



**International  
Standard**

**ISO 6872**

**Dentistry — Ceramic materials**

*Médecine bucco-dentaire — Matériaux céramiques*

**Fifth edition  
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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at [www.iso.org/patents](http://www.iso.org/patents). ISO shall not be held responsible for identifying any or all such patent rights.

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 106, *Dentistry*, Subcommittee SC 2, *Prosthetic materials*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 55, *Dentistry*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This fifth edition cancels and replaces the fourth edition (ISO 6872:2015), which has been technically revised. It also incorporates the Amendment ISO 6872:2015/Amd 1:2018.

The main changes are as follows:

- [Annex C](#) on protocol to assess the hydrothermal stability of yttria-stabilized tetragonal zirconia (Y-TZP) has been added.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

Specific qualitative and quantitative requirements for freedom from biological hazard are not included in this document, but it is recommended that in assessing possible biological or toxicological hazards, reference be made to ISO 10993-1 and ISO 7405.

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# Dentistry — Ceramic materials

## 1 Scope

This document specifies the requirements, recommendations and the corresponding test methods for dental ceramic materials for fixed all-ceramic and metal-ceramic restorations and prostheses.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 1942, *Dentistry — Vocabulary*

ISO 3696, *Water for analytical laboratory use — Specification and test methods*

ISO 13078, *Dentistry — Dental furnace — Test method for temperature measurement with separate thermocouple*

ISO 13078-2, *Dentistry — Dental furnace — Part 2: Test method for evaluation of furnace programme via firing glaze*

ISO 13078-3, *Dentistry — Dental furnace — Part 3: Test method for the evaluation of high temperature sintering furnace measurement with a separate thermocouple*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1942 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

### 3.1 Material

#### 3.1.1

##### **chromatic dentine ceramic**

dentine ceramic having a high strength or saturation of the hue (colour)

#### 3.1.2

##### **dental ceramic**

ceramic material prepared for use in the fabrication of dental prostheses and restorations

#### 3.1.3

##### **dentine ceramic**

slightly translucent, pigmented *dental ceramic* (3.1.2) used to simulate the natural appearance of dentine in a dental ceramic restoration or dental prosthesis

### 3.1.4

#### **enamel ceramic**

slightly translucent, pigmented *dental ceramic* (3.1.2) used to simulate the natural enamel in a dental ceramic restoration or dental prosthesis

### 3.1.5

#### **fluorescent ceramic**

*dental ceramic* (3.1.2) material that absorbs radiant energy and emits it in the form of radiant energy of a different wavelength band all or most of whose wavelengths exceed that of the absorbed energy

EXAMPLE Absorption of ultraviolet light with emission of blue light.

### 3.1.6

#### **glass-ceramic**

*dental ceramic* (3.1.2) material formed by the action of heat treatment on a glass in order to cause initiation and growth of a wholly or predominantly crystalline microstructure

### 3.1.7

#### **modelling fluid**

liquid with which a *dental ceramic* (3.1.2) powder is mixed in order to shape or model it into its required form prior to firing

### 3.1.8

#### **modifying enamel ceramic**

*enamel ceramic* (3.1.4) used to modify the surface contour of a restoration, for example, add a contact, often fired at a lower temperature than the enamel ceramic or *dentine ceramic* (3.1.3)

### 3.1.9

#### **monolithic ceramic**

*dental ceramic* (3.1.2) that is substantially made of a single uniform material

Note 1 to entry: A thin layer of glaze ceramic (staining technique) can be applied.

### 3.1.10

#### **opalescent enamel ceramic**

*enamel ceramic* (3.1.4) containing microfine particulates, with a refractive index significantly different from the ceramic matrix in which they are incorporated

Note 1 to entry: This material scatters shorter wavelengths of light (e.g. blue) and transmits longer wavelengths of light (e.g. red).

### 3.1.11

#### **pressable ingot**

*dental ceramic* (3.1.2), in the form of a pellet or ingot, designed for use in a specialised furnace which enables the ingot to be injected, cast or pressed into a mould prepared through the lost wax technique

## 3.2 Processing

### 3.2.1

#### **condensation**

process for *dental ceramic* (3.1.2) whereby a slurry of dental ceramic powder is vibrated to compact the powder prior to sintering

### 3.2.2

#### **firing**

process whereby heat and potentially other process parameters (e.g. mechanical or gas pressure) are applied to a ceramic powder or powder compact in order to densify the ceramic into its required form.

### 3.2.3

#### **sintering**

process of densification and consolidation of a green body by the application of heat with resulting joining of ceramic particles and increasing contact interfaces due to atom movement within and between the ceramic grains of the developing polycrystalline microstructure

Note 1 to entry: Sintering may take place either directly or through the agency of a secondary phase (e.g. reaction sintering and liquid-phase sintering).

[SOURCE: ISO 20507:2022, 3.2.69]

## 3.3 Properties

### 3.3.1

#### **class of dental ceramic**

classification of a *dental ceramic* (3.1.2) material in accordance with its intended function

### 3.3.2

#### **fracture toughness**

conventional fracture mechanics parameter indicating the resistance of a material to crack extension (propagation)

### 3.3.3

#### **glass transition temperature**

$T_g$   
approximate midpoint of the temperature range over which a glass transforms between elastic and viscoelastic behaviour characterized by the onset of a rapid change in its coefficient of thermal expansion

### 3.3.4

#### **glaze**

surface appearance obtained when the gloss is clinically and aesthetically acceptable

## 4 Types, classes, and their identification

For the purposes of this document, dental ceramics are designated into two types.

- Type I: Ceramic products that are provided as powders, pastes, or aerosols.
- Type II: All other forms of ceramic products.

Ceramics are divided into five classes in accordance with their intended clinical use and in accordance with the descriptions in [Table 1](#). If colour is added to a ceramic powder for identification purposes, then the colour coding given in [Table 2](#) is recommended.

**Table 1 — Classification of ceramics for restorations and fixed prostheses by intended clinical use and required values of mechanical and chemical properties**

Class	Recommended clinical indications	Mechanical and chemical properties	
		Flexural strength [MPa] minimum value for mean (see 7.3)	Chemical solubility [ $\mu\text{g}/\text{cm}^2$ ] (see 7.6)
1	a) Monolithic ceramic for single-unit anterior prostheses, veneers, inlays, or onlays adhesively cemented.	50	< 100
	b) Ceramic for coverage of a metal framework or a ceramic substructure.	50	< 100
2	a) Monolithic ceramic for single-unit anterior or posterior prostheses adhesively cemented.	100	< 100
	b) Fully covered substructure ceramic for single-unit anterior or posterior prostheses adhesively cemented.	100	< 2 000
3	a) Monolithic ceramic for single-unit anterior or posterior prostheses and for three-unit prostheses not involving molar restoration adhesively or non-adhesively cemented.	300	< 100
	b) Fully covered substructure for single-unit anterior or posterior prostheses and for three-unit prostheses not involving molar restoration adhesively or non-adhesively cemented.	300	< 2 000
4	a) Monolithic ceramic for three-unit prostheses involving molar restoration.	500	< 100
	b) Partially or fully covered substructure for three-unit prostheses involving molar restoration.	500	< 2 000
5	Monolithic ceramic for prostheses involving partially or fully covered substructure for four or more units.	800	< 100

**Table 2 — Recommended colour coding for the identification of type I dental ceramic powders**

Material	Colour coding
Dentine ceramic	Pink
Enamel ceramic	Blue
Fluorescent ceramic	Yellow
Highly chromatic dentine ceramic	Orange
Opalescent enamel ceramic	Blue-green
Modifying enamel ceramic (e.g. translucent, clear)	Purple

## 5 Requirements

### 5.1 Uniformity

The inorganic pigment(s) used to produce the colour of a fired dental ceramic and any organic colourants (for colour coding) shall be uniformly dispersed throughout the dental ceramic material and in powdered ceramic products, no segregation of the pigment(s) shall take place when the powder is mixed as in 7.1.4. Check by visual inspection.

