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Development of Honeycomb Sandwich Structure for Aeronautical Flooring Components

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Abstract – The sandwich structure consists of a core which holds the facing skins apart from one another. The core resists the shear loads, due to this, stiffness of the structure increases. Sandwich component is joined by adhesive which allows it to act as one unit with high torsional and bending rigidity. Nowadays, honeycomb sandwich structures are becoming more popular due to their applications in various industries like aerospace, marine, automotive, construction, because they possess properties such as high strength to weight ratio, light in weight and high energy absorbing capacity. Aim of this paper is to focus on properties, materials, manufacturing methods, and theoretical analysis of sandwich structure. This paper gives overview of honeycomb sandwich structure, its manufacturing, load distribution, deflection, and bending and shear stiffness. Paper focuses on the bending stiffness, shear stiffness and deflections of honeycomb sandwich panel made up of aluminium alloys with different core thickness and varying thickness of upper and lower plate. The different failure modes of honeycomb panel under bending tests of honeycomb sandwich panel are explained. FEA analysis shows when the load is applied the stress distribution on upper skin is higher than core and lower skin, the failure mechanism of structure is upper skin cracking or debonding between skins and core.

Keywords — Honeycomb Sandwich Structure, Manufacturing Method, Deflection, Shear Stiffness, Three-Point Bending Test, Failure Modes.

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INTRODUCTION

A honeycomb sandwich structure is a special class of materials which is fabricated by attaching two thin skins to a lightweight core. The core material is usually thick as compared to the skin material. The overall strength of honeycomb sandwich structure depends upon the strength of skin, core and interfacial bonding between core and skins. The honeycomb sandwich structure is used in aircrafts, ships and bridges due to their excellent structural efficiency and strength to weight characteristics [1]. The solid structures are replaced by composites due to their improved properties. The properties of honeycomb sandwich structure can be improved by varying core height, core shape and thickness of the face material [2]. Mechanical performance of sandwich structure is studied by three-point bending. The sandwich panels are designed such that failure occurs in the core of the panel. The honeycomb sandwich structure has better corrosion resistance, lower structural vibrations under same operational conditions due to this they replace their metallic counter parts [3]. The materials used for core are foam, balsa, corrugated aluminium, Nomex, glass thermoplastics [4], [5]. Sandwich panel consists of two skins (i. e., upper skin and lower skin) and core as shown in figure 1.

In figure 1, A-honeycomb panel, B- upper plate and lower plate, C- core. The plates are attached to the core by using suitable adhesives. Aluminium alloys, titanium and high tensile steels can be used as skin materials. Wang et al. (2011) described the mechanical response of square honeycomb sandwich plate with asymmetry face sheet when subjected to blast load [6]. Square honeycomb sandwich plate is analysed for different sizes of upper face sheet to lower face sheet, to find maximum deflection and energy absorption. The results show that, the efficiency of energy absorption increases with decrease in thickness ratio at same blast loading.

An increase in core height of a honeycomb panel will increase its energy absorbing capacity so it can be used for applications like automobile bumper [7]. Keskes et al. (2007) discussed the effects of defect in static and fatigue studies of honeycomb core sandwich panels. Two tests, static and fatigue were performed on aluminium honeycomb sandwich panel specimen with and without defect. The result shows that there were no effects of defect observed in the case of the static study. In fatigue study, the fatigue life of the defect panels decreased rapidly when the applied load increased compared to the panels without a defect. The results of the acoustic emission show the crack initiation and propagation and can be used as a reliable survey method for the damage mechanisms [9].

