Analysis of Circular Plate Vibrations in a Structure Made of Sandwich Panel

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Abstract

Sandwich panels are essential elements in many structures like space vehicles, airplanes, cars, buildings, bridges, ships, and submarines. This research focuses on analyzing the vibrations of a circular sheet composed of a sandwich panel. The circular sheet in the sandwich panel enhances its impact resistance, providing a significant advantage. A circular sandwich panel with three free states, one supporting support, and two supporting supports was designed with ANSYS software for modeling purposes. Three free boundary conditions, one supported support, and two supported supports were utilized to conduct the analysis in this research. The results obtained for all three conditions were compared. An increase of the sandwich panel thickness core generally does not impact the frequencies of its vibration modes, and this influence diminishes as the number of supports increases. Increasing the thickness of the top layers has a more significant impact on raising the vibration modes frequency of the studied sandwich panel compared to increasing the core thickness. An increase of 4 mm in the tops' thickness raises the frequency of the 10th mode to over 700 Hz. Meanwhile, a 20 mm increase in the core's thickness elevates the frequency of the 10th vibration mode from around 500 Hz to below 600 Hz. If a sandwich panel is supported, increasing the thickness of the upper layer has little or no effect on the frequency of low vibration modes up to the fourth mode. However, starting from the fifth mode, it becomes evident that increasing the thickness directly affects the frequency of vibration modes.

Keywords- Sandwich panel, vibrations, circular sheet, Ansys.

I. INTRODUCTION

Sandwich panels are unusual because of their structure; the most notable of these traits is their high stiffness-to- strength and weight - to-weight ratios. Therefore, understanding sandwich panels' mechanical qualities seems crucial given their widespread and expanding application in today's world, which ranges from the military to architectural and construction applications. Sandwich panels are made up of two shells, a core, and adhesive to join the shell and core. Auspices, or materials with a negative Poisson's ratio, are among the materials that have been utilized as sandwich panel cores recently [1].

One kind of prefabricated building material that is frequently utilized in contemporary construction is sandwich panel .The structural resemblance of the sandwich panel to a sandwich is the reason behind its name. It is composed of two metal sheets separated by an insulating foam layer. Sandwich panels are prefabricated buildings that are assembled in a factory. Because of their light weight, they are readily transported and assembled on location, making them a great substitute for traditional building materials. As previously stated, sandwich panels They are made out of a light, insulated substance in the middle layer. Polystyrene, glass wool, stone wool, polyurethane, or XPS can all be used to create this layer. Two metal layers composed of aluminum, zinc, or aluminum sheet are positioned on either side of this insulating layer. Sandwich panels can be utilized for a structure's roof as well as its walls. These two kinds of sandwich panels differ from one another in terms of their physical characteristics as well as the cuts and procedures used on their metal sheets [2]. When a mechanical system oscillates in response to an initial input and is subsequently permitted to oscillate freely, as happens when a swing is pulled back and allowed to oscillate, this is known as free vibration. When a system oscillates due to an external variable force, like an earthquake or hurricane, it is referred to as forced vibration.

The 2019 study by Yelver et al. explores the vibration effects of a lighter honeycomb sandwich structure that meets the requirements of the utility vehicle industry [3]. In order to accomplish this, glass fibers and a polypropylene matrix are used to create cladding sheets. In this investigation, polypropylene honeycomb was employed.

A novel analytical modeling technique based on Hamilton's principle is presented in the 2019 work by Sun et al. to investigate the shock response of low-speed vibration in honeycomb sandwich metal sheets with panels [4]. Next, A modified Lagrangian model of this model is proposed by extending Hamilton's elastic body concept to elastic panels.

Post-impact vibration and compression (CAI) of glass fiber reinforced polymer (GFRP) skins and synthetic foam cores under low-velocity impacts are the subject of experimental and analytical studies discussed in the study by Wang et al. Starting in 2019 [5]. According to impact test results, GFRP panels with artificial foam had substantially less penetration depth than panels without any artificial foam. The purpose of Hu et al.'s 2020 project was to examine the efficacy of various foam-core sandwich architectures as well as the shock and vibration responses at low speeds [6].

The low-speed impact and vibration behavior of sandwich panels with Nomex honeycomb core and carbon fiber reinforced plastic (CFRP) composite panels was studied in Zhang et al. Proposed using experimental and numerical methods [7]. Two thicknesses of honeycomb core were used in the experiments, and the impact energy levels varied. The dynamic reaction was recorded, together with the contact force, energy absorption history, and contact duration. The 2020 Zhu et al. study's objective. Examining the cored foam sandwich panel's dynamic response with composite plates, paying particular attention to the penetration phases against impact and low-speed vibration [8]. To forecast contact force, energy absorption, impactor displacement, contact time, energy absorption, and failure modes, an analytical model based on energy is created. In energy absorption, structural components are examined in further detail. A reasonable agreement is obtained when predictions are compared with numerical and experimental outcomes. The current study offers an analytical approach for investigating the energy absorption and damage mechanisms of composite sandwich panels with a closed-cell foam core.

