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Fixed – Free Vibration Characteristics Of Rigid Foam Glass/Epoxy Sandwich Composite Beams

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Abstract - **Sandwich composites with two different thermoset unfilled rigid foam cores (Polyurethane and Polyisocynurate) and different skin to core weight ratios of 1:1 and 2:1 are considered in the present investigation. The foam is considered in sandwich composites because of its light weight structure, easy machining, high stiffness, damping and insulation capabilities. A combined experimental and finite element analysis is used to compare the vibration characteristics of these sandwich composites in a fixed free condition using the impulse hammer technique. Fabrication of the sandwich panels was done with a hand lay-up process and a vacuum bagging film based process. The machined and honed specimen beams were impacted by striking with an impulse hammer at various points. The natural frequencies and mode shapes were obtained at a particular point of impact. Finite element analysis was carried out by means of the ANSYS 14 software for simulating the experimental conditions. Both the experimental and FE analysis were correlated and studied.**

Keywords – PUF (Polyurethane foam), PIR (Polyisocynurate), Sandwich composites, Hand lay-up, Vacuum bagging, Glass fabric/epoxy face sheet, Impulse hammer test, Finite Element Methods.

1. Introduction

Composite material is the combination of two or more constituent materials, and forms a light weight and high strength structure. The matrix and reinforcement material make the material stiffer and stronger. A typical sandwich structure, Fig.1. is a special class of composite material in which a thick foam core is attached by two thin, stiff, skin and a thick core which is lighter in weight. Honeycombs have a higher strength-to-weight ratio than foam, but foams may be used in several forms of structural contructions, for the same characteristics.Also, the compression strength of a foam core prevents the thin facesheet/skin from failure due to buckling.Its mainly a thermoset polymer,light weight and strong structure.The strength properties were studied for laminates and tapered laminates by Manchith Kumar KK [1], and discussed in case of the vibrationbehavior of the composite beams, with different configurations of internal taper.A sandwich composite is typically designed to possess high bending stiffness with low density, and, two thin, stiff skin sheets with a lightweight core [2]. So, in order to know the damping effect on the sandwich skin layer, certain vibrational tests need to be carried out with appropriate weight ratios. Rigid core glass epoxy sandwich composite exhibits different damping effects when experimented with vibration tests [3]. Porosity present in the foam influences the variation in vibration characteristics. More the porosity, higher the vibration effect. So, in order to characterize the effect it is indeed essential to know the basics of vibrational principles[4].

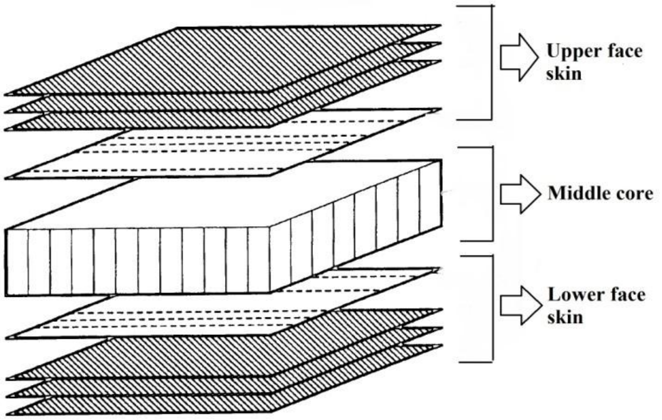

Figure 1: Typical Sandwich Structure

In this paper we discuss about the vibrational charactersistics of two different foams PUF and PIR with similar density of 125 kg/m^3 with two different skin to core weight ratio 1:1 and 2:1.

2. Experiment

1. Fabrication

The sandwich composites fabrication was done with different skin to core weight ratios 1:1 and 2:1. The skin or face sheet is the bi-directional glass fabric. Each weight ratio

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has different number of skin layers depending on the final skin to core weight ratio. The skin was layered with 280 and 100 GSM of E - glass fabric and the mass was adjusted.

