



DESIGN OPTIMIZATION FOR SANDWICH COMPOSITE PLATE

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Abstract:

Sandwich composites are widely used in aerospace and other industries due to their excellent stiffness at very low weight. This structure provides great versatility as a wide range of core and facing material combinations can be selected. This paper discusses on optimum design of sandwich plates using various materials. Isotropic Aluminium and orthotropic carbon/epoxy composites with unidirectional (UD), cross-ply, and angle-ply symmetric laminate configurations were considered as different options for face sheets. Al honeycomb was used as the common core material. Analyses based on finite element method identified angle-ply carbon/epoxy laminate as the best material for the presented sandwich plate problem.

Key Words: Composite, Sandwich, Honeycomb, Aluminium, Bending & Finite Element Analysis

1. Introduction:

Sandwich construction has attracted considerable interest [1-8], as the concept is very suitable and amenable to the development of lightweight structures with high in-plane and flexural stiffness. Sandwich panels consist typically of two thin face sheets (or facings, or skins) and a lightweight thicker core. A sandwich-structured composite is a special class of composite materials that is fabricated by attaching two thin but stiff skins to a lightweight but thick core. The core material is normally low strength material, but its higher thickness provides the sandwich composite with high bending stiffness with overall low density. Laminates of glass or carbon fiber reinforced thermoplastics or mainly thermoset polymers (unsaturated polyesters, epoxies) are widely used as skin materials. Sheet metal is also used as skin material in some cases. The core is bonded to the skins with an adhesive or with metal components by brazing together.

The strength of the composite material is dependent largely on two factors: (i) The outer skins: If the sandwich is supported on both sides, and then stressed by means of a force in the middle of the beam, then the bending moment and shear forces will be introduced in the material. The core material spaces the two skins apart and the thicker the core material the stiffer the composite will be. This principle works in much the same way as an I-beam does; and (ii) The interface between the core and the skin: Because the shear stresses in the composite material change rapidly between the core and the skin, the adhesive layer also undertakes some degree of shear force. If the adhesive bond between the two layers is weak, it will result in delamination of the sandwich composite.

The objective of this paper was to present analyses for optimization of sandwich composite for a particular type of loading. Aluminum honeycomb with orthotropic properties was used as a common core material. The analyses compared the performance of sandwich plate with different face sheet materials like isotropic Aluminum and orthotropic composite laminates under uniformly distributed loading. The effect of unidirectional, cross-ply, angle-ply laminate configurations on the bending deflection of the sandwich plate was investigated. Based on the results, optimum material and lay-up were identified for minimum having minimum deflection at less weight. A typical sandwich composite with Al honeycomb core material is shown in Fig. 1 [7].

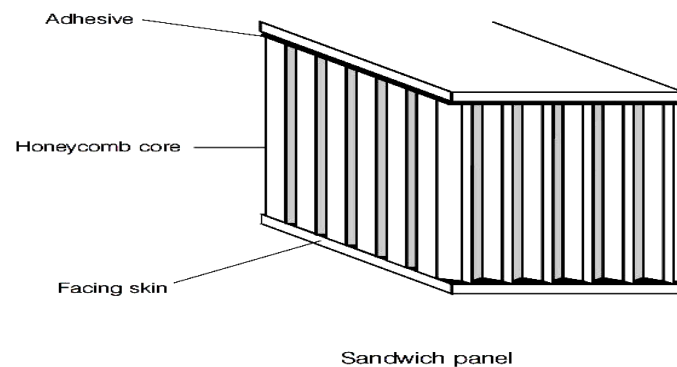


Figure 1: A typical sandwich composite with Aluminum honeycomb core [7]

2. Literature Review:

Craig A. Steeves and Norman A. Fleck (2004) have focused on the competing collapse mechanisms for simply supported sandwich beams with composite faces and a PVC foam core subjected to three point bending. They investigated the mechanical properties of the face sheets and core are measured independently and said

that depending upon the geometry of the beam and the relative properties of the constituents, collapse is by core shear, face sheet micro buckling or by indentation beneath the middle loading roller. A systematic series of experiments and finite element simulations have been performed in order to assess the accuracy of simple analytic expressions for the strength and a failure mechanism map is constructed by them to reveal the dependence of the dominant collapse mechanism upon the geometry of the beam [2].

