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Additive manufacturing — General principles —

Part 3: Main characteristics and corresponding test methods

Fabrication additive — Principes généraux —

Partie 3: Principales caractéristiques et méthodes d'essai correspondantes

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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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 261, *Additive manufacturing*.

ISO 17296 consists of the following parts, under the general title *Additive manufacturing — General principles*:

— *Part 1: Terminology*

— *Part 2: Overview of process categories and feedstock*

— *Part 3: Main characteristics and corresponding test methods*

— *Part 4: Overview of data processing*

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Introduction

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

This part of ISO 17296 aims to offer recommendations and advice to machine manufacturers, feedstock suppliers, machine users, part providers, and customers, to improve communication between these stakeholders concerning test methods.

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

The manufacturing of parts by additive manufacturing processes is subject to numerous variables. The processes described in ISO 17296-2 can be used to manufacture parts that meet technological requirements only if these factors are controlled, optimized and, if necessary, customized for each order. When assessing parts quality, comparison with the specific requirements is one of the most important aspects.

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 used and the process parameters. However, complete testing of all parts characteristics is neither cost-effective nor technologically feasible. Therefore, when formulating parts specifications, the nature and scope of testing is an important issue.

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Additive manufacturing — General principles —

Part 3:
Main characteristics and corresponding test methods

1 Scope

This part of ISO 17296 covers the principal requirements applied to testing of parts manufactured by additive manufacturing processes.

This part of ISO 17296

— specifies main quality characteristics of parts,

— specifies appropriate test procedures, and

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

This part of ISO 17296 is aimed at machine manufacturers, feedstock suppliers, machine users, part providers, and customers to facilitate the communication on main quality characteristics. It applies wherever additive manufacturing processes are used.

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 17296-1[1)], *Additive manufacturing — General — Part 1: Terminology*

ISO/ASTM 52915, *Standard specification for additive manufacturing file format (AMF) Version 1.1*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 17296-1 and the following apply.

3.1
machine manufacturer
manufacturer of additive manufacturing equipment including machine

[SOURCE: ISO 17296-1[1)]]

3.2
feedstock supplier
provider of bulk raw material/consumable to be processed in additive manufacturing equipment

[SOURCE: ISO 17296-1[1)]]

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3.3
machine user
user of additive manufacturing equipment

[SOURCE: ISO 17296-1[2)]]

3.4
part provider
provider of parts manufactured by additive manufacturing equipment

[SOURCE: ISO 17296-1[2)]]

3.5
customer
end user of parts manufactured by additive manufacturing equipment

Note 1 to entry: One company can have several roles at the same time.

[SOURCE: ISO 17296-1[2)]]

4 Main characteristics and corresponding test methods

4.1 General

Each development and fabrication phase of a part has a specific purpose. The performance criteria determine the type of part and the choice of additive manufacturing process. This part of ISO 17296 develops the following main quality characteristics:

— feedstock:

  — bulk raw material requirements: powder particle size, morphology, surface and distribution, density (tap and apparent), flowability/pourability, ash content, and carbon content;

— parts:

  — surface requirements: appearance, surface texture, and colour;

  — geometric requirements: size, length and angle dimensions, dimensional tolerances, and geometrical tolerancing (deviations in shape and position);

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

  — build material requirements: density and physical and physico-chemical properties [microstructure analyses (non-destructive testing)].

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 part of ISO 17296:

— build material requirements: ductility;

— 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);

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— physical and physico-chemical properties (e.g. internal defaults, 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 Tables 1 to 3 shall be applied to guide the relation between customer and part provider, applicable for metal parts, plastic parts, and ceramic parts. These testing categories define the level of criticality of the parts:

— H: tests for highly engineered parts (safety critical);

— M: tests for functional parts that are not safety critical;

— L: tests for design or prototype parts.

For each testing category, the characteristics indicated (+) shall be fulfilled, the characteristics indicated (o) are recommended, and the characteristics indicated (-) are not applicable. An agreement between the customer and the part provider may exclude some of them due to specific applications of the part.

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.

