Optimization of free vibration for sandwich foam core

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Received: April 12, 2023. Revised: June 24, 2023. Accepted: September 23, 2023. Published: November 20, 2023.

Abstract - The structural dynamic features of a sandwich foam core structure with core and surface thicknesses are examined to increase the structure's resistance to vibration. The thickness of the core and surface of the sandwich foam core structure are defined as design variables in the optimization function of natural frequency parameters. The finite element analysis program FEA software was used for the analyses. The multi-objective optimization problem using RMS. The derived natural frequencies are compared with the outcomes of the experiments to validate the numerical model. The calculated natural frequencies are compared with the outcomes of the experiments to validate the numerical model. The structural optimization is then completed, using a sandwich foam core structure. The results show that the Aluminium Layer and foam core Thicknesses (m) are 0.0086 and 0,0357 m respectively

Keywords - vibration, foam, sandwich, natural frequency

I. INTRODUCTION

The demand for innovative materials is increasing as a consequence of the industry's current fast advancements. The research on sandwich composites is therefore quite focused. The components of a sandwich construction are a sandwich core, surface plates, and an adhesive thin film that keeps the plates and the core together (Fig. 1), [1]. Compared to monolithic composites and metals, the sandwich structure has characteristics such as decreased density, comparatively high strength, and hardness. In this context, the sandwich structure offers significant application potential in major industries such as the automobile, ship, and aerospace.

Fig. 1 Sandwich foam core

According to research, [2], a car's fuel usage is believed to be 60% reliant on the weight of the vehicle, and a 10% weight reduction in a vehicle results in a 5% fuel savings. Lightweight materials are therefore crucial for both economic and environmental reasons. Yet the materials' lighter weight results in more vibrations when used in a working environment. Excessive vibration can have a variety of detrimental impacts, including noise pollution, damage to the employed material, and adverse effects on human health. The introduction of vibration-damping core materials in sandwich constructions will offer a remedy because of this. In this regard, foam is an excellent candidate material. Materials with low thermal conductivity, good absorption, and a strong influence on sound and heat insulation are foam cores. In addition, it is less expensive and simpler to employ for creating sandwich structures than honeycomb core materials, [3], [4], [5]. This is a summary of a few studies that were done on this subject. Sandwich structures made with various configurations for clamped-free boundary conditions were explored for their natural frequencies and mode shapes by, [6]. Moreover, they looked at the way the thickness of the core material, the foil thickness, the cell diameter, the cell angle, and the bottom and upper face sheet thickness affected the vibration characteristics. After doing their research, it was shown that the initial natural frequency decreased as the cell width increased.
Moreover, the initial natural frequency was raised when the core height and foil thickness were increased. They concluded by stating that core height was the characteristic that had the most impact on the sandwich beam's natural frequency. Under various boundary conditions, [7], studied the mode forms of the sandwich structure and natural frequencies. The program MSC-PATRAN/NASTRAN was used to construct three

models: a 1D beam, a 2D shell, and a 3D solid. For various beams, they claimed that the results show an excellent agreement with an error of < 2% between the analytical and finite element models. The analytical solution for an ALCPVC (Aluminum - Chlorinated Poly Vinyl Chloride) sandwich beam attained the goal of the natural frequencies by 27% for the first mode and increased with the number of modes until it reached 40% for the fourth mode. For the free vibration research of isotropic, orthotropic, and layered anisotropic sandwich laminates and composites, [8], demonstrated isoparametric finite element formulation based on a shear deformable model of higher-order theory using a higher-order facet shell component.

A method for predicting eigen frequencies and modes of vibration for sandwich plates that are rectangular and orthotropic was developed by, [9]. Using the Rayleigh-Ritz approach and assuming frequency-dependent material characteristics, they identified the eigenfrequencies. They looked at findings that were expected and guessed. The effects of face sheet and core thickness, as well as delamination, on damping, were examined by, [10]. The results of estimations on honeycomb-foam sandwich beams with various configurations and thicknesses were compared with theoretical predictions. The author in, [11], wanted to study how honeycomb panels vibrate. For the test, they used FEA software. The introduction of the 3-D model was made to support the continuum model, which is frequently employed while analyzing a honeycomb panel's vibrational properties, [12], [13], [14]. Al and foam were chosen as the surface and core materials in this investigation, respectively, [15], [16], [17].

