COHESIVE ZONE DESCRIPTION AND FRACTURE OF CERAMICS SIBJECTED TO ENVIRONMENTALLY ASSISTED SLOW CRACK GROWTH

M. Romero de la Osa [1,2], R. Estevez[1], C. Olagnon[1], J. Chevalier[1],

C. Tallaron[2] and L. Vignoud[2]

[1]Université de Lyon, Insa-Lyon, MATEIS CNRS UMR 5510, 20 avenue Albert Einstein, F-69621 Villeurbanne cedex, France
Marcos.Romero-de-la-Osa@insa-lyon.fr
Rafael.Estevez@insa-lyon.fr

[2] CEA Le Ripault, Laboratoire Microstructure et Comportement
37260 Monts, France
Christophe.Tallaron@cea.fr

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ABSTRACT

Polycrystalline ceramics are used in various applications because of their intrinsic advantages such as wear resistance and chemical inertness. Examples are the use of alumina and zirconia for biomedical implants.

However, oxide ceramics are prone to Slow Crack Growth (SCG) when exposed to water, humid or body fluid conditions. This is one of their major drawbacks for demanding, long term applications. Oxide ceramics are sensitive to SCG because adsorption of water can take place at the crack tip, leading to a decrease of the surface energy (i.e. crack resistance) under humid conditions, thus "assisting" failure. This process, often referred as Stress Corrosion Cracking has been first reported and modelled for glass by Michalske and Freiman [1] who provided an estimate of the slow crack velocity with the load and environmental conditions. There is now a general agreement in the ceramic community to consider that the foregoing process also takes place in other oxide ceramics (see e.g. Olagnon et al. [2]). Current SCG models derived from Michalske and Freiman pioneering work do capture the dependence of crack velocities versus water content (RH), temperature and stresses at the crack tip, but fail in reflecting the effect of the microstructure, in particular the influence of the grain size on the crack advance.

In the present numerical study, we propose a description of SCG within a cohesive zone methodology. The formulation accounts for both the thermally activated stress corrosion at the crack tip, and the influence of the microstructure on the crack path and the crack velocity.

A failure reaction-rupture mechanism has been proposed by Michalske and Freiman [1] in a seminal paper that as received agreement from the ceramic community. More recently, Zhu et al. [3] have revisited and detailed this failure process in ab-initio analyses. Albeit a full multi-scale description in which ab-initio to molecular and ultimately continuum would be connected, we here proposed a cohesive surface inspired

by those contributions.

More precisely, a rate and temperature dependent description is adopted to mimic the chemical reaction-rupture process underlying failure proposed by Michalske and Freiman [1]. The effect of humidity is incorporated through an environment (RH) dependent activation energy thus facilitating the failure process with increasing humidity. As the cohesive surface accounts for an intrinsic length scale which determines the condition for crack nucleation, effects due to the initial crack tip radius and/or the grain size on the crack growth predictions can be addressed.

The parameters involved in the cohesive zone description for failure are derived from available observations and adjusted to capture slow crack growth observations in configurations corresponding to failure of alumina single crystals, for which microstructure effect are not involved.

We then present simulations for a 2D polycristal in which intergranular failure is considered. The influence of the processing conditions (temperature cooling due to sintering) on the initial damage and the response of the polycrystal under a constant loading are addressed. We report results on the influence of the grain size and the crack bridging on the resistance to crack propagation when a constant external load is prescribed to a cracked specimen, under mode I.

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