## 5.2 Freedom from extraneous materials

5.2.1 Dental ceramic materials shall be free from extraneous materials when assessed by visual inspection.

5.2.2 Dental ceramic materials shall not have an activity concentration of more than  $1,0 \text{ Bq}\cdot\text{g}^{-1}$  of  $^{238}\text{U}$ . Test in accordance with [7.2](#).

5.2.3 Any colourants used to colour code the ceramic powder, as per [Table 2](#), are recommended to be food-quality organic materials.

## 5.3 Mixing and condensation properties of type I ceramics

When mixed as in [7.1.4](#) with water or the modelling fluid recommended by the manufacturer, a dental ceramic powder shall neither form lumps, nor granules, when assessed by visual inspection.

The paste formed shall be suitable for making the indicated restorations and prostheses by condensation of successive layers. When the paste is condensed, as in [7.1.4](#), it shall neither crack, nor crumble, when assessed by visual inspection during drying.

## 5.4 Physical and chemical properties

The physical and chemical properties of ceramic test specimens tested in accordance with the relevant methods detailed for type I and type II ceramics in [Clause 7](#) shall comply with the requirements specified in [Table 1](#). In addition to the required physical and chemical properties, there are other important physical and chemical properties that can be reported, including fracture toughness ([Annex A](#)), strength distribution parameters ([Annex B](#)), and hydrothermal stability ([Annex C](#)). The coefficient of thermal expansion of the ceramics shall not deviate by more than  $0,5 \times 10^{-6} \text{ K}^{-1}$  from the value stated by the manufacturer (see [8.2.2](#)). The glass transition temperature of the ceramics shall not deviate by more than  $20 \text{ }^{\circ}\text{C}$  from the value stated by the manufacturer (see [8.2.2](#)).

## 5.5 Shrinkage factor

The absolute uncertainty of measurement of the shrinkage factor by which the dimensions of the partially sintered material is to be divided (as provided under [9.2.2 c](#)) shall be  $\pm 0,002$ .

## 6 Sampling

### 6.1 Type I ceramics

Use retail packages from the same batch containing enough material to carry out the specified tests plus an allowance for repeated tests, if necessary. Where there is more than one shade of a dental ceramic, perform test with a colour/shade most commonly used. All of the materials tested shall be of the same lot.

Sufficient quantities of essential modelling fluids shall be obtained if their use is recommended by the manufacturers. The quantities shall be those recommended by the manufacturer concerned.

### 6.2 Type II ceramics

All of the materials procured for testing in accordance with this document shall be of the same lot. Where there is more than one shade of a dental ceramic, perform test with a colour/shade most commonly used.

## 7 Test methods

### 7.1 Preparation of test specimens

#### 7.1.1 General

For detailed instructions, see the individual test methods.

For type I ceramics (unless otherwise stated or inconsistent with the text), the apparatus detailed in [7.1.2](#) along with the conditions for mixing, condensation, and firing ([7.1.3](#), [7.1.4](#), and [7.1.5](#)) apply to all of the test methods.

#### 7.1.2 Components of test specimens (type I ceramics)

The liquid used in the preparation of test specimens shall be water that complies with the requirements for grade 3 water (ISO 3696) or, when applicable, the modelling fluid recommended by the manufacturer of the dental ceramic powder. The required amount of powder shall be taken from the appropriate pool of powder obtained in accordance with [6.1](#).

#### 7.1.3 Apparatus for mixing

All apparatus for mixing shall be clean and dry.

##### 7.1.3.1 Glass slab or mixing palette.

**7.1.3.2 Spatula**, made from material that is not readily abraded by the dental ceramic powder (glass is recommended). Instruments used for the mixing procedure shall be made of materials that do not contaminate the ceramic material.

**7.1.3.3 Open multipart mould**, from which the condensed specimen can be removed without distortion.

**7.1.3.4 Vibration system** (table or mechanical brush), capable of vibrating at a frequency of 50 Hz to 60 Hz or in accordance with the manufacturer's instructions.

#### 7.1.4 Method of mixing

Combine the water or modelling liquid and the ceramic powder in the proportions recommended by the manufacturer. Avoid vigorous mixing which will tend to incorporate air bubbles with the paste and, both during and after mixing, examine for compliance with [5.1](#) and [5.2](#).

#### 7.1.5 Procedure for specimen fabrication

Overfill the mould with dental ceramic paste and vibrate. When excess liquid appears at the free surface of the specimen, place a paper tissue (or similar absorbent material) on the surface of the specimen and remove the excess liquid continually by replacing the tissue as soon as it becomes saturated with liquid. Continue vibration and absorption until no further liquid can be removed and then level the free surface of the condensed specimen by means of a suitable instrument (a bevelled glass microscope slide is ideal for this purpose). After removing the specimen from the mould, place it on a firing tray, dry it, and check for compliance with [5.3](#).

NOTE Other forming methods such as dry pressing are acceptable for specimen fabrication.

#### 7.1.6 Firing

Position the specimens in the furnace so that they will be uniformly fired on a substrate to which they will not adhere and from which there will be no pick-up of material. Obtain guidance from the manufacturer for the firing of test specimens. These specimens should be fired in accordance with manufacturer's instructions

so that their final density and thermal history is representative of that found for indicated restorations or prostheses specific for the given test specimen which can be different from the instructions for use.

## 7.2 Radioactivity of dental ceramic

### 7.2.1 Preparation of samples

#### 7.2.1.1 Type I ceramics

A 50 g sample, as manufactured, is suitable to be collected as described in [6.1](#).

#### 7.2.1.2 Type II ceramics

Mill powder using tungsten-carbide milling media or other appropriate media (to avoid contamination by radioactive species). Sieve and obtain 50 g of powder with a particle size less than 75  $\mu\text{m}$ .

### 7.2.2 Counting procedure

Use a sample volume of 50 g bulk powder and determine the activity concentration of  $^{238}\text{U}$  by neutron activation or gamma spectroscopy.

### 7.2.3 Assessment of results

Each sample tested shall comply with the requirement in [5.2.2](#).

## 7.3 Flexural strength

### 7.3.1 General

Three flexural test methods acceptable are:

- a) three-point flexure,
- b) four-point flexure, and
- c) biaxial flexure (piston-on-three-ball).

### 7.3.2 Three-point and four-point flexure tests

#### 7.3.2.1 Apparatus

**7.3.2.1.1** Universal mechanical testing machine, capable of a crosshead speed of  $(1 \pm 0,5)$  mm/min and an ability to measure applied loads with a maximum limit of uncertainty in accordance with ISO 7500-1.

