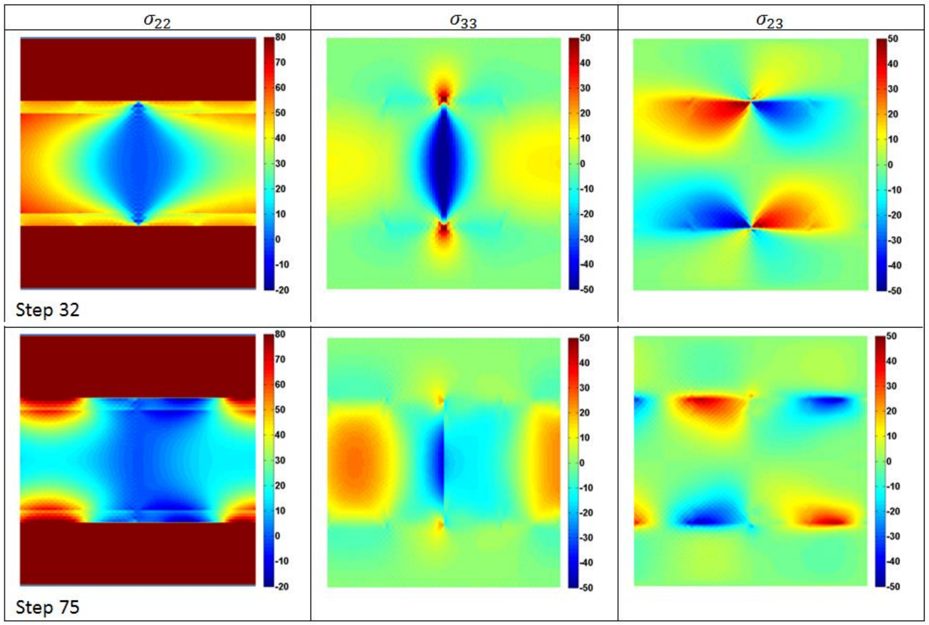
Homogenization and Computational Micromechanics of Heterogeneous Materials & Structures

We are developers of novel computational and user-friendly homogenization-based approaches for simulating the response of materials with complex microstructures across geometric scales and multidisciplinary boundaries. Parallel approaches based on geometric and function space discretizations are pursued simultaneously using finite-volume and elasticity-based techniques. The applications range from advanced aerospace engine components, multilayered laminates, structural components such as perforated plates, to biological tissues. Of primary interest is how the underpinning deformation mechanisms at lower scales percolate to upper scales, which is essential in the development of engineered materials that meet target performance. Our simulation techniques are semi-analytical and hence easily adaptable to a wide range of material behavior, including linear and nonlinear elastic, elastic-plastic and visco-elastic. We have recently incorporated damage evolution capabilities into one of our computational theories (see figure below) and coupled it with an optimization algorithm. We are also focused on incorporating nanoscale surface and multi-physics effects. Our collaborators include researchers in Brazil, China and Greece.



Simulation of damage evolution in cross-ply composite laminates using our finite-volume based homogenization approach, illustrating "on the fly" for the first time damage mode bifurcation from transverse cracking of the inner 90 deg plies to delamination of the 0/90 deg ply interface. **(Source: Tu, W. and Pindera, M-J., Damage evolution in cross-ply laminates revisited via cohesive zone model and finite-volume homogenization. *Composites Part B* 86, (2016) 40-60.)**

Pindera Research Group

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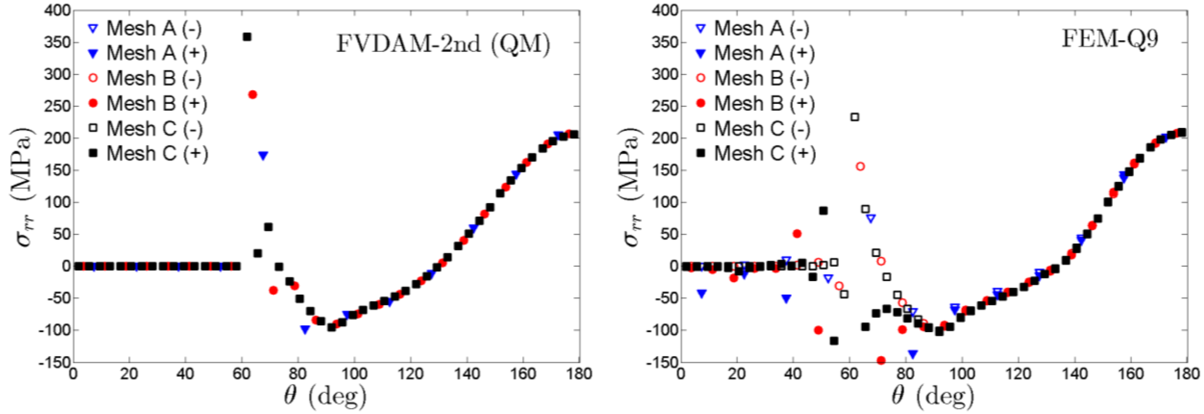
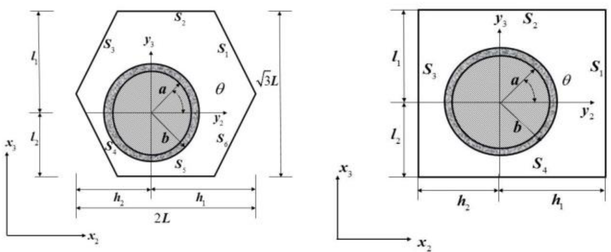
"Using our simulation techniques we strive to understand how material properties at lower scales impact the overall response in order to design engineered material architectures that meet target performance. Moreover, our user-friendly and state-of-the-art homogenization techniques enable researchers to pursue similar goals unfettered by input data construction complexities"

