SAKARYA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ DERGİSİ

Sakarya University Journal of Science
SAUJS

e-ISSN 2147-835X Period Bimonthly Founded 1997 Publisher Sakarya University
http://www.saujs.sakarya.edu.tr/

Title: An Investigation of the Effect of Asymmetry on the Free Vibration Behavior of Sandwich Structure

Authors: Ufuk DEMİRCİOĞLU, Ali Suat YILDIZ, Mutlu Tarık ÇAKIR

Recieved: 2021-06-21 00:00:00

Accepted: 2021-12-17 00:00:00

Article Type: Research Article

Volume: 26
Issue: 1
Month: February
Year: 2022
Pages: 54-61

How to cite
Ufuk DEMİRCİOĞLU, Ali Suat YILDIZ, Mutlu Tarık ÇAKIR; (2022), An Investigation of the Effect of Asymmetry on the Free Vibration Behavior of Sandwich Structure. Sakarya University Journal of Science, 26(1), 54-61, DOI: 10.16984/saufenbilder.955314
Access link
http://www.saujs.sakarya.edu.tr/tr/pub/issue/67934/955314

Sakarya University Journal of Science 26(1), 54-61, 2022

An Investigation of the Effect of Asymmetry on the Free Vibration Behavior of Sandwich Structure

Ufuk DEMİRCİOĞLU*[1], Ali Suat YILDIZ[1], Mutlu Tarık ÇAKIR[1]

Abstract

This study presents a free vibration analysis of asymmetric sandwich structures comparatively. Sandwich structures were manufactured by the hand-layup vacuum bagging method. Symmetric and asymmetric sandwich structures were analyzed experimentally to evaluate the effect of asymmetry on the free vibration characteristic of sandwich structures. Free vibration analysis was performed by using VIBXPERT II under clamped-free boundary conditions. The frequency response function (FRF) is obtained from the modal test. Modal parameters of sandwich structures were obtained from analysis by curve fitting to FRF using Matlab. The effects of asymmetry on the natural frequency of the sandwich structures are investigated and results are comparatively presented. The finite element method (FEM) was also implemented by using COMSOL Multiphysics® for verifying the selected system parameters and analyzing the experimental results. By the experimental study the accuracy of the model being having proven, it also has potential for the investigations of vibration behavior of the various applications including asymmetric sandwich structures.

Keywords: Sandwich structure, asymmetric sandwich structure, free vibration analysis, modal analysis

1. INTRODUCTION

Sandwich structures have been used in a variety of applications from sports equipment to sport car components so far. Due to the properties they possess, their usage and application area is increasing day by day especially, in the aviation, marine and, defense industry. Conventional materials are being replaced with sandwich structures in applications where a high strength to weight ratio is desired. Sandwich structure is a sub-group of composite materials consisting of a thick core material on which single or two thin face sheets materials are based. In this configuration, core material increases the stiffness of sandwich structures and face sheet materials carry tensile and compressive loads. As a result of this configuration, sandwich structures have better properties than their monolithic components. Some advantages of sandwich structures are resistant to heat and acoustic, resistance to impact loading, excellent fatigue life, resistance to corrosion and moisture, invisibility to radar waves, and better

* Corresponding author: udemircioglu@sivas.edu.tr
[1] Sivas University of Science and Technology, Faculty of Engineering and Natural Sciences, Mechanical Engineering Department
E-mail: suat@sivas.edu.tr, tcakir@sivas.edu.tr
ORCID: https://orcid.org/0000-0002-9707-8271, https://orcid.org/0000-0001-6914-5222, https://orcid.org/0000-0002-0107-594X

aerodynamic surfaces. These benefits can be further improved by using the advantages of having a variety of constituent materials. By combining the best properties of constituent materials, desired physical and mechanical properties can be obtained in a sandwich structure.

Despite fact that sandwich structures possess many advantages over conventional materials, these materials have also some drawbacks. For example, sandwich structures are not used as fabricated. Since other components like cables may have to go through them, as a result, different shaped cutouts are opened. Therefore, cutouts are inevitable, and the presents of cutouts significantly affect the dynamic behavior of the sandwich structure. Because of tool structure interactions, delamination occurs around the cutouts. Also, due to service conditions and production error, delamination may occur at a different location and in a different size. Furthermore, some components have curved shapes like leading edges of the wing consequently, there is a need for fabrication with curvatures. These aforementioned problems cause the reduction in stiffness and subsequently reduce the natural frequencies of the sandwich structures. However, the effect of these features on the vibration behavior of sandwich structures is still actively studied in theoretical and practical aspects.

