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Review Article

Study of Composite Sandwich Structure and Bending Characteristics– A Review

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Abstract

The use of sandwich structure is increased rapidly in various fields which uses many applications ranging from satellite, aircraft, ships, automobile, railcars, bridge construction and many more the purpose of following review paper is to provide general introduction to sandwich structure and discussion on structural mechanics including types of loads acting, failure modes observed in sandwich construction and typical three point bending analysis of sandwich structure.

Keywords: *sandwich structure, honeycomb core, failure modes, defects, bending analysis.*

1. Introduction

Over the last few years, the science and technology of sandwich structures and materials has gained an impressive momentum, and the use of such structures and materials in a variety of products covering the range from sporting goods to satellites is on the increase. Advances in materials processing and fabrication techniques including digital manufacturing are leading to novel applications. As the range of applications expands, particularly in the area of marine structures such as high speed craft and structures resistant to blast loading, there is increased need to understand the behavior of sandwich structures under a wide range of loading conditions and environments. This poses special challenges to experimental mechanics in characterizing the loading and deformation and failure response of sandwich structures. The characterization of mechanical properties of sandwich structures poses special challenges due to their heterogeneity and considerable mismatch in properties between core and face sheet.

Sandwich composite structures offer a very high stiffness-to-weight ratio. A sandwich composite panel is composed of high strength composite skins separated by and bonded to a light weight honeycomb cores or foam. A sandwich panel enhances the flexural rigidity of the structure without adding substantial weight. Also an increase in the thickness of honeycomb foam cores provides higher stiffness and strength of the panel at the minimum addition of weight Sandwich structures in several applications have shown to have higher fatigue strength and better acoustical and thermal insulation. Honeycomb cores have numerous advantages over the foam or wood based sandwich structures due to their high crushing strength and stiffness, fatigue and moisture resistance Sandwich panels have a variety of applications in aerospace, automobile, sports and marine industry. In aerospace industry the parts of the aircrafts like ailerons, flaps and rudders, have been manufactured from honeycomb sandwich panels. (U. Farooq *et al* 2013) a typical sandwich assembly consists of two thin exterior face sheets and one thick lightweight cellular core placed between them. These three components are forced to act as a unit by means of a joint method. The core has the most important contribution to the performance of sandwich structures. Its role is to stabilize the exterior face sheets, to keep constant the distance between them and to resist shear forces along its thickness. (Marian N. Veleaa *et al* 2011).

2. History of Sandwich Structures

Noor, Burton. And Bert state that the concept of sandwich construction dates back to Fairbairn in 1849. In England, sandwich construction was first used in the Mosquito night bomber of World War II Feichtinger states that also during World War II, the concept of sandwich construction in the United States originated with the faces made of reinforced plastic and a lower density core. In 1943 the Wright Patterson Air Force Base designed and fabricated the Vultee BT-1 5 fuselage using fiberglass-reinforced polyester as the face material and using both glass-fabric honeycomb and balsa wood core. The first research paper

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*Corresponding author: **G.R. Rayjade; G.V.R. Seshagiri Rao** is working as HOD concerning sandwich construction was written by Marguerre in 1944 dealing with sandwich panels subjected to in-plane compressive loads. Early theoretical work was all restricted to uniform lateral loads, and simply supported boundary conditions. During the early post World War II period, the USFPL was the primary group in the development of analysis and design methods for sandwich structures. (Jack R Vinson 2001).

3. Constituents of Honeycomb Sandwich Structure

A honeycomb sandwich structure consists of two thin face sheets attached to both sides of a lightweight core (see figure 3.1). The design of sandwich structures allows the outer face sheets to carry the axial loads, bending moments, and in- plane shears while the core carries the normal flexural shears. Sandwich structures are susceptible to failures due to large normal local stress concentrations because of the heterogeneous nature of the core and face sheet assembly. Component mounting must therefore use potted inserts to distribute the point loads from connections. Sandwich panel face sheets are commonly fabricated using metals like aluminium, steel or graphite/epoxy composite panels. The core is typically fabricated using a honeycomb or aluminium construction.

