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Additive manufacturing of metals — Non-destructive testing and evaluation — Classification of imperfections in DED parts

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Foreword

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The committee responsible for this document is 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.

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.

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Introduction

Directed energy deposition (DED) additive manufacturing (AM) process category is of growing interest for industry to build large metallic parts. It consists of using a concentrated energy (arc, laser, electron beam, plasma) to melt and to deposit a filler material in the form of powder or wire to produce parts on a build platform / substrate or to add functions to an existing part. In both cases, material is added to form entirely or partially a part, which distinguishes AM from welding (the assembly of parts) and surface enhancement (cladding, coating). All welding or cladding technologies that deposit material can potentially be used for AM. In practice, only a few processes are of interest from an industrial perspective, because the chosen process must at least be able to be automated and, much better, be robotized, productive, and able to produce objects with minimum material removal to obtain near net shape part after manufacturing. The family of DED AM process categories includes, as defined in ISO/ASTM 52900:

— DED-LB/P and DED-LB/W

— DED-EB/W

— DED-Arc/W with arc technologies (MIG-MAG, plasma, TIG) which are also called WAAM (Wire Arc Additive Manufacturing).

It is however essential to be able to produce parts competitively in comparison with more conventional processes (machining, casting, etc.) or to justify this option by a significant reduction of the supply lead time of a part. It is also essential to produce good quality parts. To this end, before carrying out destructive or non-destructive testing and deciding on conformity, it is necessary to have a classification of the imperfections resulting from these processes.

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Additive manufacturing of metals — Non-destructive testing and evaluation — Classification of imperfections in DED parts

1 Scope

This document specifies the classification of imperfections likely to be generated during an additive manufacturing process by DED for metallic parts.

This document also indicates the most probable causes of the formation of imperfections and includes illustrations.

Acceptance criteria for imperfections are not included in this document.

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*

ISO 6520-1, *Welding and allied processes — Classification of geometric imperfections in metallic materials — Part 1: Fusion welding*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 6520-1, 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
bead
metal deposited during one passage of a deposition process using an energy source and material feeding

Note 1 to entry: an energy source is LB, EB or Arc.

Note 2 to entry: the form of the material is powder or wire.

[SOURCE: ISO/TR 25901-1, 2.1.8.4, modified]

3.2
imperfection
any discontinuity or deviation observed from a specification (geometrical, material integrity)

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3.3
lack of fusion
type of process-induced porosity, in which the powder or wire feedstock is not fully melted or fused onto the previously deposited substrate

Note 1 to entry: This type of flaw can be an empty cavity, or contain unmelted or partially fused powder in the case of DED-LB/P process, referred to as unconsolidated powder.

[SOURCE: ISO/ASTM TS 52905, 3.2 with a modification on Note 1 and the deletion of Note 2 and 3]

3.4
substrate
base metal utilized to initiate the deposition of material that can remain a portion of the preform

[SOURCE: ISO/ASTM 52943-2, 3.6]

3.5
build direction
direction in which the part is built, locally normal to the surface of the deposited layers

4 Classification of imperfections

4.1 General

This document adopts the principle of the classification (of numbering) system used in the EN ISO 6520-1 standard and is based on six groups of imperfections according to Table 1:

Table 1 — Classification of imperfection by type

Class	Imperfection type
100	Crack (Table 2)
200	Porosity/cavity (Table 3)
300	Solid inclusion (Table 4)
400	Lack of fusion[a] (Table 5)
500	Shape imperfection and dimensional imperfection[b] (Table 6)
600	Other imperfection type (Table 7)

[a] Also defined as cross-layer or layer defects on ISO/ASTM TR 52905 and vertical or horizontal lack of fusion in ASTM E3166

[b] Equivalent to layer shift in ISO/ASTM TR 52905 and ASTM E3166

4.2 Designation

In this document, the imperfection class (or numbering) shall be preceded by the prefix DED which

corresponds to DED processes.

When a designation is required for an imperfection, it shall have the following structure:
ISO/ASTM 52969-DED-[nnn]

With

ISO/ASTM 52969 for reference to this document

DED indicating directed energy deposition (with arc, laser or electron beam)

nnn classification index according to the type of imperfection (see 4.3)

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Example The designation ISO/ASTM 52969-DED-104 according to this document refers to a crater crack within a part produced by directed energy deposition.

To simplify reading, the following, imperfections are designated by DED- [nnn].