Many researchers have studied the free vibration of the curved sandwich structure. A.V. Singh studied the free vibration of a curved sandwich structure by using the Rayleigh-Ritz method [1]. W. Wang and R.A. Shenoi investigated the free vibration of the initially stressed curved sandwich structure theoretically [2]. K.M. Ahmed studied the free vibration of curved sandwich beams by using the finite element method [3]. T. Sakiyama investigated the free vibration of sandwich structure with the elastic and viscoelastic core by applying the Greens function [4]. They reported the effect of curvature on the vibration behavior of sandwich structures.

The effects of the cutout on the vibration behavior of sandwich structures have been studied by several researchers extensively. N. Mishra et al. investigated the effect of the rectangular central cutout on the vibration behavior of sandwich structure by using the finite element method [5]. H. K. Bhardwaj investigated the influence of triangular cutout on the free vibration behavior of laminated composite plates by using ANSYS APDL code [6]. S. Ramakrishna et al. investigated the vibration of laminated composite with circular cutout at the center utilizing the finite element method [7]. S. Chikkol Venkateshappa et al. investigated the free vibration behavior of composite plates with different shaped cutouts by experiment and finite element method [8]. H. K. Bhardwaj et al. investigated the effects of skew cutouts on the vibration of a laminated composite plate by using the finite element method [9]. S. Mondal et al. investigated the influence of cutouts at a different position on the dynamic characteristic of sandwich composite plate experimentally and numerically [10]. J. Vimal et al. studied the effect of a circular hole on the vibration behavior of functionally graded composite plate by using the finite element method utilizing ANSYS [11]. J. Vimal et al. studied the free vibration of sandwich structure with different cutouts by using the finite element method [12]. They presented the influence of cutouts on the vibration behavior of composite plates.

T. Tuswan et al. investigated the influence of debonding on sandwich structure's vibration responses of the damaged stern ramp of the ferry by using the finite element method [13]. V. N. Burlayenko and T. Sadowski studied the effect of delamination at skin/core of sandwich structure on the dynamic characteristic of a sandwich structure by finite element method using ABAQUS software [14]. H. Y. Kim and W. Hwang investigated the effect of delamination on natural frequencies of honeycomb sandwich structures experimentally [15]. H. Schwarts-Givli et al. studied the influence of delamination on the free vibration behavior of sandwich beam numerically [16]. B. Saraswathy et al. investigated the effects of multiple-debond with various debond lengths on the dynamic behavior honeycomb sandwich structure using the split beam theory and fast Fourier transform [17]. V. N. Burlayenko and T. Sadowski investigated the dynamic behavior of sandwich structure having debond of different size and location by finite element method using ABAQUS software [18]. I. Jayatilake et al. investigated the influence of single-multiple debond at core/skin interface on free vibration behavior sandwich panel by using finite element method [19]. They presented the influence of delamination on the vibration behavior of composite plates.

New needs give rise to the development of new technology and demands of new materials. Asymmetric sandwich structure is one of them that came after a need which is called stealth technology [20]. Stealth is a technique that makes objects nearly invisible to radar or other detection systems. Asymmetric means that face sheet materials (FSM) are different as shown in figure 1. As a result, the configuration of asymmetry enables the sandwich structure to be utilized in stealth applications [21, 22]. Since stealth technology is mostly used in aviation in the defense industry where dynamic loadings are severe it is vitally important to characterize the dynamic behavior of an asymmetric sandwich structure. However, there is less study about the free vibration analysis of asymmetric sandwich structures in the literature. Therefore, the objective of this study is to investigate the significant influence of asymmetry on the free vibration characteristic of sandwich structure experimentally.

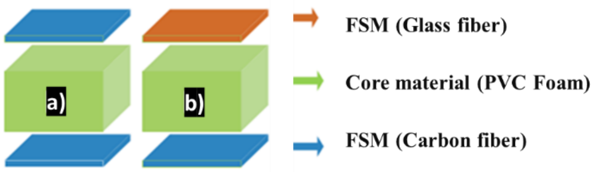

Figure 1 Configuration of sandwich structure a) Symmetric sandwich structure b) Asymmetric sandwich structure.

