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INVESTIGATION ON DYNAMIC BEHAVIOUR OF SANDWICH PANELS MADE OF ALUMINIUM AND HYBRID POLYMER AND OPTIMIZATION OF DESIGN PARAMETERS USING TAGUCHI METHOD

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The present work focuses on the experimental vibration analysis of hybrid polymer made composite sandwich panels and investigates the mode shape frequency. All the experimental results are compared with the numerical results by using ANSYS software and the error percentage is found out. In the next part of the study, optimization of parameters affecting the natural frequency has been performed. Optimization was carried out using Taguchi method. In addition, the empirical equations of mode shape frequencies were derived using regression analysis. The results from the derived equations are compared with the numerical mode shape frequencies obtained and a good agreement has been found between them.

Keywords: hybrid polymer, sandwich panels, modal analysis, finite element analysis, mode shape frequency, Taguchi method

1. Introduction

Composites are made from two or more constituent materials which retain their individual properties, while being a single component at the macroscopic level [1]. The advent of composites was propelled by the need to encapsulate different material properties as a single unit [2]. Due to their high strength to weight ratio, they are widely used in the light weight constructions and are widely preferred over metals. Sandwich panels are types of composite structures comprising of two thin outer laminates, called as face sheets with a thick light weight core sandwiched in between them. The face sheets provide good compressive and tensile strengths, while the core providing good shear strength [2]. The thicker core provides a large second moment of area at an advantage of a lower weight. In addition to high strength to weight ratio, sandwich panels can be

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made a good vibration damper by inserting a viscoelastic core between the face sheets. Various degrees of damping can be achieved, by varying the core material properties, core thickness, and wavelength of the vibration mode [3].

Vibration control in structures remains a fundamental challenge for design engineers. However, most of the vibration dampers do not have sufficient strength. Sandwich Panels are a solution to this problem incorporating high strength and good damping characteristics. As sandwich panel is required to have high stiffness, low weight and good damping characteristics it is worthwhile to investigate about the concept of a sandwich panel design [4]. However, the optimization of sandwich panels is not simple because there are many design variables, objectives and constraints to be satisfied before the 'best' sandwich panel is designed. Although sandwich panels have been a subject of study since a long time, limited literature is available on hybrid polymer cores. Cashew nut shell liquid is obtained as a byproduct from the cashew nut tree and is been used in variety of applications ranging from automotive brake lining to fabrics [5].

The advantage of using CNSL is its low cost and its easy availability. In this study, the core is a blend of general purpose resin and Cashew Nut Shell Liquid (CNSL) and the face sheets are made of commercially available pure aluminum. In this paper the vibration characteristics of sandwich panels have been investigated experimentally and the results were used to test the validity of the finite element model developed using commercial FEA software ANSYS APDL. An attempt has been made to design the sandwich panels with an objective to optimize the dynamic behavior of sandwich panels.

2. Experimental Procedure

2.1. Materials

The face sheets were made of commercially available pure Aluminium sheet of 2 mm thickness. The core is a blend of Cashew nut shell liquid and general purpose resin. The core and face sheets were bonded using a commercially available adhesive.

2.2. Sandwich panel fabrication

The hand layup technique was used to manufacture the cores. An appropriate proportion of Cashew Nut Shell Liquid (CNSL) and General Purpose resin was taken in a beaker and required quantity of hardener and catalyst were added. Hybrid polymer core was prepared by varying proportions of CNSL from 0% to 25% which is shown in Fig 1. Commercially available adhesive Araldite was used to bond the core and the Aluminium sheets. A total of 6 samples of cores having a thickness of 5mm were prepared by varying the percentage of CNSL (0%, 5%, 10%, 15%, 20%, and 25% in Table 1). The sandwich panels prepared for the vibration analysis are as shown in Fig. 2. Each sandwich panel has a dimension of 170mm x 20mm x 9mm.

