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Additive manufacturing — General principles — Main characteristics and corresponding test methods

Fabrication additive — Principes généraux — Principales caractéristiques et méthodes d'essai correspondantes

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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).

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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.

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, and 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).

The first edition of this document cancels and replaces the first edition of ISO 17296-3:2014, which has been technically revised and merged with document ASTM F3122-14 and therefore re-designated and renamed to ISO/ASTM 52927.

The main changes are as follows:

— the main types of materials (metallic, polymers and ceramics) are separated in specific annexes following the main part containing general requirements;

— This document includes the contents of ASTM F3122-14 and merges them with (formerly) ISO 17296-3.

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.

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Introduction

Additive manufacturing is a process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative methodologies. It is used to manufacture prototypes and production parts.

This document aims to offer recommendations and advice to machine manufacturers, feedstock suppliers, AM system users, part providers, and customers, to improve communication between these stakeholders concerning test methods.

This document has been developed within a set of consistent documents from terminology to test methods and data exchange.

Additive manufacturing processes require the selective application of thermo-physical and/or chemical mechanisms to generate the part. Thus, it is possible to produce parts with different characteristics, depending on the method and the process parameters used. However, complete testing of all characteristics for every part is neither cost-effective nor technologically feasible. Therefore, when formulating parts specifications, the nature and scope of testing is an important issue.

This document provides an overview of test methods for the characterization of the mechanical properties of metals, ceramics and polymers. It lists all the applicable standards based on specimens manufactured in a traditional process and gives the complement applicable when these specimens are manufactured by additive manufacturing.

At the time of publication of this document, the state of the art does not allow to describe all these specificities related to additive manufacturing. This document will therefore be regularly revised in order to incorporate the knowledge acquired in the field of additive manufacturing.

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Additive manufacturing — General principles — Main characteristics and corresponding test methods

1 Scope

This document specifies the principal requirements applied to the testing of parts produced by additive manufacturing processes.

This document

— identifies quality characteristics for feedstock and parts and the corresponding test procedures,

— provides the specific procedures to build specimens using additive manufacturing process, and

— recommends the scope and content of test and supply agreements.

This document is aimed at machine manufacturers, feedstock suppliers, AM system users, part providers, and customers to facilitate the communication on main quality characteristics. It applies wherever additive manufacturing processes are used.

NOTE It is the intent to include, in future versions of this document, other characteristics such as thermal properties, electrical requirements and physical and physico-chemical properties based upon material types.

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 17295[1)], *Additive manufacturing — General principles — Part positioning, coordinates and orientation*

ISO/ASTM 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary*

ISO/ASTM 52909, *Additive manufacturing — Finished part properties — Orientation and location dependence of mechanical properties for metal powder bed fusion*

ISO/ASTM 52915, *Specification for additive manufacturing file format (AMF) Version 1.2*

3 Terms and definitions

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

1) ISO 17295 cancels and replaces ISO/ASTM 52921-13 which is still available at: https://www.astm.org/f2921-13r19.html.

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4 Main characteristics and corresponding test methods

4.1 General

This clause contains the general requirements and recommendations for the relevant tests, regardless of the material type.

For specific requirements and recommendations regarding tests and methods on specimens made of metallic materials, see Annex A.

For specific requirements and recommendations regarding tests and methods on specimens made of polymer materials, see Annex B.

For specific requirements and recommendations regarding tests and methods on specimens made of ceramic materials, see Annex C.

Each development and fabrication phase of a part has a specific purpose. The acceptance criteria for each quality characteristic are determined based on the part requirements and these can influence the choice of additive manufacturing process. This document develops the following main quality characteristics:

— feedstock:

  — size and shape: powder particle size distribution, mean particle size, morphology;

  — packing and transport properties within the AM system: apparent and tap density, flowability, pourability, filament cast and helix;

  — chemistry: chemical composition, ash/carbon content.

— parts:

  — surface requirements: appearance and colour;

  — geometric and dimensional requirements: profile, roughness, size, shape, orientation, position, dimensional tolerancing;

  — mechanical requirements: hardness, tensile strength, impact strength, compressive strength, flexural strength, fatigue strength, creep, ageing, frictional coefficient, shear resistance, and crack extension;

  — physical and chemical properties: density, chemical composition, grain size, imperfections (e.g. porosity, cracks).

