Study of the Bending Characteristics in Composite Sandwich Structures – A Review

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Abstract: In several applications reaching from satellite, ships, aircraft, vehicles, railcars, bond construction and much extra, using sandwich constructions have increased rapidly in different fields. The aim of the subsequent paper is to include an overall summary to sandwich construction and explanation of mechanics structural including forms of actuating loads, failure modes found in sandwich panels and standard three-point bending study of sandwich construction.

Keywords: sandwich construction, failure modes, honeycomb core, bending study, defects.

1. Introduction

The technology and science of sandwich constructions and materials has been gaining imposing momentum over the last two decade, and the role of these constructions and materials in a diversity of products ranging from sports properties to spacecraft is growing. Developments in processing and manufacturing procedures of materials excluding industrial system wire to application areas. As the choice of options grows, especially in the field of marine constructions like high-speed craft and blast-resistant constructions, it is increasingly necessary to appreciate the conduct of sandwich constructions below a wide range of load levels and surroundings. This requires extra tests to investigational mechanics in symbolizing the reaction of sandwich structures to static load and fracture and loss. Characterizing the material characteristics of sandwich systems faces unique challenges owing to their variability and substantial disparity in the effects among center and face layer.
In order to understand more fully the process of damage initiation and propagation in carbon fiber composites, a series of tests have been performed by using a three-point beam test. Beam tests have an advantage over plate tests in that they allow a physical observation of the damage evolution process and information is not restricted to the post test examination of the failed specimens [1].

Composite materials have been competitive alternatives to traditional metallic materials for a while, due to their lower density, higher stiffness, higher strength, and better fatigue resistance when compared to steel or aluminum. Such properties enable composites to be an ultimate candidate for structural applications in aerospace and automotive products [2]. The polymer composites in sandwich give a really high stiffness to weight ratio. A composite sandwich panel consists of great strength polymer skins segregated by and formed a bond to a lightweight material honeycomb or bubble core. A sandwich panel increases the flexural inflexibility of the framework without contributing considerable weight. Increased thickness of the honeycomb foam cores also offers increased strength and rigidity of the module at the least weight adding Sandwich constructions have shown greater fatigue strength and well acoustic and thermal isolation in many applications. Because of their strong tolerance to crushing force and rigidity, exhaustion and moisture, the Honeycomb cores have lots of advantages on over foam or wood composite sandwich constructions. Sandwich panels have a wide range of requests in the aerospace, automotive, sports and marine sectors. The aircraft parts such as ailerons, flaps and rudders were produced from honeycomb sandwiches in the aviation industry. [3]. A standard sandwich board comprises of 2 thin outer face sheets and a thick cellular lightweight core positioned among them. Through an order for this to work, those three elements are compelled to intervene as a unit. The core contributes most to the quality of sandwich panels. Its function is to normalize the outer face sheets, to maintain the length among of us stable and to attack shear forces along its width [4].

2. History of Sandwich Structures

Honeycomb consists of arrays of cells formed from thin sheets of material. Mostly the cells are hexagonal but there are also other cell configurations like square and flex core.[5] Noor, Burton,. And Bert, clarified that the sandwich construction the idea goes back to 1849, at Fairbairn. In England the creation of sandwiches was also used in World War II's Mosquito Night Bomber. Feichtinger noted that the idea of sandwich construction in the United States had emerged during World War II with heads constructed of reinforced plastic and a low center of density. The Vultee BT-15 fuselage was designed and built by the Wright Patterson Air Force Base in 1943 using glass - fiber-reinforced polymers as the face frame, utilizing all glass-fabric honeycomb and balsa wood core. In 1944 Marguerre wrote the first research study on the construction of sandwiches dealing with sandwich structures subject to concentrated forces throughout-plane. Various theoretical operations
also were constrained to unequal axial load, and process parameters were simply supported. The USFPL was the main party in the creation of analyzes and design means for sandwich frameworks and during late post-World War II time [6].