C. W. Schwingshackl, G. S. Aglietti, and P. R. Cunningham (2006) examined several available analytic and experimental methods to determine the orthotropic material properties of honeycomb. Fifteen published sets of simple equations for the material properties were reviewed and their values calculated for a specific honeycomb aluminum core. The same core was tested with ASTM standard methods and the agreement between the theoretical material properties and the experimental results was considered. To reduce the time and cost for the experimental determination, a simple technique for measuring the main dynamic material properties of honeycomb is introduced. A good agreement was found by them between the major theoretical out-of-plane material properties of honeycomb, the experimental ASTM methods, and the presented dynamic approach [6].

Bouazza Mokhtar, Hammadi Fodil and Khadir Mostapha (2010) investigated the classical plate theory and it was assumed that the plane cross sections initially normal to the plate midsurface before deformation remain plane and normal to that surface during deformation. This was the result of neglecting the transverse shear strains. However, in thick and moderately thick laminated plates, significant transverse shear strains occurred, and the theory gave inaccurate results for the plates. So, it was obvious that the shear strains have to be taken into account. There were numerous theories of plates and laminated plates that include the transverse shear strains. One of them was the Reissner and Mindlin theory, known as the first-order shear deformation theory, which defined the displacement field as linear variations of mid plane displacements. This theory, where the relation between the resultant shear forces and the shear strains is obtained by using shear correction factors, has some advantages due to its simplicity and low computational cost. Some other plate theories, namely the higher-order shear deformation theories, include the effect of transverse shear strains. They presented a survey of plate bending of cross-ply laminate by using the finite element method (F.E.M) and used ANSYS for modeling, using a type of shell element, Shell 99 and the second was an approach based on a type of solid element, Solid 46. They obtained the results by comparing with the results of the theory of Reddy [1].

Henrik Herranen, Ott Pabut, Martin Eerme, Jüri Majak, Meelis Pohlak, Jaan Kers, Mart Saarna, Georg Allikas and Aare Aruniit (2012), the purpose of their study was to design a light-weight sandwich panel for trailers. Strength calculations and selection of different materials were carried out in order to find a new solution for this specific application. The sandwich materials were fabricated using vacuum infusion technology. The different types of sandwich composite panels were tested in 4-point bending conditions according to ASTM C393/C393M. Virtual testing was performed by use of ANSYS software to simplify the core material selection process and to design the layers. 2D Finite element analysis (FEA) of 4-point bending was made with ANSYS APDL (Classic) software. Data for the FEA was obtained from the tensile tests of glass fiber plastic (GFRP) laminates. Virtual 2D results were compared with real 4-point bending tests. 3D FEA was applied to virtually test the selected sandwich structure in real working conditions. Based on FEA results the Pareto optimality concept has been applied and optimal solutions determined [4].

M. M. Venugopal, S K Maharana and K S Badarinarayan (2013), they investigated that the sandwich composites were multilayered materials made by bonding stiff, high strength skin facings to low density core material. The main benefits of using the sandwich concept in structural components were the high stiffness and low weight ratios. These structures can carry in-plane and out-of-plane loads and exhibit good stability under compression, keeping excellent strength to weight and stiffness to weight characteristics. In order to use these materials in different applications, the knowledge of their static behavior was required and a better understanding of the various failure mechanisms under static loading condition was necessary and highly desirable. The objective of their study was to develop a modeling approach to predict response of composite sandwich panels under static bending conditions. Different models including 2D and 3D with orthotropic material properties were attempted in advanced finite element (FE) software Ansys. Analytical solutions were also used to verify the some of the mechanical properties such as bending stress and shear stress with the FEM results [8].

3. Analysis and Approach:

Classical analysis based on Strength of Materials (SOM) was performed to highlight the advantage of Sandwich Structures. The flexural rigidity of an isotropic solid beam and a sandwich beam was compared in the following analysis. Figure 2 shows the dimensions of the beams used for the analysis.

