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Additive manufacturing of polymers — Qualification principles — Classification of part properties

Fabrication additive de polymères — Principes de qualification — Classification des propriétés des pièces

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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

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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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 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).

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.

Introduction

The goal of this document is to improve the communication between providers and users of additive manufactured polymer parts in relation to the part quality to be supplied. For this purpose, quality criteria and part properties are categorised into a system of quality classes.

In the additive manufacturing processes relevant for polymers, the part properties depend very heavily on the machine systems, the material and the process control used. Typically, the process control can be optimised for productivity or quality. These goals are in principle contradictory in the context of the performance of a specific machine.

The property classes listed in this document help to make clear the differences in quality. The property classes enable the user to define part specifications for manufacturing.

Along with the specification of the property classes, this document states which property classes can be achieved with typical materials. Test specimens and their arrangement in the build space are specified (the related CAD data are included with this document as positioned STL data and amf data and available on: https://standards.iso.org/iso/52924/ed-1/en/). The determination of the mechanical tensile properties, the dimensional accuracy and the part density with the aid of these test specimens is described to make possible the assignment to property classes for the related characteristic values.

Additive manufacturing of polymers — Qualification principles — Classification of part properties

1 Scope

This document establishes the required or the achievable classes of part properties for additive manufactured polymer parts in order to get a common understanding on part quality. It is aimed at providers of manufacturing services for polymer parts who use additive manufacturing machines and at the customers for these services. Designers of parts as well as buyers and providers of manufacturing services can specify, in a traceable manner, the required or the achievable level of part properties with the aid of this document. The classification is based on mechanical, physical and geometrical properties. Further properties can be defined between buyer and provider of manufacturing.

This document is applicable to parts that have been manufactured from a thermoplastic polymer by means of thermal reaction fusion of material typically applied by a powder bed fusion (PBF) or material extrusion (MEX) processes. Certain processes within these categories have also been known under different process names and trademarks. For example, (for PBF) laser sintering when the fusion is enabled by a laser, -trademarked as SLS®, (selective laser sintering)[1)]. Other thermoplastic PBF trademarks include multi jet fusion (MJF) or high speed sintering where the fusion is enabled by infra-red light. MEX processes for thermoplastic polymers are also known by names such as fused layer modelling (FLM), fused layer manufacturing or fused filament fabrication (FFF). FDM (fused deposition modelling) is an existing trademark for this type of process. The mentioning of trademarks in this document are only for informative reasons and does not intend any form of endorsement of the mentioned products. The applicability of this document to thermoplastic part made by other processes shall be checked in the specific case.

The classification of part properties apply to parts in as-built condition, that have been unpacked from the build space, with all support structures removed, but prior to any post-processing operations.

Rather than comparing capabilities of hardware – material solutions based on common parameter set inputs, they should be compared based on part property outcomes. This document supplies a framework for comparison of those outcomes. The goal of such a comparison exercise should be one of “what does it take to get to particular class outcome". The benefit of this approach is to decouple the nuances of different hardware solution providers from the comparison process, allowing a focus on material property outcomes, which are much more impactful in terms of end user value.

Specific industries (e.g. aerospace and medical) typically specify additional requirements.

This document is not applicable to large printers with big layer heights.

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 37, *Rubber, vulcanized or thermoplastic — Determination of tensile stress-strain properties*

ISO 291, *Plastics — Standard atmospheres for conditioning and testing*

ISO 527-1, *Plastics — Determination of tensile properties — Part 1: General principles*

1) SLS® is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

ISO 527-2, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics*

ISO 10350-1, *Plastics — Acquisition and presentation of comparable single-point data — Part 1: Moulding materials*

ISO 17295, *Additive manufacturing — General principles — Part positioning, coordinates and orientation*

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
part density
ρ
density of a part in as-built condition

Note 1 to entry: The part density is calculated by the following formula:

$$\rho = \frac{m}{V} \tag{1}$$

where m is the mass of the sample and V is the nominal volume according to the external dimensions of the sample.

3.2
nominal material density
ρ_M
solid density of the part material, measured on a specimen free of pores

Note 1 to entry: In data sheets, the nominal material density is mostly stated as material density of compounded, injection molded or compression molded material.

3.3
relative part density
D
ratio of *part density* (3.1), and *nominal material density* ρ_M (3.2)

Note 1 to entry: The relative part density is calculated by:

$$D = \frac{\rho}{\rho_M} \tag{2}$$

4 Symbols and abbreviations

4.1 Symbols

The following symbols are used throughout this document:

Symbol	Designation	Unit

D	relative part density	%
m	part mass	g, kg
V	part volume	cm^3
ρ	part density	g/cm^3
P_M	nominal material density	g/cm^3

4.2 Abbreviations

The following abbreviations are used throughout this document:

ABS	acrylonitrile butadiene styrene
MEX	material extrusion
NW	non-tool related dimensions
PA6	polyamide 6
PA11	polyamide 11
PA12	polyamide 12
PAEK	polyaryletherketone
PC	polycarbonate
PE	polyethylene
PEI/PC	polyetherimide/polycarbonate blend
PP	polypropylene
TG	tolerance group
TPE	thermoplastic elastomer
TPA	thermoplastic copolyamide
TPC	thermoplastic polyester elastomer
TPU	thermoplastic polyurethane

5 Classification system

5.1 Definition of the classes of part property

Classes of part properties shall be established based on mechanical tensile properties, density and dimensional accuracy of manufactured parts.

