STRESES ANALYSIS OF LAMINATED COMPOSITE PLATE USING F. E. M

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ABSTRACT

This work presents a stress analysis of Graphite/Epoxy laminated composite plates. In the present work the stress behavior of laminated composite plates under transverse loading using a four-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes, based on first order shear deformation theory. The static stress analysis includes the all type of stress behavior in diagrammatic form and results are closed agreement with later work. In the present study the modeling is done in ANSYS 12.0 and results were closed to FEM code. In this study investigations were carried on square plates starting with 2 to 10 layer 45 degree symmetric angle ply laminated composite plates at clamped boundary condition.

Keywords: Laminated Composite, square, isotropic, stress, CC, FEM, ANSYS

1. INTRODUCTION

Composite materials are extensively used in aerospace, automobile, nuclear, marine, biomedical and civil Engineering. As composite materials having high strength to weight ratio, high stiffness to weight ratio, so it has superior fatigue characteristics and also ability to change fiber orientation to meet design requirements. Now a day’s laminated composite materials are the primary need of high rise buildings. In practical the use of laminated composite as slabs beams panels deck etc. The matrix, compared with fiber direction, limits the strength of laminated composites. However, composite structures subjected to low-velocity impacts or the drop of minor objects, such as tools during assembly or maintenance operation, exhibit a brittle behaviour and can sustain significant damage. These impacts are particularly. The structural components like beam made of composite materials are being increasingly used in engineering applications. Because of their complex behavior in the analysis of such structures some technical aspects must be taken into consideration. Finite element method is versatile and efficient for the analysis of complex structural behaviour of the composite laminated structures. The analysis of vibration and dynamics, buckling and post buckling, failure and damage analysis based on the various laminated plate theories is mainly carried out using Finite Element method.

2. REVIEWS OF LITERATURE

Wenbin Yu [30] had developed a Reissner–Mindlin theory for composite laminates without invoking adhoc kinematic assumptions by using the variational-asymptotic method. Instead of assuming a priori the distribution of three-dimensional displacements in terms of two-dimensional plate displacements as what was usually done in typical plate theories, an exact intrinsic formulation had been achieved by introducing unknown three-dimensional warping functions. Cardenas Diego et. al. [51] had developed a reduced-order finite-element model suitable for Progressive Failure Analysis (PFA) of composite structures under dynamic aeroelastic conditions based on a Thin-Walled Beam (TWB) formulation is presented. Junaid Kameran Ahmed et al. [52] presented the behavior of laminated composite plates under transverse loading using an eight-node diso-parametric quadratic element based on first order shear deformation theory, the element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes . Achchhe Lal et. al. [53] had presented the second ordered statistics of first-ply failure response of laminated composite plate with random material properties under random loading. The basic formulation is based on higher order shear deformation plate theory (HSDT) with the geometrically nonlinearity in the von-Karman.

3. MATERIALS AND METHODOLOGY

In the finite element analysis, the structure divided into a finite number of elements having finite dimensions and reducing the structure having infinite degrees of freedom to finite number of unknowns. The formulation presented here is based on assumed displacement pattern within the element and can be applied to linear, quadratic, cubic or any
other higher order element by incorporating appropriate shape functions. In the following the element mass and stiffness matrices of the plate are derived. The element mass and stiffness matrices are then assembled to form the overall mass and stiffness matrices. Necessary boundary conditions are then incorporated.

### 3.1 ELEMENT FORMULATION FOR RECTANGULAR ELEMENT

The laminated beam has been modeled here using eight noded iso-parametric bending elements. In the present formulation, transverse shear strain has been incorporated based on the first order shear deformation theory. This theory assumes a constant shear strain throughout the thickness of the laminate. A shear correction factor has been used in the formulation to account for the parabolic variation of the transverse shear strain. The mid-surface of the laminated beam is assumed as the reference plane for the laminated beam system. Thus, a coupling between the axial force and the bending moment occur at any plane. This consideration fulfils the requirement for analyzing unsymmetrical laminates (in which the middle plane of the beam is not the neutral plane) as well.