3. Structures of Honeycomb Sandwich Construction

A honeycomb sandwich construction has two thin faces plates linked to a compact center with both edges (see Figure 1)[7]. The design of the structural materials enables the outside plates to perform the gravity force, bending stresses and in-plane blades whereas the core holds the standard bending shears. Due to the heterogeneous existence of the center and face piece arrangement, sandwich systems are vulnerable to losses due to broad usual amounts of regional tension. Consequently, Mounting components can use seedlings additions to disperse structural load over links. Sandwich face sheets are normally constructed using lightweight panels consisting of metals such as aluminum, steel or graphite / epoxy. The core is classically invented using a honeycomb or aluminums structure.

![Honeycomb Sandwich Structure](image)

**Figure 1** Honeycomb Sandwich Structure [7]

3.1. Material Selection

The design of the honeycomb sandwich comprises of endless change of materials and section modules. The complex material includes a broad variety of selectable variations of central and facing materials. The following conditions must be taken into account when periodic selection of core, face and glue [8]

3.1.1. Structural Considerations
- **Strength**: Honeycomb cores and certain leaning equipment are linear in terms of mechanical properties and care has to be occupied to make sure also that items are planned in the plate to take full improvement of this element to the maximum.

- **Stiffness**: Sandwich constructions are often used to optimize very short volume stiffness. Since most core materials have a fairly small molar mass, though, the refraction designs must let for shear refraction of the construction in adding to the winding refractions generally careful.

- **Adhesive Performance**: The additive will connect the facings strictly to the core substance to transfer forces from one facing to another. Acceptable sealants also provide developed a highly, materials of high strength accessible as liquids, extracts, or warm films. A poor peel intensity or fairly weak adhesive will usually never be used with quite thin sandwich systems that can be manipulated.

- **Cell Size**: A great cell potential is the lesser price issue, and yet cabling, i.e. a wrinkled outside surface of the sandwich in conjunction with high skins can occur. A data center size may offer a remind users of the surface and provide a larger joining area though at greater price.

- **Cell Shape**: Usually complete with hexagonal cell forms, certain varieties of wicks may be provided with rectangle cell forms.

### 3.1.2. Skin Materials

Skin factors involve weight requirements, potential misuses and regional (denting) weights, erosion or cosmetic limitations, and expense. The thickness of the material straight affects together skin stress and refraction of the panels.

### 3.1.3. Adhesive Materials

For honeycomb sandwich attachment, the next standards are vital:

- **Fillet Forming**: The coating must flow reasonably to form a filet deprived of operating away from the skin to the main joint to create a better connection to an open cell core, like honeycomb.

- **Bond Line Control**: Effort will be made during joining to assure intimate communication here between components, because the additive wants to fill some holes between the bonding surfaces. A carrier fabric is also used to provide adhesives to help them keep in position when the pieces are pressed together very tightly.

### 4. Characteristics of honeycomb sandwich

There are some applications were light weight is a design criteria and usage of thin sheets causes buckling problem due to concentrated loads. In such applications honeycomb panels should be used. If the loads acting are very high then thick skins are required. In table 1 some of the standard structural panel constructions are compared for relative strength and stiffness. [9]
For mechanical structures which undergo repeated loads, fatigue properties of the core have to be investigated. Cell dimensions core density has significant influence on the fatigue strength. [10]

| Structural sandwich          | Relative strength | Relative stiffness |
|------------------------------|-------------------|--------------------|
| Honeycomb                    | 100%              | 100%               |
| Foam                         | 26%               | 68%                |
| Structural Extrusion         | 62%               | 99%                |
| Sheet and Stringer           | 64%               | 86%                |
| plywood                      | 3%                | 17%                |

5. Bending Theory of Sandwich Structure

These section relations with the applied loads of sandwich panels in three-point bending to analyze the strains in the center or skin, and therefore the lots utilized refer to different methods for failings. Consider a span length a, width b, and vital load p supported sandwich laser light (figure 2). Also every skin has width, and a relatively thick core of thickness separates the two skins (Figure 3). Both three layers are assumed to be beautifully joined both, and the face material is more rigid than the core [11].

