Latin American Journal of
Solids and Structures
www.lajss.org

Polyester Pinning Effect on Flexural and Vibrational Characteristics of Foam Filled Honeycomb Sandwich Panels

Abstract

Polyester pins are incorporated in polyurethane foam filled honeycomb core sandwich panel to increase the interfacial strength between the faces and core in order to improve the performance of sandwich structures. Foam filled Honeycomb Sandwich panel (FHS) and Pin incorporated Foam filled Honeycomb sandwich panels (PFHS) were developed. The developed sandwich panels are tested for flexural and vibration characteristics. The influence of strain rates on flexural behaviour of sandwich panels were also evaluated. The material used for face sheets and pins are same, ends of pin act as chemically cross linked polyester joint at the interfaces of faces and core in addition to the adhesive area. This modification had effectually increased the interfacial strength thereby increased the flexural and damping properties of panels significantly. Moreover, increasing the pin diameter has a larger effect, whereas, the strain rate had a moderate influence on the failure load of both types of sandwich panels. The investigation brings to light a novel pin incorporated foam filled honeycomb sandwich panels that can be used for various applications.

Keywords

Strain rate, Flexural, Vibration, Sandwich panel, Polyester pins.

R.S. Jayaram [a]
V.A. Nagarajan [b]
K.P. Vinod Kumar [c]

[a] University College of Engineering
Nagercoil, Anna University Constituent
College, Tamil Nadu, India.
rsjram@gmail.com
[b] University College of Engineering
Nagercoil, Anna University Constituent
College, Tamil Nadu, India.
nagarajanvava@gmail.com
[c] University College of Engineering
Nagercoil, Anna University Constituent
College, Tamil Nadu, India.
nanjilvino@rediffail.com

http://dx.doi.org/10.1590/1679-78253688

Received 18.01.2017
In revised form 10.05.2017
Accepted 14.05.2017
Available online 26.05.2017

1 INTRODUCTION

Sandwich panels of glass fiber composites and aluminum honeycomb cores are generally used in civil infrastructure, aerospace, marine and transportation applications. It consists of two thin but stiff glass fiber face sheets attached to a lightweight aluminum honeycomb core. By this way, moment of inertia was improved and subsequently takes the benefits of combined strength and weight minimization (Karlsson and Astrom 1997). The benefits of sandwich panels are not limited to reduce weight but also an effectual way to diminish cost (Anbusagar et al. 2015; Pflug and Verpoes 2006).

Such a laminated composite structure also possesses excellent crash worthiness, low thermal conductivity coefficients and enviable acoustic properties. In sandwich structures, prime load is carried by the face sheets and while shear is beared by the core. Face sheets play a dominant role in protecting the honeycomb core from different mechanical loading. Under flexural loading, the face sheets carry compressive and tensile stress (Meraghni et al. 1999; Galletti et al. 2008).

Numerous studies have been carried out on the structural performance and characteristics of honeycomb sandwich panels under compression, flexural, indentation and low velocity impact (Paik et al. 1999; Petras and Sutcliffe 2000; Hazizan and Cantwell 2003). The material properties, structural configuration, load distribution and face-core interface bonding were directly related to the collapse loads and the following collapse mode (Shi et al. 2014). The experimental investigations on the effects of cell size, core density, core material, thickness and face sheet material on the strength characteristics of honeycomb sandwich structures were carried out (Kaman et al. 2010; Chen et al. 2014; Jen et al. 2009; Kong et al. 2014). Studies regarding the collapse mechanism of honeycomb sandwich panels under bending and compression revealed that buckling, debonding and crushing are normally observed (Yeh and Wu 1991; Zhou et al. 2006; Hong et al. 2006). Furthermore, experimental, analytical and numerical studies on damage and failure behaviour of honeycomb sandwiches were also carried out (Gdoutos et al. 2003; Abbadi et al. 2009; Crupi et al. 2012; Besant et al. 2001). Numerical investigations on the failure initiation and propagation of honeycomb sandwich panels under distinct loading conditions, comprising compression (Jeyakrishnan et al. 2013), flexural (Wahl et al. 2014) and low-velocity impact (Foo et al. 2008) were evaluated.