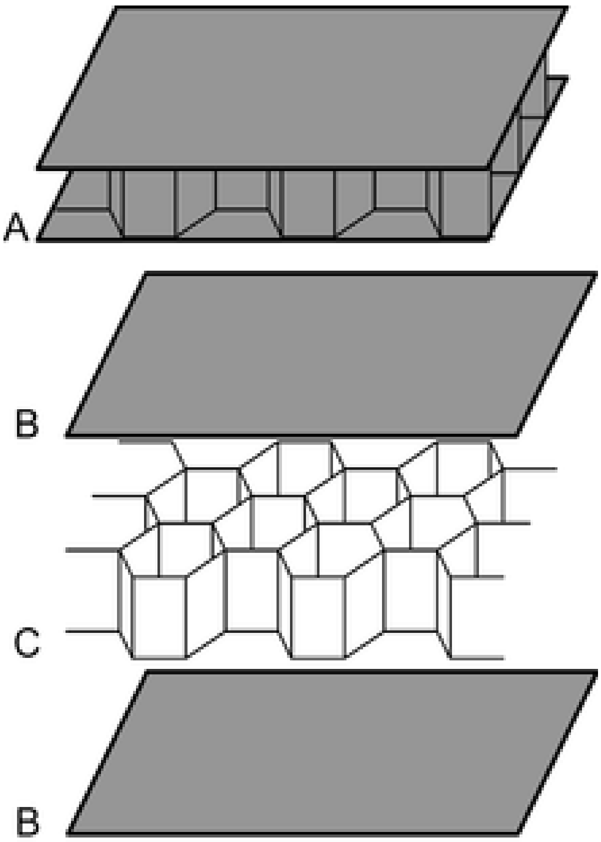


Fig. 1 Honeycomb sandwich panel

1) Tounsi et al. (2015) investigated experimentally the dynamic behavior of an aluminium alloy honeycomb under mixed shear-compression loading with a special attention on the combined effects between the cells in-plane orientation and the loading angles. An improvement of an existing experimental set-up is proposed and an original measurement technique based on an electro optical extensometer is used to overcome a separation phenomenon observed during the test [11].

PROPERTIES:

Sandwich panel offers excellent rigidity at minimal weight. The behavior of the honeycomb structures is isotropic; hence the panels react differently depending on the orientation of the structure. Therefore, it is necessary to distinguish between the directions of symmetry, the so-called L and W-direction [12]. The L-direction is the strongest and the stiffest direction. The weakest direction is at 60° from the L-direction (in the case of a regular hexagon) and the most compliant direction is the W-direction. Another important property of honeycomb sandwich core is its compression strength. Due to the efficient hexagonal configuration, where walls support each other, compression strength of honeycomb cores is typically higher (at same weight) compared to other sandwich core structures such as, for instance, foam cores or corrugated cores. Sandwich materials have high bearing capacity, good thermal insulation, excellent acoustic damping properties, and long life at low maintenance cost.

MATERIAL SELECTION:

The honeycomb sandwich structures can be made of variety of materials and panel configurations. The sandwich structure provides great versatility as different range of core and facing material combinations can be selected. The following two criteria should be considered in selection of facing skin, core and adhesive.

Structural Considerations: In this the structural efficiency, relative stiffness of material and adhesive performance should be considered. Honeycomb cores and facing material's strength depends on their mechanical properties. Stiffness of honeycomb sandwich structure is maximized at very low weights. While selection of adhesive material care is taken that, there is a rigid bonding between the facing and core material in order to transmit load from one face to the other.

Environmental Considerations: The temperature, heat transfer rate, flammability, humidity are the factors categorized under these criteria. The sandwich structures with metallic facing and metallic cores maximize heat flow characteristics. Non-burning, self-extinguishing, flammable materials selected for sandwich construction based on application. The selected material offers excellent resistance to degradation due to humidity and moisture. In selection of a material for honeycomb sandwich structure economic criteria is also considered. Materials are available in a wide range including: - Aluminium, Nomex Fibreglass, Korex, Kevlar, Carbon.

MANUFACTURING:

There are different methods by which we can manufacture honeycomb sandwich panel. Primary methods used to manufacture honeycomb are: (a) Adhesive bonding and expansion (b) Corrugation and adhesive bonding (c) Corrugation and braze welding (d) Extrusion. In case of high density honeycombs Corrugation method is used but it is slower one. Ceramic and thermoplastic honeycombs are manufactured by Extrusion process. The expansion and corrugation method for manufacturing of honeycomb panels are shown in figure 2 and figure 3 respectively.

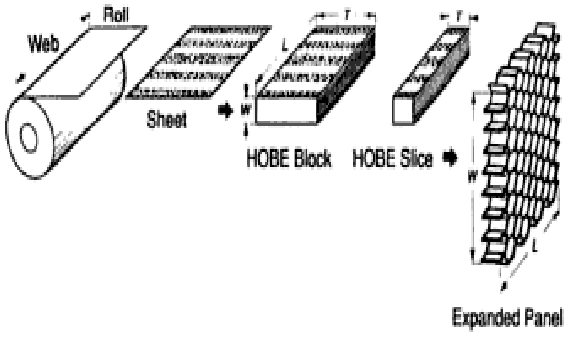


Fig. 2 Expansion manufacturing process (Campbell, 2010)

Expansion process means that layers of materials with printed adhesive lines are first glued together. After that the block, consisting of a few layers of that material, is sliced into pieces of the required size. Finally each piece is expanded and several honeycomb cores are received. Expansion process consists of five stages, which are roll, sheet, HOBE (honeycomb before expansion) block, HOBE slice, expanded honeycomb panel as shown in figure 2 [13].