![Figure 2](image)

**Figure 2** Only Supported Sandwich Beam and its Cross Unit [11].
5.1 Standards for Testing

ASTM Standard C393-62, in which 3-point and 4-point flexing is imposed on a sandwich beam. The bending strength D and the heart's flexure shear modulus can be quantified, GC, from the loading rates and the beam diversion measurements, and the beam approach without flexure deformation. This is really useful in evaluating product efficiency, for example, From the average value and the standard deviations derived from multiple beams [6].

5.2 Three Point Bending Of Sandwich Panel

For the study of leaning actions for the current sandwich structure a simpler approach is introduced. A strictly assisted honeycomb sandwich plate that is exposed to a point load at its mid-span is known as seen in Figure 4 showing the shear stress at the mid-span cross-sections of the sandwich panel. It is presumed that where the thickness range of the face plate is high, the variance of stress distribution in the line of plate thickness can be overlooked. The heart of the nymph is also expected to hold only the vertical shear strains \( \tau_c \).
6. Effect of Varying the Core Thickness of the Honeycomb Structure

Varying the core thickness will result in an result on the mechanical properties of the composite sandwich structural. In table (2) Unidirectional (UD) carbon fiber based fabrics were used as the reinforcement constituent of the composite face sheets. Epoxy resin was used as the matrix material. Aluminum honeycomb core materials with hexagonal cell configuration (with cell size of 10 mm) were provided. Three different core thicknesses; 6, 21 and 46 mm were used for the manufacturing of the composite sandwich panels [7].

The average flatwise compression strength and modulus values of composite sandwich structures for various core thicknesses were presented in Table 2. Although the strength values decrease, the compressive modulus values were found to be increased due to the increase in core thickness.

For composite sandwich structures with various core thicknesses, the ultimate compressive strength were calculated and summarized in Table 2. It was found that the ultimate compressive strength of the composite sandwich constructions increase with the increase of the core thickness.

Figure 9 shows microscope images of Al honeycomb core cross-sections for various core thicknesses.

| Core Thickness (t) [mm] | Wall Thickness \(t_w\) [mm] | Elastic Modulus [MPa] | Compressive Strength | Ultimate Compressive Strength (MPa) |
|-------------------------|-------------------------------|-----------------------|----------------------|------------------------------------|
| 6                       | 45.3 ± 3.7                    | 13.52                 | 0.56                 | 37.8 ± 3.2                         |
| 21                      | 43.5 ± 1.9                    | 18.20                 | 0.44                 | 67.8 ± 15.6                        |
| 64                      | 44.1 ± 3.1                    | 45.00                 | 0.41                 | 72.2 ± 15.3                        |

Table 2 the Experimental Mechanical Properties for Carbon-Epoxy/Al Honeycomb Composite Sandwich Structures with Various Core Thicknesses [7].
7. Effect of Varying the Core Material

The core material has an effect on the properties of mechanical of the complex sandwich construction. Table (3) indicates an evaluation between the mechanical properties of the composite materials with different core materials:

1. Jute/VE Honeycomb core [12];
2. Aluminum Plas-core [13];
3. Stainless Steel Plas-core [14]
4. Hexcel HRH 10 Nomex [15]

From table (3), the jute-vinyl ester cores own comparatively high density strengths when compared to the other offered core materials: $\sigma = 15.5$ MPa.

Table 3: Compressive Strength Data of Different Core Geometries and Material Honeycombs.
The results from this education suggested that fibre-reinforced centers in products that withstand tensile static forces have the ability to be an alternative to standard cores. Additional work is required to assess the efficiency of fibre-reinforced cores in certain loaded setups, such as bent or dynamic loads.

