TECHNICAL REPORT

ISO/ASTM TR 52906

First edition

Additive manufacturing — Non-destructive testing — Intentionally seeding flaws in metallic parts

Fabrication additive — Essais non destructifs — Implantation intentionnelle de défauts dans les pièces métalliques

PROOF/ÉPREUVE

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Contents

Page

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 can 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 on 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 the following URL: www.iso.org/iso/foreword.html.

This document was prepared by 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).

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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

This document provides information for intentionally seeding flaws in additively manufactured parts and complements ISO/ASTM TR 52905[1].

The different AM building descriptions can be found readily in published standards (see ISO 17296-2) and scientific papers.

Jargon commonly used in the literature describing AM metal process defect include “balling”, “fireworks”, “smoke” and often are not specific to the morphology of the defect and often result from widely differing mechanisms of formation.

When defining terms specific to AM metal flaws it may be useful to review some examples related to welding technology.

This document is for the creation of seeded replicas supports the user’s understanding not only for the characterization of actual flaws with respect to physical morphology but also for the materials and mechanisms of formation, location, and orientation. In addition, the fundamentals of the processes creating the replica (e.g. PBF or DED with regard to the heat sources electron beam (EB), laser beam (LB) or AP (arc processes) also need to be considered). The intentional seeding to produce flaw replicas can match the character of the actual flaw as closely as possible.

The reference photomicrographs or non-destructive testing images included in this document are in no way to be construed as specifications. These reference photomicrographs and non-destructive testing images are offered primarily to permit examples of “flaws” or replicate images thereof. They can be used for comparison of reports. Flaw seeding will be discussed without context to a specific part, location, or dimension. The material alloy will be provided as known. With some flaws the material alloy may not be as important, for example, a pore may reside in any number of alloys. It can be noted that there is currently no proven method for controlled and replicable seeding of intimate disbonds (sometimes known as “kissing bonds”) – where two surfaces are in intimate or close contact, but with compromised adhesion – in AM parts so this feature is, therefore, currently out of scope.

This document will not go into the fundamentals of each process but rather identify the parameters within each process that can lead to the intentional seeding of AM structures.

1) In preparation. Stage at the time of publication ISO/ASTM DTR 52905:2021.

Additive manufacturing — Non-destructive testing — Intentionally seeding flaws in metallic parts

1 Scope

This document is intended to serve as a best practice for the identification and “seeding” of nondestructively detectable flaw replicas of metal alloy PBF and DED processes. Three seeding categories are described:

a) process flaws through CAD design;

b) build parameter manipulation;

c) subtractive manufacturing.

These include flaws present within as-deposited materials, post heat-treated or HIP processed material, and those flaws made detectable because of post-processing operations. Geometrical aspects or measurement are not the subjects of this document.

WARNING — This document does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this document to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

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, *Standard Terminology for Additive Manufacturing — General Principles —Terminology*

ASTM B243, *Standard Terminology of Powder Metallurgy*

ASTM E7, *Standard Terminology Relating to Metallography*

ASTM E1316, *Standard Terminology for Nondestructive Examinations*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/ASTM 52900, ASTM E7, ASTM B243, ASTM E1316 and the following apply.

NOTE Terms for AM metal technology flaws are logically divided between PBF and DED categories of processes.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

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

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

3.1
coupon
piece of material from which a specimen is prepared

3.2
flaw classification
classification approach that provides a high-level system based on a primary characteristic or a combination of characteristics

Note 1 to entry: Flaw classification may include similar flaw types that were created differently.

3.3
inclusion
foreign material held mechanically

Note 1 to entry: Inclusions are typically oxides, nitrides, hydrides, carbides, or combinations thereof being formed due to contamination of the chamber gas, or already be present in the metal powder.