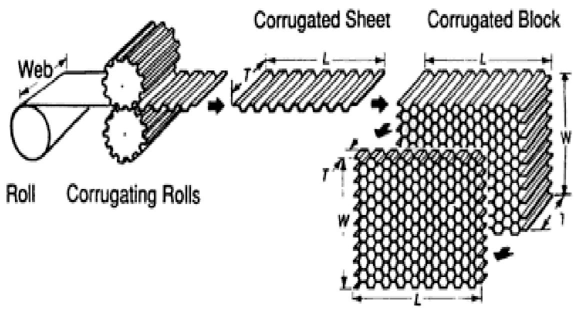


Fig. 3 Corrugation manufacturing process (Campbell, 2010)

Corrugation process consists of folding of material into certain shape followed by gluing and slicing. Corrugation manufacturing in turn consists of roll, corrugating rolls, corrugated sheet, corrugated block, honeycomb panel. Shahdin A. et al. [8] fabricated sandwich beam specimens by using an autoclave and an aluminum mold. The two skins are bonded to each side of a light weight core with the help of co-curing process. Fabian R. et al. [10] presented the additive layer manufacturing technique for sandwich structures. This technique allows placing of the face sheets on a honeycomb core by a wet lay-up process followed by curing of sandwich plate in autoclave. Paika J. et al. [12] described the adhesive bonding and brazing method to join the honeycomb core material with the skin material. The adhesive films are inserted in between the core and facing material to produce bonding followed by heating in furnace.

FAILURE MODES:

Honeycomb sandwich plate consists of mainly three parts as explained earlier. Honeycomb sandwich panel is tested on three-point machine to check its bending strength. During testing, different failure modes are observed. Giglio. et al. [14] presented the three-point bending test on a sandwich panel made with aluminium skin and nomex honeycomb core. Such types of sandwich panels are used in aeronautical components. Various modes of failures are observed during three-point bending test on MTS Alliance RT/100 testing machine (100KN maximum load) are face yielding, intra-cell dimpling, core shear and local indentation.

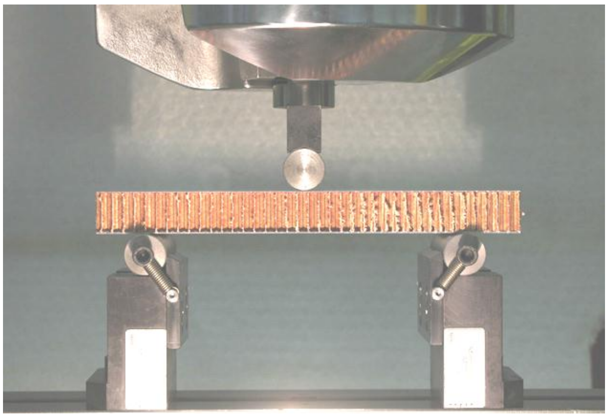


Fig. 4 Three-point bends test setup

Properties of the face and the core materials, the geometry of structure and loading arrangement are the factors on which critical failure mode and its corresponding failure load depends. Yan et al. [15] fabricated sandwich beams having empty and aluminum foam-filled corrugated cores. 304 grade stainless steel was used to fabricate sandwich plate. Closed-cell aluminium alloy foam was selected as the filling material. Fabricated sandwich plates were tested on MTS-880 materials test system. The test result shows that, there are four main modes of collapse of sandwich beam (1) face yielding, (2) face elastic/plastic wrinkling, (3) indentation and (4) core shear.

Crupi et al. [16] explained the collapse modes in aluminium honeycomb sandwich panels under bending and impact loading. The aluminium alloy (AA5052 and AA5754) sandwich panels with honeycomb core were tested on a servo-hydraulic load machine. It was concluded that, the honeycomb panels fail by the core shear failure mode. There is a perfect bond between the faces and the core and the possibility of delamination is eliminated, sandwich beams fail by several modes in bending tests: face yield, core shear, indentation and face wrinkling. The result of bending test also shows that the energy absorption capacity of sandwich panel is strongly affected by the size of the honeycomb cells.

Banghai et al. [17] presented the failure modes of foam-core sandwich beams subjected to three-point bending test. The sandwich beams were made of face sheet having aluminium alloy (3003) and core material is closed cell aluminium foam. The failure modes observed in the quasi-static three-point bending tests are facing yield, core shear and indentation. Sandwich beams failure can depend on the geometry of the sandwich structure and the relative strength of the face sheets and foam core.