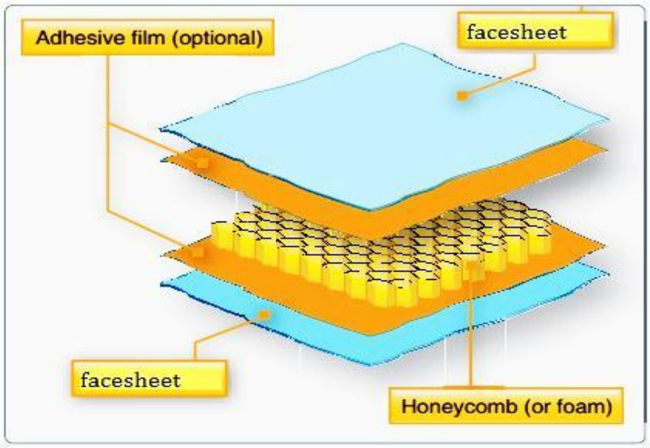


Fig 3.1 Honeycomb Sandwich Structure

3.1 Material Selection

The honeycomb sandwich construction consists of unlimited variety of materials and panel configurations. The composite structure provides a wide range of core and facing material combinations for selection. The following criteria should be considered in the routine selection of core, facing, and adhesive.

3.1.1 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.

3.1.2 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.

3.1.3 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.

4. Failure Modes of Honeycomb Structure

Designers of sandwich panels must ensure that all potential failure modes are considered in their analysis. A summary of the key failure modes is shown below:

4.1 Skin compression failure

The skin and core materials should be able to withstand the tensile, compressive and shear stresses induced by the design load. The skin to core adhesive must be capable of transferring the shear stresses between skin and core.

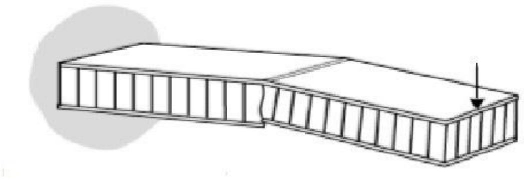


Fig 4.1 Skin compression failure of honeycomb plate

4.2 Excessive deflection

The sandwich panel should have sufficient bending and shear stiffness to prevent excessive deflection.

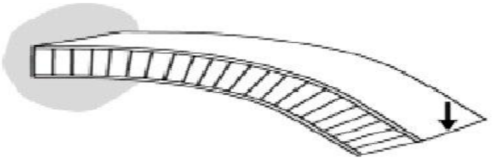


Fig 4.2 Excessive deflection of honeycomb plate

4.3 Panel buckling

The core thickness and shear modulus must be adequate to prevent the panel from buckling under end compression loads.

Fig 4.3 Panel Buckling of honeycomb plate

4.4 Shear crimping

The core thickness and shear modulus must be adequate to prevent the core from prematurely failing in shear under end compression loads.

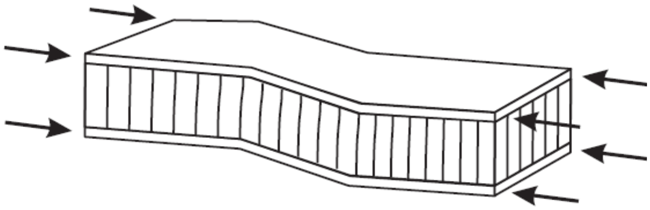


Fig 4.4 Shear Crimping of honeycomb plate

4.5 Skin wrinkling

The compressive modulus of the facing skin and the core compression strength must both be high enough to prevent a skin wrinkling failure

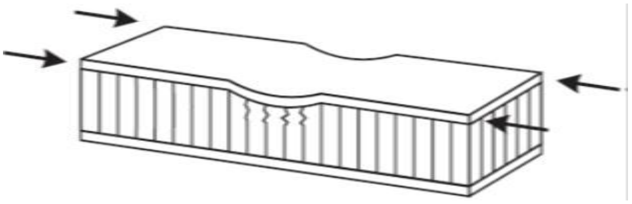


Fig 4.5 Shear Wrinkling of honeycomb plate Intra cell

4.6 buckling

For a given skin material, the core cell size must be small enough to prevent intra cell buckling.