Figure 2: Vacuum bagging process

The volume fraction was taken between skin and glass fabric as 0.3 from the study [5]. This fraction helps to determine the number of skin layer according to each weight ratio. The dimensions of the foams were 500×500×10mm. Similarly, the glass fabric of the same length and breadth is taken without over hangs. First, the working surface is properly cleaned and sprayed with silicone mould release spray. A layer of epoxy resin mixture is coated on the peel ply and first layer of 280 GSM glass fabric is laid, and rolled, to evenly spread the mixture across the area. Epoxy resin mixture (GY257& A140) is applied again over the fabric and pressed with roller uniformly. The resin bonds the layers of fabric and is a good load transferring agent. The same layering process was carried out symmetrically for the remaining layers. The whole panel is then vacuum bagged with the air from the bag, sucked out with high power vacuum pump, Fig.2. So, because of this, the sandwich panels are pressed with high pressure. After few hours, the panel is taken away from the chamber and kept for a day for curing.

TABLE I. MATERIAL PROPERTIES

Material	Properties	Values
Glass Fabric	Elasticity Modulus (GPa)	35
	Shear Modulus (GPa)	14
	Density (Kg/m^3)	2520
	Poisson's ratio	0.25
Epoxy resin	Elasticity Modulus (GPa)	2
	Shear Modulus (GPa)	0.74
	Density (Kg/m^3)	1200
	Poisson's ratio	0.35
PIR foam	Young's Modulus (MPa)	24
	Density (Kg/m^3)	125
	Poisson's ratio	0.332
PUF foam	Young's Modulus (MPa)	11
	Density (Kg/m^3)	125
	Poisson's ratio	0.312

2. *Specimen preparation*

After the fabrication process, the dimensions of the specimen were optimized and machined using hand jig saw Fig 3.Three specimens were machined from each foam panel with different skin to core weight ratio. About twelve specimens were considered for testing. The specimen thickness varies, and depends upon the number of skin layers laid. The basic dimensions of the specimens are given below.

For 1:1 weight ratio,
Length of the specimen, L = 175 mm
Thickness of the core, t_c = 10 mm
Thickness of the face, t_f= 2 mm
Width of the specimen, W = 24 mm
For 2:1 weight ratio,
Length of the specimen, L = 175 mm
Thickness of the core, t_c = 10 mm
Thickness of the face, t_f = 3 mm
Width of the specimen, W = 26 mm

Figure 3: Both PUF and PIR 125 Kg/m^3 of 1:1 and 2:1 weight ratio sandwich specimens for testing

3. *Testing*

The impulse hammer testing was carried out to find the natural frequencies. The first six natural frequencies were measured using the experimental modal analysis. The beam was fixed on the table with the help of C – clamp and the uni-axial accelerometer was glued at the free-end on to the surface of the beam[6][7]. While testing, the beam was excited using an impact hammer at the mode location points and that vibration signals were transferred to condition amplifier to amplify the signal. The signals were then sent to signal analyzer and the post processing was done using the software RT-PRO as in Fig 4.

Mode shapes of the first six modes of all the tested specimens were extracted experimentally by the roving hammer technique [8].

Figure 4: Impulse hammer experimental setup

Figure 5: Impacting by hammer on the specimen

Six different points were marked on the specimen and the accelerometer was fixed at the end of the beam for all the trials as in Figure. 5. For each trial different points were hit by the impact hammer and the corresponding response was extracted through accelerometer [9]. The data is received by data analyzer and with the help of RT PRO software, frequencies are plotted in the graph that is displayed on the computer monitor.

4. Result and Discussions

1. Experimental results

Figures 6 to 9, show the first natural frequencies of the foams with corresponding weight ratios. This graph was obtained from the RT-PRO software which is used during the experimental process. The red vertical line shows the first peak value which is the first natural frequency of that foam. Only three peaks were obtained in all the trials. So, only three natural frequencies were obtained from the experimental procedure.

