Journal of the European Ceramic Society 15 (1995) 643–650

0955-2219/95/$9.50
0955-2219(95)00030-5

Creep Crack Growth in Alumina with a Glassy Phase

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(Received 22 September 1994; revised version received 19 January 1995; accepted 31 January 1995)

Abstract

Creep-induced crack growth can be described with the C-integral as the relevant load parameter. Several possibilities of evaluating the C*-integral in single specimen tests are discussed, and the constant load and the constant loading-rate are applied to an alumina ceramic containing a glassy phase. The crack-growth rate as a function of the C*-integral is described by a power-law relation with an exponent which agrees very well with the theoretical value.*

1 Introduction

Fracture at elevated temperatures may be caused by subcritical crack propagation, which starts from existing flaws or from creep-induced damage caused by the formation and coalescence of pores. Whereas in the range of subcritical crack growth, which can be described by linear–elastic fracture mechanics, the stress intensity factor is the stress variable at the crack, this is the C^*-integral in the range of noticeable creep.[1] Creep-induced crack growth has very often been studied for metals, but investigations into ceramic materials are sparse.[2–4] It is the aim of this investigation to determine the crack-growth rates as a function of the C^*-integral for macroscopic cracks.

The C^*-integral — proposed by Landes and Begley[1] — is a path-independent energy-rate line integral. In the two-dimensional case (see Fig. 1) it is defined as

$$C^* = \int_\Gamma W^* \mathrm{d}y - T_i \frac{\partial v_i}{\partial x}\, ds \qquad (1)$$

$$W^* = \int_0^{\dot\epsilon_{ij}} \sigma_{ij} \mathrm{d}\dot\epsilon_{ij} \qquad (2)$$

where W^* is the strain-energy density rate, T_i is the traction vector, v_i is the displacement vector, and ds is a line length increment along the contour Γ.

The C^*-integral governs the stresses and strains in front of a crack tip. A premise for the applicability of the C^*-integral as a loading parameter is the occurrence of secondary creep, which may be described by a Norton power law

$$\dot\epsilon_s = D\,\sigma^n \qquad (3)$$

Under this condition, an HRR-stress field occurs ahead of the crack tip.[5,6] The stresses and strain rates are given by

$$\sigma_{ij} = \left(\frac{C^*}{I_n D r}\right)^{\frac{1}{n+1}} \tilde\sigma_{ij}(\theta) \qquad (4)$$

$$\dot\epsilon_{ij} = \left(\frac{C^*}{I_n D r}\right)^{\frac{n}{n+1}} \tilde\sigma_{ij}(\theta) \qquad (5)$$

where $\dot\epsilon$ is the strain rate and $I_n(n)$ and $\tilde\sigma_{ij}(\theta)$ are the dimensionless functions, which can be taken from Ref. 6.

Under creep conditions, the application of a load instantly yields an elastic strain reaction. This elastic strain is superposed by creep strains. In the vicinity of the crack tip eqn (5) is immediately valid, but under non-steady-state creep conditions the parameter C^* has to be replaced by the time-dependent parameter $C(t)$.[7]

For very short times after load application, the stress intensity factor K is the relevant loading parameter, which describes the stresses at the crack tip

$$\sigma_{ij} = \left[\frac{\alpha K_I^2}{I_n D r (n+1)\, t E'}\right]^{\frac{1}{n+1}} \tilde\sigma_{ij}(\theta) \qquad (6)$$

where $E' = E/(1-\nu^2)$ (E = Young's modulus, ν = Poisson's ratio). The numerical factor α is given in Ref. 7 as $\alpha \simeq 1$. With increasing size of the creep zone, the stress field is firstly governed by $C(t)$ and tends asymptotically to the C^*-controlled state. Since