Honeycomb Carbon Sandwich Composite Panel under Compressive Load Flat-wise: Experimental Analysis

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ABSTRACT

This article is an experimental study of honeycomb core carbon skin sandwich composite panel using American Standards for Testing Materials, ASTM Standards C365/C365M-11a for honeycomb structure flatwise compressive strength. The objective of this article is to describe the process of validation done in the specimens prepared in the research are, to have consistency in terms of the strength and other mechanical properties and to ensure the materials prepared in the lab and can be applied for aviation application (aircraft control surface) later. The samples were prepared in accordance with aviation industry standards using the aviation industry materials at the approved facility (Malaysian Airlines Composite workshop in Subang). The experiment was conducted using the Instron 8802 UTM by following the ASTM Standards at the Faculty of Mechanical Engineering, University Teknologi MARA. From the experiment in accordance with the test standard, the results of the experiment showed the consistency in terms of strength of the specimen. The ultimate strength was found at the average 5.88 kN.

Keywords: *honeycomb sandwich composite panel, compressive load, flat-wise, experimental*

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Introduction: Types of Sandwich Panel

There are many types of composite materials being used in modern sandwich, panel in aviation, but the most common type is honeycomb sandwich composite. Figure 1 shows the common types of sandwich composite panels used in engineering structures [1]. They have similarities in terms of the face sheet structures but different core materials make them different in their mechanical properties' variation and application.

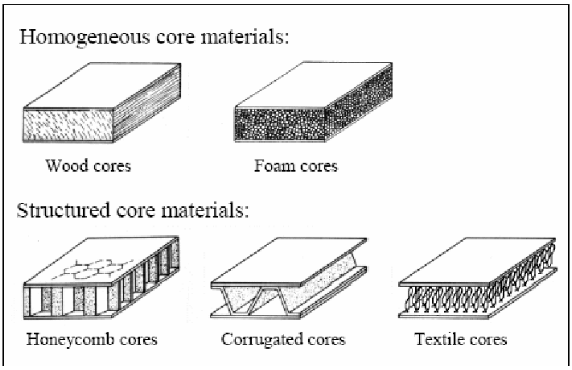


Figure 1: Different sandwich core designs in sandwich panels [1].

Definition of sandwich panel composites

According to Van Tooren [2] and Niu [3], sandwich structure is defined as a structure that is a combination of layers or plates. It consists of core in the middle, and skins or facesheets covering both sides of the core and the skins are attached to the core using adhesive. Figure 2 shows the construction of a sandwich composite panel.

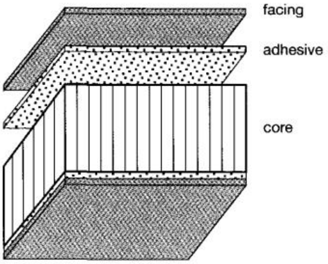


Figure 2: Construction of sandwich panels [3].

Advantages of sandwich composite panel

Sandwich composite panel is very good for its properties of stiffness to weight ratio thus can hold a large amount of lateral load, and thus helping to sustain global and local stiffness of the structures. Sandwich composite panel also is an excellent structure for damping acoustic sound making an ideal structure to isolate sound for the passengers' cabin comfort [1]. Sandwich composite panel has an excellent specific strength and stiffness compared to the weight and it does not inhibit corrosion problems compared to metallic structures [4]. Sandwich composite panel is not as prone as metallic structure when it comes to fatigue problems and it does not corrode like the aluminium especially if exposed to sea environment [2, 5] and therefore can reduce the direct operating cost (DOC) [4] since less maintenance is required. Moreover the sandwich structure is a very excellent material in lightning resistant [4] and has a very high electromagnetic resistance [6].

Honeycomb core sandwich composite and its advantages

The construction of honeycomb sandwich composite is like any sandwich composite and is like the one as shown in Figure 2. According to Niu [3], the only difference in honeycomb composite is the core shape, which has the shape of bee's honeycomb. The terminology of honeycomb core is shown in the Figure 3. The common nomenclatures for honeycomb core are the longitudinal length, L, (warp or ribbon direction), transverse width, W, (transverse direction), and thickness, T. The unique feature about honeycomb is the cell size, which can be varied according to the structural requirement. Honeycomb sandwich can be made from metals, fiberglass, papers, aramids, advanced composites and even carbon composites [2, 3].