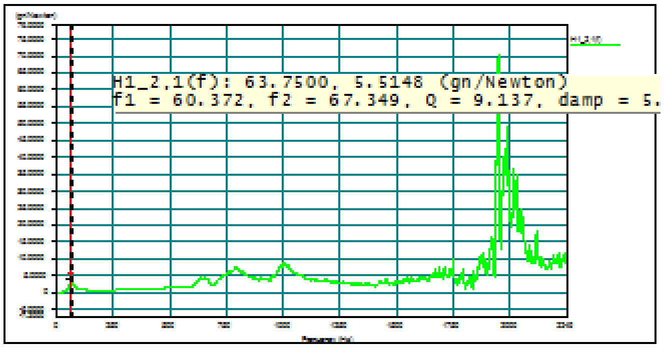

Figure 6: Ist Natural frequency for PIR 1:1

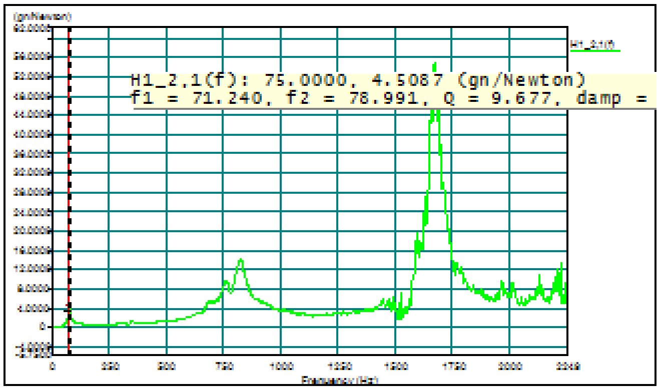

Figure 7: Ist Natural frequency for PIR 2:1

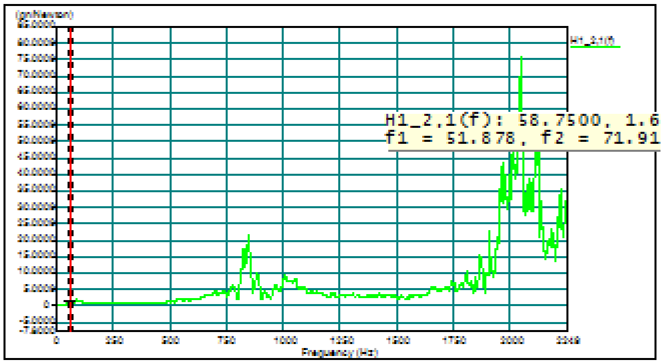

Figure 8: Ist Natural frequency for PUF 1:1

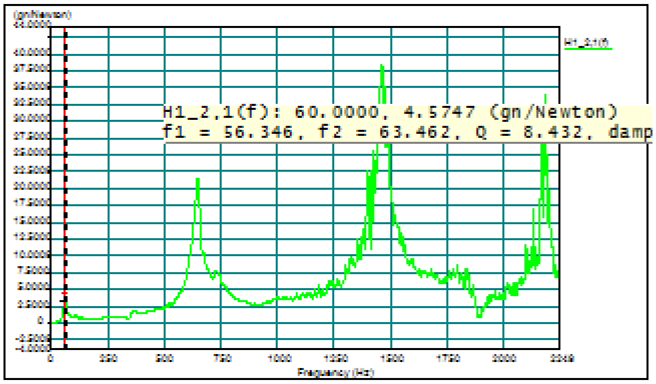

Figure 9: Ist Natural frequency for PUF 2:1

2. FE Analysis results

FE analysis was carried out in ANSYS 14 software. Modeling dimensions were in meters, and properties were given in GPa. The element type considered was SHELL181.Grid modeling technique was used for modeling. Initially, the preference was carried out with structural and later was converted into Modal analysis. There are two materials involved in this analysis - skin and the core. The skin material property was given linear orthotropic properties while the core properties were linear isotropic. The young's modulus, Poisson's ratio and the shear modulus for skin were evaluated from the CADEC. The modeling of areas was done, & then sectioning of layers with the section option, where the thickness of layers, orientation and material properties were given as input.

