



**International
Standard**

ISO/ASTM 52943-2

**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*

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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 document 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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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).

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.

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);

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- 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.				

Table 1 (continued)

Key process variable (KPV) when marked with asterisk	Information	Gas-shielded metal arc process	Tungsten inert gas process	Plasma arc process
	2.3 Delivery form (e.g. spool)	x	x	x
*	2.4 Programmed feed rate	x	x	x
3. Build platform/substrate				
*	3.1 Build platform/substrate material specification	x	x	x
	3.2 Build platform/substrate identification	x	x	x
*	3.3 Build platform/substrate dimensions	x	x	x
4. Machine				
*	4.2 Machine manufacturer and model	x	x	x
	4.3 Machine control software version	x	x	x
	4.4 Machine identification	x	x	x
5. Environment				
*	5.1 Build platform temperature (if controlled)	0	0	0
*	5.2 Interpass temperature or time (if controlled)	0	0	0
*	5.3 Shielding/process gas specification	x	x	x
	5.4. Shielding/process gas pressure	x	x	x
*	5.5 Shielding/process gas flow rate	x	x	x
*	5.6 Supplemental gas specification (if used)	0	0	0
*	5.7 Supplemental gas flow rate (if used)	0	0	0
*	5.8 Plasma gas specification			x
*	5.9 Plasma gas flow rate			x
*	5.10 Type and size of shielding equipment (e.g. nozzle size, gas trailers, control of environmental enclosure)	x	x	x
*	5.11.1 Gas purity as delivered (e.g. moisture content, oxygen content)	x	x	x
	5.11.2 Gas purity at the point of use (optional/as required by Engineering Authority)	0	0	0
	5.12 Inter-pass processing (cleaning, rolling) (if used)	0	0	0
6. Heat source				
	6.1 Torch	x	x	x
*	6.2 Voltage range	x	x	x
*	6.3 Current range	x	x	x
*	6.4 Pulsing	x	x	x
*	6.5 Pulse characteristic	x	x	x
*	6.6 Hot wire for TIG or plasma processes (preheating of feedstock/wire)	0	0	0
7. Mechanical setup				
X Data that shall be included in an APS.				
0 Data that only need to be included in an APS if used for that particular additive manufacturing procedure.				

Table 1 (continued)

Key process variable (KPV) when marked with asterisk	Information	Gas-shielded metal arc process	Tungsten inert gas process	Plasma arc process
*	7.1 Torch position/angle	x	x	x
*	7.2 Feedstock position/angle	x	x	x
*	7.3 Non-consumable electrode (type, diameter, tip angle, position)		x	x
	7.4 Fume extraction (position)	x	x	x
8. Deposition				
*	8.1 Starting working distance (e.g. electrode or contact tip to work piece distance)	x	x	x
*	8.2 Programmed travel speed(s)	x	x	x
*	8.3 Programmed layer height(s) (fixed or controlled by build height)	x	x	x
*	8.4 Programmed layer pattern(s)/build strategy(ies)	x	x	x
9. Post-build heat treatment/processing				
	9.1 Post build cool down procedure	0	0	0
	9.2 Post build heat treatment	0	0	0
10. Process interruptions and Restart				
*	10.1 Process interruptions (unplanned)	0	0	0
*	10.2 Process interruptions/sequence (planned)	x	x	x
*	10.3 Restart requirements after process interruptions	x	x	x
X Data that shall be included in an APS.				
0 Data that only need to be included in an APS if used for that particular additive manufacturing procedure.				

9.3 Procedure requalification.

If there have been changes to any of the essential variables exceeding established tolerances in the APS, there will be a need to requalify the procedure/APS.

10 Engineering documents

3D models may be used in the creation of “sliced layer models” for additive manufacturing.

The engineering authority shall define the following:

- specification of feedstock;
- specification of the build platform/existing part;
- chemical composition of the additively manufactured part;
- material properties of the additively manufactured part;
- surface condition of the additively manufactured part, e.g. roughness;
- dimensional requirements of the additively manufactured part;
- post-treatment, e.g. stress relieving, hot isostatic pressing, blasting;

- inspection requirements;
- test requirements;
- further engineering requirements to be taken into account for manufacture and testing (e.g. datum points for subsequent machining, and/or machining prior to non-destructive inspection).