To make the differences in quality during the additive manufacturing of polymer parts clearer and easier to communicate, the classification system shown in Table 1 shall be used.

This system classifies typical value ranges for important part characteristics and assigns these ranges to common materials for the powder bed fusion and material extrusion processes.

The classification system contains eleven different classes of part properties that are sequentially numbered from 0 to 10.

Material characteristic values determined as per typical standards from the tensile test (ISO 527-1 or for elastic materials ISO 37) and the density measurement in 7.4 are used as characteristic values. At the same time, the dimensional accuracy achievable with additive manufacturing is assigned to the tolerance classes according to ISO 20457 for dimensions that are not tool related.

Part property classes 0 to 10 cover ranges that can typically be achieved on consideration of all the material aspects of polymer-processing additive processes. Here each characteristic value shall be considered independent from the others and dependent on the part orientation. This means that each characteristic value can have a different class.

Table 1 — Classes of part properties for polymer parts from additive manufacturing

Characteristic value Unit		Tensile modulus MPa	Strength/ tensile strength MPa	Strain at break/ elongation at break %	Relative part density %	Dimensional accuracy
Test standard		ISO 527-1	ISO 527-1/ ISO 37	ISO 527-1/ ISO 37	according to 7.4	ISO 20457
Pro-per-ty class	Class 10	>8 000	>100	>200	>99,5	—
	Class 9	>6 000 ≤ 8 000	>85 ≤ 100	>100 ≤ 200	>99 ≤ 99,5	—
	Class 8	>5 000 ≤ 6 000	>70 ≤ 85	>50 ≤ 100	>98,5 ≤ 99	TG 1 NW
	Class 7	>4 000 ≤ 5 000	>60 ≤ 70	>35 ≤ 50	>97,5 ≤ 98,5	TG 2 NW
	Class 6	>3 000 ≤ 4 000	>50 ≤ 60	>25 ≤ 35	>95 ≤ 97,5	TG 3 NW
	Class 5	>2 500 ≤ 3 000	>45 ≤ 50	>20 ≤ 25	>92,5 ≤ 95	TG 4 NW
	Class 4	>2 000 ≤ 2 500	>40 ≤ 45	>15 ≤ 20	>90 ≤ 92,5	TG 5 NW
	Class 3	>1 500 ≤ 2 000	>30 ≤ 40	>10 ≤ 15	>85 ≤ 90	TG 6 NW
	Class 2	>1 000 ≤ 1 500	>20 ≤ 30	>5 ≤ 10	>80 ≤ 85	TG 7 NW
	Class 1	>500 ≤ 1 000	>10 ≤ 20	>3 ≤ 5	>70 ≤ 80	TG 8 NW
	Class 0	>0 ≤ 500	>0 ≤ 10	> 0 ≤ 3	>0 ≤ 70	TG 9

5.2 Typical classification of important material classes and usage of the classification system for part properties

The intention is to make the range of typical part properties for a material type and an additive manufacturing process distinguishable and comparable. To clarify this point, typical average classifications for important material classes for powder bed fusion and for material extrusion are summarised in Table 2 based on the state of the art and experts' experience.

The compilation shows that characteristic values cannot always be classified exactly in one grade. Due to differences between machines and variations in parameters, the related achievable characteristic values can fall into different classes. On the basis of Table 2, users of additive manufactured parts can compare the quality of parts from different providers, different machines and parameter sets by asking the part manufacturers on their classifications. The actual requirements on the specific parts can then be defined depending on the intended application of the final part using the classification system.

Table 2 — Examples for classifications for typical powder bed fusion and material extrusion materials

Charac-teristic value	Unit	Test standard st stand-ard	Characteristic value range	Class	PA 12 (PBF)		PA 11 (PBF)		PAEK (PBF)		TPA/TPC/TPU (PBF)		ABS (MEX)		PEI/PC (MEX)		PA 12 (MEX)	
			Alignment		XY/YX	ZX	XY/YX	ZX	XY/YX	ZX	XY/YX	ZX	XY/YX	ZX	XY/YX	ZX	XY/YX	ZX
Tensile modulus	MPa	ISO 527-1	<500	0							X	X						
			500 ≤ 1 000	1														
			1 000 ≤ 1 500	2													X	X
			1 500 ≤ 2 000	3	X	X	X	X									X	X
			2 000 ≤ 2 500	4									X	X		X		
			2 500 ≤ 3 000	5											X			
			3 000 ≤ 4 000	6					X	X								
			4 000 ≤ 5 000	7														
			5 000 ≤ 6 000	8														
			6 000 ≤ 8 000	9														
			>8 000	10														
Strain at break eng th/Strength/ Tensile strength	MPa	ISO 527-1/ ISO 37	<10	0							X	X						
			10 ≤ 20	1							X	X						
			20 ≤ 30	2										X		X		
			30 ≤ 40	3									X					X
			40 ≤ 45	4		X		X									X	X
			45 ≤ 50	5	X	X	X	X									X	X
			50 ≤ 60	6	X	X	X	X		X							X	
			60 ≤ 70	7					X	X								
			70 ≤ 85	8					X						X			
			85 ≤ 100	9														
			>100	10														
Strain at break ain at break/Elongation at break	%	ISO 527-1/ ISO 37	<3	0					X	X				X		X		
			3 ≤ 5	1											X			
			5 ≤ 10	2		X							X				X	X
			10 ≤ 15	3		X											X	
			15 ≤ 20	4	X	X		X									X	
			20 ≤ 25	5	X			X									X	
			25 ≤ 35	6				X									X	
			35 ≤ 50	7			X	X										
			50 ≤ 100	8							X	X						
			100 ≤ 200	9							X	X						
			>200	10							X	X						
Relative part density [a]	%	according to 7.4	<70	0														
			70 ≤ 80	1														
			80 ≤ 85	2														
			85 ≤ 90	3									X					
			90 ≤ 92,5	4							X		X		X			
			92,5 ≤ 95	5	X		X				X		X		X			
			95 ≤ 97,5	6	X		X		X		X				X		X	
			97,5 ≤ 98,5	7	X		X		X		X				X		X	
			98,5 ≤ 99	8	X		X		X		X						X	
			99 ≤ 99,5	9					X									
			>99,5	10														