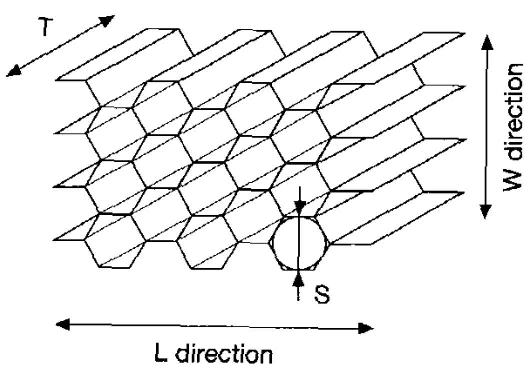


Figure 3: The terminology of honeycomb core [3].

The advantages of the honeycomb sandwich composites among others are:

a. The existence of the cells in the core makes it a very low-density composites leading to very lightweight. The density can also be varied by varying the core cell size [3]. Thus, a honeycomb sandwich composite has a very high strength to weight ratio.
b. The honeycomb sandwich composites can resist tensile and compressive stresses due to tensile, compressive and bending loads and can resist shear stresses due to in plane shear load and torsion [2].
c. The honeycomb sandwich composites can act as a thermal and sound isolation material since the inclusion of air cells in the honeycomb cells [6].
d. The honeycomb sandwich composite also has a very good damping and energy absorption behaviour if designed properly [1].
e. Honeycomb sandwich has superior mechanical properties for example high normal to surface stiffness and excellent shear stiffness, and excellent strength to weight ratio [6].

Loadings, behaviour, and failure modes of honeycomb sandwich composite panel

In civil structure, Dawood et al. [7] conducted an experiment in static and fatigue bending behaviour of GFRP sandwich panels for bridge application in the civil structure. The experiment was conducted to evaluate the insertion of the fibre insertions in the sandwich core. Camata and Shing [8] conducted an experimental study on static and fatigue load performance of GFRP honeycomb bridge deck. Their results showed that honeycomb sandwich panel can perform as intended.

Other research in the loading behaviour of honeycomb composite structure are done by Abbaadi et al. [9], who studied fatigue behaviour of composite honeycomb materials (aluminium/aramid fibre core) and Zankert and Burman [10], who studied the loading behaviour of a closed cell polymer foam which had the potential to be used in the sandwich core.

In terms of compressive load application, a very recent study were conducted on compressive loads on stiffened panel [11] and [12]. And in terms of application of compressive load in automotive structure, studies have been carried out as crush structure [13], and in the absorbent kinetic energy structure of a vehicle impact attenuator [14].

Material identification and selection

In this research, the structure to be replicated, would be a box structure of a vertical stabilizer in a civil aircraft. The specific area in the box was the skin of the vertical stabilizer. The structure in this area was constructed from honeycomb sandwich panel with the skin was made of carbon fibre. The carbon fibres used in making the specimens has the properties as shown in Table 1 and the actual sample can be seen in Figure 4.

Table 1: Mechanical properties of aircraft grade carbon fibers [3]

Mechanical Properties	**Symbol**	**Unit**	
Density	d	(kg/m^3)	1660
Tensile Strength	S	(MPa)	2400 - 3100
Young's Modulus	E	(GPa)	227 – 379
Service Temperature	T	(^{o}C)	500

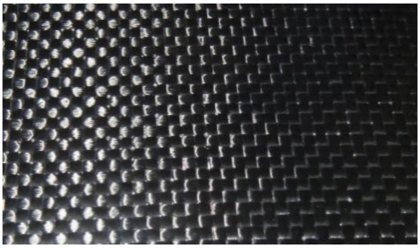


Figure 4: Actual cured plain weave carbon fiber specimen used in the experiment.

The honeycomb core used in this research was a phenolic-coated paper-based honeycomb from NOMEX ® [15]. Figure 5 shows the original sample of the honeycomb used in constructing the specimen. The properties of the honeycomb used in the research are laid in Table 2.

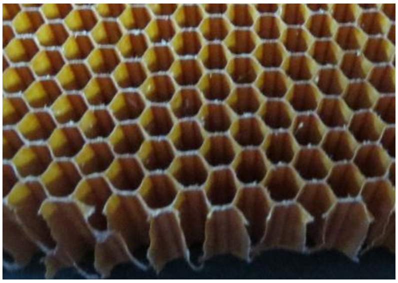


Figure 5: Actual Nomex ®honeycomb used as specimen in the experiment.

Table 2: Properties of the Nomex honeycomb used in the research [15, 16]

Density	Cell Size	Cell Configuration	Compression		Plate Shear					
			Bare Strength		L Direction			W Direction		
kg/m^3	mm		MPa		Strength, MPa		Modulus, GPa	Strength, MPa		Modulus, GPa
			Typ	Min	Typ	Min		Typ	Min	
32.037	3.175	RH	0.827	0.606	0.620	0.468	0.0296	0.344	0.262	0.0165

Note:
RH = Regular Hex
Typ = Typical
Min = Minimum

From Table 2, the honeycomb selected to be used in the research has the density of 32.037 kg/m^3. The cell size of the honeycomb is about 1/8 inches or around 3.2 mm in diameter. The material was chosen because it was commonly used material in aircraft repair procedure.

