

## MODELING OXIDATION INDUCED CRACK HEALING IN NON-OXIDE CERAMICS AND METALLO-CERAMICS

G. M. Song<sup>1</sup>, S. B. Li<sup>1</sup>, W. G. Sloof<sup>1</sup> and S. van der Zwaag<sup>2</sup>

<sup>1</sup>Delft University of Technology, Department of Materials Science and Engineering, Mekelweg 2, 2628CD, Delft, The Netherlands.

Email: [g.song@tudelft.nl](mailto:g.song@tudelft.nl)

<sup>2</sup>Delft University of Technology, Novel Aerospace Materials, Delft University of Technology, Kluyverweg 1, 2629 SH Delft, The Netherlands.

Email: [s.vanderzwaag@tudelft.nl](mailto:s.vanderzwaag@tudelft.nl)

**Keywords:** Self-healing, Ceramics, Oxidation, Modeling, Strength recovery

### ABSTRACT

Recently it has been shown for non-oxide ceramics [1] and metallo-ceramics (in particular MAX phase ceramics [2,3]) that surface cracks can heal very effectively upon exposure to air at high temperatures, leading to a partial and sometimes an almost complete restoration of the (tensile) mechanical properties [4]. This high crack healing efficiency far exceeds that of diffusive healing of two fracture surfaces in contact [5,6] and is due to the formation of (a mixture of) oxides creating an almost dense deposit in the crack. For well-performing systems three requirements have been identified: (i) the oxide must adhere very well to the matrix material of the crack faces; (ii) oxidation must induce volume expansion, allowing the crack filling with oxides; (iii) the initial crack width must not exceed the thickness of the oxide layer formed. Therefore, the oxidation behavior of the crack surface plays a critical role on the crack healing and the subsequent strength recovery of the cracked ceramics.

In this work we present a model to describe and quantify the healing efficiency of oxidative crack healing of such high temperature ceramics as a function of the exposure conditions, the oxidation kinetics and the volume expansion upon oxidation. The model is based on geometrical consideration related to crack filling as well as stress transfer across an irregular crack with partial contact along the length of the crack. The model is applied to the most promising self healing high temperature materials such as SiC, Ti<sub>3</sub>AlC<sub>2</sub>, Ti<sub>2</sub>AlC, and Cr<sub>2</sub>AlC. Figure 1 shows a V-notch crack in a non-oxide ceramics. Figure 2 shows that the evolution of the crack length in Figure 1 with healing time at various temperatures.

The model calculations are supported by both 3-point bend test experiments on healed samples as well as by X-ray tomographic experiments on healed and partially healed samples

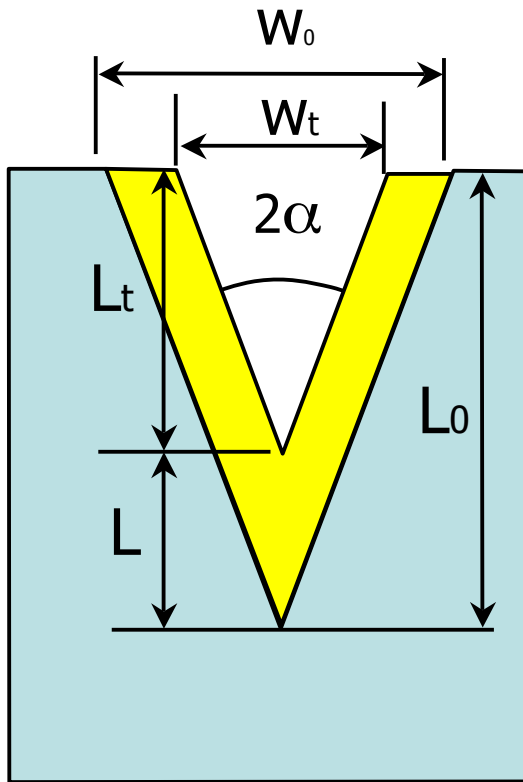


Figure 1: A V-notch crack

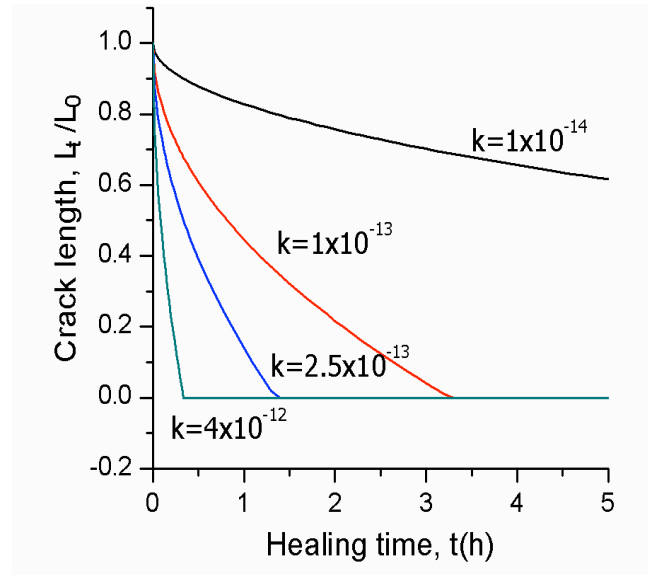


Figure 2: The healed crack length vs healing time

## REFERENCES

- [1] K. Ando, T. Ikeda, S. Sato, F. Yao, Y. Kobayasi, Fatigue strength of crack-healed  $\text{Si}_3\text{N}_4/\text{SiC}$  composite ceramics, *Fatigue Fract. Eng. Mater. Struct.*, **21** (1998), pp. 119-122.
- [2] G. M. Song, Y. T. Pei, W. G. Sloof, S. B. Li, J. Th M De Hosson, S. van der Zwaag, Oxidation induced crack healing in  $\text{Ti}_3\text{AlC}_2$  ceramics, *Script. Mater.* **58** (2008), pp. 13-16.
- [3] G. M. Song, Y. T. Pei, W. G. Sloof, S. B. Li, J. Th M De Hosson, S. van der Zwaag, Early stages of the oxidation of  $\text{Ti}_3\text{AlC}_2$  ceramics, *Mater. Chem. Phys.* **112** (2008), pp.762-768.
- [4] S. B. Li, *Repeatable crack healing of  $\text{Ti}_2\text{AlC}$* , Technical report, Delft University of Technology, Delft, The Netherlands. 2010.
- [5] T. K. Gupta, Crack healing and strength of thermally shocked alumina, *J. Am. Ceram. Soc.*, **59** (1976), pp. 259-262.
- [5] P. Hrma, W. T. Han, A. R. Cooper, Thermal healing of cracks in glass, *J. Non-Cryst. Solids*, **102** (1988), pp. 88-94.