INTERNATIONAL STANDARD

ISO 13356

Third edition
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Implants for surgery — Ceramic materials based on yttria-stabilized tetragonal zirconia (Y-TZP)

Implants chirurgicaux — Produits céramiques à base de zircone tétragonal stabilisée à l'yttrium (Y-TZP)

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Foreword

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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 documents 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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary Information

The committee responsible for this document is ISO/TC 150, *Implants for surgery*, Subcommittee SC 1, *Materials*.

This third edition cancels and replaces the second edition (ISO 13356:2008), which has been technically revised.

Introduction

No known surgical implant material has ever been found to cause absolutely no adverse reactions in the human body. However, long-term clinical experience regarding the use of the material referred to in this International Standard has shown that an acceptable level of biological response can be expected if the material will be used in appropriate applications.

Implants for surgery — Ceramic materials based on yttria-stabilized tetragonal zirconia (Y-TZP)

1 Scope

This International Standard specifies the requirements and corresponding test methods for a biocompatible and biostable ceramic bone-substitute material based on yttria-stabilized tetragonal zirconia (yttria tetragonal zirconia polycrystal, Y-TZP) for use as a material for surgical implants.

2 Normative references

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

ISO 3310-1, *Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth*

ISO 3611, *Geometrical product specifications (GPS) — Dimensional measuring equipment: Micrometers for external measurements — Design and metrological characteristics*

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

ISO 13383-1, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Microstructural characterization — Part 1: Determination of grain size and size distribution*

ISO 14704, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Test method for flexural strength of monolithic ceramics at room temperature*

ISO 14705, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Test method for hardness of monolithic ceramics at room temperature*

ISO 17561, *Fine ceramics (advanced ceramics, advanced technical ceramics) - Test method for elastic moduli of monolithic ceramics at room temperature by sonic resonance*

ISO 18754, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Determination of density and apparent porosity*

ISO 20501, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Weibull statistics for strength data*

ISO 22214, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Test method for cyclic bending fatigue of monolithic ceramics at room temperature*

EN 623-2, *Advanced technical ceramics — Monolithic ceramics — General and textural properties — Part 2: Determination of density and porosity*

EN 843-2, *Advanced technical ceramics — Mechanical properties of monolithic ceramics at room temperature — Part 2: Determination of Young's modulus, shear modulus and Poisson's ratio*

EN 843-4, *Advanced technical ceramics — Mechanical properties of monolithic ceramics at room temperature — Part 4: Vickers, Knoop and Rockwell superficial hardness*

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

ASTM C1161, *Standard Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature*

ASTM C1198, *Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Sonic Resonance*

ASTM C1239, *Standard Practice for Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters for Advanced Ceramics*

ASTM C1259, *Standard Test method for Dynamic Young's Modulus. Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Impulse Excitation of Vibration*

ASTM C1327, *Standard Test Method for Vickers Indentation Hardness of Advanced Ceramics*

ASTM C1331, *Standard Test Method for Measuring Ultrasonic Velocity in Advanced Ceramics with Broadband Pulse-Echo Cross-Correlation Method*

ASTM E112, *Standard Test Method for Determining Average Grain Size*

3 Physical and chemical properties

The physical and chemical properties, when tested as specified in Clause 4, shall comply with the values specified in Table 1.

3.1 Test category

3.1.1 General

The required tests are divided into two categories.

3.1.2 Category 1

The following test shall be performed for periodical production control:

a) bulk density;

b) chemical composition;

c) microstructure;

d) strength (including Weibull modulus);

e) accelerated aging (monoclinic fraction).

3.1.3 Category 2

The manufacturer shall define the general materials specification. In addition to all tests in 3.1.2, the following tests shall be performed to demonstrate compliance with the material specification:

a) hardness;

b) Young's modulus;

c) fatigue strength;

d) accelerated aging (strength);

e) quantity of monoclinic phase;

f) radioactivity.