3.4
keyhole
type of porosity characterised by a circular depression formed due to instability of the vapour cavity during processing

3.5
pore
inherent or induced cavity within a powder particle or within an object not connected to an exterior surface

3.6
porosity
presence of small voids in a part making it less than fully dense

3.7
replica
intentional manipulated condition (flaw) to serve as the "seed" in a *coupon* (3.1) representing a known flaw type

3.8
seeding
act of intentionally creating flaws, through CAD or manipulation of designated processing parameters, that results in the placement of the anticipated *replica* (3.7) or the act of intentionally creating a *replica* (3.7) through the insertion of a foreign object

3.9
sintering
process of heating a powder metal compact to increase density and/or improve mechanical properties via solid state diffusion

3.10
surface-connected flaw
flaw that is in the body of the material but its boundaries reach to the material's surface

3.11
unsintered
powder unaffected or affected but not fully consolidated during the additive manufacturing printing process

4 Abbreviated terms

AM	Additive Manufacturing
BM	Base Metal

CAD	Computer-Aided Design/Computer-Aided Drafting/Computer-Aided Drawing
CNC	Computer Numerical Control
CT	Computed Tomography
DDC	Ductility-Dip Cracking
DED	Directed Energy Deposition
EB-DED	Electron Beam Directed Energy Deposition
DR	Digital Radiography (non-film)
EB-PBF	Electron Beam Powder Bed Fusion
EDM	Electrode Discharge Machining
GMA-DED	Gas Metal Arc Directed Energy Deposition
HAZ	Heat Affected Zone
L-DED	Laser Directed Energy Deposition
L-PBF	Laser Beam Powder Bed Fusion
NDE	Non-destructive evaluation
NDT	Non-destructive Testing
OEM	Original Equipment Manufacturer
PBF	Powder Bed Fusion
PSD	Particle Size Distribution
RT	Radiography Testing(film)
HIP	Hot Isostatic Pressing
Tm	Temperature melting point
WM	Weld Metal

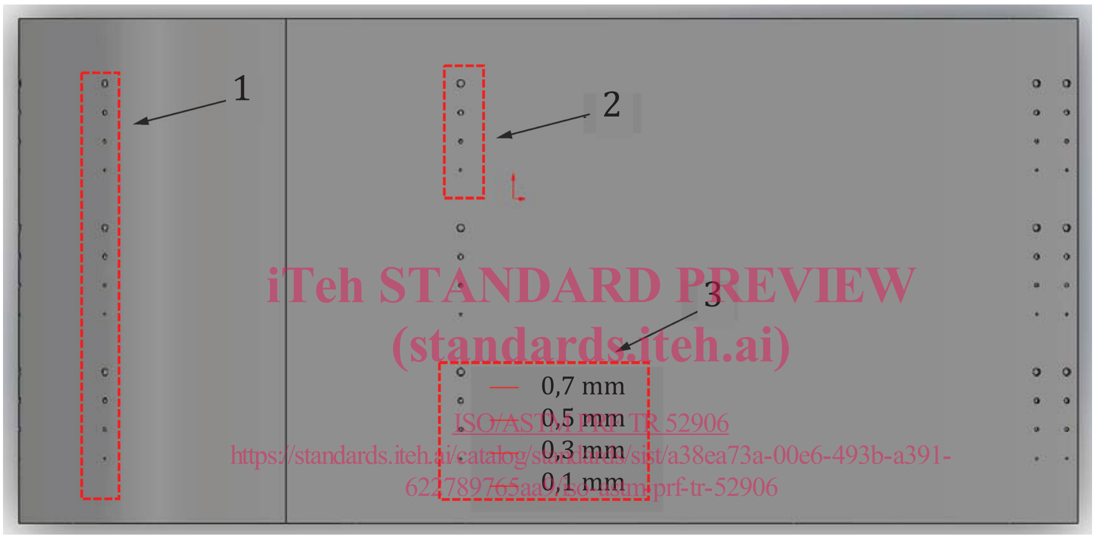
5 Typical AM flaws

Typically, additive manufacturing flaws in materials fabricated using optimised parameters have small spherical flaws. Builds with less developed parameters may have a keyhole or larger angular pores. However, high value components are often screened for flaws at a level determined by fracture analysis such as those described below. The ability to create replicas to support the NDT detection capability of complex structures is unique to additive manufacturing and can be considered when standard inspection techniques are not adequate to ensure inspection reliability.