Property Analysis of aluminium honeycomb sandwich structure:

This section focuses on the theoretical analysis of honeycomb sandwich panel in three-point bending test. The honeycomb sandwich structure is made using aluminium alloys. The material used for core is aluminium alloy 3003 and for the upper and lower skin of panel is aluminium alloy 6061. The honeycomb core is attached to the upper and lower skin by epoxy film adhesive. Honeycomb core has a hexagonal cell structure. Sandwich structure specimens have a rectangular shape of 150×50mm., honeycomb cells orientation have ribbon direction, which is also called as L. The sample calculations of bending stiffness, shear stiffness and deflections of honeycomb sandwich panel are shown below. The dimensions of sandwich plate are, Upper and lower plate thickness is 0.75mm, core thickness is 10mm. The geometrical and mechanical properties of the sandwich panels are listed in Table 1.

Table1: Properties of Honeycomb Panel	
Honeycomb Core	
Material	Al3003
Thickness (mm)	10
Cell size (mm)	9
Density (kg/m^3)	43.2
Bonding strength (kg /mm^3)	36
Panel Skin	
Material	Al6061
Upper and lower skin thickness (mm)	0.75
Density (kg/m^3)	2700
Poissons ratio	0.33
Modulus of elasticity (GPa)	70
Shear modulus (MPa)	220

- **Bending stiffness:**

The bending stiffness of the honeycomb sandwich panel is calculated by using formula as [15]:

$$D = \frac{E t_f h^2 b}{2} \quad (1)$$

In equation 1, E- Modulus of elasticity, t_f-Skin thickness; h-core and skin thickness; b-panel width.

So, the bending stiffness of the honeycomb sandwich panel (150×50×11.5mm) is calculated as151.67 N.m^2

- Shear stiffness:

It is calculated using equation 2.

Where, Gc-Shear modulus (MPa);

$$S = bhG_c \quad (2)$$

So, shear stiffness for same panel is 118.250×10^{3}N.

- **Deflection:**

2) The total deflection at the center of honeycomb panel is sum of the deflections due to bending of upper plate and shearing of core [18]. The formula used to calculate deflection is given by equation 3.

$$\delta = \frac{k_b F L^3}{D} + \frac{k_s F L}{4S} \quad (3)$$

Where, F- Load, L-length of panel; kb and ks are deflection coefficients; D-bending stiffness and S-shear stiffness. The values of deflection coefficients when panel is simply supported are taken as1/48 and1/4 [15]. By using equation 3, deflection of honeycomb sandwich panel with 0.75mm face thickness and 10mm core thickness is calculated and the value is 0.89mm. The actual photographs of hexagonal honeycomb core and honeycomb sandwich panels are shown in Figure 5.

Table 2 shows the deflections for the honeycomb sandwich panels with different core thickness, different upper and lower plate thickness which are theoretically calculated. The two cores were used in the theoretical analysis of honeycomb sandwich panel one is 10mm core and other is 14mm core. The densities of core are calculated and listed in the table 2 for all the specimens. The density for 10mm core is less than that of 14mm core. The bending stiffness for honeycomb sandwich panel made of aluminium alloys is shown in table 2, the values of bending stiffness increases as the load increases.

Numerical analysis for three point bending test:

The numerical models of aluminium honeycomb sandwich panel were developed to investigate the bending behaviour of sandwich panel. The solid model is generated using CATIA and it is imported to Ansys workbench. The figure 6 shows the model of honeycomb sandwich panel and its analysis on ANSYS showing total deformation, Max. Von-misses stress. In analysis, the honeycomb sandwich panel made of aluminium alloys is simply supported on the two rollers. The diameter of roller is 10mm and its width is 50mm which is equal to width of sandwich panel. In three-point bending test the load is applied on sandwich panel at its centre by using roller having same dimensions as that of the supporting rollers. When the load is applied on the sandwich panel it shows the buckling behaviour. The buckling behaviour of panel is shown in the figure 6. The result of analysis shows that the maximum stress is 169 MPa when panel suffers from a 1137.52 N bending load. It can be seen that the failure of sandwich panel starts at its top plate first, as the load increases the core de-bonding will take place. The stress distribution on top plate is much higher than the bottom plate and core.