Table 1 — Limits for material properties

Property	Unit	Test category	Requirement	Reference	Subclause
Bulk density	g/cm^3	1	≥ 6,00	ISO 18754 EN 623–2	4.2
Chemical composition					4.3
ZrO_2+HfO_2+Y_2O_3[a]	% mass fraction	1	≥ 99,0		
Y_2O_3			> 4,5 to ≤ 6,0		
HfO_2			≤ 5		
Al_2O_3			≤ 0,5		
Other oxides			≤ 0,5		
Microstructure					4.4
Grain size	µm	1	Intercept distance ≤ 0,4 Standard deviation < 0,2	ISO 13383-1 ASTM E112	
Amount of monoclinic phase	% molar fraction	2	≤ 20	See 4.4.3	
Strength: alternative of 1) or 2)					
1a) Biaxial flexure[a]	MPa	1	≥ 500	ASTM C1499	4.5
1b) Weibull modulus		1	≥ 8	ISO 20501 EN 843–5 ASTM C1239	4.7
2a) 4-point bending[a]		1	≥ 800	ISO 14704 EN 843–1 ASTM C1161	4.6
2b) Weibull modulus		1	≥ 8	ISO 20501 EN 843–5 ASTM C 1239	4.7
Young's modulus	GPa	2	≥ 200	ISO 17561 EN 843–2 ASTM C1198 ASTM C1259 ASTM C1331	4.8
Hardness	GPa	2	≥ 11,8	ISO 14705 EN 843–4 ASTM C1327	4.9
Cyclic fatigue limit stress at 10^6 cycles	MPa	2	≥ 320	ISO 22214	4.10
Radioactivity[b]	Bq/kg	2	≤ 200	—	4.11
Accelerated aging					4.12

NOTE The number of fractional digits given for each limit value in this table indicates the appropriate number of fractional digits which should be given for the respective measured values.

a Measured on a minimum of 10 test specimens.

b The radioactivity, defined as the sum of the mass activity of U^{238}, Ra^{226}, Th^{232}, and determined by gamma spectroscopy on the ready-to-use powder should be equal or less than 200 Bq/kg. This value will be reviewed at the next revision of this International Standard and will be based upon the radioactivity data from implant ceramic manufacturers. All naturally occurring gamma emitters are to be analysed.

Table 1 *(continued)*

Property	Unit	Test category	Requirement	Reference	Subclause
Maximum amount of monoclinic phase after accelerated aging	% molar fraction	1	≤ 25	See 4.4.3	
Residual biaxial flexure strength after accelerated aging	MPa	2	≥ 500, and decrease not more than 20 %	See 4.5	
Residual 4-point bending strength after accelerated aging		2	≥ 800, and decrease not more than 20 %	See 4.6	

NOTE The number of fractional digits given for each limit value in this table indicates the appropriate number of fractional digits which should be given for the respective measured values.

a Measured on a minimum of 10 test specimens.

b The radioactivity, defined as the sum of the mass activity of U^{238}, Ra^{226}, Th^{232}, and determined by gamma spectroscopy on the ready-to-use powder should be equal or less than 200 Bq/kg. This value will be reviewed at the next revision of this International Standard and will be based upon the radioactivity data from implant ceramic manufacturers. All naturally occurring gamma emitters are to be analysed.

4 Test methods

4.1 General

All test specimens shall be prepared using the same production methods as regular implant components, including, but not limited to: the precursor powder; pressing technique; pressure; and firing conditions, unless justified by the manufacturer.

Where the requirements for the test report are not explicitly specified in this standard, the test report for a given property shall be written according to the referenced standard described in the subclause of this property and shall include a reference to this International Standard, i.e. ISO 13356:2015.

4.2 Bulk density

The bulk density shall be determined and reported in accordance with ISO 18754 or EN 623-2.