[a] The component density is specified independent of orientation.

Table 2 *(continued)*

Charac-teristic value	Unit	Test standard st stand-ard	Characteristic value range	Class	PA 12 (PBF)		PA 11 (PBF)		PAEK (PBF)		TPA/TPC/ TPU (PBF)		ABS (MEX)		PEI/PC (MEX)		PA 12 (MEX)	
			Alignment		XY/YX	ZX	XY/ YX	ZX	XY/ YX	ZX	XY/ YX	ZX	XY/ YX	ZX	XY/ YX	ZX	XY/ YX	ZX
Dimensional accuracy		ISO 20457	TG 9	0														
			TG 8 NW	1														
			TG 7 NW	2									X	X	X	X	X	X
			TG 6 NW	3	X	X	X	X	X	X	X	X	X	X	X	X	X	X
			TG 5 NW	4	X	X	X	X	X	X	X	X	X	X	X	X	X	X
			TG 4 NW	5	X	X	X	X			X	X	X	X			X	X
			TH 3 NW	6														
			TG 2 NW	7														
			TG 1 NW	8														
				9														
				10														

[a] The component density is specified independent of orientation.

It shall be noted that the upper classes of part properties listed usually define the maximum values currently technically possible. The definition of a requirement for a specific material with a higher class is therefore not appropriate in this context and can only be achieved by a few specialists in exceptional cases. At the same time, it shall be noted that the information relates to the unfilled material types in each case.

6 Test specimens for determining the characteristic values for the classification system

6.1 General

To perform a classification in the established system in Clause 5, a sufficiently large data base must be created by producing and testing a sufficient number of suitable test specimens under specified conditions. These data can only be determined by measurements on a minimum number of at least 7 test specimens depending on the size of the build space. However, higher number of specimens leads to more detailed classification.

Test specimen shall be manufactured under defined process conditions and in particular with defined test specimen arrangements.

In systems with multiple lasers the overlap region may be considered, e.g. by building a set of test specimens in the overlap region.

Requirements established in 6.2 to 6.7 apply.

6.2 Tensile properties

Tensile test specimens in accordance with ISO 527-1 type 1A with a total length of at least 150 mm and a test cross-section of 4 mm × 10 mm shall be used. For elastic materials (TPE, TPA, TPC, TPU), a test specimen in accordance with ISO 37 type S2 shall be used.

An alternative type of test specimen may be used, in consultation between suppliers and customers and deviating from this document, only in machines with a smaller usable build space (longest build space edge or build space height less than 150 mm) on which the dimensions of the test specimens cannot be met. This deviation shall be stated with the information on the classification with the tensile bar used.

6.3 Dimensional accuracy

Bars with a cross-section of 5 mm × 10 mm and different test specimen lengths shall be manufactured. The lengths to be manufactured are around 24 mm, 40 mm, 65 mm, 100 mm and 150 mm and are therefore in the middle of the nominal dimension ranges to be checked according to ISO 20457. Before manufacturing, the length dimensions shall be adjusted to an integer multiple of the layer thickness used. This is done to exclude measurement deviations due to the layer thickness during classification. For this purpose the stated length dimensions are divided by the layer thickness, and the resulting number shall be rounded to the next whole number. This rounded number is in turn multiplied by the layer thickness. The resulting length is the test specimen length to be manufactured.

The larger lengths may be excluded, in consultation between suppliers and customers, only in machines with a smaller usable build space (longest build space edge or build space height less than 150 mm) on which the dimensions of the test specimens cannot be met. This deviation shall be stated with the information on the classification with the modified validity range.

6.4 Density

Cubes with an edge length of 20 mm shall be used.

6.5 Labelling

All test specimens (specimen for tensile tests, dimensional bars, density cubes) shall be unambiguously labelled such that the test specimens manufactured can be assigned unambiguously to the build position.

The labelling shall not distort the mass of the density cubes. This can be achieved, e.g. by attachment of easily removable flags to the STL file or the AMF file for the cube. Alternatively, the density cubes shall be manufactured without labelling and to be labelled using a permanent pen during part removal from the AM machine.

6.6 Orientation, grid arrangement, and distribution in the build space

6.6.1 General

To create a pool of data that is as comparable as possible between different suppliers, machines and materials for the classification system, the orientation, the grid arrangement, and the distribution of the test specimens in the build space during the build process shall be stated.

6.6.2 Orientation and grid arrangement to be used

For test specimen for tensile testing and dimensional accuracy in 6.2 and 6.3 different build orientations in the entire usable build area including the corner areas shall be taken into account.

