Diagnostic and prognostic of composite structures by coupled NDT based inspection and computational multiscale approaches

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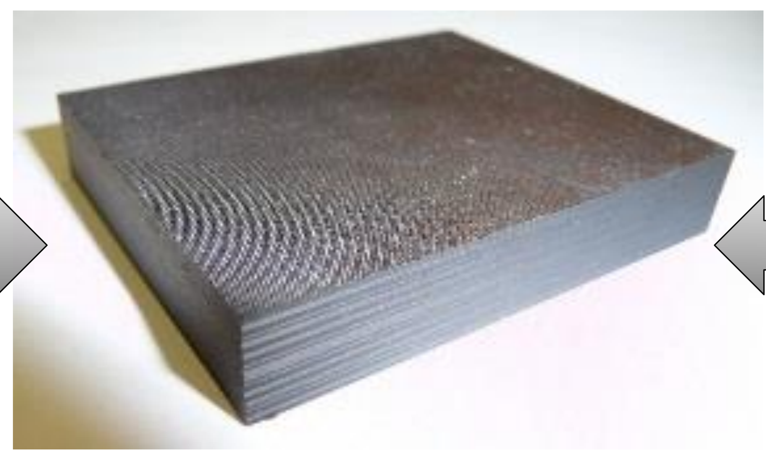
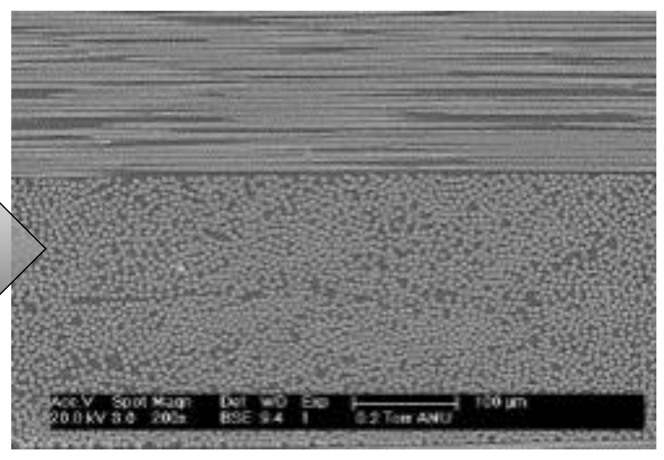
Overview

macro



meso



micro

Multiscale analysis for composite structures

Composite structures are widely used nowadays in many engineering aplications since they offer a good balance between mechanical properties and weight. Despite its extended use and decades of research, the correct prediction of the strength and failure of these structures has proven to be a very challenging. In order to understand the mechanical response of these materials under different loadings it is necessary to have a look into the different scales that are involved, from the structural level (macro-scale), down to the fiber-matrix scale (micro-scale).

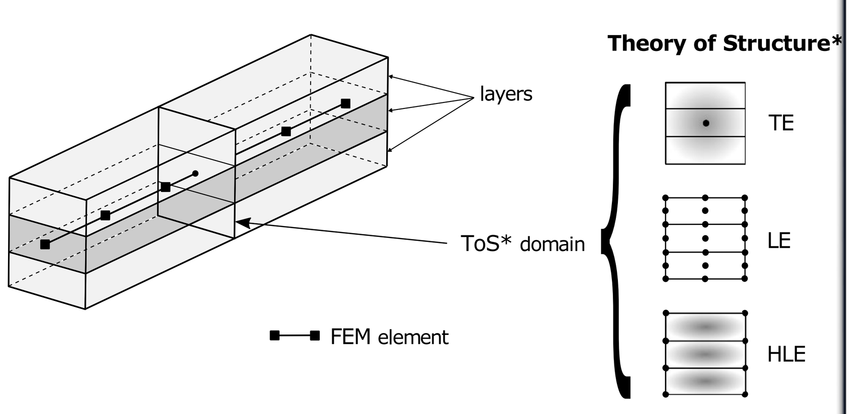
Methodology

Carrera Unified Formulation

The unified formulation works as a generator of structural theories that present many advantages in comparison to classical FEM. The CUF kinematics for 1D models read:

$$\boldsymbol{u}(x,y,z) = N_i(x)\, F_\tau(y,z)\boldsymbol{u}_{\tau i}$$

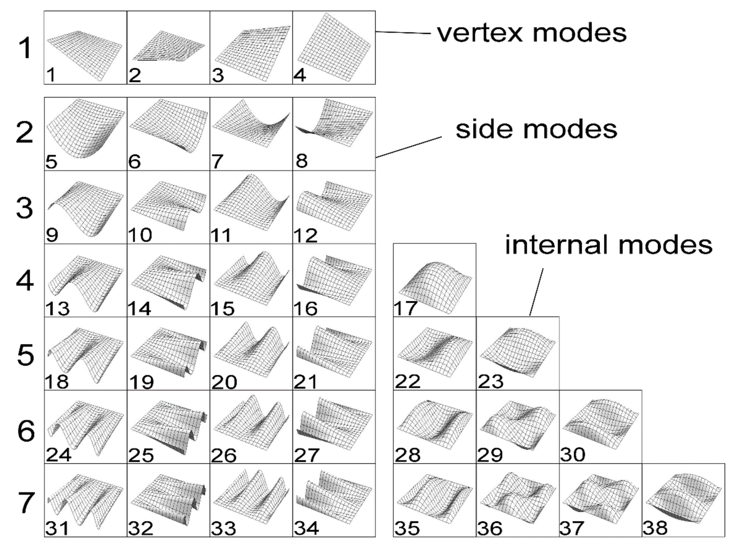
where N_i are the shape functions along the beam axis, and F_τ are the assumed expansions over the cross-section.



Hierarchical Legendre Expansion

A novel higher-order 1D model is introduced to enhance the structural analysis of composite materials. Some of its main features are the following:

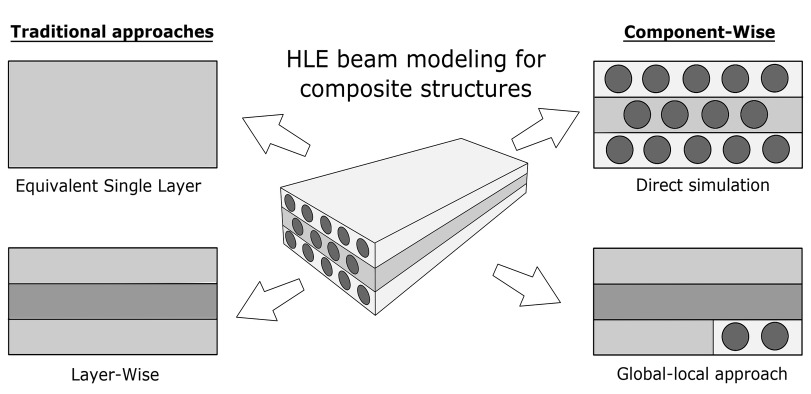
- Vertex, side and internal modes
- Hierarchical kinematics
- Non-local distribution of the unknowns
- Geometrically exact curved sections



Accurate stress analysis

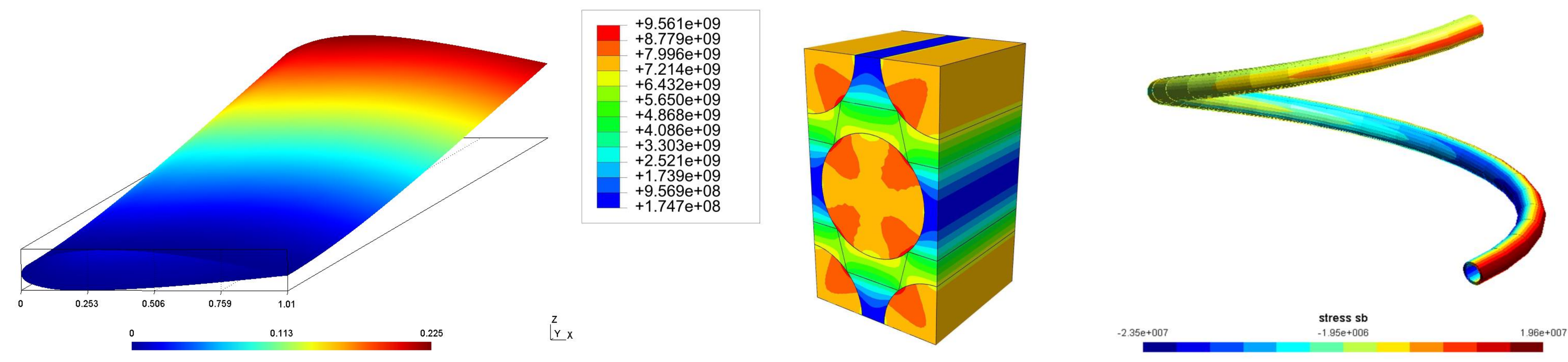
Different methodologies are developed aiming to reduce the computational costs of composite analysis while keeping 3D-like accuracy.

- A global/local approach allows to use ESL, LW and DNS within the same model.
- Transverse stresses are captured with unprecedent accuracy using displacement-based and mixed formulations.
- Curved MITC 1D elements are formulated for the study generic geometries.

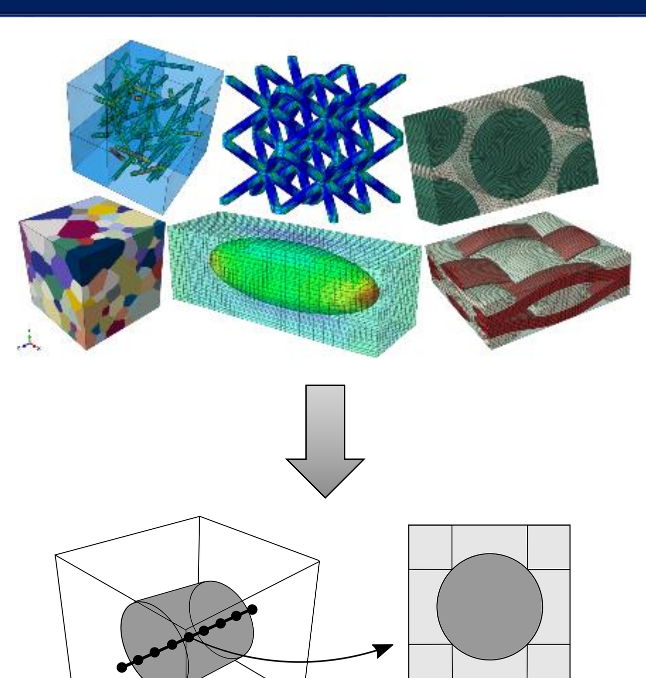


High-fidelity beam models

- The proposed hierarchical higher-order models extends the beam modelling to a wide range of structural problems. Thin-walled structures, multi-component bodies, laminates, composite microstructures or curved geometries can be studied with no loss in accuracy.
- Once the model is set up, the approximation is controlled by the polynomial order of the beam theory. No remeshing procedures are required.
- Reduction of computational costs of at least one order of magnitude. For example, each of the models below make use of less than 10000 degrees of freedom, showing the same levels of fidelity of commercial 3D softwares.



Micromechanics



A fruitful collaboration with Purdue University (IN, USA) was started to extend our simulation techniques to the micromechanical field (UC analysis).