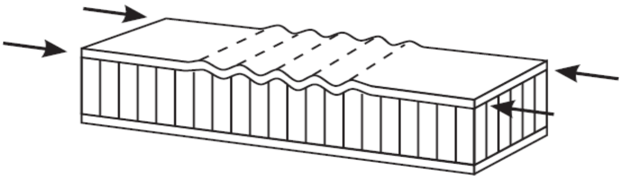


Fig 4.6 Intra Cell Buckling of honeycomb plate

4.7 Local compression

The core compressive strength must be adequate to resist local loads on the panel surface.

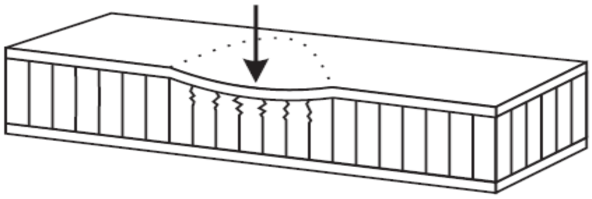


Fig 4.7 Local compression of honeycomb plate

5. Defects in Sandwich Honeycomb Structure

Generally the defects or the damage emerges in the sandwich honeycomb structures are due to the skin problems, core defects or due to the delamination in the core and the skin. So the practical types of the damages in honeycomb structure are as follows:

5.1 Debonding of Honeycomb structure

In this type of defect of honeycomb structure the contact between the skin plate and the honeycomb core cut and then at that position the section becomes weak and there is irregular frequency distribution finally results in crack in the structure. This generally occurs due to intra cell buckling or panel buckling.

5.2 Delamination in Honeycomb structure:

This type defect is incurred due the change in the temperature conditions and the impact load on the specific point. Local compression may lead to the delamination of the skin or adhesive contact between the core and the adhesive.

5.3 Core crushing in Honeycomb structure

In this type of damage in honeycomb structure the sudden impact may result in the inner part of the honeycomb to be damaged by getting crushed at some parts. Maximum deflection, local compression and shear wrinkling may result in the crushed core.

6. Bending Theory of Sandwich Structure

This section deals with the elastic analysis of sandwich beams in three-point bending in order to evaluate the stresses in the core or skin and hence the applied loads are corresponding to various failure mechanisms. Consider a simply supported sandwich beam (Fig.6.2.1) of span length a, width b and central load p. Each skin has thickness t_f and the two skins are separated by a relatively thick core of thickness h_c. It is assumed that all three layers are perfectly bonded together and the face material is much stiffer than the core. (Jeom Kee Paik *et al* 1999)

6.1 Standards for Testing

ASTM Standard C393-62, in which a sandwich beam is subjected to 3-point and 4-point bending. From the load values and the mid-span deflection measurements, and the beam solution including transverse shear deformation, one can calculate the flexural stiffness *D* and the transverse shear modulus of the core, G_C. For instance this is very useful for assessing the quality of manufacturing, from the mean values obtained from several beams and the standard deviations obtained. (Jack R Vinson 2001)

6.2 Three Point Bending Of Sandwich Panel

A simplified method is adopted for the analysis of bending behaviour for the present sandwich panel. A simply supported honeycomb sandwich panel subjected to a line load at its mid-span is considered as shown in Fig.6.2.3 showing stress distribution at the mid-span cross section of the honeycomb sandwich beam. It is assumed that the facing plate carries only bending stresses σ_f When the thickness t_f 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 τ_c. The stresses and deflections in a beam of this type may be found, to a first approximation, by the use of ordinary bending theory. (Jeom Kee Paik *et al* 1999) This theory is based on these assumptions:

1. The beam bends in a cylindrical manner with no curvature in lateral plane.
2. Cross-sections which are plane and perpendicular to the longitudinal axis of the beam remain so when the bending takes place.
3. The sandwich structure is assumed to act compositely.

