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

*Fabrication additive des polymères — Principes de qualification — Classification des propriétés de la pièce*



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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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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.

This document refers to parts produced by PBF and 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.

Rather than comparing capabilities of hardware, material solutions based on common parameter set inputs, are compared based on part property outcomes. This document supplies a framework for comparison of those outcomes. The goal of such a comparison exercise is one of “what does it take to get to a 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.

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.

# 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. This document is also applicable to thermoplastic parts made by other processes, provided that due consideration is given to process-specific topics.

The classification of part properties applies 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.

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



## 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*

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[2)], *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.

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

 

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:

$$\rho = \frac{m}{V} \qquad (1)$$

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**
$\rho_M$
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* $\rho_M$ (3.2)



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

$$D = \frac{\rho}{\rho_M} \qquad (2)$$

# 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 | $cm^3$ |
| $\rho$ | 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 in accordance with 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 | | 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 | In accordance with 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 | 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 | | | | | | | | | | | | | | |

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

**Table 2** *(continued)*

| Characteristic value | Unit | Test standard | 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 |
| Strain at break/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] | % | in accordance with 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 | | | | | | | | | | | | | | |
| 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