Damage and Fracture of Quasibrittle Composites: Computational Modeling and Experimental Characterization with Applications to Car Crashworthiness Analysis

INSTRUCTORS:

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ABSTRACT:

Thanks to their excellent specific mechanical performances and the recent developments in manufacturing technologies, the range of engineering applications of composites is continuously expanding. Current applications include land, marine and air transportation, wind and tidal energy production, and blast protection of civil infrastructures and vehicles. Composites, as several other materials such as concrete, tough ceramics, rocks, sea ice, rigid foams and bone among others, are quasibrittle materials. This means that failure occurs by localization of softening damage into discrete fracture and, in contrast to plasticity, is characterized by a material characteristic length which inevitably leads to a strong energetic size effect when geometrically similar structures of different sizes are compared. These aspects, of utmost importance for damage tolerance design of large composite structures, are completely neglected by the current design paradigm which relies on strength-based failure criteria inherited from plasticity. This course aims at providing the attendees with a sound alternative, based on computational quasibrittle fracture mechanics. First, the course discusses the main damage mechanisms of composites and the scaling of their mechanical properties, highlighting the need for a quasibrittle fracture mechanics framework. Then, novel experimental techniques to characterize the fracturing behavior of these materials are described, with examples of application to textile composites and providing a comprehensive comparison with traditional approaches. The course discusses how to use the obtained experimental results to correctly model fracture in composites. A general computational framework to simulate the orthotropic stiffness, pre-peak nonlinearity, failure envelopes, and the post-peak softening and fracture is described together with the crack band model which inherently introduces a material length scale in the formulation. Finally, the course concludes with some examples of application of the presented concepts to the crashworthiness analysis of composite structures for automotive.
TABLE OF CONTENTS:

**Introduction to composite materials** 90 min
- Classification
- Anisotropic elasticity
  - Anisotropic material
  - Monoclinic material
  - Orthotropic material
  - Transversely isotropic material
  - Relation of compliance and stiffness matrix to engineering elastic constants of a lamina
- Strength failure theories of a lamina
  - Maximum stress failure theory
  - Maximum strain failure theory
  - Tsai-Hill failure theory
  - Tsai-Wu failure theory

**Introduction to quasibrittle fracture mechanics for composite materials** 90 min
- Quasibrittleness of composites
- Size effect in composite structures
- Quasibrittle fracture mechanics for composite materials
- Limitations of the current design paradigm for composites

**Experimental characterization of composite damaging, fracturing and size effect** 90 min
- Classical Linear Elastic Fracture Mechanics approaches
- Challenges in fracture characterization: *snap-back instability* of composite structures
- A novel experimental protocol for stable post-peak softening characterization of composites
- Extrapolation of intra-laminar fracture energy from size effect tests
- Extrapolation of mode I and I inter-laminar fracture energy from size effect tests

**Computational modeling of composite materials** 90 min
- *The Spectral Stiffness Microplane Model*: a general theoretical framework for damage and fracture of unidirectional, 2D and 3D textile composites
- Modeling intra-laminar fracture in composites: *the crack band model*
- Case study 1: application of the Spectral Stiffness Microplane model to car crashworthiness analysis
- Case study 2: numerical investigation on the importance of quasibrittle fracture mechanics in crashworthiness applications
Length of the course: 6 hours

Suggested readings:


