SLOVENSKI STANDARD
SIST ENV 843-3:2000

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Advanced technical ceramics - Monolithic ceramics - Mechanical properties at room temperature - Part 3: Determination of subcritical crack growth parameters from constant stressing rate flexural strength tests

Advanced technical ceramics - Monolithic ceramics - Mechanical properties at room temperature - Part 3: Determination of subcritical crack growth parameters from constant stressing rate flexural strength tests

Hochleistungskeramik - Monolithische Keramik - Monolithische Keramik, mechanische Eigenschaften bei Raumtemperatur - Teil 3: Bestimmung der Parameter des unterkritischen Rißwachstums aus Biegefestigkeitsprüfungen mit konstanter Spannungsrate

Céramiques techniques avancées - Céramiques monolithiques - Propriétés mécaniques a température ambiante - Partie 3: Détermination des parametres de propagation sous-critique des fissures a partir des essais de résistance a la flexion réalisés a vitesse de contrainte constante

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CEN

European Committee for Standardization
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Contents

Foreword

This European Prestandard has been prepared by Technical Committee CEN/TC 184 “Advanced technical ceramics”, the secretariat of which is held by BSI.

EN 843 has four Parts:

Part 1 :Determination of flexural strength
Part 2 :Determination of elastic moduli (ENV)
Part 3 :Determination of sub-critical crack growth parameters (ENV)
Part 4 : Vickers, Knoop and Rockwell superficial hardness tests (ENV)

CEN/TC184 approved this European prestandard by resolution 1/12/92 during its sixth meeting held in Berlin, Germany on 8-9 December 1992.

According to the CEN/CENELEC Internal Regulations, the national standards organisations of the following countries are bound to announce this European Prestandard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This part of ENV 843 specifies a method for the determination of subcritical crack growth parameters of advanced monolithic technical ceramics in the temperature range from 15 °C to 30 °C by measuring the dependence of mean fracture strength on the rate of loading. The method is based on strength test procedures described in Part 1 of this standard. This prestandard is not applicable to test pieces with artificially introduced flaws or cracks.

2 Normative references

This prestandard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 843-1	Advanced technical ceramics - Monolithic ceramics - Mechanical properties at room temperature - Part 1: Determination of flexural strength.
EN 10002-2	Metallic materials - Tensile testing - Part 2: Verification of the force measuring system of the tensile testing machine.
EN 45001	General criteria for the operation of testing laboratories.
ISO 3611	Micrometer callipers for external measurement
ISO 4677 -1	Atmospheres for conditioning and testing - Determination of relative humidity - Part 1: Aspirated psychrometer method
ISO 4677 -2	Atmospheres for conditioning and testing - Determination of relative humidity - Part 2: Whirling psychrometer method

3 Definitions

For the purposes of this prestandard the following definitions apply:

3.1 nominal flexural strength: The maximum nominal stress at the instant of failure supported by the material when loaded in linear elastic bending.

3.2 three-point flexure: A means of bending a beam test piece whereby the test piece is supported on bearings near its ends and a central load is applied.

3.3 four-point flexure: A means of bending a beam test piece whereby the test piece is supported on bearings near its ends and is equally loaded at two positions symmetrically disposed about the centre of the supported span.

3.4 subcritical crack growth: The extension of existing cracks or flaws under a stress which does not produce instant failure.

3.5 subcritical crack growth parameters: Parameters describing the relationship between crack velocity and stress intensity factor, as explained in clause 4.

4 Significance and application

Subcritical crack growth can occur in brittle solids at stress levels below that required to cause instantaneous failure. This effect may be caused by the testing environment, or by the intrinsic crack propagation behaviour of the material. The phenomenon leads to a decay of remaining strength in a manner determined by the loading history of the component or test piece.

NOTE 1: A review of subcritical crack growth may be found in A.1

The determination of crack growth parameters in accordance with this standard allows the characterisation of the susceptibility of the material to subcritical crack growth, and thus its ability to support continued mechanical loading. Using these parameters it is possible to compare materials for susceptibility to loss of strength under load in particular environments, and to estimate the lifetime of a component used under similar loading and environmental conditions.

NOTE 2: The use of these parameters in design and lifetime estimation is not within the scope of this standard.

The relationship between the stress intensity factor at the tip of a crack or flaw and the velocity of the subcritically growing crack may be given by:

$$v = A_O \left(\frac{K_I}{K_{Ic}} \right)^n \qquad .....(1)$$

where:

v is the velocity of the growing crack in metres per second;

A_0 is the constant in metres per second;

K_I is the stress intensity factor developed at the crack tip by the applied stress in Megapascals metres$^{1/2}$;

K_{Ic} = critical stress intensity factor at the crack tip required to cause instantaneous crack propagation.