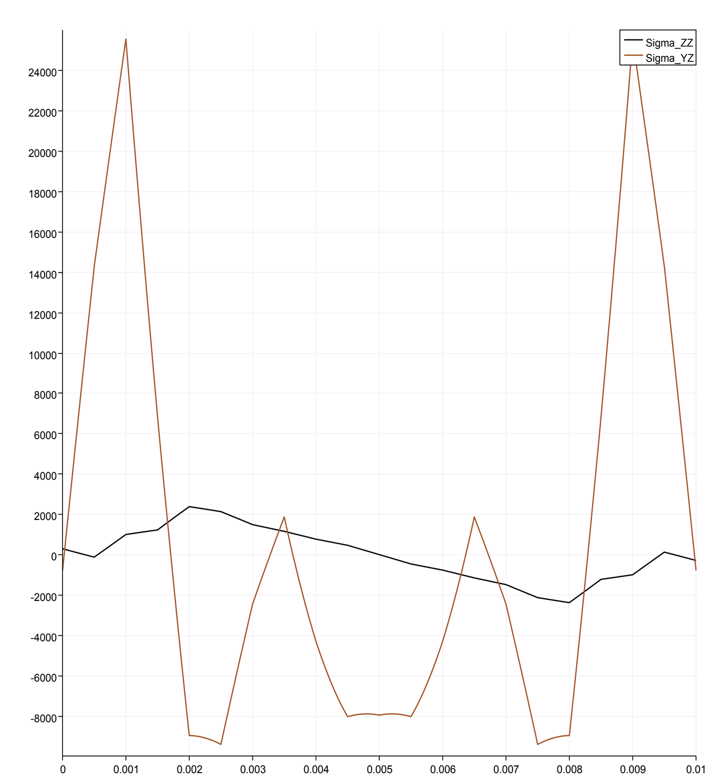
- The Mechanics of Structure Genome is employed to compute the effective properties and the local fields of the composite by minimizing the energy functional of the microstructure:

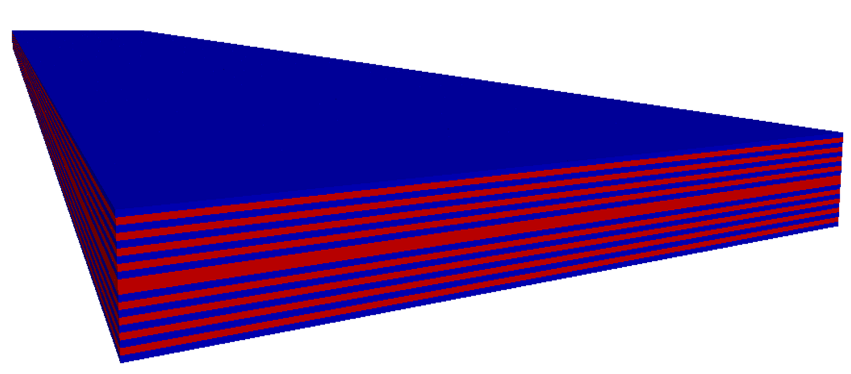
$$\min_{\chi}\; U\big(\bar{\varepsilon}_{ij},\, \chi_{(i,j)}\big) - U\big(\bar{\varepsilon}_{ij}\big)$$

- Refined beam models are used to reduce the computational size of the UC, which is one of the main limitations of the multiscale analysis.

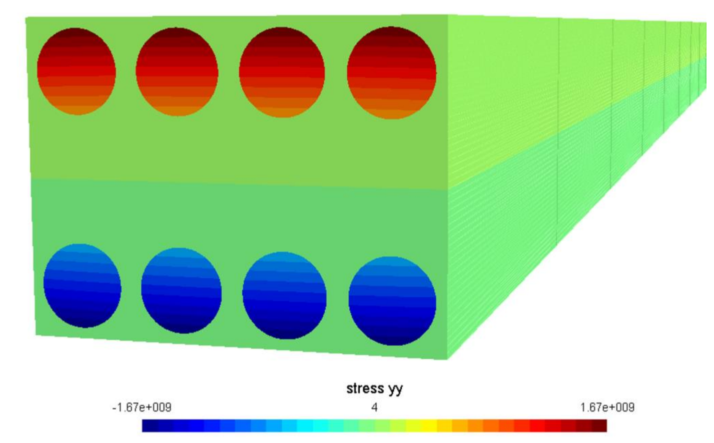
Composite laminates

- The accurate study of damage and failure of composite structures can only be done through a proper representation of the complete state of stress over the laminate.
- The Reissner's mixed variational theorem is employed to obtain the correct transverse stress distributions in laminates.
- A laminate such as the one in the figure below normally employs millions of degrees of freedom. Our refined beam model can do the job for less than 50000.