4.3 Detailed classification of imperfections occurring in DED additive manufacturing

4.3.1 General

For each type of imperfection, the Tables 2 to 7 indicate its designation, typical location and orientation, provide an illustration if applicable, and the main causes and associated comments. Additional illustrations can be found in Annex A.

4.3.2 Crack

A crack shall be classified according to Table 2.

NOTE ISO/ASTM 52911-1 on conception on post-treatment provides guidance on how to reduce cracks.

4.3.3 Porosity

Porosities shall be classified according to Table 3.

4.3.4 Inclusion

Inclusions shall be classified according to Table 4.

4.3.5 Lack of fusion

Lack of fusion shall be classified according to Table 5.

4.3.6 Shape imperfection and dimensional imperfection

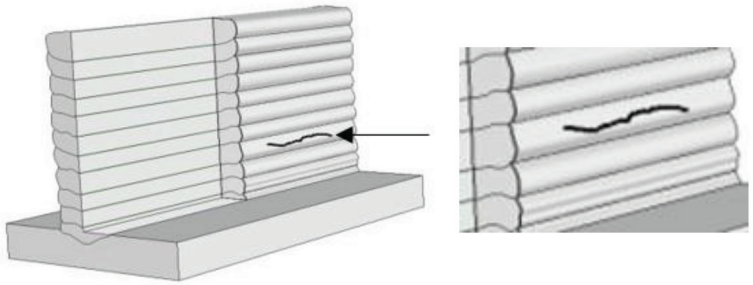
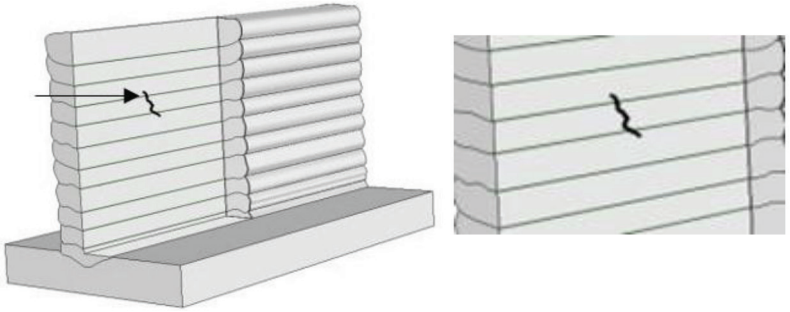
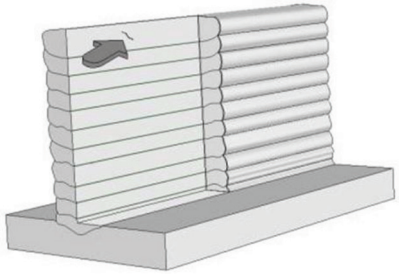
Shape imperfections and dimensional imperfections shall be classified according to Table 6.

4.3.7 Other imperfection

Other imperfections shall be classified according to Table 7.

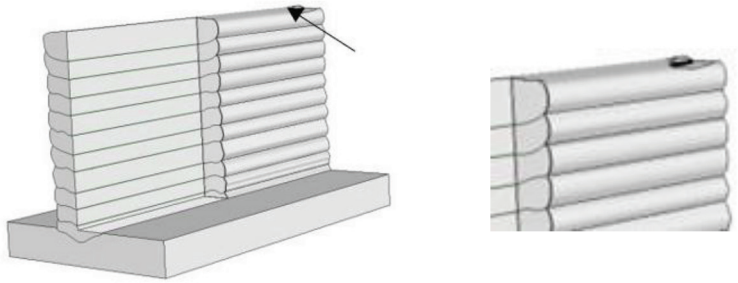
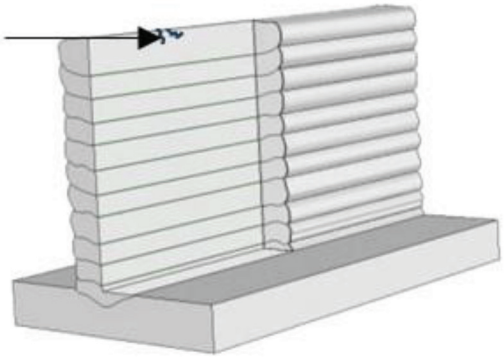
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Table 2 — Classification of cracks

