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Additive manufacturing — Design —

Part 1:
Laser-based powder bed fusion of metals

Fabrication additive — Conception —

Partie 1: Fusion laser sur lit de poudre métallique

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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 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 metals (PBF-LB/M) describes an additive manufacturing (AM) process and offers an additional manufacturing option alongside established processes. PBF-LB/M 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 PBF-LB/M 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 PBF-LB/M 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 this document on PBF-LB/M, ISO 52911-2[1] on laser-based powder bed fusion of polymers (PBF-LB/P), and ISO 52911-3[2] on electron beam powder bed fusion of metals (PBF-EB/M). Each document in the series shares Clauses 1 to 5, where general information including terminology and the PBF process is provided. The subsequent clauses focus on the specific technology.

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

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[1] Under preparation.

[2] Under preparation.

INTERNATIONAL STANDARD **ISO/ASTM 52911-1:2019(E)**

Additive manufacturing — Design —

Part 1:
Laser-based powder bed fusion of metals

1 Scope

This document specifies the features of laser-based powder bed fusion of metals (PBF-LB/M) 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 http://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1
curl effect
thermal and residual stress effect
<aspect of heat-induced warping> dimensional distortion as the printed part cools and solidifies after being built or by poorly evacuated heat input

3.2
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.

3.3
downskin angle

δ

angle between the plane of the build platform and the *downskin area* (3.2) where the value lies between 0° (parallel to the build platform) and 90° (perpendicular to the build platform)

Note 1 to entry: See Figure 1.

3.4
upskin area

U

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

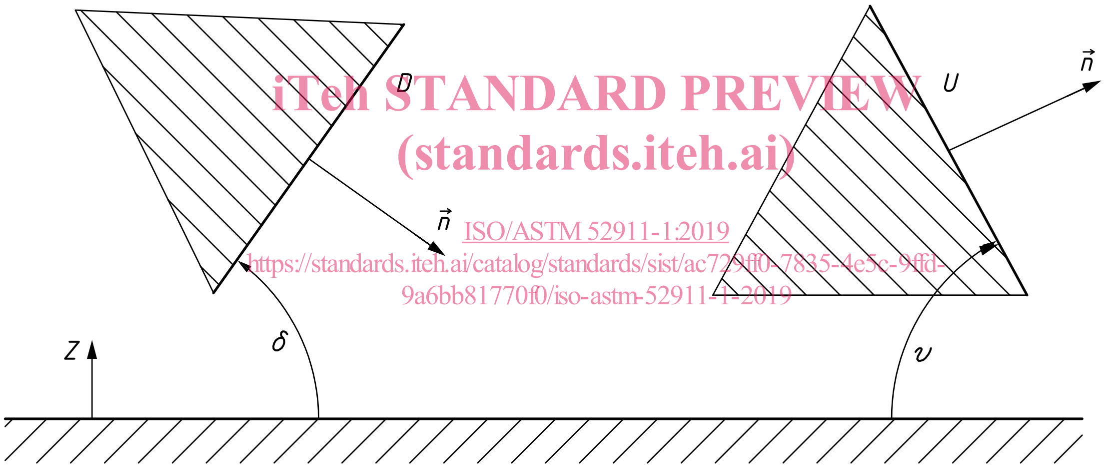
Note 1 to entry: See Figure 1.

3.5
upskin angle

υ

angle between the plane of the build platform and the *upskin area* (3.4) where the value lies between 0° (parallel to the build platform) and 90° (perpendicular to the build platform)

Note 1 to entry: See Figure 1.



Key

δ	downskin angle
$\vec{n}$	normal vector
D	downskin (left) area
U	upskin (right) area
υ	upskin angle

SOURCE VDI 3405-3:2015.

Figure 1 — Orientation of the part surfaces relating to the build platform

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	—
R_a	mean roughness	µm
R_z	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
HIP	hot isostatic pressing
MRI	magnetic resonance imaging
PBF	powder bed fusion
PBF-EB/M	electron beam powder bed fusion of metals
PBF-LB	laser-based powder bed fusion
PBF-LB/M	laser-based powder bed fusion of metals (also known as, for example, laser beam melting, selective laser melting)
PBF-LB/P	laser-based powder bed fusion of polymers (also known as, for example, laser beam melting, selective laser melting)
STL	stereolithography format or surface tessellation language

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. With regards to metal processing, a distinction can be made between, for example, laser-based PBF (applied for metals and polymers) and electron beam-based PBF (applied for metals only).

Polymers PBF uses, in almost every case, low-power lasers to sinter polymer powders together. As with polymer powders PBF, metals PBF includes varying processing techniques. Unlike polymers, metals PBF often requires the addition of support structures (see 6.4.3). Metals PBF processes may use low-power lasers to bind powder particles by only melting the surface of the powder particles or high-power (approximately 200 W to 1 kW) beams to fully melt and fuse the powder particles together.

Electron beam-based melting and laser-based melting have similar capabilities, although the beam energy transferred from the electron beam to the metal is of a higher intensity and the process most commonly operates at higher temperatures than the laser counterpart, therefore typically also supporting faster build rates at lower resolutions. In general, since the powder bed is preheated and kept close to the melting temperature during the building operation, electron beam processes subject parts to less thermal induced stresses and have faster build rates, but the trade-off often comes with much longer times needed for the build chamber to cool down after the build cycle has been completed, and in general larger minimum feature sizes and greater surface roughness than laser melting.