4.3 Chemical composition

The chemical compositions shall be determined by ICP-OES (Inductively Coupled Plasma – Optical Emission Spectrometry), X-ray fluorescence,[1] or atomic absorption spectrum analysis methods.

4.4 Microstructure

4.4.1 Principle

To describe the microstructure, the average grain size is determined by measuring the linear intercept size in accordance with ISO 13383-1 or ASTM E112.

Five test specimens shall be used for the determination of microstructure.

NOTE The linear intercept method results in a nominal average grain size for the selected position of micrograph, not the distribution of the size of individual grains.

For selection, preparation, and evaluation of the specimens, the following guidelines shall be followed:

a) the use of final device components as specimens for microstructure evaluation is recommended;

b) the wall thickness of the specimens shall represent the maximum and minimum of the manufacturer's device components;

c) Four micrographs on each surface shall be taken; the positions of which shall include regions in the bulk as well as at the edges of the specimen;

d) the specimen selection shall reflect the possibility of temperature deviation in the furnace;

e) the requirement for mean linear intercept grain size given in Table 1 shall be met at each selected position of the micrographs;

f) the standard deviation of the mean linear intercept grain size shall be determined from the data of all selected micrographs; the standard deviation shall meet the requirement given in Table 1.

The determination of mean linear intercept grain size shall be organized such that consistency of regular production can be assessed to a sufficient statistical relevance. The manufacturer shall justify the procedure implemented for grain size determination for its specific manufacturing process. It is recommended that the manufacturer analyse the reliability, repeatability, and maintenance of the manufacturing process with respect to microstructure (e.g. validation) and utilize this information to implement the regular routine production control. If this detailed analysis is successfully completed, regular control of the microstructure can be controlled with a reduced number of specimens and micrographs.

For improved contrast and grain boundary detection, it is recommended to use a scanning electron microscope (SEM) at a high acceleration voltage in conjunction with secondary electron detection capabilities.

4.4.2 Test report

The test report shall be prepared in accordance with ISO 13383-1 or ASTM E112 whichever is applicable.

The test report shall contain at least the following information:

a) identity of the ceramic material, details of batch number or other codes sufficient to identify the test specimens uniquely;

b) method of preparation of the test specimens, including details of the grinding and polishing procedure employed to prepare the test surfaces, as well as the etching procedure;

c) mean linear intercept size and its standard deviation shall be expressed in micrometres;

d) at least one micrograph from the specimen taken to show the microstructure after the thermal etch; the sample region from which the micrograph was taken does not have to be identified;

e) a reference to this International Standard, i.e. ISO 13356.

4.4.3 Amount of monoclinic phase

The X-ray measurement shall be conducted on the specimen prepared as described in 4.5.3 and the surface to be tested shall be in a polished state.

The amount of monoclinic phase, α, shall be determined using X-ray diffraction methods according to Formula (1):

$$\alpha = \frac{M(\bar{1}11)+M(111)}{M(\bar{1}11)+T(111)+M(111)} \tag{1}$$

where

$M(\bar{1}11)$ is the peak height of monoclinic phase at around 2θ=28,2°;

$M(111)$ is the peak height of monoclinic phase at around 2θ = 31,3°;

$T(111)$ is the peak height of tetragonal phase at around 2θ = 30,2°.

NOTE The method is also described in Reference [4].

4.5 Biaxial flexural strength

4.5.1 Principle

A disc of the test material is placed between two coaxial rings of unequal diameters and a compressive force is applied until the disc fractures. The force applied at fracture of the test disc and the location of the fracture are recorded and the fracture stress is calculated. This test method is standardized in ASTM C 1499.

4.5.2 Apparatus

4.5.2.1 Mechanical testing machine, suitable for applying a compressive load of at least 5 kN at a nominal loading rate of (500 ± 100) N/s and equipped to record the peak force applied to an accuracy of better than 1 % shall be used.

Calibration of the force-measuring device shall be performed in accordance with ISO 7500-1.