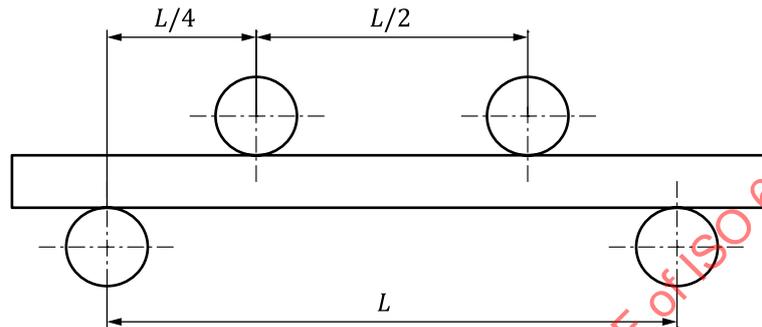
NOTE Usually not more than 5 kN of load is needed.

#### 7.3.2.1.2 Flexural test fixtures

**7.3.2.1.2.1 Fixture for three-point flexure**, consisting of support rollers (1,5 mm to 5 mm  $\pm$  0,2 mm, in diameter) positioned with their centres 12,0 mm to 40,0 mm ( $\pm$ 0,5 mm) apart. The load shall be applied at the midpoint between the supports by means of a third roller (1,5 mm to 5 mm  $\pm$  0,2 mm, in diameter). Rollers shall be made from hardened steel or other hard material having a hardness greater than 40 HRC (Rockwell C-scale) and have a smooth surface with a roughness less than 0,5  $\mu\text{m}$ . It is recommended that the actual spacing between the support roller centres ( $L$ ) be measured to within 0,1 mm.

**7.3.2.1.2.2 Fixture for four-point flexure**, consisting of 1/4-point test configuration such that the test piece is loaded by two inner bearing rollers located at 1/4 of the total span ( $L$ ) from the outer support bearing rollers (see [Figure 1](#)).

Support rollers (1,5 mm to 5 mm  $\pm$  0,2 mm, diameter) shall be positioned with their centres apart such that  $L = 16,0$  mm to 40,0 mm. Rollers shall be made from hardened steel or other hard material having a hardness greater than 40 HRC (Rockwell C-scale) and have a smooth surface with a roughness less than 0,5  $\mu$ m. The two loading rollers of identical material and size to the support rollers shall be located at the quarter points yielding an inner span ( $L/2$  in [Figure 1](#)) of 8,0 mm to 20,0 mm. The loading arrangement shall ensure that equal forces are applied to the loading rollers and that torsional loading is minimized. It is recommended that the actual spacing between the roller centres ( $L$  for support and  $L/2$  for inner) be measured to within 0,1 mm. It is also recommended that the inner span be centred over the support span to within 0,1 mm.



NOTE Moment arm =  $L/4$

**Figure 1 — Schematic of the four-point-1/4-point fixture configuration**

### 7.3.2.2 Preparation of test specimens

#### 7.3.2.2.1 Test specimen dimensions and test parameters

##### 7.3.2.2.1.1 Dimensions:

Specimens for three-point and four-point flexure testing have a rectangular cross section and most preferably an edge chamfer as per the diagram in [Figure 2](#) and dimensions listed below. The edge chamfer should be ground or rounded lengthwise along the long axis of the specimen so that grinding damage and chipping is minimized. The edge chamfer can be ground prior to final sintering if kept within below values after final sintering.

Specimen dimensions:

Width  $w = (4 \pm 0,2)$  mm (dimension of the side at right angles to the direction of the applied load)

Thickness  $b = (2,1 \pm 1,1)$  mm (with 3,0 mm recommended; dimension of the side parallel to the direction of the applied load)

Chamfer  $c = (0,12 \pm 0,03)$  mm [with a maximum of 0,10 mm recommended for small thickness specimens ( $b < 2,0$  mm)]

##### 7.3.2.2.1.2 Test parameters:

Test span:

For four-point flexure;  $L$  in millimetres (centre-to-centre distance between outer support roller, see [Figure 1](#). In the four-point 1/4 configuration specified, the moment arm =  $L/4$ ).

For three-point flexure;  $l$  in millimetres (centre-to-centre distance between support rollers).

Breaking load:  $P$  in newtons

Specimen lengths shall be at least  $2b$  mm longer than the test span ( $L$  or  $l$ ), and the ratio of thickness to length ( $b/L$  or  $b/l$ ) shall be  $\leq 0,1$ .

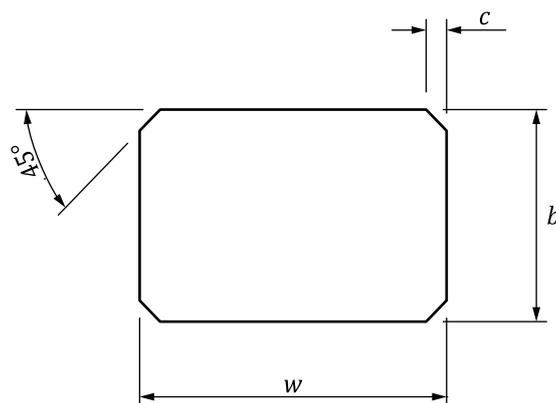


Figure 2 — Specification of indicated dimensions

### 7.3.2.2.2 Type I ceramics

Prepare at least 10 and preferably 30 specimens of dimensions as specified in 7.3.2.2.1. Use a mould appropriately sized to allow for dimensional changes resulting from sintering and finishing. Fire the specimens in accordance with the manufacturer's instructions modified as needed due to specimen dimensions. Grind each specimen so as to produce a rectangular test piece as specified in 7.3.2.2.1. Final grind on diamond-embedded media having a nominal grit size of  $30\ \mu\text{m}$  to  $40\ \mu\text{m}$  and final polish on media having  $15\ \mu\text{m}$  to  $20\ \mu\text{m}$  diamond grit. Grinding of all four long faces should be done lengthwise parallel to the specimen long axis wherever possible to minimize grinding damage that can alter the strength. Polishing does not always remove prior grinding damage unless the polishing removes  $20\ \mu\text{m}$  to  $30\ \mu\text{m}$  of the material. Ensure that opposing faces of the test pieces are flat and parallel within  $0,05\ \text{mm}$ . Where appropriate, testing of specimen "as fired" (without further grinding at the edge or on the surface) should be done so long as the shape and dimensions are within the limits specified. Thoroughly clean the test pieces ensuring that all traces of grinding debris are removed.

### 7.3.2.2.3 Type II ceramics

Prepare in accordance with the manufacturer's instructions at least 10 and preferably 30 specimens of dimensions as specified in 7.3.2.2.1. In the case of ceramic material produced for machining, prepare the specimens from ceramic blocks made by the manufacturer. Grind each specimen to produce test pieces using the protocol specified in 7.3.2.2.2. Where appropriate, testing of specimen "as fired" (without further grinding at the edge or on the surface) can be done as long as the shape and dimensions are within the limits specified.