NOTE The following other characteristics of parts have been identified but, due to the specificity of additive manufacturing, will be provided in a future version of this document:

— thermal properties (e.g. operating temperature range, dimensional stability in heat, softening temperatures, melting point, specific heat, thermal conductivity, and coefficient of linear thermal expansion);

— electrical requirements (e.g. disruptive strength, dielectric properties, magnetic properties, and electrical conductivity);

— physical and physico-chemical properties (e.g. internal flaws, flammability, toxicity, chemical composition, chemical resistance, water absorption, crystalline structure, suitability for food, biocompatibility, sterility, photostability, translucence, solidification point, glass transition, and corrosion).

4.2 Selection criteria

Testing categories given in Table A.1, Table B.1 and Table C.1 shall be applied to guide the relation between customer and part provider, applicable for metallic parts, polymer parts and ceramic parts respectively.

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The choice of a testing category shall be subject to agreement between customer and part provider.

NOTE Test categories are defined according to the application and the type of material.

5 Part and process testing — Specifications and quality criteria

5.1 General

The quality of a part is determined by comparing its characteristics against an agreed set of requirements. The requirements shall be precisely specified within the purchase specification and include suitability for the intended application in conjunction with any specified geometric, material or performance requirements. Inspection and testing of the part and associated test specimens are performed to demonstrate compliance with the requirements.

NOTE 1 ISO/ASTM 52901 provides guidance on requirements for purchase specifications.

NOTE 2 A definition or discussion that lacks clarity can result in considerable additional costs and delays and/or inferior quality.

The form of specifications depends on the application, the nature of the features being tested, and the materials used. Specifications may also vary within one part (e.g. critical mass). Some intrinsic properties depend on the choice of material and the technology used. Relevant test procedures shall be stipulated and adhered to.

5.2 Testing the feedstocks

The condition of the feedstock can have a significant impact on the part properties. Significant variations can arise due to storage and reuse of the feedstock and variations between batches. Essential data relating to the feedstock shall be provided by the feedstock supplier.

5.3 Monitoring the process

All additive manufacturing processes are computer-assisted. This allows for the recording and statistical analyses of certain process-related data, such as process parameters and - in most cases - certain environmental conditions, which can be recorded at specified time intervals. The need to monitor the process depends on the required or anticipated reproducibility of the process and part quality for each application. Process monitoring can also be required by customer.

Where the process stability is assessed, at different intervals, consideration shall be given to selecting monitoring points where variables are consistent (e.g. constant geometry) such that any identified variations are indicative of process instability (e.g. mechanical properties, geometric features, chemical composition).

Test specimens for process monitoring should be as representative as possible compared to the part. Complementary test specimens can be used to improve the testing of dimensional accuracy, reproduction accuracy and process stability. The shape of test specimen and the nature and frequency of testing shall be specified in agreement between the customer and part provider for each application in accordance with applicable standards.

5.4 Testing the part

Relevant testing standards are given in Table A.2 for metallic parts, Table B.2 for polymer parts and Table C.2 for ceramic parts.

Tests and their acceptance criteria shall be set out in the purchase specification or agreement between customer and part provider prior to manufacturing.

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Annex A
(normative)

Test methods for metallic materials

A.1 General

Testing categories given in Table A.1 to Table A.4 can be applied to guide the relation between customer and part provider, applicable for metallic parts. These testing categories define the level of criticality of the parts:

— H: tests for highly engineered or safety critical parts (e.g. safety valve);

— M: tests for functional parts that are not safety critical (e.g. flow conditioner to improve performance);

— L: tests for design or prototype parts.

For each testing category, the characteristics indicated (+) shall be considered, the characteristics indicated (o) are recommended for consideration, and the characteristics indicated (-) are not applicable.

A.2 Surface requirements

Surface requirements for metallic parts are given in Table A.1.

Table A.1 — Surface requirements for metallic parts

	Surface requirement		
	Appearance	Surface texture	Colour
H	o	+	-
M	o	+	-
L	o	o	-

A.3 Geometric and dimensional requirements

Whilst geometric dimensioning and tolerance (GD&T) and/or geometrical product specifications (GPS) requirements shall be met for all categories, tighter requirements are typically specified for parts with higher criticality levels.