2. MATERIALS and METHODS

This study consists of fabrication and free vibration analysis of sandwich structures which is followed by experimental modal analysis and determining the influence of asymmetry on the free vibration behavior of a sandwich structure. The sandwich structures that were fabricated in this study consist of 2x2 twill weave carbon fiber, 2x2 twill weave glass fiber fabrics, closed-cell rigid polyvinyl chloride (PCV) foam core, epoxy resin, and its hardener which were obtained from the market (Dost Kimya Inc.) were used. The properties of materials used in this study are given in Table 1. The sandwich structures were fabricated with the hand lay-up vacuum bagging method as shown in Figure 2. The matrix material was prepared considering the total weight of fabrics and foam core materials. And the weight ratio of the epoxy resin to its hardener was set to 100:40. The thickness of fabrics and foam is 0.26 mm and 10 mm respectively. The length and width of sandwich structures are 500 mm and 100 mm, respectively. As shown in Table 2 three different sandwich structures were prepared. Responses of sandwich structures were measured by using an impact hammer and accelerometer as shown in Figure 3. An accelerometer 3055D2 by Dytran (sensitivity 100 mV/g on the range 50 g) and dynapulse impact hammer were used in this study. The roving accelerometer procedure was selected for obtaining the FRF measurements. In this technique, the sandwich structure is divided into 40 nodes as shown in Figure 3. The external force was applied by the impact hammer at “Location 1” for each time while the measurements were taken from the rest of the location by VIBXPERT II. All signals were processed at 0.5 Hz resolution by using rectangular windowing at the frequency range of 0-700 Hz.

Table 1
Properties of all materials used in the study.

Property	Carbon Fiber Epoxy	Glass Fiber Epoxy	PVC Foam
Density (Kg/m^3)	1440	2000	60
Young’s Modulus E_x (Pa)	59.65x10^9	2x10^{10}	7 x10^7
Young’s Modulus E_y (Pa)	59.65 x10^9	2x10^{10}	
Young’s Modulus E_z (Pa)	10.65 x10^9	1x10^{10}	
Poisson’s Ratios ν_{xy}	0.26	0.3	0.3
Poisson’s Ratios ν_{yz}	0.26	0.4	
Poisson’s Ratios ν_{zx}	0.26	0.3	

Modulus of Rigidity G_{xy} (Pa)	4 x10^9	5 x10^9	2.69 x10^7
Modulus of Rigidity G_{xz} (Pa)	4 x10^9	3.84x10^9	
Modulus of Rigidity G_{yz} (Pa)	3.3 x10^9	5x10^9	

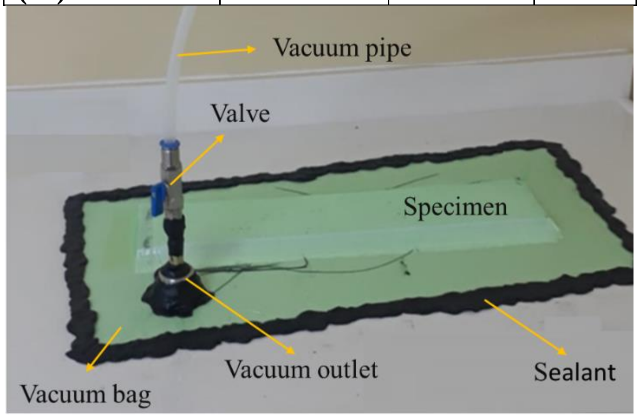

Figure 2 Production of sandwich structures by hand layup vacuum method.

Table 2
Configuration of sandwich samples

Sample-1 (CPC)	**Sample-2 (GPG)**	**Sample-3 (GPC)**
Carbon Fiber (2 layers)	Glass Fiber (2 layers)	Glass Fiber (2 layers)
PVC Foam	PVC Foam	PVC Foam
Carbon Fiber (2 layers)	Glass Fiber (2 layers)	Carbon Fiber (2 layers)