### 7.3.2.3 Procedure

Measure the cross-sectional dimensions of each test piece to  $\pm 0,01\ \text{mm}$ . Then, place a test piece centrally on the bearers of the test machine so that the load is applied to a  $4\ \text{mm}$  wide face along a line perpendicular to the long axis of the test piece and determine to  $\pm 0,1\ \text{N}$  the load required to break the test piece. Use a crosshead speed of  $(1 \pm 0,5)\ \text{mm/min}$ . Repeat the procedure with the remaining test pieces.

### 7.3.2.4 Calculation of strength

#### 7.3.2.4.1 Three-point flexure

From Formula (1), calculate the flexural strength,  $\sigma$ , in megapascals and report the mean and standard deviation of the strength data. Means should equal or exceed the requirements listed in Table 1. In addition,

if at least 15 specimens have been tested, the Weibull characteristic strength and Weibull modulus should be reported as well, per [Annex B](#).

$$\sigma = \frac{3Pl}{2wb^2} \quad (1)$$

where

$P$  is the breaking load, in newtons;

$l$  is the test span (centre-to-centre distance between support rollers), in millimetres;

$w$  is the width of the specimen, i.e. the dimension of the side at right angles to the direction of the applied load, in millimetres;

$b$  is the thickness of the specimen, i.e. the dimension of the side parallel to the direction of the applied load, in millimetres.

#### 7.3.2.4.2 Four-point flexure

From [Formula \(2\)](#), calculate the flexural strength,  $\sigma$ , in megapascals and report the mean and standard deviation of the strength data. Means should equal or exceed the requirements listed in [Table 1](#). In addition, if at least 15 specimens have been tested, the Weibull characteristic strength and Weibull modulus should be reported as well, per [Annex B](#).

$$\sigma = \frac{3PL}{4wb^2} \quad (2)$$

where

$P$  is the load at failure, in newtons;

$L$  is the centre-to-centre distance between outer support rollers, in millimetres;

$w$  is the width of the specimen, i.e. the dimension of the side at right angles to the direction of the applied load, in millimetres;

$b$  is the thickness of the specimen, i.e. the dimension of the side parallel to the direction of the applied load, in millimetres.

NOTE [Formula \(3\)](#) can be used if the spans are such that the loading points are not exactly at  $L/4$ .

$$\sigma = \frac{3P(L_0 - L_i)}{2wb^2} \quad (3)$$

where

$L_0$  is the outer loading span;

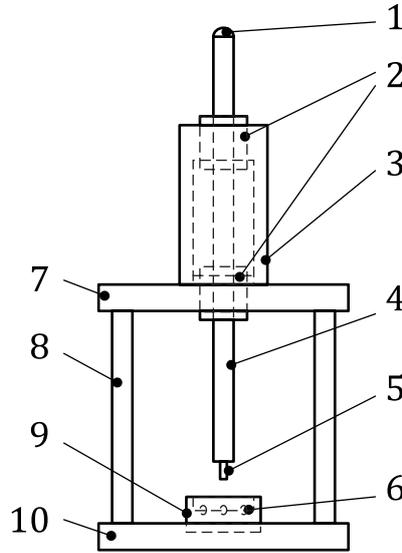
$L_i$  is the inner loading span.

### 7.3.3 Biaxial flexure test (piston-on-three-ball test)

#### 7.3.3.1 Apparatus

**7.3.3.1.1 Universal mechanical testing machine**, capable of a crosshead speed of  $(1 \pm 0,5)$  mm/min and an ability to measure applied loads of between 10 N and 2 500 N ( $\pm 1$  %).

**7.3.3.1.2 Biaxial flexural strength test fixture.** For the support of the test specimen, three hardened steel balls with a diameter of  $(4,5 \pm 2)$  mm positioned  $120^\circ$  apart on a support circle with a diameter of  $(11 \pm 1)$  mm shall be provided. The sample shall be placed concentrically on these supports and the load shall be applied with a flat punch with a diameter of  $(1,4 \pm 0,2)$  mm at the centre of the specimen (see [Figure 3](#)).



**Key**

- 1 12,5 mm steel ball
- 2 precision ball bushings
- 3 upper bushing holder
- 4 ram, hardened, precision ground rod
- 5 hardened, precision ground dowel pin (1,4 ± 0,2) mm diameter
- 6 three (4,5 ± 2) mm steel balls  $120^\circ$  apart on (11 ± 1) mm diameter circle
- 7 top plate
- 8 three separator posts
- 9 sample holder
- 10 bottom plate

**Figure 3 — Schematic of a piston-on-three-ball test fixture**

**7.3.3.2 Preparation of test specimens**

**7.3.3.2.1 Type I ceramics**

Prepare at least 10 and preferably 30 discs having a thickness of  $(1,2 \pm 0,2)$  mm and a diameter of  $(14 \pm 2)$  mm. Use a mould appropriately sized to allow for dimensional changes resulting from sintering and finishing. Final grind each specimen through diamond-embedded media having a nominal grit size of 30  $\mu$ m to 40  $\mu$ m and final polish on media having 15  $\mu$ m to 20  $\mu$ m diamond grit. Ensure that opposing faces of the test pieces are flat and parallel within 0,05 mm. Thoroughly clean the test pieces ensuring that all traces of grinding debris are removed. Where appropriate, testing of specimen “as fired” (without further grinding at the edge or on the surface) should be done so long as the shape and dimensions are within the limits specified.

**7.3.3.2.2 Type II ceramics**

Prepare in accordance with the manufacturer’s instructions at least 10 and preferably 30 discs having a diameter between  $(14 \pm 2)$  mm and an approximate thickness of  $(1,5 \pm 0,5)$  mm. In the case of ceramic material produced for machining, prepare the specimens from ceramic blocks made by the manufacturer. Grind each specimen so as to produce a test piece of thickness  $(1,2 \pm 0,2)$  mm and a diameter of  $(14 \pm 2)$  mm.

Grind and finish specimens using the protocol specified under [7.3.3.2.1](#). Where appropriate, testing of specimen “as fired” (without further grinding at the edge or on the surface) should be done so long as the shape and dimensions are within the limits specified.

### 7.3.3.3 Procedure

For the biaxial flexural strength test, a fixture as shown in [Figure 3](#) should be used. Measure the dimensions of each test piece and of all other relevant variables to  $\pm 0,01$  mm. Then, place a test piece concentrically on the supporting balls of the testing machine so that the load is applied at the centre of the test piece. Place a film of non-rigid material between the supporting balls and the specimen and another film between the loading piston and specimen to evenly distribute contact pressures.

EXAMPLE Polyethylene sheet with a thickness of 0,05 mm.

Determine to  $\pm 0,1$  N the load required to break the test piece. Use a crosshead speed of  $(1 \pm 0,5)$  mm/min. Repeat the procedure with the remaining test pieces.