A.4 Mechanical requirements

Depending on the class of the part and the technical specification, the mechanical tests shall be adapted accordingly

A.5 Physical and chemical property requirements

A.5.1 General

The physical and chemical property requirements shall be adapted according to the class of the part.

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A.5.2 Specificities for additive manufacturing

A.5.2.1 General

No requirement or recommendation at the date of publication of this document.

A.5.2.2 Processing

No requirement or recommendation at the date of publication of this document.

A.5.2.3 Post-processing

In order to be representative, post-processing activities applied to the part that affect the material properties shall also be applied to the test specimens.

A.6 Performance criteria and quality characteristics

A.6.1 General

Table A.2 contains the list of main quality characteristics required from both materials and metallic parts produced by additive manufacturing, with recommended International Standards. Due to the current maturity of additive manufacturing technologies, development work is in progress to define and describe specific characteristics, but in the interim it is recommended to use the standards stated within this Annex.

Reporting guidelines should be followed in accordance with each applicable standard mentioned in Table A.2.

NOTE The test is performed with the heat treatment corresponding of the final use of the part.

A.6.2 Specificities for additive manufacturing

Due to the possibility for anisotropic behaviour in metallic parts produced by additive manufacturing processes, additional information shall be included in the reports.

NOTE 1 ISO 17295 gives guidance for location and orientation of parts and specimens within the build volume of the additive manufacturing system. ISO/ASTM 52915 provides for location and orientation of parts within a multi-part assembly (constellation) that can impact the orientation of the print on the build plate of an additive manufacturing system.

Specificity of additive manufacturing (e.g. anisotropy, test direction vs building direction) shall be indicated for all measured characteristics and shall be reported in the test report. Test results shall be reported by using the orientation and location specified in ISO 17295.

Restrictions exist for some non-homogenous materials, such as porous materials, lattice structures, etc. when using mechanical testing results.

If the metallic parts are produced using a powder bed fusion process, the specimens shall comply with the requirements of ISO/ASTM 52909.

More information on the method to characterize metallic powders are provided in ISO/ASTM 52907.

More information about NDT test methods are available in ISO/ASTM TR 52905 and ASTM E3166.

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Table A.2 — List of main quality characteristics and corresponding recommended test standards for metallic parts

	Quality characteristic	Test standard
Feedstock		
Size and shape	Powder particle size and distribution	ISO 4497 ISO 8130-1 ISO 13319-1 ISO 13320
	Morphology	ISO 9276-6
	Surface	ISO 9277 ISO 10070 ASTM B922 ASTM B330 ASTM E2980
Packing and transport properties	Density (tap and apparent)	ISO 3923-2
	Flowability/ pourability	ISO 4490
Chemistry	Quality characteristics	See relevant material standards
Moisture	Moisture	ASTM E1868-10
Parts/specimens		
Surface requirements	Appearance	ISO 16348
	Colour	ISO/CIE 11664-1 ISO/CIE 11664-2 ISO/CIE 11664-4 ISO/CIE 11664-5
Geometric requirements	Size, length and angle dimensions, dimensional tolerances	ISO 129-1 ISO 286-1 ISO 8015 ISO 14405 (all parts) (specification) ISO 1938-1 (measurement) ISO 2768-1
	Surface texture	ISO 21920-1 (specification) ISO 21920-2 (specification) ISO 21920-3 (specification) ISO 21920 (all parts) (2D profile method) ISO 25178 (all parts) (3D areal)
	Geometrical tolerancing (deviations in form, position and orientation)	ISO 1101 (specification) ISO 22081

[a] This standard is applicable to materials made additively, but the surface finish requirements and some thickness requirements for the specimen can be problematic for some additive manufacturing processes.

