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Additive manufacturing — Design —

Part 2:
Laser-based powder bed fusion of polymers

Fabrication additive — Conception —

Partie 2: Fusion laser sur lit de poudre polymère

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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.

This document was prepared by Technical Committee ISO/TC 261, *Additive manufacturing*, in cooperation with ASTM 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.

A list of all parts in the ISO 52911 series can be found on the ISO website.

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

Laser-based powder bed fusion of polymers (LB-PBF/P) describes an additive manufacturing (AM) process and offers an additional manufacturing option alongside established processes. LB-PBF/P has the potential to reduce manufacturing time and costs, and increase part functionality. Practitioners are aware of the strengths and weaknesses of conventional, long-established manufacturing processes, such as cutting, joining and shaping processes (e.g. by machining, welding or injection moulding) and of giving them appropriate consideration at the design stage and when selecting the manufacturing process. In the case of LB-PBF/P and AM in general, design and manufacturing engineers only have a limited pool of experience. Without the limitations associated with conventional processes, the use of LB-PBF/P offers designers and manufacturers a high degree of freedom and this requires an understanding about the possibilities and limitations of the process.

The ISO 52911 series provides guidance for different powder bed fusion (PBF) technologies. It is intended that the series will include ISO 52911-1 on laser-based powder bed fusion of metals (LB-PBF/M), this document on LB-PBF/P, and ISO 52911-3[1)] on electron beam powder bed fusion of metals (EB-PBF/M). Clauses 1 to 5, where general information including terminology and the PBF process is provided, are similar throughout the series. The subsequent clauses focus on the specific technology.

This document is based on VDI 3405-3:2015[8]. It provides support to technology users, such as design and production engineers, when designing parts that need to be manufactured by means of LB-PBF/P. It will help practitioners to explore the benefits of LB-PBF/P and to recognize the process-related limitations when designing parts. It also builds on ISO/ASTM 52910[4] to extend the requirements, guidelines and recommendations for AM design to include the PBF process.

1) Under preparation.

Additive manufacturing — Design —

Part 2: Laser-based powder bed fusion of polymers

1 Scope

This document specifies the features of laser-based powder bed fusion of polymers (LB-PBF/P) and provides detailed design recommendations.

Some of the fundamental principles are also applicable to other additive manufacturing (AM) processes, provided that due consideration is given to process-specific features.

This document also provides a state-of-the-art review of design guidelines associated with the use of powder bed fusion (PBF) by bringing together relevant knowledge about this process and by extending the scope of ISO/ASTM 52910.

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/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 terminological databases for use in standardization at the following addresses:

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

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

3.1
downskin area
D
(sub-)area where the normal vector $\vec{n}$ projection on the z-axis is negative

Note 1 to entry: See Figure 1.

3.2
downskin angle
δ
angle between the plane of the build platform and the *downskin area* (3.1)

Note 1 to entry: The angle lies between 0° (parallel to the build platform) and 90° (perpendicular to the build platform).

Note 2 to entry: See Figure 1.

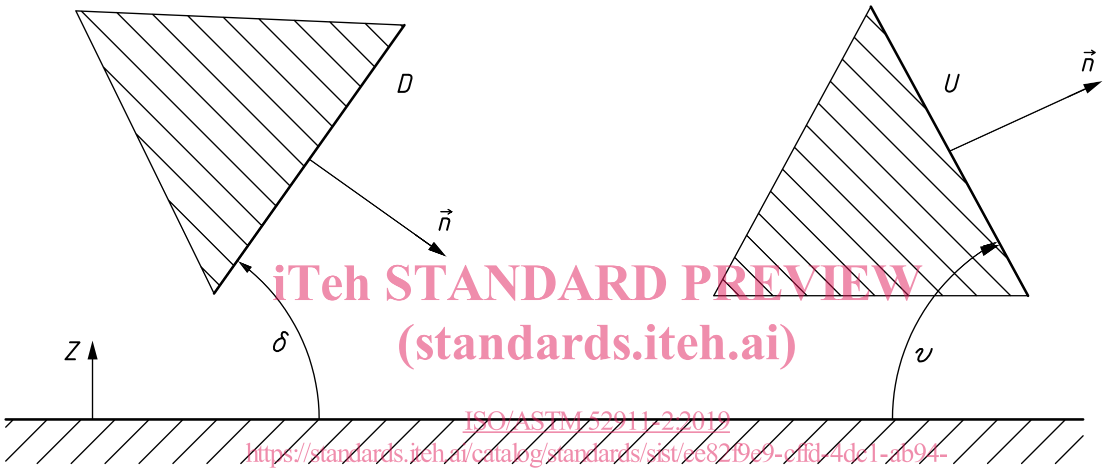
3.3
upskin area
U
(sub-)area where the normal vector $\vec{n}$ projection on the z-axis is positive

