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Bending Behavior of Aluminum Honey Comb Sandwich Panels

K.Kantha Rao, K. Jayathirtha Rao, A.G.Sarwade, B.Madhava Varma

ABSTRACT:- Aluminum sandwich construction has been recognized as a promising concept for structural design of light weight systems such as wings of aircraft. A sandwich construction, which consists of two thin facing layers separated by a thick core, offers various advantages for design of weight critical structure. Depending on the specific mission requirements of the structures, aluminum alloys, high tensile steels, titanium or composites are used as the material of facings skins. Several core shapes and material may be utilized in the construction of sandwich among them, it has been known that the aluminum honeycomb core has excellent properties with regard to weight savings and fabrication costs. This paper is theoretically calculate bending behavior, of sandwich panels and to compare the strength to weight ratios of Normal Aluminium rod(panel) and Aluminium Honey Comb Panel .

Key words:- Aluminium material, Sand witch Panel , Honey Comb core, Adhesive .

1. INTRODUCTION

Sandwich panels are used for design and construction of lightweight transportation systems such as satellites, aircraft, missiles, high speed trains. Structural weight saving is the major consideration and the sandwich construction is frequently used instead of increasing material thickness. This type of construction consists of thin two facing layers separated by a core material. Potential materials for sandwich facings are aluminum alloys, high tensile steels, titanium and composites depending on the specific mission requirement. Several types of core shapes and core material have been applied to the construction of sandwich structures. Among them, the honeycomb core that consists of very thin foils in the form of hexagonal cells perpendicular to the facings is the most popular. A sandwich construction provides excellent structural efficiency, i.e., with high ratio of strength to weight. Other advantages offered by sandwich construction are elimination of welding, superior insulating qualities and design versatility. Even if the concept of sandwich construction is not very new, it has primarily been adopted for non-strength part of structures in the last decade. This is because there are a variety of problem areas to be overcome when the sandwich construction is applied to design of dynamically loaded structures. To enhance the attractiveness of sandwich construction, it is thus essential to better understand the local strength characteristic of individual sandwich panel/beam members. The conventional single skin structure, which is of single plates reinforced with main frames and stiffeners normally necessitates a fair amount of welding, and has a considerable length of weld seams. Further, the lighter but thinner plates employed tend to increase weld distortions that may in some cases require more fabrication work to rectify. More weld seams also mean a greater number of fatigue initiation locations as well. Honeycomb sandwich construction, with a honeycomb core is sandwiched by two outer facing skins is better able to cope with such difficulties.

Sandwich panels also provide added structural weight savings in the structure. It is for these reasons that the sandwich construction has been widely adopted for large weight critical structures. Honeycomb-cored sandwich panels have been used as strength members of satellites or aircraft, thus efficiently reducing their structural weight. In the railroad industry, passenger coaches of high-speed trains such as the TGV have been designed and fabricated using aluminum honeycomb sandwich panels. Recently, attempts to use aluminum sandwich panels as strength members of high-speed vessel hulls have also been made.

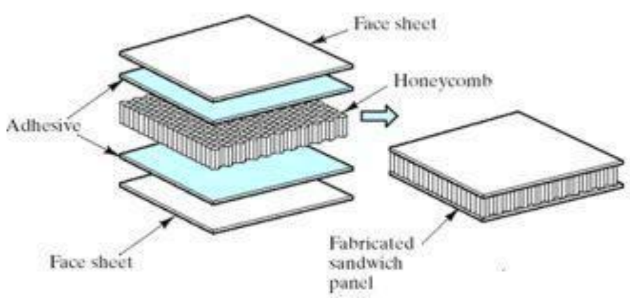

Fig1. Honey Comb Sandwich Panel

This paper deals with the design and analysis of aerospace lifting surface with honeycomb core. Lifting surfaces are essentially designed to take up bending loads due to lift. Bending stresses will be maximum at the top and bottom surfaces, low stresses at the middle. Honeycomb panel construction suits this requirement, where top and bottom skin takes the bending load.

To understand the bending behavior of honeycomb Sandwich panels, analysis is carried out for the specimen level three point bending test. The honeycomb

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* Correspondence Author (s)
K.Kantha Rao*, Associate Professor CMR College of Engineering and Technology, Hyderabad.
K. Jayathirtha Rao, Director(Retd.), RCI, Hyderabad.
A.G.Sarwade, Professor, Malla Reddy College of Engineering and Technology, Hyderabad.
B.Madhava Varma, Assistant Professor. MVGR College of Engineering, Vizianagaram, Email:kkrao_konka@yahoo.com).