The displacement was given on the line and was fixed at one end because the modeling is of the simply supported cantilever beam. After applying loads, modal analysis was selected and its types were input. Then the solution was solved. The modal analysis with Block Lanczos conditions was used to find the natural frequencies of the beams in the ANSYS 14 software[10]. Experimental investigations were carried out with fixed free condition for all the beams. Layers were defined in the software for both the weight ratios as in Fig. 10.

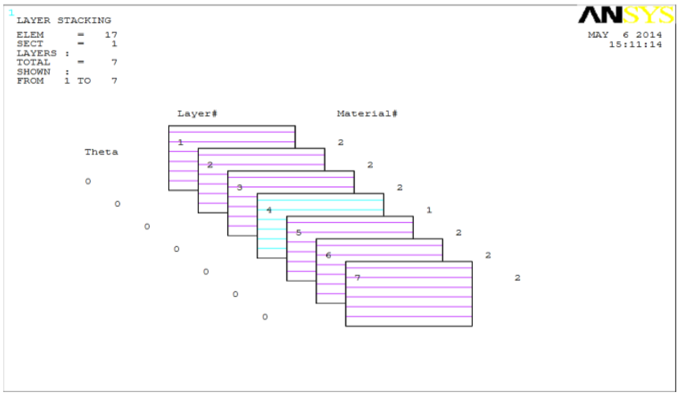

Figure 10: Determination of section layers of 2:1 weight ratios of both the foam in FEM