It was obvious from the above literatures, strong interface bonding between the faces and core was vital for the structural integrity of the sandwich panels. The most common interfacial toughening methodology's applied for sandwich structures encompasses Z-pinning (Rice et al. 2006; Cartie and Fleck 2003; Marasco et al. 2006) and stitching (Potluri et al. 2003; Lascoup et al. 2006), refers to sewing the face and core mutually by Z-directional or through-thickness reinforcements. This method increased the compression properties of sandwich panel by more than 100% (Nanayakkara et al. 2011). Compared to Z-pinning, stitching method is tedious and consume much process time or requires expensive machinery (Yalkin et al. 2015). Abdi et al. (2014a, 2016b) fabricated through thickness pin reinforced sandwich panel and they used face sheet matrix material to develop pins in a single step process by using vacuum infusion method. They reported that reinforcing foam with pins increased the compression, flexural and indentation properties significantly. Through thickness pins connecting faces and core is an effective way to enhance the interfacial strength and in addition strengthen the properties of sandwich panel in both in-plane and out-plane direction to improve the overall performance of the panel.

As the core of honeycomb sandwich panel was hollow metal, common through thickness interfacial toughening methods are not suitable. To make these methods suitable for honeycomb sandwich panels, the honeycomb core was filled with foam. Furthermore, foam filling prevents premature bending, buckling, shear failure of honeycomb cell walls and have improved damage resistance to the debond propagation due to increased adhesive area compared to the unfilled honeycomb cores (Mozafari et al. 2015; Burlayenko and Sadowski 2009). The interfacial strength between the face sheets and core will be enhanced by incorporating two supplementary materials in the core of sandwich panels, i.e. by filling the honeycomb core with foam and then reinforcing foam with cylindrical polyester pins firmly joining the top and bottom face sheets of the panel.

Recently, the vibration properties of sandwich panel have gained more interest. The dynamic properties such as natural frequency and damping are determined by vibration testing, which gives the base for fast and inexpensive characterization (Gibson 2000). Numerous studies were carried out to find the influence of various parameters such as face sheet material and core thickness, material on dynamic response of sandwich structures (Sargianis and Suhr 2012a, 2012b; Sargianis et al. 2013). The material damping plays an important role in the design process as the control of vibration in high performance structures has become a crucial concern.

The aim of this investigation is to study the effectiveness of pin toughened interfaces on flexural loads and vibration characteristics, evaluating two different diameters of pins, such as 2 mm and 3mm and different strain rate 1, 10, and 100 mm/min on flexural behavior of sandwich panel.

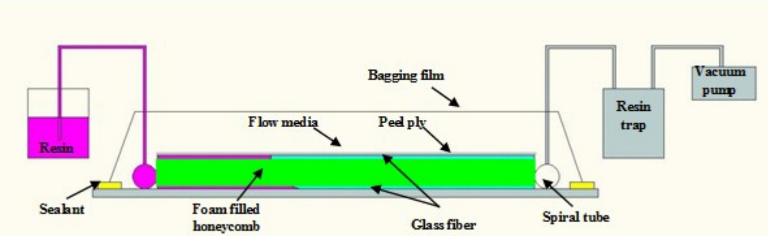
2 EXPERIMENTAL DETAILS

2.1 Materials and Manufacturing

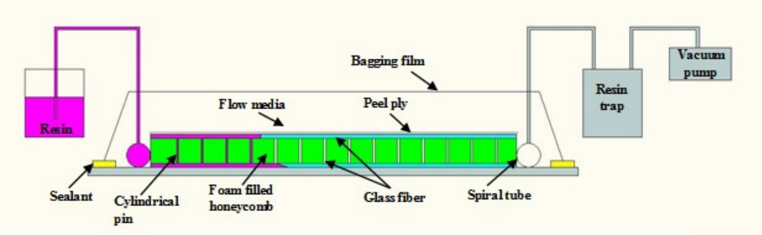
Aluminium honeycomb core with cell size 6.3 mm, wall thickness 0.068 mm and height 10 mm made of Aluminium alloy 3003 was used as the core material in this study. The sandwich face sheets are made of two layers of plain weave glass fabric with areal density 600 g/m^2 and polyester resin. Methyl Ethyl Ketone Peroxide (MEKP) as hardener and Cobalt Naphthenate as accelerator were used. For filling the honeycomb core, polyurethane foam of density, 52 kg/m^3 was used, as estimated following ASTM D-1622. To fill the honeycomb cells with foam, a die with required dimensions were prepared. The foam in solution state was poured into the die and honeycomb core was set on it instantly with a small space from the die bottom. At the end of solidification, the foam fills the honeycomb cells (Nia and Sadeghi 2010).

Both FHS and PFHS panels were prepared by vacuum infusion method. Figures 1a and 1b shows the schematic showing the difference in fabrication of FHS and PFHS panels by vacuum infusion process. In this method a glass plate was employed at the base as holder, and then coated on the mold surface with a releasing agent. The glass fiber is placed on both sides of the foam filled honeycomb core and placed on the glass holder, and then covered with peel ply and silk ply. Then the laminate was closed by vacuum bagging film and sealant tape. To confirm the resin could flow uniformly, a delivery pipe was fixed at the inlet. Once infusing the resin, the system was cured at room temperature and vacuum level of 0.6 bar for 24 hours.