### 7.3.3.4 Calculation of strength

From [Formula \(4\)](#), calculate the flexural strength,  $\sigma$ , in megapascals and report the mean and standard deviation of the strength data. Means shall equal or exceed the requirements listed in [Table 1](#). In addition, if at least 15 specimens have been tested, the Weibull characteristic strength and Weibull modulus should be reported as well, per [Annex B](#).

$$\sigma = -0,238 \ 7 P(X - Y) / b^2 \quad (4)$$

where

$\sigma$  is the maximum centre tensile stress, in megapascals;

$P$  is the total load causing fracture, in newtons;

$$X = (1 + \nu) \ln(r_2 / r_3)^2 + [(1 - \nu) / 2] (r_2 / r_3)^2$$

$$Y = (1 + \nu) \left[ 1 + \ln(r_1 / r_3)^2 \right] + (1 - \nu) (r_1 / r_3)^2$$

where

$\nu$  is Poisson's ratio (if the value for the ceramic concerned is not known, use Poisson's ratio = 0,25);

$r_1$  is the radius of support circle, in millimetres;

$r_2$  is the radius of loaded area, in millimetres;

$r_3$  is the radius of specimen, in millimetres;

$b$  is the specimen thickness at fracture origin, in millimetres.

## 7.4 Linear thermal expansion coefficient

### 7.4.1 Apparatus

**7.4.1.1 Equipment**, for making bar specimens from type I and type II ceramics.

**7.4.1.2 Dental ceramic oven**, for firing Type I ceramics and controlling thermal history for type I and type II ceramics.

### 7.4.1.3 Calibrated dilatometer.

### 7.4.2 Preparing of test specimens (type I and type II ceramics)

Prepare four test specimens in the form of rods or bars having a length between 5 mm and 50 mm with a cross-sectional area not exceeding 30 mm<sup>2</sup>. Fire two specimens once in vacuum and once at atmospheric pressure in air and the other two specimens three times in vacuum and once at atmospheric pressure in air. Multiple firing is not obligatory for materials where the linear thermal expansion coefficient is not influenced by multiple firing. Grind the ends of the test specimens so that they are flat, parallel, and perpendicular to the axis of the test specimens.

### 7.4.3 Dilatometric measurement

Place each specimen in the dilatometer's oven at room temperature and wait 15 min so that the sample is at the same temperature as the oven.

Set the sample's "preloading" to the value specified by the instrument manufacturer for measuring ceramics.

Perform an expansion measurement of the test specimen at 5 °C/min to 10 °C/min between either 25 °C or 50 °C and approximately 500 °C (or approximately 30 °C above the  $T_g$ ; lower or higher than 500 °C as required) sufficient to determine  $T_g$  graphically (as per [Figure 4](#)). For each test specimen, determine the linear expansion coefficient between either 25 °C or 50 °C and 500 °C (or  $T_g$ ) by referring to plotted curves or recorded values indicating the expansion in relation to temperature.

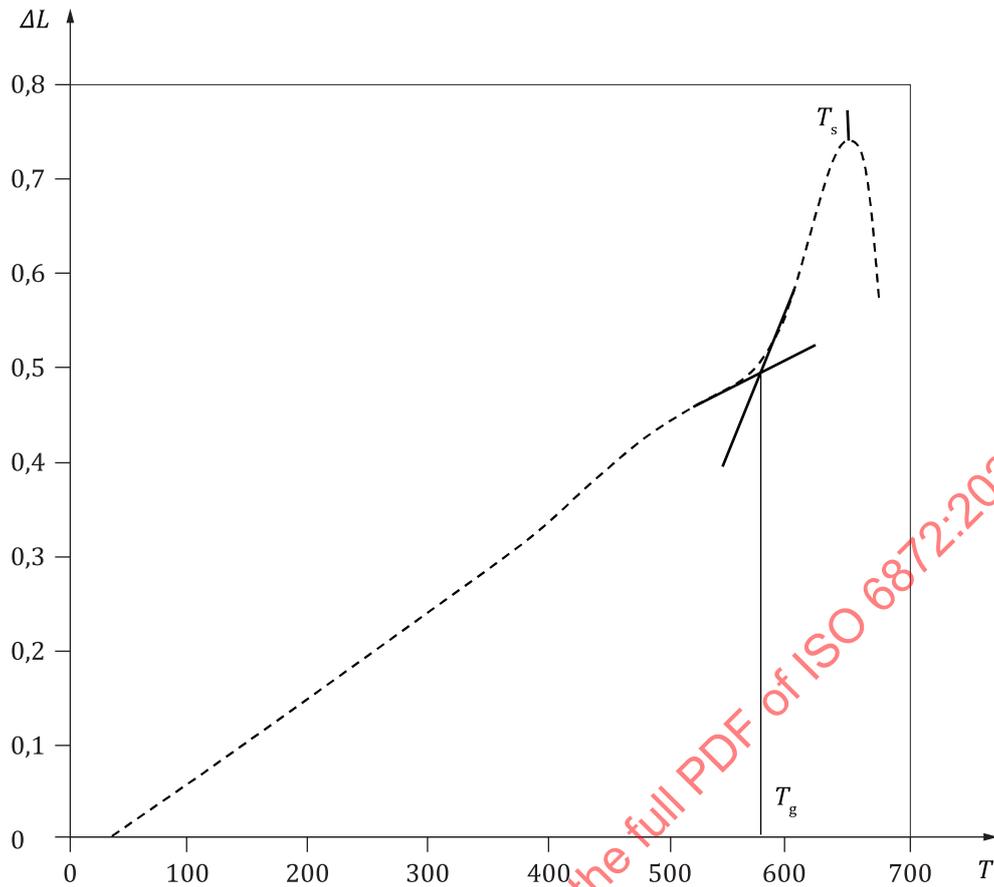
### 7.4.4 Assessment of results

Report the average value and standard deviation of the linear thermal expansion coefficient for the four specimens (fired twice and four times only in the case of Type I ceramics) between either 25 °C or 50 °C and 500 °C (or  $T_g$ ). Report the mean coefficient of thermal expansion rounded off to the nearest  $0,1 \times 10^{-6} \text{ K}^{-1}$ .

## 7.5 Glass transition temperature

### 7.5.1 Operating procedure

Graphically, determine the glass transition temperature ( $T_g$ ) for each specimen (where applicable) by referring to the expansion curves obtained in accordance with [7.4.3](#) (as illustrated in [Figure 4](#)).

**Key**

- $T$  temperature, expressed in °C  
 $\Delta L$  change in length of the specimen, expressed in  $\mu\text{m}$   
 $s$  dynamic softening point  
 $g$  glass transition point

**Figure 4 — Typical dilatometry curve demonstrating graphical method of determining glass transition temperature**

## 7.5.2 Assessment of results

Report the mean and standard deviation of the glass transition temperature measured in [7.5.1](#) in degrees Celsius (°C).

## 7.6 Chemical solubility

### 7.6.1 Reagent

**Acetic acid** (analytical grade), a volume fraction of 4 % solution in water of grade 3 as specified in ISO 3696.

### 7.6.2 Apparatus

**7.6.2.1 Balance**, accurate to 0,1 mg.

**7.6.2.2 Drying oven**, capable of being controlled at  $(150 \pm 5)$  °C.

### 7.6.3 Preparation of test specimens

#### 7.6.3.1 Type I ceramics

Prepare specimens using the powder collected as per [6.1](#). Fire these specimens according to the manufacturer's instructions modified as needed due to specimen dimensions. Prepared specimens shall provide at least 30 cm<sup>2</sup> of exposed surface area freely accessible to the test solution.

