PhD Program in Civil, Chemical and Environmental Engineering
November 2023 Call, XXXIX cycle - Starting date: March 1st 2024

Curriculum in Structural and Geotechnical Engineering, Mechanics and Materials

Project: Mechanics of lightweight composites for sustainable mobility

Keywords: mechanics of composite materials; fracture mechanics; analytical and numerical modeling

Brief Description:

The PhD project focuses on the optimal design of lightweight laminated and sandwich composites and structures with special emphasis on those used in the construction of mobility systems with improved energy efficiency in waterways.

The student will join the newly formed National Center on Sustainable Mobility and collaborate to the research activities of the Spoke 3: Waterways, Work Package WP1: Energy Efficiency. The project will be performed as part of a collaboration with researchers of the Naval Engineering Department of the University of Genova.

In the PhD project the student will formulate analytical and numerical models to investigate the elastic behavior and damage response of composite structural systems when used in extreme marine environments, and work on the optimal design of composite lightweight systems in line with current regulations.

The student joining the program will develop advanced knowledge in Mechanics of Materials and Structures, Composite Materials, Fracture Mechanics and learn how to formulate and rigorously solve mechanics problems through analytical and numerical techniques. The knowledge acquired during the PhD will be applicable to the solution of a wider class of problems in the mechanics of materials and structures for civil, naval, aeronautical and mechanical applications.

The project to be submitted for the admission to the PhD program should be developed on the Mechanics of layered structures using structural theories, such as first- and higher-order shear deformation beam and plate theories or theories based on a zigzag approach (see e.g. [1] and [2] for reviews). Below, as an example, an introduction to the latter is presented, along with some further suggested reading [3-6].

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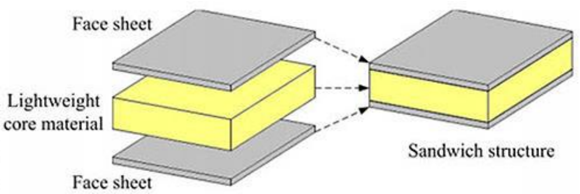

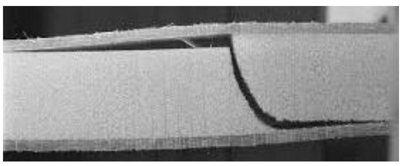

Figure: **S**andwich marine composite and failure caused by crack propagation at the facesheet/core interface followed by kinking and propagation into the core.

Introduction to the Mechanics of layered structures through a zigzag approach

The project could focus on the analysis of layered systems, such as laminated and sandwich composites, which are used in various applications where high strength/stiffness to weight ratios are required.
These composites are made by layers of different materials and thciknesses. The internal layered structure ensures high flexural stiffness and strength and limited weight, and this explains the increasing use of these materials for different applications.
However, layered composites are highly sensitive to the presence of deformable or damaged interfaces, and delaminations which may propagate at the interface, and lead to catastrophic collapses. These failure mechanisms must be understood in order to design structures with improved resistance.

Discrete-layer structural theories are typically used to study layered systems, but the presence of imperfect interfaces complicates their analysis. This drawback was overcome by multiscale structural models based on the coupling of a zigzag kinematics approximation and a cohesive crack approach. They allow to effectively analyze the response of shear deformable layered structures with imperfect interfaces and describe progressive delamination fracture in these systems (see [1,2] for reviews). The zigzag kinematics accounts for zigzag effects associated to the elastic mismatch of the layers and for displacement jumps due to interfacial imperfections/delaminations using a reduced number of variables, which is independent of the number of layers. The effects of imperfect interfaces on the response of structures subjected to thermo-mechanical loading and on wave propagation and dispersion were analyzed and the advantages of this approach over discrete layer models and layerwise theories were highlighted and discussed in [1,3-4]. More recently, these models have been reviewed in [5] where preliminary results on novel single-variable formulations for layered beams, inspired by the technique developed for homogeneous Timoshenko beams in [6], have been presented.

REFERENCES

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[2] **Abrate, S., Di Sciuva, M., (2018) Multilayer models for composite and sandwich structures, in *Comprehensive Composite Materials* II, ed. by C. H. Zweben, P. W. R. Beaumont, (Elsevier, Amsterdam), pp. 399–425**

[3] **Pelassa M., and Massabò, R., (2015), Explicit solutions for multi-layered wide plates and beams with perfect and imperfect bonding and delaminations under thermo-mechanical loading, *Meccanica*, 50, 2497-2524**

[4] **Massabò, R., Propagation of Rayleigh-Lamb waves in multilayered plates through a multiscale structural model, *Int. Journal of Solids and Structures*, 124, 2017, 108-124.**

[5] **Monetto, I., Massabò, R., A single-variable zigzag approach to model imperfect interfaces in layered beams, (2023) *Coatings*, 13, 445.**

[6] **Kiendl, J., Auricchio, F., Hughes, T.J.R., Reali, A., Single-variable formulations and isogeometric discretizations for shear deformable beams, (2015) *Computer Methods in Applied Mechanics and Engineering*, 284, 988-1004.**

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