5.2 Size of the parts

The size of the parts is not only limited by the working area/working volume of the PBF-machine. Also, the occurrence of cracks and deformation due to residual stresses can limit the maximum part size. Another important practical factor that can limit 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. The cost of the volume of powder required to fill the bed should be considered. Powder reuse rules impact this cost significantly. If no reuse is allowed then all powder is scrapped regardless of volume solidified.

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.

- Integration of multiple functions in the same part.
- Parts can be manufactured to near-net shape (i.e. close to the finished shape and size).
- 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,
  - topologically optimized structures, in order to reduce mass and optimize mechanical properties, and
  - infill structures, e.g. honeycomb.
- The degree of part complexity is largely unrelated to production costs, unlike most conventional manufacturing.
- Assembly and joining processes can be reduced through part consolidation, potentially achieving en bloc construction.
- Overall part characteristics can be selectively configured by adjusting process parameters locally.
- Reduction in lead times from design to 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 forging and casting. Material properties can be influenced significantly due to process settings and control.
- Excessive use and/or over-reliance on support structures can lead to both high material waste and increased risk of build failure.
- Powder removal post processing is necessary.

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 building time and build costs. Parts should be orientated in such a way that the build height is kept to a minimum.

If the intention is to manufacture a larger number of units, then the build space should be used as efficiently as possible. Parts should be orientated so as to minimize the number of build runs required. Strategies for nesting can also be included to maximize the available build space. If the same parts are oriented differently for best packing, i.e. results in building at different angles, then the mechanical properties can vary from part to part.

The use of powder that remains in the system depends on the application, material and specific requirements. Powder changes can be inefficient and time consuming. Though they are necessary when changing material type, powders from same-material builds can be reused if permitted in the governing specification. It is important to note, however, that recycling of powder can affect the powder size distribution, surface characteristics and alloy composition, and this in turn affects final part characteristics. In addition, the reusable powder characteristics and therefore recyclability can be different for electron beam-based and laser beam-based powder bed fusion. The number of times a powder can be recycled is dependent on the machine manufacturer and the part specification.

Many poorly designed parts (particularly those designed for conventional processes with little or no adaptation) necessitate a specific orientation either to minimize the use of supports or to increase the likelihood of build success. Indeed, parts designed for additive manufacture should be devised such that build orientation is obvious and/or specified.

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

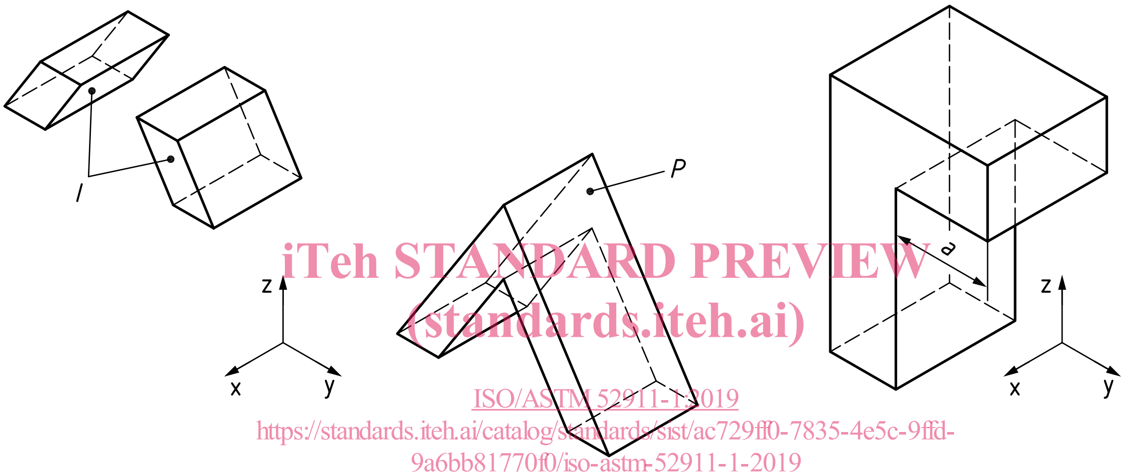
5.6.1 General

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 described in 5.6.2 to 5.6.4 can 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 during 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.



Key

I	islands
P	part
a	overhang

SOURCE VDI 3405-3:2015.

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

5.6.3 Overhang

Areas with an overhang angle of 0° produce an overhang with length *a* (see Figure 2, right). Small overhangs do not need any additional geometry in the form of support structures. In such cases, the projecting area is self-supporting during manufacturing. The permissible values for *a* depend on the specific PBF process, the material and the process parameters used. Significant overhangs can induce a collapse or deformation of the length *a* of Figure 2, which can lead to the machine standstill.

5.6.4 Stair-step effect

Due to the layer-wise build-up, the 3D geometry of the part is converted into a 2,5D image before production, with discrete steps in the build direction. The resulting error caused by deviation of this 2,5D image from the original geometry is described as the stair-step effect. The extent of this is largely dependent on the layer thickness (see Figure 3).