Figure 2 shows the schematic representation of PFHS panels. It also depicts the alternative (W) and adjacent (L) arrangements of pins in the foam filled honeycomb structure for which the enlarged view is given in Figure 3 for PFHS panels. For the manufacturing of cylindrical pins in PFHS panels, the foam filled honeycomb core was drilled in the foam areas of hexagonal cells to make cylindrical holes by using a CNC machine, so that the polyester resin would flow into these holes to form the solid cylindrical pins after cured. As a result, foam filled honeycomb core with drilled holes are used as a simple and effective method to fabricate pin reinforced sandwich panel without extra preparation or processing.



(a) FHS panel



(b) PFHS panel

Figure 1: Schematic showing the difference in fabrication of FHS and PFHS panel by vacuum infusion process.

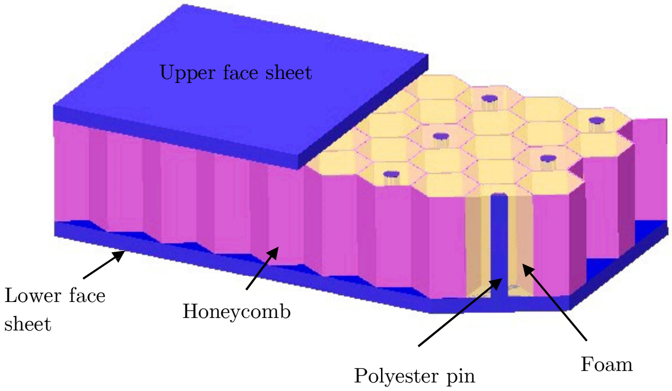


Figure 2: Schematic representation of PFHS panel.

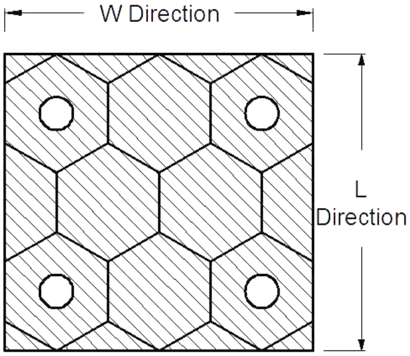


Figure 3: Typical arrangements of pins in PFHS panels.

The purpose of polyester pins is to increase the interface strength, thereby increasing the resistance of the face sheets and foam filled honeycomb core from debonding and delamination. The pins are made of the polyester matrix that is used in the face sheets. As the manufacturing takes place together; the face sheets, foam filled honeycomb core and polyester pins are built-in to form a single inclusive solid structure.

2.2 Flexural Tests of Sandwich Panels

Flexural tests were carried out using Kalpak Computerized Universal Testing Machine in accordance with ASTM C-393/393M standards. All tests were performed at a constant crosshead displacement rate of 1 mm/min. For flexural test of both FHS and PFHS panels, span length was set at 180 mm. Five replicate samples were used for each test to ensure the repeatability of test results. The details of sandwich panel samples for flexural test are listed in Table 1.

Samples	No of samples	Diameter of pins (mm)	Sample size (mm^2)	Weight (gram)
FHS	5	-	240 × 30	46±1
PFHS2	5	2	240 × 30	50±1
PFHS3	5	3	240 × 30	53±1

Table 1: Detail of samples for flexural tests.

2.3 Vibration Test of Sandwich Panels

The basic impulse frequency response vibration test was performed on sandwich specimens using a data acquisition system (DAS) (DEWE 41, Dewetron Corp., Austria) and an ICP conditioner (MSI-BR-ACC). The specimens were tested under free–free (F–F) boundary conditions, which is attained by suspending the specimens using a thin elastic string, located at first nodal points (Figure 4). To obtain high frequency, nylon tipped hammer (YMC IH-02) was used. Two adaptors were used to acquire the output signals of accelerometer and magnitude of the response by hammer. The damping ratio is determined by using half power bandwidth method:

$$\zeta = \frac{\Delta f}{f_n}$$

where Δf is the band width at the half power points down from the peak, f_n is the peak frequency for mode n and ζ is the damping ratio for the n^{th} mode.

3 RESULTS AND DISCUSSION

3.1 The Effect of Reinforcing Foam Filled Honeycomb Sandwich Panel with Polyester Pins under Flexural Loading

Flexural tests were conducted to determine the bending properties of FHS and PFHS panels with two distinct diameters of polyester pins. Figure 5 shows the load–deflection curves of sandwich panels subjected to flexural loading.

