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Classification of ceramics and glass (edge chipping and fracture toughness)

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Abstract

The standard classification of advanced ceramics is based on their strength, although in many cases the performance of products made of such materials is controlled by their deformation behavior and fracture resistance. In this article, ceramics and glass are classified according to their edge chipping resistance (EF-method). Such a classification is based on the idea of a baseline (direct proportionality between edge chipping resistance and fracture toughness of ceramics that are similar to the model material of linear elastic fracture mechanics). Use was made of various elastic and inelastic, oxide and non-oxide ordinary ceramics, composite ceramics capable and incapable of retarding cracks and intended for engineering and biomedical applications. Attention is also given to silicate glass.

Keywords: C. Indentation; C. Fracture; E. Structural and biomedical applications; Edge fracture (flaking)

1. Introduction

Ceramic materials are classified according to characteristics [1] that are of practical interest. Little attention is given, however, to their mechanical behavior, which in many cases controls the performance of these materials in not only engineering devices, but also in orthopedic and dental implants. This problem was for the first time addressed in [2] where the brittleness measure[1] [3] was used as a classification parameter, making it possible to classify ceramics according to their deformation behavior. No classification has yet been made of ceramics and glass according to their fracture resistance, which is often used as a performance criterion for these materials. In this case, a classification parameter may be fracture resistance (F_R) measured in edge-chipping tests with Rockwell indenter [4,5]. Such a classification is based on the fact that the fracture resistance F_R and the critical stress intensity factor K_{Ic} (fracture toughness) of ceramics similar to the model material of linear elastic fracture mechanics (LEFM) [6] are in linear relationship represented by a baseline (Fig. 1) [4]. Comparing F_R and K_{Ic}, it is possible to select materials that are similar to the LEFM model material and whose crack resistance can reliably be evaluated using LEFM-based test methods [6]. Note that neglecting the above facts was one of the reasons why ceramic steel was failed to be created [7]. The LEFM-based evaluation of these inelastic ceramics [8] was incorrect (the LEFM model material is linear elastic and homogeneous and may be inelastic only at a crack tip [9]). It was also disregarded that ceramics do not deform plastically, and their inelasticity is related to microstructural fracture. This became clear only after attempts to widely use these ceramics, now almost forgotten. The aforesaid is indicative of the importance of classifying (and understanding

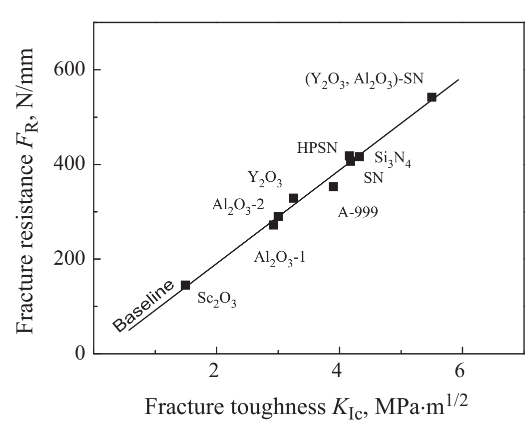

Fig. 1. Base diagram with base line.

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[1]Brittleness measure is equal to the ratio of stored strain energy to the total strain energy to fracture [3].

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the mechanical behavior of ceramics according to their fracture resistance). This issue is addressed in the present paper.

2. Classification parameter and materials

For a classification parameter, we propose the fracture-resistance characteristic F_R of brittle materials, which is determined in edge-chipping tests performed with a standard Rockwell indenter (see [4,5] for more details):

$$F_R = \frac{1}{n}\sum_{i=1}^{n}\frac{P_{fi}}{L_i},$$

where P_{fi} and L_i are the current values of the fracture load and fracture distance measured from the edge of the specimen to the extreme point of the chip (Fig. 2), and n is the number of chips on the edges of the tested specimens. To determine F_R, we used polished standard $3 \times 4 \times 45\ \mathrm{mm}^3$ specimens with sharp edges (rounded radius of no greater than 10–15 μm), which had been used to determine the fracture toughness K_{Ic} of the material with the SEVNB method [10]. Then the edges of the fragments of specimens were chipped with a standard Rockwell indenter with a tip radius of 200 μm (Gilmore Diamond Tools, Inc., the USA). After the tests, the distance L was measured with a BX51M Olympus binocular microscope (× 50–1000) and QuickPhotoMicro 2 software. The

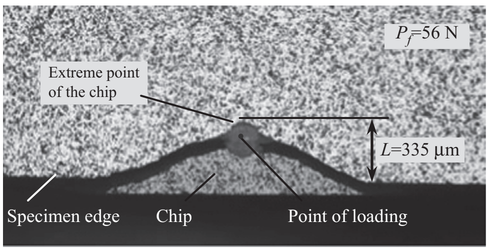

Fig. 2. Chip scar of Sc_2O_3 ceramics (indentation direction)): L is fracture distance.

