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Experimental Investigation of Dynamic Characteristics of Multilayer PU Foam Sandwich Panels

Sourabha S. Havaldar[*]**, Ramesh S. Sharma**

Department of Mechanical Engineering, R V College of Engineering, Bangalore, India
Email: [*]shsourabha@rediffmail.com

ABSTRACT

In the present work the dynamic characteristics of Multilayer Polyurethane foam glass/fiber composite sandwich panels have been determined through Experimental Investigations. Using a Multilayer Polyurethane foam sandwich panel with rectangular cross-section, the natural frequencies, mode shapes and the damping ratio of sandwich panels were evaluated. Three types of boundary conditions were simulated namely, C-F-F-F (Clamped Free-Free-Free), C-F-C-F (Clamped-Free-Clamped-Free), C-C-C-C-(Clamped-Clamped-Clamped-Clamped). Experimental modal tests were conducted on sandwich panels with available polyurethane foam of densities 56 kg/m^3, 82 kg/m^3 and 289 kg/m^3. The traditional "strike method" has been used to measure vibration properties. The modal characteristics of the specimens have been obtained by studying their impulse response. Each specimen has been subjected to impulses through a hard tipped hammer which is provided with a force transducer and the response has been measured through the accelerometer. The impulse and the response are processed through a computer aided FFT Analyzing test system in order to extract the modal parameters. Finite Element modeling was carried out treating the facing and core as orthotropic with different elastic constants as recommended in the literature. The experimental results were validated with FEA and were found to be in good agreement. The results obtained through modal test on multilayer sandwich panels are presented. They indicate a significant variation in the dynamic parameters in case of multilayer sandwich panels for the same core density as compared to a monolayer sandwich panel.

Keywords: Multilayer; Sandwich Panel; Modal Testing; Impulse; Frequency; PUF

1. Introduction

Sandwich structures that employ a polyurethane foam core between two relatively thin skins of glass fiber reinforced plastics are desirable in several engineering applications that require high strength-to-weight ratios with good damping capacity. Because of their ability to absorb large amounts of energy, they are also often used as a "cushion" against external loads. Polyurethane foam sandwich structures are currently being used in many engineering applications, in local automotives, and within and outside of aerospace engineering. Light weight polyurethane foam materials can be used in the construction of composite panels, shells, and tubes with high structural efficiency. In recent years, research pertaining to polyurethane foam sandwich structures has focused on effective numerical modeling methods, vibration proper-

ties, crash-worthiness, damage, and failure and impact response [1,2]. A number of researchers have investigated the dynamic behavior of sandwich panels. Mohammed F. Aly *et al.* [3], have experimentally investigated the dynamic characteristics of laminated composite beams, in which they have conducted impact experimental tests. In these tests, FRFs (Frequency Response Functions) were determined that relate the response given by the specimen when loaded with a signal, allowing for the determination of natural frequencies. Ziad K. Awad *et al.* [4] have investigated frequency characteristics of GFRP/ Phenolic sandwich beams experimentally by strike method using the LMS Test-lab instrument, in which the tests were carried out for three different boundary conditions. Jafar Eskandari & Jam, *et al.* [5] developed theories for the dynamic response of sandwich panels. Zhuang Li [6] emphasized more on introduction of viscoelastic core layer between two face sheets that can produce a

[*]Corresponding author.

sandwich structure with high damping. Jian Xiong *et al.* [7], have studied the mechanical response and failure mechanisms of two-layer carbon fiber composite sandwich panels with pyramidal truss cores under uniform quasistatic compressive loading and low-speed concentrated impact, as an initial step in understanding the performance of multi-layer composite panels. Marco Matter *et al.* [8] have developed a mixed numerical-experimental identification procedure for estimating the storage and loss properties in sandwich structures with a soft core. The method uses at the experimental level, a precise measurement setup with an electro-dynamic shaker and a scanning laser interferometer, and at the computational level, an original structurally damped shell finite element model derived from the higher-order shear deformation theory with piecewise linear functions for the through-the-thickness displacement. Qunli Liu and Yi Zhao [9] have studied the vibration of a sandwich panel with two identical isotropic facesheets and with an orthotropic core. The governing partial differential equation was derived using a variational principle and predicted the natural frequencies of a rectangular sandwich panel proposed analytical model. The effects of the structural and material parameters such as core anisotropy, core density, and facesheet thickness on natural frequencies were discussed. Amir Shahdin *et al.* [10] carried out compression tests in order to calculate the compressive modulus for the sandwich honeycomb, foam and entangled specimens. Hualin Fan *et al.* [11] fabricated multi-layered panels by stacking thin monolayer panels to improve the energy absorption ability of the woven textile sandwich. Quasistatic compression experiments were conducted to get the stress-strain curves and to reveal the energy absorption mechanism. Dharmasena *et al.* [12], and Wadley *et al.* [13] found that FRP multi-layered sandwich structure were effective at resisting dispersing high intensity impact impulses, as well as reducing the peak pressure transmitted to the underlying structure. The dynamic crush response of a low relative density, multilayered corrugated core is investigated by combining insights from experiments and 3D finite element simulations.