For a flat orientation (orientation XY according to ISO 17295; alternatively YX for the case that during the powder bed fusion the powder is applied along the Y-axis), at least one test specimen per grid dimension of 100 mm × 200 mm, however at least seven test specimens in total shall be manufactured in the direction of the two main plane axes of the machine.

For an upright orientation (orientation ZX according to ISO 17295; alternatively ZY for the case that during the powder bed fusion the powder is applied along the Y-axis), at least one test specimen per grid dimension of 50 mm × 50 mm (powder bed fusion) or 100 mm × 100 mm (material extrusion) shall be manufactured. The same grid arrangement shall be used for density cubes in 6.1. At least seven test specimens in total shall be manufactured.

For the arrangement within the grid dimensions, the arrangements shown in Figure 1 (XY direction) and Figure 2 (ZX direction) shall be used for powder bed fusion and the arrangements shown in Figure 3 (XY direction) and Figure 4 (ZX direction) shall be used for material extrusion.

NOTE The related pre-positioned arrangements are provided with this document as CAD files and available on: https://standards.iso.org/iso/52924/ed-1/en/.

6.6.3 Distribution in the build space

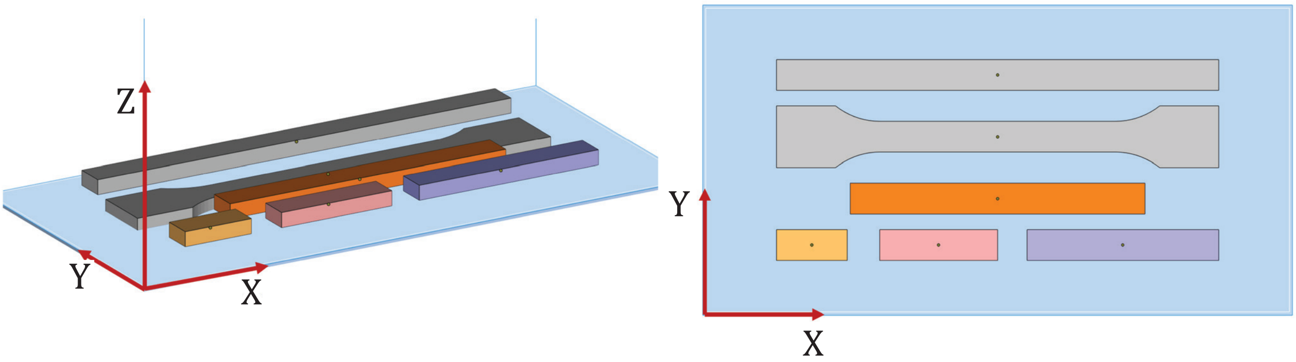
The test specimens shall be manufactured in the entire usable build area including the corner areas.

If, due to the size of the build space and the usage of the grid arrangement, open areas exist that are smaller than the grid at one or two build space edges, the arrangement shall be modified as follows:

The next grid field shall be added in each direction.

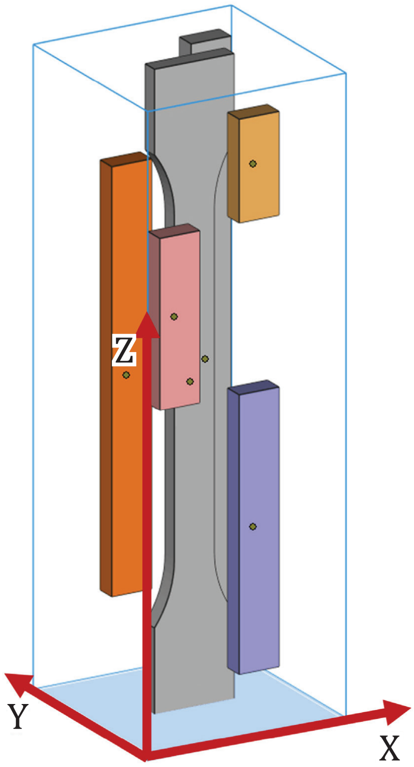
The entire arrangement shall be centred.

If the next grid field along an edge is at least 50 % inside the build area where building is possible, the distances between the individual grid arrangements shall be reduced uniformly in such a way that all test specimens (tensile bars, dimensional accuracy test specimens, density cubes) are in the build space where building is possible.



a) View from top front b) View from above

Figure 1 — Grid arrangement XY test specimens during powder bed fusion



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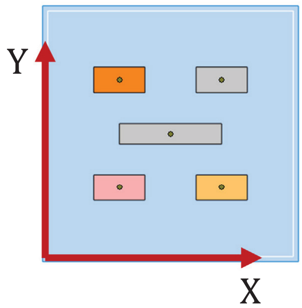
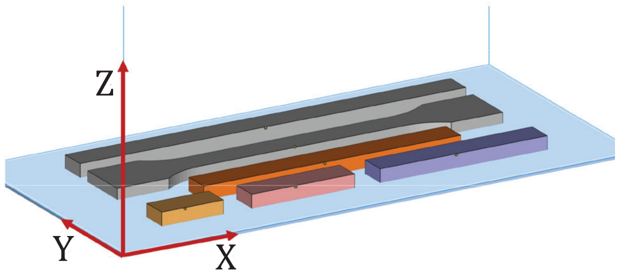