The depth and breadth of the core damage zone in four aluminum panels with scarcely noticeable impact and vibration damage were measured in a 2020 investigation by Wook et al. [9]. Using a pendulum mechanism, several core honeycomb configurations and parameters impacts were examined both numerically and empirically through the use of dynamic finite element simulation. Another option was a retired airplane panel that had been damaged in in-service collisions.

The low-speed effects of honeycomb sandwich panels with honeycomb cores of various shapes, including plate thickness, height, honeycomb cell wall, and cell size thickness. are examined in a 2021 study by Sun et al. using a combination of experimental and numerical methods [10]. The 2021 study by Zhou and Sun [11] experimental studies and focuses on analytical of the multi-layer foam core sandwich panels with vibration response and composite sheets' low-speed shock. An energy-based analytical model of a laminated sandwich panel was created to estimate contact forces, impactor displacement , and energy absorption taking into account reinforcement of the panel by the foam core. The experimental and numerical behavior of sandwich panels with an aluminum skin and a bamboo core under vibration is reported in a publication published in 2021 by Oliveira et al. [12].

The low-speed vibration behavior of composite sandwich panels with various auxic (negative Poisson's ratio) and non-auxic prismatic core structures is described in a study conducted in 2021 by Yusta et al. [13].

The low velocity impact depended on dynamic response of U-type corrugated sandwich panels was investigated in Cheng et al.'s 2022 investigation using a droplet apparatus with the impact velocity of ((4.43 m/s)); and the results were compared with predictions using finite elements [14]. Sun et al.'s 2022 study used both numerical and experimental methods to examine the impact damage of adhesive-coated aluminum sandwich panels [15]. According to finite element calculations and physical tests, the core damage depth can be linearly related to the indentation depth and depends on the height of the bonded joint. According to an article by Deng et al. The S-shaped ceramic core is manufactured using the hot pressing method, and then the S-shaped carbon fiber folded sandwich structure is constructed through coating. Published in 2022, studying the impact resistance of structures [16].

The goal of Wang et al.'s study from 2023 was to look into how foam sandwich panels responded dynamically to low-velocity penetration [17]. three-stage penetration model was established based on experimental data. Theoretically, based on the principle of energy conservation, minimum potential energy and cumulative damage theory, the time course of load and energy absorption, displacement and initial failure mode during sandwich panel penetration is predicted. Comparing the theoretical prediction results with the actual results, it was found that the predicted failure load and deformation were within 10% of the experimental data.

Li and Sun studied the low-speed impact response of diagonally reinforced square honeycomb core (BSHC) sandwich structures modeled on biopanels in their 2023 paper "Modeling Hexagonal Honeycomb Core (HHC) Sandwich Panels," which also Includes finite element numerical model: proposed for low-speed high-precision sandwich panel impact [18].

Jules et al.'s study [19]. Using the company's screens and two intermediate materials—recycled containers composed of high-density polyethylene and low-aluminum cellulose and polyethylene-aluminum—they created sandwich panels in 2023. Low density, which requires Tetra Pak containers to be recycled. A PAC core is not as stiff or flexible as a PAL core, according to tests. The tensile strength of sandwich panels made of PAC and PAL is equal. However, the PALS panel was less prone to crack and more flexible. The porcelain sheet's behavior is influenced by the identical bending behavior of both varieties of sandwich panels.

The study by Yang et al. Study of the bending behavior under vibration of sandwich elements made of alkali-resistant glass fabric concrete (ARG-TRC) with different fabric layers, interface shapes and core thicknesses from 2023 [20]. ARG-TRC sandwich panel manufacture is given a new go-ahead using this method. The load carrying vibration resistance and capacity of four-layer textile sandwich panels are higher than those of two layers.

The investigation in this paper has focused on the vibration analysis of sandwich panel circular sheets. The circular sheet on the sandwich panel is one of its benefits since it makes the panel more impact resistant. Sandwich panel samples were subjected to low speed impact using a drop weight device with three energies of 20, 45, and 55 joules and a hemispherical impactor with a diameter of 16 mm. sandwich panel with a circular sheet made of eight layers of PVC foam and Kevlar. Polyethylene glycol and nano silica are present in the circular sheet itself, with varying percentages of 0 and 25 of the latter substance. The maximum contact force rises as the nano percentage grows; at 25% nano, it is 1.6 times more than the maximum contact force without nano. Additionally, the structure's energy absorption improves by roughly 12% as a result of nano.