#### 7.6.3.2 Type II ceramics

Prepare specimens in accordance with the manufacturer's instructions providing at least 30 cm<sup>2</sup> of exposed surface area freely accessible to the test solution. If applicable, fire the specimens to achieve a medium glaze or give an appropriate surface finish using polishing procedures as specified by the manufacturer to simulate the surface finish used for clinical indications.

### 7.6.4 Procedure

Wash the specimens with water of grade 3 as per ISO 3696, dry them at (150 ± 5) °C for 4 h, and weigh them to the nearest 0,1 mg. Determine the total surface area to the nearest 0,5 cm<sup>2</sup>. Use a 250 ml or several 100 ml Pyrex glass or plastic bottles with 100 ml acetic acid (analytical grade) volume fraction of 4 % solution in water of grade 3 as specified in ISO 3696. Preheat to (80 ± 3) °C and place specimens into the bottle. Close the bottle and place it in an oven at (80 ± 3) °C for 16 h. Wash the specimens with water of grade 3 as per ISO 3696, dry them at (150 ± 5) °C to constant mass, and reweigh the specimens.

### 7.6.5 Calculation and assessment of results

Calculate the mass loss in micrograms per square centimetre (µg/cm<sup>2</sup>) of specimen surface area using [Formula \(5\)](#). Check for compliance with the requirements stated in [Table 1](#).

$$\frac{W_B - W_A}{SA} \quad (5)$$

where

$W_B$  is the mass of the specimens before the chemical solubility challenge, micrograms (µg);

$W_A$  is the mass of the specimens after 16 h of challenge and after drying, micrograms (µg);

$SA$  is the total surface area of specimens, centimetres squared (cm<sup>2</sup>).

## 8 Information and instructions

### 8.1 Information

#### 8.1.1 General

At least the information specified in [8.1.2](#) and [8.1.3](#) supplied by the manufacturer shall be included on the containers or in accompanying literature.

#### 8.1.2 Type I ceramics

- a) A time-temperature cycle for the firing schedule (including the final temperature, the time it should be held, and the rate of heating and cooling) and, in the case of a vacuum-fired ceramic, the vacuum level and timing of application.
- b) The glazing temperature.

### 8.1.3 Type II ceramics

Detailed information regarding the handling and treatment of the material. In the case of ceramic material produced for machining, information on recommended type of grinding and polishing equipment.

For partially sintered ceramics and glass-ceramics that require further heat treatment, this shall be specified by heating rates and holding times with temperatures and times assigned permissible ranges appropriate to furnaces calibrated according to ISO 13078, ISO 13078-2 and ISO 13078-3, or an equivalent standard.

## 8.2 Instructions for use

8.2.1 Instructions for the processing shall be made available to the purchaser by the distributor.

8.2.2 The following information shall accompany the instruction materials:

- a) the trade name or the brand name of the ceramic;
- b) name and address of the manufacturer and/or his authorized representative;
- c) the type and class of dental ceramic;
- d) the coefficient of thermal expansion between either 25 °C or 50 °C and 500 °C (or  $T_g$ ) and the  $T_g$  (where applicable);
- e) the shade as identified in the manufacturer's shade guide (if applicable);
- f) any special storage conditions;
- g) a general warning regarding the potential health hazards (if any), for example, associated with inhalation of ceramic dust.
- h) effective date for this edition of the instructions for use.

## 9 Packaging, marking, and labelling

### 9.1 Packaging

Dental ceramic powdered and non-powdered products shall be supplied in sealed containers that will not contaminate nor permit contamination of the contents.

### 9.2 Marking and labelling

9.2.1 The following information shall be clearly marked on each container or on a label securely attached to the container:

- a) a lot number or combination of letters and numbers which refers to the manufacturer's records for the particular lot or batch of ceramic;
- b) the manufacturer's name and/or his authorized representative (or the distributor's name if privately labelled);
- c) the shade as identified in the manufacturer's shade guide (if applicable);
- d) product trade name;
- e) the minimum net mass, in grams, of the contained ceramic powder, the net volume in millilitres or the number of dose units such as preformed ceramic tablets, or ceramic blocks;
- f) a general warning regarding the potential health hazards (if any), for example, associated with inhalation of ceramic dust.

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**9.2.2** The following information shall be clearly marked on ceramic blocks for CAD/CAM:

- a) a lot number or combination of letters and numbers which refer to the manufacturer's records for the particular lot or batch of ceramic;
- b) product trade name;
- c) for partially sintered ceramic materials, the shrinkage factor by which the dimensions of the partially sintered material is to be divided shall be quoted as a factor to three decimal places.

**9.2.3** The following information shall be clearly marked on pressable ingots: the shade as identified in the manufacturer's shade guide (if applicable).

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## Annex A (informative)

### Fracture toughness

#### A.1 Fracture toughness

##### A.1.1 General

Fracture toughness is an important property of dental ceramics since it is often “inherent” to the material and can be used to predict other properties such as strength (which is sensitive to specimen size and flaw population). Therefore, fracture toughness values allow meaningful comparisons to be made among ceramics used for structural purposes. [Table A.1](#) lists the minimum fracture toughness value that should be demonstrated by dental ceramics for each clinical indication. Numerous methods are in use that provide good estimates of fracture toughness and vary in their degree of difficulty to execute.

This document recommends the Single-edge V-Notch Beam (SEVNB) method according to ISO 23146:2012 or alternatively, by a simplified version as described in [A.1.2](#). The SEVNB-method has undergone international evaluation for standardization and was found to be user-friendly, easy, reliable, and accurate (see References [\[1\]](#) and [\[11\]](#)). According to ISO 23146:2012, the SEVNB method states that it should not be used to measure the fracture toughness of fine grained materials with grain sizes of less than 1 µm since the interlaboratory test exercise<sup>[11]</sup> showed that most participants were not able to obtain sharp notch-tip radius with the razor sharpening method. The majority of fracture toughness data overestimated the true fracture toughness due to notch bluntness<sup>[11]</sup> Also, ISO 23146:2012 specifically states in [Clause 1](#) that the method should not be used for yttria-tetragonal polycrystal zirconia because of the difficulties in forming sharp notch-tip radius.

Alternatively, fracture toughness can be evaluated by the following methods according to: single-edge precracked beam (ISO 15732), surface crack in flexure (ISO 18756), or chevron-notched beam (ISO 24370). The SEP, CNB, and SCF methods can be used for yttria-tetragonal polycrystal zirconia. Each of these methods has pros and cons and some experience is needed to readily obtain precise and accurate results.

Fracture toughness should not be estimated by methods relying on indentation crack lengths (e.g. where toughness is estimated based on the surface crack lengths associated with the corners of Vickers indentations).

##### A.1.2 Single-edge v-notched beam method-apparatus

**A.1.2.1 Equipment**, for producing parallel-sided beams by firing or machining followed by grinding and polishing.

**A.1.2.2 Diamond saw**, for cutting a starter notch in one surface of the beams.

**A.1.2.3 Single-edged razor blade**, and diamond polishing paste to refine the starter notch.

**A.1.2.4 Three-point or four-point test fixture**, as described in [7.3.2](#).

### A.1.3 Preparation of test specimens

#### A.1.3.1 Five beam specimens

Five beam specimens are used to measure fracture toughness according to this method. Specimens have a rectangular cross section as per the diagram and dimensions listed below and in [Figure A.2](#). The edge chamfer specified for strength test specimens should not be used.