b) View from above

Figure 2 — Grid arrangement ZX test specimens during powder bed fusion



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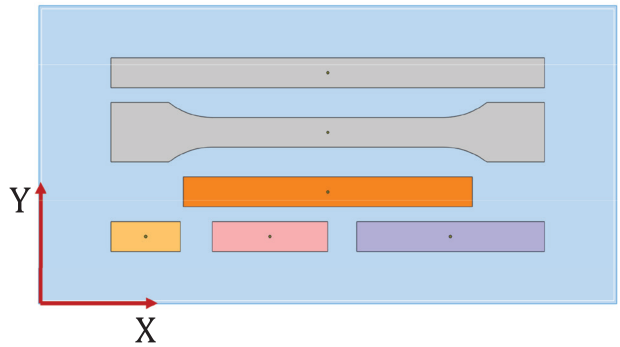
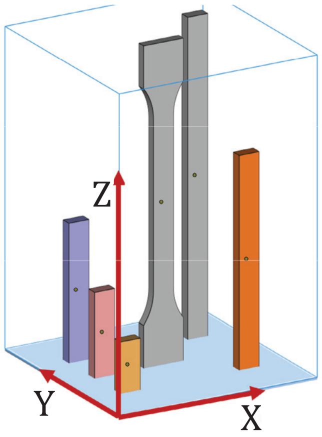
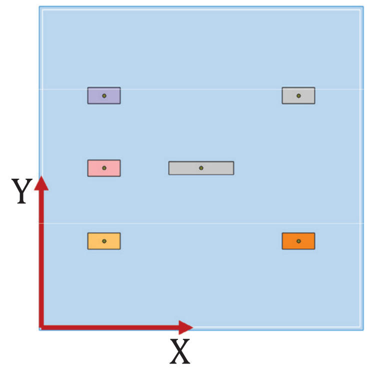


b) View from above

Figure 3 — Grid arrangement XY test specimens during material extrusion



a) View from top front



b) View from above

Figure 4 — Grid arrangement ZX test specimens during material extrusion

— If, after centering, less than 50 % of the additional grid field is within the build area where building is possible, the arrangement shall be expanded by increasing the distances until an even distribution is achieved.

— If the minimum number of test specimens does not fit in the machine's build area on maintaining the grid dimensions, the distances between the parts shall be correspondingly reduced.

— If, despite reducing the spacing between the parts, the build space in a machine is still not adequate to manufacture the minimum number of grid arrangements in one plane, they may be distributed over several layers or several build cycles.

Figure 5, Figure 6 and Figure 7 show the application of the instructions on the distribution in the build space for an example machine during powder bed fusion (size of build area 700 mm × 380 mm).

Figure 5 shows the multiplication of the grid dimensions in 6.6.2 for the XY plane.

Figure 6 shows the corrected and centred arrangement from Figure 5.

Figure 7 shows a corrected and centred arrangement for the grid arrangement in the ZX direction.

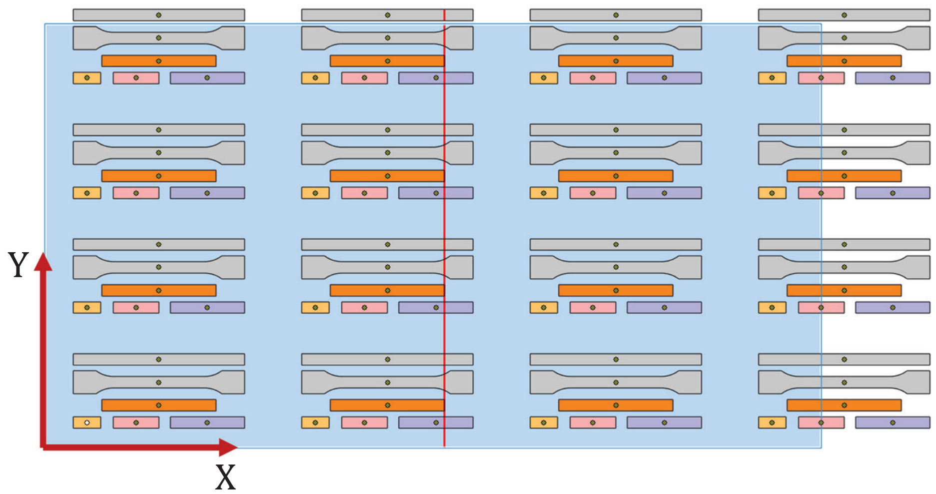


Figure 5 — Multiplied grid arrangement for test specimens in XY direction for an example machine during powder bed fusion (build area size 700 mm × 380 mm)

