# Strength Analysis on Honeycomb Sandwich Panels of different Materials

**K.Kantha Rao[1], K. Jayathirtha Rao[2] A.G.Sarwade[3], M.Sarath Chandra[4]**
[1]Associate Professor [2]Director(Retd.) [3]Professor [4]Assistant Professor
[1,4]CMR College of Engineering and Technology, Hyderabad; [2] RCI, Hyderabad ,[3]Malla Reddy College of Engineering and Technology, Hyderabad;.

## 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 Strength Analysis on Honeycomb Sandwich Panels of different materials

***Key words-*** Aluminium panel, Honey Comb structure, Adhive material

## 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.

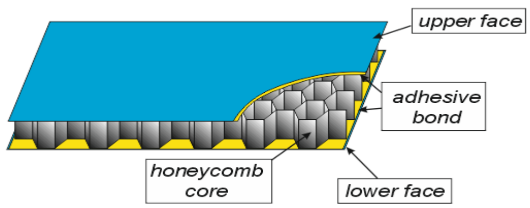


Fig1. Honey Comb Sandwich Panel

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

## 2. THEORETICAL BENDING ANALYSIS OF THE HONEY COMB SANDWICH PANELS OF DIFFERENT MATERIALS

Bending test is conducted on honeycomb sandwich panels of four different materials to study the effect of material properties on ultimate point and strength to weight ratio.They are as follows

1)Titanium( Ti-6Al-4V)

2)4340 High tensile steel

3)Aluminium (A 5500-H 19)

### 2.1. Bending analysis on Titanium( Ti-6Al-4V)

Composition of Titanium( Ti-6Al-4V)

**Table 1**
**Composition of Titanium( Ti-6Al- 4V)**

| Ti(%) | Al(%) | V(%) | Fe(%) | O(%) |
|---|---|---|---|---|
| 90 | 6 | 4 | 0.25 | 0.2 |

Physical properties:

Density = 4430 kg/m$^3$

Melting point=1640°C

Mechanical properties:

Modulus of elasticity =113.8 Gpa

Modulus of rigidity = 44 Gpa

Yield strength = 880 MPa

poisson's ratio = 0.342

**Table 2**
**Dimensions of the Titanium honeycomb panel**

| Item | Specimen | Honeycomb panel |
|---|---|---|
| Core | Cell size (mm) S | 6.35 |
| | Thickness (mm) $t_c$ | 0.0381 |
| | Height (mm) $h_c$ | 12.7 |
| | Average Density | 82 |
| Facing | Thickness (mm) $t_f$ | 3.0 |

Mass of the facing material $m_f$ =2(ab) $\rho_f t_f$

=(2*500*100*3*4.43)/1000=1329 g

Average density of honeycomb core

$$\rho_{ca}=\frac{8dt_c}{A}\cdot\rho_c\cong\frac{8}{3\sqrt{3}}\cdot\frac{t_c}{d}\cdot\rho_c$$

= 0.0184* $\rho_c$=0.0184*4.43=0.082g/cc

Therefore mass of honeycomb core $m_c$ =a*b*$h_c$*$\rho_{ca}$=(500*100*12.7*0.082)/1000=52.07g

Mass of the honeycomb panel=$m_f$+$m_c$=1329+52.07=1381g

Critical load:( $P_O$)

$$P_o = C \cdot \frac{bh^2 \sigma_{fo}}{a} \cdot \left\{ 1 - \left( \frac{h_c}{h} \right)^2 \right\}$$

$I_f = b(h^3 - h_c^3)/12 = 100(18.7^3 - 12.7^3)/12 = 37423.5 mm^4$

$A_c = b*h_c = 100*12.7 = 1270\ mm^2$

$G_{ca} = (G_{cw} + G_{cl})/2 = (44000+22000)/2 = 33000$ Mpa

$C_1 = 500^3/(48*113800*37423.5) = 6.115*10^{-4}$

$C_2 = 500/(4*1270*33000) = 0.0298*10^{-4}$

And C =6.115/(6.115+0.0298)=0.995

Therefore critical load( $P_O$)

$=0.995*100*18.7^2*880*(1-(12.7/18.7)^2)/500$

=33 KN

**strenth to weight ratio =33*1000/(1.381*9.81)=2435.8**

Deflections of Titanium honeycomb panel under different loads:

Central deflection of the honeycomb panel is given by

$$w = \frac{Pa^3}{48E_f I_f} + \frac{Pa}{4A_c G_{ca}}$$

**Table 3**
**Deflections of honeycomb panel**

| Load (KN) | Deflection (mm) | Load (KN) | Deflection (mm) |
|---|---|---|---|
| 2 | 1.23 | 20 | 12.30 |
| 4 | 2.46 | 22 | 13.53 |
| 6 | 3.69 | 24 | 14.76 |
| 8 | 4.92 | 26 | 15.99 |
| 10 | 6.15 | 28 | 17.22 |
| 12 | 7.38 | 30 | 18.45 |
| 14 | 8.61 | 32 | 19.68 |
| 16 | 9.84 | 32 | 19.68 |
| 18 | 11.07 | 33 | 20.3 |

Model calculation for central deflection:

When P=2KN,deflection(w):

$$w = \frac{Pa^3}{48E_f I_f} + \frac{Pa}{4A_c G_{ca}}$$

$=(2*1000*500^3)/(48*113800*37423.5) +(2*1000)/(4*1270*33000)$

= 1.23mm

### 2.2. Bending analysis on 4340 High tensile steel

Composition of 4340 High tensile steel:

**Table 4**
**Composition of 4340 High tensile steel**

| C (%) | Si (%) | Mn (%) | Ni (%) | Cr (%) | Mo (%) | S (%) | P (%) |
|---|---|---|---|---|---|---|---|
| 0.40 | 0.25 | 0.70 | 1.80 | 0.80 | 0.25 | 0.025 | 0.025 |

Physical properties:

Density = 7850 kg/$m^3$

Mechanical properties:

Modulus of elasticity =210 Gpa

Modulus of rigidity = 81 Gpa

Yield strength = 700 MPa

Poisson's ratio = 0.3

**Table 5**
**Dimensions of the High tensile steel honeycomb panel**

| Item | Specimen | Honeycomb panel |
|---|---|---|
| Core | Cell size (mm) S | 6.35 |
| | Thickness (mm) $t_c$ | 0.0381 |
| | Height (mm) $h_c$ | 12.7 |
| | Average Density (kg/$m^3$) | 144 |
| Facing | Thickness (mm) $t_f$ | 3.0 |

Mass of the facing material mf =2(ab) ρf tf

=(2*500*100*3*7.85)/1000=2355 g

Average density of honeycomb core

$$\rho_{ca}=\frac{8dt_c}{A}\cdot\rho_c\cong\frac{8}{3\sqrt{3}}\cdot\frac{t_c}{d}\cdot\rho_c$$

= 0.0184*

ρc=0.0184*7.85=0.144g/cc

Therefore mass of honeycomb core mc =a*b*hc*ρca=(500*100*12.7*0.144)/1000=91.44g

Mass of the honeycomb panel=$m_f$+$m_c$=2355+91.44=2446.7g

**Critical load:( $P_O$)**

$$P_o=C\cdot\frac{bh^2\sigma_{fo}}{a}\cdot\left\{1-\left(\frac{h_c}{h}\right)^2\right\}$$

$I_f$ =$b(h^3-h_c^3)/12=100(18.7^3-12.7^3)/12=37423.5mm^4$

$A_c$ =b*$h_c$ =100*12.7=1270 $mm^2$

$G_{ca}$ =($G_{cw}$+ $G_{cl}$)/2 = (80000+40000)/2=60000 Mpa

$C_1$ =$500^3$/(48*210000*37423.5)=3.312*$10^{-4}$

$C_2$ =500/(4*1270*60000) =0.016*$10^{-4}$

And C =3.312/(3.312+0.016)=0.995

Therefore critical load( $P_O$)

=0.995*100*$18.7^2$*700*(1-$(12.7/18.7)^2$)/500

=26.3 KN

**strenth to weight ratio**

**=26.3*1000/(2.45*9.81)=1095.78**

Deflections of High tensile steel honeycomb panel under different loads:
Central deflection of the honeycomb panel is given by

$$w = \frac{Pa^3}{48E_f I_f} + \frac{Pa}{4A_c G_{ca}}$$

**Table 6. Deflections of High tensile steel**

Model calculation for central deflection:

| Load (KN) | Deflection(mm) | Load(KN) | Deflection (mm) |
|---|---|---|---|
| 2 | 0.67 | 16 | 5.36 |
| 4 | 1.34 | 18 | 6.03 |
| 6 | 2.01 | 20 | 6.7 |
| 8 | 2.68 | 22 | 7.37 |
| 10 | 3.35 | 24 | 8.04 |
| 12 | 4.02 | 26 | 8.71 |
| 14 | 4.69 | 26.3 | 8.81 |

