

BS EN 843-8:2010



BSI Standards Publication

# Advanced technical ceramics — Mechanical properties of monolithic ceramics at room temperature

Part 8: Guidelines for conducting proof  
tests

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**National foreword**

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The UK participation in its preparation was entrusted to Technical Committee RPI/13, Advanced technical ceramics.

A list of organizations represented on this committee can be obtained on request to its secretary.

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ISBN 978 0 580 68822 5

ICS 81.060.30

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 July 2010

**Amendments issued since publication**

Date	Text affected
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EUROPEAN STANDARD

EN 843-8

NORME EUROPÉENNE

EUROPÄISCHE NORM

June 2010

ICS 81.060.30

English Version

## Advanced technical ceramics - Mechanical properties of monolithic ceramics at room temperature - Part 8: Guidelines for conducting proof tests

Céramiques techniques avancées - Propriétés mécaniques des céramiques monolithiques à température ambiante - Partie 8: Lignes directrices de conduite d'épreuves

Hochleistungskeramik - Mechanische Eigenschaften monolithischer Keramik bei Raumtemperatur - Teil 8: Leitlinien zur Durchführung von Überlast-Prüfungen

This European Standard was approved by CEN on 13 May 2010.

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## Foreword

This document (EN 843-8:2010) 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of an identical text or by endorsement, at the latest by December 2010, and conflicting national standards shall be withdrawn at the latest by December 2010.

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EN 843, *Advanced technical ceramics — Mechanical properties of monolithic ceramics at room temperature*, consists of the following nine parts:

- *Part 1: Determination of flexural strength*
- *Part 2: Determination of Young's modulus, shear modulus and Poisson's ratio*
- *Part 3: Determination of subcritical crack growth parameters from constant stressing rate flexural strength tests*
- *Part 4: Vickers, Knoop and Rockwell superficial hardness*
- *Part 5: Statistical analysis*
- *Part 6: Guidance for fractographic investigation*
- *Part 7: C-ring tests*
- *Part 8: Guidelines for conducting proof tests*
- *FprCEN/TS 843-9, Advanced technical ceramics — Mechanical properties of monolithic ceramics at room temperature — Part 9: Method of test for edge-chip resistance*

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## 1 Scope

This European Standard describes requirements and methods for proof testing of advanced technical ceramic components. It provides general guidance concerning the design of the test and the methodology for the selection of loading conditions.

## 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 843-3, *Advanced technical ceramics — Mechanical properties of monolithic ceramics at room temperature — Part 3: Determination of subcritical crack growth parameters from constant stressing rate flexural strength tests*

EN 843-5, *Advanced technical ceramics — Mechanical properties of monolithic ceramics at room temperature — Part 5: Statistical analysis*

CEN/TS 14425-1, *Advanced technical ceramics — Test methods for determination of fracture toughness of monolithic ceramics — Part 1: Guide to test method selection*

EN ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories (ISO/IEC 17025:2005)*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

- 3.1**  
**delayed failure**  
fracture of an item after an extended period under stress
- 3.2**  
**item under test**  
component to be subjected to the proof test
- 3.3**  
**proof test**  
short-term test designed to investigate the mechanical or thermo-mechanical potential of a component, removing by fracture those components which do not meet specified levels
- 3.4**  
**proof-test ratio**  
ratio of the stress to be applied in a short-term proof test to the expected long-term service stress within an item under test
- NOTE "Item under test", see 3.2.
- 3.5**  
**sub-critical crack growth**  
extension of existing cracks or flaws under a stress which does not produce instant failure

## 4 Principle

Since advanced technical ceramic components can contain microstructural inhomogeneities and mechanical damage which are difficult to detect by non-destructive observations (dye tests, ultrasonics, etc.), an individual component can have insufficient strength to perform adequately in a particular application. The objective of mechanical or thermo-mechanical proof testing is to determine whether an individual item has adequate mechanical properties before being placed into service. The principle is to apply a short-term stressing operation to the item under test, the level of stress in which exceeds the expected service conditions. Items which fail in this test, are removed from the population, providing a guarantee of a minimum life in the survivors. The stressing can be directly mechanical, or as a result of thermal stress, such as in a thermal shock test.

This guarantee is valid only for the conditions and state of the test piece item under test directly after the proof test. Any change in the material, the geometry or structure of the item after the proof test (e.g. mechanical, thermal, oxidative, corrosive, wear or other damage) can change the strength and can shorten the minimum life of the item.

## 5 Main considerations

The short-term fracture stress of an advanced technical ceramic component is determined by the most highly stressed microstructural inhomogeneity or discontinuity, and is therefore determined by the method of manufacture and surface finishing. In general, it is not possible to predict with any certainty the forces that can be applied to a component without risking failure. For some applications where premature failure carries with it considerable costs, it can be beneficial to take steps to minimise the risks by removing from the population of items those individuals which are most at risk from failure.