Specimen dimensions:

Thickness  $w = (4,0 \pm 0,2)$  mm

Width  $b = (3,0 \pm 0,2)$  mm

The difference between specimen length and support span length should be at least twice the specimen thickness (e.g. 8 mm when  $w = 4$  mm). This specimen is tested at a  $90^\circ$  angle to strength test specimens such that the specimen thickness exceeds the specimen width.

#### A.1.3.2 Starter notch formation and refinement

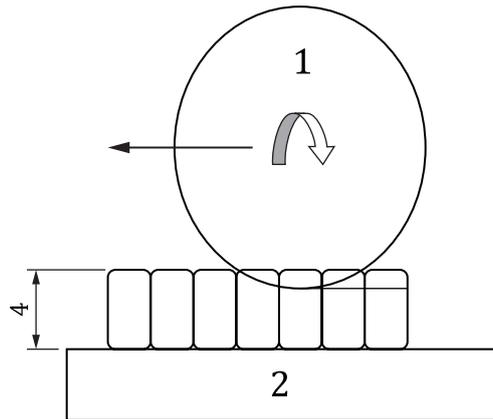
Mount five specimens and two dummy specimens (used to protect test specimens during saw cutting and polishing of the starter notch) as close together as possible onto a flat holder that allows uniform cutting in your diamond saw as shown in [Figure A.1](#). Face one 3 mm wide side up to receive the starter notch (this side will be in tension during the fracture test). Draw a pencil line along the measured centre of the beam lengths for orientation of the saw cut.



NOTE The vertical line in the middle (arrow) indicates the pencil line. The top and bottom specimens are dummy specimens.

**Figure A.1 — Starter notch formation**

Mount the holder in your diamond saw. Use a blade having thickness as close to or only slightly larger than the thickness of the razor blade used in order that the blade is well-guided during polishing of the notch (described below). Saw a starter notch along the length of the pencil line to a uniform depth over all specimens of approximately 0,5 mm. Clean the specimens, especially the notch, following the saw cut to remove debris prior to polishing the notch.

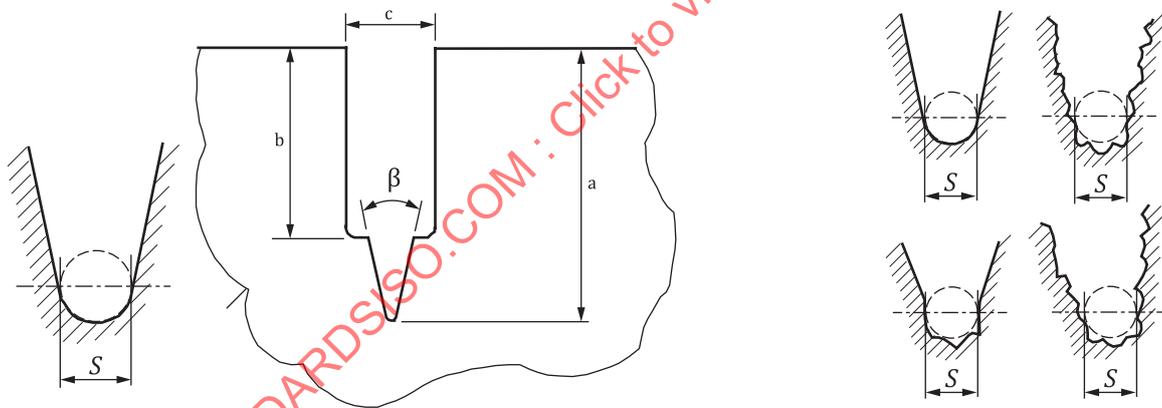


**Key**

- 1 diamond grinding wheel
- 2 specimen holder

**Figure A.2 — Formation with diamond wheel**

Following cleaning, fill the notch with diamond polishing paste having a maximum grain size between 3  $\mu\text{m}$  and 6  $\mu\text{m}$ . Put razor blade into starter notch and apply light force (5 N to 10 N) and polish using a gentle back and forth motion as straight as possible. Using a light microscope, examine both ends of the V-notch occasionally for evenness of depth. The final V-notch depth shall be uniform and lie between 0,8 mm and 1,2 mm. The final V-notch depth should be deeper than the starting notch depth such that  $a - c > b$  as shown below. Remove the specimens from the holder and clean them with acetone in an ultrasonic bath. Dry the specimens well, for example, by heating to 110 °C for 1 h.



**a) Notch width and angle measurement**

**b) Interpretation of notch root shape from ISO 23146**

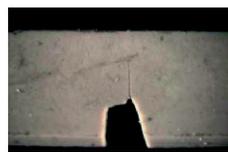
**Key**

- $\beta$  approximately 30 degrees ( $^\circ$ ) or as small as possible
- S V-notch width
- a 0,8 mm up to 1,2 mm.
- b Approximately 0,5 mm.
- c Width of razor blade,  $a - b > c$ .

**Figure A.3 — Schematic geometry of V-notches**



a) Acceptable notch



b) Notch improperly centred



c) Poor notch development



d) Notch insufficiently sharp

**Figure A.4 — Examples of acceptable and unacceptable notch geometries**

Control the V-notch geometry with the help of the photograph. Report any deviation from the geometry shown in [Figure A.3](#) and [Figure A.4](#) a). The notch geometry shown in [Figure A.4](#) b-d) is unacceptable.

Photograph the V-notch tip on the same two test pieces with a magnification approximately 300x. Measure the V-notch angle and width according to [Figure A.3](#). Report the V-notch angle  $\beta$  and width  $S$ .

The notch width,  $S$ , should be of the same order as, or smaller than, twice the average grain size of the test material. Notches of width greater than 20  $\mu\text{m}$  are not acceptable in any test material irrespective of grain size.

NOTE 1 The average grain size can be determined by a linear intercept method such as that described in References [\[9\]](#) and [\[13\]](#).

NOTE 2 It is helpful to determine the acceptability of the notch width on the outermost test pieces before removing them from the mounting plate. This allows the notch honing process to be continued if the notch width is too large.

### A.1.3.3 Mechanical testing

Specimens will be tested for fracture toughness in four-point flexure (preferably) or in three-point flexure using a fixture as described in [7.3.2.1.2](#).

Place the 3 mm width face with the V-notch down. Load the specimens with a crosshead speed of 0,5 mm/min at room temperature in air. Record the fracture load to three significant figures. Record the width ( $b$ ) and thickness ( $w$ ) of each specimen from measurements made using a micrometer capable of measuring to three decimal places. The depths of the V-notches are measured using a calibrated microscope with a magnification  $\geq 50\times$ . Read the depth,  $a_1$ ,  $a_2$ , and  $a_3$ , to three significant figures. Check to ensure that fracture started at the bottom of the V-notch over its entire length (if this is not the case, the test is invalid). On the fracture surfaces, examine the notch root for any evidence of stable crack extension prior to fracture. If stable crack extension occurred and can be measured, include the stable extension in the calculations below. Inspect the load-displacement or load-time record from the fracture test to check whether any nonlinearity occurred just prior to fracture. If nonlinearity is detected, it is a sign of possible slow crack growth extension of the notch precrack.