When P=2KN,deflection(w):

$$w = \frac{Pa^3}{48E_f I_f} + \frac{Pa}{4A_c G_{ca}}$$

$=(2*1000*500^3)/(48*210000*37423.5) +(2*1000)/(4*1270*60000) = 0.67$mm

**2.3. Bending analysis on Aluminium 5500-H19**

Composition of Aluminium 5500-H19

**Table 7**
**Composition of Aluminium 5500-H19**

| Al | Mg | Cu | Si | Fe | Mn | Ni | Zn | Pb | Sn | Ti |
|---|---|---|---|---|---|---|---|---|---|---|
| 90 | 11 | 0.1 | 0.25 | 0.4 | 0.1 | 0.1 | 0.1 | 0.05 | 0.05 | 0.2 |

**Physical properties:**
Density = 2700 kg/m$^3$

**Mechanical properties:**
Modulus of elasticity =71.07Gpa

Modulus of rigidity = 26 Gpa

Yield strength = 268 MPa

Poisson's ratio = 0.33

**Table 8.**
**Dimensions of the High tensile steel honeycomb panel**

| Item | Specimen | Honeycomb panel |
|---|---|---|
| Core | Cell size (mm) S | 6.35 |
| | Thickness (mm) $t_c$ | 0.0381 |
| | Height (mm) $h_c$ | 12.7 |
| | Average Density (kg/m$^3$) | 50 |
| Facing | Thickness (mm) $t_f$ | 3.0 |

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

Average density of honeycomb core

$$\rho_{ca} = \frac{8dt_c}{A} \cdot \rho_c \cong \frac{8}{3\sqrt{3}} \cdot \frac{t_c}{d} \cdot \rho_c$$

= 0.0184*
$\rho_c$=0.0184*2.7=0.050g/cc

Therefore mass of honeycomb core $m_c$

$=a*b*h_c*\rho_{ca}=(500*100*12.7*0.05)/1000=31.54$

Mass of the honeycomb

panel$=m_f+m_c=810+31.54=841.54$g

**Critical load:( $P_O$)**

$$P_o = C\cdot\frac{bh^2\sigma_{fo}}{a}\cdot\left\{1-\left(\frac{h_c}{h}\right)^2\right\}$$

$I_f = b(h^3-h_c^3)/12=100(18.7^3-12.7^3)/12=37423.5\text{mm}^4$

$A_c = b*h_c = 100*12.7=1270 \text{ mm}^2$

$G_{ca} = (G_{cw}+ G_{cl})/2 = (26000+13000)/2=19500$ Mp

$C_1 = 500^3/(48*71070*37423.5)=9.79*10^{-4}$

$C_2 = 500/(4*1270*19500) = 0.05*10^{-4}$

And $C = 9.79/(9.79+0.05)=0.995$

Therefore critical load( $P_O$)
$=0.995*100*18.7^2*268*(1-(12.7/18.7)^2)/50$

=9.99 KN

**strenth to weight ratio =9.99*1000/(0.84*9.81)=1211**

**Deflections of Aluminium honeycomb panel under different loads**

Central deflection of the honeycomb panel is given by

$$w=\frac{Pa^3}{48E_fI_f}+\frac{Pa}{4A_cG_{ca}}$$

**Table 9**
**Deflections of Aluminium honeycomb panel**

| Load (KN) | Deflection (mm) | Load (KN) | Deflection (mm) |
|---|---|---|---|
| 2 | 1.97 | 7 | 6.89 |
| 3 | 2.96 | 8 | 7.88 |
| 4 | 3.94 | 9 | 8.87 |
| 5 | 4.93 | 9.99 | 9.83 |
| 6 | 5.91 | | |

Model calculation for central deflection:

When P=2KN,deflection(w):

$$w=\frac{Pa^3}{48E_fI_f}+\frac{Pa}{4A_cG_{ca}}$$

$=(2*1000*500^3)/(48*71070*37423.5)$
$+(2*1000)/(4*1270*19500)$

= 1.97mm

Load vs deflection graph of Ti,High tensile steel & Aluminium is shown in Fig 6.3