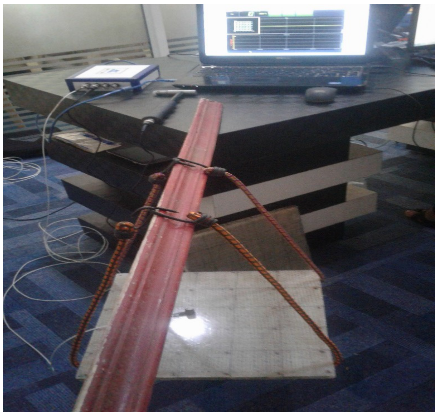


Figure 4: Schematic of the experimental set-up for vibration test.

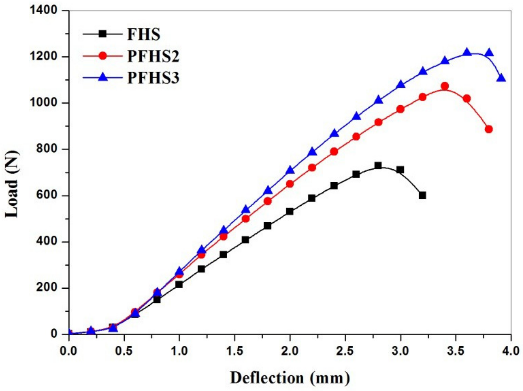


Figure 5: Load–deflection curves of sandwich panels subjected to flexural loading.

For both sandwich panels with and without the pin toughened interfaces, load rises up to the maximum failure load, then load drops progressively. From Figure 5, it can be seen that, by incorporating polyester pins in foam filled honeycomb core, the maximum failure load of 736 N for FHS panels increased to 1079 N and 1228 N of PFHS2 and PFHS3 panels, respectively. Compared with the FHS panel, the deflection at failure load of PFHS2 and PFHS3 panels increased by 18.2 % and 25 %, correspondingly. Table 2 represents the experimental results of flexural tests. The results of PFHS2 and PFFS3 panels show that, pin diameter has a major influence on the enhancement of strengths and stiffness.

Sample type	Failure load (N)	Failure load/Weight (N/N)	Deflection at failure load (mm)	Flexural stiffness (M N mm^2)
FHS	736.2	1631.41	2.91	21.59
PFHS2	1079.72	2201.2	3.44	26.77
PFHS3	1228.61	2363.7	3.71	28.25

Table 2: The experimental results of FHS and PFHS sandwich panels subjected to flexural tests.

From Table 2, it was observed that, for PFHS2 and PFHS3 panels, the flexural stiffness has improved to 24 % and 31 % respectively over the FHS panels. The failure load to weight of PFHS2 and PFHS3 panels are enhanced by 34.9 % and 45 % than FHS panels.

Figures 6a to 6d show the failure modes of both types of sandwich panels under flexural test. From Figure 6a, in FHS panels with the initiation of bending but after maximum load values, the upper face sheet was failed due to indentation over the loading line which is a main failure mode in circumstances of highly localized external loads, such as point or line loads. Also core crushed beneath loading line and no failure is perceived in the bottom face sheet as shown in Figure 6b. For FHS panel, the criterion for failure condition is that the core reaches the maximum stress; compressive stress in top face sheet, becomes critical under combined local and global bending load, which causes indentation.

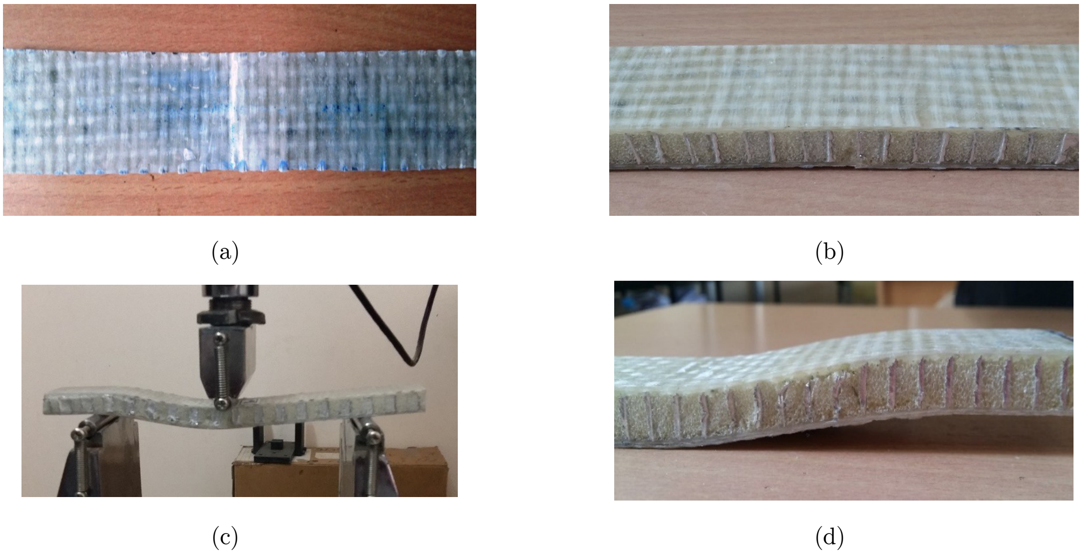

(a) (b)
(c) (d)

Figure 6: Failure modes of sandwich panels under flexural loading (a–b) FHS panel, (c–d) PFHS panel.

