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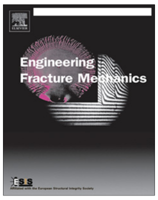

Determination of Young's modulus, fracture energy and tensile strength of refractories by inverse estimation of a wedge splitting procedure

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ABSTRACT

The wedge splitting test according to Tschegg provides a technique to characterize the fracture behavior of ordinary ceramic refractory materials. By fitting the data from finite element simulation to the results of the wedge splitting test, Young's modulus and parameters describing the failure behavior under Mode I conditions can be inversely estimated through an adaptive nonlinear least-squares algorithm. The results show Young's modulus is accurately identified as well as the tensile strength and total specific fracture energy when a trilinear strain softening law is employed. The inversely estimated parameters from three experimental curves of the same material at room temperature are very consistent as well as the values of thermal stress resistance parameter R and characteristic length l_{ch}. The method developed enables the identification of the total specific fracture energy, tensile strength and Young's modulus with numerically robust method in the relatively short time from a single wedge splitting procedure.

1. Introduction

Considerable deviations from pure linear elastic fracture mechanics have to be expected when the process zone size (the length of the process wake Δa plus the size of the frontal process zone, see Fig. 1) is not negligibly small relative to the crack length or the specimen size [1–4]. This might be the case for materials showing a considerable size of the structural elements (e.g. large grains) relative to the size of the whole part and not behaving totally brittle. Examples are common building materials (especially concrete and mortar) and refractories. For those cases a material model allowing numerical treatment of crack propagation is desirable. For this purpose the fictitious crack model according to Hillerborg was already introduced 30 years ago and especially applied for concrete [1,2]. It assumes a strain softening behavior characterized by a monotonously decreasing stress transferred between the crack faces until an ultimate crack opening of X_{ult} is achieved (Fig. 2a), whereas a normally linear stress/strain relation is applied in the uncracked region (Fig. 2b). As Eq. (1) shows, the area below the strain softening curve is equal to the total specific fracture energy G_f.

The wedge splitting test according to Tschegg [5,6] is suitable for the determination of the specific fracture energy of refractories by favoring stable crack propagation in specimens with sufficiently large dimension [7]. The detailed description of the wedge splitting test and its applications are available in Refs. [8–12], and here only the schematic representation of this test is shown in Fig. 3a. Out of this test, a load/displacement curve can be registered (Fig. 3b) and the specific fracture energy can be further obtained by calculating the area under:

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Nomenclature

X_i	crack opening
X_{ult}	ultimate crack opening
σ_i	stress transferred by material
σ_{NT}	nominal notch tensile strength
G'_f	specific fracture energy
R	thermal stress resistance parameter
ℓ_{ch}	characteristic length
f_t	tensile strength
G_f	total specific fracture energy
v	Poisson's ratio
α	thermal expansion coefficient

$$G_f = \int_0^{X_{ult}} \sigma(X)dX \tag{1}$$

the load/displacement curve relative to the projected area of the fracture surface. In many cases the test could be performed until the descending load approaches to zero, and thus the total specific fracture energy can be gained practically. Nevertheless, in the case of refractories with largely reduced brittleness, the wedge might eventually hit the groove of the specimen before the load approaches to zero. A premature termination of the test is necessary for safety considerations and hence only a major part of the specific fracture energy (denoted as G'_f) can be calculated by integration:

$$G'_f = \frac{1}{A}\int_0^{\delta_{ult}} F_H d\delta \tag{2}$$

where δ_{ult} is the ultimate displacement and A the area of the projection of the fracture surface. As a compromise the test may be terminated in case the descending load reaches 15% of the maximum force. Besides, a nominal notch tensile strength σ_{NT} is yielded which comprises both tensile stresses and flexural stresses in the ligament of the specimens and can be determined:

$$\sigma_{NT} = \frac{F_{H,\max}}{b \cdot h}\left(1 + \frac{6y}{h}\right) \tag{3}$$

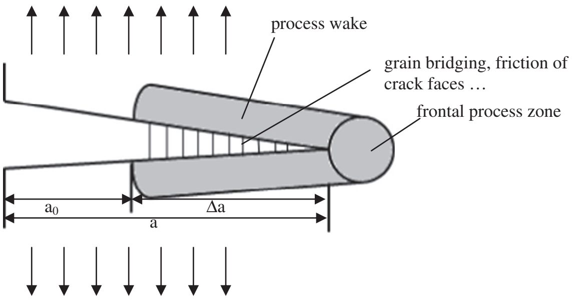

Fig. 1. Schematic representation of a process zone.

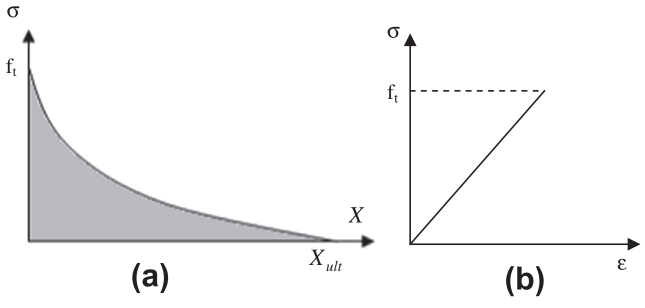

Fig. 2. Strain softening behavior (a) and linear elastic behavior (b) contributing to the fictitious crack model.