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**Additive manufacturing — Design —
Part 3:
PBF-EB of metallic materials**

Fabrication additive — Conception —

Partie 3: PBF-EB de matériaux métalliques

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 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).

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

Powder bed fusion of metals (PBF/M) is an additive manufacturing (AM) process that offers additional manufacturing options alongside other established AM processes. PBF/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/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/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. In addition to this document on PBF-EB/M, the series is made up of ISO 52911-1 on laser-based powder bed fusion of metals (PBF-LB/M) and ISO 52911-2 on laser-based powder bed fusion of polymers (PBF-LB/P). 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 provides support to technology users, such as design and production engineers, when designing parts that need to be manufactured by means of PBF-EB/M. It will help practitioners to explore the benefits of PBF-EB/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-EB/M process.

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Additive manufacturing — Design —

Part 3: PBF-EB of metallic materials

1 Scope

This document specifies the features of electron beam powder bed fusion of metals (PBF-EB/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 <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

curl effect

<aspect of heat-induced warping> dimensional distortion as the melted material 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**

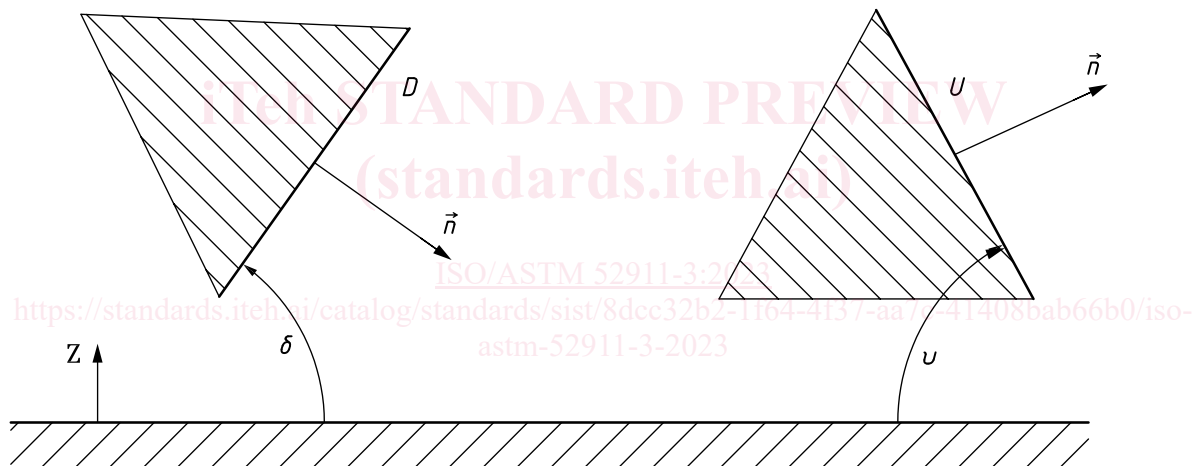
U
(sub-)area where the normal vector \vec{n} in relation to Z-axis is positive

Note 1 to entry: See [Figure 1](#).

**3.5
upskin angle**

ν
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 angles
- \vec{n} normal vector
- D downskin (left) areas
- U upskin (right) areas
- ν upskin angles
- Z build direction

NOTE Source: VDI 3405-3:2015[3].

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 |

Table 1 (continued)

| Symbol | Designation | Unit |
|-----------|----------------|-----------------|
| D | downskin area | mm ² |
| I | island | mm ² |
| \vec{n} | normal vector | — |
| U | upskin area | mm ² |
| δ | downskin angle | ° |
| ν | upskin angle | ° |

4.2 Abbreviated terms

The following abbreviated terms are used in this document.

| | |
|----------|---|
| CT | computed tomography |
| DICOM | digital imaging and communications in medicine |
| PBF-EB/M | electron beam powder bed fusion of metals |
| HIP | hot isostatic pressing |
| 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) |
| MRI | magnetic resonance imaging |

5 Characteristics of powder bed fusion (PBF) processes

5.1 General

Consideration should 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. Electron beam powder bed fusion for polymers is not usually considered because the negative charge from the electron beam will accumulate in non-conductive polymer powder and cause repulsive events that will ruin powder layer continuity and make any controlled sintering or melting impossible. As with polymer powders PBF, metals PBF includes varying processing techniques. Like polymers, metals PBF often requires the addition of support structures (see 6.3.3). 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) energy beams to fully melt and fuse the powder particles together.

PBF-EB/M and PBF-LB/M have similar capabilities, although differences between these processes leads, in general, to PBF-EB/M supporting faster build rates at lower feature resolution compared to PBF-LB/M. The beam energy from the electron beam is of a higher intensity (due to a high energy source 3 kW to 6 kW), and the mechanism to raster the beam (i.e. electromagnetics for PBF-EB/M, optics for PBF-LB/M) differs between the two types of PBF processes. PBF-EB/M also tends to utilize a larger beam spot size, larger powder size distribution, and larger layer thickness. In general, PBF-EB/M

subjects parts to less thermal stresses (as powder layers are preheated before melting) and have faster build rates, but the trade-off often comes with general greater minimum feature sizes and greater surface roughness compared to PBF-LB/M.