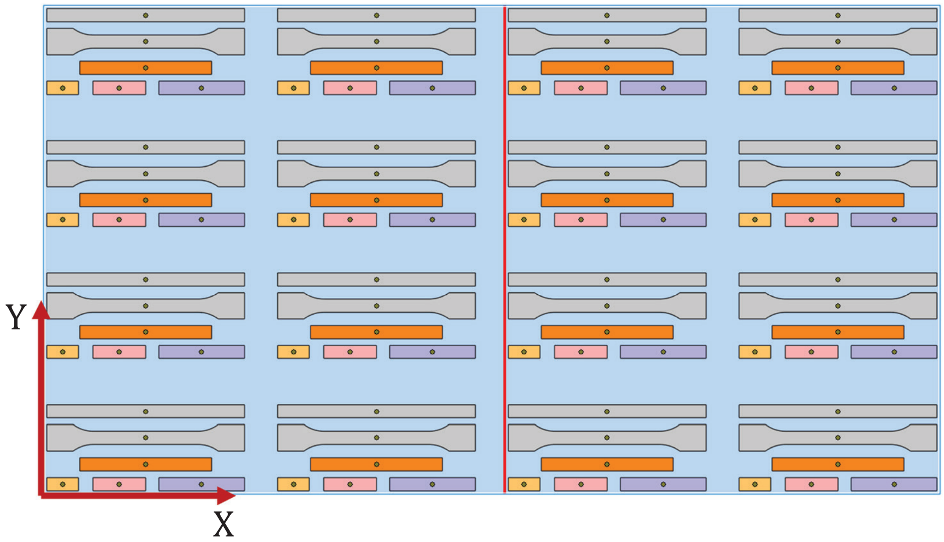


Figure 6 — Corrected and centred grid arrangement from Figure 5 for test specimens in XY direction for an example machine during powder bed fusion (build area size 700 mm × 380 mm)

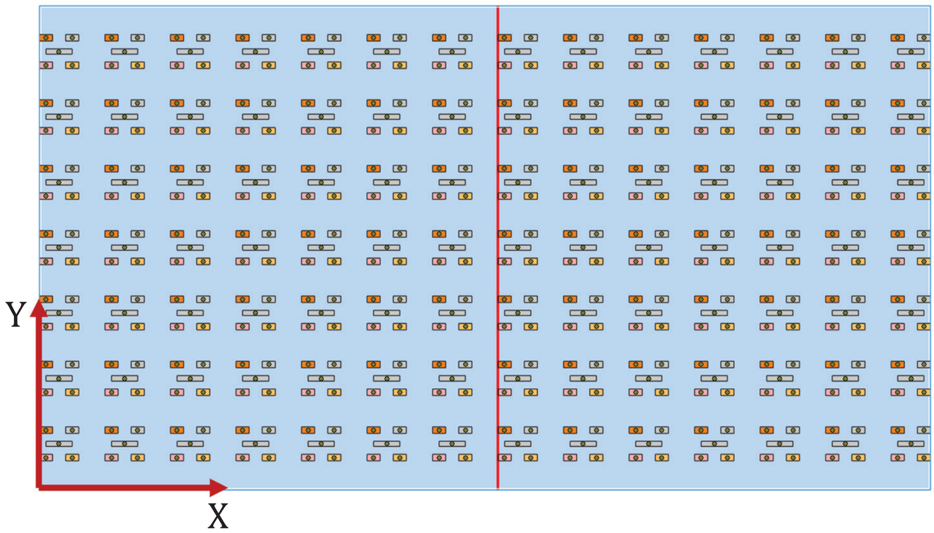


Figure 7 — Corrected and centred grid arrangement for test specimens in ZX direction for an example machine during powder bed fusion (build area size 700 mm × 380 mm)

The parts shall be positioned at the start of a build cycle after completion of the warm-up layers (powder bed fusion) or the generation of the supports (material extrusion), where test specimens in the XY and ZX direction as well as density cubes may be manufactured in the same build cycle with a height spacing of 4 mm starting with the XY test specimens. This statement applies in particular to powder bed fusion. In relation to the positioning of the test specimens in the build space, the minimum Z coordinate shall be selected as a multiple of the layer thickness.

In the build cycle, no other parts than the parts to be manufactured to determine the characteristic values for the classification system should be build. In material extrusion, suitable support structures may be added to ensure robust process control during the manufacturing of the test specimens. Here the usage of supporting material in the test area for the test specimen for tensile testing shall be avoided.

During the arrangement of the test specimen, for some powder bed fusion machines attention shall be paid to an arrangement as per a possibly fixed hatch line layout. In this situation the position of the laser, scan and hatch lines in the build area is fixed, i.e. all scan lines for hatching the parts are calculated from one point (0 point) and are distributed equidistantly across the build area. For such machines all parts should align with this layout (= positioning to suit the hatch lines). This means that the distances between parts that are the same (e.g. Z test specimen for tensile testing) should be an integer multiple of the hatch distance. In this way it is ensured that all parts compared with each other also contain the same number of hatch lines.

Furthermore, the parts shall then be aligned such that hatch lines parallel to the outer sides of the part are an identical distance from the two outer sides. For other machines, the calculation of the hatch lines is always equidistant distributed within the part contour. If in doubt contact the machine manufacturer to establish whether such a fixed hatch line layout is used.

6.7 Manufacturing

Because the parameter set and the class of part properties used correlate directly, classes of part properties can always only be stated for a specific parameter set. From there, the application of the classification system requires that parts to be supplied and the test specimens for the classification system are manufactured with the same parameter set and the same subsequent process-typical cleaning process (cooling time, powder or support removal, blasting in case of powder bed fusion).

The class of part properties shall be determined from parts in as-built condition.

In relation to the determination of the relative part density values in 6.4 and 7.4, a densely arranged filling pattern (maximum percentage fill) shall be used for material extrusion. Less dense filling patterns may also be used to determine the classification of the mechanical properties as well as the dimensional accuracy. However, if there are excessively large hollow spaces in the filling pattern, such a pattern can no longer be used meaningfully to determine mechanical characteristic values in the Z direction or the dimensional accuracy as per the methodology in this document. If such a parameter set is used, the quality of parts manufactured in this manner shall be defined in consultation between provider and user.

