FLEXURAL BEHAVIOR OF ALUMINUM HONEYCOMB CORE SANDWICH STRUCTURE

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Abstract----This project is concerned with the fabrication and flexural testing of aluminium honeycomb sandwich structure which is a special case of composite materials that is fabricated by attaching two thin but stiff skins to a light weight but thick core. The core material is normally low density material but its high thickness provide the sandwich composite with high bonding stiffness. Honeycomb core are classified into two types based on the materials and structures. Hexagonal shape has a unique properties i.e has more bonding strength and less formation time based on the cell size and sheet thickness. Sandwich structure exhibit different properties such as high load bearing capacity at low weight and has excellent thermal insulation. By considering the above properties it has tendency to minimize the structural problem. So honey comb sandwich structure is choosed. The core structure has a different applications such as aircraft, ship interiors, construction industries. As there is no proper research on strength characteristics of sandwich structure. So, we use light weight material to desire the strength. There are different parameters involved in this structure i.e cell size, sheet thickness and core height. In this project we considered 3 level of comparison among the 3 different parameters cell size of 4, 6 and 8 mm, sheet thickness of 0.3, 0.5 and 0.7 mm, and core height of 20, 25 and 30 mm. In order to reduce the number of experiment we use taguchi design of experiment, and we select the L8 orthogonal array is the best array for this type of situation, which clearly identifies the parameters by independent of material weight to support this we add the minitab software, to identify the main effective plots and regression equation which involves the individual response and corresponding parameters. Aluminium material is used for the fabrication of Honeycomb sandwich structure among the various grades of aluminium we consider the AL6061 which is light weight material and has more strength. By the power press used as forming method we fabricate the honey comb core and stacking the sheets with adhesive as epoxy resin or laser beam welding and sandwich structure will form with two face sheets. Then the specimen is taken to be tested to know the flexural behaviour by the flexural test as 3 point and 4 pont bend test. After testing of two different tests then we get the force vs displacement curve by this we can know the maximum force and by loading configurations and its displacement or deflection then we can calculate flexural stiffness and core shear modulus by the variation of three parameters. Our ultimate aim is to achieve maximum strength by minimum weight.
1. Introduction
A sandwich-structured composite is a special case of composite materials that is fabricated by attaching two thin but stiff and skins to a light weight, thick core as shown in figure 1. The core material is normally low strength material, the higher thickness provides a sandwich composite with high bending stiffness with overall low density.

![Honeycomb Core Sandwich Structure](image)

**Figure 1. Honeycomb Core Sandwich Structure**

Honeycomb sandwich materials are being widely used in weight sensitive and damping structures where high flexural rigidity is required in many fields mainly in the automobile industry. Honeycomb core sandwich panel is formed by adhering two high strength-rigidity thin-face sheets with a low-density, honeycomb core possessing high-strength and stiffness, by varying the core, thickness and material of the face sheet. Which is possible to obtain various properties and desired performance, particularly in high strength-to-weight ratio. Sandwich construction is widely used because of its ability to provide high bending stiffness coupled with lightweight. Sandwich panels are made of two stiff, strong skins separated by a light weight core.

The objectives of the study is to examine the influence of aluminium honey comb sandwich structure having core of different sheet thickness, cell size and core height on the static flexural stiffness of sandwich panel with face sheets and to investigate the extent of improvement in the flexural performance characteristics of the aluminum honeycomb sandwich panel.

2. Methodology
Taguchi’s Design of Experiment is a well ordered and effective way to find the contribution of structural parameters. This method utilizes the orthogonal array of combinations to reduce the number of experiments. Flexural stiffness and core shear modulus in honeycomb core sandwich structure is usually higher in the out-of-plane loading because of the high load carrying capacity compared to the in-plane loading. As the Flexural stiffness and core shear modulus highly depends on the material properties and structural parameters and hence there is a need to find the contribution. To identify the most influencing structure parameters three different parameter has chosen such as cell size, cell wall thickness and core height. Three variations of the parameters or factors are representative of their low, medium and higher
levels respectively assuming that the factor effects are linear when the factor changes from one level to the other one. Three factors at three levels results in nine combinations and hence experimental trials are listed in table