DED no.	Designation	Typical location/ orientation	Illustration	Main causes and comments
101	Longitudinal crack	Deposited metal or at the junction between deposited metal and substrate.		A metallurgical imperfection due to the susceptibility of the deposited material to cold and/or hot cracking. In most cases, this imperfection can be avoided by adapting the operating conditions (use of minimum or maximum deposition heat input, pre- and/or post-heating or low heat input deposition and low interpass temperatures, etc.). This kind of crack can occur between manufacturing part and the substrate. This imperfection can be avoided with an adapted geometry (chamfer).
102	Transverse crack	Deposited metal		The transverse crack is perpendicular to the deposited layers or to the deposited beads. It can cross several layers or several beads in the same layer. This usually occurs when the two following conditions are met: a fragile microstructure and residual stress build-up.
1001	Micro-crack	Deposited metal		A metallurgical imperfection which is often difficult to detect by NDT due to its size. Certain materials, such as nickel-based alloys and superalloys, are more susceptible to microcracking.

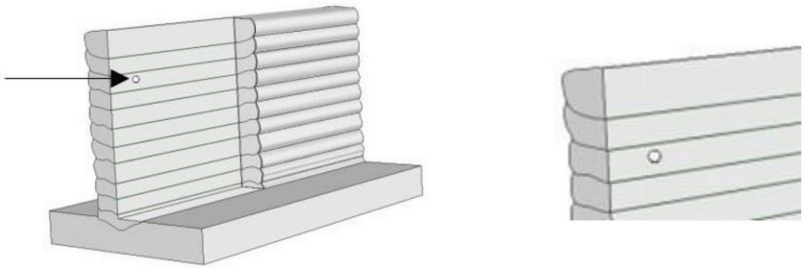
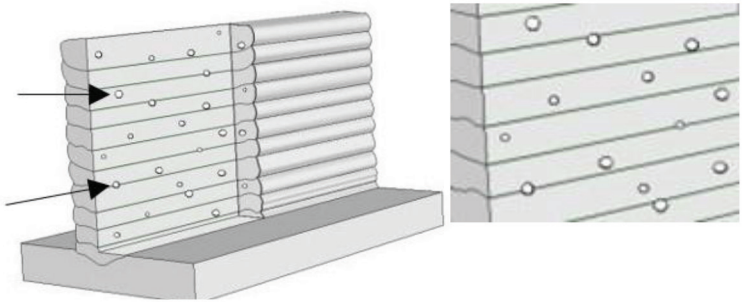
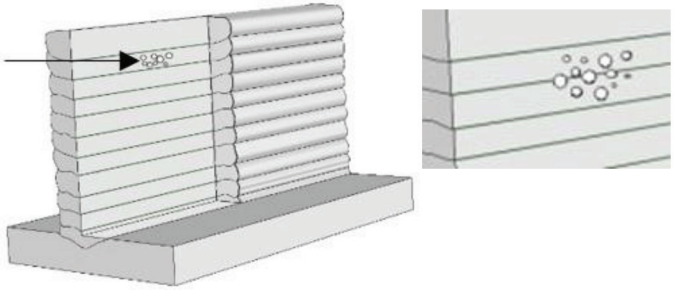
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Table 2 *(continued)*

DED no.	Designation	Typical location/ orientation	Illustration	Main causes and comments
104	Crater crack	End crater of the last deposited bead		This imperfection is rarely observed in AM. This imperfection is defined as shrinkage hole which is caused by shrinkage during solidification of a weld.
105	Group of disconnected cracks	Deposited metal		Group of disconnected cracks in any direction located in the deposited metal. These imperfections appear during process and are essentially due to copper pollution of the melt pool (for example, melting of an element of the welding torch).

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Table 3 — Porosity classification

DED no.	Designation	Typical location/ orientation	Illustration	Main causes and comments
201	Gas cavity	Deposited material	n/a	A spherical imperfection caused by the aggregation of gas molecules in the metal during solidification. Numerous factors can result in the formation of porosity, often starting with the nature of the deposited material and the operating conditions (torch travel speed, insufficient gas shielding, disturbances of the molten pool by an incorrectly regulated gas jet, etc.).
2011	Gas pore	Deposited material		Isolated gas cavity (see 201) of essentially spherical form.
2012	Uniformly distributed porosity	Deposited material		Isolated and uniformly distributed gas cavity (see 201). This imperfection can be caused by a sudden decrease of the solubility of various gases from the liquid to the solid state (e.g. in aluminium alloys) and often linked to the presence of low melting point elements in the deposited material.
2013	Clustered porosity	Deposited material		Group of gas pores having a random geometric distribution (see 201). This type of imperfection is typical of a temporary lack of gas shielding.

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