2. DISPLACEMENT THEORY

The two-dimensional sheet displacement components can be considered as follows:

$$u(x,y,t)=U(x,y)e^{j\omega t}$$
$$v(x,y,t)=V(x,y)e^{j\omega t} \tag{1}$$

The relationships, (j=√ (-1)); ω represents the natural frequency of in-plane vibrations (rad) and ; t represents time. By placing the relationships of the improved the components displacement of the sheet rectangular in the in-plane state in the ((X and Y)) directions in the above relations, the displacements of the sheet in the in-plane state can be rewritten as follows:

$$\begin{aligned} u(x,y,t)=\Bigg\{&\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}A_{mn}\cos\lambda_{am}x\cos\lambda_{bn}y \\ &+\xi_{1b}(y)\sum_{m=0}^{\infty}a_m\cos\lambda_{am}x+\xi_{2b}(y)\sum_{m=0}^{\infty}b_m\cos\lambda_{am}x \\ &+\xi_{1a}(x)\sum_{n=0}^{\infty}c_n\cos\lambda_{bn}y+\xi_{2a}(x)\sum_{n=0}^{\infty}d_n\cos\lambda_{bn}y\Bigg\}e^{j\omega t} \end{aligned} \tag{2}$$

$$\begin{aligned} v(x,y,t)=\Bigg\{&\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}B_{mn}\cos\lambda_{am}x\cos\lambda_{bn}y \\ &+\xi_{1b}(y)\sum_{m=0}^{\infty}e_m\cos\lambda_{am}x+\xi_{2b}(y)\sum_{m=0}^{\infty}f_m\cos\lambda_{am}x \\ &+\xi_{1a}(x)\sum_{n=0}^{\infty}g_n\cos\lambda_{bn}y+\xi_{2a}(x)\sum_{n=0}^{\infty}h_n\cos\lambda_{bn}y\Bigg\}e^{j\omega t} \end{aligned} \tag{3}$$

According to the assumptions of rectangular plate theory, the total potential energy ((VTotal)) and total kinetic energy ((TTotal)) of the considered plate in the plane free vibration state can now be introduced as follows:

$$V_{Total}=V_{p\_in}+V_{b\_in}$$
$$T_{Total}=T_{in} \tag{4}$$

In these relationships, (V_(p_in)) is the potential energy caused by the in-plane vibrations of the sheet and (V_(b_in)) is the energy strain caused by the deformation of the boundary springs on the edges of the sheet. Also, (T_in) is the kinetic energy caused by the in-plane vibrations of the sheet.

Considering that in this research, the in-plane vibrations of the isotropic sheet are considered, therefore, the energy potential of the sheet rectangular can be introduced as follows:

$$V_{p\_in}=\frac{G_k}{2}\int_0^a\int_0^b\left\{\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)^2-2(1-\mu)\frac{\partial u}{\partial x}\frac{\partial v}{\partial y}+\frac{1-\mu}{2}\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)^2\right\}dxdy \tag{5}$$

In this relationship, G_k=Eh/(1-μ^2) is the sheet's tensile strength. Also, the strain energy of the deformation of the boundary springs of the sheet can be introduced as follows:

ISSN: 2710-2165

$$V_{b\_in} = \frac{1}{2}\int_0^b \{ [k_{nx0}u^2 + k_{px0}v^2]|_{x=0} + [k_{nx1}u^2 + k_{px1}v^2]|_{x=a}\}dy$$
$$+\frac{1}{2}\int_0^a \{ [k_{ny0}u^2 + k_{py0}v^2]|_{y=0} + [k_{ny1}u^2 + k_{py1}v^2]|_{y=b}\}dx \quad (6)$$

In this case, for example, kpy1 and knx0 are the stiffnesses of the linear spring at the limit. A rectangular leaf spring is stiff at the edges at x=0 in the longitudinal force direction and at the edges at y=b in the shear force direction. The kinetic energy of the sheet vibrating in the plane can be introduced in the following ways.

$$T_{in} = \frac{1}{2}\int_0^a\int_0^b \rho h \left\{\left(\frac{\partial u}{\partial t}\right)^2 + \left(\frac{\partial v}{\partial t}\right)^2\right\} dxdy = \frac{1}{2}\rho h \omega^2 \int_0^a\int_0^b (u^2 + v^2)\, dxdu \quad (7)$$

In these relationships, ρ and ω, h, and μ are the density, natural frequency, sheet thickness, and Poisson's ratio, respectively.
The Lagrangian function L of the modeled rectangular sheet can be defined as follows:

$$\mathcal{L} = T_{Total} - V_{Total} \quad (8)$$

3. GEOMETRIC MODELING

Sandwich panel refers to walls or roofs that are made of light compounds and are limited to two layers of sheets on both sides, and there is an insulation layer in between. Figure 1 shows an example of a sandwich panelA circular sandwich panel in three different free states was built in Ansys Workbench software, with one supporting support and two supporting supports, as shown in Figure 2, for modeling purposes. The part has a diameter of 400 mm, a core thickness of 20 mm, and top thickness of 5 mm.