Note 1 to entry: See Figure 1.

3.4
upskin angle
υ
angle between the build platform plane and the *upskin area* (3.3)

Note 1 to entry: The angle lies between 0° (parallel to the build platform) and 90° (perpendicular to the build platform).

Note 2 to entry: See Figure 1.



Key

z build direction

SOURCE VDI 3405-3:2015.

Figure 1 — Upskin and downskin areas *U* and *D*, upskin and downskin angles *υ* and *δ*, normal vector $\vec{n}$

4 Symbols and abbreviated terms

4.1 Symbols

The symbols given in Table 1 are used in this document.

Table 1 — Symbols

Symbol	Designation	Unit
a	overhang	mm
D	downskin area	mm^2
I	island	mm^2
$\vec{n}$	normal vector	—
P	part	mm^3

Table 1 *(continued)*

Symbol	Designation	Unit
Ra	mean roughness	µm
Rz	average surface roughness	µm
U	upskin area	mm^2
δ	downskin angle	°
υ	upskin angle	°

4.2 Abbreviated terms

The following abbreviated terms are used in this document.

AM additive manufacturing

AMF additive manufacturing file format

CT computed tomography

DICOM digital imaging and communications in medicine

CAD computer aided design

EB-PBF/M electron beam powder bed fusion of metals

LB-PBF laser-based powder bed fusion

LB-PBF/M laser-based powder bed fusion of metals (also known as e.g. laser beam melting, selective laser melting)

LB-PBF/P laser-based powder bed fusion of polymers (also known as e.g. laser beam melting, selective laser melting)

MRI magnetic resonance imaging

PBF powder bed fusion

STL stereolithography format or surface tessellation language

3MF 3D manufacturing format

5 Characteristics of powder bed fusion (PBF) processes

5.1 General

Consideration shall be given to the specific characteristics of the manufacturing process used in order to optimize the design of a part. Examples of the features of AM processes which need to be taken into consideration during the design and process planning stages are listed in 5.2 to 5.8.

5.2 Size of the parts

The size of the parts is limited by the working area/working volume of the PBF-machine. Also, the occurrence of cracks and deformation due to residual stresses limits the maximum part size. Another important practical factor that limits the maximum part size is the cost of production having a direct relation to the size and volume of the part. Cost of production can be minimized by choosing part location and build orientation in a way that allows nesting of as many parts as possible. Also, the cost of powder needed to fill the bed to the required volume (part depth × bed area) may be a consideration.

Powder reuse rules impact this cost significantly. If no reuse is allowed, then all powder is scrapped regardless of solidified volume.

5.3 Benefits to be considered in regard to the PBF process

PBF processes can be advantageous for manufacturing parts where the following points are relevant:

— Parts can be manufactured to near-net shape (i.e. close to the finished shape and size), without further post processing tools, in a single process step.

— Degrees of design freedom for parts are typically high. Limitations of conventional manufacturing processes do not usually exist, e.g. for:

  — tool accessibility, and

  — undercuts.

— A wide range of complex geometries can be produced, such as:

  — free-form geometries, e.g. organic structures[17],

  — topologically optimized structures,

  — infill structures, e.g. honeycomb, sandwich and mesh structures.

— The degree of part complexity is largely unrelated to production costs.

— Assembly and joining processes can be reduced through single-body construction.

— Overall part characteristics can be selectively configured by adjusting process parameters locally.

— Reduction in lead times until part production.

5.4 Limitations to be considered in regard to the PBF process

Certain disadvantages typically associated with AM processes shall be taken into consideration during product design.

— Shrinkage, residual stress and deformation can occur due to local temperature differences.