NOTE 3: There are other algebraic representations of this relationship which are less convenient mathematically, but may be physically more realistic in practice, e.g. A.2 and A.3 in. A.2 considers that practical data cannot reliably distinguish between various relationships. The mathematical analysis in this standard therefore does not cover such alternative relationships.

In Equation (1), the value of n at room temperature is normally high, typically in the range fifteen to several hundred. At the lower end of this range, materials are very susceptible to subcritical crack growth, while at the upper end the phenomenon becomes insignificant. It should be noted that Equation (1) implies a single simple relationship, but in practice there may be non-linearities. There are thought to be two principal causes of non-linearity:

a) At low stress intensity factors there may be no subcritical crack growth. This is called the subcritical crack growth threshold, or "fatigue limit".

b) At intermediate stress intensity factors, the crack growth rate may be limited by the rate at which the environment can penetrate along the crack to control fracture at the tip. This results in a plateau effect, which is maintained to K_I levels at which crack growth can occur in the absence of an environmental effect.

It should be noted that n and A_0 are often subject to the environmental conditions used. In particular, many ceramics show marked subcritical crack growth in humid air or in water, and much less marked effects in dry or inert conditions. The test environment shall be defined and controlled for reproducible results.

In this standard, the parameter n and a parameter B_0, which is related to A_0, are determined by the effect of stressing rate on flexural strength.

NOTE 4: The term "dynamic fatigue" is frequently used to describe such tests, but tends to be misunderstood. Its use is discouraged.

Annex B shows how the mathematical formulation of the relationship between the subcritical crack growth parameters based on Equation (1) and the effect of stressing rate on strength is derived, yielding the basic formula:

$$\log \sigma_f = \log B_0 + \frac{1}{(n+1)} \log \dot{\sigma} \qquad (2)$$

where:

s_f is the fracture stress of a test piece in megapascals;

B_0 is the constant;

$\dot{\sigma}$ is the stressing rate employed in megapascals per second.

NOTE 5: This equation is strictly correct only if a consistent failure probability at each loading rate is employed, e.g. $P_f = 0,5$, which is calculable from a test piece population of ³ 30, for example, fitting a Weibull distribution. If a smaller number of tests is used, as in this test method, the potential uncertainty is likely to be greater.

NOTE 6: This test method can be used only to measure B_0. Calculation of A_0 requires knowledge of other material parameters not determined by this test method.

The subcritical crack growth parameters are determined by employing several different stressing rates, plotting a graph of log s_f versus log $\dot{\sigma}$, and calculating the slope (1/(n+1)) and the intercept (log B_0).
The accuracy of determination of n is governed by the number of test pieces employed at each stressing rate, and the range of stressing rates employed. Since n may be a large number (typically greater than 15, up to several hundred), a wide range of stressing rates is required. It should be noted that small differences in values of n and B_0 between materials are not significant because of the propagation of uncertainties in the analysis of this method (see below). This test method is considered appropriate for values of n less than 80.

When using the flexural strength test procedure in accordance with part 1 of this standard, the error of any individual strength test result is small compared to the statistical spread of strengths at any loading rate. The principal uncertainty in the present originates from the statistical variation of the strength at each rate. The coefficient of variation of the results is typically ± 10%; for 10 test-pieces, the standard error of the mean is then approximately

(± (standard deviation / $\sqrt{n}$ = ± 10% $\sqrt{10}$ ~) ± 3%,

and the 95% confidence limit is typically 6% either side of the mean strength level. This uncertainty is propagated through the least squares line-fitting routine applied to the sets of data, and assuming that a true linear relationship exists, can result in typically ± 20% in the value of n fitted over four orders of magnitude. Similar large errors can occur in the value of B_0.

This level of uncertainty may appear high, but nevertheless, estimation of n is valuable in determining the relative susceptibility of different materials to different environments, especially for materials selection purposes. Small differences in values of n between materials within these typical uncertainty bands are therefore not significant.

NOTE 7: This standard has been drafted taking into account the results of demonstrations in the open literature and two interlaboratory tests. The results of the interlaboratory tests can be found summarised in A.4 and A.5.

5 Apparatus

5.1 Test jig

The test jig shall be in accordance with the provisions described in Part 1 of this standard, with the force being applied to the test piece through parallel self-aligning freely rotating loading rollers of adequate hardness. The test jig span may be either 20 mm ± 0,5 mm (span A) or 40 mm ± 0,5 mm (span B), and the loading may be in either three-point flexure or four-point flexure. In four-point flexure, the central loading span may be either 10 mm ± 0,2 mm for span A or 20 mm ± 0,2 mm for span B, and shall be symmetrically positioned to within 0,1 mm with respect to the outer support span. The spans and distances between load and support rollers shall be measured with a travelling