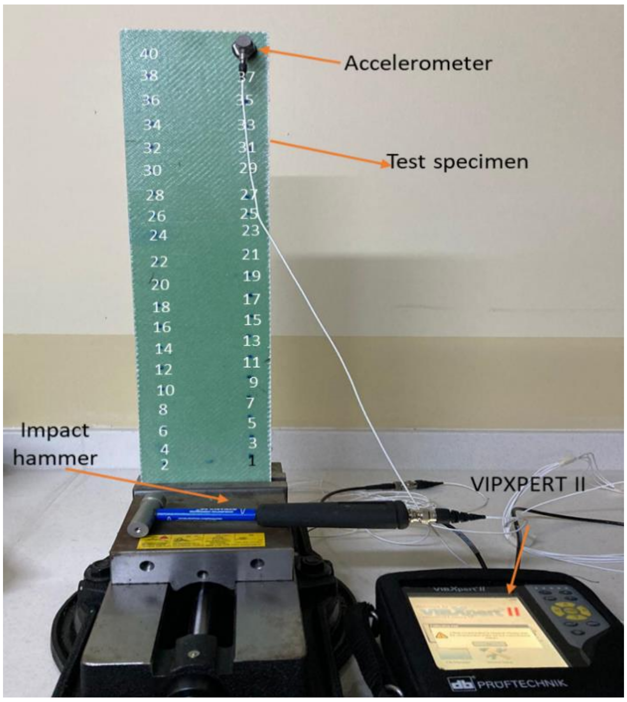

Figure 3 Roving accelerometer method.

Experimentally obtained results are used to calculate natural frequencies, damping ratios, and modal constants of manufactured sandwich structures. A curve fitting method was employed to extract modal parameters using rational fraction polynomials for multi-degree of freedoms system (MDOF) [23]. In this approach, curve-fitting is performed for experimentally obtained FRF values using rational fraction polynomials. The system can be expressed as follows, with the numerator and denominator degrees m and n, respectively.

$$\alpha(\omega) = \left. \frac{\sum_{k=0}^{m} a_k s^k}{\sum_{k=0}^{n} b_k s^k} \right|_{s=j\omega} \tag{1}$$

Here a_k and b_k are unknowns which are determined by curve fitting method such that the error between the analytical expression and an FRF measurement is minimized over a chosen frequency range. α is the reception. S values are called the roots of the characteristic polynomial. In this approach, rational fraction coefficients are obtained by forming complex orthogonal polynomials given in the reference work of Richardson and Formenti [23]. Then, the damping and modal parameters depending on these values are obtained. The system receptor response is defined in terms of orthogonal polynomials as follows,

$$\alpha(\omega_i) = \left. \frac{\sum_{k=0}^{m} c_k \phi_{i,k}^{\ +}}{\sum_{k=0}^{n} d_k \theta_{i,k}^{\ +}} \right|_{s=j\omega} \quad (i = 1,\ldots,L) \tag{2}$$

Here the functions $\phi_{i,k}^{\ +}$ and $\theta_{i,k}^{\ +}$ are called the right half functions of the orthogonal functions of the numerator and denominator. Here c_k and d_k are unknowns which when determined is used to recover a_k and b_k. Orthogonal functions are given below in terms of rational fraction coefficients.

$$\begin{aligned} \phi_{i,0} &= a_0 \\ \phi_{i,1} &= a_1\left(j\omega_i\right) \\ \phi_{i,2} &= a_2\left(j\omega_i\right)+a_3\left(j\omega_i\right)^2 \\ \phi_{i,3} &= a_4\left(j\omega_i\right)+a_5\left(j\omega_i\right)^3 \end{aligned} \tag{3}$$

The error in any frequency value can be defined as the difference between analytical and measured FRF values.

$$e_i = a_k\left(j\omega_i\right)^k - h_i\left[\sum_{k=0}^{n} b_k\left(j\omega_i\right)^k + \left(j\omega_i\right)^n\right] \tag{4}$$

Here, h_i is the FRF value measured at the relevant frequency. The square of error criterion is as follows.

$$J = \sum_{i=1}^{L} e_i^* e_i = \left\{E^*\right\}^T \left\{E^*\right\} \tag{5}$$

A system with multiple modes can be defined as follows.

$$\alpha\left(\omega\right) = \sum_{n=1}^{N} \frac{A_r}{\omega_n^{\ 2} - \omega^2 + 2j\omega\omega_n\zeta_n} \tag{6}$$

Equation 6 is obtained by using the peak picking method as follows[24]. Here ω_n are the natural frequencies of the MDOF system. And ζ_n is the viscous damping ratio of the MDOF system.