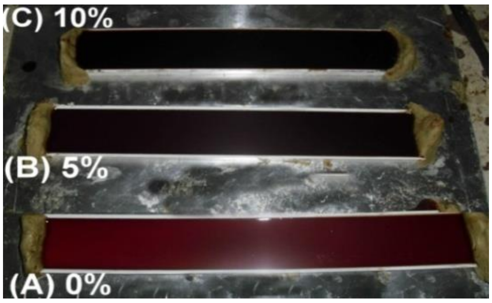


Fig. 1. Hybrid polymer core preparation with varying proportions of CNSL

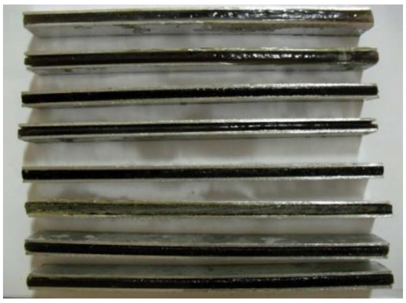


Fig. 2. Hybrid Polymer Samples

2.3. Modal Analysis of Sandwich Panels

Modal analysis is the study of the dynamic properties of structures under vibration excitation. Sandwich panels from the hybrid polymer with varying CNSL from 0% to 25% were again manufactured for the modal analysis. The samples made are shown in Fig. 2. The sandwich panels are fixed to the vibration fixture and the testing was carried out as shown in Fig. 3. The tests are carried out in two different boundary condition namely Fixed-Free and Fixed-Fixed condition. The Fixed-Free condition is shown in Fig. 3. Span length of the sandwich panel used for modal analysis is 150 mm. The vibration analysis kit consists of an accelerometer, an impact hammer, an amplifier and a data acquisition system. Initially, the accelerometer attached with sandwich panel as shown in figure 3 measures the acceleration of the sandwich panel. The sandwich panel is excited by less impact force through the impact hammer. The transducers are connected to an amplifier for amplifies the input signal and send it to the data acquisition system for signal processing. All these input and output signal are monitored using workstation computer as shown in Fig. 4.

The frequency response function is the ratio of output to input signals. This frequency response is a function of frequency and at the peak it will give the natural frequency.

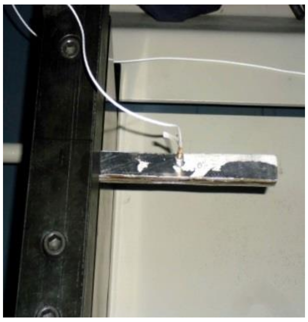


Fig. 3. Sandwich panel in fixed-free condition

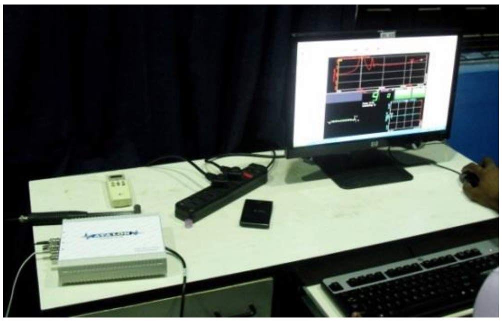


Fig. 4. Vibration analysis test system

The data acquisition system consists of a computer provided with a graphical-user interface (DEWESoft software) which shows the data in real-time. The natural frequency and mode shapes for different sandwich panels at different modes were obtained from the analysis using DEWESoft software. The same analysis was then carried out with Fixed-Fixed condition as shown in Fig. 5. The DEWSoft user interface from which the natural frequency and mode shapes of the sandwich panels at different modes were achieved is shown in Fig. 6.

