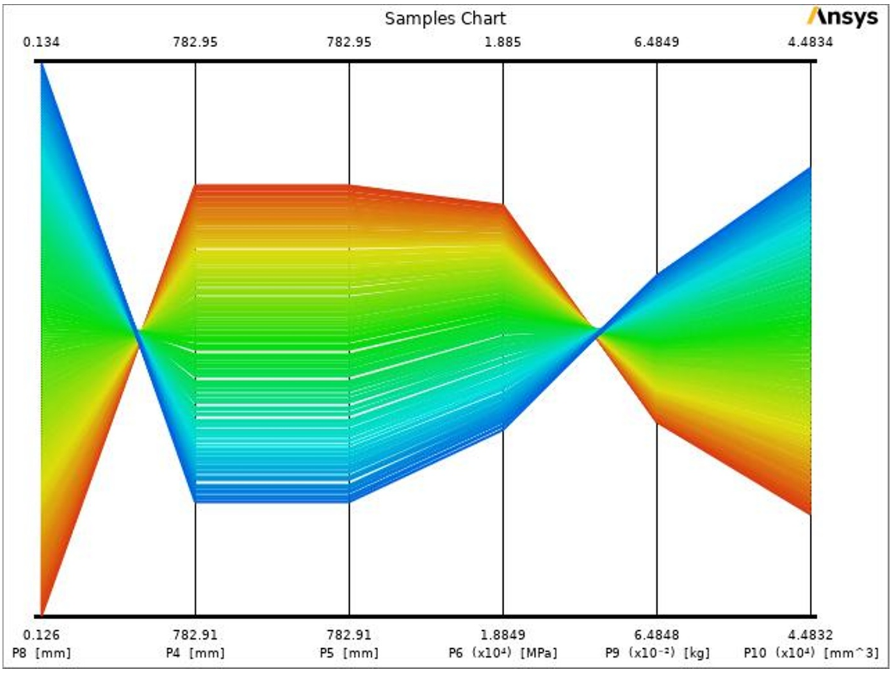

Fig. 9. Samples chart with parametric points

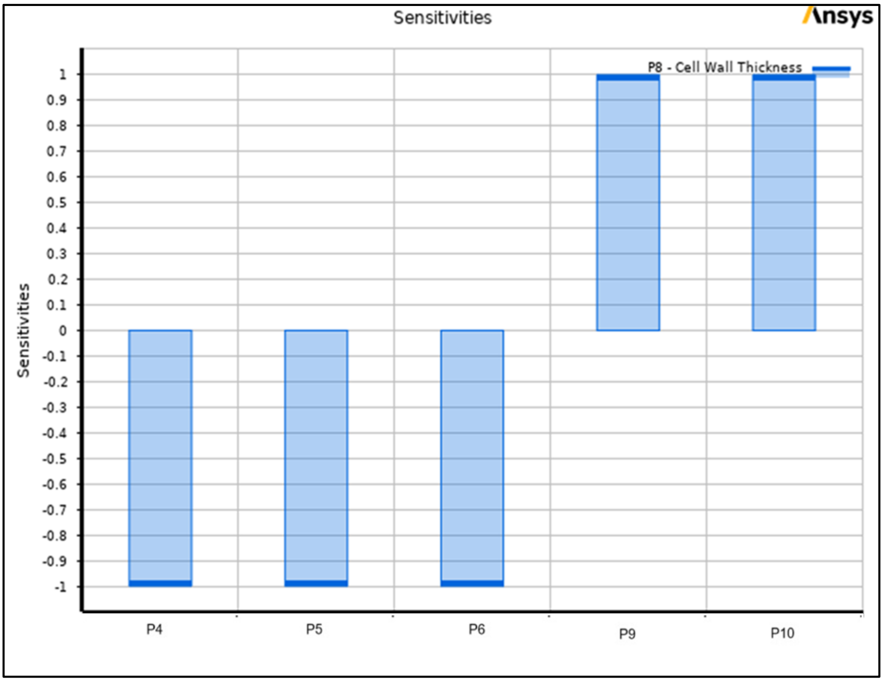

Fig. 10. Sensitiveness chart with parametric points

Table 4. Candidate points for cell wall thickness as only variable

Candidate points	Cell wall thickness(t) (mm)	Overall Deformation (mm)	Von -misses Equivalent Stress (MPa)
1.	0.13398	782.9204984	18849.70348
2.	0.13318	782.9228787	18849.7334
3.	0.13234	782.925076	18849.76387