8. Effect of Varying the Face Sheet Material

Kuldeep P. Toradmal experimentally conducted a three-point bending exam on honeycomb sandwich panels. And. Al. Al. Glass reinforced polymer (GFRP), aluminium (A3003 H19) and stainless steel (SS-304) were used in three separate types of facing material. Polypropylene with all three tests is used as the main factor.

Table (4) shows a comparison between the three different types, from this table it may be understood that the least ultimate load value was for stainless (SS-304) — polypropylene board between very 3 samples, whereas aluminum (A3003 H19) — polypropylene honeycomb frames have the average total load values. [16]

Every sample is classified as follows for very three styles of panels; stainless steel samples (SS-304)-polypropylene panel are classified as SS-I, SS-II and SS-III. Aluminum samples (A3003 H19) – Panel polypropylene is as called as AL-I, AL-II and AL-III. GFRP- Panels of polypropylene are known as FR-I, FR-II and FR-III.
Table 4: Comparing the Results for Three Different Face Sheet Materials [16].

| Panel  | Ultimate Load (N) | Average Ultimate Load (N) |
|--------|------------------|---------------------------|
| SS-I   | 2240             |                           |
| SS-II  | 2040             |                           |
| SS-III | 1960             |                           |
| AL-I   | 2480             |                           |
| AL-II  | 2560             | 2427                      |
| AL-III | 2240             |                           |
| FR-I   | 2280             |                           |
| FR-II  | 2080             | 2147                      |
| FR-III | 2080             |                           |

9. Experimental Analysis of sandwiches with varying core orientation

For Sandwich structure optimization, it is critical to determine the effects of varying the honeycomb core orientation. Varying core orientation effects ultimate core strength, sandwich ultimate load at failure, and sandwich extension at failure. The longitudinal orientation of the honeycomb shall be considered 0 degrees orientation and the transverse orientation being 90 degrees of orientation. Table 5 shows how varying the orientation of the honeycomb within the composite sandwich affects the structural properties of the sandwich when subjected to 3-point bending [17].

Table 5. Effects of core angle on composite sandwich structural properties

| Core Orientation | Ultimate Load (lbf) | Extension at Failure (in) | Core Shear Ultimate Stress (psi) |
|------------------|---------------------|---------------------------|---------------------------------|
| 0                | 301.61              | 0.1016                    | 262.27                          |
| 15               | 274.9               | 0.1007                    | 237.80                          |
| 30               | 264.71              | 0.1042                    | 228.86                          |
| 45               | 248.16              | 0.1170                    | 214.67                          |
| 60               | 246.02              | 0.1336                    | 213.09                          |
| 75               | 238.13              | 0.1425                    | 207.19                          |
| 90               | 240.73              | 0.1450                    | 205.93                          |
10. Conclusions

In the above an effort was made to review different aspects of the sandwich panel.

The main conclusions from this review for may be summarized as:

1. Increasing the core thickness (up to 46mm) for Carbon-Epoxy/Aluminum Honeycomb Composite Sandwich Structures will cause an increase in the Ultimate Compressive Strength and the Elastic Modulus.
2. Between the four different core materials (Jute/VE Honeycomb core, Aluminum Plas-core, Stainless Steel Plas-core and Hexcel HRH 10 Nomex), the Composite Sandwich Structures with Jute/VE Honeycomb core tend to have the higher Compressive Strength (15.5 MPa).
3. Stainless steel (SS-304) has the lowest ultimate load when compared to Glass fiber reinforced polymer (GFRP) and aluminium (A3003 H19) with the same core material for very the three examples (The Polypropylene).
4. Aluminum (A3003 H19) – Polypropylene honeycomb plates have the highest values of final weight when compared to Glass fiber protected polymer (GFRP) and Stainless steel (SS-304) with the same core material.
5. Varying core orientation effects ultimate core strength, sandwich ultimate load at failure, and sandwich extension at failure
6. The previous researchers did not take into consideration some features may affect the mechanical properties of the composite sandwich construction (the Ultimate Compressive Strength and the Elastic Modulus) like; surface roughness, heat treatment, temperature, moisture ...etc.