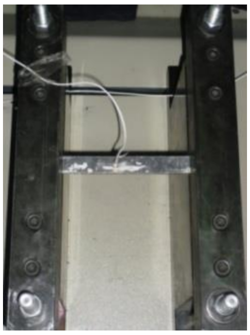


Fig. 5. Sandwich panel in fixed-fixed condition

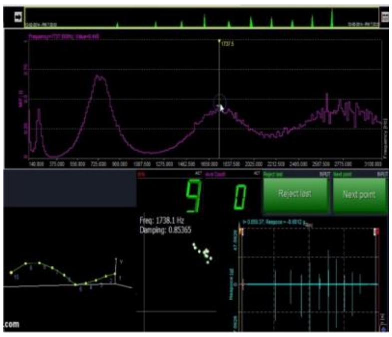
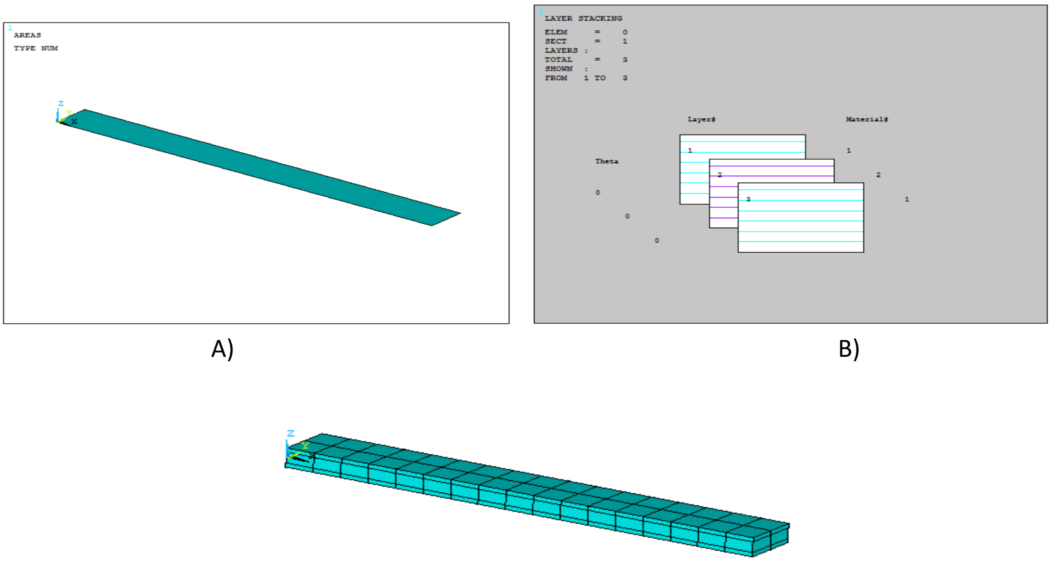


Fig.6. DEWESoft user interface

3. Finite Element Analysis

The sandwich composite was modelled in ANSYS using lay-up technique by specifying the thickness of each layer. At first one area was created as shown in Figure 7, a. Figure 7, b presents the layer arrangement of the sandwich panel. The model is then meshed with SHELL181 element type which is a four node element with six degrees of freedom at each node and usually used for layered applications for modeling composite shells or sandwich constructions. Figure 7, c shows the meshed FEA model for modal analysis. The properties for the core are obtained from experiments. Fixed-free and fixed-fixed boundary conditions were applied to the model separately and the model was solved.



c)

Fig 7. Finite Element Model for modal analysis

a) Layer area created for lay-up; b) Layer arrangement of sandwich panel; c) Meshed model for analysis.

4. Results and Discussions

The natural frequencies of the sandwich panels at different boundary conditions were found by both experimentally and numerically. Table 1 illustrates the comparison of natural frequencies at different modes obtained from experimental and finite element analysis. Different mode shapes of free vibration of sandwich panels with fixed – free condition obtained from ANSYS software are shown in Fig. 8. The data for fixed-fixed condition is tabulated in Table 2. Different mode shapes of free vibration of sandwich panels obtained from ANSYS software for the fixed-fixed condition is shown in Fig. 9.