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sandwich construction is one of the most valued structural engineering innovations developed by the composites industry.

2. MATERIALS SELECTION

The honeycomb sandwich construction can comprise an unlimited variety of materials and panel configurations. The composite structure provides great versatility as a wide range of core and facing material combinations can be selected. The following criteria should be considered in the routine selection of core, facing, and adhesive.

2.1 Structural Considerations

Strength: Honeycomb cores and some facing materials are directional with regard to mechanical properties and care must be taken to ensure that the materials are orientated in the panel to take the best advantage of this attribute.

Stiffness: Sandwich structures are frequently used to maximize stiffness at very low weights. Because of the relatively low shear modulus of most core materials, however, the deflection calculations must allow for shear deflection of the structure in addition to the bending deflections usually considered.

Adhesive Performance: The adhesive must rigidly attach the facings to the core material in order for loads to be transmitted from one facing to the other. Suitable adhesives include high modulus, high strength materials available as liquids, pastes or dry films. As a general rule, a low peel strength, or relatively brittle adhesive should never be used with very light sandwich structures which may be subjected to abuse or damage in storage, handling or service.

Cell Size: A large cell size is the lower cost option, but in combination with thin skins may result in telegraphing, i.e. a .dimpled. outer surface of the sandwich. A small cell size will give an improved surface appearance, and provides a greater bonding area, but at higher cost.

Cell Shape: Normally supplied with hexagonal cell shapes, a few honeycomb types can be supplied with rectangular cell shapes

2. 2 Skin Materials: Skin considerations include the weight targets, possible abuses and local (denting) loads, corrosion or decorative constraints, and costs. Facing material thickness directly affects both the skin stress and panel deflection.

Adhesive Materials: For honeycomb sandwich bonding, the following criteria are important:

Fillet Forming: To achieve a good attachment to an open cell core such as honeycomb, the adhesive should flow sufficiently to form a fillet without running away from the skin to core joint.

Bond Line Control: Every Endeavour should be made to ensure intimate contact between the parts during bonding, as the adhesive needs to fill any gaps between the bonding surfaces. Adhesives are often supplied supported by a carrier cloth, for the purpose of helping them to remain in place where the parts are squeezed particularly tightly together.

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3. SANDWICH PANEL LOADS

3.1 Loads: Consider a cantilever beam with a load applied at the free end. The applied load creates a bending moment which is a maximum at the fixed end, and a shear force along the length of the beam. In a sandwich panel these forces create tension in the upper skin and compression in the lower skin. The core spaces the facing skins and transfers shear between them to make the composite panel work as a homogeneous structure. Cantilever beam with hexagonal core is shown in Fig 2

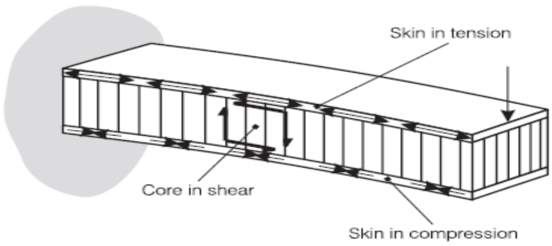

Fig. 2 Cantilever honeycomb beam

3.2 Deflections: The deflection of a sandwich panel is made up from bending and shear components. The bending deflection is dependant on the relative tensile and compressive module of the skin materials. The shear deflection is dependant on the shear modulus of the core.

Total Deflection = Bending Deflection + Shear Deflection.

4. THEORETICAL ANALYSIS OF THE SANDWICH PANELS

Quick strength estimation methods are required in the preliminary structural design stage. For this purpose, the present paper is to predict the strength of aluminum honeycomb sandwich panels using simplified approaches.