Flexural Rigidity, $EI = \frac{bh^3}{12}$, where E = elastic modulus and I = moment of Inertia

$$\text{For Isotropic Solid, } EI_{sol} = \frac{Ebh^3}{12} = \frac{Eb(2t)^3}{12} = \frac{8Ebt^3}{12} \quad (1)$$

For core, $EI_{cor} = \frac{E_c bc^3}{12}$

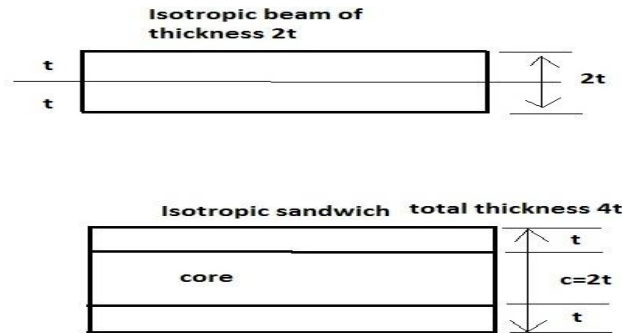


Figure 2: Dimensions of isotropic solid and sandwich beams

For faces (using parallel axes theorem), $EI_{face} = 2E_f \left[I_{faces} + bt \left(\frac{d}{2} \right)^2 \right]$

If $d=c+t$, then $EI_{eq} = \left(\frac{E_f bt^3}{6} \right) + \left(\frac{E_f btd^2}{2} \right) + \left(\frac{E_c bc^3}{12} \right)$

Since $t \ll d$ and $E_c \ll E_f$, $EI_{eq} = \frac{E_f btd^2}{2}$ (2)

Now dividing eq. (2) by eq. (1) we get, $\frac{EI_{eq}}{EI_{sol}} = \left(\frac{12E_f btd^2}{16Ebt^3} \right) = \left(\frac{3d^2}{4t^2} \right)$

For condition, $c=t$ and $d=2t$, then $\frac{EI_{eq}}{EI_{sol}} = 3$

For condition, $c=2t$ and $d=3t$, then $\frac{EI_{eq}}{EI_{sol}} \cong 7$

As shown above, the flexural rigidity of the sandwich beam was 3 times higher than the equivalent Isotropic solid beam, when $c=t$ and 7 times higher when $c=2t$. So as shown in the analysis, flexural rigidity of the Sandwich beam can be increased further by increasing the separation between the face sheets.

With this background analysis on sandwich composite beam, Finite element analysis of solid plate and sandwich composite plates were performed using ANSYS (v 11.0). Shell 91 element was used to model the panels. Analyses were also performed to compare the effect of unidirectional, cross-ply and angle-ply laminate configurations on the bending deflection of the sandwich plate. The geometry and loading of sandwich panel is shown in Fig. 3. The panel was simply supported on all its four edges. Same configuration except the core was used for isotropic solid plate made of Aluminium (thickness = 0.1"). The lay ups used for orthotropic composite face sheets were (i) UD = [0/0/0/0], (ii) Cross-ply = [0/90/90/0], and (iii) Angle-ply = [60/-60/-60/60]. The material properties used for the face sheets and core material are given in Table 1 [9]

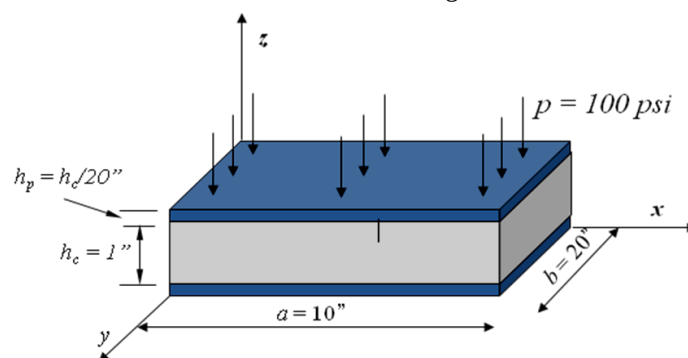


Figure 3: Geometry and loading conditions for simply supported sandwich panel

Table 1: Material Properties Used For Face Sheets and Core [9]

Property	Isotropic Al	Orthotropic Carbon/Epoxy Composite	Al Honeycomb
E_x (psi)	1e6	20.6e6	1440
E_y (psi)		1.5e6	870
E_z (psi)		1.5e6	350000
G_{xy} (psi)		1.04e6	500
G_{yz} (psi)		0.53e6	92610
G_{xz} (psi)		1.04e6	92610
ν_{xy}	0.3	0.3	0.005
ν_{yz}		0.4	0.009
ν_{xz}		0.3	0.025

4. Results and Discussion:

Typical deflection (U_z) contours obtained from finite element analyses are shown in Fig. 4-6. As expected, the deflection at the centre of the panel was high when compared to the deflection away from the centre.