Table 1

Comparison of Experimental and Finite Element data obtained from the modal analysis of sandwich panels with fixed-free condition

	Frequency [Hz]								
	1st mode			2nd mode			3rd mode		
CNSL %	Experiment	FEA	%error	Experiment	FEA	%error	Experiment	FEA	%error
0	367.66	330.57	10	1489.7	1418.2	4.80	3242.9	3018	6.94
5	319.89	320.58	0.22	1363.9	1303.4	4.44	2687.5	2723.3	1.33
10	307.96	306.28	0.55	1091.8	1170.5	7.21	2478.8	2394.5	3.40
15	285.64	285.92	0.10	1062	1022.6	3.71	1987.5	2040.8	2.68
20	241.8	257	6.29	985.05	861.92	2.61	1725	1668.3	3.29
25	226.46	239.37	5.70	736.89	780.96	5.98	1738.1	1486	9.29

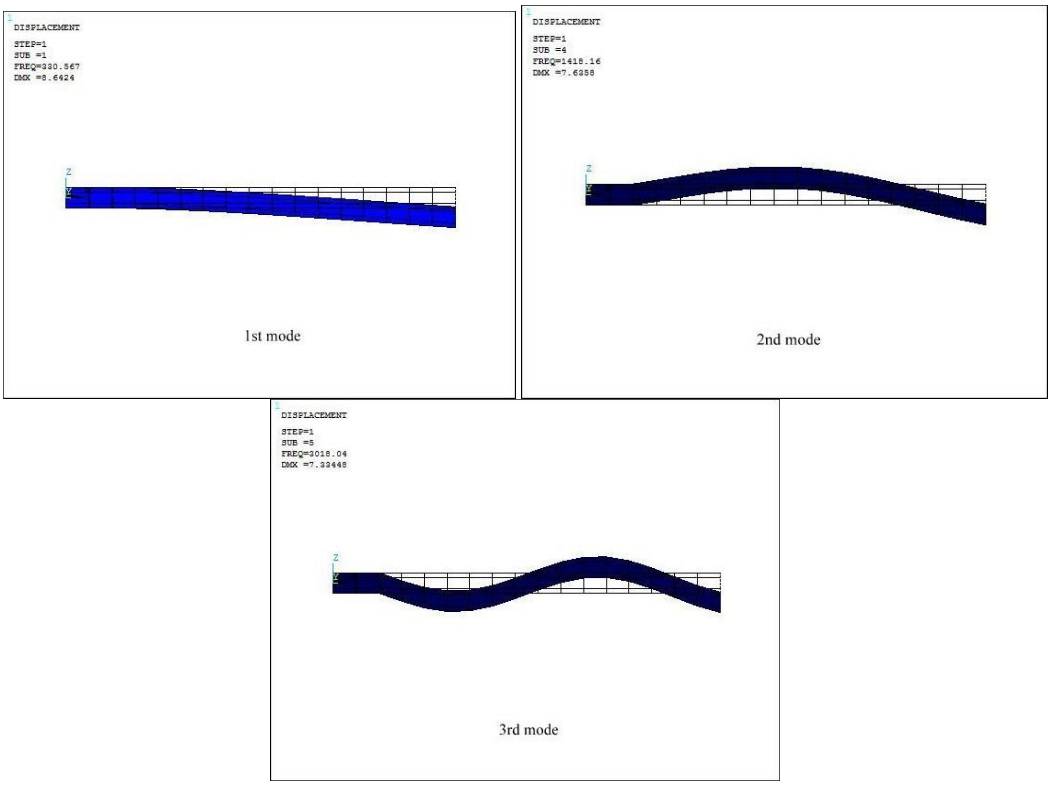


Fig. 8. Mode shapes of free vibration of sandwich panels with fixed-free condition