If several different parameter sets are used at the same time (e.g. involving different layer thicknesses), corresponding classes of part properties shall be determined for each of these parameters. Characteristic values determined using test specimens do not permit direct conclusions as to the part properties, because other manufacturing effects and the geometry can also have an effect on the characteristic values. However, based on the classes of part properties, statements can be made as to the quality to be expected under standardised conditions. Dedicated classifications shall be determined for individual machines and material systems.

7 Determination of characteristic values and classification in the classification system

7.1 General

To build up comparable data records, the methods set out in this clause shall be applied. An example of a form containing all data required for classes of part properties specification is given in Annex A.

7.2 Mechanical properties

7.2.1 General

To determine classes of properties for the mechanical characteristics, proceed as described in 7.2.2 and 7.2.3.

7.2.2 Determination of characteristic values

7.2.2.1 General

A tensile test in accordance with ISO 527-1 with the measuring conditions from ISO 10350-1 or for TPEs a tensile test in accordance with ISO 37 with measuring conditions form ISO 10350-1 shall be undertaken.

7.2.2.2 Conditioning during powder bed fusion

If the material has a tendency to absorb moisture, test the specimen under the standard climate according to ISO 291 for as build parts. In terms of this test procedure as build state is the state of a cooled part after the end of the powder bed fusion process immediately after unpacking.

NOTE 1 Powder bed fusion parts as manufactured are generally dry.

NOTE 2 The powder bed fusion part as build state exists for the materials PA12, PA11, PP, PE, PAEK, TPE in the following conditions:

— The build job is cooled to room temperature in a nitrogen atmosphere, where the supply of air during cooling until the parts are unpacked shall be avoided if possible or reduced to a minimum.

— The parts are unpacked within three days of the end of the build job.

— The parts have been subjected to the air for a maximum of 4 h since the start of part removal.

— The parts removed are stored with the exclusion of air, e.g. in air-tight and moisture-tight packaging.

As an optional, additional method for the determination of characteristic values, test specimens can be tested in the conditioned state. The conditioning of the specimens shall be undertaken according to the requirements of the material supplier.

Based on experience, the minimum conditioning time in the standard climate according to ISO 291 should be 30 days for powder bed fusion PA12 and PA11 specimens. After this time no more significant characteristic value changes are expected, although after 30 days a moisture equilibrium has not yet become established in the part.

7.2.2.3 Conditioning for material extrusion

Test the specimen in the standard climate in accordance with ISO 291. If test specimens from material extrusion from materials such as ABS, PC, or PEI/PC are stored in the washing bath to remove support constructions, it does not affect the characteristic values of the parts. The determination of the characteristic values is therefore independent of the moisture content. On the other hand, for polyamide materials (PA6 and PA12) conditioning as per the requirements from the material supplier shall achieve adequate moisture absorption and therefore the application-related characteristics of the material.

7.2.2.4 Test speed

The test speed during the tensile test has a major effect on the resulting characteristic values of polymer parts. The test speed is defined in ISO 10350-1. For additive manufactured polymer specimens, the mean value of the strain at break in the XY direction defines the test speed to be chosen for all part orientations. This applies even if there are lower strain at break values without a yield point in the build direction (ZX direction). If the mean value of the strain at break in the XY direction is over 10 %, all specimens are drawn at 50 mm/min independent of the sample orientation. If the mean value is below 10 % and a yield point is not achieved, the test speed is 5 mm/min. For elastomeric polymers (TPE), the measuring conditions set out in ISO 37 apply using a test speed of 200 mm/min.

7.2.3 Classification in the classification system

The classification in the classification system is undertaken as per the mean characteristic values measured. The test and conditioning parameters are always to be stated with the class information. On stating the class, it is also possible to differentiate between different parts of the build area. The percentage portion of the characteristic values that falls in a certain class is then stated.

7.3 Dimensional accuracy

7.3.1 General

To determine the classes of material properties for the dimensional accuracy, proceed as described in 7.3.2 and 7.3.3.

7.3.2 Determination of characteristic values

The parts manufactured shall be measured for the categorisation of the dimensional accuracy classes. Here the measuring instrument used shall have a highest permissible measuring uncertainty of ±0,1 mm for dimensions >10 mm in accordance with ISO 16012. For statistical evaluation, the length dimension shall be measured at least three times for manual measurement (eg calipers) on each test specimen manufactured. If a gage-r&r-validated measuring system is used one measurement per test specimen is sufficient. The characteristic value for the length dimension is the mean of the three measured values. Attention shall be paid to implementation as precise as possible both during part cleaning (in particular the removal of the support structure for material extrusion) and during the measurement, because otherwise implementation-related deviations can occur. All measured values are used to establish the classes.

7.3.3 Classification in the classification system

The classification in the classification system is initially undertaken separately for each nominal dimension range based on the maximum deviation determined from all test specimens. This shall be determined as the difference between the measured value and the nominal value modified to suit the layer thickness (see 6.3). The related tolerance group for non-tool related dimensions (NW) is determined according to the maximum deviation by comparison with the limit dimensions in ISO 20457 for the five nominal dimension ranges considered. The highest resulting tolerance group for all five ranges defines the classification in the class of part properties. On stating the class, it can be differentiated between different parts of the build area. The percentage of the characteristic values that fall into a certain class is then specified.

7.4 Relative part density

7.4.1 General

To determine the class of part properties for the part density, proceed as described in 7.4.2 and 7.4.3.

7.4.2 Determination of characteristic values

The part density is determined by measuring and weighing according to Formula (1) and Formula (2). The dimensions in the three spatial directions shall be determined separately using an external micrometre (measuring uncertainty <0,02 mm) in the middle of the cube surfaces. The mass shall be determined using a balance with a maximum measuring uncertainty of 0,01 g.