S. C. Mohanty [14], proposed a finite element for modeling a generalized multi-layered symmetric sandwich beam, with alternate elastic and viscoelastic layers. The detailed derivation of the element mass and stiffness matrices have been presented. He presented numerical results for three, five and seven layered viscoelastic core material. He proposed an element that can be used for vibration analysis of sandwich beams having any number of layers. Nakra [15] explained about the use of vibration control of machines and structures incorporating viscoelastic materials in suitable arrangement as an important aspect of investigation. Multilayered sandwich like structures can be used in aircraft structures and other applications, such as robot arms for effective vibration control.

Much of the literature is related to one of the attributes (high strength/weight or increased energy absorption) as mentioned above. Also, most of the available literature discusses about the dynamic parameters of single layer polyurethane foam sandwich beams. With regard to the development of a multilayer polyurethane foam sandwich panel, one issue that has been overlooked is the scaling of multilayer polyurethane foams properties with respect to different foam densities. The variation in staking of different foam densities (as core of the sandwich panels) may have a significant large influence on the dynamic properties of sandwich panels.

The present paper expands upon this study. The results from the experimental program are presented and discussed. Of interest in this study is the effect of multilayer foams with different densities on the fundamental frequency of sandwich panels.

2. Experimental Methodology

2.1. Fabrication of Multilayer Polyurethane Foam Sandwich Panels

FRP polyurethane foam sandwich panels have been fabricated through vacuum bag molding technique as shown in **Figure 1**. Vacuum is used to eliminate the entrapped air and excess resin. The adhesive used is epoxy resin LY 556 mixed with hardener HY 951 in the weight ratio of 10:1. After ensuring the surface is clean and free from foreign particles, a coat of release agent is applied. Subsequently, two layers of polyurethane foams of different densities were bonded using the same adhesive to obtain three combinations of multilayer sandwich panels as shown in **Figure 2**. The sandwich panels were cured for three hours at a temperature of 100˚C.

Cured sandwich panels were further prepared for different boundary conditions namely, C-F-F-F (Clamped-Free-Free-Free), C-F-C-F (Clamped-Free-Clamped-Free) and C-C-C-C (Clamped-Clamped-Clamped-Clamped) conditions.

Figure 1. Vacuum pressure application.

2.2. Specimen Details

For the preparation of multilayer sandwich panels, three different density polyurethane foams of 56 Kg/m^3, 82 Kg/m^3, 289 Kg/m^3 were considered. Face sheets made of bi-woven glass cloth (considered as orthotropic material) are used and their elastic properties are as shown in **Table 1**. In all, 27 sandwich panels were prepared with dimensions maintained at 160 mm × 160 mm × 15 mm for the three boundary conditions *viz.*, C-F-F-F, C-F-C-F and C-C-C-C. A multilayer sandwich panel after fabrication (at Reinforced Plastics Industries, Bangalore) is as shown in **Figure 3**. Sandwich panel specimens are designated as mentioned in **Table 2**.

2.3. Modal Test Method

The modal characteristics of the specimen have been obtained by studying its impulse response. The specimen has been subjected to impulses through a hard tipped

Figure 2. Preparation of multilayered sandwich panel.

Figure 3. Multilayer sandwich panels.

Table 1. Elastic properties of the bi-woven FRP facings.

E_1 (GPa)	E_2 (GPa)	E_3 (GPa)	G_{12} (GPa)	G_{23} (GPa)	G_{13} (GPa)	υ_{12}	υ_{23}	υ_{13}
16.84	16.84	7.78	2.46	2.38	2.38	0.15	0.49	0.49

Table 2. Specimen designation.

