MFG58002 Advanced Mechanics of Composite Structures

Instructor	Adnan Kefal *(adnankefal@sabanciuniv.edu)*
Course Attributes	Sabanci University – 2022-23 Fall Semester
	Doctorate/Masters Level
	3 SU Credit / 10 ECTS / 42 Teaching Hours
Course Schedule	Tuesday at 13:40 am – 16:30 am FASS 1096

Course Relevance

Composite materials and sandwich structures are being used in an ever-increasing range of applications and industries; therefore, manufacturing/mechanical/aerospace/mechatronics engineers/researchers need acquiring practical skills about theoretical and experimental mechanics of such material systems to be able perform reliable and lightweight design of structural components. The current course aims at providing such skills through advanced theories of continuum mechanics within the context of applications to composite structures.

Objectives

This course will cover advanced mechanics of composite structures through macroscale modelling of composite materials using high-order laminate theories, and through experimental characterization, and data acquisition and analysis. To carry out conceptual design, initial sizing and preliminary modelling of composite structural components, design engineers need a thorough understanding of the experimental mechanics as well as strength, stability, and dynamic mechanical response of thin and thick plates/shells made of composite materials. In this context, students will be given an overview of standards and tests methods for experimental identification of material properties of laminates and sandwich structures. In addition, the constitutive equations and strain-stress transformation equations will be reviewed in the context of modelling composite structures. Beam, plate, and shell kinematics will be introduced based on different lamination theories including layer-wise, zigzag, high-order shear deformation theories. Principles of virtual work and minimum potential energy will be presented for bending, buckling, vibration problems of plate and shell structures. Analytical/numerical solutions of these problems will be included. Computational modelling will include post-processing methods to obtain accurate interlaminar and transverse-shear stresses and quantify damage mechanisms such as delamination, impact, and fracture resistance of composite materials.

Learning Outcomes

At the conclusion of this course, students should be able to:

(i) Design and set up experiments for identifying effective mechanical properties of composite structures.

(ii) Perform strain measurements using different measurement techniques and process experimental data.

(iii) Perform coordinate transformation of stress, strain, and stiffness properties of isotropic, orthotropic, and anisotropic materials.

(iv) Perform analytical and numerical structural analysis of unidirectional ply, composite layer, laminates, and sandwich structures using layerwise, zigzag, and higher-order shear deformation theories.

(v) Predict interlaminar displacements/stresses/strains of laminated composites and sandwich structures (beams, plates, shells) under tensile, bending, torsion, and buckling loads.

(vi) Assess strength, damage, and failure mechanisms of laminates based on various failure criterions

Course Syllabus

Week	Topic
Lecture 1	**Review of Solid Mechanics** Fundamental principles and governing equations, kinematics, kinetics, compatibility, constitutive relations, laws of thermodynamics
Lecture 2	**Micromechanics of Lamina** Introduction to composite materials, polymer matrix composites, fiber-glass/carbon epoxy composites, volume fractions, fiber-matrix properties, rule of mixtures, representative volume element, Halpin–Tsai equations
Lecture 3	**Macro Mechanics, Strength and Failure of Lamina** Deformations of unidirectional laminate, lamina material transformations, engineering constants for generally orthotropic lamina, lamina invariants, hygrothermal effects, failure mechanisms: maximum-strain/stress, Tsai–Hill, Tsai-Wu criterions etc.
Lecture 4	**Experimental Tests Methods for Lamina Mechanics** Coupon-level tests: Constituent-level tests—tests on fibers and resin, lamina-level tests, laminate-level tests, ASTM standards Structural element-level tests Component-level tests: Subscale component-level tests, Full-scale component-level tests
Lecture 5	**Macro Mechanics of Laminate** Laminate notation, classification, laminate types, classical lamination theory, stress resultants, plate constitutive relations, thermo-mechanical analysis
Lectures 6-7 **(Midterm)**	**Structural Analysis of Laminated Beams and Design** Governing equations of Euler-Bernoulli beam for laminated composite structures, analytical solutions to laminated beam bending, buckling, vibrations, interlaminar stresses from equilibrium equations Design of composite structures: Basic features of structural design, laminate design, lamina stacking sequence selection, carpet plots, solution of design examples.

Lectures 8-9 **(Project assignment)**	**Structural Analysis of Laminated Plates** Kirchhoff-Love equilibrium equations for laminated plate bending, plate buckling and vibration, boundary conditions, solution methods including Navier, Levy, and Ritz methods, analytical solutions to specially orthotropic plates
Lectures 10-11	**Finite Element Analysis of Laminated Plates** General finite element procedures, Reissner-Mindlin plate element, kinematic relations, shape functions and displacement approximation, principal of virtual work and energy, ANSYS Mechanical APDL coding for solutions of laminated beam/plate/shell example problems.
Lecture 12-13	**Refined Zigzag Theory (RZT)** Introduction to layerwise formulation, RZT governing equations for beams and plates, finite element implementation and in-house coding algorithm.
Lectures 14 **(Project Deadline)**	**Nondestructive Testing and Structural Health Monitoring** Different experimental measurement techniques for composite materials, digital image correlation, strain gauge/FBG sensor measurement, thermography, acoustic emission, shape sensing and real-time structural health monitoring.
Exam Week	**Final Exam**

Books and References

1. Buragohain, M.K., 2017. Composite structures: design, mechanics, analysis, manufacturing, and testing. CRC press.
2. Altenbach H., Altenbach J., Kissing, W., 2018. Mechanics of composite structural elements. Springer-Verlag.
3. Oñate, E., 2013. Structural analysis with the finite element method. Linear statics: volume 2: beams, plates and shells. Springer Science & Business Media.
4. Barbero, E.J., 2007. Finite element analysis of composite materials. CRC press.
5. Reddy, J.N., 2003. Mechanics of laminated composite plates and shells: theory and analysis. CRC press.

Assessment Criteria

Group Project (20%), Midterm Exam (30%), Final Exam (50%)

- *There will be a semester-project and groups of three will be formed to work on the projects.*

Course Material

The outline of lecture notes, project guidelines, and other course-related material will be posted at the SUCourse site *(https://sucourse.sabanciuniv.edu/)*.