University of Bremen
Advanced Ceramics Group
Bremen Institute of Mechanical Engineering

Faculty of Production Engineering (FB4)
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Master Thesis

Modelling and Simulation of Ceramic Matrix Composites

We offer the opportunity to write an interdisciplinary Master Thesis on the modelling and simulation of ceramic matrix composites (CMCs). The project is a cooperation between the Advanced Ceramics Group and the Bremen Institute of Mechanical Engineering (bime) within the Faculty of Production Engineering at the University of Bremen.

Introduction:

Ceramic matrix composites are a class of materials within the groups of composite materials and technical ceramics. They are characterized by a ceramic matrix embedded between long ceramic fibers, where the fibers reinforce the matrix material. CMCs offer several advantages over conventional technical ceramics, particularly in terms of increased ductility, significantly higher crack resistance, thermal shock resistance and improved dynamic load capacity. CMCs can be tailored to a desired application due to the anisotropic properties associated with the distinct fibre orientations.

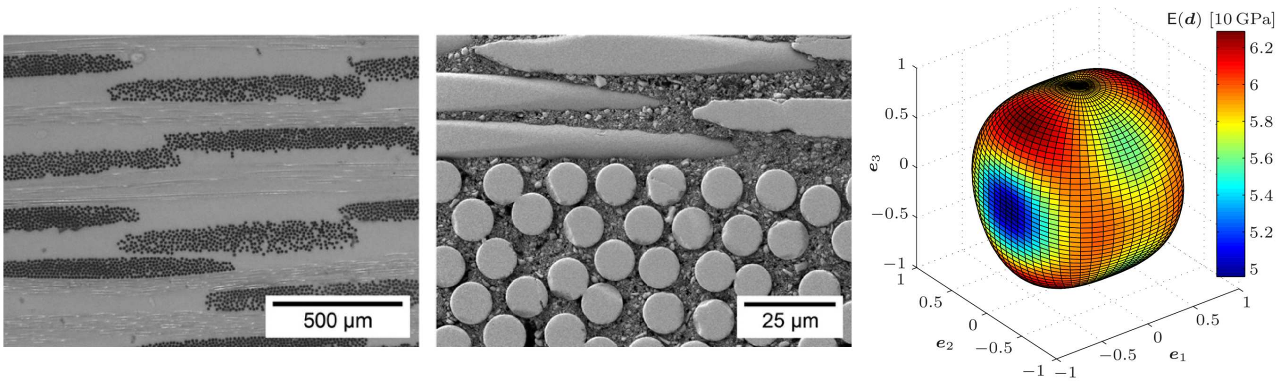

Figure 1: Microstructure of a ceramic matrix composite (left and mid) [1] and Young's modulus surface plot visualizing an anisotropic fourth-order elasticity tensor (right) [2].

Theoretical background:

Following the theories of porous media and multi-phase materials [2,3], the overall Helmholtz free energy density of an elastic multi-phase material within a small-strain setting takes the form

$$\Psi(\boldsymbol{\varepsilon}) = \sum_{\alpha} \xi_\alpha \, \rho_\alpha^{\mathrm{p}} \, \psi_\alpha(\boldsymbol{\varepsilon}) \ ,$$

with $\xi_\alpha \in [0,1]$ subject to $\sum_\alpha \xi_\alpha = 1$ the volume fraction, $\rho_\alpha^{\mathrm{p}} \in [0,1]$ the porosity, and ψ_α the energy contribution of a given phase α. The overall Helmholtz free energy density of a two-phase elastic CMC consisting of matrix and fibres and undergoing matrix damage then follows as

$$\Psi_{\mathrm{CMC}}(\boldsymbol{\varepsilon}) = f_{\mathrm{d}}(\kappa) \, \rho_{\mathrm{M}}^{\mathrm{p}} \, \xi_{\mathrm{M}} \, \psi_{\mathrm{M}}(\boldsymbol{\varepsilon}; \mathbf{E}_{\mathrm{iso}}) + \xi_{\mathrm{F}} \, \psi_{\mathrm{F}}(\boldsymbol{\varepsilon}; \mathbf{E}_{\mathrm{ani}}) \ ,$$

with $f_\mathrm{d}(\kappa) = \exp(-\eta\,\kappa) = [1 - d]$ an exponential-saturation type damage function accounting for the evolution of damage in the matrix material, $\rho_\mathrm{M}^\mathrm{p}$ the porosity of the matrix material, and ξ_M and ξ_F the volume fractions of matrix and fibres, respectively, with $\xi_\mathrm{M} + \xi_\mathrm{F} = 1$. Both matrix isotropy and fibre anisotropy are accounted for by means of appropriate fourth-order elasticity tensors, E_iso and E_ani. The internal damage variable κ is governed by an associated scalar-valued evolution equation.

Tasks:

- Derivation, analysis and visualization of a fourth-order elasticity tensor E_ani that accurately reflects the anisotropic fibre properties
- Derivation of the Cauchy stress tensor based on the above Helmholtz free energy density within a small-strain setting
- Specification and implicit backward Euler time-integration based numerical solution of the damage evolution equation
- Optimization-based parameter identification for representative homogeneous load cases
- Implementation of the constitutive formulation in a finite element program and computation of representative inhomogeneous boundary value problems

Literature:

[1] R. Almeida, T. Pereira, K. Tushtev, K. Rezwan: Obtaining complex-shaped oxide ceramic composites via ionotropic gelation, Journal of the American Ceramic Society, 102(1):53–57, 2018

[2] R. Ostwald, T. Bartel, A. Menzel: A Gibbs-energy-barrier-based computational micro-sphere model for the simulation of martensitic phase-transformations, Int. J. Numer. Meth. Engng., 97:851–877, 2014

[3] S. Nemat-Nasser, M. Hori: Micromechanics: overall properties of heterogeneous materials, Elsevier, 1999

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