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Rangasamy Mahendren, Sharan Raj<sup>✉</sup> and Weleman, Hélène<sup>✉</sup> and Dalverny, Olivier<sup>✉</sup> and Tongne, Amèvi<sup>✉</sup> *Modelling and simulation of brittle damage in ceramic assemblies*. (2018) In: International Conference on Structural Analysis of Advanced Materials (ICSAAM 2018), 28 August 2018 - 31 August 2018 (Tarbes, France). (Unpublished)

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# Modelling and simulation of brittle damage in ceramic assemblies

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## Abstract

**T**he design and realization of optimized technological systems are increasing through development and integration of different functions and combining elements of varied nature. Not only in the field of space but also in power electronics, many ceramic parts are linked by various processes to metallic elements of different physical and mechanical properties. When these assemblies are subjected to high levels of thermomechanical loadings, their heterogeneities generate significant over-stresses that can lead to irreversible damage. A damage model for microcracking in brittle materials taking into account the opening or closing of microcracks (unilateral effect) has been developed by Weleman and Cormery [1] under isothermal conditions. This article gives an overview of damage modelling and the progress made in accounting for temperature effects.

**Keywords:** Thermomechanics, mechanics of materials, damage, constitutive law, finite element modelling

## 1 Damage by microcracking

Damage in brittle materials like concrete, ceramics, rocks, CMC etc. is predominantly due to microcracking, which can be generated due to formation process (rocks) or manufacturing processes. Moreover, during service conditions, some solids show many kinds of defects based on their exposure to various factors say mechanical loads, temperature or any environmental conditions. The main consequences of microcracking in brittle materials are stress-strain nonlinearity related to deterioration of properties, induced anisotropy and unilateral effect. Thermal load results in significant physical and chemical changes in the microstructure of brittle materials. For instance, the growth of thermal cracks has been observed in granites in which the crack density increases with increase in temperature [2]. Such damage induces a decrease in mechanical characteristics such as elastic properties, strength and stiffness of concretes at temperatures above 300 °C [3]. Also, properties like density, thermal diffusivity and thermal conductivity decrease with increasing temperature. The same behaviour has been identified in rocks and glass ceramics.

## 2 Damage modelling

Damage mechanics is the most appropriate tool for macroscopic modelling of materials with nonlinear behaviour. Based on the local continuum theory, a damaged macrostructure can be divided into a number of subsystems, each of representative volume element (RVE) size to allow homogenization. Damage models fall under two categories (a) Micromechanical models (b) Phenomenological models. The combination of both approaches gives an acceptable damage model with a good physical basis and helps overcome the shortcomings of one another.

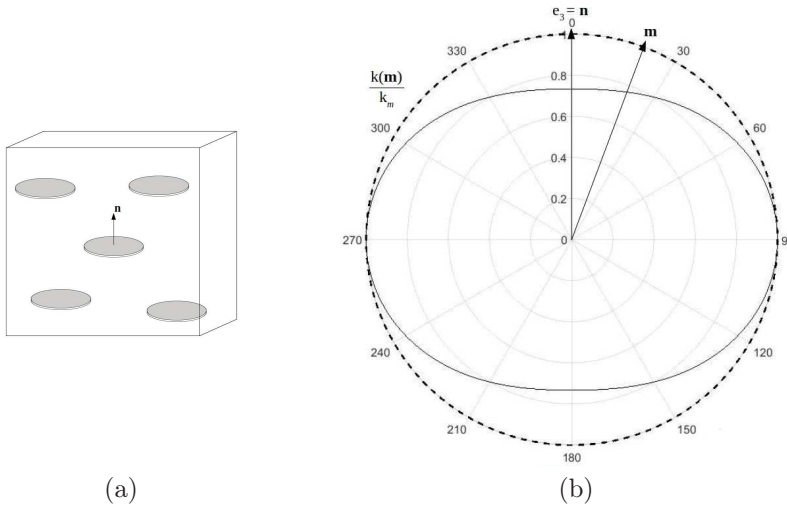
The question of unilateral effect is still a difficult task for damage modelling in brittle materials. Several authors (for instance see [4]) have pointed out that accounting for unilateral effect often leads to inaccuracy. The formulation proposed by Weleman and Cormery [1] offers a new solution to these problems providing a more precise, physical and continuum description of the unilateral effect. All these salient features make this model ideal for further development. As this model was developed in isothermal conditions, it is important

to widen the scope of its application by incorporating thermal effects. This will allow us to account for the thermo-mechanical coupling which affects several technological assemblies made of brittle materials.

### 3 Work in progress

The influence of unilateral effect on elastic properties has been studied extensively, but when it comes to thermal properties, there is a lack of experimental data. So, we propose to use micromechanical results to justify the representation of thermal effects. First of all, we are focusing on thermal conductivity as it is one of the parameters affected by damage. Our aim is to determine the influence of unilateral effect on the thermal conductivity of a microcracked material, by homogenization technique. We consider an isotropic material (of scalar thermal conductivity  $k_m$ ) weakened by a single array of parallel penny-shaped microcracks with unit normal  $\mathbf{n}$  and scalar density  $d$ . Assuming dilute scheme, effective thermal conductivity  $\mathbf{k}_{\text{eff}}$  has been derived through Eshelby-like approach by introducing a fictitious conductivity for closed defects [5]:

$$\mathbf{k}_{\text{eff}} = k_m \mathbf{I} + \Delta \mathbf{k}(d) \quad \text{where} \quad \Delta \mathbf{k}(d) = \begin{cases} -\frac{8}{3} k_m d (\mathbf{n} \otimes \mathbf{n}) & \text{if crack is open} \\ \mathbf{0} & \text{if crack is closed} \end{cases} \quad (1)$$



**Figure 1:** (a) Representative Volume Element and (b) Generalized conductivity  $k(\mathbf{m})$  in direction of unit vector  $\mathbf{m}$  by its initial value  $k_m$  for a microcracked material (—: open cracks, - - - closed cracks and unit circle,  $d=0.1$ ).

Figure 1 illustrates the thermal conductivity dependence upon the space direction (induced anisotropy) as derived through Eqn.(1). Especially, note the main degradation of the conductivity of the microcracked material in the direction  $\mathbf{n}$  normal to the open cracks. Also, the influence of unilateral effect can be seen through the full damage deactivation at microcracks closure, which leads to complete recovery of thermal conductivity ( $\Delta \mathbf{k}(d)=\mathbf{0}$ ). Based on such micromechanical analysis, we propose a condition for unilateral effect regarding the thermal conductivity as follows: "A set of closed microcracks with a unit normal  $\mathbf{n}$  does not contribute to the degradation of thermal conductivity related to any direction of unit vector  $\mathbf{m}$ ."

This preliminary result will provide arguments for the extension of the model [1] in near future.

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