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11. References

1. Azzam A and Li W, (2014) “An experimental investigation on the three-point bending behavior of composite laminate”, IOP Conf. Series: Materials Science and Engineering.
2. Q Shen, M Omar and S Dongri (2012) “Ultrasonic NDE Techniques for Impact Damage Inspection on CFRP Laminates”, Journal of materials science research.
3. U. Farooq, A. A. Khurram, M.S.Ahmad, A. Rakha, N. Ali, A. Munir, T. Subhani, (2013). “Optimization of the Manufacturing Parameters of Honeycomb Composite Sandwich Structures for Aerospace Application”, International Conference on Aerospace Science & Engineering.
4. Marian N. Velea, Simona Lache, (2011). “Numerical simulations of the mechanical behavior of various periodic cellular cores for sandwich panels”, Procedia Engineering, 10, 287–292.

5. Bitzer, T. N. (2012) Honeycomb technology: materials, design, manufacturing, applications and testing. Springer Science & Business Media.

6. Jack R Vinson, (2001). Sandwich structures ASME, Applied Mechanics, 54, 201-213.

7. Mehmet Ziya Okur, Serkan Kangal, Metin Tanoglu, (2018). “Development of Aluminum Honeycomb Cored Carbon Fiber Reinforced Polymer Composite Based Sandwich Structure”, İzmir Institute of Technology, Department of Mechanical Engineering, İzmir Turkey.

8. G.R. Rayjade and G.V.R. Seshagiri Rao, (2015) “Study of Composite Sandwich Structure and Bending Characteristics”, International Journal of Current Engineering and Technology, Vol.5, No.2

9. Shubham V. Rupani, Shivang S. Jani, G.D.Acharya, (2017). “Design, Modelling and Manufacturing aspects of Honeycomb Sandwich Structures: A Review”, International Journal of Scientific Development and Research (IJSDR), Volume 2, Issue 4

10. Jen, Y. M., Ko, C. W., & Lin, H. Bin. (2009). Effect of the amount of adhesive on the bending fatigue strength of adhesively bonded aluminum honeycomb sandwich beams. International Journal of Fatigue, Vol.31 (Issue 3), 455–462.

11. Jeom Kee Paik, Anil K. Thayamballi, Gyu Sung Kim, (1999). “The strength characteristics of aluminum honeycomb sandwich panels Thin-Walled Structures”, 35, 205–231.

12. Ariel Stocchi, Lucas Colabella, Adrián Cisilino, Vera Álvarez, (2013), “Manufacturing and Testing of a Sandwich panel honeycomb core reinforced with natural-fiber fabrics”, Materials and Design.

13. Khan MK, Baig T, Mirza S., (2012). “Experimental investigation of in-plane and out-of-plane crushing of aluminum honeycomb”, Materials Science and Engineering.

14. Giglio M, Manes A, Gilioli A. (2012). “Investigations on sandwich core properties through an experimental–numerical approach”, Composites Part B: Engineering.

15. Rao S, Jayaraman K, Bhattacharyya D., (2010). “Natural fibre reinforced hollow core sandwich panels”, 14th European Conference on Composite Materials, Budapest Hungary.

16. Kuldeep P.Toradmal, Pratik M.Waghmare, Shrishail B.Sollapur, (2017). “Three Point Bending Analysis of Honeycomb Sandwich Panels: Experimental Approach”, International Journal of Engineering and Techniques - Volume 3 Issue 5, Sep - Oct.

17. Joshua M. Lister, (2014), “Study the Effects of Core Orientation and Different Face Thicknesses on Mechanical Behavior of Honeycomb Sandwich Structures under Three Point Bending”, Thesis, the Faculty of California Polytechnic State University, USA.