Image based lifetime evaluation of self-healing CMCs coupling solid mechanics and a parallel finite element simulation of the healing process in 3D crack networks

Context and Background
Because of their high strength and low weight, ceramic-matrix composite materials (CMCs) are the focus of active research, for aerospace and energy applications involving high temperatures, either military or civil. In particular, hot parts in civil aircraft jet propellers are target components for this class of materials, since they are markedly lighter than state-of-the-art metallic alloys and they may allow operation at higher temperatures, therefore reducing cost and environmental impact of civil aviation.

Self-healing (SH) CMCs are composed of a complex 3D topology of woven fabrics containing fibre bundles immersed in a matrix coating that can contain several phases. An example of fabric topology and a micrograph of a fibres bundle with alternating layers of silicon and of boron carbide (Cerasep®A410) is given in Figure 1. The key feature of these materials is their ability to seal cracks due to the passive action of an oxide produced by the reactive layers (boron carbide). This seal protects fibres from oxidation and provides very long life times with excellent mechanical strength. In this context the ViSCAP project aims at providing new tools to improve the understanding of the behaviour of these materials.

Fig. 2. Mini-composite degradation. Top: a) Application of a tensile stress; b) Transverse crack; c) Multilayer matrix structure (reactive in blue); d) oxide growth (in red); e,f) fibre breakage and side view of the crack; g,h) oxide growth and sealing again the bundle. Bottom: lifetime of the mini-composite.

Very promising preliminary results have been obtained by Inria and the LCTS lab with a prototype model involving the coupling of a structural mechanics (finite element) model with a PDE-based multidimensional closure model for the physico-chemical behaviour Figure 2 shows an example obtained with this coupling allowing to compute the lifetime (time to rupture) of a single fibre bundle (mini-composite).
**Objective of the PhD**

The main objective of this PhD is to develop a parallel library allowing the simulation of the lifetime of a SH-CMC, starting from 3D images (e.g. tomographs) of the material. The main milestones of the work will consist in: (i) developing a graph representation of the network of domains, using crack detection algorithms developed by the LCTS laboratory; (ii) design a method of generation of the constrained unstructured triangulations respecting the numerous interfaces present in the material (multi-layer matrix) ; (iii) design and implement the necessary physical pre-processing of the realistic data acquired from the image to define the computational parameters of the simulation; (iv) set up a parallel algorithm coupling all the domains in the network, as well as the crack network to the solid mechanics solver; (v) apply the resulting tool to the simulation of real materials.

The key scientific contributions will be related to:

- the finite element formulation involving the coupling of 2D domains criss-crossing in the 3D network, and in particular comparing approaches involving fitting all the intersections, with cut-finite elements or other embedded methods
- the efficient hybrid parallelization of the main library as well as of the coupling with the solid mechanics solver (in house solver by LCTS)
- the application to realistic simulations and in particular to new experimental images and measurements acquired in the VISCAP project

**Interaction with the VISCAP WPs**

Strong interactions are expected with another PhD devoted to the development of an improved PDE and FEM model of a single crack transversal to the fibers, with a simplified representation of longitudinal cracks impinging on this one. Strong interactions also with (or even partial participation to) the experimental activities related to the imaging of SH-CMCs.

**Conditions**

3-year grant starting preferably before Sept. 2018. Host: Inria Bordeaux – Sud-Ouest, team CARDAMOM: [https://team.inria.fr/cardamom/](https://team.inria.fr/cardamom/)

**Profile**

The candidate will be required to have very good programming skills and familiarity with engineering and mechanical problems related to the proposal. In particular a strong background in scientific computing and in particular high level/object oriented programming (C/C++/Fortran, Python, etc). A good background in applied maths, and in particular PDE modeling, and numerical methods is also required.

**Contacts**

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