

## **Designing, exploiting and modeling nonlinear behavior of ceramic materials**

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Ceramic materials are traditionally perceived as exhibiting a predominantly linear stress–strain response up until failure, which is typically abrupt and characterized by the rapid propagation of a dominant crack. This brittle behavior is indeed common for most ceramics at room temperature. However, in a number of specialized applications, ceramics demonstrate markedly different mechanical responses. Instead of catastrophic failure, these materials develop a distributed network of micro-cracks that can provide a measurable degree of apparent ductility at the macroscopic level prior to final failure. This more ductile-like behavior is particularly advantageous in applications involving thermal shock, such as those found in the refractory industry, diesel particulate filters, and various high-temperature systems where thermal shock resistance is critical. At the micro- and nano-scale, the underlying mechanisms responsible for this behavior are well understood and are largely attributed to the anisotropic nature of the crystalline lattice. Many ceramic materials exhibit directionally dependent thermal expansion coefficients, which induce internal stresses and promote controlled micro-cracking under thermal loading.

Despite these insights at smaller scales, modeling and characterizing the behavior of such ceramics across multiple length scales remains a significant challenge. Accurate simulation requires integrating phenomena from the atomic level up to the macroscopic structural behavior, often necessitating sophisticated multiscale modeling approaches.

This lecture will explore recent advances in the numerical modeling of micro-cracked ceramic materials, with a focus on model calibration, material parameter identification, and the application of topology optimization techniques for designing structurally efficient components. While the primary focus will be on refractory ceramics used in extreme high-temperature environments, the methodologies discussed are broadly applicable to the modeling and characterization of other brittle and quasi-brittle materials as well. Most of the results presented in this lecture are achieved within the framework of Horizon H2020 – ITN REFRACTORY2 project.