BS EN 843-7:2010

BSI Standards Publication

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

Part 7: C-ring tests

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National foreword

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

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Foreword

This document (EN 843-7:2010) 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of an identical text or by endorsement, at the latest by December 2010, and conflicting national standards shall be withdrawn at the latest by December 2010.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 tests*

— *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 a method for undertaking ultimate strength tests on slotted rings (C-rings) in order to determine the strength of ring or tube-shaped components in the manufactured geometry.

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 843-5:2006, *Advanced technical ceramics — Mechanical properties of monolithic ceramics at room temperature — Part 5: Statistical analysis*

EN 1006, *Advanced technical ceramics — Monolithic ceramics — Guidance on the selection of test pieces for the evaluation of properties*

EN ISO 7500-1:2004, *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)*

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

ISO 3611:1978, *Micrometer callipers for external measurement*

ISO 6906:1984, *Vernier callipers reading to 0,02 mm*

3 Definitions

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

3.1
C-ring test piece
ring-shaped test piece in which a radial slot has been cut to convert it into an incomplete ring

3.2
C-ring compression test
test in which a C-ring test piece is compressed across a diameter away from the slot, and which imposes the maximum tensile stress on the outside surface of the ring remote from the points of compression load application

3.3
C-ring tension test
test in which a C-ring test piece is pulled across a diameter away from the slot, and which imposes the maximum tensile stress on the inside surface of the ring remote from the point of tensile load application

4 Significance and use

This method of test permits the strength of circular symmetry test pieces such as thin-walled rings or tubes to be determined. The diametral loading of a short length of slotted tube or a slotted ring produces a tensile stress in the mid-section of the tube wall, either in the outside region of the wall thickness if the ring is compressed, or in the inside region if the ring is pulled in tension. In both cases the maximum stresses are in the tube surface, and are remote from the points of load application, and thus only weakly influenced by the precise geometry of load application. In contrast, diametral compression of a ring without a slot leads to high tensile stresses immediately opposite the points of load application, with much poorer calibration and greater sensitivity to the precise geometry of loading.

The result of a C-ring test is sensitive to the surface finish applied to the cylindrical surfaces of the ring, for example by the method of shaping the article, and additionally to the planar ring faces. Thus if a ring is cut from a tube, the cutting shall be done in such a manner as not to influence the result of the test if the purpose of the test is to determine the as manufactured tube strength.

The results obtained from this test are representative of the strength of pressurized tubes and other cylindrical shapes.

