ASTM INTERNATIONAL

DRAFT International Standard

ISO/ASTM DIS 52922

Additive manufacturing — Design — Directed energy deposition of metals

Fabrication additive — Conception — Dépôt de matière sous énergie concentrée de métal

ICS: 25.030

ISO/TC **261**

Secretariat: **DIN**

Voting begins on:
2025-09-12

Voting terminates on:
2025-12-05

This document has not been edited by the ISO Central Secretariat.

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Published in Switzerland

Contents

Page

Foreword ..... **v**

Introduction ..... **vi**

1 Scope **1**

2 Normative references **1**

3 Terms and definitions **1**

4 Symbols and abbreviated terms **2**
4.1 Symbols 2
4.2 Abbreviated terms 3

5 Characteristics of directed energy deposition processes **3**
5.1 General 3
5.2 Build options and variations 4
5.2.1 Build set up and fixturing 4
5.2.2 Incorporate substrate into part 4
5.2.3 Symmetric build configurations 5
5.2.4 Asymmetric build configurations 6
5.2.5 DOF of the DED system 7
5.2.6 Avoidance of overhangs 7
5.3 Size of the parts 8
5.4 Typical advantages of the DED process 8
5.5 Typical disadvantages of the DED process 9
5.6 Material, economic and time efficiency 10
5.7 Design feature types 11
5.7.1 General 11
5.7.2 Design feature hierarchy 11
5.7.3 Wall features 12
5.8 Manufacturing features and effects 12
5.8.1 Overhang 13
5.8.2 Islands 13
5.8.3 Wall intersections 13
5.8.4 Stair-step effect 13
5.8.5 Accessibility 14
5.9 Dimensional, form and positional accuracy 15
5.10 Software workflow for DED 16
5.11 Data quality, resolution, representation 16
5.12 DED processes 16

6 Design guidelines for DED **17**
6.1 General 17
6.1.1 Selecting DED 17
6.1.2 Design and test cycles 17
6.2 Materials and structural characteristics 17
6.2.1 Feedstock materials 17
6.2.2 Substrate materials 18
6.2.3 Microstructures 18
6.2.4 Mechanical properties 18
6.3 Support structures 18
6.4 Build orientation, multi-axis deposition and substrate/build platform position 20
6.4.1 General 20
6.4.2 Build orientation and substrate/build platform position 20
6.4.3 Multi-axis deposition 22
6.4.4 Substrate thickness 23
6.4.5 Distortion 24
6.4.6 Work holding and fixturing 24
6.4.7 Surfaces 27

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6.5 Post-production finishing 27
6.5.1 General 27
6.5.2 Surface finishing 27
6.5.3 Removal of support structures 27
6.5.4 Adjusting geometric tolerances 28
6.5.5 Heat treatment 28
6.6 Design considerations 29
6.6.1 General 29
6.6.2 Cavities 29
6.6.3 Slots and grooves 29
6.6.4 Wall thicknesses 29
6.6.5 Holes 29
6.6.6 Coverage 30
6.6.7 Inspectability 30

7 Cost estimation for DED 30

8 Part examples 31
8.1 Exemplar thin-walled part (provided by GKN Aerospace) 31
8.2 Part for benchmarking DED processes (provided by GKN Aerospace) 32
8.3 Example of part with multiple build directions (provided by Missouri University of Science & Technology) 33
8.4 Landing gear rib part (provided by Cranfield University) 33
8.5 Pressure vessel (provided by Cranfield University) 34
8.6 Shaft repair (provided by Boeing) 34
8.7 Silicon wafer carrier tray (provided by Norsk Titanium) 36
8.8 Commercial aerostructure support bracket (provided by Norsk Titanium) 37

Bibliography 38

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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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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.

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Introduction

Directed energy deposition (DED) is a process category within additive manufacturing (AM) processes in which focused thermal energy is used to fuse materials by melting as they are being deposited, described in detail in ASTM F3187, and offers an additional manufacturing option alongside established processes. DED has the potential to reduce manufacturing time and costs, lead time, and increase part functionality. Typically, DED is used to process metal feedstock to perform one of the following tasks: fabricate net and near-net shape parts, fabricate features on conventionally processed parts, surface modification (cladding) for wear and corrosion protection, or repair metal parts by adding metal to a broken or worn part.

DED processes differ according to several factors, including feedstock type (wire or powder), energy source (laser, electron beam, arc, plasma), number of energy sources, and machine architecture. The process can utilize one or more real time sensors to monitor various indications of performance, such as melt pool temperature or size. Some systems could also include a subtractive process to machine parts and features to final dimensions.

Practitioners are aware of the strengths and weaknesses of conventional, long-established manufacturing processes, such as cutting, joining and shaping processes (for example, by machining, welding or casting), and of giving them appropriate consideration at the design stage and when selecting the manufacturing process. Design and manufacturing engineers may only have limited experience in the use of DED, or AM in general, and the high degree of design freedom it provides over conventional processes. This document is intended to provide information and design guidance illustrating the possibilities and limitations in using the DED process.