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Table A.2 *(continued)*

	Quality characteristic	Test standard
Mechanical requirements	Hardness	See A.7.2
	Tensile strength	See A.7.3
	Impact strength	See A.7.5
	Compressive strength	ISO 4506, see A.7.4
	Flexural strength	ISO 3327
	Fatigue strength	See A.7.6
	Creep	ISO 204
	Frictional coefficient	No standard identified
	Shear resistance	ISO 148-1
	Crack extension	See A.7.7
	Bend test	ISO 7438
	Transverse strength	ISO 3327
Build material requirements	Density	ISO 3369 ISO 12154 ASTM B962 ASTM B963
Physical and physico-chemical properties: microstructure analyses (non-destructive testing)	Radiographic examination	ISO 5579
	Penetrant testing	ISO 3452-1 ISO 3452-2
	Tomography	IEC 61675–1 IEC 61675–2
	Magnetic particle testing	ISO 9934-1
Metallurgical analysis	Grain size	ISO 643 ASTM E112 ASTM E1382
	Inclusions	ISO 4967 ASTM E45 ASTM B796 ISO 4499 (all parts) ISO 12154 ISO 3369 ASTM B962 ASTM B963
Bearing	Bearing yield strength Bearing strength	ASTM E238 [a]

[a] This standard is applicable to materials made additively, but the surface finish requirements and some thickness requirements for the specimen can be problematic for some additive manufacturing processes.

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A.7 Specific comment on characteristics

A.7.1 General

Specific requirements shall be considered for the following characteristics.

A.7.2 Hardness

The following indentation tests in Table A.3 can help to specify the hardness of additive manufactured parts. Hardness is not a fundamental material property, but the wide variety of hardness test methods in use today helps to predict a material's resistance to plastic deformation or wear resistance, or both against abrasive

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stress. Due to the subjective nature of the present hardness tests, the desired test method and force shall be specified prior to testing. Regardless of the hardness test specified, all methods require preparation of the material's surface before testing. Prior to testing, the specimen thickness shall also be considered, because if the specimen is too thin, the hardness value measured can be inaccurate.

Hardness testing can be performed on dedicated specimens or on smooth finished and undeformed surfaces of the tensile or impact test specimens.

Table A.3 — Recommended standards for indentation tests for metallic parts

Type of indentation test/type of material	Test standard
Brinell	ASTM E10 or ISO 6506-1
Knoop	ASTM E384 or ISO 4545-1
Leeb	ISO 16859-1
Vickers	ASTM E384 or ISO 6507-1
Rockwell	ASTM E18 or ISO 6508-1
Dynamic test	ISO 14577-1
Mobile Hardness tests by Webster, Barcol and Newage	ASTM B647 and ASTM B648
Sintered materials	ISO 4498
Verification of case-hardening depth	ISO 4507

A.7.3 Tensile strength

The procedures outlined in ASTM E8/E8M, ASTM E21, ASTM E1450, ISO 2740, ISO 6892-1, ISO 6892-2, ISO 6892-3, ISO 15579, and ISO 19819 explain guidelines for tension testing under various conditions to determine a material's yield and tensile strengths. All are applicable to metallic materials made additively, but certain shapes (e.g. sheet-, wire-, and rod-shaped specimens with small diameters) are difficult to build through an additive process.

Additional information about size and shape of specimen and orientation are available in ISO/ASTM 52909.

A.7.4 Impact strength

ASTM E23 covers impact testing to determine the behaviour of metal when subjected to multi-axial stresses, coupled with a high loading rate and with either low or high temperatures. This standard describes the requirements, preparation and qualifying test specimens for both Charpy and Izod methods. ISO 148-1 is the equivalent ISO standard, but includes only guidelines for the Charpy test. Alternatively, ISO 14556 can be utilised, which is similar to ISO 148-1 but is limited in scope to steel materials only.

A.7.5 Compressive strength

ASTM E9, ASTM E209 and ISO 4506 describe the basic method for uniaxial compression testing of metallic specimens at various temperatures. The procedures are used in determining a material's compressive yield strength and compression strength. These standards are applicable to materials made additively, but not all of the specimen types (thin sheets) can be successfully built through an additive process.

For sintered materials having a porosity of 50 % or more and lattice structures, ISO 13314 and ISO 17340 can be applied. For sintered materials, ISO 14317 can be used except for hard materials.