| Trial # | Factors | Cell size (mm) | Core sheet thickness (mm) | Core height (mm) | Flexural stiffness (Mpa) | Core shear modulus (Mpa) |
|---------|---------|----------------|---------------------------|-----------------|------------------------|------------------------|
| 1       | 4       | 0.3            | 20                        |                 | 3                      | 0.5                    |
| 2       | 4       | 0.5            | 25                        |                 | 2                      | 0.837                  |
| 3       | 4       | 0.7            | 30                        |                 | 6                      | 2.215                  |
| 4       | 6       | 0.3            | 25                        |                 | 8                      | 0.355                  |
| 5       | 6       | 0.5            | 30                        |                 | 9                      | 2.7                    |
| 6       | 6       | 0.7            | 20                        |                 | 3                      | 1.6497                 |
| 7       | 8       | 0.3            | 30                        |                 | 9                      | 6.9                    |
| 8       | 8       | 0.5            | 20                        |                 | 8                      | 0.5                    |
| 9       | 8       | 0.7            | 25                        |                 | 4.2                    | 1.69                   |

3. Experiments and Specimens

To Evaluate static flexural stiffness of sandwich panels with different cell wall thickness, cell size and core height of the core by 3-point and 4-point Bend Tests. Flexural tests as per ASTM C393 were carried out to determine sandwich structure bending stiffness (D) and Core Shear Modulus (G) on the Sandwich panels. Three-point and four-point bend tests were conducted at the method of each loading case Flexural testing with central loading has been carried out in accordance with ASTM C 393 using indigenously designed and developed Digital Flexural Test System. The movable carriage of the machine is brought by the loading bar and load is applied gradually at the cross head displacement ratio of 2 mm/min and Plot of load versus deflection is recorded. The two methods were most usually used for the determination of flexural properties of laminates are the three-point and four-point tests. The states of stress in specimens subjected to three-point or four-point bending tests are somewhat different and may lead to differences in the results.

Sandwich structures subject to three-point bending test are to analyze the local buckling modes of the upper face sheet and cores. TPBT involves the combined load of the bending moment associated with the
plastic buckling of compressed upper face sheet, transverse shear between face sheet and core and collapse of compressed cores. The loading configuration was shown in figure 2.

\[ D = \frac{P_1 S_1^2 (1 - \frac{13 S_2^2}{8 S_1})}{48 \Delta_1 (1 - \frac{2 P_1 S_2^2}{P_2 S_2^2 \Delta_1})} \]

\[ U = \frac{P_2 S_2}{4 \Delta_1 \left( \frac{16 P_1 S_2^2 \Delta_2}{11 P_2 S_2^2 \Delta_1} - 1 \right)} \]

Figure 2: Three Pointbend test and loading configuration

Four point bend test is used effectively to measure the bond, strength in four-point bending a uniform maximum moment and an area of maximum tension at the bottom of the specimen is achieved, it provides values for the modulus of elasticity in bending, flexural stress, strain and the flexural stress-strain response of the material. This test is very similar to the three points bending flexural test. The major difference is that the addition of a 4th bearing brings a maximum larger area of the beam to the maximum stress, as opposed to only the material right under the central bearing.

Figure 3: Four Point Loading Configuration

One 3-Point Mid-Span Loading Configuration and One 4-Point Quarter-Span Loading Configuration—The solution for this case (L1 = 0, L2 = S2/2) then calculate the flexural stiffness, shear rigidity, and core shear modulus for each selected value of P1.
\[ \Delta = \frac{P(2S^3 - 3SL^2 + L^3)}{96D} + \frac{P(S - L)}{4U} \]

**G = core shear modulus, MPa [psi]**,
\[ G = \frac{U(d^2 - 2t)}{(d-t)^2b} \]

Where,
- \( D \) = beam mid-span deflection, mm [in.],
- \( P \) = total applied force, N [lbf],
- \( d \) = sandwich thickness, mm [in.],
- \( b \) = sandwich width, mm [in.],
- \( t \) = facing thickness, mm [in.],
- \( S \) = support span length, mm [in.],
- \( L \) = load span length, mm [in.]

### 3.1. Materials and specimens

Preparation of honeycomb core sandwich structure and face sheets according to ASTM standards of length 200mm and width 50mm and it is fabricated by using power press method. In all, nine specimens were prepared with different cell size, sheet thickness core height with an insert face sheet. Use of appropriate test methods as per standards and guidelines in order to evaluate the flexural properties like stiffness and core shear modulus by the digital flexural system we get the maximum load carrying capacity for clear understanding of static behavior of Honeycomb sandwich structure.