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Table 1 — Metal parts

	Surface requirements			Geometric requirements		Mechanical requirements											Build material requirements	
	Appearance	Surface texture	Colour	Size, length and angle dimensions, dimensional tolerances	Geometrical tolerancing (deviations in shape and position)	Hardness	Tensile strength	Impact strength	Compressive strength	Flexural strength	Fatigue strength	Creep	Ageing	Frictional coefficient	Shear resistance	Crack extension	Density	Physical and physico-chemical properties
H	o	+	-	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+
M	o	o	-	+	+	+	+	+	+	o	o	o	-	o	o	o	+	o
L	o	o	-	+	+	+	+	o	o	o	-	-	-	-	o	-	+	-

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Table 2 — Plastic parts

	Surface requirements			Geometric requirements		Mechanical requirements											Build material requirements	
	Appea-rance	Sur-face tex-ture	Colour	Size, length and angle dimensions, dimensional tolerances	Geometrical tolerancing (deviations in shape and position)	Hard-ness	Tensile strength	Impact strength	Com-pressive strength	Flexural strength	Fatigue strength	Creep	Ageing	Frictio-nal coeffi-cient	Shear resis-tance	Crack exten-sion	Density	Physical and physico-chemical properties
H	o	+	o	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
M	o	o	o	+	+	+	+	+	+	o	o	o	o	o	o	o	+	o
L	o	o	o	+	+	+	+	o	o	o	-	-	-	-	o	-	+	-

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Table 3 — Ceramic parts

	Surface requirements			Geometric requirements		Mechanical requirements												Build material requirements	
	Appearance	Surface texture	Colour	Size, length and angle dimensions, dimensional tolerances	Geometrical tolerancing (deviations in shape and position)	Hardness	Tensile strength	Impact strength	Compressive strength	Flexural strength	Fatigue strength	Creep	Ageing	Frictional coefficient	Shear resistance	Crack extension	Density	Physical and physico-chemical properties
H	o	+	o	+	+	+	+	+	+	+	-	-	-	o	o	o	+	+
M	o	o	o	+	+	o	o	o	o	o	-	-	-	o	o	o	+	o
L	o	o	o	+	+	o	o	o	o	o	-	-	-	-	o	-	+	-

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4.3 Performance criteria and quality characteristics

Table 4 contains the list of main quality characteristics required from both materials and parts manufactured by additive manufacturing, with recommended International Standards. 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 International Standards.

NOTE Specific test methods, if necessary, are also the aim of future works in ISO/TC 261.

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 defined in ISO/ASTM 52915.

Table 4 — List of main quality characteristics and corresponding recommended test standards

Quality characteristics		Metal	Plastics	Ceramics
Feedstock				
Bulk raw material requirements	Powder particle size and distribution	ISO 4497 ISO 8130-1 ISO 13319 ISO 13320	ISO 4610 ISO 13319 ISO 13320	ISO 13319 ISO 13320 ISO 24235 ISO 14703
	Morphology	ISO 9276-6	ISO 9276-6	ISO 9276-6
	Surface	ISO 9277	ISO 9277	ISO 18757 ISO 9277
	Density (tap and apparent)	ISO 3923-2	ISO 1068	ISO 18753 ISO 23145-1 ISO 23145-2
	Flowability/ pourability	ISO 4490	ISO 6186 ISO 4324	ISO 14629
	Ash content	Not relevant	ISO 3451-1	Not relevant
	Carbon content	ISO 7625	No standard identified	Not relevant
Parts				
Surface requirements	Appearance	ISO 16348	ISO 16348	ISO 16348
	Surface texture	ISO 1302 (specification) ISO 4288 (measurement)	ISO 1302 (specification) ISO 4288 (measurement)	ISO 1302 (specification) ISO 4288 (measurement)
	Colour	ISO 11664-1 ISO 11664-2 ISO 11664-4 ISO 11664-5	ISO 11664-1 ISO 11664-2 ISO 11664-4 ISO 11664-5	ISO 11664-1 ISO 11664-2 ISO 11664-4 ISO 11664-5

[a] ISO/TC 261 will define specific standards for sample geometry and sample direction.

