



**International
Standard**

ISO/ASTM 52957

**Additive manufacturing of
ceramics — Design — Design
guidelines**

*Fabrication additive de céramiques — Conception — Lignes
directrices relatives à la conception*

**First edition
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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11

Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

ASTM International
100 Barr Harbor Drive, PO Box C700
West Conshohocken, PA 19428-2959, USA
Phone: +610 832 9634
Fax: +610 832 9635
Email: khooper@astm.org
Website: www.astm.org

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Foreword

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This document was prepared by Technical Committee ISO/TC 261, *Additive manufacturing*, in cooperation with ASTM Committee F42, *Additive Manufacturing Technologies*, on the basis of a partnership agreement between ISO and ASTM International with the aim to create a common set of ISO/ASTM standards on Additive Manufacturing, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 438, *Additive manufacturing*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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.

Additive manufacturing of ceramics — Design — Design guidelines

1 Scope

This document specifies part properties, design freedom, strengths and applications of additively manufactured (AM) ceramic materials. It is aimed at product planners and designers and provides the necessary basic knowledge about ceramics and the possibilities specific to AM ceramics, including strengths and limitations of the most utilized ceramic AM process categories. In-depth previous knowledge in these areas is not assumed.

2 Normative references

The following document is referred to in the text in such a way that some or all 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/ASTM 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/ASTM 52900 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 binder system

mixture of different organic or inorganic materials that after curing/drying/solidification bind the particulate material together forming the *green body* (3.8) before shaping

3.2 brown body

green body (3.8) that has undergone pyrolysis/*debinding* (3.5)

Note 1 to entry: The brown body has very low mechanical strength, as the individual particles adhere to each other solely due to surface forces as well as frictional and positive locking.

3.3 ceramic

any material that is classified as an inorganic, non-metallic crystalline solid

3.4 cleaning

removal of adhering excess of feedstock from the *green body* (3.8)

3.5 debinding

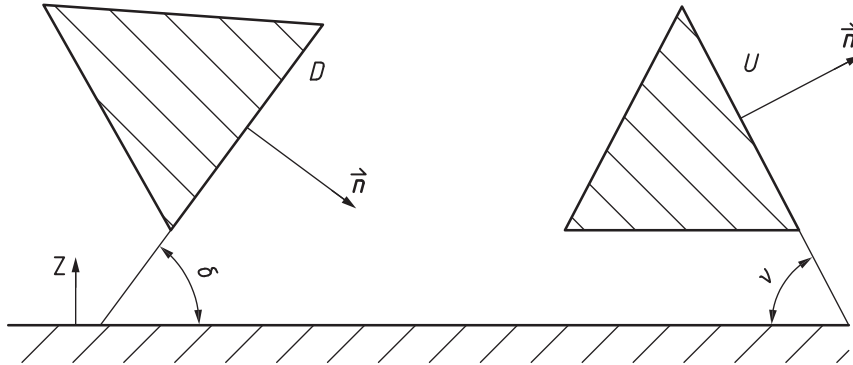
process of removing all binder from the *green body* (3.8)

3.6 downskin angle

δ

angle between the build platform plane and a downskin area, D , whose value lies between 0° (parallel to the build platform) and 90° (perpendicular to the build platform)

Note 1 to entry: See [Figure 1](#).



Key

D	downskin area
U	upskin area
$\vec{n}$	normal vector

Figure 1 — Upskin angle, v , and downskin angle, δ , according to ISO/ASTM 52911 series

3.7 granulate

solid, flowable feedstock for powder bed-based AM processes

Note 1 to entry: Granulate is a specially produced compound of many individual powder particles that has significantly improved flow properties compared to a standard powder.

3.8 green body

part in intermediate state of processing, where the intended geometrical shape is given, but the bonding of the intended part material is yet to be established (which occurs during *sintering* ([3.14](#)))

Note 1 to entry: For multi-step ceramic processes, the green body typically will consist of a powder held together by the binder system.

Note 2 to entry: The mechanical properties of a green body made from powder materials are essentially determined by the binder system.

3.9 green machining

machining of the *green body* ([3.8](#)) to attain the desired geometry or surface quality

Note 1 to entry: Green processing can include the removal of supports and the integration of special geometric features.

3.10 hard machining

machining of the *sintered part* ([3.13](#)) to achieve the desired geometry, dimension or surface quality to the final dimension

Note 1 to entry: Due to the high hardness of the sintered part, hard machining is very time-consuming and places very high demands on the machining processes and tools.