The mode of failure and location for PFHS panels differs from the FHS panels. At maximum load, the failure initiates through the breaking of pin near to the loading line and propagates towards support fixtures as shown in Figure 6c. Due to the strong interface bonding between the face sheet and core through polyester pins, the applied load was transferred to the lower face sheet via polyester pins and foam filled honeycomb core. For both PFHS specimens the damage is observed only in the core which is attributed to the tough bridging between faces through the incorporated through thickness reinforcement pins (Henao et al. 2010) and no visual damage is perceived in the face sheets as shown in Figure 6d. The failure criterion is that the state of stress in polyester pins in the core reaches the maximum and subsequently initiates cracking of pins. At last, failure takes place at different interface between core and face sheets in PFHS panels, but at much higher load than FHS panels.

3.2 The Effect of Strain Rate in Flexural Properties

To determine the effect of strain rate in flexural properties of sandwich panels, FHS and PFHS panels were tested at a strain rates of 1 mm/min, 10 mm/min and 100 mm/min. Figure 7 shows the stress-deflection curve of FHS panels under flexural test.

From Figure 7, it can be seen that the strain rate has a moderate influence on the flexural behaviour of FHS panels. Increasing the strain rate, results in increased failure load. For FHS panels, when the strain rate increased from 1 mm/min to 10 mm/min and 100 mm/min, the flexural strength increases by 5.81 % and 14.9 %. Figure 8 shows the stress-deflection curve of PFHS panels under flexural test. The similar behavior was obtained from a study on sandwich panel of mineral filled core (Abdi et al. 2012). At low strain rates, failure initiated on the core prior to face sheet and at high strain rates failure takes place on face sheet prior to core.

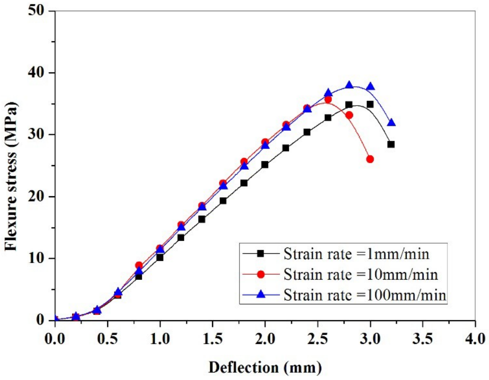


Figure 7: Stress–deflection curves of FHS sandwich panels under flexural loading.

From Figure 8 and 9, it can be seen that PFHS panel also influenced by strain rate. By increasing the strain rate from 1 to 10 mm/min and 100 mm/min, the flexural strength of PFHS2 panel increased by 9.8 % and 15.32 %, respectively. Whereas for PFHS3 panel, flexural strength increased by 6.3 % and 7.6 %, correspondingly.

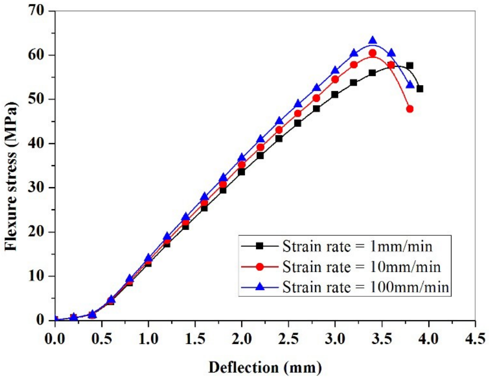


Figure 8: Stress–deflection curves of PFHS2 sandwich panels under flexural loading.

It is very clear that, strain rate has a moderate influence on the flexural response of PFHS panels. Table 3 shows the flexural properties of sandwich panels with respect to strain rates, it is observed that the strain rate has positive influence on flexural properties of PFHS panels than FHS panels.