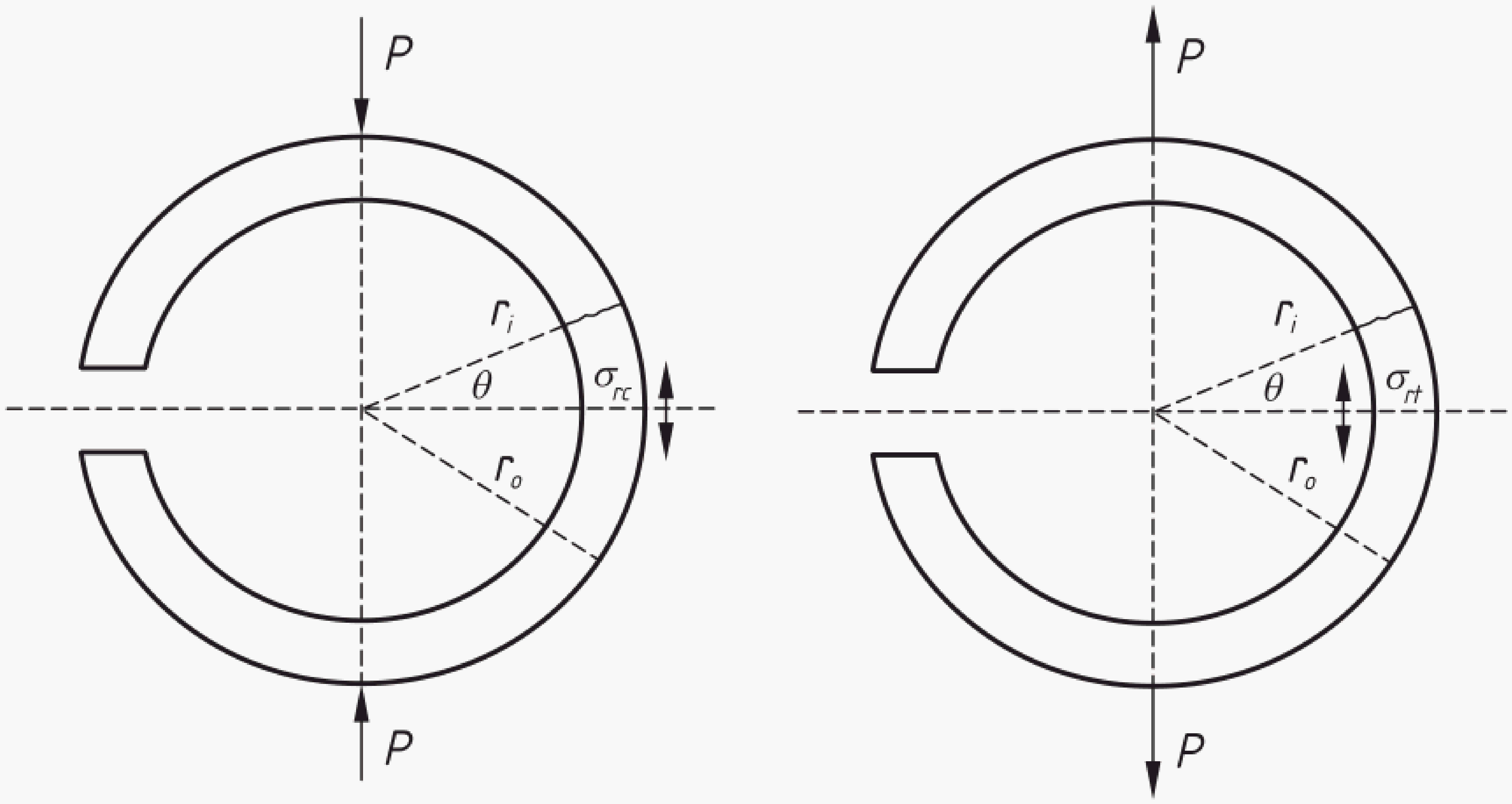
5 Principle

5.1 Method A: C-ring compression

A slotted ring test-piece is placed on its cylindrical surface on a flat anvil of a mechanical testing machine with the slot remote from anvil (Figure 1a)). The second anvil of the test machine is brought into contact with the top surface of the ring, and the load is increased until failure occurs by closing the C-ring. The strength is computed from the ring geometry and the maximum force applied.

5.2 Method B: C-ring tension

Two opposed horizontal pull bars connected to a mechanical testing machine are used to contact the slotted ring at diametrally opposed positions remote from the slot (Figure 1b)). The force is increased until failure by opening the ring. The strength is computed from the ring geometry and the maximum force applied.



a) C-ring test in compression **b) C-ring test in tension**

Key

θ angle between the mid-plane and the location of the crack developed during the test

σ_{rc} C-ring strength determined in compression mode

σ_{rt} C-ring strength determined in ring tension mode

r_0 outside wall tube radius

r_i inside wall tube radius

P applied load

Figure 1 — C-ring test in compression and in tension

6 Apparatus

6.1 Cutting machine

A cutting machine equipped with a diamond saw blade suitable for preparing parallel faced slices from tube material. The saw blade may be selected to be appropriate for the material being cut, but the grit size should be minimised, and the cutting process adjusted to minimise edge chipping and other damage. If the available machine does not cut adequately dimensioned test-pieces (see Clause 7), test-pieces may be subsequently ground or lapped flat and parallel faced using other appropriate machines.

6.2 Vernier callipers

Vernier callipers reading to 0,02 mm in accordance with ISO 6906:1984, but additionally equipped with the ability to measure internal diameters of test pieces, or other suitable measurement device of equivalent accuracy.

6.3 Micrometer callipers

Micrometer callipers reading to 0,01 mm or better in accordance with ISO 3611:1978, or other suitable measurement device of equivalent accuracy.

NOTE Micrometer callipers with flat anvils are normally recommended for making measurements on ceramic materials to avoid risks of indentation associated with rounded anvils. However, rounded anvils will be required for measuring wall thickness, and should be used with considerable caution.

6.4 Mechanical testing machine

A mechanical testing machine capable of applying a force to the test jig at a constant displacement rate or at constant loading rate. The testing machine shall be equipped for recording the load applied to the test jig at any point in time. The accuracy and calibration of the testing machine shall be in accordance with EN ISO 7500-1:2004, Grade 1 (1 % of indicated load).

For Method A, the testing machine shall be equipped with hard flat anvils with faces either fixed parallel to within 0,05 mm over the area to be used for testing, or self-aligning during testing.