4.5.2.2 Testing jig, comprising unequal diameter loading rings and having a geometry as shown in Figure 1 shall be used.

The jig shall have a support ring diameter of (30,0 ± 0,1) mm at the diameter of contact with the test specimen, and a loading ring mean diameter of (12,0 ± 0,1) mm at the diameter of contact with the test specimen. The radius of curvature of the test specimen contact surface of the rings shall be (2,0 ± 0,2) mm. The jig shall have a means of centering the loading, support rings and test specimen on a common axis to within ±0,2 mm. The rings shall be made of hardened steel (>HV 500 or >HRC 40) in order to minimize damage or roughness caused by fracture of the test specimens. In order to accommodate slight departures from surface flatness of the test specimens, a (0,6 ± 0,1) mm thick rubber plate with a Shore hardness of 60 ± 5 shall be placed between the support ring and the test specimen on both surfaces.

4.5.2.3 Micrometer, in accordance with ISO 3611, capable of measuring to an accuracy of ±0,01 mm shall be used.

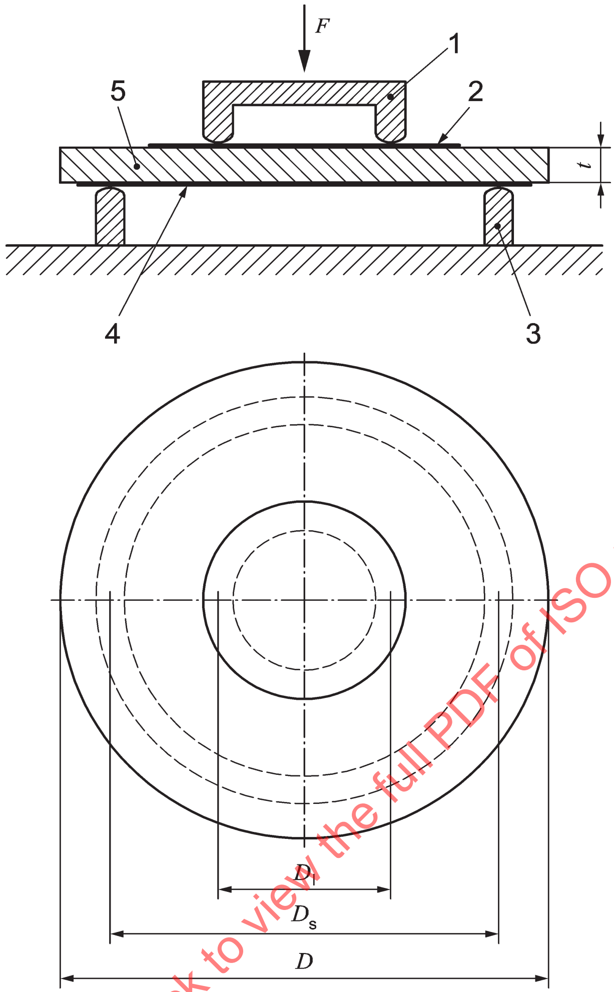
4.5.3 Preparation of test specimens

Prepare billets or discs of the zirconia ceramic using the same methods as the production of final components for surgery, using the same precursor powder, pressing technique, pressure, and firing conditions.

Test specimens (see Figure 1) shall be circular plates of diameter D = (36,0 ± 1,0) mm, thickness t = (2,0 ± 0,1) mm and shall be flat on the test face to less than 0,3 mm.

The surface finish of the specimen shall be specified. For an as-fired surface, specify the green processing methods.

At least 10 test specimens shall be prepared for determination of mean strength.