### 3.2 SHELL181 Element Description [ansys help]

SHELL181 is suitable for analyzing thin to moderately-thick shell structures. It is a four-node element with six degrees of freedom at each node: translations in the $x$, $y$, and $z$ directions, and rotations about the $x$, $y$, and $z$-axes. (If the membrane option is used, the element has translational degrees of freedom only). The degenerate triangular option should only be used as filler elements in mesh generation. SHELL181 is well-suited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness is accounted for in nonlinear analyses. In the element domain, both full and reduced integration schemes are supported. SHELL181 accounts for follower (load stiffness) effects of distributed pressures. SHELL181 may be used for layered applications for modeling composite shells or sandwich construction. The accuracy in modeling composite shells is governed by the first-order shear-deformation theory (usually referred to as Mindlin-Reissner shell theory). The element formulation is based on logarithmic strain and true stress measures. The element kinematics allow for finite membrane strains (stretching). However, the curvature changes within a time increment are assumed to be small. See SHELL181 in the Theory Reference for the Mechanical APDL and Mechanical Applications for more details about this element.

The following figure shows the geometry, node locations, and the element coordinate system for this element. The element is defined by shell section information and by four nodes (I, J, K, and L).

![Figure 3.1 SHELL181 Geometry](image)

Xo = Element $x$-axis if ESYS is not provided.

$x$ = Element $x$-axis if ESYS is provided.

Element Reference Contains proprietary and confidential information of ANSYS.

### 4 Materials and methodology

#### 4.1 Single-Layer Definition

To define the thickness (and other information); use section definition, as follows:

- **SEC-TYPE, SHELL**
- **SEC-DATA, THICKNESS**

A single-layer shell section definition provides flexible options. For example, we can specify the number of integration points used and the material orientation.
4.2 Multilayer Definition

The shell section commands allow for layered shell definition. Options are available for specifying the thickness, material, orientation, and number of integration points through the thickness of the layers. You can designate the number of integration points (1, 3, 5, 7, or 9) located through the thickness of each layer when using section input. When only one, the point is always located midway between the top and bottom surfaces. If three or more points, two points are located on the top and bottom surfaces respectively and the remaining points are distributed equal distance between the two points. The default number of integration points for each layer is three; however, when a single layer is defined and plasticity is present, the number of integration points is changed to a minimum of five during solution. The following additional capabilities are available when defining shell layers:

SHELL181 accepts the preintegrated shell section type (SEC-TYPE, GENS). When the element is associated with the GENS section type, thickness or material definitions are not required. You can use the function tool to define thickness as a function of global/local coordinates or node numbers.

4.3 BASIC ASSUMPTIONS

The basic assumptions for the formulation include the following:

1. A laminated composite beam consists of a number of perfectly bonded layers. Each layer is treated as homogeneous and orthotropic in which the fibers are orientated arbitrarily with respect to the reference axis system.
2. The beam is composed of linear and elastic material.
3. The deformation follows Mindlin’s hypothesis. Therefore the linear element perpendicular to the middle plane of beams before bending remains straight but not necessarily normal to the mid-surface after bending.
4. The in-plane displacement components are assumed to vary linearly along the thickness direction to yield constant transverse shear strain.
5. The effect of transverse normal stress on the gross response of laminated is assumed to be negligible.

5 Result and discussion

5.1 Problem Description

An orthotropic plate with various numbers of layers is subject to transverse loading condition for clamped boundary condition has been considered for the present study, and the results were given in diagrammatic form.

**Table 5.1:** Geometric properties of orthotropic plates [Pal et al 2013]

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>No. of layers</th>
<th>Stacking sequence</th>
<th>Fiber orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length=1.0m</td>
<td>2, 4, 6, 8, 10</td>
<td>45/-45</td>
<td>Symmetric ply</td>
</tr>
<tr>
<td>Width=1.0m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness=0.01m</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 5.2:** Material Properties of graphite/epoxy composite material [Pal et al 2013]

<table>
<thead>
<tr>
<th>Elastic Constants</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_1$</td>
<td>$175 \times 10^6 \text{ N/m}^2$</td>
</tr>
<tr>
<td>$E_1$</td>
<td>$7 \times 10^6 \text{ N/m}^2$</td>
</tr>
<tr>
<td>$E_1$</td>
<td>$7 \times 10^6 \text{ N/m}^2$</td>
</tr>
<tr>
<td>$V_{12}=V_{13}$</td>
<td>0.25</td>
</tr>
<tr>
<td>$V_{23}$</td>
<td>0.01</td>
</tr>
<tr>
<td>$G_{12}=G_{13}$</td>
<td>$3.5 \times 10^6 \text{ N/m}^2$</td>
</tr>
<tr>
<td>$G_{23}$</td>
<td>$1.4 \times 10^6 \text{ N/m}^2$</td>
</tr>
</tbody>
</table>
Table 5.3: Loading condition and boundary condition [Pal et al 2013]

<table>
<thead>
<tr>
<th>Uniformly Distributed load (q)</th>
<th>boundary condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 N/m²</td>
<td>Clamped at all sides</td>
</tr>
</tbody>
</table>