A.7.6 Fatigue strength

The standards applicable for fatigue strength testing of metallic materials are listed in Table A.4

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Table A.4 — List of standards for metallic part in fatigue strength testing

Standard	Description
ASTM E 466 ISO 1099	Fatigue testing of metals at room temperature. Both standards provide guidelines for an axial force-controlled fatigue test.
ISO 12106	Covers fatigue testing of metal specimens where the axial-strain is controlled.
ASTM E606	Intended for primarily strain controlled fatigue tests, in which the magnitude of time dependent inelastic strains are on the same order or less than the magnitudes of time-independent inelastic strains. In addition, ASTM E606 determines the cyclic stresses and strains any time during the tests and provides guidance to determine the fatigue life.
ASTM E2368 ISO 12111	To determine the thermo mechanical fatigue properties of materials under uniaxial loaded strain-controlled conditions.
ISO 1143	Determination of the fatigue life of a rotating bar while bending.
ISO 1352	For torque-controlled fatigue testing which is carried out at ambient temperature in air, under constant amplitude angular displacement control, and which leads to failure in a few thousand cycles.
ASTM E2760	Covers the determination of creep fatigue growth properties of nominally homogeneous materials by using pre-cracked compact specimens. It involves fatigue cycling with long loading/unloading rates or hold times, or both.
ASTM E2789	For the fretting fatigue test. Fretting fatigue is generally characterized by a sharp decrease in fatigue life at the same stress level as that of a standard specimen.
ISO 3928	Fatigue test piece for sintered material, excluding hardmetals.

A.7.7 Crack extension

The standards applicable for crack extension testing of metallic materials are listed in Table A.5.

Table A.5 — List of standards for crack extension applicable to metallic part

Standard	Description
ASTM E647 ISO 12108	To determine the rate of crack growth on notched specimens. The results of this test method determine the resistance of a material against crack propagation under cyclic force test conditions.
ISO 22889	For measuring the resistance to stable crack extension of metallic materials with low constraint to plastic deformation under quasi-static loading
ASTM E 740 ASTM E 399 ASTM E 1820	For fracture testing with surface-crack tension specimens. The test is performed with a continuously increasing force and sustained loading. This standard also provides the procedure to determine the residual strength of a specimen with a semi-elliptical or circular segmented fatigue crack
ASTM E 1457	For measurement of creep crack growth times in metal specimens that are subjected to static or quasi-static loading condition
ASTM E 1681	For determining the threshold stress intensity factor for environmentally-assisted cracking of metallic materials, and requires an environmental chamber
ASTM E 2472 ASTM E 561	For determination of resistance to stable crack extension under low-constraint conditions, which occurs when the crack-length-to thickness and uncracked-ligament-to-thickness ratio are greater than or equal to four

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Annex B
(normative)

Test methods for polymer materials

B.1 General

Testing categories given in Table B.1 and Table B.2 can be applied to guide the relation between customer and part provider, applicable for polymer parts. These testing categories define the level of criticality of the parts:

— H: tests for highly engineered or safety critical parts (e.g. safety valve);

— M: tests for functional parts that are not safety critical (e.g. flow conditioner to improve performance);

— L: tests for design or prototype parts.

For each testing category, the characteristics indicated (+) shall be considered, the characteristics indicated (o) are recommended for consideration, and the characteristics indicated (-) are not applicable.

B.2 Surface requirements

Surface requirements for polymer parts are given in Table B.1.

Table B.1 — Surface requirements for polymer parts

	Surface requirement	
	Appearance	Colour
H	o	o
M	o	o
L	o	o

B.3 Geometric and dimensional requirements

Whilst geometric dimensioning and tolerance (GD&T) and/or geometrical product specifications (GPS) requirements shall be met for all categories, tighter requirements are typically specified for parts with higher criticality levels.

B.4 Mechanical requirements

Depending on the class of the part and the technical specification, the mechanical tests shall be adapted accordingly.

B.5 Formed material requirements

B.5.1 General

The physical and chemical property requirements shall be adapted according to the class of the part.

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B.5.2 Specificities for additive manufacturing

B.5.2.1 General

No requirement or recommendation at the date of publication of this document.

B.5.2.2 Processing

No requirement or recommendation at the date of publication of this document.

B.5.2.3 Post-processing

No requirement or recommendation at the date of publication of this document.

B.6 Performance criteria and quality characteristics

B.6.1 General

Table B.2 contains the list of main quality characteristics required from both materials and polymer parts manufactured by additive manufacturing, with recommended International Standards.

B.6.2 Specificities for additive manufacturing

Due to characteristics of the additive manufacturing technologies, work is in progress in order to define and describe their specific characteristics but in the intermediate period, it is recommended to use these ISO or ASTM standards in the following subclauses, unless otherwise specified.