TABLE 2: PROPERTY ANALYSIS OF ALUMINIUM HONEYCOMB STRUCTURE

Sr. No.	Plate thickness (mm)		Core thickness (mm)	Core density (Kg/m^3)	Bending Stiffness ($N.m^2$)	Load (N)	Shear Stiffness $S\times10^5$ N	Deflections (mm)
	Upper plate	Lower Plate						
1.	0.75	0.75	10	43.20	151.670	1137.52	1.18250	0.89
2.	0.5	0.5	14	48.14	183.980	1379.76	1.59500	0.96
3.	0.5	0.5	10	43.20	96.468	723.51	1.15500	0.76
4.	0.75	0.75	14	48.14	285.550	2141.62	1.62250	1.02
5.	0.75	0.5	14	48.14	233.943	1754.57	1.68875	0.92
6.	0.75	0.5	10	43.20	246.948	1852.11	1.16875	1.12
7.	0.5	0.75	10	43.20	246.948	1852.11	1.16875	1.12
8.	0.5	0.75	14	48.14	233.943	1754.57	1.68875	0.92

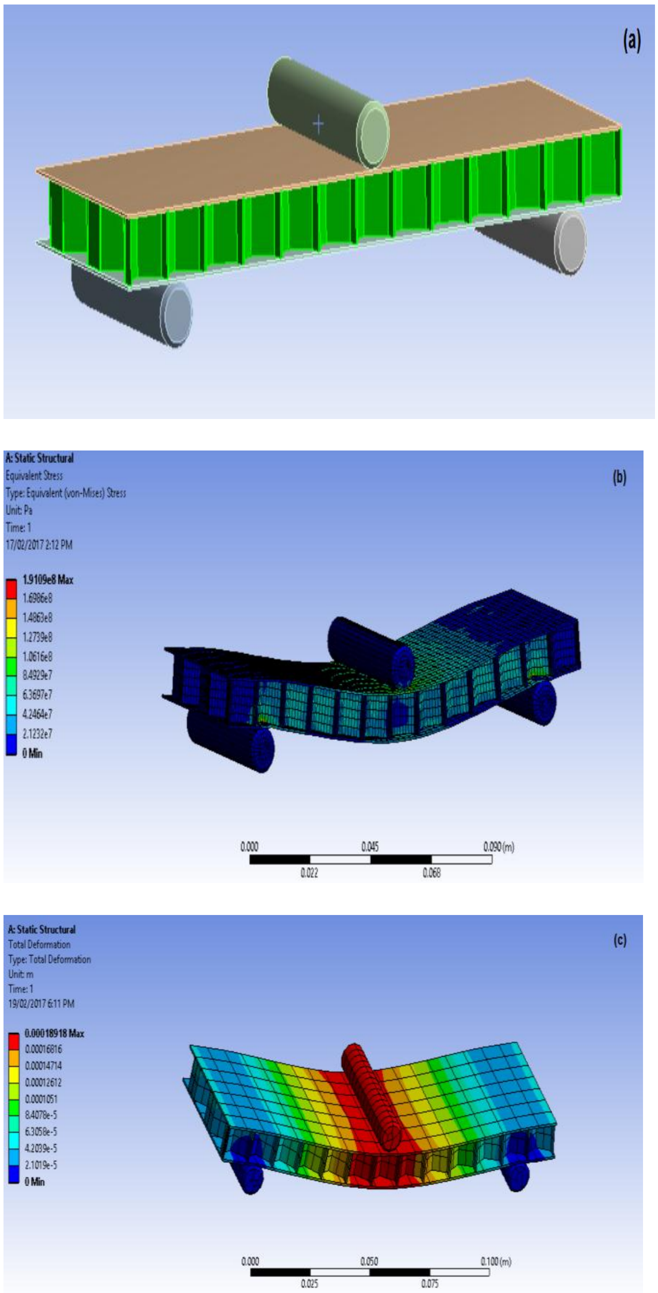
The total deformation of honeycomb sandwich panel is 0.16 mm. The honeycomb sandwich panel under loading conditions shows the failure mechanisms, the crack points were observed on the top plate of panel. The core of honeycomb panel is fails due to shear failure. The thickness of panel increases its energy absorbing capacity, as thickness increases time to reach peak load is increases.

CONCLUSION

The theoretical approaches have been used to find out the deflections of honeycomb sandwich structures, from that following points are concluded.

1. An overview is carried out on different manufacturing methods of honeycomb sandwich structures. The buckling behaviour of honeycomb sandwich panel is highlighted.

2. The bending stiffness, shear stiffness and deflections of sandwich panel were calculated by theoretical analysis. The analytical calculations show that deflections of sandwich panel for three-point bending is not much affected by varying core thickness and with different combinations of face sheets.



3. The numerical analysis of honeycomb sandwich panel for three-point bending shows the maximum stress on upper plate

and its value decreases for core and bottom plate. Also, the deformation of panel is found out through analysis.

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