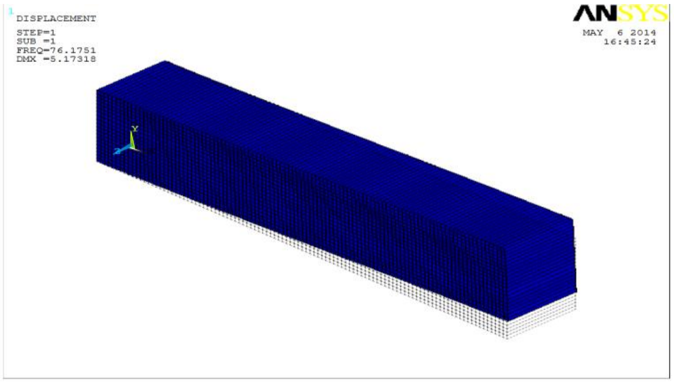

Figure 11: Mode 1 shape of PIR 2:1, f1= 76.17 Hz

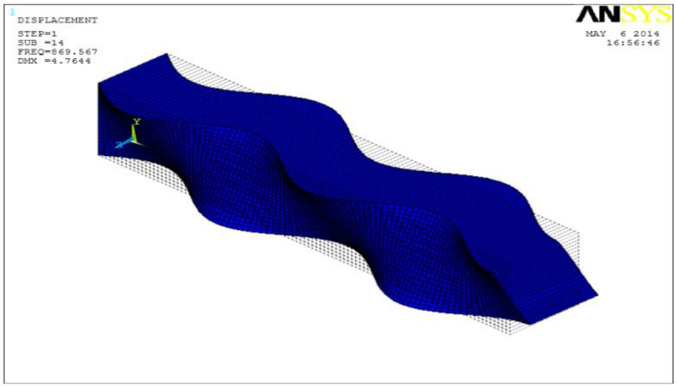

Figure 12: Mode 2 shape of PIR 2:1, f2= 869.57 Hz

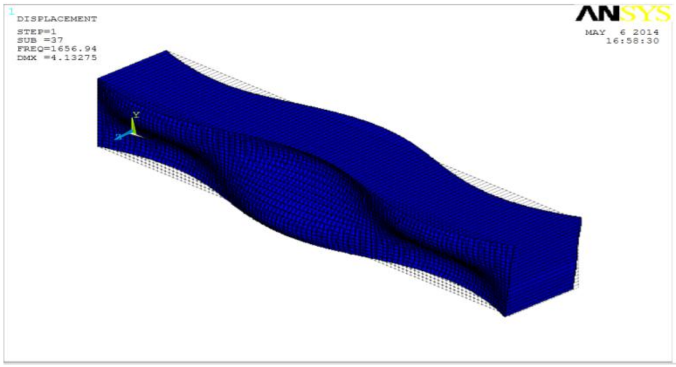

Figure 13: Mode 3 shape of PIR 2:1, f3= 1656.94 Hz

Figures. 11 to 13, shows the mode shapes of first natural frequency and corresponding frequencies of PIR 2:1 foam.

3. Experimental and FEA correlation

TABLE II: COMPARISON OF NATURAL FREQUENCIES OF PIR 1:1 AND 2:1 DERIVED FROM EXPERIMENTAL AND FEA METHODS

Modes	PIR 1:1		PIR 2:1	
	Measured	**FEM**	**Measured**	**FEM**
1	63.75 Hz	62.99 Hz	75.00 Hz	76.17 Hz
2	788.75 Hz	793.87 Hz	826.00 Hz	869.57 Hz
3	1006.25 Hz	901.46 Hz	1670.00 Hz	1656.94 Hz

TABLE III: COMPARISON OF NATURAL FREQUENCIES OF PUF 1:1 AND 2:1 DERIVED FROM EXPERIMENTAL AND FEA METHODS

Modes	PUF 1:1		PUF 2:1	
	Measured	**FEM**	**Measured**	**FEM**
1	58.75 Hz	59.15 Hz	60.00 Hz	59.04 Hz
2	625.00 Hz	678.08 Hz	646.25 Hz	637.43 Hz
3	846.20 Hz	887.48 Hz	1457.50 Hz	1443.16 Hz

Table II and Table III compare the natural frequencies of both the foam with respect to its weight ratios. It was observed that the first natural frequencies and the corresponding frequencies are increased in 2:1 when compared with 1:1 weight ratios in both the foams. This is due to skin stiffness and number of layers, which is more in 2:1 than in 1:1. But, the first natural frequency is slightly lower in PUF than PIR as the damping properties are little higher in PUF foam.

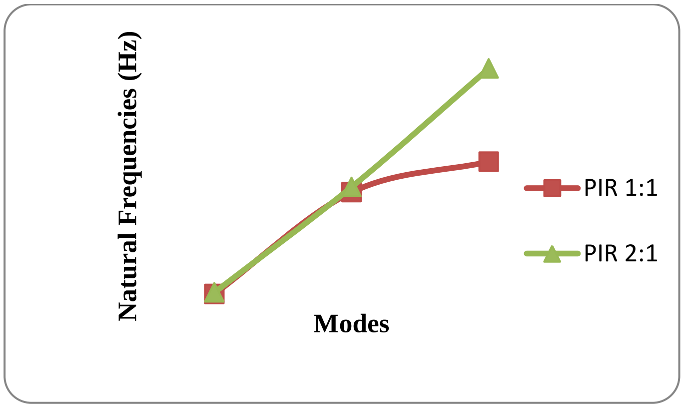

Figure 14: Comparison of natural frequencies of PIR foam of 1:1 and 2:1 corresponding to modes from experimental test

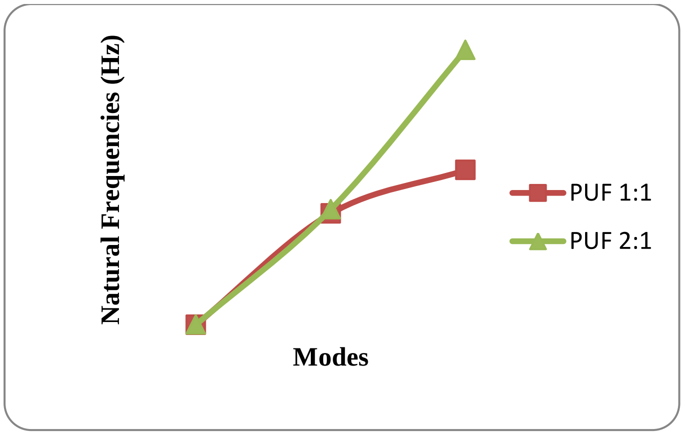

Figure 15: Comparison of natural frequencies of PUF foam of 1:1 and 2:1 corresponding to modes from experimental test