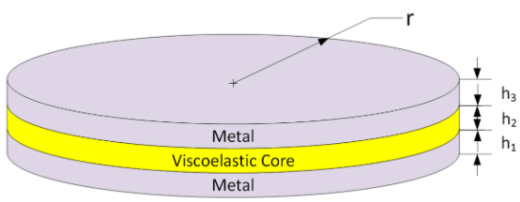


Figure 1. Geometry and layout of the circular sandwich plate[21]

Free A strong support Two supports

Figure 2. Geometry of the problem in different support conditions

4.1. PROPERTIES OF SANDWICH PANEL MATERIALS

Panel shells are made of aluminum alloy and its core is considered to be made of PVC foam, whose properties are presented in Table 1. A structure is usually subjected to dynamic loads during its working life. The sandwich panel supports the loads directly applied to them, but does not support the full load of the building. Inertia forces, moments of inertia and shear deformations in the middle core and the tops are considered. The load was used based on Brind's stress and moment of inertia, which was reduced to the thickness of the metal layer and several layers of a composite.

	PVC foam	Aluminum (Al2024-

Table 1. properties of sandwich panel ingredients [22]

		T3)
density (kg/m3)	60	2700
Modulus of elasticity (MPa)	70	72400
Rtio Poisson's	0.3	0.3

4.2. MESH CONVERGENCE

Figure 2 displays the visual representation of quadrilateral elements. Figure 3 displays the deformation computed for the primary vibration mode of the sandwich panel when it is not supported, using tetrahedral elements of various sizes. Figure 3 shows that the maximum deformation in the first mode of vibration of the sandwich panel decreases after fluctuating between dimensions of 15 and 10 mm for the four-sided parts. Once the elements' dimensions approach 8 mm, there are no further significant changes in the findings, indicating that the outcomes have converged. Hence, for further investigation, four-sided elements with diameters smaller than 8 mm are appropriate.

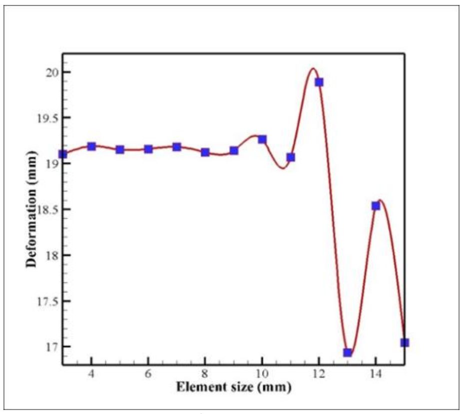


Figure 2. Appearance of tetrahedral elements

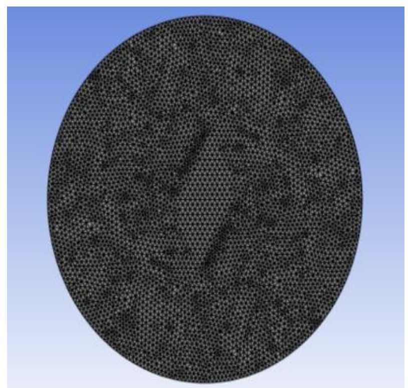
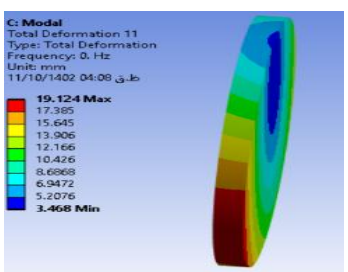


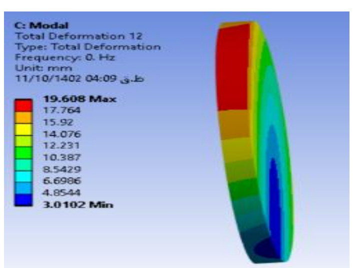
Figure 3. Changes in the shape of the panel in relation to the dimensions of the tetrahedral elements