The mechanical properties of the carbon fibre cured with resin at 120°C are shown in Table 3. From Table 3, the plain weave carbon fibre cloth has identical Young's Modulus in x and y directions. It also has identical ultimate tensile strength and ultimate compressive strength in the x and y directions.

Table 3: Mechanical properties of carbon fiber composite materials, fiber / epoxy resin (120°C Cure) [17]

Fibres @ 0° (UD), 0/90° (fabric) to loading axis, Dry, Room Temperature, Vf = 60% (UD), 50% (fabric)

Mechanical Properties	Symbol	Units	Number
Young's Modulus 0°	E1	GPa	70
Young's Modulus 90°	E2	GPa	70
In-plane Shear Modulus	G12	GPa	5
Major Poisson's Ratio	ν12	--	0.10
Ult. Tensile Strength 0°	σt	MPa	600
Ult. Comp. Strength 0°	σc	MPa	570
Ult. Tensile Strength 90°	σt	MPa	600
Ult. Comp. Strength 90°	σc	MPa	570
Ult. In-plane Shear Strength.	τ	MPa	90
Ult. Tensile Strain 0°	εxt	%	0.85
Ult. Comp. Strain 0°	εxc	%	0.80
Ult. Tensile Strain 90°	εyt	%	0.85
Ult. Comp. Strain 90°	εyc	%	0.80

Mechanical Properties	Symbol	Units	Number
Ult. In-plane shear strain	γs	%	1.80
Density	d	g/cc	1.60

Specimen preparation

The actual specimen was constructed using the materials which were available at Composite Workshop at MAS Engineering, Malaysia Airlines Berhad, which is located at Subang, Selangor Malaysia [18]. The following flow chart in Figure 6 explains the detail process of fabricating the honeycomb sandwich panel for the research. The raw materials for making the specimen were Nomex ® phenolic-coated honeycomb core [16], plain weave carbon fibre cloth, and Hysol ® EA 9390 structural adhesive resin [19]. The curing process required HEATCON ® hot bonder [20], heat element blanket, and vacuum bagging system which consisted of vacuum pump, breathable cloth and air-tight plastic sheets with sealant tape.

The curing process of wet honeycomb sandwich panel in the vacuum bag was regulated using Heatcon ® Hot Bonder [20]. The wires from the heat blanket were connected to the Heatcon system and the vacuum line from the bag was also attached to the Heatcon system as shown in Figure 7. The curing process was done in a controlled environment; the maximum temperature was set at 180 degrees F (82 degrees C) for 90 minutes and the vacuum pressure was set at negative 16 psi (110.5 kPa). The specimen was left overnight to cool off before debagging process and the completed specimen was ready as shown in Figure 8.

