PROPOSITION DE SUJET DE THESE

Intitulé : Thermomechanical modeling of thermal shock on ceramics using an adaptive multi-physics FEM-DEM coupling strategy

Référence : **MAS-DMAS-2025-16**
(à rappeler dans toute correspondance)

Début de la thèse : October 2025	**Date limite de candidature :** April 2025

Mots clés

Discrete Element Method (DEM), Finite Element Method (FEM), Thermomechanics, Ceramics, Brittleness, Adaptive FEM-DEM coupling, C++, python

Profil et compétences recherchées

M. Sc. in material science, mechanics or computational mechanics. The candidate must have a good level of knowledge in continuum mechanics and good skills in numerical methods. C++ and python programming experiences would be really appreciated.

Présentation du projet doctoral, contexte et objectif

Ceramics, used extensively in aeronautics, steel or glass industries, are complex, highly heterogeneous materials subject to extremely severe stresses (very high temperatures, liquid or gaseous corrosion, thermal shock). To meet these extreme conditions, the design of their microstructures is still challenging. Optimizing their behavior in service requires a better understanding of their physical properties. With this in mind, over the last 15 years, the IRCER laboratory developed original thermomechanical characterization techniques which, when combined with microstructural investigations, provide a better understanding of the in-service behavior of these materials. Among these characterization methods, the ATHORNA bench is currently under development.

This bench is based on a set of innovative measurement techniques (acoustic and optical) that enable the thermomechanical behavior of samples to be in situ monitored under severe and controlled thermal shock stress using a CO_2 laser source conducting to the partial or complete rupture of the sample, as illustrated on the postmortem observation of Figure 1.

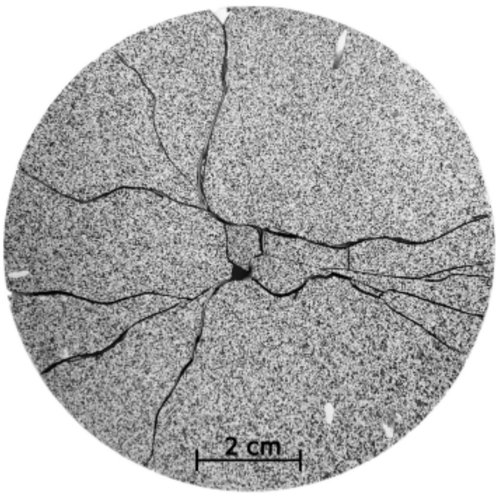

Figure 1: Fractured ceramic disk after thermal shocks using the ATHORNA device (parts were reassembled)

In addition to these experimental developments, over the last ten years, IRCER, I2M and LAMIH laboratories have been developing an original numerical tool to simulate the initiation and propagation of brittle cracks using the Discrete Element Method (DEM) within the free calculation code GranOO (www.granoo.org). In particular, the Distinct Lattice Spring Method (DLSM), which is a continuous local method that can be implemented into a DEM context, was proposed to employ directly thermo-mechanical constitutive (stress/strain) laws without any fastidious preliminary calibration steps such as in standard DEM calculations [1,2]. More recently, the LAMIH and the ONERA laboratories proposed an innovative coupling strategy of the DEM with the Finite Element Method (FEM) that enables dynamic and adaptive coupling [3]. In this method, FEM is applied to the continuous part of the sample whereas DEM is applied only to the discontinuous part, where the fractures occur and propagate. In the proposed method, the discontinuous DEM domain is able to dynamically adapt its geometry depending on the different crack paths and internal stresses.

The aim of the proposed PhD is to combine all these developments in order to tackle multi-physics problems in an adaptive FEM-DEM (DLSM) coupling strategy by taking into account both thermal and mechanical phenomena. It will require in particular the formulation of the FEM-DEM thermomechanical coupling and a methodology for the transfer of the thermomechanical fields from FEM to DEM. These developments should lead to simulate the ATHORNA [4] device including boundary conditions, loadings and multi-fracturation (Figure 1) of the sample due to the applied thermal shock using the CO2 laser source.

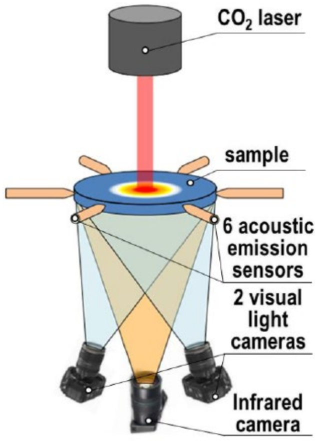

Figure 2: The ATHORNA device for thermal shock in-situ measurement [3]

References

[1] D. André, J. Girardot, and C. Hubert. A novel dem approach for modeling brittle elastic media based on distinct lattice spring model. Computer Methods in Applied Mechanics and Engineering, 350:100–122, 2019.

[2] D. André and M. A. Celigueta. A dem bonded particle model compatible with stress/strain constitutive relations. International Journal of Rock Mechanics and Mining Sciences, 170:105437, 2023.

[3] F. Yahya, C. Hubert, N. Leconte, and L. Dubar. A FEM/DEM adaptive remeshing strategy for brittle elastic failure initiation and propagation. International Journal for Numerical Methods in Engineering, page e7503, May 2024.

[4] R. P. Kaczmarek. Improvement of strain field monitoring at high temperature and thermomechanical characterization of alumina spinel refractory materials. PhD thesis, Limoges, 2021.

Collaborations envisagées

The thesis will be part of a collaboration between IRCER (Limoges), I2M (Bordeaux), ONERA, and LAMIH (Valenciennes).

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