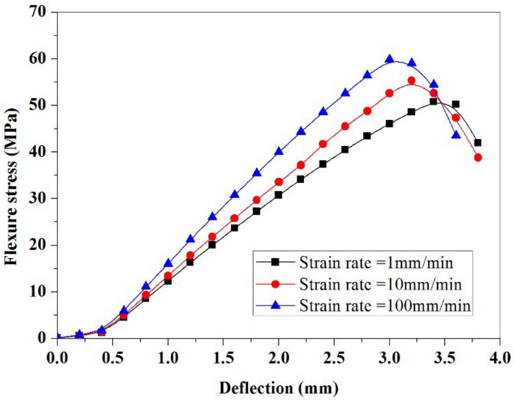


Figure 9: Stress–deflection curves of PFHS3 sandwich panels under flexural loading.

Panel type	Failure load (N)	Deflection at failure load (mm)	Flexural strength (MPa)
Strain rate at 1 mm/min			
FHS	736.2	2.91	32.76
PFHS2	1079.72	3.44	49.34
PFHS3	1228.61	3.71	55.27
Strain rate at 10 mm/min			
FHS	764.9	2.62	34.63
PFHS2	1163.6	3.29	54.18
PFHS3	1292.52	3.47	58.77
Strain rate at 100 mm/min			
FHS	816.8	2.74	37.66
PFHS2	1237.61	3.11	56.29
PFHS3	1334.4	3.53	59.41

Table 3: Experimental results of FHS and PFHS sandwich panels subjected to flexural tests at different strain rates.

3.3 The Effect of Reinforcing Foam Filled Honeycomb Sandwich Panel with Polymer Pins, in Vibration Characteristics

The vibration characteristics such as natural frequency and damping ratio were obtained for the FHS and PFHS panels with two distinct diameters of polyester pins are shown in Table 4. The natural frequency of FHS and PFHS panels are quite comparable; but damping ratios differ. Figure 10 shows the frequency response function (FRF) curve of PFHS3 panel.

The peaks in the frequency response function are the positions of natural frequencies of the sandwich panel. It can be seen from Table 4 that higher damping ratio is observed for PFHS panels in comparison to the FHS panel. As the materials used for both FHS and PFHS panels are same, it is evident from the analysis that the inclusion of polyester pins in foam filled honeycomb core improves the damping ratio of the foam filled honeycomb sandwich panel. This is owing to the high stiffness of the PFHS panels, which results in lower dissipation of energy. Therefore, PFHS panels are observed to deliver minimum damping ratio. Similar observation was made by Abdi et al. (2014) for polyester column incorporated polyethylene foam core sandwich panels. In the damping mode 1, the damping ratios of the FHS and PFHS3 sandwich panel with polyester pins are 0.0448 and 0.0574 respectively, that is an enhancement of about 22 %.

Panel type	Natural frequency (Hz)			Damping ratio		
	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
FHS	247.92	607.23	745.86	0.0448	0.0189	0.0199
PFHS2	245.40	587.61	751.15	0.0527	0.0236	0.0159
PFHS3	243.08	592.26	771.37	0.0574	0.0253	0.0168

Table 4: Vibrational characteristics of FHS and PFHS sandwich panels.

Furthermore, pin diameter has an effect on the damping ratio, because when the diameter of the pin is increased from 2 to 3 mm, the damping ratio of PFHS3 panel improved by 8.1 %, 6.7 % and 5.3 % for mode 1, mode 2 and mode 3, respectively. The results reveal that PFHS3 with 3 mm diameter pins possess high strength and have high damping ratios compared to the PFHS2 and FHS with inconsequent increase in weight.

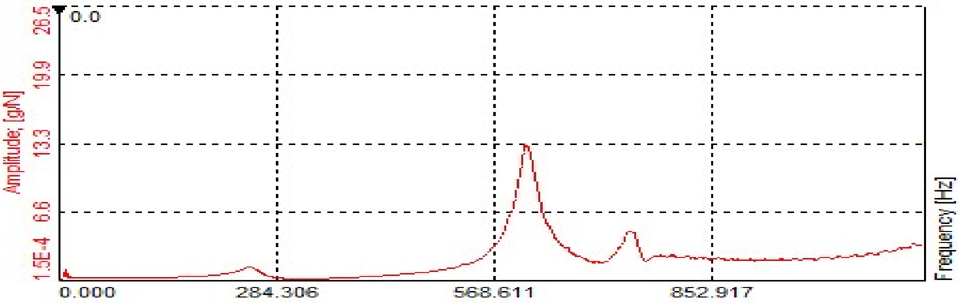


Figure 10: Frequency response function (FRF) for the PFHS3 sandwich panels.