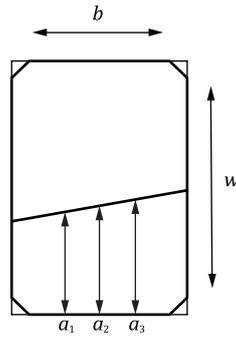


Figure A.5 — Depth of V-notch measurement

### A.1.3.4 Calculations

**A.1.3.4.1 Average ( $a$ ) and relative ( $\alpha$ ) V-notch depths** are calculated for each specimen from [Formula \(A.1\)](#) below. The relative V-notch depth,  $\alpha$ , should be between 0,2 and 0,3 and the relationship involving the variation in notch depths shall be satisfied. The proper locations for measurement are shown in [Figure A.5](#).

$$a = (a_1 + a_2 + a_3) / 3$$

$$(a_{\max} - a_{\min}) / a \leq 0,1 \text{ (this relationship is assumed to be satisfied)}$$
(A.1)

$$\alpha = a / w$$

where

$a$  is the average notch depth (m);

$a_{\max}$  is the maximum among  $a_1$ ,  $a_2$ , and  $a_3$  (m);

$a_{\min}$  is the minimum among  $a_1$ ,  $a_2$ , and  $a_3$  (m);

$\alpha$  is the relative V-notch depth.

**A.1.3.4.2 Fracture toughness,  $K_{Ic}$**  is calculated for each specimen using [Formulas \(A.1 to A.9\)](#) as follows:

$$K_{Ic} = \frac{F}{b\sqrt{w}} \cdot \frac{S_1 - S_2}{w} \cdot \frac{3\sqrt{\alpha}}{2(1-\alpha)^{1,5}} Y$$
(A.2)

NOTE 1  $S_2 = 0$  in three-point testing.

For four-point flexure, use References [\[1\]](#), [\[7\]](#), and [\[13\]](#).

$$Y = 1,988 - 7 - 1,326\alpha - \frac{(3,49 - 0,68\alpha + 1,35\alpha^2)\alpha(1-\alpha)}{(1+\alpha)^2}$$
(A.3)

For three-point flexure, the formula depends upon the ratio of the support span,  $S_1$ , to the beam thickness.

For  $S_1/w = 10$ , use References [\[1\]](#), [\[7\]](#), and [\[13\]](#).

$$Y = 1,947 - 2 - 5,024 - 7\alpha + 11,895 - 4\alpha^2 - 18,063 - 5\alpha^3 + 14,598 - 6\alpha^4 - 4,689 - 6\alpha^5$$
(A.4)

For  $S_1/w = 7,5$  (e.g.  $S_1 = 30$  mm,  $w = 4$ ), use References [\[1\]](#) and [\[7\]](#)

$$Y = 1,964 - 2,837\alpha + 13,771 - 4\alpha^2 - 23,250\alpha^3 + 24,129\alpha^4$$
(A.5)

NOTE 2 There is no  $\alpha^5$  term in this case.

For  $S_1/w = 8$ , use Reference [13].

$$Y = 1,938\ 1 - 5,094\ 7\ \alpha + 12,386\ 1\ \alpha^2 - 19,214\ 2\ \alpha^3 + 15,774\ 7\ \alpha^4 - 5,127\ 0\ \alpha^5 \quad (\text{A.6})$$

For  $S_1/w = 7$ , use Reference [13].

$$Y = 1,932\ 2 - 5,100\ 7\ \alpha + 12,362\ 1\ \alpha^2 - 19,551\ 0\ \alpha^3 + 15,984\ 1\ \alpha^4 - 5,173\ 6\ \alpha^5 \quad (\text{A.7})$$

For  $S_1/w = 6$ , use Reference [13].

$$Y = 1,923\ 0 - 5,138\ 9\ \alpha + 12,619\ 4\ \alpha^2 - 19,551\ 0\ \alpha^3 + 15,984\ 1\ \alpha^4 - 5,173\ 6\ \alpha^5 \quad (\text{A.8})$$

For  $S_1/w = 5$ , use Reference [13].

$$Y = 1,910\ 9 - 5,155\ 2\ \alpha + 12,688\ 0\ \alpha^2 - 19,573\ 6\ \alpha^3 + 15,937\ 7\ \alpha^4 - 5,145\ 4\ \alpha^5 \quad (\text{A.9})$$

where

$K_{Ic}$  is the fracture toughness (MPa $\sqrt{\text{m}}$ );

$F$  is the fracture load (MN);

$b$  is the specimen width (m);

$w$  is the specimen thickness (m);

$S_1$  is the support span, three-point, and four-point (m);

$S_2$  is the inner, four-point (m);

$Y$  is the stress intensity shape factor.

NOTE 3 The three-point equations are consistent with those in References [1], [7], and [13]. Several were originally limited to  $0,35 < \alpha < 0,6$ , but their use has been expanded to include  $0,2 < \alpha < 0,6$  with only a slight increase in uncertainty of measurement.

Perform all calculations to three significant figures. Calculate the mean,  $K_{Ic}$ , value and standard deviation and report the result rounded to two decimal places.

#### A.1.3.4.3 Control calculation values.

For four-point flexure,  $K_{Ic} = 7,42$  MPa $\sqrt{\text{m}}$  when:

$$F = 100 \cdot 10^{-6} \text{ MN}; b = 3 \cdot 10^{-3} \text{ m}, w = 4 \cdot 10^{-3} \text{ m}; a = 2 \cdot 10^{-3} \text{ m}, S_1 = 40 \cdot 10^{-3} \text{ m}, \text{ and } S_2 = 20 \cdot 10^{-3} \text{ m}.$$

For three-point flexure,  $K_{Ic} = 7,07$  MPa $\sqrt{\text{m}}$  when:

$$F = 100 \cdot 10^{-6} \text{ MN}, b = 3 \cdot 10^{-3} \text{ m}, w = 4 \cdot 10^{-3} \text{ m}, a = 2 \cdot 10^{-3} \text{ m}, \text{ and } S_1 = 20 \cdot 10^{-3} \text{ m}.$$

NOTE All calculations above use MN and m.

**Table A.1 — Classification of ceramics for fixed prostheses by intended clinical use with recommended fracture toughness values**

Class	Recommended clinical indications	Fracture toughness MPa√m (minimum)
1	a) Monolithic ceramic for single-unit anterior prostheses, veneers, inlays, or onlays adhesively cemented. b) Ceramic for coverage of a metal framework or a ceramic substructure.	0,7
2	a) Monolithic ceramic for single-unit anterior or posterior prostheses adhesively cemented. b) Fully covered substructure ceramic for single-unit anterior or posterior prostheses adhesively cemented.	1,0
3	a) Monolithic-ceramic for single-unit anterior or posterior prostheses and for three-unit prostheses not involving molar restoration, adhesively, or non-adhesively cemented. b) Fully covered substructure for single-unit anterior or posterior prostheses and for three-unit prostheses not involving molar restoration, adhesively, or non-adhesively cemented.	2,0
4	a) Monolithic-ceramic for three-unit prostheses involving molar restoration. b) Fully covered substructure for three-unit prostheses involving molar restoration.	3,5
5	Monolithic-ceramic for prostheses involving four or more units or fully covered substructure for prostheses involving four or more units.	4,0

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