Commercially available of aluminum of different thickness 0.3, 0.5 and 0.7 mm is used for making the honeycomb sandwich structure the material was cut into correct size and built to a length of 120cm and width of 10 cm by using shearing machine.

Press brake is used to forming the hexagonal structure by aluminum sheet. A press brake is a special type of machine press which bends the sheet metal into required shape and size. A good example of the type of work a press brake can do is the back plate of a computer case. The die press sheets were trimmed according to the ASTM standards of length of 200mm and width of 50mm through band saw.

Adhesive bonding, are currently being used for joining aluminum alloy facing material and honeycomb core. An adhesive is the mixture of resin and hardener mixed in equal ratio and weight was then applied. Adhesive joints for the sandwich construction is having advantages such as fewer pieces, lower weight, good load distribution and lower cost. Epoxy resin is the best adhesive for the metallic materials to stack one over another.

### 4. Results and Discussion

The Flexural stiffness (D) is the resistance of a member against bending deformation. It is a function of elastic modulus E, the area moment of inertia I of the beam cross-section about the axis of interest, length of the beam and beam boundary condition. Bending stiffness of a beam can be analytically derived from the equation of beam deflection when it is applied by a force. Bending stiffness in beams is also known as Flexural rigidity.
The shear modulus is used for the deformation which takes place when a force is applied parallel to one face of the object while the opposite face is held by another equal force. That’s why the shear modulus is sometimes called the modulus of rigidity. In first approximation there is no change in volume in this deformation.

Load vs. deflection curve for three point bend test were shown in the figure

Figure 4. Load Vs. Deflection curve for three point bend test

From the above graphs the maximum load and its corresponding deflection of specimen in three point bend test is tabulated in table 2.

| Experiment | Deflection (mm) | Yield load (kN) | Young’s Modulus (Mpa) |
|------------|----------------|----------------|-----------------------|
| 1          | 0.8045         | 2.777          | 7901                  |
Load vs deflection curve for three point bend test were shown in the figure.

|   |   |   |   |
|---|---|---|---|
| 2 | 2.397 | 1.22 | 2269 |
| 3 | 0.7618 | 2.512 | 2233 |
| 4 | 17.83 | 0.7497 | 6573 |
| 5 | 6.268 | 1.007 | 1061 |
| 6 | 4.026 | 0.7941 | 396.4 |
| 7 | 0.7061 | 1.513 | 1717 |
| 8 | 0.9906 | 0.456 | 1662 |
| 9 | 0.4074 | 1.319 | 3603 |

From the four point bend test, the maximum load and its deflection is tabulated in the below table.

**Figure 5.** Load Vs. Deflection curve for Four point bend test
Table 3. Load vs Deflection of Four point bend Test

| Experiment | Deflection (mm) | Yield load (kN) | Youngs Modulus |
|------------|----------------|-----------------|----------------|
| 1          | 22.24          | 1.203           | 59.23          |
| 2          | 24.39          | 3.838           | 189.2          |
| 3          | 8.593          | 5               | 905.4          |
| 4          | 26.62          | 2.196           | 57.68          |
| 5          | 27.42          | 2.911           | 42.26          |
| 6          | 19.52          | 2.561           | 245            |
| 7          | 5.016          | 2.88            | 486.9          |
| 8          | 25.76          | 1.426           | 67.84          |
| 9          | 0.7586         | 2.689           | 2506           |

In the main effects plot, the deviation from horizontal line indicates the process parameter has more influence on response variables. Cell size and cell wall thickness the lower level has average effect and medium level has poor effect and higher level has very good effect on core shear modulus and flexural stiffness. Whereas core height effect is moderate in the beginning and for higher value the properties got increased more.
The interaction plots among all the parameters were shown in figure. There exists a strong interaction among all the parameters.

**Figure 6.** Main Effects Plot for Flexural Stiffness

**Figure 7.** Main Effects Plot for Core Shear Modulus
Figure 8. Interaction Plot for Flexural Stiffness

Figure 9. Interaction Plot for Core Shear Modulus
5. CONCLUSION
In this finding, Taguchi’s design of experiment with orthogonal array was used to optimize the response characteristics of aluminum honeycomb core sandwich structure. The order of importance of the influencing factor is as follows: core height, cell wall thickness and cell size respectively.

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