



Stress and Failure Analysis of Laminated Composite Structures

An Online Continuing Education Course for Engineers

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**STRESS AND FAILURE ANALYSIS OF
LAMINATED COMPOSITE STRUCTURES**

(Emphasis on Classical Lamination Theory)

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1.0 INTRODUCTION

This course focuses on presenting a well established computational method for calculating stresses/strains in reinforced laminated composite structures. The basis for the presented computational method is often referred to as *classical lamination theory*. A clear understanding of this approach is supported by the development of the fundamental mechanics of an orthotropic lamina (ply). Various failure theories are presented each requiring that stresses/strains be quantified on a ply-by-ply basis in order to make failure predictions. Both applied loads and hygrothermal (thermal and moisture) effects are treated in the computational procedure. Stress and failure predictions are an important part of the process required in the design of laminated composite structures.

The *learning objectives* for this course are as follows:

1. Understanding the differences between isotropic, orthotropic and anisotropic material behavior
2. Having knowledge of the material constants required to define Hooke's law for an orthotropic lamina (ply)
3. Understanding the restrictions on the material constants required in evaluating experimental data
4. Knowing the difference between reference and natural (material) coordinates for an orthotropic lamina
5. Being familiar with the stress-strain relations in reference and natural coordinates for an orthotropic lamina
6. Understanding the coordinate transformations used in transforming stresses and/or strains from one coordinate system to another
7. Knowing generally the types of tests performed to determine the stiffness and strength properties of an orthotropic lamina
8. Having knowledge of a number of biaxial strength (failure) theories used in the design of laminated composite structures
9. Understanding which in-plane strength quantities are needed, as a minimum, in applying various failure theories
10. Knowing the difference between separable and generalized failure theories
11. Understanding that the maximum stress and maximum strain failure theories make similar predictions except under certain material behavior
12. Appreciating under what conditions the Chang failure criteria reduces to the Hashin failure criteria
13. Knowing the basis for the fact that the Tsai-Wu failure criteria is more general than the Tsai-Hill failure criteria
14. Being familiar with the effect of the direction of shear stress on lamina strength
15. Understanding the laminate orientation code used to define stacking sequence
16. Being familiar with a number of special laminate constructions designed to eliminate undesirable composite material behavior
17. Understanding the computational procedure for determining the stresses/strains in a laminated composite subject to applied loads and/or hygrothermal effects
18. Having knowledge of the limitations of classical lamination theory.

It is important to note a limitation on the computational methodology presented in this course. Stress predictions from *classical lamination theory* are quite accurate in locations away from boundaries, e.g., free edges, edge of a hole or cutout, etc., of the laminate. Thus at distances equal to the laminate plate(shell) thickness or greater, the computational method presented herein is accurate and useful in the preliminary design of laminated composite structures. The basis for this limitation is that lamination theory assumes a generalized state of plane stress which is reasonably accurate away from boundaries. Along boundaries, the state of stress becomes three-dimensional with the possibility that interlaminar shear and delamination stresses can become significant. Deviation of the stress state from the plane stress assumption is often referred to as a boundary layer. The thickness of this boundary layer is dependent on the size of the element or mesh used in the analysis and the scope of the analysis.

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