Sl. No.	Specimen Designation	Boundary Conditions
	[All ends fixed]	
1	A0	PUF-56
2	B0	PUF-82
3	CO	PUF-289
4	AOBO	PUF-56 + PUF-82
5	BOAO	PUF-82 + PUF-56
6	AOCO	PUF-56 + PUF-289
	[Two ends fixed]	
10	A1	PUF-56
11	B1	PUF-82
12	C1	PUF-289
13	A1B1	PUF-56 + PUF-82
14	B1A1	PUF-82 + PUF-56
15	A1C1	PUF-56 + PUF-289
	[One ends fixed]	
19	A2	PUF-56
20	B2	PUF-82
21	C2	PUF-289
22	A2B2	PUF-56 + PUF-82
23	B2A2	PUF-82 + PUF-56
24	A2C2	PUF-56 + PUF-289

hammer that is provided with a force transducer (PCB make) with a sensitivity of 2.25 mV/N. The response has been measured through the accelerometer (PCB make) with an accelerometer of sensitivity 10 mV/g. The impulse and the response are processed on a computer aided FFT analyzer test system in order to extract the modal parameters with the help of a built-in software.

The sandwich specimen has been subjected to impulses at 25 station locations. The response has been measured by placing the accelerometer at station 19 as shown in **Figure 4**. Due to inherent damping in the specimen, the test was restricted to fundamental vibration mode with the impact hammer. Tests were conducted for all types of specimen with the three separate boundary conditions and the results recorded.

Figures 5-7 indicate the multi-layered sandwich panels subjected to modal excitation under different boundary conditions such as (a) cantilever, (b) two sides fixed and (c) all sides fixed respectively.
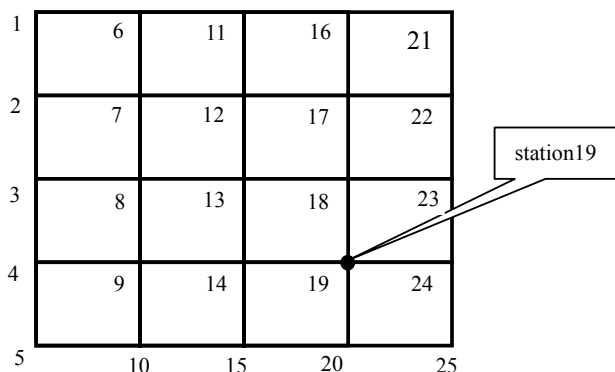
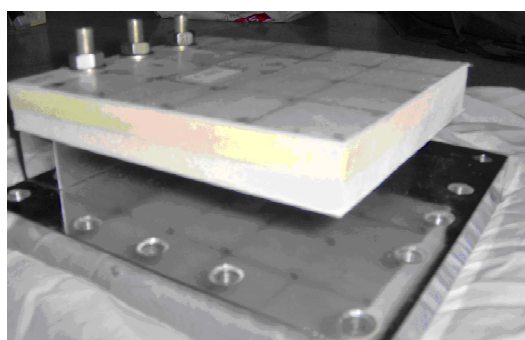**Figure 4. Grid points for impact and accelerometer location.**
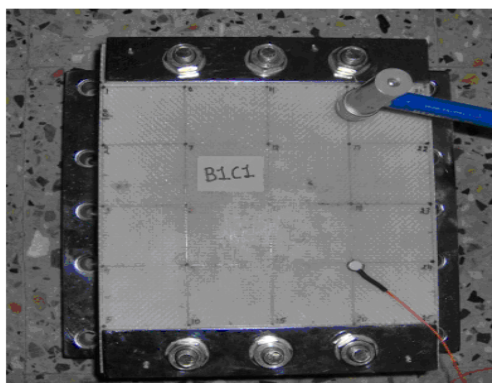

Figure 5. Cantilever condition.
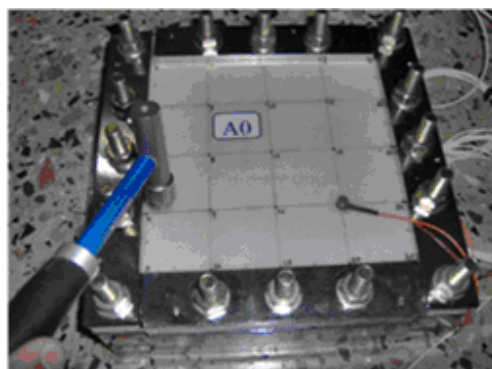

Figure 6. Two end fixed condition.

Figure 7. All end fixed condition.

3. Results

Table 3 provided below indicates the natural frequencies of the test specimens obtained by both experimental and FEA methods. **Figure 8** shows a typical mode shape of multilayered sandwich panel with cantilever condition.

The results in **Table 3** and **Figures 9** and **10** indicate the effect of boundary conditions on the natural frequency of the Multilayer polyurethane foam sandwich panels. By strike method, the first three natural frequencies and their related damping ratios were investigated. Graphs for monolayer and multilayer sandwich panels for "frequency vs. mode number" for foam density of 56 kg/m^3 have been indicated in **Figures 9** and **10**. A similar trend has been observed for other combinations of sandwich panels as well. Finite Element simulation has also been carried out and results recorded in **Table 3**. The results are found to be in good agreement with the experimental results.