4.1 Bending Behavior

A simplified method is employed for the analysis of bending behavior for the present sandwich panel specimen. A simply supported honeycomb sandwich beam subjected to a line load at its mid-span is considered as shown in Fig. 3.1. Fig. 3.2 shows assumed stress distribution at the mid-span cross section of the honeycomb sandwich beam. It is assumed that the facing plate carries only bending stresses .When the thickness of facing plates is small, the variation of bending stress through plate thickness direction may be ignored. It is also supposed that the honeycomb core carries only the vertical shear stresses. A simply supported honeycomb sandwich beam subjected to a line load at its mid-span is considered as shown in Fig. 2

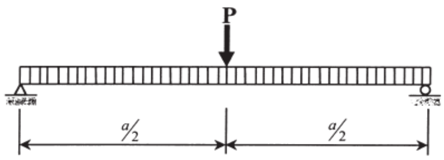

Fig. 3 A Simply supported honeycomb sandwich beam

Assumed stress distribution at the mid-span cross **section of the honeycomb sandwich beam is shown in Fig 4**

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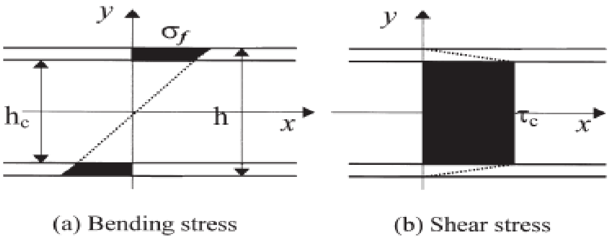

Fig 4. Idealized distributions of bending and shear stresses in an aluminum sandwich beam

Considering the rotational restraints between facing plates and core, the distribution of shear stresses tc is assumed to be uniform through the core depth hc. Kelsey et al provide a formula of the mid-span deflection for the sandwich beam in the linear elastic regime as follows

$$w = \frac{Pa^3}{48E_f I_f} + \frac{Pa}{4A_c G_{ca}} \quad \text{...........(1)}$$

The first term of the right hand side in Eq. (1) is due to bending effect alone and the second one accounts for the shear effect. A comparison of theoretical predictions (i.e., between load and mid-span deflection) using Eq. (1) is made for different material specimens under bending. The theoretical results neglecting shear effects are also compared in the figure. It is seen that Eq. (1) predicts the linear elastic bending response of aluminum honeycomb sandwich beam well. It is clear that the shear stress related effects brought on by the honeycomb core cannot be neglected.

A simplified formula for predicting the critical value of applied loads is also studied. Considering the assumed stress distribution shown in Fig the bending moment of a simply supported honeycomb sandwich beam can be approximately calculated by integrating the first moment of the bending stress with regard to the neutral axis as follows:

$$M = C.\frac{bh^2\sigma_f}{4}.\left\{1-\left(\frac{h_c}{h}\right)^2\right\} = \frac{Pa}{4} \quad \text{.......(2)}$$

where C is a constant representing the shear effects due to honeycomb core on the resistive bending moment.

The constant C in the above may be obtained from Eq. (3) by assuming that the shear effects of cores for panel strength are likely to be similar to those for panel stiffness. This results in,

$$C = \frac{C_1}{C_1 + C_2} \quad \text{..................(3)}$$

where

$$C_1 = \frac{a^3}{48E_f I_f}, \qquad C_2 = \frac{a}{4A_c G_{ca}}$$

The critical load is obtained when the bending stress of facing plate reaches the yield stress, i.e., $\sigma_f = \sigma_{fo}$. Therefore, by replacing P by Po, Eq. (7) leads us to the following critical load.

$$P_0 = C.\frac{bh^2\sigma_{fo}}{a}\left\{1-\left(\frac{h_c}{h}\right)^2\right\} \quad \text{.........(4)}$$

The bending test setup is shown in Fig 5

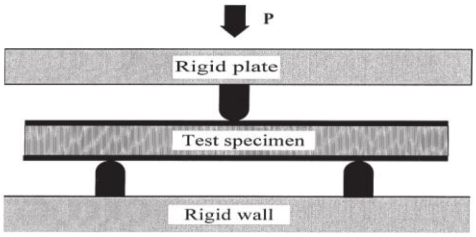

Fig 5. Bending test setup

The honeycomb panel after test is shown in the following Fig 6

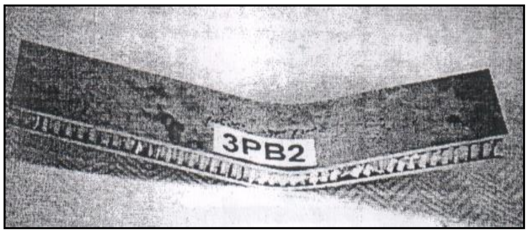

Fig 6. Honeycomb panel after test

4.2 Critical load(P_O)

Maximum bending moment for the simply supported honeycomb beam(M) = pa/4……(5)
We know bending equation
ie, M/I=E/R= σ/Y ….. (6)
Where M= maximum bending moment
I =area moment of inertia of the beam vertical cross section
E = modulus of elasticity of aluminum
σ = bending stress
Y = distance of any fibre from neutral axis