3.11

infiltration

process where a fluid material (liquid, vapor or slurry) is introduced into the connected pores of a porous ceramic preform

3.12

shrinkage

volume reduction of a part without mass change during *sintering* ([3.14](#))

Note 1 to entry: Volume reduction due to material removal (machining) is not referred to as shrinkage.

3.13

sintered part

part after *sintering* ([3.14](#)) with the final (*ceramic* ([3.3](#))) properties

3.14

sintering

thermal process for compacting and bonding the (*ceramic* ([3.3](#))) particles, taking place at temperatures below the melting temperature

Note 1 to entry: Generally, sintering is accompanied by shrinkage.

Note 2 to entry: The temperature during sintering is above the debinding temperature but below the melting temperature of the ceramic material.

3.15

suspension

liquid feedstock with suspended particulate (i.e. *ceramic* ([3.3](#)) powder)

EXAMPLE Slip, ink, paste, slurry, etc.

Note 1 to entry: The suspension can be solidified by removing components of the binder system or initiating cross-linking reactions.

3.16

undercut

design feature, such as a horizontal protrusion, cavity or internal channel, that juts out from the main body and cannot be produced without supports

3.17

upskin angle

ν

angle between the build platform plane and an upskin area, U , whose value lies between 0° (parallel to the build platform) and 90° (perpendicular to the build platform)

Note 1 to entry: See [Figure 1](#).

3.18

white machining

machining of the white body to realize the desired geometry or surface quality

Note 1 to entry: The subsequent shrinkage during sintering should be considered and compensated for by an appropriate oversize.

Note 2 to entry: White machining processing can include the removal of supports and the integration of special geometric features.

3.19

white body

green body (3.8) or *brown body* (3.2) in which initial *sintering* (3.14) of the particles, including the formation of sinter necks, has been initiated by thermal treatment

Note 1 to entry: The mechanical strength of the white body is significantly higher than that of the brown body, but still significantly lower than that of the sintered part.

4 Manufacture and properties of ceramic parts

4.1 General

In this clause, the properties and applications are first presented (see 4.2). Then the ceramic manufacturing process is explained (see 4.3), from which general design recommendations are then derived (see 4.4).

4.2 Properties and applications

The specific properties of ceramic materials, which in various relationships typically cannot be matched by other materials, offer versatile applications.

Compared to metals, ceramic materials can offer higher hardness, thermal resistance, corrosion resistance and wear resistance, as well as lower density and thermal expansion. An essential difference between ceramic materials and metals is that ceramics usually do not show plastic deformation but fail after elastic deformation when the load limit is exceeded. An example are MAX ($M_{n+1}AX_n$) phases, which can show plastic deformation when a load is applied.

An overview of the properties of ceramic materials is given in Table 1. The last column lists properties of structural steel for comparison. The properties listed in Table 1 can vary depending on the processing and raw materials utilized.

NOTE Polymeric materials are not included due to their distinctly different material properties.

Table 1 — Overview of typical properties of ceramic parts in comparison with structural steel^{[3][4]}

Material property	Material					
	Porcelain	Aluminium oxide (>99 %)	Zirconium oxide (3Y-TZP) ^a	Silicon nitride (SiN) ^b	Silicon carbide (SiC) ^c	Structural steel St 37
Density in g/cm ³	2,2	3,9	5...6	3,2...3,3	3,08...3,15	7,8
Hardness (Vickers) in GPa	5...9	13...23	10...14	14...18	22...34	2...4
Flexural strength in MPa	50	300...450	500...1,000	700...1,000	260...500	340...470
Young's modulus in GPa	60	300	200...210	290...330	350...450	200...210
Fracture toughness in MPa m ^{1/2}	–	4...5,5	5,8...10,5	5...8,5	3,0...4,8	200
Thermal expansion in 10 ⁻⁶ K ⁻¹	4...7	7...8	10...12,5	2,5...3,5	4,0...4,8	10...12

^a 3Y-TZP – tetragonally stabilized zirconium oxide with 3 % molar content of yttrium oxide.

^b SiN – silicon nitride.

^c SiC – silicon carbide.

Figure 2 through Figure 5 illustrate the relationship between different properties for selected ceramics compared to metals. In this way, characteristics of ceramic materials can be both quickly compared among each other as well as to metals^{[3][4]}.