- Natural frequencies: Each resonant frequency is determined from the maximum points of the response function, $\alpha_{maks} = \left|\alpha_n\left(\omega_n\right)\right|_{maks}$
- Damping ratio: The lower and upper-frequency values of the band with the center frequency is determined as $\zeta_r = \left(\omega_b^{\ 2} - \omega_a^{\ 2}\right)/4\omega_n^{\ 2}$, ω_a and ω_b are amplitude ($\alpha_{maks}/\sqrt{2}$) of frequencies.
- Modal Constant: From a single degree of freedom system, $A_r = 2\alpha_{maks}\zeta_n\omega_n^{\ 2}$

3. RESULTS and DISCUSSIONS

The study reveals the relationship between the asymmetry and cross-ponding natural frequency changes due to the change in rigidity. An experimental modal test was performed to study the effect of asymmetry on the free vibration behavior of sandwich structures under clamped-free boundary conditions. The natural frequencies, damping ratios, and modal constants of samples are extracted from the measured FRF and presented in table 3. Figures 4, 5, and 6 show the frequency responses of sample 1, sample 2, and sample 3 respectively that were obtained curve fitting method using MATLAB®. To validate experimental results, FEM is employed by using COMSOL Multiphysics® software, and results are presented in Table 2 comparatively.

Table 3
Modal parameters of MDOF curve fit.

MDOF Natural Frequencies (Hz)					
Sample 1		Sample 2		Sample 3	
Exp.	FEM	Exp.	FEM	Exp.	FEM
39.84	37.29	28.31	29.58	32.54	32.04
237.35	210.49	172.49	168.47	196.42	181.57
581.94	519.26	445.78	418.68	499.20	449.56
MDOF Damping Ratios					
Sample 1		Sample 2		Sample 3	
0.0026		0.0065		0.0016	
0.0083		0.0054		0.0094	
0.0156		0.0105		0.0096	
MDOF Modal Constant					
Sample 1		Sample 2		Sample 3	
430		260		570	
71150		32710		65630	
729820		6350		783980	

By replacing the MDOF system parameters given in Table 2, Equation 6 can be rewritten for Sample-1 as follows,

$$\begin{aligned} \alpha(\omega) = &\frac{430}{4\pi^2(39.84)^2 - \omega^2 + 4\pi j\omega(39.84)(0.0026)} \\ &- \frac{71150}{4\pi^2(237.35)^2 - \omega^2 + 4\pi j\omega(237.35)(0.0083)} \\ &+ \frac{729820}{4\pi^2(581.94)^2 - \omega^2 + 4\pi j\omega(581.94)(0.0156)} \end{aligned} \tag{7}$$

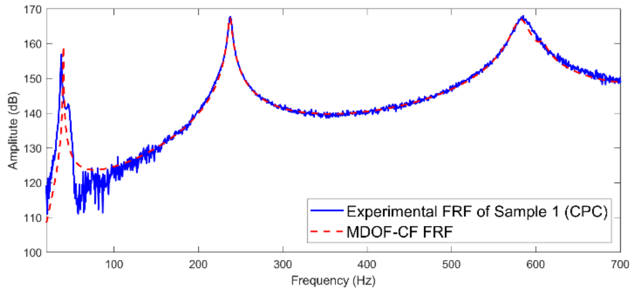

Figure 4 Curve fit-FRF response of Sample 1.

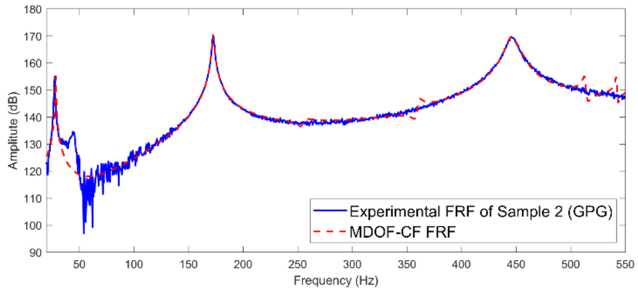

Figure 5 Curve fit-FRF response of Sample 2.

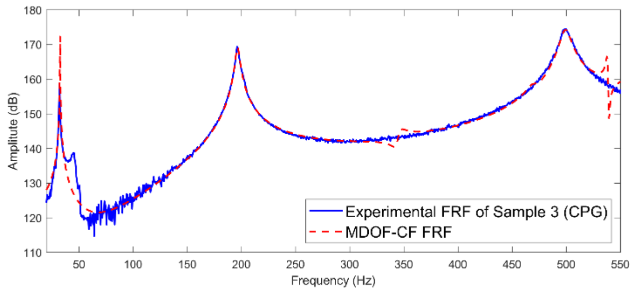

Figure 6 Curve fit-FRF response of Sample 3.