This study aims to determine the optimum value of the thickness of the foam core material and the Al surface material to affect free vibration frequency. Before that, the finite element method should be validated with experiment results.

II. MATERIAL AND METHOD

A. Finite Element model

With the assistance of the FEA software package program [18]. [19], three different types of sandwich foam structures (SF) depicted in Table I were modeled and put through a free vibration analysis. 3 Aluminum layers compensate for the sandwich structures' surfaces (SF1, SF2, and SF3), while foam consists of the sandwich structures' cores. SF1 form consists of two layers of aluminum (6 mm thick) on the surface, a foam core (35 mm thick), and two layers of adhesive (0.25 mm thick) binding the aluminum layers and core together. Total thickness for SS1 is (6x2)+35+(2x0.25)=22.5 mm. By employing SF1 and SF2, while maintaining a constant core thickness, it is hoped to evaluate the impact of surface layer thickness on natural frequency. Even though SF2 and SF3 have the same surface but different core thicknesses, the impact of core thickness on natural frequency was examined using the two systems.

Table I. Sandwich foam layer thicknesses

Sandwich foam (SF) Structures	**Aluminium Layer Thicknesses (mm)**	**Foam Core Thicknesses (mm)**	**Adhesive Thicknesses (mm)**
SF1	6	35	0.5
SF2	8	35	0.5
SF3	8	40	0.5

The beam was modeled with dimensions of 400 mm in length, 47.5 mm in depth, and various layer thicknesses as indicated in Fig. 2. Density, young module, and Poisson ratio were the characteristics of the material employed in the free vibration analysis. Table II lists the mechanical characteristics of Al, foam, and adhesive materials.

Table II. Materials made of foam and aluminum have mechanical characteristics.

	Aluminium	Al Foam	Adhesive
Density (kg/m^3)	2710	200	2500
Young Modulus (GPa)	70	0.23	4.39
Poisson Ratio	0.33	0.33	0.34

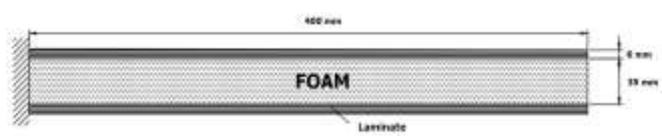


Fig. 2 Cantilever sandwich beam

Cantilever modeling was used for the sandwich beam's left end. The structure is formed by five layers in total, including 1 core, 2 surface layers, 2 adhesive layers, and 35000 individual parts. The Al layer had the highest mesh application, whereas the core layer had the lowest mesh application. Eight-noded brick elements were used to simulate sandwich structures. A layer of adhesive was used to connect the layers. FEA software is used to simulate the single-core composite sandwich beam. The eight-noded structural shell 281, which is best suited for modeling thick composite structures, was used to model the sandwich beam. It has six degrees of freedom at each node. FEA software's section-layup features were used to implement the layup. The numerical model of a sandwich beam with several cores and laminated composite face sheets is demonstrated in Fig. 3.

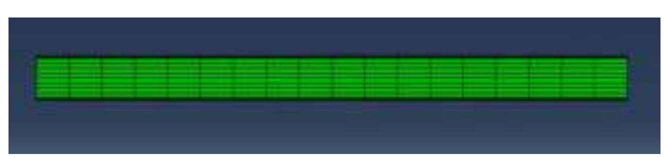


Fig. 3 Model of finite element

B. Optimization method

The challenge of structural optimization can be reduced to a search for a set of design variables inside the design domain that optimize the structural stiffness. The goal of structural optimization for sandwich foam structures is to increase the structural stiffness of each sandwich foam core structure cell under a given mass, which means that the maximum natural frequency involves several orders of mode. The design factors for the geometry parameters are established, and the maximizing of natural frequencies is used to optimize the structure.