Key

1	loading ring	D_l	loading ring mean (contact) diameter
3	support ring	D_s	support ring mean (contact) diameter
2	paper disc	D	test specimen diameter
4	rubber sheet	F	force applied at fractures
5	specimen	t	test specimen thickness

Figure 1 — Schematic diagram of the biaxial flexure testing device employing concentric loading and support rings

4.5.4 Procedure

a) Measure the diameter of the test specimen to an accuracy of 0,1 mm and the thickness to an accuracy of 0,01 mm, each in at least three random positions. Calculate the mean diameter and mean thickness.

b) Place the rubber sheet on the support ring of the test jig. Place the test specimen on the rubber sheet, with the surface to be tested in contact with the rubber, and center it. Place a paper disc on the top of the test specimen; place the loading ring on the paper and center it relative to the test specimen and support ring.

c) Apply a steadily increasing compressive force, *F*, to the jig at a loading rate of (500 ± 100) N/s until the test specimen fractures. Record the load at fracture and the position of fracture.

d) Inspect the fragments for evidence of the failure origin. If the failure origin is identified as being more than 0,5 mm outside the contact circle between the inner loading ring and the specimen, record this position in the test report [see 4.5.6 c)]. For the purpose of calculation of the fracture stress, assume failure within the inner loading ring. Do not discard the result in calculating the mean strength of the test batch.

e) Repeat the procedure for each test specimen in the batch.

4.5.5 Calculation of results

For each test specimen, calculate the nominal fracture stress, σ, in MPa, according to Formula (2):

$$\sigma = \frac{3F}{2\pi \cdot t_m^{\ 2}} \left[(1+\nu) \cdot \ln(\frac{D_s}{D_l}) + (1-\nu) \cdot (\frac{D_s^2 - D_l^2}{2D^2}) \right] \qquad (2)$$

where

F is the force applied at failure, in N;

t_m is the mean test specimen thickness, in mm;

D_l is the loading ring mean (contact) diameter, in mm;

D_s is the support ring mean (contact) diameter, in mm;

D is the test specimen diameter, in mm;

ν is the Poisson's ratio for zirconia (assume to be 0,3).

Calculate the mean stress and the standard deviation for the batch of test specimens.

4.5.6 Test report

The test report shall contain at least the following information:

a) the identity of the ceramic material including batch number or other codes sufficient to uniquely identify the test specimens;

b) method of preparing the test specimens;

c) the mean value and standard deviation of the fracture stresses. If appropriate, the individual fracture stresses of the series of test specimens as well as Weibull modulus can be given in accordance with 4.7. If the fracture location of a specimen lies outside of the loading rings, the location of failure shall be reported [see 4.5.4 d)];

d) a reference to this International Standard, i.e., ISO 13356:2015.

4.6 Four-point bending strength

The four-point bending strength shall be determined and reported in accordance with ISO 14704, ASTM C1161 or EN 843-5 using 4-point (20 ± 1) mm × (40 ± 1) mm spans.

The test specimens shall be (45 ± 1) mm in length, (4,0 ± 0,2) mm in width, and (3,0 ± 0,2) mm in thickness. The test specimen is supported by two parallel rollers of diameter (5,0 ± 0,2) mm. The two rollers shall be positioned symmetrically with respect to the length of the test specimen with their centers (40,0 ± 0,5) mm apart (outer span).

The two loading rollers shall be symmetrically located with respect to the outer roller and shall have a span of (20 ± 0,2) mm. The surface to be tested shall be in contact with the outer rollers.

At least 10 test specimens shall be used for the determination of the mean strength.

Calculate the individual nominal flexural strength, the mean, and the standard deviation.

4.7 Weibull modulus

The strength data from the biaxial flexural tests or the 4-point bending test shall be analysed in accordance with ISO 20501, EN 843-5 or ASTM C1239 using Weibull statistics. At least 30 test specimens shall be selected to be used for Weibull statistical analysis. Weibull modulus shall meet the limits given in Table 1.

For the test report, the characteristic strength (scale parameter) and the Weibull modulus shall be used.

4.8 Young’s modulus

The Young’s modulus shall be determined and reported in accordance with ISO 17561, EN 843-2, ASTM C1331, ASTM C1198, or ASTM C1259. At least 3 test specimens shall be prepared for determination of mean value.