5.2 Part size and cost considerations

Part size is not only limited by the working area/working volume of the PBF-machine. The occurrence of cracks and deformation due to residual stresses can also limit the maximum part size. Another important practical factor that can limit the maximum part size is part cost having a direct relation to part size.

Part cost can be minimized by choosing part location and build orientation in a way that allows nesting of as many parts as possible.

Also, powder reuse protocols impact part cost significantly. If no reuse is allowed then all remaining 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 higher. Limitations of conventional manufacturing processes do not usually exist, e.g. for
 - tool accessibility, and
 - machining undercuts.
- A wide range of complex geometries can be produced, such as
 - free-form geometries, e.g. organic structures,
 - topologically optimised structures, in order to reduce mass and optimize mechanical properties,
 - infill structures, e.g. honeycomb, and
 - porous lattice structure on surface of otherwise solid component, e.g. osteosynthesis structures in medical device industry.
- 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 in 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 should be taken into consideration during product design:

- Shrinkage, residual stress and deformation can occur due to temperature differences. Preheating of the powder bed (which is the normal procedure in PBF-EB/M) can be used to minimize these effects.

- The surface quality of AM parts is typically influenced by the layer-wise build-up technique (stair-step effect) and utilized powder size distribution. Post-processing may be required, depending on the application.
- Consideration should be given to deviations from form, dimensional and positional tolerances of parts. A machining allowance should therefore be provided for post-production finishing. Specified geometric tolerances can be achieved by precision post-processing operations.
- Anisotropic characteristics typically arise due to the layer-wise build-up and should 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.
- Unmelted powder removal after processing is necessary. For PBF-EB/M this powder is often lightly sintered instead of loose due to powder bed preheating during processing.

5.5 Build layout, part orientation, and cost considerations

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 criteria for optimization are available depending on the number of units planned.

- Build height is a factor that has significant impact on building time and build costs. Parts should be oriented in such a way that the build height is kept to a minimum. However, additional and sometimes competing factors should also be considered when deciding on part orientation. Simplifying post-processing operations such as powder and support removal, as well as ensuring features that are critical to the function of the part building appropriately are two such additional considerations.
- 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 oriented so as to minimize the number of build runs required. Strategies for three-dimensional nesting can also be included to maximize the available build volume.
- 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 powder reuse can affect the powder size distribution, surface characteristics and alloy composition, and this will in turn affect final part characteristics. In addition, the reusable powder characteristics may be different for PBF-EB/M and PBF-LB/M. The number of times a powder can be recycled is dependent on the requirements outlined in the material and part specifications, and the powder reuse scheme implemented by the user and machine manufacturer.
- 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)

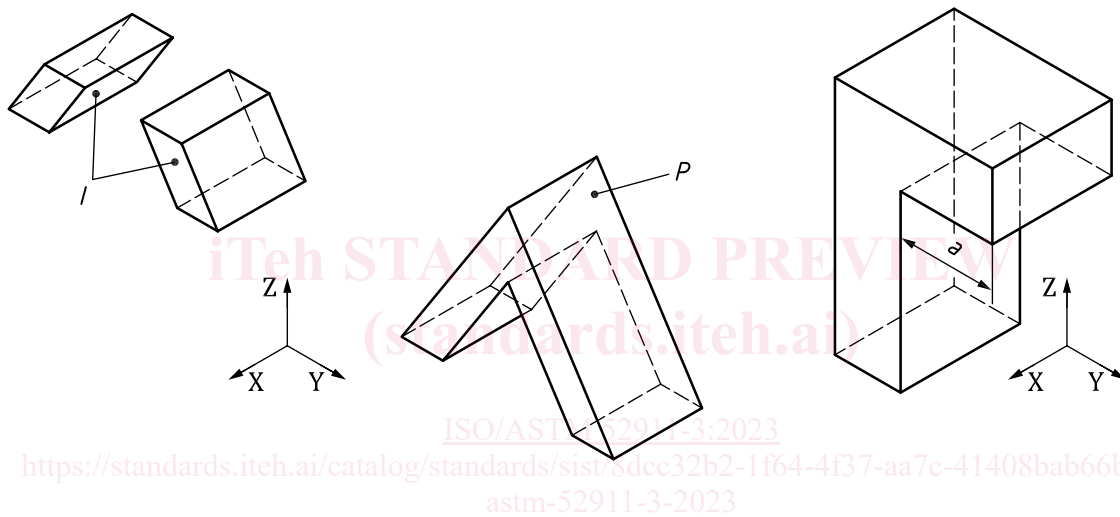
5.6.1 General

Since AM parts are built up in successive layers, separation of features may 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 these connections occur should 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
- Z* build direction

NOTE 1 Overhang *a* illustrated in separate part (right).

NOTE 2 Source: VDI 3405-3:2015^[3].

Figure 2 — Islands *I* (left) during the construction of part *P* (centre)

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* will 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*, which can lead to the machine standstill (build crash).

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