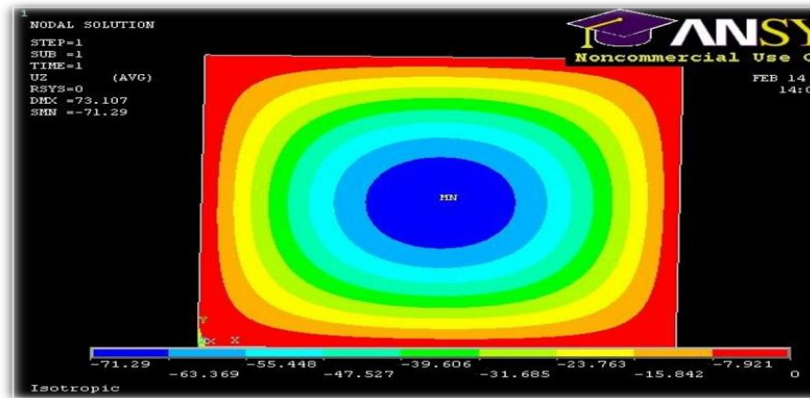


Figure 4: Deflection contour for isotropic solid plate

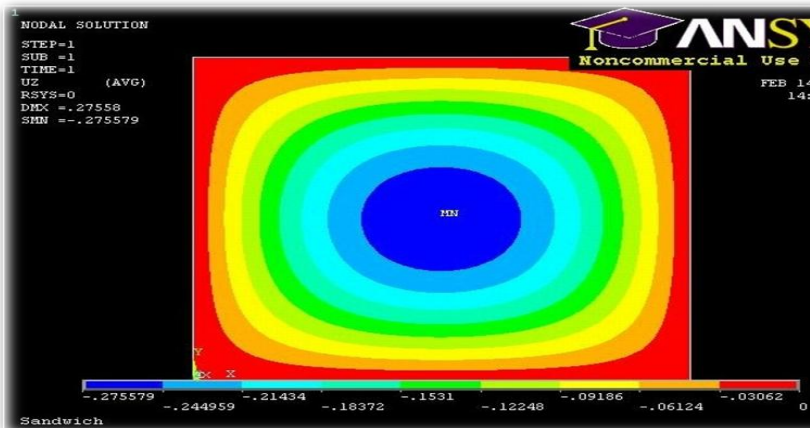


Figure 5: Deflection contour for isotropic sandwich plate

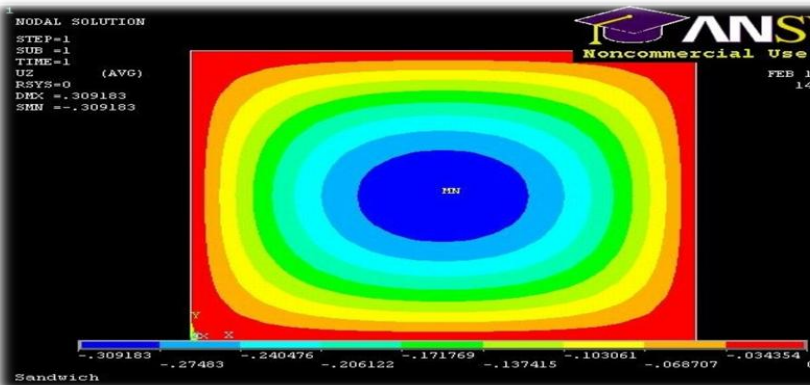


Figure 6: Deflection contour for angle-ply sandwich plate (at $\theta=60^\circ$)

From the above results, it can be concluded that the minimum deflections are 0.27" for isotropic sandwich plate and 0.3" for angle-ply orthotropic sandwich plate (at $\theta=60^\circ$). The deflection for angle-ply sandwich plate was measured for various orientation angles. The variation in the deflection with respect to fiber orientation is shown in Fig. 7. The minimum deflection was obtained for $\theta=45^\circ$ [45/-45/-45/45] laminate configuration. Table 2 summarizes the deflections obtained for solid panel and various types of sandwich panels. The deflections for sandwich panels were significantly less when compare to that of Isotropic Solid panel.