5.2 Results of two layered laminated composite plates

Fig. 4.1 two layer cross ply laminated composite plate

Fig. 4.2 first principle stress for two layers cross ply laminated composite plate
Fig. 4.3 second principle stress for two layers cross ply laminated composite plate

Fig. 4.4 third principle stress for two layers cross ply laminated composite plate

Fig. 4.5 shear stress (xy) for two layers cross ply laminated composite plate
**Fig. 4.6** shear stress (xz) for two layers cross ply laminated composite plate

**Fig. 4.7** shear stress (yz) for two layers cross ply laminated composite plate

**Fig. 4.8** X component of stress for two layers cross ply laminated composite plate
Fig. 4.9 Y component of stress for two layers cross ply laminated composite plate

Fig. 4.10 Displacement in z direction for two layers cross ply laminated composite plate

5.3 Results of four layered laminated composite plates

Fig. 4.11 Four layers cross ply laminated composite plate
Fig. 4.12 First principle stress for four layers cross ply laminated composite plate

Fig. 4.13 Second principle stress for four layers cross ply laminated composite plate

Fig. 4.14 Third principle stress for four layers cross ply laminated composite plate
Fig. 4.15 XY shear stress for four layers cross ply laminated composite plate

Fig. 4.16 XZ shear stress for four layers cross ply laminated composite plate

Fig. 4.17 YZ shear stress for four layers cross ply laminated composite plate
Fig. 4.18 X component of stress for four layers cross ply laminated composite plate

Fig. 4.19 Y component of stress for four layers cross ply laminated composite plate

Fig. 4.10 Displacement in z direction for four layers cross ply laminated composite plate
Fig. 4.11 Six layers cross ply laminated composite plate

Fig. 4.12 First principle stress six layers cross ply laminated composite plate

Fig. 4.13 Second principle stress six layers cross ply laminated composite plate
Fig. 4.14 Third principle stress six layers cross ply laminated composite plate

Fig. 4.15 XY stress six layers cross ply laminated composite plate

Fig. 4.16 XZ stress six layers cross ply laminated composite plate
Fig. 4.17 YZ stress six layers cross ply laminated composite plate

Fig. 4.18 X component of stress six layers cross ply laminated composite plate

Fig. 4.19 Y component of stress six layers cross ply laminated composite plate
5.5 Results of eight layered laminated composite plates

Fig. 4.20 Z component displacement six layers cross ply laminated composite plate

Fig. 4.21 Eight layers cross ply laminated composite plate

Fig. 4.22 First principle stress eight layers cross ply laminated composite plate

Fig. 4.23 Second principle stress eight layers cross ply laminated composite plate

Fig. 4.24 Third principle stress eight layers cross ply laminated composite plate
Fig. 4.26 XZ component stress of eight layers cross ply laminated composite plate

Fig. 4.28 X component stress of eight layers cross ply laminated composite plate

Fig. 4.29 Y component stress of eight layers cross ply laminated composite plate

Fig. 4.31 Ten layers cross ply laminated composite plate

Fig. 4.30 Z component displacement of eight layers cross ply laminated composite plate

Fig. 4.32 First principle stress ten layers cross ply laminated composite plate
Fig. 4.33 Second principle stress ten layers cross ply laminated composite plate

Fig. 4.44 XY component stress ten layers cross ply laminated composite plate

Fig. 4.43 Third principle stress ten layers cross ply laminated composite plate

Fig. 4.45 XZ component stress ten layers cross ply laminated composite plate

Fig. 4.46 YZ component stress ten layers cross ply laminated composite plate

Fig. 4.48 Y component stress ten layers cross ply laminated composite plate
6 CONCLUSIONS
The following conclusions may be drawn The first principle stress for given failure load in anti-symmetric angle ply is responsible for failure at support however as the number of layers increases its effect diminish. The second and third principle stress for given failure load in anti-symmetric angle ply is responsible for failure at middle with large stress concentration however as the number of layers increases its effect diminish and for higher number of layers it also affects stacking properties of laminations. The XY, XZ, and YZ component of stress for given failure load in anti-symmetric angle ply is responsible for middle layer delamination; it does not effects the top and bottom failure. It also not affected by increasing the layers. The X and Y component stress for given failure load in anti-symmetric angle ply is responsible for side failure in X and Y directions. The Z component stress for given failure load in anti-symmetric angle ply is responsible for side failure in Z direction and well defined stress contour have been found. In other words we can say it is responsible for overall failure of plates. But it does not effects stacking property of layers.

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