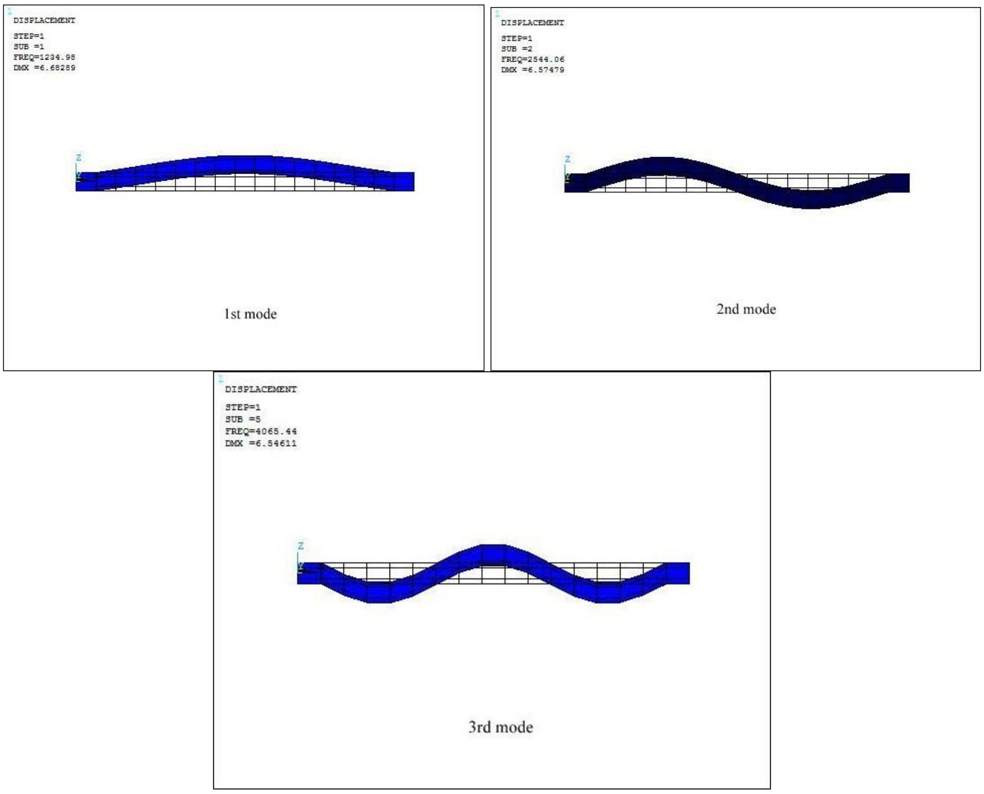


Fig 9. Mode shapes of free vibration of sandwich panels with fixed-fixed condition

Table 2

Comparison of Experimental and Finite Element data obtained from modal analysis of sandwich panels with fixed-fixed condition.

	Frequency [Hz]								
	1st mode			2nd mode			3rd mode		
CNSL %	Experiment	FEA	%error	Experiment	FEA	%error	Experiment	FEA	%error
0	1307.6	1235	5.55	2765.8	2544.1	8.02	4289	4065	5.22
5	1065.61	1114.3	4.57	2440.5	2271.3	6.93	3792.3	3606.2	4.91
10	945.07	978.16	3.50	2070.2	1976.7	4.52	3464.8	3115.9	10.07
15	802.43	830.81	3.54	1639.2	1669.1	1.82	2518.6	2610.3	3.64
20	689	675.84	1.91	1318.8	1353.9	2.66	2284.1	2099.4	8.09
25	541.828	600.32	10.80	938.31	1202.2	28.12	1684.71	1856.5	10.20

5. Optimization of Parameters by Taguchi method

The optimization of parameters which influence the natural frequency was performed by using Taguchi method. The control factors considered were percentage of CNSL, core thickness and face-sheet thickness. Each factor with three levels were chosen such as 5%,15% and 25% CNSL, core thickness as 3 mm, 5 mm and 7 mm and face sheet thickness as 1.5 mm, 2 mm and 2.5 mm. The response chosen was the natural frequencies at different modes. For the experimental planning L9 orthogonal array was chosen. MINITAB software was used for determining the optimum condition as well as for the regression analysis to find the empirical equation for natural frequency correlating the different parameters. The L9 orthogonal array is shown in Table 3. In this study, ‘it is the-larger-the-better’ case, this means that the largest natural frequency would be the ideal case. The obtained results were plotted in an S/N response graphical form as in Figure 10. The optimum condition corresponding to the parameters were shown as the peak point.