Critical load is the load at which bending stress is equal to yield stress.
Then $\sigma = \sigma_f$,
From equation (6), $M/I = \sigma_f/Y$
$M = \sigma_f (I/Y) = \sigma_f(Z)$, where Z=section modulus

5. AVERAGE DENSITY OF HEXAGONAL HONEY COMB SAND WICH PANEL

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In each honeycomb cell there are two interbonded double cell walls of thickness 2tc,and four cell walls with single

Al	Mg	Cu	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti
rem	9.5	0.1	0.25	0.4	0.1	0.1	0.1	0.05	0.05	0.2

thickness tc. In the calculations of the wall cross sectional area AW of the unit cell, only one - half of the cell wall thickness is used because each cell wall panel is naturally shared by two adjacent cells. Namely, for the free cell walls ,thickness tc/2 is used, and for the bonded double walls, thickness 2(tc/2)= tc is used. the length "d" of the side of the hexagon is related to the cell size "s" through d= s/2

The cross sectional area of the unit right hexagonal cell (consisting of 6 equilateral triangles) can be calculated as

$$A_c = 6\left(\frac{\sqrt{3}}{4}\times d^2\right) = 3\left(\frac{\sqrt{3}}{2}\right)\times d^2 \quad \text{.............(7)}$$

The cross sectional area of A_W of the unit hexagonal cell wall, which consists of two bonded side, and four free sides, can be calculated as

$$A_w = 2d\left(\frac{2t_c}{2}\right) + 4d\left(\frac{t_c}{2}\right) = 4d\times t_c \quad \text{...... (8)}$$

From equations (12) & (13) ,the effective or average density ρ_{ca} of the right hexagonal cell can be represented as

$$\rho_{ca}/\ \rho_c = A_W/\ A_C$$

$$\Rightarrow \qquad \rho_{ca} = \frac{8}{3\sqrt{3}}\cdot\frac{t_c}{d}\cdot\rho_c$$

The formula for predicting the maximum compressive load of honeycomb panel under lateral crushing loads is given by

$$P_{uc} = 8d.t_c\left[\frac{\pi^2 E_c \sigma_{co}^2}{3\left(1-v_c^2\right)}\cdot\left(\frac{t_c}{d}\right)^2\right]^{1/3} \quad \text{.........(9)}$$

To predict mean crushing load for the honeycomb sandwich panel under crushing loads, the following simplified formula is used in our study.

$$P_m = 16.56 A.\sigma_{co}\cdot\left(\frac{t_c}{S}\right)^{5/3} \quad \text{.........(10)}$$

Where A=L*W and

L =2d(1+ cos(α/2)),

W =2(tc+d·sin(α/2))

6. THEORETICALLY CALCULATIONS

6.1. Strength to weight ratio of normal Aluminum Panel(Bending Test)

Dimensions : Length(a) =500 mm, Width (b) =100mm, Height(h)=18.7mm

Mechanical properties: Density =2700 kg/m^3, Young's modulus= 71,070 Mpa

Yield strength = 268 Mpa

Composition of Al 5500:

TABLE 1
Composition of Aluminum

Critical load (P_O) : Maximum bending moment for the simply supported honeycomb beam(M) = pa/4

We know bending equation ie, M/I=E/R= σ/Y

Where M= maximum bending moment,

I =area moment of inertia of the beam vertical cross section

E = modulus of elasticity of aluminum

σ = bending stress

Y = distance of any fibre from neutral axis

Critical load is the load at which bending stress is equal to yield stress.