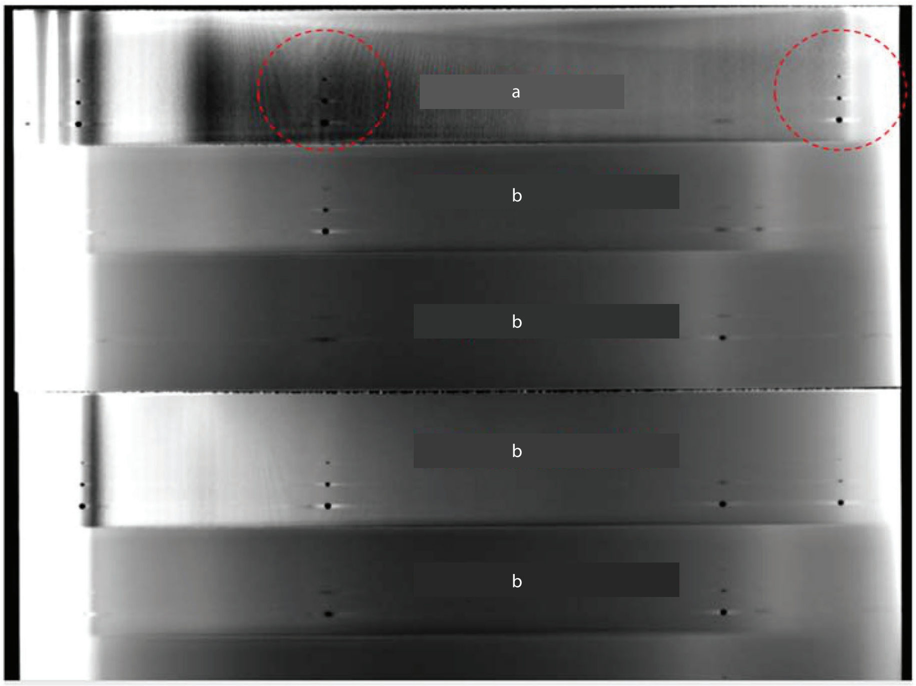
The occurrence of unintentional flaws during the additive manufacturing build is a possibility. The flaw classification has been laid out in ISO/ASTM TR 52905 both L-PBF and DED. These flaws are: layer-defects (horizontal lack of fusion), cross-layer (vertical lack of fusion), unconsolidated powder, trapped powder, inclusion, layer shift, porosity and void; moreover, incomplete fusion, hole and cracking. It is important to highlight that some DED defects are similar to those produced during the welding process, while for L-PBF some defects are unique.

In addition to flaws created to replicate naturally occurring anomalies, replicas may be generated to serve as targets that can be used to understand x-ray, ultrasonic or other NDT capabilities (see Figure 1). It is important that the fabricator of such replicas understands the physics of the NDT's method for which the flaws will be used. Capabilities demonstrations include detection in a specific complex geometry such as a Representative Quality Indicator (RQI) according to ASTM E1817[5], or detection at a specific orientation relating to to the radiation beam. This replica is "seeded" intentionally around the needs of the demonstrations. Ultrasonic sensing may find applicability through the technical approach of ASTM E127[3]. Additionally, some of these seeding methods are implemented and detection capabilities of seven NDT methods are assessed in ISO/ASTM TR 52905.

It has been found that replica size, orientation, and location can be designed into the build model to create shapes (spheres, cubes, and rectangular prisms), sizes (lengths and diameters), and depths. An example is shown in Figure 1 where embedded defects were designed into the step wedge with CAD software, and since they are embedded with no powder removal vent, they are filled with unmelted powder (unconsolidated powder/trapped powder).



a) CAD model showing the set of clusters and dimensions of the holes in the airfoil



b) XCT scan displaying the visibility of the replicas seeded at different locations and those that are not visible

Key

1 sets of holes containing 3 cluster

2 number of holes per cluster

3 holes dimensions per cluster

[a] All 4 are visible.

[b] ⌀ 0,1 mm not visible.

Figure 1 — Model-designed replicas a), Computed tomography image of a generic airfoil built on Ti-6Al-4V b)

With adjustments to the optimum build parameters, replicas can provide a desired off-nominal build parameter. The shape of the replica can be planar, elliptical, rounded or another modelled configuration. Two such off-nominal build parameters for seeding replicas are lowering laser power and increasing the trace width larger than optimal.

Both of these types of replicas can be used to show the various NDT methods detection potentials. For example, the computed tomography scans of the seeding replicas resulted in different yet detectable material density changes created by each build parameter adjustment. The level of detail and different views possible through computed tomography is shown in Figure 2 and Figure 3. The images in both figures are not comparatives as those only illustrate differences in the detail when different magnifications and methods are used.

Figure 2 — Computed tomography (CT) slice (left) with microscopy image at 50× (right): large hatch spacing