Additionally, many types of advanced technical ceramic suffer from the slow growth of small cracks under maintained stress, with a consequent loss of the remaining strength. This thermally activated process may be accelerated by the presence of water, or by a corroding environment, which can react with the crystalline or amorphous bonding at the tip of crack. Thus if a component is held under stress for a prolonged period, it can weaken with time and lead to delayed failure. The tendency of a material to behave in this way can be detected, for example, by undertaking strength tests at different stressing rates (see EN 843-3) or by statically stressing the material until failure occurs. Generally, the effect is most marked in silicate glasses, and in glass-phase containing oxide ceramic materials. It is less marked in purely crystalline oxide ceramics, and least marked in non-oxide ceramics.

The principle of the proof-test (see Annex A) is to stress the item to such a level as will probe the item to determine the presence of features that would result in low strength. The stress distribution should ideally match that seen in the application of the item, and should be applied smoothly and quickly, and then removed in a similar manner such that the strength of the surviving items is not reduced by non-catastrophic crack growth. There are several philosophies that can be adopted:

- a) Select a stress level which pragmatically removes a certain fraction of the population, by a few percent, providing a guaranteed minimum strength for the remainder.
- b) Select a stress level which is a factor of typically two or three times the expected stress level in service, providing a greater assurance that it will survive in service.
- c) Numerically determine the over-stress level factor from the fracture mechanical behaviour of the material, specifically the critical stress intensity factor (see CEN/TS 14425-1) and the sub-critical crack growth characteristics (see EN 843-3), combined with Weibull parameters (see EN 843-5) to provide stress-volume or stress-area predictions of the risk of failure. This method, while scientifically rigorous, is time-consuming and effective only if the fracture mechanical data that can be acquired are applicable to the item in every respect.

**NOTE** Components may be produced and finished in ways which are not equivalent to the conditions employed for manufacturing, and testing test pieces of closely defined geometry, and thus may vary in density, microstructural homogeneity, surface finishing and residual stress levels. Predictions may be poor unless the equivalence is good.

Of these three philosophies, a) and b) are pragmatic and can be set by simple judgement. They are typically used to ensure that each item, as supplied, has adequate strength at the point of delivery, but the procedures take no account of the potential of the material to age in service and to fail as a consequence of progressive loss of remaining strength with time. The third philosophy, c), additionally takes the slow loss of strength into account, and has been used successfully on safety-critical components under long-term stress.

The effectiveness of a proposed proof-testing method can be determined by evaluating the short-term strength distribution of proof-tested items compared with the strength distribution before proof testing. In the prior proof-tested batch, there should be an absence of items failing at less than the set proof-test level. The continued presence of items failing at less than the proof-test level is an indication that there is some weakening of items during the proof-test, which either has to be taken into account in selecting the proof-test loading level, or the proof-test schedule itself has to be examined to reduce or eliminate the effect.

Overload proof-testing will not be successful in guaranteeing a component in service in the following circumstances:

- where the item becomes damaged in service, particularly where such damage is in regions of high stress;
- where the stresses in service are poorly defined or undefined, such as shock loading, or localised hard contact;
- where temperature changes are significant;
- where the item has features that would suffer unduly in overload proof-testing, such as sharp edges, joints to other materials or surface coatings, or marking of items by the testing system;
- where the stress distribution under the service conditions cannot be conveniently modelled in a proof-testing situation;
- where proof-testing cannot be performed quickly and smoothly, particularly the unloading part of the cycle;
- where it may not be possible adequately to design an overload thermo-mechanical proof-test because of temperature limitations, oxidation, or unknown or undefinable heat transfer conditions.

The principal considerations are therefore the design of the system for undertaking the proof-test, and ensuring that it adequately matches the service stress condition during item testing.

## 6 Design of proof-test equipment

The principal factors in the appropriate design of proof-testing equipment are:

- clear understanding of service conditions to be experienced by the item under test, and the lifetime to be expected;
- definition of the stress distribution to be achieved in the item during testing;
- definition of and agreement concerning the overload factor to be employed;
- evaluation of methods of achieving the stress distribution in a non-destructive manner;
- design of a proof-testing system which provides the appropriate stress distribution without otherwise marking or damaging the items under test.

Ideally, the proof-testing system should incorporate the following features:

- easy insertion and removal of the item to be tested;
- contacts between the item under test and metallic parts of the system to be minimised to avoid marking. Use of polymeric loading devices is recommended where practical;
- where possible, protection of parts of the system adjacent to the item under test against fracture of items which fail the proof test;
- easy replacement of parts of the system which become damaged by failures of items under test;
- means of applying a defined loading cycle to the item under test, with a defined dwell time and rapid unloading.

The means of applying stress to the item under test can, for example, be via one of the following:

- hydraulic pressurization directly or through use of a rubber bag that adapts appropriately to the surface profile of the item under test;

NOTE Use of a rubber bag is convenient, since it avoids the need to clean items after testing.