7.4.3 Classification in the classification system

The classification in the classification system is undertaken as per the mean characteristic values measured. On stating the class, it can be differentiated between different parts of the build area. The percentage of the characteristic values that fall into a certain class is then specified.

7.5 Classification in classes of part properties

After the determination of the classifications in 7.2 to 8.4, the part property classifications according to this document shall be stated according to the example in Table 3.

Table 3 — Example part properties classification for PA12 for powder bed fusion

Classes of part properties according to this document – General information		
Material	PA12 (manufacturer's product identifier)	
AM machine	Manufacturer's type identifier	
Parameter set	parameter set identifier	
Test specimens for mechanical characteristics	ISO 527-2 type 1A or as in Clause 6	
Tensile bar conditioning for mechanical characteristics	powder bed fusion parts as-built or e.g. 30 days in standard climate according to ISO 291 or unconditioned (only for materials not affected by moisture)	
Test conditions for determining mechanical properties	ISO 527-1 and ISO 10350-1 at 50 mm/min test speed	
Largest nominal dimension range considered according to ISO 20457 (dimensional accuracy validity range)	120 mm or 180 mm	
Part properties classification according to this document		
Characteristic values	XY plane	ZX direction
Tensile modulus	class 3	class 3
Strength/ Tensile strength	class 5	class 5
Strain at break/ Elongation at break	class 5	class 3 (class 4 for 70 % of the characteristic values)
Relative part density	class 7	
Dimensional accuracy	class 3 (class 4 for 80 % of the characteristic values)	class 3 (class 4 for 70 % of the characteristic values)

8 Initial classification and regular checking of the classifications

8.1 Standard classification procedure

The classification in the classification system shall be done by undertaking the initial classification in 8.2. Then they shall be checked regularly (see 8.3).

8.2 Initial classification

To classify the classes of part properties, the qualification build processes described in Clause 6 shall be undertaken at least twice, and the corresponding classes shall be determined for the characteristic values described. However, repetition three times shall be preferred for statistical evaluation.

8.3 Regular checking

The ageing of machines will cause a change in the characteristic values that can be achieved. Therefore, the part property classifications shall be checked regularly.

To check the part property classifications, a check per machine shall be made and evaluated every six months or after 180 build cycles, whichever comes first, with the single implementation of the qualification build processes in Clause 6.

If significant deviations occur during this process (a change of at least two characteristic classifications), initial classification in 8.2 shall be determined. In any case, even a single change in a characteristic value classification shall be stated in the form of an update to the classifications in Clause 7.

8.4 Renewed determination of the classifications in case of replacement of relevant machine components

Some machine components have a major effect on the characteristic values that can be achieved during part manufacturing. The replacement of such relevant components due to faults or ageing can therefore result in a significant change in the characteristic values or characteristic value distributions. For the powder bed fusion and material extrusion processes considered in this document the following components are identified as relevant:

— powder bed fusion with laser beam (PBF-LB): laser, scanning head, heaters, machine axes and machine drives (X-axis, Y-axis, rotation axis, Z-axis), machine relocation and new installation of the machine, process-relevant software updates; peripherals (mixer, sieving machine);

— material extrusion with thermal reaction bonding (MEX-TRB): machine axes and machine drives (X-axis, Y-axis, Z-axis, robots, etc.), extrusion head (motors, die), renewed installation of the machine, process-relevant software updates.

In case of replacement of such relevant components, a differentiation is also to be made as to whether the change is a pure replacement or the machine is upgraded. In case of pure replacement of a component with the same type, only a regular check according to 8.3 shall be undertaken. If significant deviations occur during this process (a change of at least two characteristic classifications), initial classification in 8.1 shall be determined. In any case, even a single change in a characteristic value classification shall be stated in the form of an update to the classifications in Clause 7. If the machine is upgraded with new relevant components of a different type, in general renewed determination of the classification according to 8.1 shall be undertaken.

For material extrusion, although the die represents a relevant component, if the die replacement interval is respected as per the requirements of the die supplier and material supplier, and the same die type is used on replacement, no measurable deviations should occur. If there are no requirements in relation to the die replacement intervals, the AM machine user shall monitor the wear on the die. Ahead of any build job, the die shall be visually inspected for possible damage and soiling. On some machine systems available on the market, the material throughput through the die is also monitored; larger deviations result in the output of an error message. In this situation, the classifications shall not be checked on each replacement if frequent die replacements are necessary. Here checking shall be performed at least in the context of the regular checking according to 8.3. On the other hand, a die replacement can result in larger deviations on machines without monitoring of the material throughput.

Annex A
(informative)

Form for part property classification according to this document

Table A.1 shows a form for inserting all data required for classes of part property specification.

Table A.1 — Form for part property classification

Classes of part properties according to this document – General information		
Material		
AM machine		
Parameter set		
Test specimens for mechanical characteristics		
Tensile bar conditioning for mechanical characteristics		
Test conditions for determining mechanical properties		
Largest nominal dimension range considered according to ISO 20457 (dimensional accuracy validity range)		
Part property classification according to this document		
Characteristic values	XY plane	ZX direction
Tensile modulus		
Strength/ Tensile strength		
Strain at break/ Elongation at break		
Relative part density		
Dimensional accuracy		
NOTE See data carrier.		

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