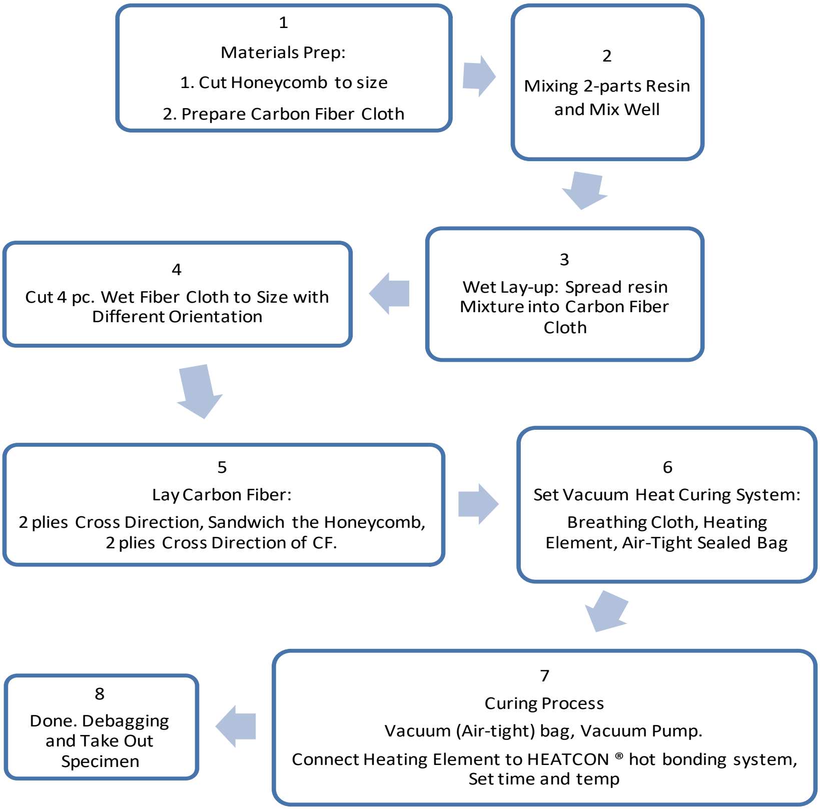


Figure 6: Flow chart of the honeycomb sandwich panel fabrication.

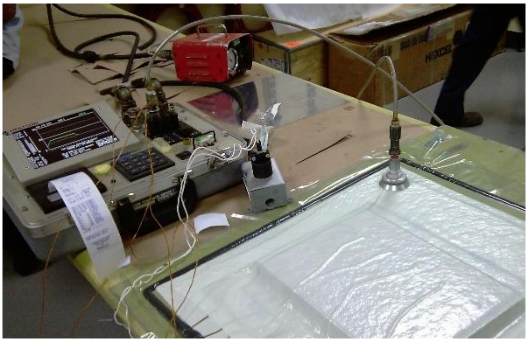


Figure 7: Heatcon ® Hot Bonder system and curing process of honeycomb core sandwich composite panel under vacuum and heat.

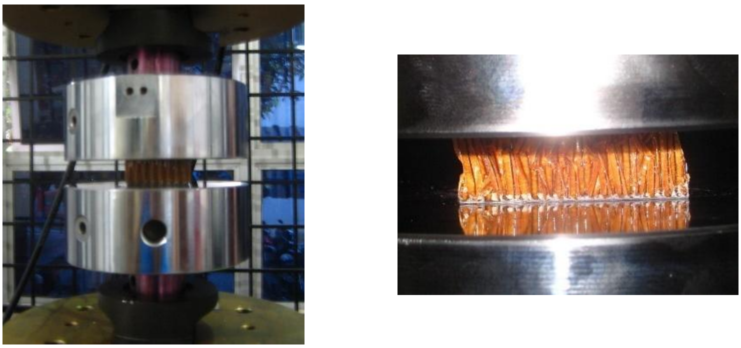
Figure 8: Completed and well cured specimen of honeycomb core sandwich composite panel.

Mechanical properties of honeycomb sandwich panel

In order to investigate the properties of the honeycomb sandwich panel, the 200 mm by 300 mm panel was cut into smaller 50 mm by 50 mm pieces for ASTM standard tests compression flatwise [21]. For the compressive flatwise test, the test was done in accordance to the ASTM Standards C365/C365M-11a [21]. The test investigated and determined the compressive strength and modulus of the sandwich panel cores. The properties investigated for the test usually involved the load being applied to the panel normal (perpendicular) to the plane of the skin where the core acted as a structure in the middle (sandwiched). Usually the test would evaluate how much the core could resist a uniaxial compression with the skin. The test sample was placed between a pair of platens attached to the testing machine as shown in the following Figure 9.

Figure 9: Sandwich panel placed between a set of loading platens in the testing machine [21].

According to the standard, at least five (5) test samples should be used to attain proper results. The sample geometry should be either square or circle. In this research five (5) square samples were used with the size of 50 mm by 50 mm. For the ramp speed of the test, it is recommended that 0.5 mm/min should be used to produce failure within 3 to 6 minutes [21]. Figure 10 shows the actual sample being tested.



(a) (b)

Figure 10: Sample between loading platen (a), sample being compressed (b).

Experimental compressive test flat-wise result

For the compressive test flat-wise, the test was done in accordance to the ASTM Standards C365/C365M-11a [21]. The test investigates and determines the compressive strength and modulus of the sandwich panel cores. The properties investigated for the test usually involved the load being applied to the panel normal (perpendicular) to the plane of the skin where the core acts as a structure in the middle (sandwiched). Usually the test will evaluate how much the core can resist a uniaxial compression with the skin.

There were five test samples used in accordance to the standard to attain proper results. The sample geometry used in this research was five (5) square samples with the size of 50 mm by 50 mm. The ramp speed of 0.5 mm/min was used to produce failure within 3 to 6 minutes per sample. The machine was stopped at the extension of 2 mm when the load reached plateau.