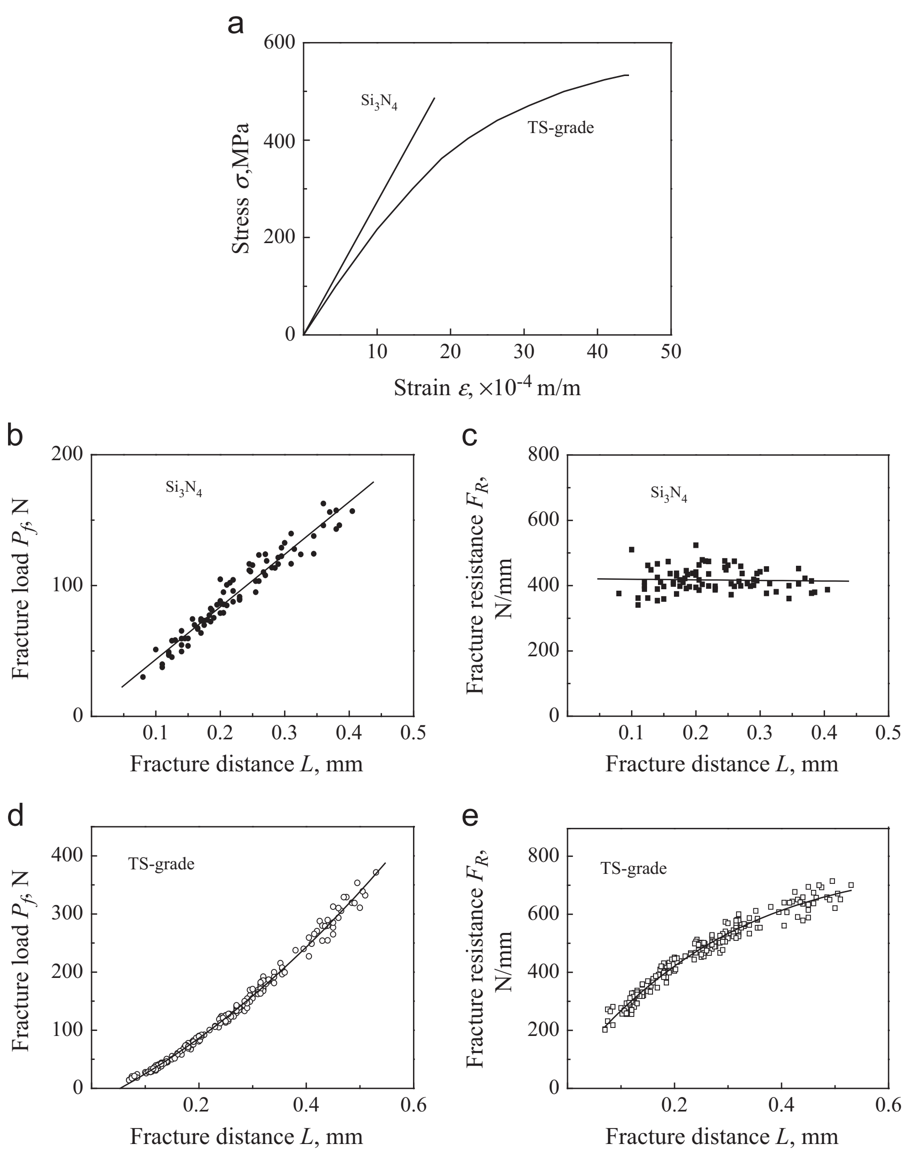

Fig. 3. Stress–strain curves (a), fracture diagrams ((b) and (d)), and R-lines ((c) and (e)) for silicon nitride and zirconia ceramics.

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