The literature values used in Figure 2 through Figure 5 were determined with standardized test specimens from conventional manufacturing processes and are to provide general guideline comparisons. In AM, there are different manufacturing process categories and material formulations, which means that the property values can vary greatly. Porosity is particularly affected by this. For example, density and flexural strength decrease as porosity increases. Because of this, it is advised that the investigator research the more specific values for their ceramic system.

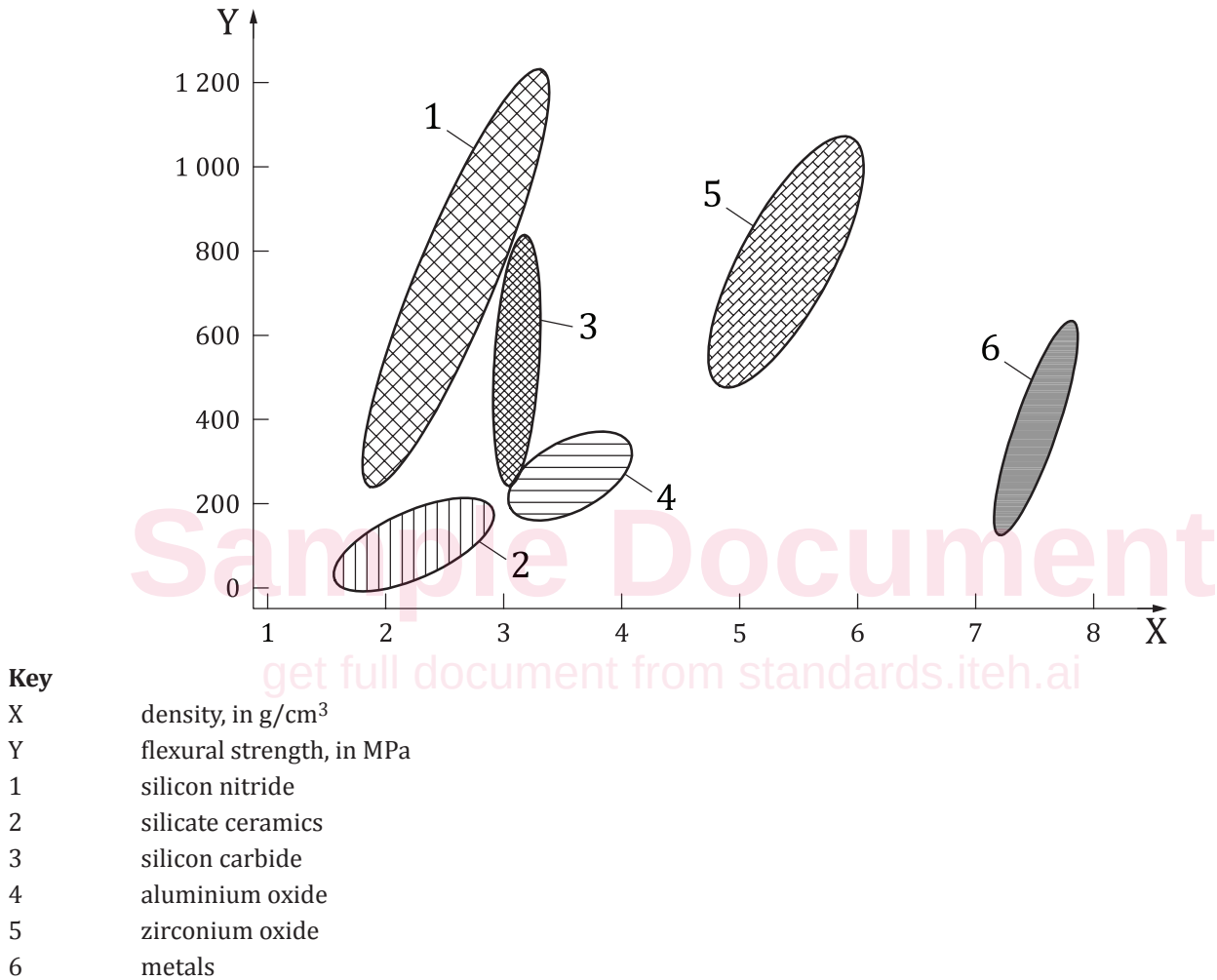


Figure 2 — Relationship between density and flexural strength for selected ceramics compared to metals^[3]