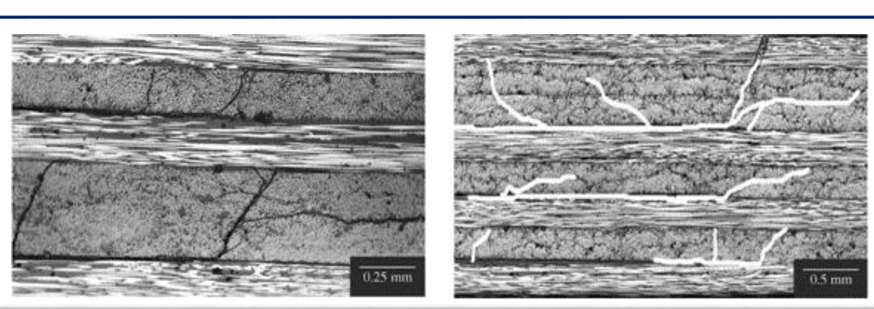
- The global/local approach allows the user to enrich the kinematics of the model in the most critical zones of the structure.
- Different scales can be accounted in the same numerical model, from the whole body down to the fiber/matrix level.



Structural Health Monitoring

Composite structures need to be continously monitored in order to guarantee their integraty and safety during operation. An extended method to achieve so relies on the use of elastic guided waves and a network of piezoelectric transducers to inspect the structure online. In this context, ultrasonic guided waves, a.k.a. Lamb waves, offer many advantages for the identification of structural damage in thin-walled components.

- Issue: conventional low-order FEM codes are not fitted for the simulation of the propagation of ultrasonic waves and require huge models.
- Goal: apply HLE higher-order models and multi-field simulation techniques to increase efficiency in laminated structures.

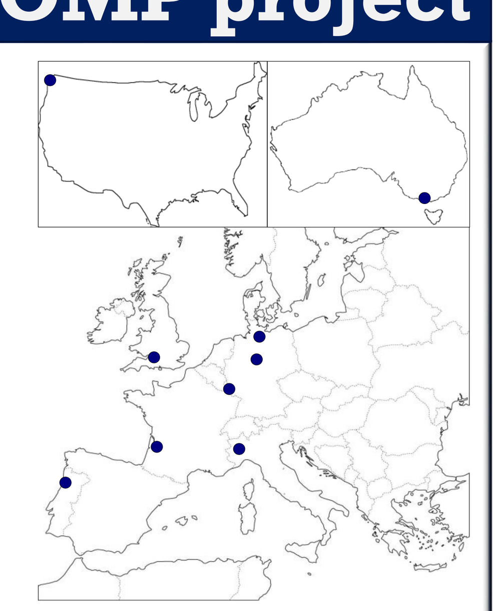


Dissemination

- A. Pagani, **A.G. de Miguel**, M. Petrolo and E. Carrera. *Analysis of laminated beams via Unified Formulation and Legendre polynomial expansions.* Composite Structures (2016) 156:78-92.
- A. Pagani, **A.G. de Miguel** and E. Carrera. *Cross-sectional mapping for refined beam elements with applications to shell-like structures.* Computational Mechanics (2017) 59(6): 1031-1048
- **A. G. de Miguel**, A. Pagani, W. Yu and E. Carrera. *Micromechanics of periodically heterogeneous materials using higher-order beam theories and the mechanics of structure genome*. Composite Structures (2017) 180:484-496.
- E. Carrera, **A. G. de Miguel** and A. Pagani. *Extension of MITC to higher-order beam models and shear locking analysis for compact, thin-walled and composite structures.* Int'l Journal of Numerical Meth. in Eng. (2017) 10.1002/nme.5588
- E. Carrera, **A. G. de Miguel**, A. Pagani and E. Zappino. *Reissner's mixed varational theorem for layer-wise refined beam models based on the unified formulation*. Proceedings of ASME 2017.

FULLCOMP project

- FULLy integrated analysis, design, manufacturing and health-monitoring of COMPosite structures.
- Funded by the European Commision under a Marie Sklodowska-Curie Innovative Training Networks, grant agreement No. 642121.
- Numbers: 7 universities, 1 research center, 1 company, 12 Early Stage Researchers and 10 work-packages.
- Politecnico di Torino is the coordinator of the project and hosts 3 PhD students.



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Project website: www.fullcomp.net
Group website: www.mul2.polito.it