11 Production documents

The manufacturing documentation shall be prepared on the basis of the requirements provided by the engineering authority.

Where necessary, support structures shall be defined and documented.

All parameters necessary for the process shall be defined in an instruction for APS. The APS shall be approved by the responsible additive manufacturing supervisor and be recorded in a procedure qualification record.

The manufacturing documentation shall contain all information relevant to the manufacturing process and process, equipment and operator controls, including any upstream and downstream processes. The relevant information includes in particular the arrangement and sequence of the applied beads as well as the associated local heat input.

NOTE The arrangement and sequence of the applied beads as well as the associated local heat input are usually stored in the relevant build file.

12 Process monitoring

The additive manufacturing process shall be monitored and recorded, where required by the engineering authority. Where required, statistical process control shall be used to demonstrate process control based on the applicable information identified in [Table 1](#) (e.g. ASTM E2586, ASTM E2587). Where required, the manufacturer shall have in place a control and reaction plan, authorized by the engineering authority, to respond to variations detected in process control charts.

If the key process variables deviate from the target value ranges, the reasons for this shall be determined and appropriate corrective measures taken, including requalification of the machine and/or the procedure (see [6.2](#)).

13 Product acceptance testing

Product acceptance criteria shall be defined by the engineering authority.

The nature and extent of the minimum tests to be carried out shall be determined by the engineering authority.

ASTM E3166 describes NDT methods that may be used for aerospace parts made with additive manufacturing and includes DED manufacturing processes in its scope.

The following contains a non-exhaustive list of tests and inspections that can be specified:

- dimensional inspection;
- visual inspection (see ISO 19828);
- surface roughness measurement;
- penetrant test (see ISO 23277);
- computed tomography (see ISO 15708-2);
- radiographic examination [see ISO 17636 (all parts)];

- ultrasonic testing (see ISO 16810);
- eddy current testing (see ISO 15549);
- optical metrology;
- process compensated resonance testing;
- infrared thermography;
- hardness test [see ISO 9015-1, ISO 6507-1, ISO 6506-1 or ISO 6508 (all parts)];
- destructive tests, such as but not limited to tensile, fracture toughness, fatigue as required by the engineering authority on samples accompanying the production parts;
- composition of build material, surface contamination (e.g alpha case contamination on Ti parts), and microstructural checks.

14 Build documentation and traceability

The build documentation shall allow full traceability with regard to the APS identification and revision, to the manufacturing steps, the materials used, the build platform and the persons who carried out the manufacturing and testing steps.

The orientation and arrangement of parts, test coupons and any support structures shall be included in the traceability documentation.

The build documentation shall be retained according to the contractual arrangements of the engineering authority and/or the customer.

15 Delivery documentation

The manufacturer of additively manufactured parts shall document to the customer the conformity of the delivery with the specifications of the engineering authority.

Annex A
(informative)

**Operator test certificate for additive manufacturing machines by
material application with directed energy deposition**

Photograph
(if required)

Examiner/examining body or company:

Test certificate No: _____ Operator identity No: _____

Surname, first name: _____

Date of birth (optional): _____

Machine identification: _____

Fabricator and location: _____

has successfully passed the qualification for the operation of machines for additive manufacturing by material application with directed energy deposition on aerospace equipment in accordance with the operator test designation:

Operator qualification ISO/ASTM 52943-2

Description of the conditions of the special test or any adverse effects, if any:

This certificate will expire on yyyy-mm unless renewed by notation below after passing a repeat test.

Place and date of issue: _____

Coordinator/examiner/examining body

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Test certificate No: _____ Operator identity No: _____

Surname, first name:

Requalification test successfully passed on:
Place and date of verification:
Examiner/examining body

Changes to preceding qualification test certificate:

Requalification test successfully passed on:
Place and date of verification:
Examiner/examining body

Changes to preceding qualification test certificate:

Requalification test successfully passed on:
Place and date of verification:
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