For Method B, the testing machine shall be equipped with a device for permitting two hard steel rollers to be inserted through the ring and supported at each end by yokes connected to the testing machine which permit a tensile force to be applied. Universal joints shall be incorporated into the load train to permit alignment and to minimise stress concentrations towards one face or other of the ring.

NOTE Any suitable alternative arrangement may be used in which the load can be applied in compression mode using a lever system containing the loading rollers.

Precautions shall be taken to avoid flying fragments from the test-piece during fracture.

6.5 Interface material

Thin, compliant materials such as cardboard, metal foil or rubber sheet, to be placed between the test piece and the compression anvils (Method A) or steel rollers (Method B).

7 Test pieces

Test pieces or test material shall be selected in accordance with the guidelines in EN 1006. If the test rings are to be cut from tube stock, select stock which is acceptably round and straight.

This standard does not prescribe any particular dimensions for test pieces, but the following size ratios are recommended to avoid problems with alignment or validity of the calculation equations:

a) 0,05 < (wall thickness/outer ring radius) < 0,5;

b) 0,2 < (axial length/outer ring radius) < 1,0;

c) 1,0 < (axial length/wall thickness) < 4,0.

Cut or otherwise machine the side faces of the test pieces to a parallelism of better than 0,015 mm using a diamond saw with or without additional machining by lapping or surface grinding. This process shall introduce a minimum of damage such that failure does not occur from the cut face.

NOTE 1 Guidance on machining processes may be found in EN 843-1 [6] and ASTM C1495 [1].

Make an axial cut through the wall of the ring using a diamond saw. For Method A the slot width shall be sufficiently large that the sides of the slot do not close during the test before failure of the test-piece. For thick-walled test-pieces, a slot of 1 mm to 2 mm is adequate, but for thinner walled test-pieces, the slot shall be rather wider.

All edges shall be chamfered at 45° to a distance of at least (0,15 ± 0,05) mm or rounded to a radius of at least (0,15 ± 0,05) mm to avoid edge dominated failures.

NOTE 2 It is necessary only to make the chamfer over an arc length of at least 90° of the tube wall adjacent to region of maximum tensile stress.

NOTE 3 Chamfering may be done by machine or by hand. The size of chamfer may need to be increased above the minimum values above for high-strength materials if it is found by fractography that chamfer dominated failure rather than surface dominated failures result. See [4] and [5].

At least ten test pieces shall be tested for determination of a mean strength, or at least 30 test pieces if a Weibull statistical analysis in accordance with EN 843-5:2006 is to be performed.

8 Test procedure

8.1 Test-piece dimensions

Measure the axial length of the each test piece to the nearest 0,01 mm in several places using the micrometer. Compute the mean result.

Measure the outside diameter of each test piece to the nearest 0,02 mm using the vernier callipers, ensuring that several measurements are made along the axial length across the diameter adjacent to that expected to become the mid plane in the test. Compute the mean result.

Measure the inside diameter of each test piece to the nearest 0,02 mm using the vernier callipers, ensuring that several measurements are made from both sides of the ring across diameters adjacent to the diameter expected to become the mid plane in the test. Compute the mean result.

NOTE The ring dimensions should be measured after cutting the slot, since this may release residual stresses and cause a shape change.

Measure the wall thickness of each test piece to the nearest 0,01 mm using the ball-anvil micrometer, ensuring that several measurements are made in the region adjacent to that expected to be in the mid plane during the test. Take great care not to introduce indentation damage during the measurement. Compute the mean result. Alternatively, measure the wall thickness after the test at the site of fracture.

8.2 Mechanical testing

In turn, place each test-piece between the anvils of the testing machine (Method A) or between the pull-yokes of the testing machine (Method B), using thin foil or rubber sheet as an interface between the test piece and the contacting metallic parts. Take up the slack in the load train and ensure that the test-piece remains centrally positioned, particularly the contact positions of the pull bars in Method B.

Load the test-piece at a constant rate of load increment, or at a constant crosshead displacement rate, until fracture occurs within a timescale of 10 s to 30 s.

NOTE 1 The rate selected will be determined by the dimensions of the test-piece, and may require some trials before the above condition is met. A method of calculating the required cross-head displacement rate is given in Annex A.

Recover the fragments of the test piece and inspect for unusual fracture patterns suggesting poor alignment in the test.

NOTE 2 Guidance on conducting fractographic examinations is given in EN 843-6 [5].