5. Result

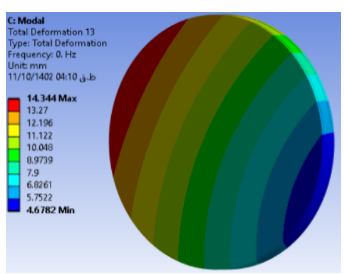
Figure 4 displays the displacement distribution contour of the first 8 vibration modes of the sandwich panel when the support is not taken into account



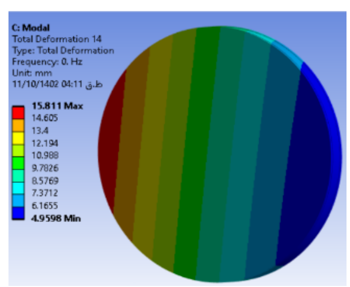
Mod1



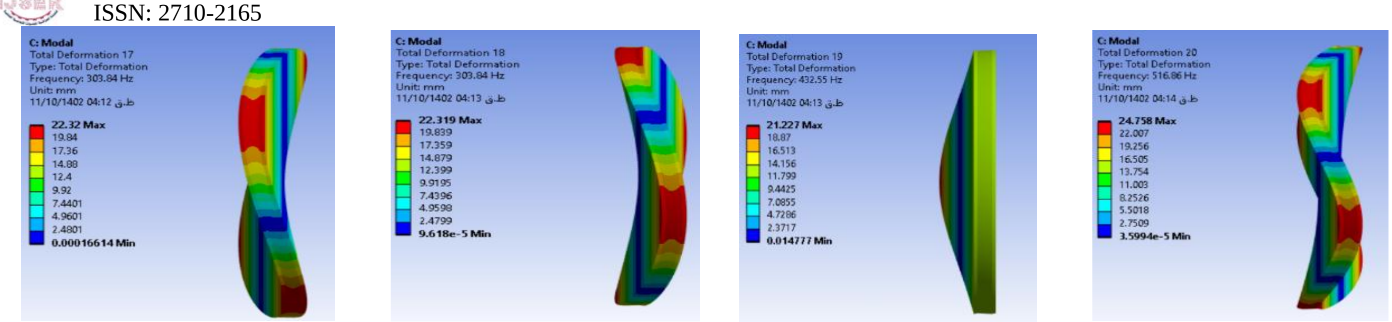
Mod2



Mod3



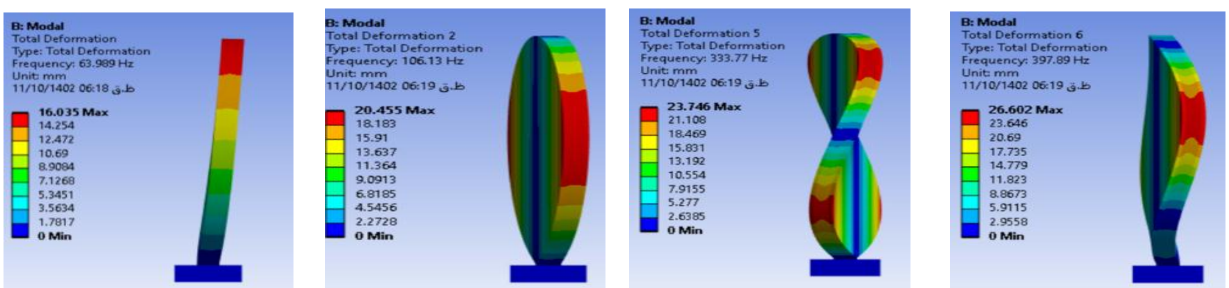
Mod4



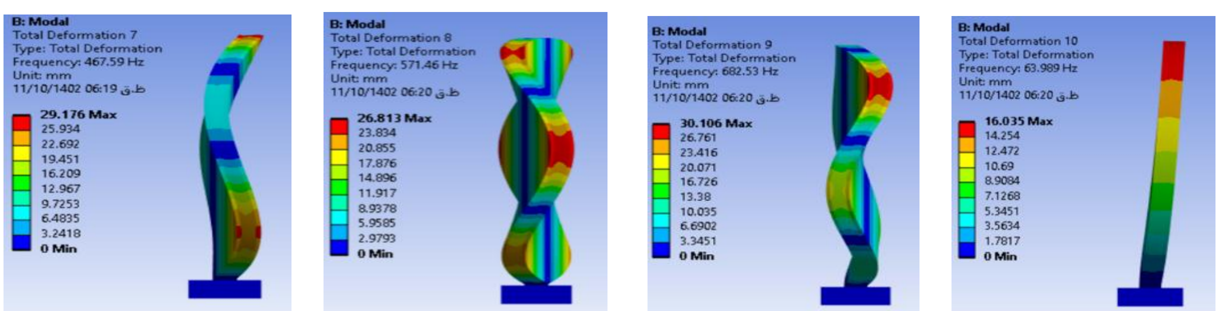
Mod5 Mod6 Mod7 Mod8

Figure 4. The first 8 free vibration modes of the sandwich panel

Figure 5 displays the displacement contours for the initial 8 vibration modes of the sandwich panel supported by clamps.