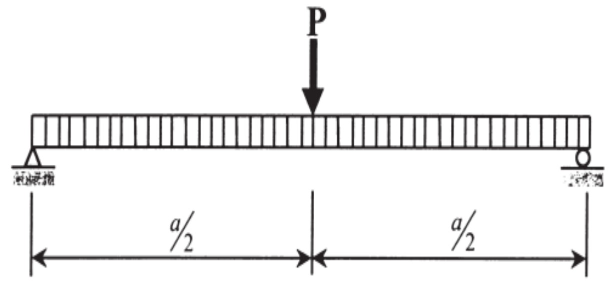


Fig.6.2.1 Simply supported sandwich beam and its cross section

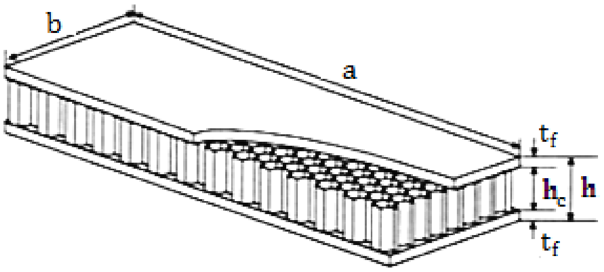
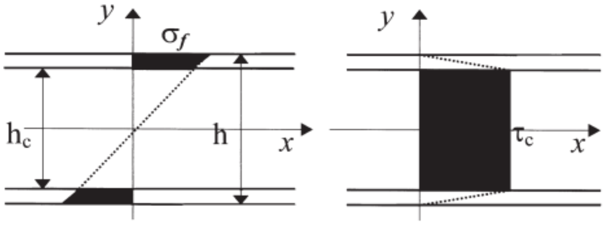


Fig.6.2.2 Honeycomb-cored sandwich panel



(a) Bending stress (b) Shear stress

Fig.6.2.3 Idealized distributions of bending and shear stresses in sandwich beam.

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

$$w = \frac{Pa^3}{48E_f I_f} + \frac{Pa}{AcGca} \tag{5}$$

Where E_f and I_f are modulus of elasticity and moment of inertia of face sheet respectively. While Ac and Gca are cross sectional area of honeycomb core and average value of elastic shear modulus of the honeycomb core cell respectively. The first term of the right hand side in Eq. (5) is due to bending effect alone and the second one account for the shear effect. 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.6.2.3, 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

$$M = C.\frac{bh^2\sigma_f}{4}\left\{1-\left(\frac{hc}{h}\right)^2\right\} = \frac{Pa}{4} \tag{6}$$

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. (5) by assuming that the shear effects of cores for panel strength are likely to be similar to those for panel stiffness.

This result in

$$C = \frac{c_1}{c_1 + c_2}$$

Where

$$c_1 = \frac{a^3}{48E_f I_f}$$

$$c_2 = \frac{a}{4A_c G_{ca}}$$

The critical load in sandwich panel is obtained when the bending stress of facing plate reaches the yield stress.

Therefore, by replacing P by Po (Equ.6) leads us to the following critical load (Po).

$$Po = C.\frac{bh^2\sigma_f}{a}\left\{1-\left(\frac{hc}{h}\right)^2\right\}$$

Conclusions

In the above, an attempt has been made to provide a review of various aspects of sandwich structures. Although not all significant research findings are included, but remarked that there now exists a Journal of Sandwich Structures and Materials through which one may keep up to date on the latest research in this area. This paper will also helpful for understanding failure modes and analytical study for three point bend test.

The future for sandwich construction looks bright indeed. Sandwich construction will continue to be the primary structure for satellites. In aircraft, sandwich construction will be increasingly used particularly for large aircraft, such as the Global Range Transport. Many countries are using composite sandwich constructions for their navies' ship hulls. However one of the largest uses may be for bridge constructions.

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