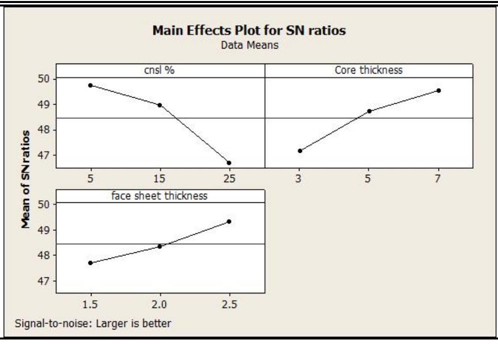


Fig. 10. Mean S/N ratio graph for Natural Frequency

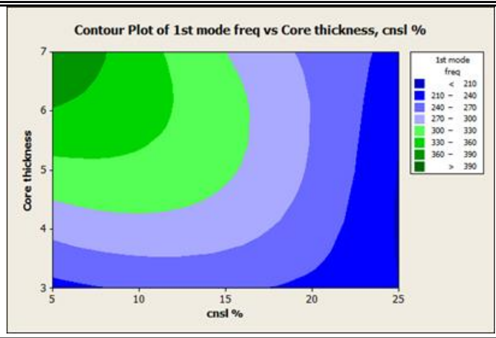


Fig. 1. Contour plot for variation in natural frequency with CNSL% and core thickness.

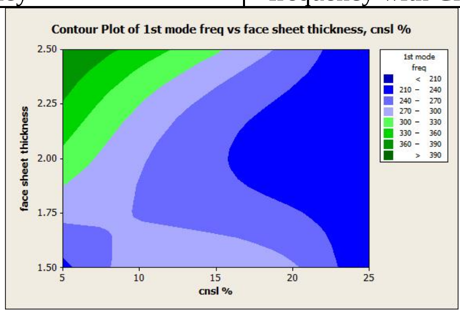


Fig. 2. Contour plot for variation in natural frequency with CNSL% and core thickness.

Table 3

L9 orthogonal array

CNSL %	Core Thickness [mm]	Face Sheet Thickness [mm]	1st Mode Frequency [Hz]	2nd Mode Frequency [Hz]	3rd Mode Frequency [Hz]
5	3	1.5	230.71	1099.81	2438.51
5	5	2.0	320.57	1303.30	2723.06
5	7	2.5	390.28	1426.34	2873.40
15	3	2.0	243.22	958.22	1979.93
15	5	2.5	303.95	1052.23	2070.47

15	7	1.5	299.85	1060.95	2108.29
25	3	2.5	211.41	690.76	1315.28
25	5	1.5	207.80	675.72	1282.50
25	7	2.0	230.73	718.47	1311.56

The contour plots for the variation in natural frequency due to the factors such as the percentage of CNSL, the core thickness and the face sheet thickness are shown in Figure 11 and Figure 12. The darker region shows the higher natural frequency and lighter region shows the lower natural frequency. This helps to identify that the frequency is higher when the core thickness and the face sheet thickness is higher and also when the percentage of CNSL is minimum.

The correlations between the three factors and the frequency response were obtained by regression analysis. The different natural frequency equations obtained with regression analysis using MINITAB software were as follows:

$$1^{st}\text{ mode freq.} = 134 - 4.86 * \text{CNSL \%} + 19.6 * \text{Core thick} + 55.8 * \text{face sheet} \quad (1)$$

$$2^{nd}\text{ mode freq.} = 1022 - 29.1 * \text{CNSL \%} + 38.1 * \text{Core thick} + 111 * \text{face sheet} \quad (2)$$

$$3^{rd}\text{ mode freq.} = 2523 - 68.8 * \text{CNSL \%} + 46.6 * \text{Core thick} + 143 * \text{face sheet} \quad (3)$$

6. Conclusion

Modal Analysis for the sandwich panels was conducted with fixed-free and fixed-fixed conditions and the natural frequencies at different modes were found out. FEA of the modal analysis was also done in ANSYS and good correlation was obtained with the experimental results. Graphical results of Taguchi method give the optimum combination of factors which are 5% of CNSL, 7mm of core thickness and 2.5mm of face sheet thickness. The regression equation results were compared with the numerical mode shape frequencies obtained and a good agreement among them.

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