Figure 9 and Figure 10 respectively show Sample Chart and Sensitiveness Chart of 200 parametric points and their output parameters, which include overall deformation (P4), deformation measured along specific direction (P5), Von-Mises equivalent stress (P6), geometric mass (P9) and geometric volume (P10) to cell wall thickness (P8). The sensitiveness chart indicates that cell wall thickness has an almost negligible effect on overall deformation, directional deformation, and von Mises distribution in the sandwich structures. Table 4 presents the best three candidate points obtained from the optimization study with cell wall thickness of 0.13398 mm resulting in the lowest Von Mises equivalent stress and overall deformation.

3.3 Stage III - Taking cell size and cell wall thickness as design variables

In this study cell size and cell wall thickness are considered as design variables along with Von-Mises equivalent stress and overall deformation as the objective function to be minimized. The target values are set to 18,849 MPa and 782.81 mm respectively, as these represent the highest values in the raw optimization data. A total of 200 parametric points for cell size and cell wall thickness are considered within the same range values specified in the previous sections.

Figure 11 and Figure 12 respectively show Sample Chart and Sensitiveness Chart of 200 parametric points and their output parameters, which include overall deformation (P4), directional deformation (P5), Von-Mises equivalent stress (P6), geometric mass (P9) and geometric volume (P10) to cell size (P2) and cell wall thickness (P8). The sensitiveness chart indicates that varying the cell size relative to cell wall thickness has a greater effect on directional deformation, overall deformation and von Mises stress distribution in the sandwich structures. Table 5 presents the best three candidate points obtained from the optimization study, with a cell size of 12.412 mm and a cell wall thickness of 0.13252 mm resulting in the lowest equivalent von Mises stress and overall deformation.