According to the standard, the purpose of the test is to find ultimate flatwise compressive strength according to the following equation:

$$F_z^{fcu} = \frac{P_{\max}}{A} \tag{1}$$

where:

F_z^{fcu} = ultimate flatwise compressive strength, MPa

P_{max} = ultimate force prior to failure, N

A = cross-sectional area, mm^2

During the test, the test samples under compressive load were observed. According to the observation, the failure of the core can occur anywhere and there was no specific failure location which can be concluded. The results of the observation can be seen in Figure 12.

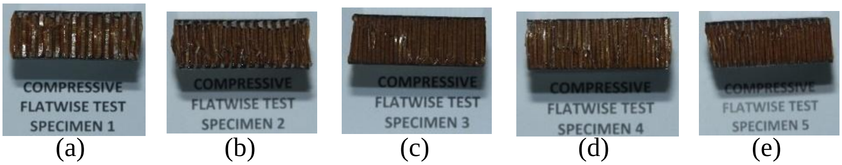


Figure 11: Photos show the test samples of sandwich panel after compressive flatwise tensile test.

From Figure 11, the failure within the honeycomb core occurred anywhere within the core. The result data of the test is plotted in the following Figure 12.

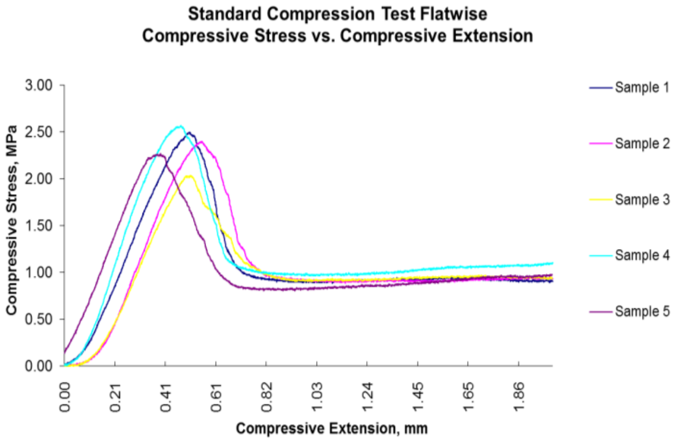


Figure 12: Result of flat-wise compressive test of the honeycomb core sandwich panel.

From Figure 12, the maximum compressive load, the maximum deflection at the maximum load and the ultimate compressive strength is tabulated in the following Table 4.

Table 4: Results of compressive flatwise test

Sample	Maximum compressive load, (kN)	% Errors	Maximum deformation at maximum load, (mm)	% Errors	Ultimate flatwise compressive strength (MPa)	% Errors
1	6.248	6%	0.5061	4%	2.499	4%
2	6.001	2%	0.5546	14%	2.400	0%
3	5.094	-13%	0.5123	5%	2.038	-15%
4	6.427	9%	0.4725	-3%	2.571	7%
5	5.672	-4%	0.3914	-20%	2.269	-6%
Average	5.888	0	0.4874	0%	2.409	0

From Figure 12, all samples show the same strength where the ultimate strength was observed to occur near of each other. From Table 4, the highest compressive load was observed at 6.427 kN (ultimate compressive strength of 2.571 MPa) while the lowest load was observed at 5.094 kN (ultimate compressive strength of 2.038 MPa). The average maximum compressive load was observed at 5.888 kN (ultimate compressive strength of 2.409 MPa). From this load, it was seen that at the maximum load, the sample failed at 0.4725 mm. At the minimum load, the sample failed at 0.5123 mm. At the average load of 5.888 kN, the sample failed at 0.4874 mm. At the position of 0.82 mm, the sample did not hold any more load as it can be observed from Figure 4-5, the compressive stress is just constant at around 1.0 MPa from 0.82 mm. The machine was stopped when the sample was compressed at 2.0 mm.

Percentage difference of experimental results

From Table 4, the error is lowest for sample 3 in terms of compressive load (-13%), and ultimate strength compressive strength (-15%). However, Sample 5 has the lowest error of maximum deformation at maximum load (-20%) while Sample 2 has the highest error (14%). According to the standard the errors recorded should be less than ± 50%.

Conclusion

This article is reporting the experiment conducted to investigate whether the honeycomb core sandwich composite panel is up to standard or otherwise. From the experiment and the Test Standards (ASTM Standards C365/C365M-11a for honeycomb structure flatwise compressive strength), it proved that the samples preparation meets the aviation industry standards, from the materials selection and their mechanical properties, methods of preparation and steps in preparation of specimens. It can be concluded that using the aviation industry materials, the aviation industry standard method of manufacturing, prepared at the approved centre, the final product can be used in the repair process in the aircraft composite skin structure as the test standards results showed.

Acknowledgement

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