The sandwich panels with viscoelastic cores represent the physical application of the viscoelastic integrated damping treatment concept. The panels associate different materials, each having a specific structural contribution. The stiff material of the outside faces guarantees the

Table 3. Results of modal testing and FEA.

| Sl. No	Specimen Designation	Boundary Conditions	EXPERIMENTAL		FEA
			Frequency Hz	% Damping	
1.	A0		506	0.75	505
2.	B0		558	0.54	555
3.	C0		1090	0.69	1137
		C-C-C-C			
4.	A0B0		607	1.32	624
5.	A0C0		777	1.14	669
6.	B0C0		883	1.19	855
7.	A1		330	0.28	357
8.	B1		350	0.89	392
9.	C1		709	1.03	801
		C-F-C-F			
10.	A1B1		396	1.37	442
11.	A1C1		484	1.48	474
12.	B1C1		557	1.79	535
13.	A2		77	0.69	67
14.	B2		75	0.94	78
15.	C2		146	1.02	148
		C-F-F-F			
16.	A2B2		84	1.24	88
17.	A2C2		97	1.58	92
18.	B2C2		109	1.91	114
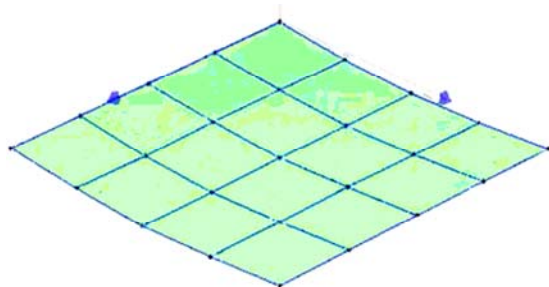
Figure 8. Typical mode shape of multilayered sandwich panels (Mode 1—Symmetric Bending).
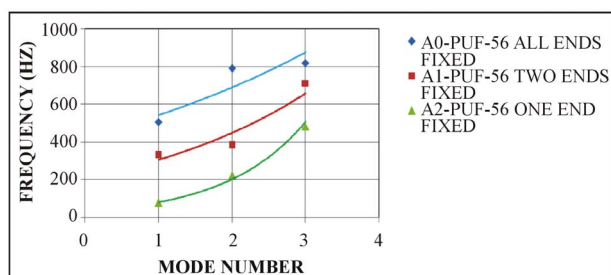

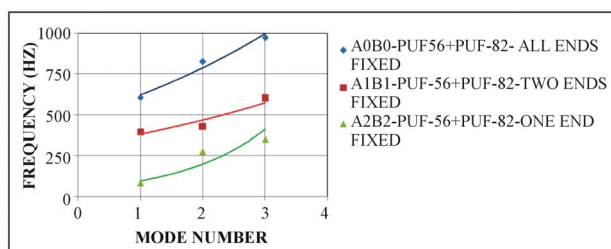**Figure 9. Frequency vs mode number for single layer sandwich construction.**

Figure 10. Frequency vs mode number for multilayer sandwich construction.

stiffness of the composite structure and the viscoelastic soft core provides the damping capability. The application of foam as core, specially the thick ones, into sandwich panels produces an important decoupling effect. This leads to a significant reduction of flexural stiffness of the sandwich panels as evidenced by experimental and numerical results.

To minimize such reduction of flexural stiffness, the portioning of the core layer into multiple layers, separated by thin constraining viscoelastic layers in the sandwich core, is considered. Given the advantage of the application of multiple layers of sandwich core, the potential use of different viscoelastic materials in order to obtain a range of damping treatment has been analyzed. It can be observed from **Table 3** that for mono-layered sandwich panels, the modal damping is very low as compared to multilayered sandwich panels. Hence, the results of this experimental study demonstrate the applicability of two multilayered configurations of core with different

densities, resulting in improved damping.

4. Research Findings

During this investigation on dynamic response of Multilayer polyurethane foam with GFRP laminate as face sheet, following inferences were drawn:

1) For the same mass and geometry, with change in the boundary conditions, natural frequency increased several folds.

2) Dynamic responses of the sandwich panels can be altered by modifying the number of core layers and also by varying core densities.

3) Finite Element simulation can be implemented for free vibration analysis to predict the natural frequencies, and mode shapes of the panels accurately and efficiently.

4) The results obtained from FEA were found to be in good agreement with the experimental results to both monolayer and multilayer sandwich panels.

5. Acknowledgements

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