Find,

$$X = (x_1, x_2, \ldots, x_i)^N, (i = 1,2, \ldots, N)$$

$$Max\ R_f(x) = \sum_{i=1}^{N} W_i \frac{f_i^*(x)}{f_i^0(x)},$$

St.

$$h_p(x_i) \le 0, \sum_{i=1}^{N} W_i = 1, x_i^l \le x_i \le x_i^u, (i = 1,2, \ldots., N)$$

where $X = (x_1, x_2, \ldots, x_i)$ are design variables for n dimensions, like the thickness of the core of a node; $R_f(x)$ is the natural frequency normalization value; $h_p(x_i)$ is a constraint condition, such as the mass of a cell structure; and x_i^l and x_i^u are lower and upper bounds for design variables, respectively.

C. Response surface methodology and experiment design

In this study, to search for the globally optimum, response surface method (RSM) is proposed. The response surface method can construct polynomial approximations of functional relationships between design variables and performances, it is a statistical approach based on the experimental design. With the experimental design, the expressed relations between the design variables and objective function will be deduced. By using the results of a numerical experiment in the points of orthogonal experimental design, the response surface method is computationally much less expensive than a solution using the original method.

D. The technique of experimental design

Experimental design is the process of choosing a small number of sample points in the design space that, to the maximum extent possible, reflect the properties of the design space. It will directly impact the accuracy of the approximate model, making the experimental design of the selection method especially crucial. The experimental design is to build essential to the approximate model of the process aspect of the design of sample points selected is appropriate to build plays an important role in the subsequent response surface approximation model. The best sample points are chosen using the uniform Latin square approach.

By considering it as an input-output model, the natural frequency optimization problem may be represented as a response surface. These variables are converted into coded variables in the RSM that have the same standard deviation, zero mean, and no dimensions. In this study, the sampling points are distributed as equally as feasible over the design space using a Latin square experimental design and an optimization method. Fig. 4 shows the uniform Latin square approach used to create the two-factor, rational experimental samples. There are 11 points sampled across the spatial configuration.

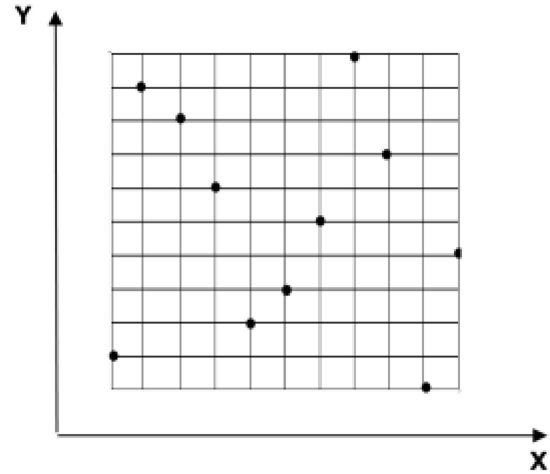


Fig. 4 Uniform Latin square method

III. RESULTS AND DİSCUSSİONS

A. Validation

The single-core sandwich beams were also subjected to experimental free vibration analysis under the clamped free end conditions. Fig. 5 displays a picture of the experimental setup and single-core sandwich beam. The 300 mm (length) x 50 mm (width) homogeneous dimensions of the single-core sandwich beams were maintained, and the single-core sandwich beam was stimulated using the roving hammer technique. To measure the reaction signals, the accelerometer was positioned over the beam. The response signals are transformed into digital form using the data collection system so that they may be analyzed using the fast Fourier transform (FFT) technique included in *Vibert expert II* and OMNITREN software Subsequently, the frequency response function peaks are graphed and analyzed using OMNITREN software to determine the natural frequencies (Hz) of the single core sandwich beam. Using the matching mode morphologies of the single-core sandwich beam, the first three natural frequencies (Hz) were determined. All experimental findings are compared with the finite element method.

