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Sodobna tehniļna keramika - Mehanske lastnosti keramiļnih kompozitov pri temperaturi okolice - Ovrednotenje odpornosti proti ģirjenju razpoke s preskuģanjem obļutljivosti zareze

Advanced technical ceramics - Mechanical properties of ceramic composites at ambient temperature - Evaluation of the resistance to crack propagation by notch sensitivity testing

Hochleistungskeramik - Mechanische Eigenschaften von keramischen Verbundwerkstoffen bei Umgebungstemperatur - Beurteilung der Rissausbreitungsbeständigkeit durch die Kerbempfindlichkeitsprüfung

Céramiques techniques avancées - Propriétés mécaniques des céramiques composites a température ambiante - Evaluation de la résistance a la propagation de fissure par un essai de sensibilité a l'entaille

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Advanced technical ceramics - Mechanical properties of ceramic composites at ambient temperature - Evaluation of the resistance to crack propagation by notch sensitivity testing

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This European Standard was approved by CEN on 11 September 2006.

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Foreword

This document (EN 13234:2006) has been prepared by Technical Committee CEN/TC 184 "Advanced technical ceramics", the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2007, and conflicting national standards shall be withdrawn at the latest by April 2007.

This document supersedes ENV 13234:1998.

ENV 13234 was approved by CEN/TC 184 for development into a full European Standard. The principal changes to the ENV are in the normative references, as follows:

- in 6.1, reference to EN 10002-2 has been replaced by reference to EN ISO 7500-1;

- in 6.2.1, reference to WI 136 has been removed.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

1 Scope

This European Standard describes a method for the classification of ceramic matrix composite (CMC) materials with respect to their sensitivity to crack propagation using tensile tests on notched specimens with different notch depths. Two classes of ceramic matrix composite materials can be distinguished: materials whose strength is sensitive to the presence of notches and materials whose strength is not affected. For sensitive materials, this European Standard defines a method for determining equivalent fracture toughness.

The parameter, K_{eq}, is defined as the fracture toughness of a homogeneous material which presents the same sensitivity to crack propagation as the ceramic matrix composite material which is being considered. The definition of the K_{eq} parameter offers the possibility to compare ceramic matrix composite materials with other materials with respect to sensitivity to crack propagation.

For notch insensitive materials, the concept of K_{eq} does not apply.

This European Standard applies to all ceramic matrix composites with a continuous fibre reinforcement, unidirectional (1 D), bidirectional (2 D), and tridirectional (x D, where $2 < x \leq 3$), loaded along one principal axis of reinforcement.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 658-1:1998, *Advanced technical ceramics — Mechanical properties of ceramic composites at room temperature — Part 1: Determination of tensile properties*

EN ISO 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system (ISO 7500-1:2004)*

ISO 3611, *Micrometer callipers for external measurement*

3 Principle

Tensile tests are carried out on double edge notched test specimens with notches of different depths. The results of these tests are compared with the results of tensile tests on specimens without notches. The cross sectional dimensions of the notched specimens between the notches are equal to those of the un-notched specimens.

The strength values observed on both types of specimens as a function of notch depth allow the determination of the range of notch size for which the tested composite is sensitive to the presence of notches.

4 Significance and use

The fracture toughness is a material property which characterises the initiation of fracture from a sharp crack (usually obtained by fatigue cracking under plane strain conditions). The fracture toughness of materials at the onset of crack extension from a pre-existing fatigue crack is characterised by the value of one of the following parameters:

i) K_{Ic}, a critical value of K_I (the stress intensity factor of the elastic stress field in the vicinity of the crack front), at the point of instability of the crack extension;

ii) G_{Ic}, a critical value of G_I (the strain-energy release rate with crack extension per unit area of newly created crack surface) at the point of instability of the crack extension;

iii) J_{Ic}, a critical value of J_I (a line or surface integral used to characterise the local stress-strain field around the crack front) at the onset of stable crack extension.

The J integral plays an important role in non-linear fracture mechanics. It applies to non-linear elastic bodies, whereas linear elastic fracture mechanics (K_{Ic} and G_{Ic}) consider linear elastic bodies.

Several problems arise in determining and even in defining K_{Ic}, G_{Ic} and J_{Ic} in fibre reinforced ceramic matrix composites, as a result of the following features:

1) CMC are generally highly heterogeneous, consisting of different constituents (fibres and matrix), and containing pores and cracks;

2) in some CMC a damage zone of multiple matrix cracks forms ahead of a notch prior to ultimate failure;

3) the associated deformations are non-linear.

The load versus load line displacement curve from a fracture test on a notched specimen involves a non-linear domain induced by diffuse micro-cracking within the matrix at the notch tip. The damage zone is in the millimetre to centimetre scale (from one to several tow diameters). At maximum load, a macroscopic crack is created from the random failure of fibres within those tows located in the damage zone. Crack extension in CMC, hence, does not result from the mechanism of extension of a single macroscopic crack as observed in monolithic materials.

Because of the presence of the damage zone and of heterogeneous microstructure, the stress distribution in the damage zone differs from the one induced ahead of the crack tip in linear elastic bodies. The K_I parameter does not describe the stress field in the region ahead of the crack tip. A critical value K_{Ic} cannot be defined.