Specificity of additive manufacturing (e.g. anisotropy, test direction vs building direction, infill strategies) shall be indicated for all measured characteristics and shall be reported in the test report. Test results shall be reported by using the orientation and location specified in ISO 17295.

Table B.2 — List of main quality characteristics and corresponding recommended test standards for polymer parts

	Quality characteristic	Test standard
Feedstock		
Bulk raw material requirements	Powder particle size and distribution	ISO 4610 ISO 13319-1 ISO 13320
	Morphology	ISO 9276-6
	Surface	ISO 9277
	Density (tap and apparent)	ISO 1068
	Flowability/ pourability	ISO 6186 ISO 4324
	Quality characteristics	See relevant material standards
	Moisture	ASTM D6980 ASTM D7191 ASTM D6869 ASTM D7191 ASTM E1868
Parts/Specimens		

[a] The influence of the infill/wall for notched test specimen can influence the results of the impact test. In this case, the un-notched specimens can be preferred.

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Table B.2 *(continued)*

	Quality characteristic	Test standard
Surface requirements	Appearance	ISO 16348
	Colour	ISO/CIE 11664-1 ISO/CIE 11664-2 ISO/CIE 11664-4 ISO/CIE 11664-5
Geometric requirements	Size, length and angle dimensions, dimensional tolerances	ISO 129-1 ISO 286-1 ISO 14405-1 (specification) ISO 1938-1 (measurement) ISO 2768-1 ISO 8015 ISO 14405 (all parts)
	Surface texture	ISO 21920-1 (specification) ISO 21920-2 (specification) ISO 21920-3 (specification) ISO 25178 (all parts) (3D, Surface texture: Areal)
	Geometrical tolerancing (deviations in form, position and orientation)	ISO 1101 (specification) ISO 22081

[a] The influence of the infill/wall for notched test specimen can influence the results of the impact test. In this case, the unnotched specimens can be preferred.

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Table B.2 *(continued)*

	Quality characteristic	Test standard
Mechanical requirements	Preparation of test specimen	ISO/ASTM 52903-2 ISO/ASTM 52936-1
	Hardness	ISO 2039 (all parts) ISO 868
	Tensile strength	ISO 527-1 ISO 527-2 ISO 527-3 ISO 527-4 ISO 527-5 ASTM D1708
	Impact strength	ISO 179-1[a] ISO 179-2[a] (charpy) ISO 180[a] (izod)
	Compressive strength	ISO 604
	Flexural strength	ISO 178 ASTM D790 ASTM D6272
	Fatigue strength	ISO 13003 ISO 15850
	Creep	ISO 899-1 ISO 899-2
	Ageing	ISO 4892-1 ISO 4892-2 ISO 4892-3 ISO 4892-4
	Frictional coefficient	ISO 6601
	Shear resistance	ISO 14129
	Crack extension	ISO 15850
Formed material requirements	Density	ISO 1068 ISO 12154 ISO 3369 ASTM B962 ASTM B963
Physical and physico-chemical properties: microstructure analyses (non-destructive testing)	Radiographic examination	consult relevant standards
	Penetrant testing	ISO 3452-1 ISO 3452-2
	Tomography	IEC 61675–1 IEC 61675–2
	Magnetic particle testing	Not relevant
Material analysis	Grain size	ISO 4499 (all parts)

[a] The influence of the infill/wall for notched test specimen can influence the results of the impact test. In this case, the un-notched specimens can be preferred.

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Annex C
(normative)

Test methods for ceramic materials

C.1 General

Testing categories given in Table C.1 and Table C.2 can be applied to guide the relation between customer and part provider, applicable for ceramic parts. These testing categories define the level of criticality of the parts:

— H: tests for highly engineered or safety critical parts (e.g. safety valve);

— M: tests for functional parts that are not safety critical (e.g. flow conditioner to improve performance);

— L: tests for design or prototype parts.

For each testing category, the characteristics indicated (+) shall be considered, the characteristics indicated (o) are recommended for consideration, and the characteristics indicated (-) are not applicable.

C.2 Surface requirements

Surface requirements for ceramic parts are given in Table C.1.

Table C.1 — Surface requirements for ceramic parts

	Surface requirement	
	Appearance	Colour
H	o	o
M	o	o
L	o	o

C.3 Geometric and dimensional requirements

Whilst geometric dimensioning and tolerance (GD&T) and/or geometrical product specifications (GPS) requirements shall be met for all categories, tighter requirements are typically specified for parts with higher criticality levels.

