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Additive manufacturing — Qualification principles — Classification of part properties for additive manufacturing of polymer parts

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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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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.

The committee responsible for this document is 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.

This is the first edition of this document.

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 standard 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 standard 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.). 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 — Qualification principles — Classification of part properties for additive manufacturing of polymer parts

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 standard.

This document applies to parts that have been manufactured from a thermoplastic polymer by means of powder bed fusion with laser for polymers (PBF-LB/P), alternatively named laser sintering (LS) or material extrusion (MEX). Its applicability to other processes for polymers shall be checked in the specific case.

NOTE Laser sintering is also known as *selective laser sintering* (SLS®).

NOTE The process called *material extrusion* (MEX) in ISO/ASTM 52900 is also known as *fused layer modelling* (FLM), *fused layer manufacturing* or *fused deposition modelling* (FDM) or *fused filament fabrication* (FFF).

The classification of part properties apply to parts that have not been post-processed after unpacking from the build space and after removing possible support structures.

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 37:2017, *Rubber, vulcanized or thermoplastic — Determination of tensile stress-strain properties*

ISO 291:2008, *Plastics — Standard atmospheres for conditioning and testing*

ISO 527-1:2012, *Plastics - Determination of tensile properties - Part 1: General principles*

ISO 3167:2014, *Plastics — Multipurpose test specimens*

ISO 10350-1:2017, *Plastics — Acquisition and presentation of comparable single-point data — Part 1: Moulding materials*

ISO 20457:2018, *Plastics moulded parts — Tolerances and acceptance conditions*

ISO/ASTM 52900:2018, *Additive manufacturing; General principles — Terminology*

ISO/ASTM 52921:2013-06, *Standard terminology for additive manufacturing - Coordinate systems and test methodologies*

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 terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
part density
ρ
ratio of part mass, *m,* and measured part volume, *V,* of a laser sintered or material extruded part

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

Note 1 to entry: The part is generally cubeshaped.

3.2
laser sintered as manufactured
state of a cooled part after the end of the laser sintering process immediately after unpacking

Note 1 to entry: Laser sintered parts as manufactured are generally dry.

Note 2 to entry: The laser sintered part as manufactured 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.

3.3
nominal material density
ρ_M
solid density of the feedstock, 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.

3.4
relative part density
D
ratio of part density, *ρ* (3.1), and nominal material density, ρ_M (3.3)

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

4 Symbols and abbreviations

4.1 Symbols

The following symbols are used throughout this standard:

Symbol	Designation	Unit
D	relative part density	%
m	part mass	g, kg
V	part volume	cm^3

Symbol	Designation	Unit
ρ	part density	g/cm^3
ρ_M	nominal material density	g/cm^3

4.2 Abbreviations

The following abbreviations are used throughout this standard:

ABS	acrylonitrile butadiene styrene
LS	laser sintering
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 *laser sintering* 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.

The part property classes in the 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 — (1 of 3)— Classes of part properties for polymer parts from additive manufacturing

Characteristic value		Tensile modulus	Strength/ Tensile strength	Strain at break/ Elongation at break	Relative part density	Dimensional accuracy
Unit		MPa	MPa	%	%	
Test standard		ISO 527-1/	ISO 527-1/ ISO 37	ISO 527-1/ ISO 37	acc. to 8.3	ISO 20457
Property 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 classifications for important material classes for laser sintering 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, the quality of parts from different providers and parameter sets can be compared and requirements on the specific parts can be defined.

Table 2 — (2 of 3)— Examples for classifications for typical laser sintering and material extrusion materials

Characteristic value	Unit	Test standard	Characteristic value range	Class	PA 12 (LS)		PA 11 (LS)		PAEK (LS)		TPA/TPC/TPU (LS)		ABS (MEX)		PEI/PC (MEX)		PA 12 (MEX)	
			Alignment		XY	ZX	XY	ZX	XY	ZX	XY	ZX	XY	ZX	XY	ZX	XY	ZX
Tensile modulus	MPa	ISO 527-1/	< 500	0							X	X						
			500≤1000	1														
			1000≤1500	2													X	X
			1500≤2000	3	X	X	X	X									X	X
			2000≤2500	4									X	X		X		
			2500≤3000	5											X			
			3000≤4000	6					X	X								
			4000≤5000	7														
			5000≤6000	8														
			6000≤8000	9														
			> 8000	10														
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/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 8.3	< 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.