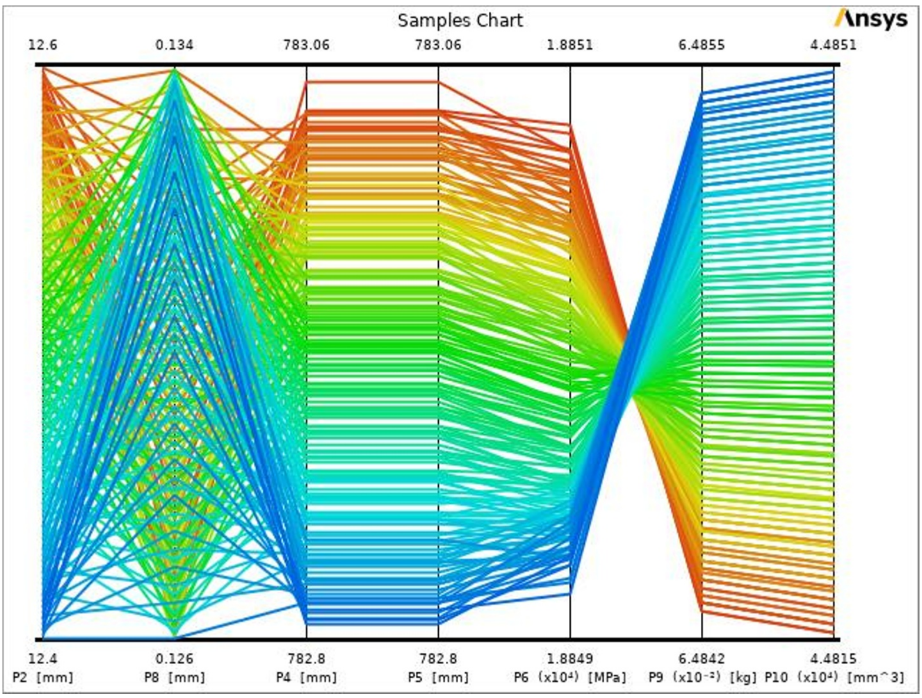

Fig. 11. Samples chart with parametric points

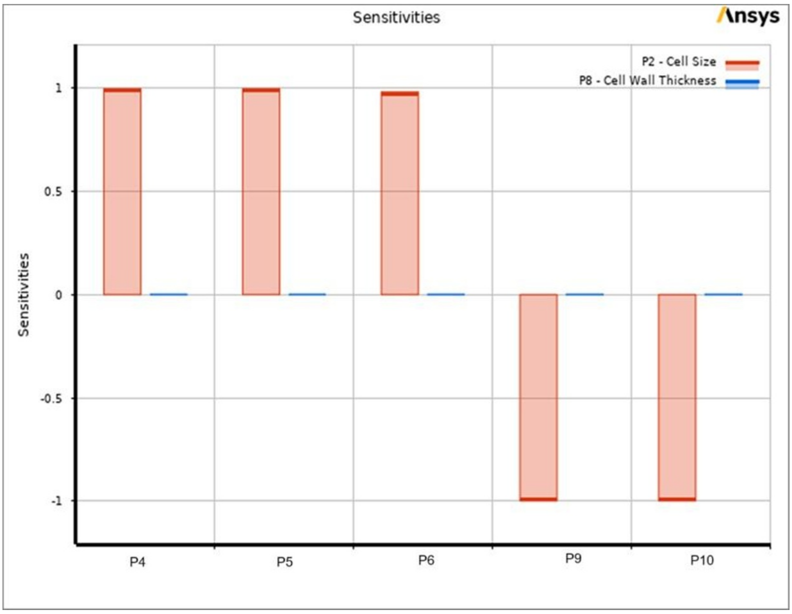

Fig. 12. Sensitiveness chart with parametric points

Table 5. Candidate points for cell size and cell wall thickness as variables

Candidate point	Cell Size (D) (mm)	Cell Wall Thickness(t) (mm)	Overall deformation (mm)	Von-Mises equivalent Stress (MPa)
1.	12.412	0.13252	782.8160058	18849.16055
2.	12.432	0.13377	782.8379786	18849.29356
3.	12.452	0.1324	782.8656886	18849.42253

Conclusion

This study presents a detailed parametric optimization of an Al3003 honeycomb sandwich panel using ANSYS, incorporating isotropic face sheets and an orthotropic core to accurately capture the structural behavior. By selecting cell size and cell wall thickness as key design variables, and targeting the minimization of equivalent Von Mises stress and overall deformation, the study systematically evaluates their individual and combined effects on structural performance. The results reveal that cell size plays a more dominant role than wall thickness in influencing directional deformation, overall stiffness, and stress distribution within the sandwich construction. Through simultaneous multi-variable optimization, the study identifies an optimal configuration comprising a 12.412 mm cell size and a 0.13252 mm cell wall thickness, which yields the lowest deformation and stress values. The findings highlight the effectiveness of using multi-objective optimization for enhancing mechanical efficiency and provide a robust framework that can be extended to the design of other sandwich structures involving complex geometries and multiple interacting parameters.