Mod1 Mod2 Mod3 Mod4



Mod5 Mod6 Mod7 Mod8

Figure 5. The first 8 modes of vibration of a sandwich panel with a girder support

Figure 6 displays the displacement contours for the initial 8 vibration modes of the sandwich panel supported by two clamped supports

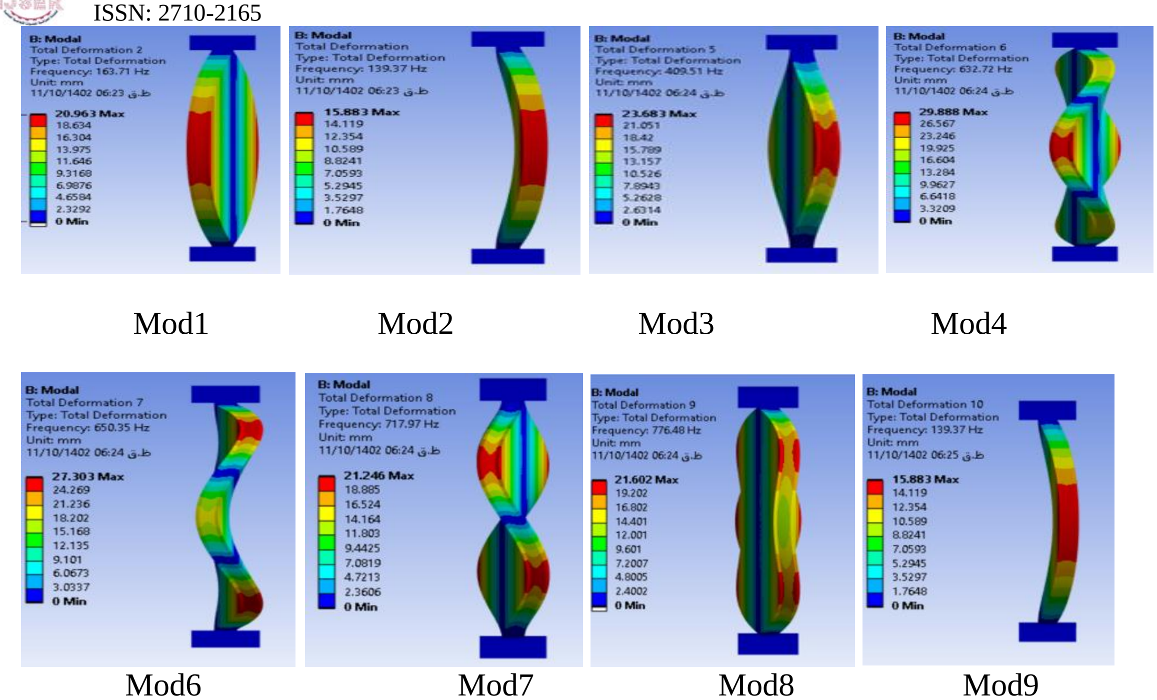


Figure 6. The first ten free vibration modes of the sandwich panel

The first and eighth vibration modes of the sandwich panel exhibit similarities, whereas the other modes show less resemblance. As the mode number increases, the number of waves generated in the sandwich panel also increases. Supports on both sides of the sandwich panel minimize displacement at their location.

5.1. The effect of core thickness on vibration modes

Figure 7 displays the progression of the first through tenth vibration modes. The figure illustrates that as the core thickness of the sandwich panel increases, the frequencies of vibration modes above 6 also rise. Vibration modes below this specific mode have shown minimal change and continue to be within the zero range. Vibration modes 7 and 8 exhibit minimal differences. The core thickness of the sandwich panel has a greater impact on the main frequencies as the number of modes grows, resulting in a noticeable increase in the spacing between the graphs.