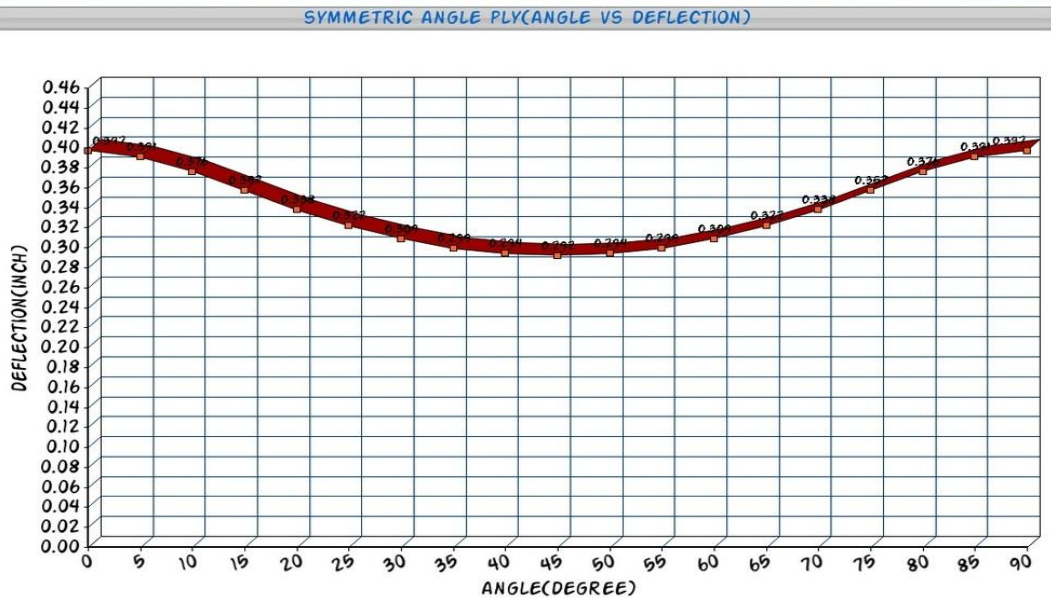


Figure 7: Deflection of angle-ply orthotropic sandwich plate for various angles

Comparing the weight of sandwich panels, Aluminum panel was found to have much more weight than carbon/epoxy composites because of the high density of Aluminum (2.8 g/cc) compared to that of carbon/epoxy composite (1.58 g/cc) [9]. So, the weight of Aluminum sandwich panel was almost twice than that of carbon/epoxy composite sandwich panel for almost the same deflection. Therefore, it can be concluded that the sandwich panel with orthotropic angle-ply laminate ($\theta=45^\circ$) face sheets as an optimum design for plate problem presented in this paper.

Table 2: Deflections for Various Sandwich Plates

Material	Deflection (inch)
Isotropic Solid plate	71.29
Isotropic Sandwich plate	0.2755
Unidirectional Sandwich plate	0.3971
Cross-ply Sandwich plate	0.3911
Angle-ply Sandwich plate at $\theta=45^\circ$	0.2922

5. Conclusions:

The paper presented an optimized design for a sandwich composite plate. Classical SOM analysis was used to highlight the advantage of sandwich composite. For core thickness equal to the thickness of one face sheet, the flexural rigidity of the sandwich beam was three times higher than that of the solid beam. The flexural rigidity was found to increase further by increasing the thickness of the core. Finite element analysis was conducted to study the behavior of solid and sandwich plates. The objective was to identify the best material configuration for the given sandwich plate. Isotropic Aluminium and orthotropic carbon/epoxy composites with unidirectional (UD), cross-ply, and angle-ply symmetric laminate configurations were used as face sheets. Al honeycomb was used as the common core material. For the same bending deflection, sandwich composite with angle-ply carbon/epoxy laminate ($\theta=45^\circ$) weighed almost twice less than that with Al face sheets. Thus, angle-ply carbon/epoxy laminate with $\theta=45^\circ$ was identified as the best material for the presented sandwich plate problem.

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