The main difficulty in the determination of the strain energy release rate G_I, as well as the J integral, results from the presence of the micro-cracked zone at the notch tip (which is not small compared with the specimen dimensions) and the jagged surface of the macroscopic crack. As a consequence an increase in crack length can neither be easily defined nor measured.

Tensile tests performed on specimens containing holes or notches have demonstrated that many CMC are relatively notch-insensitive over a range of notch sizes. The net-section stress at fracture is typically (80 to 100) % of the un-notched strength. Notch insensitivity results from a stress relaxation at the notch tip due to the development of the damage zone. As a consequence, the fibres in the damage zone are subjected to stresses that are comparable in magnitude to the remote stresses.

A measure of the notch sensitivity at a given notch depth is provided by the ratio of the failure stress of a notched tensile specimen (σ_n) to the failure stress of a corresponding un-notched tensile specimen (σ_r):

a) when $\sigma_n < \sigma_r$, the composite is notch sensitive;

b) when $\sigma_n \geq \sigma_r$, the composite is notch insensitive.

The stress ratio σ_n/σ_r is a useful parameter for component design purposes. It allows the selection of the composites that are able to tolerate notches, holes etc.

For material comparison purposes, an equivalent fracture toughness K_{eq} is defined over the notch depth range where the stress ratio is less than 1.

K_{eq} represents the fracture toughness of the equivalent homogeneous monolithic material which exhibits the same notch sensitivity as the actual composite. K_{eq} is calculated from the dependence of the σ_n/σ_r stress ratio on notch depth, using linear elastic fracture mechanics equations.

Over the range of notch depths where the CMC is notch sensitive, the calculation of the equivalent fracture toughness for the different notch depths does not usually result in a single value for K_{eq}. For reasons of conservatism, the minimum value is used.

For some CMC, a transition from notch insensitive to notch sensitive has been observed with increasing notch depth. The determination of equivalent fracture toughness is not recommended when the notch insensitive range extends beyond a minimum value of notch depth (1 mm).

NOTE Additional testing at different notch depths may be performed to provide a more complete understanding of the notch depth range where the CMC is notch insensitive.

5 Terms, definitions and symbols

For the purposes of this document, the terms, definitions and symbols given in EN 658-1:1998 and the following apply.

5.1
ligament
part of the double edge notched specimen that is located between the notches. The width of the ligament is denoted b; the cross-section of the ligament is denoted A

5.2
notch depth, a
distance between the side of specimen and the tip of the notch

5.3
notched specimen width, b_n
width of the notched specimen outside the notched cross-section

5.4
maximum tensile force, F_m
highest recorded tensile force on the test specimen when tested to failure

5.5
un-notched specimen tensile strength, $\sigma_{t,m}$
tensile strength determined by measurement according to EN 658-1. The value of this parameter is designated σ_r

5.6
notched specimen tensile strength, $\sigma_{t,m,n}$
ratio of the maximum tensile force to the ligament cross section area. The value of this parameter is designated σ_n

5.7
equivalent fracture toughness K_{eq}
fracture toughness of a homogeneous and isotropic material which presents the same dependence of the stress ratio σ_n/σ_r on the notch depth as the investigated composite

6 Apparatus

6.1 Test machine

The machine shall be equipped with a system for measuring the force applied to the test specimen, which, when tested in accordance with EN ISO 7500-1, shall meet the requirements of grade 1 or better of that standard.

6.2 Load train

6.2.1 General

The load train is composed of the moveable and fixed crosshead, the loading rods, and the grips. Load train couplers may additionally be used to connect the grips to the loading rods.

The load train shall align the specimen axis with the direction of load application without introducing bending or torsion in the specimen. The alignment shall be verified and documented. The maximum percent bending shall not exceed 5 at an axial strain of 500×10^{-6}.

6.2.2 Grips

The grips transmit the axial load applied by the testing machine to the specimen. They shall prevent slipping of the specimen in the gripping section. The selection of a particular type of grips depends on the specimen design and critically influences the alignment.

NOTE 1 When the grip design relies on friction to transmit the axial load to the specimen, the use of an adjustable clamping pressure is recommended.

NOTE 2 Care should be taken to avoid the introduction of torsional loading on the specimen when tightening the grips.

6.2.3 Load train couplers

Load train couplers may be used to connect the grips to the loading rods. Their primary function is to assure axial alignment of the grips in the loading train.

NOTE 1 Load train couplers are of two types: fixed or non-fixed. Fixed couplers usually consist of angularity and/or concentricity adjusters. Non fixed couplers promote self-alignment of the load train upon movement of the cross-head. This self-aligning action is limited by the inherent friction between moving parts of the couplers.

NOTE 2 The self-aligning action of non-fixed load train couplers may result in non-uniform loading of the unbroken ligament of the specimen after appearance of damage in the specimen, which can modify the shape of the tensile curve.

NOTE 3 The use of well-aligned couplers and grips does not guarantee low bending in the specimen. The latter additionally depends on the type and operation of the grips, and on the type of specimen.

6.3 Data recording system

A calibrated recorder may be used to record the force-deformation curve. However, the use of a digital data recording system combined with an analogue recorder is recommended.