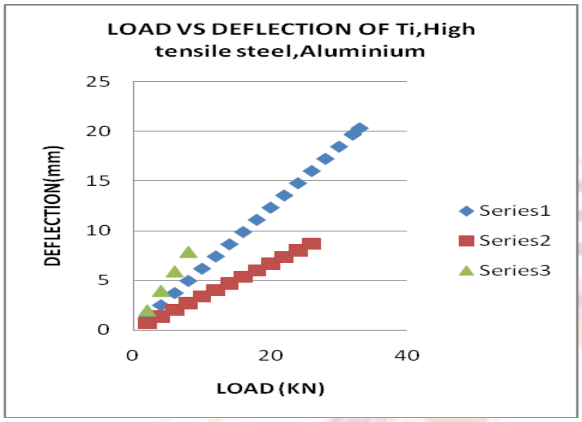


**Fig 2 load vs deflection**

Bar chart of strength to weight ratio's is shown in Fig 3

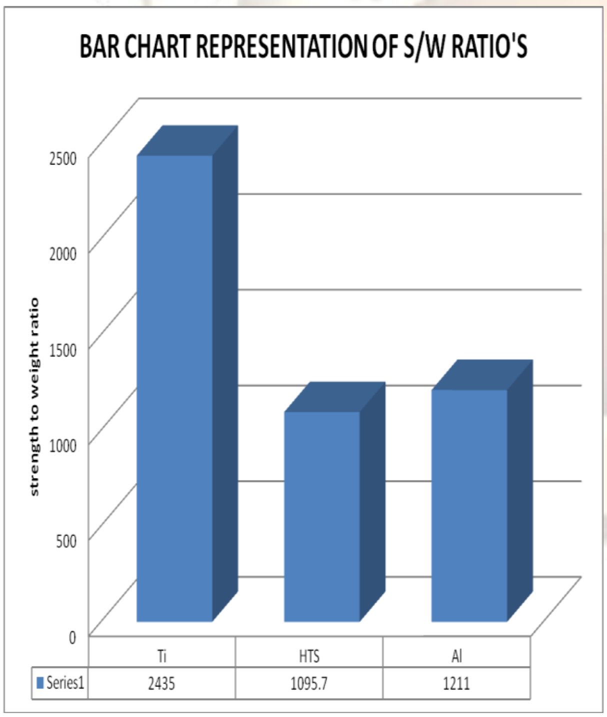


**Fig 3 Bar chart of strength to weight ratio's**

## 3. BENDING TEST ON TWO AL HONEYCOMB PANELS WITH DIFFERENT CORE THICKNESS

**Table 10**
**Dimensions of three point bending test specimens**

| Item | Specimen | Specimen 1 | Specimen 2 |
|---|---|---|---|
| Core | Cell size (mm) S | 6.35 | 6.35 |
| | Thickness (mm) $t_c$ | 0.0381 | 0.0635 |
| | Height (mm) $h_c$ | 12.7 | 12.7 |
| | Density (kg/m$^3$) | 54.4 | 83.2 |
| Facing | Thickness (mm) $t_f$ | 3.0 | 3.0 |
| weight | Grams | 841.75 | 862.5 |

Mechanical properties of facing plate material :

| Young's modulus(Mpa) | Yield strength (Mpa) | Tensile strength (Mpa) |
|---|---|---|
| 71,070 | 268 | 367 |

A5500-H19

**Table 11**

**Mechanical properties of aluminum honeycomb core material A5500-H19**

| Item | Average Core density ( 54.4 kg/m$^3$ ) | Average Core density ( 83.2 kg/m$^3$ ) |
|---|---|---|
| Elongation % | 4 | 4 |
| Compressive strength (MPa) | 2.5 | 4.6 |
| Compressive modulus (MPa) | 540 | 1000 |
| Shear modulus, *L* (MPa) | 26000 | 44000 |
| Shear modulus, *W* (MPa) | 13000 | 22000 |

**ANALYSIS:**

Three point bending test is conducted on aluminium honeycomb panls varying the honeycomb core cell thickness, it was observed that with an increase in the thickness of honeycomb cell ,the start of plastic deformation is delayed, resulting in incrase of ultimate strength.Also the sandwich beam bending stiffness subsequent to plastic buckling becomes more moderate as the thickness of the honeycomb core cell increases.This would imply that undesirable effects of instability in the structure after collapse can be reduced by using a larger thickness

**Table 12**

CRITICAL LOAD FOR THE SPECIMEN OFCORETHICKNESS 0.0381mm = 9.99KN
CRITICAL LOAD FOR THE SPECIMEN OF CORE THICKNESS 0.0381mm = 10.01KN

| 3PB1 | | 3PB2 | |
|---|---|---|---|
| Load (KN) | Deflection(mm) | Load (KN) | Deflection(mm) |
| 2 | 1.97 | 2 | 1.97 |
| 3 | 2.96 | 3 | 2.95 |
| 4 | 3.94 | 4 | 3.93 |
| 5 | 4.93 | 5 | 4.91 |
| 6 | 5.91 | 6 | 5.89 |
| 7 | 6.89 | 7 | 6.88 |
| 8 | 7.88 | 8 | 7.86 |
| 9 | 8.87 | 9 | 8.85 |
| 9.99 | 9.83 | 10.01 | 9.84 |