— The surface quality of AM parts is typically influenced by the layer-wise build-up technique (stair-step effect). Post-processing can be required, depending on the application.

— Consideration shall be given to deviations from form, dimensional and positional tolerances of parts. A machining allowance shall therefore be provided for post-production finishing. Specified geometric tolerances can be achieved by precision post-processing.

— Anisotropic characteristics typically arise due to the layer-wise build-up and shall be taken into account during process planning.

— Not all materials available for conventional processes are currently suitable for PBF processes.

— Material properties can differ from expected values known from other technologies like injection moulding and casting. Material properties can be influenced significantly by process settings and control.

5.5 Economic and time efficiency

Provided that the geometry permits a part to be placed in the build space in such a way that it can be manufactured as cost-effectively as possible, various different criteria for optimization are available depending on the number of units planned.

— In the case of a one-off production, height is the factor that has the greatest impact on build costs. Parts shall be oriented in such a way that the build height is kept to a minimum, provided that the geometry permits such an orientation.

— If the intention is to manufacture a larger number of units, then the build space shall be used as efficiently as possible. Provided that the part geometry permits such orientation, strategies for reorientation and nesting shall be utilized to maximize the available build space.

— The powder that remains in the system after a build can be reused in some cases. Reuse depends on the application, material, and specific requirements. Powder changes can be inefficient and time consuming. Although they are necessary when changing material type, powders from same-material builds can be reused. It is important to note, however, that recycling of powder can affect the powder size distribution, which in turn affects final part characteristics. The number of times a powder can be recycled is dependent on the machine manufacturer and the material.

5.6 Feature constraints (islands, overhang, stair-step effect)

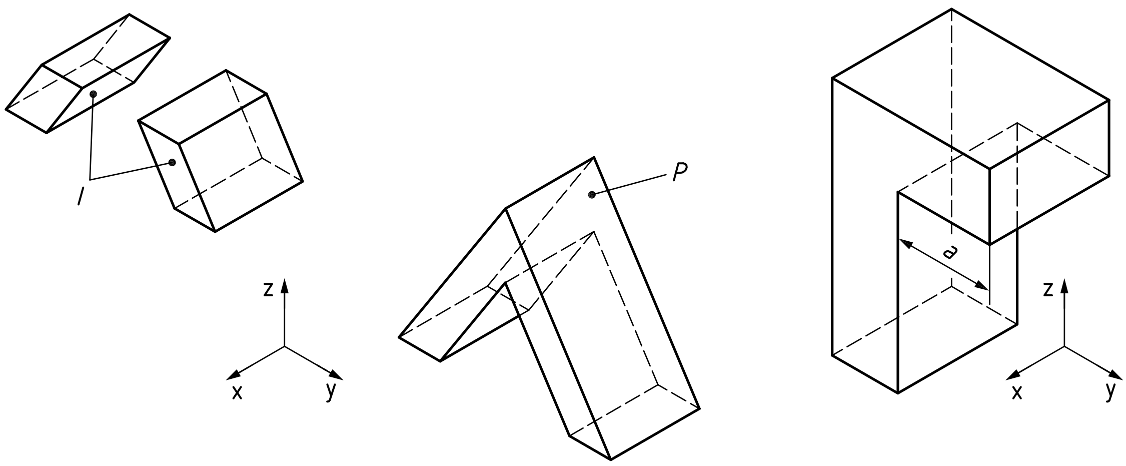
5.6.1 General

Since AM parts are built up in successive layers, separation of features can occur at some stage of the build. This depends on the part geometry. The situations in 5.6.2 to 5.6.4 shall be regarded as critical (the level of criticality depends on the PBF technology in focus) in this respect.

5.6.2 Islands

Islands (*I*) are features that connect to form a part (*P*) only at a later stage of the build process. How this connection will occur shall be taken into consideration at the design stage. Parts that are stable in terms of their overall design can be unstable at some stage of the build process (see Figure 2, left and centre).

NOTE In some circumstances, islands are not protected against mechanical damage during the powder application process. This can lead to deformation of the islands.



SOURCE VDI 3405-3:2015.

Figure 2 — Islands *I* (left) and overhang *a* (right) during the construction of part *P* in *z*-axis