The comparisons demonstrate an excellent correlation, as shown in Table III. The table shows that there is significant agreement between the comparisons. therefore it indicates that the numerical model is accurate (2.51%)

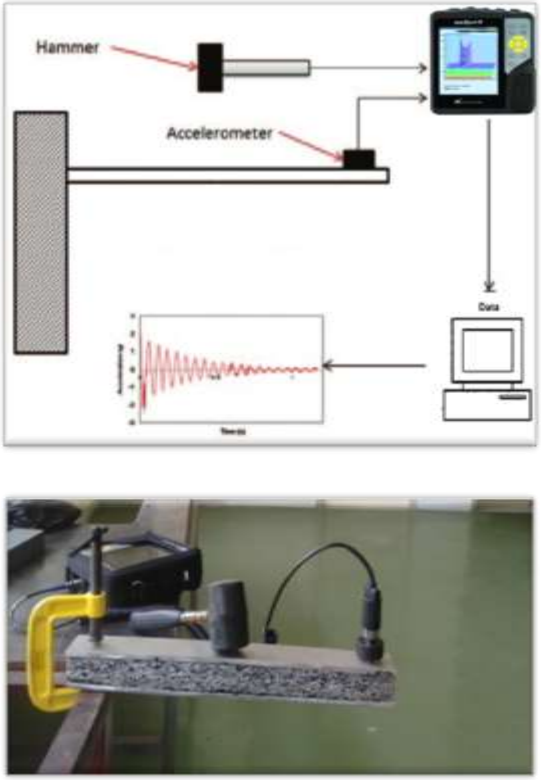


Fig. 5 Experimental setup for free vibration measurement

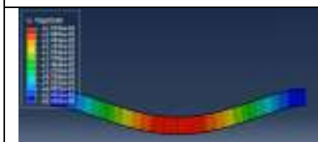
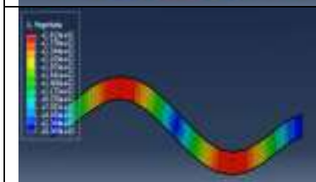
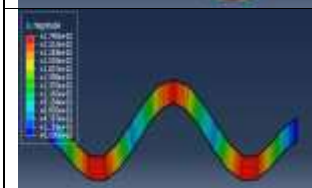
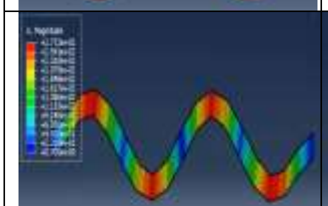
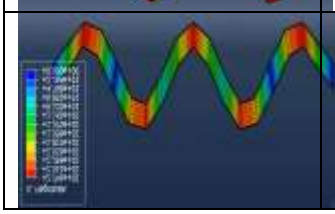
Table III. Differences between simulation and experiment results

Mode	Simulation	Experiment	%Differences
1	467.86	463.51	2.51
2	896.12	881.89	0.39
3	981.54	981.54	1.34
4	1287.72	1285.19	1.88
5	1468.95	1467.02	2.34

B. *Finite element analysis*

In the case of free vibration in engineering projects, the design needs to understand the mode shapes and vibration frequency values. Table III provides the frequencies following the first five modes. Table IV contains the numbers for the first eight modes for SF1, SF2, and SF3. Illustration of a sandwich beam, Fig. 6. The following is the impact of different foam and aluminum layer thicknesses on free vibration: Although the frequency generally decreases as the Al layer's thickness increases, this is not a particularly noticeable decrease—in fact, it may even increase in some modes. Thus it would be more appropriate to look at each mode independently. The frequency of the sandwich construction has significantly increased due to the rise in core thickness. This was explained by the fact that the thickness growth is significant. It should not be ignored that modes 3 and 5 are in direct opposition to this general situation. When the modes for the three sandwich constructions are compared, mode 1 has the lowest frequency value for all three, while mode 6 has the highest. Also, changing between the modes is preferable since a frequency magnitude cannot be ordered between SF1, SF2, and SF3.

Table IV. Natural frequencies of the sandwich foam

	MODE	SF1	SF2	SF3
	1	467.86	471.62	472.86
	2	896.12	916.77	923.01
	3	981.54	1009.62	1012.71
	4	1287.72	1293.94	1315.72
	5	1468.95	1468.95	1487.13