- pressurization using a soft polymeric former which is mechanically deformed to contact the item under test;
- pneumatic loading of mechanical contacts on the item under test;
- direct mechanical loading via a testing machine;
- subjection to an appropriate temperature gradient or to a rapid cooling process sufficient to generate appropriate thermoelastic stresses in the item under test.

In all cases, a means shall be provided for independently determining the loading being applied, particularly the pressure or force.

## 7 Test operation

The following issues shall be taken into account when undertaking proof testing:

- items for testing should be at an appropriate stage in their manufacture or should be ready to go into service, incorporating all aspects of processing and handling;
- care shall be taken that the item for testing is handled carefully, and is not impacted with metallic parts of the testing system, with tools, or with other components;
- a record shall be kept of the loading time, the peak load, the duration at peak load, and the time to unload the items under test.

## 8 Report

The test report shall be in accordance with the reporting provisions of EN ISO/IEC 17025 and shall contain the following items:

- a) name of the testing establishment;
- b) date of the tests, a unique identification of the report and of each page, the name and address of the customer, and the signatory of the report;

- c) reference to this European Standard where appropriate;
- d) description of the test system employed and evidence of the stress distribution being applied to the items under test;
- e) details of the items under test, including design codes, material codes and any relevant processing information;
- f) details of the loading schedule applied to the items under test;
- g) details of the number of items failing the proof test and, where relevant, the load levels at which they failed;
- h) where required, any additional relevant details concerning the mode of failure.

## Annex A (informative)

### Basis of proof-testing

#### A.1 Short-term strength

Consider a flaw or short crack of length  $c$  in an item under test, subjected to a stress  $\sigma$ . The stress intensity at the crack tip is given by:

$$K_I = Y\sigma c^{1/2} \quad (\text{A.1})$$

During a fast fracture test, the fracture stress  $\sigma_f$  corresponds with the critical stress intensity factor level  $K_{Ic}$ . Since the initial flaw length is generally not known, the fracture stress cannot be predicted for an individual item under test. Application of a proof-test stress  $\sigma_p$  will cause those items with strengths less than  $K_{Ic}/(\sigma_p c^{1/2})$  to fail, while those of strength equal to or greater than this level will survive, provided that the crack length  $c$  does not increase during the testing.

The net effect is to truncate the distribution of strength levels of a batch of items under test at the lower end, such that, under the assumptions given in Clause 4, there is a guarantee of a minimum remaining short-term strength, which previously did not exist.

#### A.2 Long-term effects

If the rate of growth,  $v$ , of a flaw or crack is given by the relationship:

$$v = AK_I^n \quad (\text{A.2})$$

where

$A$  is a constant,

the time to failure,  $t_f$ , of a statically loaded component is given by:

$$t_f = \int_{c_i}^{c_c} \frac{dc}{v} \quad (\text{A.3})$$

where the integration is from the starting crack size  $c_i$  to a critical crack size  $c_c$ . Substituting Equations (A.1) and (A.2) into (A.3) gives:

$$t_f = \frac{2}{Y^2 \sigma^2 A} \int_{K_{Ii}}^{K_{Ic}} \frac{dK_I}{K_I^{n-1}} = \frac{2}{Y^2 \sigma^2 A(n-2)} \left( \frac{1}{K_{Ii}^{n-2}} - \frac{1}{K_{Ic}^{n-2}} \right) \quad (\text{A.4})$$

which has the simplified form:

$$t_f = \frac{B}{\sigma^n} - \frac{C}{\sigma^2} \quad (\text{A.5})$$

In practice,  $n \gg 2$ , and a simple plot of  $\log \sigma$  vs.  $\log t_f$  has a slope of  $n^{-1}$ . In the case of a short-term proof test, the time to failure at a service stress of  $\sigma_s$  of the weakest item surviving after an initial proof test at a stress of  $\sigma_p$  can be predicted as being:

$$t_f = \frac{2}{Y^2 \sigma_s^2 K_{Ic}^{n-2} A(n-2)} \left( \left( \frac{\sigma_p}{\sigma_s} \right)^2 - 1 \right) \quad (\text{A.6})$$

The term  $(\sigma_p/\sigma_s)$  is the proof test ratio. The relationship in this last equation shows that a minimum service life following proof-testing can be estimated from fundamental material characteristics, and can be raised by raising the proof-test stress.

This analysis can be extended to cases of variable stress or fatigue loading, but is clearly complex, and requires understanding of the crack growth behaviour under such conditions.

### A.3 Defining the need to proof-test

Whether a proof-test is needed or not depends on the risk of failure that is to be predicted. To undertake such an assessment requires statistical information on fracture stresses of components, combined with the predictions given above. Generally speaking, if the probability of failure during service is likely to be less than  $10^{-6}$ , there will be no need to proof-test. If it is higher than this, then the cost of an occasional in-service failure should be balanced against the cost of proof-testing every item in an effective manner.

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