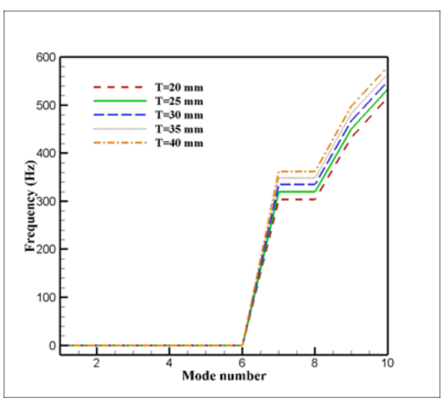


Figure 7. The effect of thickness core on the frequencies of vibration modes in the state without support

Figure 8 illustrates how altering the core thickness impacts the frequencies of vibration modes in the sandwich panel with a supporting support. The figure below indicates that increasing the thickness of the sandwich panel core when a support is stuck does not significantly impact the frequency rise of its vibration modes. The most significant effect is noticed in modes 5 to 8. During this time frame, the gap between the graphs widens.

The key observation in this image is the overall rise in frequency values across all vibration modes when compared to the vibration mode of the unsupported sandwich panel. In the initial modes, the frequency value ranges from approximately zero for the unsupported mode to around 100. It has achieved the status of becoming a support. In the 9th and 10th modes, the frequency range has increased from 500-600 to 700-800.

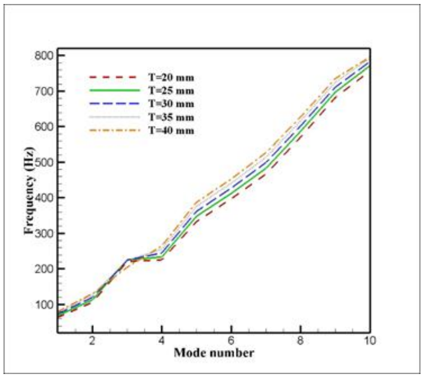


Figure 8. The effect of thickness core on the frequencies of vibration modes of a sandwich panel with a support

Figure 9 displays how differences in the core consistence impact the frequentness of the vibration modes of the sandwich panel supported by two supports. The figure shows that adding the core consistence of the sandwich panel has minimum impact on the frequentness associated with its vibration modes. As the core consistence increases, there are many variations in these frequentness.

The rise in the number of supports has led to an increase in all frequencies associated with various modes. The main frequencies have risen from below 100 Hz to a range of 100 to 200 Hz. The end modes varied from 700 to 800 Hz to 900 to 1000 Hz.

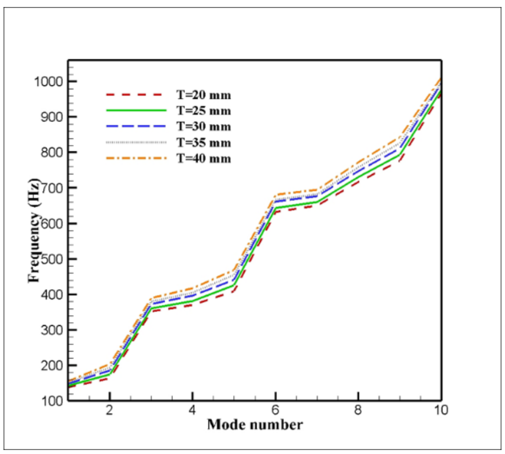


Figure 9. Effect of core thickness on vibration mode frequencies of sandwich panel with two supports

An increase in the thickness of the sandwich panel core generally does not impact the frequencies of its vibration modes. This influence diminishes as the number of supports increases

5.2. The effect of the thickness of the surfaces on the vibration modes

Figure 10 illustrates how the thickness of surfaces impacts the frequency of vibration modes in an unsupported state. Upon close examination of the figure and comparison with Figure 8-4, it is evident that increasing the thickness of the layers significantly impacts the frequency of vibration modes in the sandwich panel. Specifically, a 4 mm increase in layer thickness raises the frequency of the 10th mode to over 700 Hz. Conversely, a 20 mm increase in core thickness decreases the frequency of the 10th vibration mode from approximately 500 Hz to below 600 Hz. The varying slope of the graphs in this figure, in comparison to Figure 10, suggests that the increase in layer thickness in higher modes has a more significant impact on the frequency of that mode.

ISSN: 2710-2165

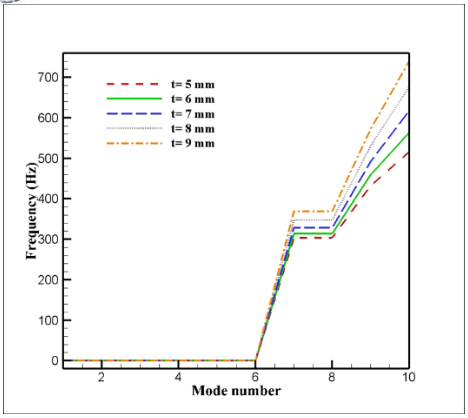


Figure 10. Effect of surface thickness on frequency of vibration modes in unsupported condition