Then $\sigma = \sigma_f$,

From equation (11), $M/I=\sigma_f/Y$

$M= \sigma_f\,(I/Y)= \sigma_f(Z)$,

where Z=section modulus, I=b.h^3/12=100(18.7)^3/12 mm^4

Y=h/2=18.7/2=9.35 mm

Z=I/Y=5826.2mm^2

P(a/4)=268(5826.2)

P(500/4) =268(5826.2)

P =12588.8 N=12.6 KN

Therefore critical load is obtained as 12.6 KN

<u>Mass of the Al rod of the given dimensions:</u>

Mass =a.b.h.ρ=500(100)(18.7)(2.7)/1000=2524.5 g=2.52 kg

Therefore weight of the specimen=2.52*9.81=24.76 N

strength to weight ratio =12.6(1000)/24.76 =510

6.2. Strength to Weight Ratio of Aluminum Honeycomb Panel

<u>Mechanical properties of facing plate material:</u> <u>A5500-H19</u>

TABLE 2
Mechanical Properties of Facing Material

Young's modulus(Mpa)	Yield strength (Mpa)	Tensile strength (Mpa)	Elongation at rupture(%)
71,070	268	367	13

<u>Mechanical properties of aluminum honeycomb core material A5500-H19</u>

TABLE 3
Mechanical Properties of Facing Material Aluminum Honeycomb Core Material

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Item	Average Core density (54.4 kg/m^3)
0.2% yield stress (MPa)	190
Elongation %	4
Compressive strength (MPa)	2.5
Compressive modulus (MPa)	540
Shear modulus, *L* (MPa)	26000
Shear modulus, *W* (MPa)	13000

Dimensions of the honeycomb panel are given in table 4.

TABLE 4
Dimensions of The Honeycomb Panel

Item	Specimen	Honeycomb panel
Core	Cell size (mm) :S	6.35
	Thickness (mm): t_c	0.0381
	Height h_c(mm)	12.7
	Density (kg/m^3)	54.4
Facing	Thickness (mm) : t_f	3.0
weight	Grams	841.75

Calculation of mass of honey comb panel:

Mass of the facing material m_f =2(ab) $\rho_f t_f$ =(2*500*100*3*2.7)/1000=810 g

Mass of the honeycomb core material m_c =a*b*h_c*ρ_{ca}=(500*100*12.7*0.05)/1000=31.75 g Mass of the honeycomb panel=m_f+m_c=810+31.75=841.75 g

Critical load (P_O): The bending moment of a simply supported honeycomb sandwich beam can be approximately calculated by integrating the first moment of the bending stress with regard to the neutral axis as follows

$$M = C\frac{bh^2\sigma_f}{4}\left\{1-\left(\frac{h_c}{h}\right)^2\right\} = \frac{Pa}{4}$$

$$C = \frac{C_1}{C_1+C_2}$$

Where,

$$C_1 = \frac{a^3}{48E_f I_f},\quad C_2 = \frac{a}{4A_c G_{ca}}$$

I_f =b(h^3-h_c^3)/12=100(18.7^3-12.7^3)/12=37423.5mm^4
A_c =b*h_c =100*12.7=1270 mm^2
G_{ca} =(G_{cw}+ G_{cl})/2 = (26000+13000)/2=19500 MPa
C_1 =500^3/(48*71070*37423.5)=9.79*10^{-4}
C_2 =500/(4*1270*19500) =0.05*10^{-4}
And C =9.79/(9.79+0.05)=0.995.
Therefore critical load(P_O) =0.995*100*18.7^2*268*(1-$(12.7/18.7)^2$)/500 =9.99 KN
Strength to Weight Ratio= 9.99*1000/(0.841*9.81)=1211

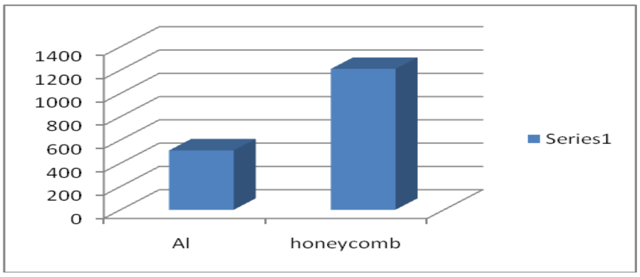

Fig 7. Bar Chart Representing Strength to Weight Ratio

7. CONCLUSIONS AND FUTURE SCOPE

Three point bending test is conducted theoretically on aluminum honeycomb sandwich panel and uniform aluminum rod and it is observed that aluminum honeycomb sandwich panel has more strength to weight ratio compared to uniform aluminum rod. From three point bending test on the aluminum honeycomb sandwich beam specimen varying the honeycomb core cell thickness ,it was observed that with an increase in the thickness of honeycomb core cell, the start of plastic deformation could be delayed, resulting in increase of ultimate strength. Bending analysis is done on hexagonal honeycomb cored panels and there will be scope for study on square, TPS (flat walls) and TPS(corrugated walls) honeycomb cored panels.

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