## 4. DIMENSIONS OF THE CRUSHING TEST SPECIMENS

**Table 13**

**Dimensions of the crushing test specimens**

| property | specimen | LP1 | LP2 | LP3 |
|---|---|---|---|---|
| CORE | Material | A5500-H19 | A5500-H19 | A5500-H19 |
| | Cell size(mm) | 6.35 | 6.35 | 6.35 |
| | Thickness (mm) | 0.0381 | 0.0635 | 0.0381 |
| | Height(mm) | 25.4 | 12.7 | 12.7 |
| | Avg.Density (kg/m$^3$) | 54.4 | 83.2 | 54.4 |
| FACING | Material | A5500-H19 | A5500-H19 | A5500-H19 |
| | Thickness (mm) | 3 | 3 | 3 |

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

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

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

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

Where A=L*W and

L =2d(1+ cos(α/2)), W =2(tc+d·sin(α/2))

**Model calculations**

**Ultimate crushing load for specimen 1(LP1):**

$P_{uc}$= 8*3.175*0.0381*(Π$^2$*71070*268$^2$*0.0381$^2$/3*(1-0.33$^2$)*3.175$^2$)$^{(1/3)}$

= 139.47 KN

**Mean crushing load for specimen 1(LP1):**

$P_m$ = 16.56*9.525*5.5755*268*(0.0381/6.35)$^{(5/3)}$ =46.7 KN

**RESULTS**:

**Table 14**
**Ultimate crushing load & mean crushing load**

| Type of load | LP1 | LP2 | LP3 |
|---|---|---|---|
| Ultimate crushing load(KN) | 139.47 | 316.25 | 139.47 |
| Mean crushing load(KN) | 46.7 | 109.39 | 46.7 |

The mean crushing strength of the honeycomb panel is one of the most important properties on which the energy absorbing capability of the entire structure will depend. For the sandwich this strength depends on the yield strength of the bare core as well as geometrical dimensions such as cell size and wall thickness. Since the density of the honeycomb is in turn affected by the geometrical dimensions of the honeycomb, the crushing strength also has a strong relationship with the density as is evident from the results.

**Analysis**: Crushing test is conducted on three aluminum honeycomb panels and it is observed that under lateral crushing loads varying the cell thickness and height of honeycomb core ,it is seen that core height is not an influential parameter on the crushing behavior of honeycomb core. The wall thickness of the honeycomb core cell is a critical variable effecting the crushing strength of the sandwich panel subject to lateral pressure loads.

## 5. CONCLUSIONS & FUTURE SCOPE

The three point bending test is conducted theoretically on aluminum, titanium and high tensile steel honeycomb sandwich panels and it is observed that titanium alloy has more strength to weight ratio.

From the crushing tests on the aluminum honeycomb sandwich panel specimens under lateral crushing loads varying the cell thickness and height of the honeycomb core, it is seen that the core height is not an influential parameter on the crushing behavior of the honeycomb core. However the wall thickness of a honeycomb core cell is a critical variable affecting the crushing strength of the sandwich panels subject to lateral pressure loads.

**Future Scope:** Bending and crushing analysis is done by taking aluminum, titanium and high tensile steel honeycomb panels and the same analysis can also be extended to composite materials.

## REFERENCES

[1] Hexcel. Honeycomb sandwich design technology. Publication No. AGU 223, Hexcel Co., Ltd., Duxford (UK), 1995.

[2] Thomsen, O.T. and W. Rits, Analysis and design of sandwich plates with inserts - a high order sandwich plate theory approach. Composites Part B: Eng., 1998. **29B**: p. 795-807.

[3] Gaetano G.Galletti, Christine UinQuist, OmarS.Es-Said. Theoretical Design and Analysis of a Honeycomb Panel Sandwich Structure Loaded in Pure Bending, Elser, May 2007.

[4] D.H. Chen. Bending deformation of Honeycomb consisting of regular hexagonal cells, Elsevier, August 2010.

[5] Annette Meidell. Minimum Weight Design of Sandwich beams with honeycomb core of arbitrary density, Elsevier January 2009.

[6] Kesley S,Gellatly RA,clark BW.The shear modulus of foil honeycomb cores.

[7] Metals data hand book by NAYAR

[8] Bitzer, T (1997). Honeycomb Technology: Materials, Design, Manufacturing, Applications and Testing, London: Chapman & Hall.