International Standard

ISO/ASTM 52943-2

First edition
2024-04

Additive manufacturing for aerospace — Process characteristics and performance —

Part 2: Directed energy deposition using wire and arc

Fabrication additive pour l'aérospatiale — Caractéristiques et performances du procédé —

Partie 2: Dépôt de matière sous énergie concentrée utilisant du fil et un arc

Reference number
ISO/ASTM 52943-2:2024(en)

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Published in Switzerland

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Foreword

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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).

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Additive manufacturing for aerospace — Process characteristics and performance —

Part 2: Directed energy deposition using wire and arc

1 Scope

This document specifies requirements for the additive manufacturing of metallic parts with directed energy deposition (DED) in the aerospace industry.

Within the application scope of this document, wire is used as feedstock, and arc processes (gas-shielded metal arc processes (MIG/MAG/GMAW), tungsten inert gas processes (TIG/GTAW), plasma arc processes (PAW)) are used as the main energy source.

This document is to be used in conjunction with the engineering documents, if required by the engineering authority.

This document does not address health and safety issues.

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 14175, *Welding consumables — Gases and gas mixtures for fusion welding and allied processes*

ISO/ASTM 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary*

ISO/ASTM 52926-5, *Additive manufacturing of metals — Qualification principles — Part 5: Qualification of operators for DED-Arc*

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 terminology 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
preliminary additive procedure specification
pAPS
document containing the required variables of the additive manufacturing process which has to be qualified

Note 1 to entry: The pAPS contains process specific parameters and will form a section of the manufacturing plan.

3.2
additive procedure specification
APS
document that has been qualified and provides the required variables of the additive manufacturing process to ensure repeatability during production

Note 1 to entry: The APS contains process specific parameters and will form a section of the manufacturing plan.

Note 2 to entry: Further information on the qualification of processes can be found in the ISO 15614 series.

3.3
key process variable
KPV
aspects of the manufacturing process that may impact the capability to meet the specified requirements that include physical, chemical, metallurgical, mechanical and dimensional properties

[SOURCE: SAE AMS 7005:2019-01-31, 8.2.1]

3.4
engineering authority
organization that has the responsibility for the structural integrity or maintenance of airworthiness of the hardware and compliance with all relevant documents

[SOURCE: ISO 24394:2023, 3.8, modified — "design" was removed from the term and Notes to entry have been deleted.]

3.5
build platform
base which provides a surface upon which the building of the part/s, is started and supported throughout the build process

[SOURCE: ISO/ASTM 52900:2021, 3.3.5]

3.6
substrate
base metal utilized to initiate the deposition of material that can remain a portion of the preform

[SOURCE: SAE AMS 7005:2019-01-31, 8.2.1, modified — “may” has been replaced with “can”. Note 1 to entry added]

Note 1 to entry: A substrate can be integral to the final part whereas a build platform will be removed from the final part.

3.7
point of use
location where the process is performed e.g. gas nozzle or torch, trailing nozzle, gas chamber (if used)

4 Requirements for the feedstock

The properties of the feedstock to be used shall be specified. In order to guarantee a constant delivery quality ISO 544, ISO 15792 (all parts) and ISO 14344 can be used. Typical properties include:

— feedstock diameter;

— chemical composition;

— surface condition;

— storage conditions;

— traceability (e.g. heat lot, batch).

5 Qualification of the machine operator

The qualification of the machine operator shall be carried out in accordance to ISO/ASTM 52926-5 and the examination shall be taken every 2 years to ensure certification to the process. Alternative qualification of machine operator may be carried out, if approved by the engineering authority. Example of such are included in SAE AMS 7005:2019, 4.8 and Appendix C and ISO 24394 but with adaptations to the specific DED process and type of DED machine user interface.

NOTE DED processes within the scope of this document share many of the key characteristics with established welding processes such as MIG/MAG (GMAW), TIG (GTAW) and plasma (PAW) as well as mixed variants. The user interface is standardized or manufacturer-specific.

Practical and theoretical examinations are required. For the practical examination. the machine operator sets up the machine for the process and prepares it for the product to be manufactured. This is done on the basis of an APS and a prepared product-specific programme as well as internal specifications.

Machine set-up can include the following:

— wire change;

— change of protective gas supply;

— replacement of wearing parts;

— cleaning of the machine;

— loading the production programme;

— inspection of the overall condition of the machine;

— maintenance.

The content of the theoretical examination shall be adapted to the DED process and the DED machine type of user interface. Testing and evaluation are the responsibility of the welding or additive manufacturing coordinator, examiner or examining body and shall be documented. For the theoretical examination, the guidelines for the theoretical part of the examination from ISO 24394 can be applied, if applicable. A company defined training program per SAE AMS 7005:2019, Clause C.2 may be used if approved by the engineering authority.

In the practical part of the test, the machine operator shall prove the ability to operate the DED machine according to an existing APS. Defined test pieces or production parts can be used for practical testing.

An example for a certificate for a machine operator test can be found in Annex A.

6 Qualification of the DED machine

6.1 Machine qualification

Each individual DED machine shall be qualified by a qualification test programme within its working range, (see ISO 17662 or SAE AMS 7032 for information) as specified by the machine user and approved by the engineering authority.