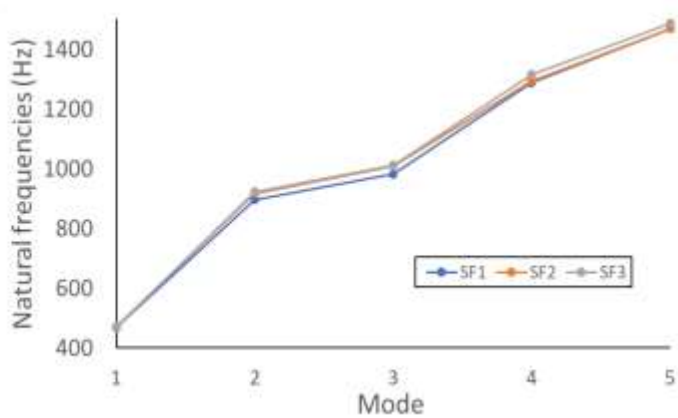


Fig. 6 Frequencies of sandwich foam core

The following outcomes were obtained when the modes were looked at independently, as shown in Fig. 6. Compared to SF1 and SF2, the frequency of SF3 in mode 1 increased. With the SF1, SF2, and SS3 at mode 2, a predictable decline was seen. For SF1, SF2, and SF3, there was barely any frequency variation in mode 3. The difference between SF1 and SF2 was quite small when mode 4 was investigated, however in SF3, this value has significantly grown. SF1, SF2, and SF3 behaved similarly in mode 4. The frequency values of the sandwich structures in mode 5 have decreased to an insignificant level equal to that of mode 3. It is believed that the quantity of this adjustment will only slightly alter. The fact that the mode shapes are torsional and lateral bending is assumed to be the cause of the accuracy's small magnitude.

C. Structural optimization

The core and surface thicknesses are both defined as design variables in the structural optimization function, and they are all discrete variables. The first five orders are employed for computation in structural optimization, where the objective function is comprised of natural frequencies. The fundamental frequency's weight coefficient value is the biggest, whilst those of the subsequent orders are getting smaller since the first-order frequency most closely approximates the intrinsic properties of the structure. They are chosen 0.2 and 0.1 for modes 1 – 2 and 3 – 5 respectively, [4], [5]. Also, the value of the weighting coefficient is presented in Table V.

Table V. Values of the weighSting coefficient.

Mode order	1	2	3	4	5
weighting coefficient	0.2	0.2	0.1	0.1	0.1

The structural optimization of a sandwich foam core structure using a natural frequency parameter is performed using the response surfaces approach. The optimized sandwich foam core structure is found to have a mass of 0.00276 kg and the natural frequencies of its various orders are determined. In Table VI, it is contrasted between the 1-5 orders of the structure's natural frequency. The natural frequency of the sandwich foam core structure has grown by 12.07%, as shown in Table VI, while the total mass of the structure has decreased by 0.4%. These natural frequency characteristics of the sandwich foam core structure have been considerably improved by structural optimization. The substantial improvement in the structure's performance demonstrates the high efficacy and successful optimization of the proposed approach.

Title VI. Optimum Result for structure

Design variables	Initial thickness	Optimum thickness
Aluminum Layer Thicknesses (m)	0.008	0.0086
Foam Core Thicknesses (m)	0.035	0.0357
Total mass (kg)	0.00754	0.00753

IV. CONCLUSION

The finite element approach was used in this work to examine the impact of the core and surface layer thicknesses of sandwich constructions made of foam core and Al surfaces. As a consequence of employing finite element software, the following findings were obtained. The findings of the sandwich foam structure's free vibration study indicated that decreasing the Al layer's thickness contributed to a slight decrease in natural frequency. The natural frequency of the sandwich foam structures as well as the affected type of same mode shape have significantly increased as a result of the core's thickness being increased. The maximum and minimum frequency values of the structure are 1487.13 Hertz for SF3 (mode 5) and 467.86 Hertz for SF1 (mode 1).

The structural optimization equation is created and the structural optimization is completed by determining the natural frequency parameters. The findings demonstrate that by properly optimizing the sandwich foam design parameters, the optimum value is reached for the aluminum layer and core layer at 0.0086 m and 0.0357 m respectively.

References

[1] Burlayenko, V. N. and Sadowski, T. “Influence Of Skin/Core Debonding On Free Vibration Behavior Of Foam And Honeycomb Cored Sandwich Plates” Internatıonal Journal Of Non-Lınear Mechanıcs 45 (10): 959–968, (2010).