References

1. Avilés, F., Ac México, And La Carlsson., Experimental studies of compression failure of sandwich specimens with face/core debond. Delamination Behaviour of Composites, 344-363 (2008).
2. Charkaoui, Assil, Noha M. Hassan, and Zied Bahroun. Enhancing mechanical properties of cellular core sandwich panels: a review of topological parameters and design improvements. Materials Research Express **10.10** (2023).
3. Rajkumar, S., et al. Evaluation of elastic constants of A3003 honeycomb core with varying hexagonal cell geometries through finite element approach. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science **228**,10 (2014).
4. Swaeh, Karema J., and Ahmad F. Hamzah. Numerical and Experimental Analysis for Flexure Behavior of Pyramidal Core Sandwich Composite. Annales de Chimie. Science des Materiaux. **Vol. 48.** No. 6. International Information and Engineering Technology Association (IIETA), 2024.
5. Zamani, Mohammad Hossein, Mohammad Heidari-Rarani, and Keivan Torabi. A novel graded auxetic honeycomb core model for sandwich structures with increasing natural frequencies. Journal of Sandwich Structures & Materials **24**,2 (2022).
6. Yang, Dongxia, Lihua Guo, and Changsheng Fan. Mechanical behavior of 3D-printed thickness gradient honeycomb structures. Materials **17**,12 (2024).
7. Gigi, Chinnu, and Dalmiya Rajan. A review on honeycomb sandwich structures and hybrid structures. Carbon **1000** (2022).
8. Li, Shiqiang, et al. Finite element analysis of sandwich panels with stepwise graded aluminum honeycomb cores under blast loading. Composites Part A: Applied Science and Manufacturing **80** (2016).
9. Rahman, Hammad, et al. Finite element analysis (FEA) of honeycomb sandwich panel for continuum properties evaluation and core height influence on the dynamic behavior. Advanced Materials Research **326** (2011).
10. Ma, Quanjin, et al. A review of the recent trends on core structures and impact response of sandwich panels. Journal of Composite Materials **55**.18 (2021).
11. de Oliveira, Lívia Ávila, et al. An investigation on the mechanical behaviour of sandwich composite structures with circular honeycomb bamboo core. Discover Mechanical Engineering **1**,1 (2022).
12. Kumar, Anil, Surjit Angra, and Arindam Kumar Chanda. Analysis of effect of variation of honeycomb core cell size and sandwich panel width on the stiffness of a sandwich structure. Research on Engineering Structures & Materials **8**,1 (2022).
13. Sun, Wei, et al. Study on Bearing Capacity of Honeycomb Sandwich Structure Embedded Parts. Journal of Composites Science **7**, 7 (2023).
14. Serjouei, A., et al. 4D printed shape memory sandwich structures: experimental analysis and numerical modeling. Smart Materials and Structures **31**, 5 (2022).
15. Huang, Yu-Hsi, and Chun-Yi Lin. "Measurement of orthotropic material constants and discussion on 3D printing parameters in additive manufacturing. Applied sciences **12**, 13 (2022).
16. Sivanraju, Rajkumar. Kumaravel R. Arul, Shetty P.K., Experimental Investigation of stiffness characteristics of tee joints of aluminium honeycomb core sandwich

panels with different edging configurations, International conference on applications and design in mechanical engineering Feb 2012.

17. Grebenişan, Gavril, and Nazzal Salem. The multi-objective genetic algorithm optimization, of a superplastic forming process, using ansys®. MATEC Web of Conferences. Vol. 126. EDP Sciences, 2017.
18. Gavade, N. K., et al. Design and Analysis of Corrugated Aluminium Sandwich Structures Using Ansys Workbench. International journal **3**, 6 (2018).
19. Aslantas, Kubilay, Ekrem Özkaya, and Waleed Ahmed. "ibration analysis of 3D printed PLA beam with honeycomb cell structure for renewable energy applications and sustainable solutions. Materials Research Proceedings 43 (2024).
20. Sun, Risi, Xuefeng Liu, and Ningbo He. Modal analysis of honeycomb panel satellite structure based on MSC Apex. Journal of Physics: Conference Series. Vol. 2762. No. 1. IOP Publishing (2024).
21. Marythraza, M., et al. Vibration analysis of honeycomb sandwich panel in spacecraft structure. International Journal of Mechanical and Production Engineering Research and Development **8**, 3 (2018).
22. Gupta, Krishanu, Prasun Chakraborti, and Chiranjit Bhowmik. Study of Modal Behaviour of Sandwich Structure with Various Core Materials-An Analytical Approach. Journal of Composite & Advanced Materials/Revue des Composites et des Matériaux Avancés **30**.1 (2020).
23. Safaei, Babak, Emmanuel Chukwueloka Onyibo, and Dogus Hurdoganoglu. Effect of static and harmonic loading on the honeycomb sandwich beam by using finite element method. Facta Universitatis, Series: Mechanical Engineering **20**, 2 (2022).