4.9 Hardness

For the characterization of the hardness of the material, the Vickers hardness method and the result report shall be used in accordance with ISO 14705, EN 843-4 or ASTM C1327. A test load of 9,81 N (HV1) shall be applied.

4.10 Cyclic fatigue

4.10.1 Principle

No test specimen should fail in less than 10^6 cycles. The cyclic fatigue shall be determined by a four-point bend cycling fatigue test under simulated physiological conditions in accordance with ISO 22214.

4.10.2 Apparatus

a) **Mechanical testing machine**, suitable for applying a cycling sinusoidal load. The testing machine shall be in accordance with ISO 7500-1:2004, Class 1 with an accuracy of 1 % of the maximum load, or better. The machine shall have instrumentation to monitor the maximum and minimum loads, and to record the number of cycles or the elapsed time of the test.

b) **Testing jig**, in accordance with ISO 14704. The test specimen is supported by two parallel rollers. Each roller shall be positioned symmetrically with respect to the length of the test specimen with their centres (40,0 ± 0,1) mm apart for the outer span. The two loading rollers shall be symmetrically located with respect to the outer rollers and shall have a span of (20,00 ± 0,05) mm.

4.10.3 Sample size and preparation of test specimens

At least five specimens shall be used to determine the cyclic fatigue. The preparation of the test specimens and their geometry shall be in accordance with ISO 14704.

4.10.4 Procedure and sample requirement

The test shall be performed at a frequency between 5 Hz and 20 Hz, and at a peak stress of σ_{max} = 320 MPa using a peak force calculated from the relationship according to Formula (3) and an R-ratio (relation between the applied minimum and maximum forces) of 0,1. The test shall be conducted in a physiological saline solution at (37 ± 2) °C. The test shall continue until the specimen fractures or one million cycles.

$$F_{max} = \frac{2bh^2\sigma_{max}}{3(S_1 - S_2)} \quad (3)$$

where

b is the width, in millimetres;

h is the height of the test specimen, in millimetres;

S_1 is the outer span of the jig, in millimetres;

S_2 is the inner span of the jig, in millimetres.

4.10.5 Test Report

The test report shall contain at least the following information:

a) batch number or other code sufficient to uniquely identify the test specimens;

b) method of preparation of the test specimens;

c) whether or not all specimens passed the test (10^6 cycles);

d) a reference to this International Standard, i.e., ISO 13356.

4.11 Radioactivity

4.11.1 Principle

This International Standard describes the use of gamma spectrometry for the measurement of gamma photons emitted from radio nuclides in the sample without the need to separate the radio nuclides from the sample matrix. The simultaneous detection of several gamma emitters in the sample is carried out with a high resolution single germanium semi-conductor detector, connected to a multichannel analyser (MCA). Automatic processing of the collected data can be conveniently controlled by a computer system with selected software recommended for processing data.

4.11.2 Apparatus

4.11.2.1 Marinelli beakers, 500 mL minimum with lids.

4.11.2.2 Ball mill.

4.11.2.3 Sieve, complying with ISO 3310-1.

4.11.2.4 Gamma spectrometer system, comprised of a low background vertical high purity germanium detector (HPGe), efficiency 20 % to 25 %; energy range 10 keV to 10 MeV; resolution full width half maximum (FWHM) at 1,33 MeV-1,8 keV to 2 keV shall be used.

The spectrometer shall have a Peak to peak Compton ratio > 46:1. A Detector pre-amplifier is contained on the detector capsule. It shall also have a biased high voltage power supply and a linear amplifier.

4.11.2.5 Lead detector shield, with cavity adequate to accommodate the Marinelli beaker (4.11.2.1), shielded wall 50 to 100 mm thickness lined with cadmium (1,6 mm) and copper (0,4 mm) layers shall be used.