The machine qualification test programme shall include the main activities of calibration/verification, deposition of test specimens and established maintenance plan.

Within the scope of this document, a DED machine can consist of the following components. Depending on the type of machine, the following can be verified, if applicable:

— power source (see IEC 60974-14);

— moving axes (see ISO 14744-4, ISO 14744-5 and ISO 15616-2 for general guidance, although the application is formally limited to beam welding, or for industrial robots see ISO 9283);

— wire feed rate according to the wire diameter and the wire feedstock;

— wire straightening;

— wire alignment to melt pool feed point;

— machine environment;

— enclosure of the machine or the work area, if needed;

— machine controller;

— control systems (e.g. temperature, weld pool size, process height);

— process gases;

— hot wire system;

— heat treatment system for substrate/build platform (if applicable);

— appropriate build of test samples to evaluate the machine functionality;

— machine and auxiliary equipment software version(s);

— maintenance plan and maintenance schedule is up to date;

— calibration plan and calibration schedule is up to date;

— safety features for proper operation;

— floor layout for proper spacing to other equipment and room to perform maintenance.

The results of the qualification testing shall be documented.

6.2 Machine requalification

Relevant qualification testing shall be repeated for the following cases:

— operational conditions have changed substantially;

— modification of the machine which can impact key process variables (KPVs);

— process deterioration;

— repair or replacement of key parts;

— relocation of the machine.

To ensure that when there is deterioration of the DED process as identified by a decrease in the equipment performance or quality of the parts, there shall be a documented procedure that controls how this is tracked and resolved.

Key parts of the machine include, but are not limited to

— power source,

— type of torch,

— motion control system, and

— hot wire system.

7 Build platform/substrate requirements

The build platform is subject to the following requirements:

— the appropriate platform/substrate material shall be specified;

— it shall be defined geometrically and positioned such that the substrate should not pose a collision hazard during the build that prevents the required geometry being deposited;

— the surface shall be free of grease or other impurities which have a negative influence on the DED process and product quality;

— the required clamping force and positions are defined.

The requirements listed here also apply to wire and arc additions to existing parts.

8 Environment requirements

8.1 General

A facility and process environment control plan shall be established before production. Materials with a high affinity for the absorption of atmospheric gases shall be protected during the process by the use of inert gases in accordance with ISO 14175. For this purpose, auxiliary equipment (e.g. drag nozzles or protective gas chambers) can be used.

8.2 Facility environment

The following shall be addressed in the facility environment control plan:

— feedstock handling and storage;

— build platform handling and storage;

— process gases (e.g. shielding gas, chamber gas, plasma gas) and auxiliary equipment (e.g. drag nozzles or protective gas chambers), where used;

— cleaning routines;

— gas distribution;

— temperature/humidity control;

— process fumes (filtering system).

For more information on these aspects see ISO/ASTM 52920.

8.3 Process environment

The following shall be addressed in the process environment control plan:

— contamination, moisture, oxygen level or draughts;

— location of feedstock (avoidance of cross contamination);

— process gases (e.g. shielding gas, chamber gas, plasma gas);

— process fumes (local extraction ventilation).

For more information on these aspects see ISO/ASTM 52920.

9 Procedure qualification

9.1 General

Procedure qualification is required before the start of production. For this purpose, a procedure qualification plan shall be prepared on the basis of the requirements provided by the engineering authority.

The following may be addressed in a procedure qualification plan:

— test sample configuration;

— number of test samples/builds;

— variation of key process variables to establish a tolerance;

— process interruptions;

— non-destructive testing (e.g. surface, volumetric);

— destructive testing (e.g. microstructure, contamination, composition);

— material properties testing (as required by the Engineering Authority e.g. tensile, hardness, fatigue, creep)

— characterisation testing of the interface between the deposited material and the substrate, if the final product contains both the substrate and the deposited material.

9.2 APS

An APS is required for each production build job. The APS shall include the applicable essential information identified in Table 1 either as part of a program or documentation.

NOTE The list in Table 1 is not necessarily exhaustive.

For this purpose, a preliminary additive procedure specification (pAPS) shall be prepared. The manufacturer shall ensure that the information contained therein reproducibly meets the requirements for the parts. This shall be demonstrated and documented by tests on test samples and/or reference parts using non-destructive and/or destructive tests as determined by the engineering authority. If the procedure qualification is successful, the pAPS data is transferred to the APS. A documented procedure for recording the location of each process interruption needs to be in place, that defines how the location of process interruptions are recorded, and to validate each layer in respect of possible build defects.

Table 1 — APS data

Key process variable (KPV) when marked with asterisk	Information	Gas-shielded metal arc process	Tungsten inert gas process	Plasma arc process
1. General				
*	1.1 Part number, drawing number and revision identifier	x	x	x
	1.2 Build model number (3D-model number)	x	x	x
*	1.3 Part specific build program	x	x	x
2. Feedstock				
*	2.1 Specification	x	x	x
*	2.2 Dimension (size/diameter)	x	x	x
X Data that shall be included in an APS. O Data that only need to be included in an APS if used for that particular additive manufacturing procedure.				