[b] Specific to implants for surgery.

[c] To be published.

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Table 4 *(continued)*

Quality characteristics		Metal	Plastics	Ceramics
Geometric requirements	Size, length and angle dimensions, dimensional tolerances	ISO 129-1 ISO 286-1 ISO 14405-1 (specification) ISO 1938-1[c] (measurement) ISO 2768-1	ISO 129-1 ISO 286-1 ISO 14405-1 (specification) ISO 1938-1[c] (measurement) ISO 2768-1	ISO 129-1 ISO 286-1 ISO 14405-1 (specification) ISO 1938-1[c] (measurement) ISO 2768-1
	Geometrical tolerancing (deviations in shape and position)	ISO 1101 (specification) + Isostatism ISO 2768-2	ISO 1101 (specification) + Isostatism ISO 2768-2	ISO 1101 (specification) + Isostatism ISO 2768-2
Mechanical requirements	Hardness	ISO 6507	ISO 2039 ISO 868	ISO 14705
	Tensile strength	ISO 6892-1[a]	ISO 527-1 ISO 527-2 ISO 527-3 ISO 527-4 ISO 527-5[a]	ISO 15490
	Impact strength	ISO 148-1 ISO 148-2 (charpy)[a]	ISO 179-1 ISO 179-2 (charpy)[a] ISO 180 (izod)	ISO 11491[b c]
	Compressive strength	ISO 4506	ISO 604	ISO 17162
	Flexural strength	ISO 3327	ISO 178	ISO 14704 ISO 14610
	Fatigue strength	ISO 1099 ISO 1143	ISO 13003 ISO 15850	ISO 22214 ISO 28704
	Creep	ISO 204	ISO 899-1 ISO 899-2	ISO 22215
	Ageing	Not relevant	ISO 4892-1 ISO 4892-2 ISO 4892-3 ISO 4892-4	Not relevant
	Frictional coefficient	No International Standard identified	ISO 6601	ISO 20808

[a] ISO/TC 261 will define specific standards for sample geometry and sample direction.

[b] Specific to implants for surgery.

[c] To be published.

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Table 4 *(continued)*

Quality characteristics			Metal	Plastics	Ceramics
Mechanical requirements		Shear resistance	ISO 148-1	ISO 14129	ISO 14129
		Crack extension	ISO 22889	ISO 15850	ISO 15732 ISO 18756 ISO 24370 ISO 23146
Build material requirements		Density	ISO 3369	ISO 1068	ISO 18754
	Physical and physico-chemical properties: microstructure analyses (non-destructive testing)	Radiographic examination	ISO 5579	Not relevant	Not relevant
		Penetrant testing	ISO 3452-1 ISO 3452-2	ISO 3452-1 ISO 3452-2	ISO 3452-1 ISO 3452-2
		Tomography	IEC 61675–1 IEC 61675–2	IEC 61675–1 IEC 61675–2	IEC 61675–1 IEC 61675–2
		Magnetic particle testing	ISO 9934-1	ISO 9934-1	ISO 9934-1

[a] ISO/TC 261 will define specific standards for sample geometry and sample direction.

[b] Specific to implants for surgery.

[c] To be published.

5 Part and process testing — Specifications and quality criteria

5.1 General

The quality of a part is determined by its suitability for a specific application and therefore by its ability to meet those specific requirements. Since parts need to satisfy a number of requirements, these shall be precisely defined during the design and order stage.

NOTE 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 material

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

5.3 Monitoring the process

All additive manufacturing processes are computer-assisted. Therefore, it is fundamentally possible to record and statistically analyse important process-related data such as process temperature, process environmental conditions, time lapse and process speeds, beam parameter and emitted radiation, and other process-related parameters. The need for and scope of process monitoring depends on the required or anticipated reproducibility of the process and part quality for each application. Process monitoring may be required by customer.

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The process stability can also be monitored repeatedly at different intervals at a constant geometry.

Test specimens for process monitoring should be as representative as possible compared to the part. Complementary test specimens could 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 defined 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 4.

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

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