C.4 Mechanical requirements

Depending on the class of the part and the technical specification, the mechanical tests shall be adapted accordingly.

C.5 Formed material requirements

C.5.1 General

The physical and chemical property requirements shall be adapted according to the class of the part.

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C.5.2 Specificities for additive manufacturing

C.5.2.1 General

No requirement or recommendation at the date of publication of this document.

C.5.2.2 Process

No requirement or recommendation at the date of publication of this document.

C.5.2.3 Post-processing

No requirement or recommendation at the date of publication of this document.

C.6 Performance criteria and quality characteristics

C.6.1 General

Table C.2 contains the list of main quality characteristics required from both materials and ceramic parts manufactured by additive manufacturing, with recommended International Standards.

C.6.2 Specificities for additive manufacturing

Due to the character of the additive manufacturing technologies, work is under progress in order to define and describe their specific characteristics but in the intermediate period, it is recommended to use these ISO or ASTM standards otherwise specified in the following subclauses.

Specificity of additive manufacturing (e.g. anisotropy, test direction vs building direction) shall be indicated for all measured characteristics and shall be reported in the test report. Test results shall be reported by using the orientation and location specified in ISO/ASTM 52915.

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Table C.2 — List of main quality characteristics and corresponding recommended test standards for ceramic parts

	Quality characteristic	Test standard
Feedstock		
Raw material requirements	Powder particle size and distribution	ISO 13319-1 ISO 13320 ISO 24235 ISO 14703 ISO 22412 ISO 13322-1 ISO 13322-2
	Ceramics content of slurry or paste	ISO 11358-1 ISO/ASTM 52940 (specific for vat photopolymerization)
	Dynamic viscosity of slurry or paste	ISO 6721-10 (paste, gel, high-viscosity sample) ISO 3219-2 (low-viscosity liquid resins) ISO 2555 ISO 12058-1 ISO 2884-2 ISO/ASTM 52940 (specific for vat photopolymerization)
	Solid dispersion stability	ISO 13097 ISO/ASTM 52940 (specific for vat photopolymerization)
	Morphology	ISO 9276-6
	Surface	ISO 18757 ISO 9277 ASTM C1069 ASTM C1274 ASTM C721 ASTM E2980
	Density (tap and apparent)	ISO 18753 ISO 23145-1 ISO 23145-2
	Flowability/ pourability	ISO 14629
	Quality characteristics	See relevant material standards
Parts/Specimens		
Surface requirements	Appearance	ISO 16348

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Table C.2 *(continued)*

		Quality characteristic	Test standard
		Surface texture	ISO 4288 (measurement) ISO 21920-1 (specification) ISO 21920-2 (specification) ISO 25178 (series) (3D, Surface texture: areal)
		Colour	ISO/CIE 11664-1 ISO/CIE 11664-2 ISO/CIE 11664-4 ISO/CIE 11664-5
Geometric requirements		Size, length and angle dimensions, dimensional tolerances	ISO 129-1 ISO 286-1 ISO 14405-1 (specification) ISO 1938-1 (measurement) ISO 2768-1 ISO 8015 ISO 14405 (all parts)
		Geometrical tolerancing (deviations in form, position and orientation)	ISO 1101 (specification) ISO 22081
Mechanical requirements		Hardness	ISO 14705
		Tensile strength	ISO 15490
		Impact strength	ISO 11491
		Compressive strength	ISO 17162
		Flexural strength	ISO 14704 ISO 14610 ASTM C1161 ASTM C1211 ASTM C1674
		Fatigue strength	ISO 22214 ISO 28704
		Creep	ISO 22215
		Frictional coefficient	ISO 20808
		Shear resistance	ISO 14129
		Crack extension	ISO 15732 ISO 18756 ISO 24370 ISO 23146
Formed material requirements		Density	ISO 18754
	Physical and physico-chemical properties: microstructure analyses (non-destructive testing)	Radiographic examination	consult relevant standards
		Penetrant testing	ISO 3452-1 ISO 3452-2
		Tomography	IEC 61675–1 IEC 61675–2
		Magnetic particle testing	Not relevant

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