4 CONCLUSIONS

The incorporation of polyester pins in foam filled honeycomb core sandwich panel improved the flexural and damping properties significantly. The pin incorporation effect is significant on the flexural properties of PFHS panels. It was found that increasing the pin diameter, results in improved properties of PFHS3 panels. Compared to the load bearing capability of FHS panel under flexural loading configuration, the pin incorporated PFHS have better properties, particularly PFHS3 panel more by 66.8%. Strain rate has an influence on the flexural properties, it was seen that increasing the strain rate increased flexural properties of PFHS panels more than FHS panel. Vibration tests revealed that polyester pin reinforced sandwich panel, particularly PFHS3 panel possess 22 %

higher damping ratios in mode 1 than FHS panel. Thus the pin incorporated PFHS panels are superior with insignificant increase in weight compared to FHS panel to develop any engineering structures.

References

Abbadi, A., Koutsawa, Y., Carmasol, A., Belouettar, S., Azari, Z., (2009). Experimental and Numerical Characterization of Honeycomb Sandwich composite Panels. Simulation Modelling Practice and Theory 17:1533-1547.

Abdi, B., Azwan, S., Abdullah, M.R., Ayob, A., Yahya, Y., (2016). Comparison of foam core sandwich panel and through thickness polymer pin reinforced foam core sandwich panel subject to indentation and flatwise compression loadings. Polymer Composites 37:612-619.

Abdi, B., Azwan, S., Abdullah, M.R., Ayob, A., Yahya, Y., Xin, L., (2014). Flatwise compression and flexural behavior of foam core and polymer pin-reinforced foam core composite sandwich panels. International Journal of Mechanical Sciences 88:138-144.

Abdi, B., Azwan, S., Amran, A., Rahman, R.A. and Abdullah, R.A., (2014). Experimental Investigation on Free Vibration of Foam-Core Sandwich Plate with and without Circular Polymer Columns. Advanced Materials Research 845:297-301.

Abdi, B., Koloor, S.S.R., Abdullah, M.R., Ayob, A., Yahya, M.Y.B., (2012). Effect of strain rate on flexural behavior of composite sandwich panel. Applied Mechanics and Materials 229:766–770.

Anbusagar, N.R.R., Palanikumar, K., Giridharan, P.K., (2015). Study of sandwich effect on nanoclay modified polyester resin GFR face sheet laminates. Composite Structures 125: 336-342.

Besant, T., Davies, G.A.O., Hitchings, D., (2001). Finite element modelling of low velocity impact of composite sandwich panels. Composites Part A: Applied Science and Manufacturing 32:1189-1196.

Burlayenko, V.N., Sadowski, T., (2009). Analysis of structural performance of sandwich plates with foam-filled aluminum hexagonal honeycomb core. Computational Materials Science 45:658–662.

Cartie, D.D., Fleck, N.A., (2003). The effect of pin reinforcement upon the through-thickness compressive strength of foam-cored sandwich panels. Composites Science and Technology 63:2401-2409.

Chen, Z., Yan, N., Sam-Brew, S., Smith, G., Deng, J., (2014). Investigation of mechanical properties of sandwich panels made of paper honeycomb core and wood composite skins by experimental testing and finite element (FE) modelling methods. European Journal of Wood and Wood Products 72:311-319.

Crupi, V., Epasto, G., Guglielmino, E., (2012). Collapse modes in aluminium honeycomb sandwich panels under bending and impact loading. International Journal of Impact Engineering 43: 6-15.

Foo, C.C., Seah, L.K., Chai, G.B., (2008). Low-velocity impact failure of aluminium honeycomb sandwich panels. Composite Structures 85:20-28.

Galletti, G.G., Vinquist, C., Es-Said, O.S., (2008). Theoretical design and analysis of a honeycomb panel sandwich structure loaded in pure bending. Engineering Failure Analysis 15:555-562.

Gdoutos, E., Daniel, I., Wang, K.A., (2003). Compression facing wrinkling of composite sandwich structures. Mechanics of Materials 35:511-522.

Gibson, R.F., (2000). Modal vibration response measurements for characterization of composite materials and structures. Composites Science and Technology 60:2769-2780.

Hazizan, M.A., Cantwell, W.J., (2003). The low velocity impact response of an aluminium honeycomb sandwich structure. Composites Part B: Engineering 34:679-687.

Henao, A., Carrera, M., Miravete, A., Castejon, L., (2010). Mechanical performance of through-thickness tufted sandwich structures. Composite Structures 92:2052–2059.

Hong, S.T., Pan, J., Tyan, T., Prasad, P., (2006). Quasi-static crush behavior of aluminum honeycomb specimens under compression dominant combined loads. International Journal of Plasticity 22:73–109.

Jen, Y.M., Chang, L.Y., (2009). Effect of thickness of face sheet on the bending fatigue strength of aluminum honeycomb sandwich beams. Engineering Failure Analysis 16:1282–1293.