University of Virginia Engineering

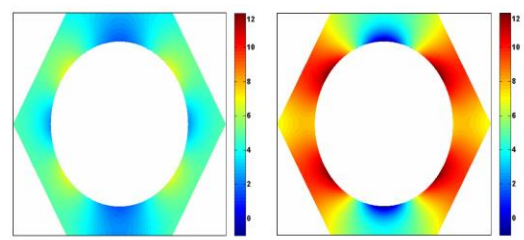


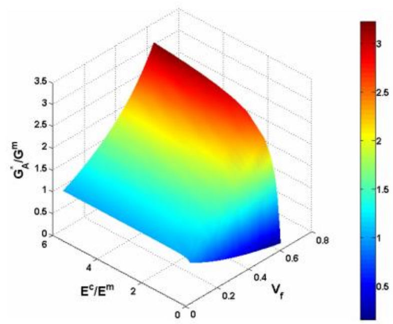
Radial stress distributions around the fiber/matrix interface of a unidirectional metal/matrix composite reinforced by ceramic fibers with a partially debonded interface subjected to transverse tension, illustrating superior traction continuity satisfaction of the generalized FVDAM theory relative to the finite-element method. **(Source: Cavalcante, M.A.A, Pindera, M-J., Generalized FVDAM theory for elastic-plastic periodic materials. *Int. J. Plasticity* 77 (2016) 90-117.)**

Rapid Analysis and Design of Coated and Hollow Reinforcement Composites via Elasticity-Based Homogenization

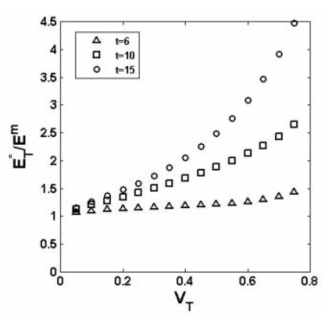


Hexagonal or tetragonal material microstructures

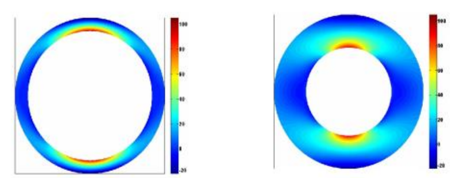




Coated fiber reinforcement



Alumina nanotube reinforcement



Effect of alumina nanotube thickness on transverse stress fields $\sigma_{22}(x_2, x_3)$ under loading by $\bar{\sigma}_{22} \neq 0$

Using our locally-exact homogenization theory, a user with minimal mechanics exposure can rapidly investigate the effect of coatings on homogenized moduli of both coated fiber composites as well as hollow nanotubes. **(Source: Wang, G. and Pindera, M-J., Locally-exact homogenization of unidirectional composites with coated or hollow reinforcement. *Materials and Design* 93 (2016) 514–528.)**

RECENT GRANTS

- NSF – Microstructural Effects in Tayloring the Response of Engineered Bio-Materials
- U.S. DOD/Army – Mechanical Behaviors of Materials: Micromechanics-Based Homogenized Constitutive Equations for Porous Periodic Materials

RECENT RESEARCH DEVELOPMENTS

- Incorporation of CZM-based damage evolution capability into our finite-volume based homogenization theory (FVDAM)
- Generalization of the FVDAM theory through local displacement enrichment that produces results superior to comparable FEM-based analyses
- Construction of an elasticity-based homogenization theory for rapid identification of material/geometry design variables that meet target performance of advanced composite materials

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