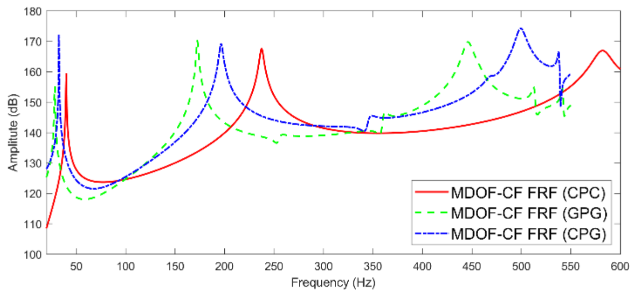

Figure 7 Curve fit results for all samples.

Figure 7 shows the comparison of the natural frequencies for different sandwich samples. The shift in natural frequencies of the asymmetric sandwich structure was observed for all modes concerning symmetric sandwich structures. It is obvious from Figure 7 that asymmetry affects the natural frequencies of sandwich structures. Sample one and sample two give the highest and the lowest frequencies for all modes, respectively. Significant damping value was not observed. As can be seen from Table 2, each sample gives the best damping value at different modes. That is because in sandwich structure surface waves are restricted only to the face sheet [25]. It is clear from table 3 that the modal constant of the MDOF system is affected by the asymmetric configuration. The asymmetry causes an increase in the modal constant.

4. CONCLUSION

In this study, free vibration analysis of asymmetric sandwich structure was investigated by both experiment and FEM. The objective of the study is to evaluate the influence of asymmetry on the free vibration behavior of the sandwich structure. Three natural frequencies and damping ratios of symmetric and asymmetric sandwich structures were obtained by model vibration tests. The relationship between symmetry, asymmetry, and natural frequencies was observed and conclusions were made. From results, it was obtained that as configuration shifted from symmetric configuration to asymmetric configuration natural frequencies changed. This change gives the designer opportunity to get rid of resonance when occurred by manipulating the face sheet material. It was also obtained that a significant damping ratio was not observed. However, it was found out that asymmetry has a great effect on the modal constant of sandwich structures.

Acknowledgments

The Declaration of Conflict of Interest/ Common Interest

"No conflict of interest or common interest has been declared by the authors".

Authors' Contribution

The authors contributed equally to the study.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

"The authors of the paper declare that they comply with the scientific, ethical, and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science."

REFERENCES

[1] A. V. Singh, "Free vibration analysis of deep doubly curved sandwich panels," Comput. Struct., vol. 73, no. 1–5, pp. 385–394, 1999.

[2] W. Wang and R. A. Shenoi, "Local Free Vibration Analysis of Initially Stressed Curved Sandwich Beams," Sandw. Struct. 7 Adv. with Sandw. Struct. Mater., pp. 547–555, 2005.

[3] K. M. Ahmed, "Free vibration of curved sandwich beams by the method of finite elements," J. Sound Vib., vol. 18, pp. 61–74, 1971.

[4] T. Sakiyama, H. Matsuda, and C. Morita, "Free vibration analysis of sandwich arches with elastic or viscoelastic core and various kinds of axis-shape and boundary conditions," J. Sound Vib., vol. 203, no. 3, pp. 505–522, 1997.

[5] N. Mishra, B. Basa, and S. K. Sarangi, "Free vibration Analysis of Sandwich Plates with cutout," IOP Conf. Ser. Mater. Sci. Eng., vol. 149, no. 1, 2016.

[6] H. K. Bhardwaj, J. Vimal, and A. K. Sharma, "Study of free vibration analysis of laminated composite plates with triangular cutouts," Eng. Solid Mech., vol. 1, no. 1, pp. 43–50, 2015.

[7] S. Ramakrishna, K. M. Rao, and N. S. Rao, "Free vibration analysis of laminates with circular cutout by hybrid-stress finite element," Compos. Struct., vol. 21, no. 3, pp. 177–185, 1992.

[8] S. Chikkol Venkateshappa, P. Kumar, and T. Ekbote, "Free vibration studies on plates with central cut-out," CEAS Aeronaut. J., vol. 10, no. 2, pp. 623–632, 2019.