Jeyakrishnan, P.R., Chockalingam, K.K.S.K., Narayanasamy, R., (2013). Studies on buckling behavior of honeycomb sandwich panel. The International Journal of Advanced Manufacturing Technology 65:803–815.

Kaman, M.O., Solmaz, M.Y., Turan, K., (2010). Experimental and Numerical Analysis of Critical Buckling Load of Honeycomb Sandwich Panels. Journal of Composite Materials 44:2819-2831.

Karlsson, K.F., Astrom, B.T., (1997). Manufacturing and Application of Structural Sandwich Components. Composites Part A: Applied Science and Manufacturing 28 (2): 97–111.

Kong, C.W., Nam, G.W., Jang, Y.S., Yi, Y.M., (2014). Experimental strength of composite sandwich panels with cores made of aluminum honeycomb and foam. Advanced Composite Materials 23:43–52.

Lascoup, B., Aboura, Z., Khellil, K., Benzeggagh, M., (2006). On the mechanical effect of stitch addition in sandwich panel. Composites Science and Technology 66:1385–1398.

Marasco, A.I., Cartie, D.D.R., Partridge, I.K., Rezai, A., (2006). Mechanical properties balance in novel Z-pinned sandwich panels: Out-of-plane properties. Composites Part A: Applied Science and Manufacturing 37:295-302.

Meraghni, F., Desrumaux, F., Benzeggagh, M.L., (1999). Mechanical behaviour of cellular core for structural sandwich panels. Composites Part A: Applied Science and Manufacturing 30(6):767-779.

Mozafari, H., Molatefi, H., Crupi, V., Epasto, G., Guglielmino, E., (2015). In plane compressive response and crushing of foam filled aluminium honeycombs. Journal of Composite Materials 49:3215–3228.

Nanayakkara, A., Feih, S., Mouritz, A.P., (2011). Experimental analysis of the through-thickness compression properties of z-pinned sandwich composites. Composites Part A: Applied Science and Manufacturing 42:1673-1680.

Nia, A.A., Sadeghi, M.Z., (2010). The effects of foam filling on compressive response of hexagonal cell aluminum honeycombs under axial loading-experimental study. Materials & Design 31:1216-1230.

Paik, J.K., Thayamballi, A.K., Kim, G.S., (1999). The strength characteristics of aluminum honeycomb sandwich panels. Thin-Walled Structures 35:205-231.

Petras, A., Sutcliffe, M.P.F., (2000). Indentation failure analysis of sandwich beams. Composite Structures 50:311-318.

Pflug, J., Verpoest, I., (2006). Sandwich Materials Selection Charts. Journal of Sandwich Structures and Materials 8:407-421.

Potluri, P., Kusak, E., Reddy, T.Y., (2003). Novel stitch-bonded sandwich composite structures. Composite Structures 59:251-259.

Rice, M.C., Fleischer, C.A., Zupan, M., (2006). Study on the collapse of pin-reinforced foam sandwich panel cores. Experimental Mechanics 46:197–204.

Sargianis, J., Kim, H.I., Andres, E., Suhr, J., (2013). Sound and vibration damping characteristics in natural material based sandwich composites. Composite Structures 96:538–544.

Sargianis, J., Suhr, J., (2012). Core material effect on wave number and vibrational damping characteristics in carbon fibre sandwich composites. Composites Science and Technology 72:1493–1499.

Sargianis, J., Suhr, J., (2012). Effect of core thickness on noise and vibration mitigation in sandwich composites. Composites Science and Technology 72:724–730.

Shi, S.S., Sun, Z., Hu, X.Z., Chen, H.R., (2014). Carbon-fiber and aluminum-honeycomb sandwich composites with and without Kevlar-fiber interfacial toughening. Composites Part A: Applied Science and Manufacturing 67:102-110.

Wahl, L., Maas, S., Waldmann, D., Zurbes, A., Freres, P., (2014). Fatigue in the core of aluminum honeycomb panels: Lifetime prediction compared with fatigue tests. International Journal of Damage Mechanics 23:661-683.

Yalkin, H. E., Icten, B. M., Alpyildiz, T., (2015). Enhanced mechanical performance of foam core sandwich composites with through the thickness reinforced core. Composites Part B: Engineering, 79:383-391.

Yeh, W.N., Wu, Y.E., (1991). Enhancement of buckling characteristics for sandwich structure with fiber reinforced composite skins and core made of aluminum honeycomb and polyurethane foam. Theoretical and Applied Fracture Mechanics 15:63–74.

Zhou, G., Hill, M., Loughlan, J., Hookham, N., (2006). Damage characteristics of composite honeycomb sandwich panels in bending under quasi-static loading. Journal of Sandwich Structures and Materials 8:55-90.