SLOVENSKI STANDARD
SIST ENV 13234:2000

01-december-2000

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

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

Hochleistungskeramik - Keramische Verbundwerkstoffe - Mechanische Eigenschaften bei Umgebungstemperatur - Beurteilung der Rißausbreitbeständigkeit durch die Kerbempfindlichkeitsprüfung

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

Ta slovenski standard je istoveten z: **ENV 13234:1998**

ICS:

81.060.30	Sodobna keramika	Advanced ceramics

SIST ENV 13234:2000 **en**

EUROPEAN PRESTANDARD
PRÉNORME EUROPÉENNE
EUROPÄISCHE VORNORM

ENV 13234

November 1998

ICS 81.060.99

Descriptors: composite materials, reinforcing materials, ceramics, technical ceramics, mechanical properties, environmental tests, crack strength

English version

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Ref. No. ENV 13234:1998 E

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Foreword

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

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

1 Scope

This European prestandard 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 Prestandard defines a method for determining an equivalent fracture toughness. This 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 prestandard applies to all ceramic matrix composites with a continuous fibre reinforcement, unidirectional (1D), bidirectional (2D), and tridirectional (xD, with $2 < x \leq 3$), loaded along one principal axis of reinforcement.

2 Normative references

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

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

EN 10002-2 Metallic materials - Tensile testing - Part 2 : Verification of the force measuring system of the tensile testing machines

WI 136 Code of practice: Code of practice for the measurement of misalignment induced bending in uniaxially loaded tension compression test pieces

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 unnotched 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 :

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

(ii) in some CMC a damage zone of multiple matrix cracks forms ahead of a notch prior to ultimate failure,

(iii) 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 microcracking 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 heterogenous 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 microcracked 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 or 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 (80-100) % of the unnotched 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 unnotched tensile specimen (σ_r):

(i) when $\sigma_n < \sigma_r$, the composite is notch sensitive,

(ii) 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 Definitions and symbols

For the purposes of this prestandard, the definitions and symbols of EN 658-1 and the following apply :

5.1 ligament

The part of the double edge notched specimen which 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

The 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 unnotched specimen tensile strength, $\sigma_{t,m}$

Tensile strength obtained by applying EN 658-1. This strength value is defubed as σ_r.

5.6 notched specimen tensile strength, $\sigma_{t,m,n}$

Ratio of the maximum tensile force to the ligament cross section area. This strength value is defined as 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 shall conform to grade 1 or better according to EN 10002-2.

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 misalignment shall be verified and documented according to, for example, the procedure described in WI 136. 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 3 : Load train couplers are of two types : fixed or non-fixed. Fixed couplers usually consist of an 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 4: 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 5: 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.

6.4 Micrometers

Micrometers used for the measurement of the dimensions of the test specimen shall be in accordance with ISO 3611.

6.5 Ligament size measuring device

A profile projector or any other suitable instrument to measure the width of the ligament between notches.

7 Specimens

7.1 Unnotched test specimens

All flat specimens from EN 658-1 can be used except type 2.