Figure 11. Illustrates how the thickness of the layers impacts the frequencies of the vibration modes of the sandwich panel with a support. The figure shows that increasing the thickness of the sandwich panels has no impact on the frequency of low vibration modes up to the fourth mode, but becomes more noticeable from the fifth mode onwards. Increasing the thickness enhances the frequency of vibration modes. Comparing the figure with the diagrams in Figure 4-9 reveals that the increase in the top's thickness has a more significant impact on the frequency of vibration modes than the increase in the core's thickness. For instance, in the 10th mode, a 20 mm increase in core thickness results in a frequency change from 700 to 800 Hz, while a 4 mm increase in thickness raises the frequency from 700 to 800 Hz to over 1000 Hz.

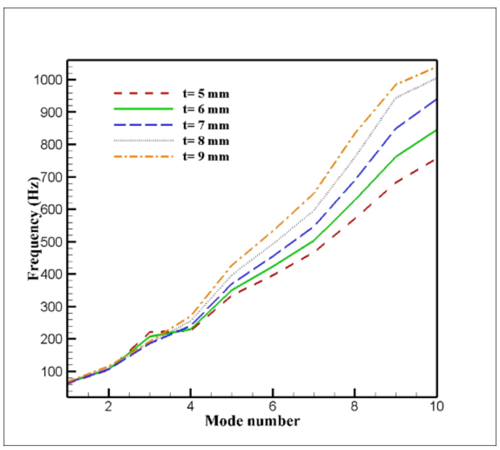


Figure 11. The influence of the thickness of the layers on the frequencies of the vibration modes of the sandwich panel with one support

Figure 12. shows the effect of the thickness of the layers on the frequencies of the vibration modes of the sandwich panel with two supports.

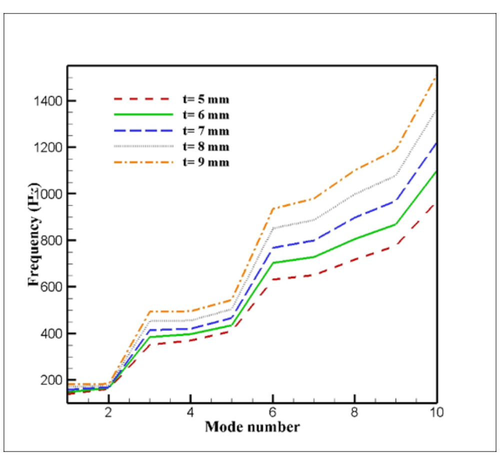


Figure 12 The effect of the thickness of the layers on the frequencies of the vibration modes of the sandwich panel with two supports

Increasing the thickness of the layers has a minimal impact on the frequency of the first and second vibration modes shown in the figure. However, as the mode number increases beyond 2, the effect of layer thickness on frequency becomes more pronounced. Increasing the thickness of the surfaces from 5 to 9 mm in the 10th vibration mode raises the frequency from 900 to 1000 Hz to around 1500 Hz.

6. Conclusion

The results from the vibration study of the circular sandwich sheet are presented in an organized manner in this section.

Increasing the thickness of the sandwich panel core results in higher frequencies for vibration modes above 6. Vibration modes lower than this specific mode have shown minimal change and continue to be in the zero range.

Increasing the number of modes amplifies the impact of the core thickness of the sandwich panel on the primary frequencies.

• Augmenting the core thickness of the sandwich panel when a support is stuck does not significantly impact the increase in its vibration modes frequency.

• Augmenting the thickness of the sandwich panel core minimally impacts the frequencies associated with its vibration modes, and as the core thickness increases, there is little alteration in these frequencies.

• Adding more supports raises the frequencies associated with various modes.

Increasing the thickness of the sandwich panel core generally does not impact the frequencies of its vibration modes. This impact diminishes as the number of supports increases.

Increasing the thickness of the top layers has a more significant impact on raising the frequency of vibration modes in the sandwich panel compared to increasing the thickness of the core.

Increasing the top thickness by 4 mm causes the frequency of the 10th mode to exceed 700 Hz. However, increasing the core thickness by 20 mm lowers the frequency of the 10th mode from about 500 Hz to around 600 Hz.

When a sandwich panel is supported, increasing the thickness of the top layer has no impact on the frequency of low vibration modes up to the fourth mode. However, starting with the fifth mode, the influence becomes more noticeable. Increasing the thickness directly correlates with an increase in the frequency of vibration modes.

When a sandwich panel is supported by two supports, increasing the thickness of the layers has a minimal impact on the frequency of the first and second vibration modes. However, as the mode number increases beyond 2, the effect of increasing the layer thickness becomes more noticeable

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