[9] H. K. Bhardwaj, J. Vimal, and A. K. Sharma, "Study of Free Vibration Analysis of Laminated Composite Plates with Skew Cut-outs based on FSD," J. Civ. Eng. Environ. Technol., vol. 1, no. 1, pp. 71–75, 2014.

[10] S. Mondal, A. K. Patra, S. Chakraborty, and N. Mitra, "Dynamic performance of sandwich composite plates with circular hole/cut-out: A mixed experimental-numerical study," Compos. Struct., vol. 131, no. April 2016, pp. 479–489, 2015.

[11] J. Vimal, R. K. Srivastava, A. D. Bhatt, and A. K. Sharma, "Free vibration analysis of functionally graded skew plates with circular cutouts," Int. J. Eng. Sci. Technol., vol. 6, no. 3, 2014.

[12] J. Vimal, R. K. Srivastava, A. D. Bhatt, and A. K. Sharma, "Free vibration analysis of moderately thick functionally graded plates with multiple circular and square cutouts using finite element method," J. Solid Mech., vol. 7, no. 1, pp. 83–95, 2015.

[13] T. Tuswan, A. Zubaydi, B. Piscesa, A. Ismail, and M. F. Ilham, "Free vibration analysis of interfacial debonded sandwich of ferry Ro-Ro's stern ramp door," Procedia Struct. Integr., vol. 27, pp. 22–29, 2020.

[14] V. N. Burlayenko and T. Sadowski, "Influence of skin/core debonding on free vibration behavior of foam and honeycomb cored sandwich plates," Int. J. Non. Linear. Mech., vol. 45, no. 10, pp. 959–968, 2010.

[15] H. Y. Kim and W. Hwang, “Effect of debonding on natural frequencies and frequency response functions of honeycomb sandwich beams,” Compos. Struct., vol. 55, no. 1, pp. 51–62, 2002

[16] H. Schwarts-Givli, O. Rabinovitch, and Y. Frostig, “Free vibrations of delaminated unidirectional sandwich panels with a transversely flexible core-a modified Galerkin approach,” J. Sound Vib., vol. 301, no. 1–2, pp. 253–277, 2007.

[17] B. Saraswathy, R. Ramesh Kumar, and L. Mangal, “Dynamic Analysis of Honeycomb Sandwich Beam with Multiple Debonds,” ISRN Mech. Eng., vol. 2012, pp. 1–7, 2012.

[18] V. N. Burlayenko and T. Sadowski, “Dynamic behaviour of sandwich plates containing single/multiple debonding,” Comput. Mater. Sci., vol. 50, no. 4, pp. 1263–1268, 2011.

[19] I. Jayatilake, W. Karunasena, and W. Lokuge, “Influence of Single and Multiple Skin-Core Debonding on Free Vibration Characteristics of Innovative GFRP Sandwich Panels,” vol. 17, no. 5, pp. 1505–1510, 2015.

[20] M. A. M. Hunjra, M. A. Fakhar, K. Naveed, and T. Subhani, “Polyurethane foam-based radar absorbing sandwich structures to evade detection,” J. Sandw. Struct. Mater., vol. 19, no. 6, pp. 647–658, 2017.

[21] A. A. Khurram, M. A. Raza, P. Zhou, and T. Subhani, “A study of the nanocomposite sandwich structures for broadband microwave absorption and flexural strength,” J. Sandw. Struct. Mater., vol. 18, no. 6, pp. 739–753, 2016.

[22] A. A. Khurram, S. A. Rakha, N. Ali, M. T. Asim, Z. Guorui, and A. Munir, “Microwave Absorbing Properties of Lightweight Nanocomposite/Honeycomb Sandwich Structures,” J. Nanotechnol. Eng. Med., vol. 6, no. 1, pp. 1–6, 2015.

[23] M. H. Richardson and D. L. Formenti, “Parameter Estimation From Frequency Response Measurements Using Rational Fraction Polynomials.,” Proc. Int. Modal Anal. Conf. Exhib., pp. 167–181, 1982.

[24] J. He and Z.-F. Fu, Modal Analysis, 1st ed. butterworth heinemann, 2001.

[25] R. P. Chennuri, “Dynamic Analysis of Sandwich Composites,” Int. J. Appl. Eng. Res., vol. 10, no. 71, pp. 485-488, 2015.