[2] Goh, C. S., Gupta, M. J., Wei, L. and Lee, C. “Characterization Of High Performance Mg/MgO Nanocomposites.” Journal of Composite Materials 41(19): 2325–2335,(2007).

[3] Petrone, G., Alessandro, V. D., Franco, F. Mace, B. and De Rosa, S. “Modal Characterisation Of Recyclable Foam Sandwich Panels.” Composite Structures 113(1): 362–368, (2014).

[4] Apalak, Z. G., Ekici, R., Yildirim, M., Apalak, M. K. “Free Vibration Analysis Of An Adhesively Bonded Functionally Graded Double Containment Cantilever Joint.” Journal of Adhesion Science and Technology 28(12): 1117–1139, (2014).

[5] Chen, J. E., Zhang, W., Sun, M., Yao, M. H., Liu, J. “Free Vibration Analysis Of Composite Sandwich Plates With Different Truss Cores.” Mechanics of Advanced Materials and Structures, 24(1): 1–13, (2017).

[6] Sakar, G., and Bolat, C. “The Free Vibration Analysis of Honeycomb Sandwich Beam Using 3D and Continuum Model” International Journal of Mechanical and Mechatronics Engineering 9 (6): 1077-1081, (2015).

[7] Lashin, M. M. A, and Nady, A. O. E. “The Free Vibration Analysis of Sandwich Beam Stracture Using Finite Element Approach” Journal of Mechanical and Civil Engineering 12 (1): 34-42, (2015).

[8] Khare, R. K., Kant, T., and Garg, A. A. “Free Vibration of Composite and Sandwich Laminates With a Higher-Order Facet Shell Element.” Composite Structures 65: 405–418, (2004).

[9] Nilsson, E., and Nilsson, A. C. “Prediction and Measurement of Some Dynamic Properties of Sandwich Structures with Honeycomb and Foam Cores.” Journal of Sound and Vibration, 251: 409- 430, (2002).

[10] Li, Z., and Crocker, M. J. “Effects of Thickness and Delamination on the Damping in Honeycomb–Foam Sandwich Beams.” Journal of Sound and Vibration 294: 473-485, (2006).

[11] Lai, L. "Study of Free Vibration of Aluminum Honeycomb Panels." MSc. Thesis, Toronto University, (2002).

[12] Nipun, G. and Mallika, A. "Free Vibration Analysis Of Aluminium Sandwich Panels Using Fem." ELK Asia Pacific Journals Special Issue ISBN: 978-81- 930411-5-4, (2016).

[13] Kumar, A. "Free Vibration Analysis Of Sandwich Panel" MSc. Thesis, National Institute of Technology Rourkela (2007).

[14] Şen, M., Hüseyinoğlu, M. "Investigation of the Effects of Polyurethane Foam Reinforcement Thickness on Modal Properties of Sandwich Beams." MSU Journal of Science. 6, 1, 511-517, (2018).

[15] Ertan K, Recep E. "Free Vibration Analysis of Foam-Core Sandwich Structures" Journal of Polytechnic, 24 (1): 69-74 (2021).

[16] Hussam R, Muhannad W, Emad K. "Free Vibration Analysis of Sandwich Plate-Reinforced Foam Core Adopting Micro Aluminum Powder" Physics And Chemistry Of Solid State V.23, No.4 (2022)

[17] Arunkumar, Pitchaimani and Gangadharan. "Bending and free vibration analysis of foam-filled truss core sandwich panel" Journal of Sandwich Structures and Materials (2016).

[18] Djamaluddin F, Mat F. "Optimization and crush characteristic of foam-filled fender subjected to transverse loads" Ocean Engineering (2021), Vol.242, 15 December 2021, 110085, https://doi.org/10.1016/j.oceaneng.2021.110085.

[19] Djamaluddin F. "Review : deformation and optimisation crashworthiness method for foam filled structures" Latin American Journal of Solids and Structures, vol.16(7), (2019), https://doi.org/10.1590/1679-78255702.

Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Fauzan Djamaluddin carried out the simulation and the optimization.

Sources of funding for research presented in a scientific article or scientific article itself

No funding was received for conducting this study.

Conflicts of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.