Figures. 14 & 15 show the graphical comparison of the measured natural frequencies, of the first three modes, from experimental tests. As expected, higher thickness and high stiffness increases the natural frequencies. A beam of lower mass or stiffness increases the natural frequency, while a beam of higher mass or lesser stiffness, decreases the natural frequency.

4. Conclusion

The first natural and corresponding natural frequencies were obtained experimentally. Later FEA analysis was carried out with fixed free condition parameter and modal analysis was done. In the analysis, the mode shapes of the corresponding natural frequencies are plotted. Finally, both the experimental and FEA results were correlated. From this experiment, we understand that the natural frequencies are higher with the higher weight ratio. This is because the number of skin layers is increased and stiffness is also higher. Among the foams, PIR has higher frequencies and has good vibration characteristics than PUF. So, the PIR foam sandwich composites can be used for structural applications and also where the composite requires higher stiffness at different locations.

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References

1. Manchith Kumar. KK, “Dynamic characterization of glass epoxy ply-drop off tapered composite beams,” master thesis project done at VIT University, Vellore,2013, India
2. Padmanabhan k, “Strength based design optimization studies on rigid polyurethane foam core Glass and carbon-Glass fabric face sheet/epoxy matrix sandwich composites”, Mechanics of advanced materials and structures (2014), 21, ISSN No: 1537/6/94. p191-196
3. Amithkumar. SJ, Sabeel Ahmed. K,Santhosh. MB, “Parametric analysis on the vibration characteristics of the sandwich composites,” ISSN: 2321-5747, Volume-1, Issue-1, 2013.
4. “Investigation on vibration and bagged modal response of glass/carbon hybrid composite beams subjected to higher frequency of operation using finite element method”, Selected papers of Mechanical, Civil and Chemical engineering Tracks of 4th Nirma University International Conference on Engineering, Ahmedabad,2013
5. Allan Manalo and Thiru Aravinthan (2012), "Behaviour of glued fiber composite sandwich structure in flexure: Experiment and Fiber Model Analysis", Materials and Design, 39 (2012) 458-468.
6. Mustapha Assarar, Abderrahim El Mahi, Jean-Marie Berthelot**,** “Analysis of the damping of sandwich materials and effect of the characteristics of the constituents,” International Journal of Material Science (IJMSCI) Volume 3 Issue 2, June 2013
7. Pizhong Qiao, Mijia Yang, “ Impact analysis of fiber reinforced polymer honeycomb composite sandwich beams,” Composites: Part B 38 (2007) 739–750
8. Abdel Salam. M ,Nadia. E, Bondok, “Free Vibration Characteristics for Different Configurations of Sandwich Beams,” International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS Vol:10 No:03, June,2010 Page no 27-36.
9. Jinshui Yang, JianXiong, Li Ma, Bing Wang, Guoqi Zhang, Linzhi Wu, “Vibration and damping characteristics of hybrid carbon fiber composite pyramidal truss sandwich panels with viscoelastic layers,” Composite Structures 106 (2013) 570–580
10. Ansys Technical Manual, version 14
11. A text book of “Mechanical behaviour and structural analysis of composite materials” by Jean Marie Berthelot, published by springer – theory of sandwich plates page 382-391 , Vibration of laminates or sandwich beam and plates page 54-570
12. A text book of “ Finite element analysis of composite materials” by Ever J. Barbero published by CRC Press – 2008