9 Calculation

9.1 Method A: C-ring compression

Compute the nominal exterior surface C-ring compression fracture strength using the following equation:

$$\sigma_{rc} = \frac{FR}{btr_o}\left[\frac{r_o - r_a}{r_a - R}\right] \quad (1)$$

where

$$R = \frac{(r_o - r_i)}{\ln(r_o / r_i)}; \quad r_a = \frac{r_o + r_i}{2} \quad (2)$$

and

σ_{rc} is the C-ring strength determined in ring compression mode, expressed in megapascals;

F is the applied force at fracture, expressed in newtons;

b is the axial length of test piece, expressed in millimetres;

t is the test-piece wall thickness = $(r_o - r_i)$, expressed in millimetres;

r_o is the outside wall tube radius expressed in millimetres;

r_i is the inside wall tube radius expressed in millimetres.

9.2 Method B: C-ring tension test

Compute the nominal interior surface C-ring tension fracture strength using the following equation:

$$\sigma_{rt} = \frac{FR}{btr_i}\left[\frac{r_a - r_i}{r_a - R}\right] \quad (3)$$

where

σ_{rt} is the C-ring strength determined in ring tension mode, expressed in megapascals.

9.3 Mean and standard deviation

For both methods, compute the average value of strength and the standard deviation.

9.4 Fractures away from the centre-line

Equations (1) and (3) are valid for the maximum stress in the test piece which occurs at a position 90° to the axis of force application. They are used to calculate the nominal fracture stress, and these data shall be used in any Weibull statistical analysis.

If it is required to measure the actual fracture stress at the fracture site, the angle θ between the position of maximum stress at the mid-plane and the fracture site (Figure 1) shall be measured to the nearest 1°. The calculated fracture stress using Equations (1) or (3) for the respective geometries is then corrected by multiplying it by a factor cos θ.

NOTE Details of stress analyses for the C-ring geometry can be found in [2] and [3] in the Bibliography.

10 Interferences

The principal sources of error in this test are caused by imperfections in geometry of the test piece, and in poor alignment and/or contact of the test piece with the loading system. The use of compliant layers between irregularly shaped test pieces and the anvils or loading bars will help to eliminate misalignments, but with as-fired dimensions in test pieces, the results still have to be treated as nominal.

11 Report

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

a) name of the testing establishment;

b) unique identification of the report and signatory;

c) name and address of the client;

d) dates or receipt of the test item and of the test;

e) reference to this standard, i.e. determined in accordance with EN 843-7:2010, Method A or Method B;

f) details of the material type, manufacturing code, batch number, etc.;

g) number of test pieces tested (minimum 10);

h) dimensions of each test piece, and if relevant, orientations in which test pieces are prepared from components or blocks;

i) method of cutting and chamfering test pieces into slotted rings;

j) details of the test jig design, alignment facilities, etc.;

k) individual values of nominal C-ring strength expressed in megapascals to three significant figures;

l) mean result from all tests and the standard deviation;

m) any unusual appearance of fractures or any other comment about the test or test method applicability and any fractographic conclusions.

Annex A
(informative)

C-ring compliance

In order to compute the crosshead displacement rate required to achieve fracture within the recommended range of times, or the slot width required for given expected strength and Young's modulus, the following relationship may be used:

For compression Method A:

$$\delta = \frac{\sigma_{rc}}{E} \frac{6\pi r_a^3}{(r_o - r_i)^2} \left[\frac{r_o (r_a - R)}{R(r_o - r_a)} \right] \quad \text{(A.1)}$$

For tension Method B:

$$\delta = \frac{\sigma_{rt}}{E} \frac{6\pi r_a^3}{(r_o - r_i)^2} \left[\frac{r_i (r_a - R)}{R(r_i - r_a)} \right] \quad \text{(A.2)}$$

where

δ is the deflection at failure in millimetres;

E is Young's modulus in newtons per square metre;

σ_{rc} and σ_{rt} are the ring compression or ring tension strengths in newtons per square metre;

and other symbols are as defined in 9.1 and 9.2 in units of millimetres.

Thus if the Young's modulus and stress at failure are estimated, the test piece deflection required can be computed, and hence the displacement rate required to fracture within the 10 s to 30 s range computed.

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[1] ASTM C1459:01, *Standard test method for the effect of grinding on flexural strength of advanced ceramics*

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[4] Jadaan, O.M., Wereszczak, A.A., "Revisiting the recommended geometry for the diametrally compressed ceramic C-ring specimen", Oak Ridge National Laboratory Technical Memo: ORNL-TM-2009/090

[5] EN 843-6, *Advanced technical ceramics — Mechanical properties of monolithic ceramics at room temperature — Part 6: Guidance for fractographic investigation*

[6] EN 843-1, *Advanced technical ceramics — Mechanical properties of monolithic ceramics at room temperature — Part 1: Determination of flexural strength*

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