This design guide provides guidance for different DED technologies by providing information about typical characteristics of DED parts and features, insights into the process-based causes of these characteristics, and an understanding of process capabilities and limitations. The information and understanding should provide guidance to designers that they can exploit to take advantage of DED capabilities, design around limitations, and avoid process disadvantages. This document extends ISO/ASTM 52910, the general design guide, and complements powder bed fusion design guides for metal and polymer materials (ISO/ASTM 52911-1 and -2), as well as other process-specific design guides that are under development. In addition, it specializes and builds upon the general DED descriptions in ASTM F3187.

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Additive manufacturing — Design — Directed energy deposition of metals

1 Scope

This document specifies the features of directed energy deposition (DED) and provides detailed design recommendations. This document also provides a state-of-the-art review of design guidelines associated with the use of DED 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 17295[1)], *Additive manufacturing — General principles — Part positioning, coordinates and orientation*

ISO/ASTM 52900, *Additive Manufacturing — General Principles — Fundamentals and vocabulary*

ISO/ASTM 52904, *Additive manufacturing of metals — Process characteristics and performance — Metal powder bed fusion process to meet critical applications*

ISO/ASTM 52910, *Additive manufacturing — Design — Requirements, guidelines and recommendations*

ISO/ASTM 52911-1, *Additive manufacturing — Design — Part 1: Laser-based powder bed fusion of metals*

ISO/ASTM 52911-2, *Additive manufacturing — Design — Part 2: Laser-based powder bed fusion of polymers*

ISO/ASTM 52915, *Specification for additive manufacturing file format (AMF) Version 1.2*

ASTM F3187, *Standard Guide for Directed Energy Deposition of Metals*

VDI 3405 Part 3:2015, *Additive manufacturing processes, rapid manufacturing - Design rules for part production using laser sintering and laser beam melting*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/ASTM 52900, ASTM F3187, and the following apply.

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
5+ axis system
DED system with five or more degrees of freedom.

1) ISO 17295 cancels and replace ISO/ASTM 52921-13 which is still available at https://www.astm.org/f2921-13r19.html

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3.2
buy-to-fly ratio
ratio of the mass of material purchased to the mass of the finished component

Note 1 to entry: The term originated in the aerospace industry and refers to the finished component mass that is flown on the aircraft.

3.3
deposition axis
axis parallel to the direction in which the deposition head deposits material

3.4
hybrid system
system that includes both additive and subtractive processes

Note 1 to entry: In the context of DED, the term typically indicates that an additive process has been added to a machining tool.

3.5
near-net shape
close to the finished shape and size

3.6
overhang
feature with a downfacing surface that is a candidate to be supported with support structure

3.7
powder-fed
variant of DED process where powder feedstock is fused to the substrate or previous layer by melting

3.8
symmetric build, symmetric build configuration
build where two parts are fabricated on opposite sides of the substrate, typically alternating between parts after each layer

3.9
tool path
set of scan vectors that the deposition head traverses when fabricating a part

3.10
wire-fed
variant of DED process where wire feedstock is fused to the substrate or previous layer by melting

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
R_a	Roughness average[1], [2]	µm
R_z	Average maximum height of the profile[1], [2]	µm
W_a	Waviness average[1], [2]	µm
θ	Angle	°

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4.2 Abbreviated terms

The following abbreviated terms are used in this document:

AM	additive manufacturing
AMF	additive manufacturing file format
BTF	buy-to-fly ratio
DED	directed energy deposition
DED-LB	laser-based DED
DED-EB	electron-beam-based DED
DED-Arc	wire-arc DED
DOF	degree of freedom
HIP	hot isostatic pressing
PBF	powder bed fusion
PBF-LB	laser-based powder bed fusion
PBF-LB/M	laser-based powder bed fusion of metals
STL	stereolithography format

5 Characteristics of directed energy deposition 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 5.12. With regards to metal processing, a distinction can be made between powder and wire feedstocks, energy source options of laser, electron beam, and arc, deposition environment requirements such as air, inert gas or vacuum and usage of several different types of post-processing operations such as machining or rolling.

DED describes a class of AM processes and offers an additional manufacturing option alongside established processes. DED has the potential to reduce manufacturing time and costs, and increase part functionality. Typically, DED is used to process metal feedstock to perform one of the following tasks:

(a) fabricate net and near-net-shape parts,

(b) fabricate features onto conventionally processed parts, to:

1. produce a final part through hybrid manufacture;
2. modify surface (cladding) for wear and corrosion protection;
3. repair metal parts by adding metal to a broken or worn part.

DED processes differ according to several characteristics, including feedstock type (wire or powder), energy source (laser, electron beam, arc), environment, number of energy sources, and machine architecture or platform. These different DED processes are presented in Table 2. Some implementations include a subtractive process to machine parts and features to final dimensions; these system implementations are commonly referred to as hybrid systems. Some implementations utilize one or more real-time sensors for in-process monitoring of various indications of performance, such as melt pool temperature or melt pool

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