
**Additive manufacturing —
Qualification principles — Qualifying
machine operators of laser metal
powder bed fusion machines and
equipment used in aerospace
applications**

*Fabrication additive — Principes de qualification — Qualification des
opérateurs machine des machines à fusion laser sur lit de poudre et
équipements utilisés dans les applications aérospatiales*

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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 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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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 ISO/TC 261, *Additive manufacturing*, in cooperation with ASTM F 42, *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 — Qualification principles — Qualifying machine operators of laser metal powder bed fusion machines and equipment used in aerospace applications

1 Scope

This document specifies requirements for the qualification of operators of laser metal powder bed fusion machines and equipment for additive manufacturing in aerospace applications.

This document is applicable if the operator qualification testing is required by contract or by application standards in the field of aerospace.

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 — Part 1: Fundamentals and vocabulary*

ISO/ASTM 52921, *Standard terminology for additive manufacturing — Coordinate systems and test methodologies*

ISO 18490, *Non-destructive testing — Evaluation of vision acuity of NDT personnel*

EN 4179, *Aerospace series — Qualification and approval of personnel for non-destructive testing*

NAS 410, *NAS CERTIFICATION & QUALIFICATION OF NONDESTRUCTIVE TEST PERSONNEL*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/ASTM 52900, ISO/ASTM 52921 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 <http://www.electropedia.org/>

3.1

examiner

person who has been appointed to verify conformance to the applicable standard

Note 1 to entry: In certain cases, an external independent examiner can be required.

[SOURCE: ISO 14732:2013, 3.12]

3.2

examining body

organization that has been appointed to verify conformance to the applicable standard

Note 1 to entry: In certain cases, an external independent examining body can be required.

[SOURCE: ISO 14732:2013, 3.13]

3.3

operator

person who operates laser metal powder bed fusion machines and equipment for additive manufacturing

3.4

additive manufacturing procedure specification

APS

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

3.5

preliminary additive manufacturing procedure specification

PAPS

document containing the required variables of the additive manufacturing procedure which has yet to be qualified

4 Qualification

4.1 General

There shall be a coordinator designated, in writing, as responsible for the operator qualification test, requalification and disqualification. The coordinator shall have knowledge and experience relevant to the laser powder bed fusion process, and be acceptable to the responsible authority.

Qualification tests of operators shall include the following aspects:

- a) theoretical test;
- b) practical test;
- c) evidence of visual acuity.

The practical test for operators shall follow an additive manufacturing procedure specification. An example of an additive manufacturing procedure specification (APS) is given in [Annex D](#).

4.2 Essential variables and range of qualification

4.2.1 General

The qualification of operators of laser metal powder bed fusion machines for additive manufacturing is based on essential variables. For each essential variable, a range of qualification is defined. If the operator has to work outside the range of qualification, a new qualification test is required. The essential variables are:

- a) powder material groups;
- b) machine model.

NOTE For machine model, see [4.2.3](#).

4.2.2 Powder material group

The theoretical test in the framework of the qualification scope shall be adapted according to the powder material group in use for production.

Material group A: unalloyed steels, low-alloyed steels, high-alloyed ferritic steels.

Material group B: austenitic, martensitic and precipitation hardening steels.

Material group C: titanium and titanium alloys, niobium, zirconium and other reactive metals.

Material group D: aluminium and magnesium alloys.

Material group E: materials that do not conform to other material groups (e.g. molybdenum, tungsten, copper alloys, titanium aluminide).

Material group F: nickel alloys, cobalt alloys.

A qualification performed in a material group only qualifies for that specific group.

4.2.3 Machine model

The machine model is related to the machine manufacturer and the specific machine type.

4.3 Evidence of visual acuity

Any limitations (e.g. visual aids when required to pass the eye sight test), shall be documented on the qualification test certificate. Any limitations in colour perception shall be evaluated prior to qualification and shall be documented on the qualification test certificate.

Eye sight requirements shall be achieved by using one eye or both eyes. The candidate shall successfully achieve the near vision acuity and colour perception specified herein.

Eye sight tests shall be administered by competent personnel.

The method for testing near vision acuity shall be chosen from one of the following:

- a) Jaeger No. 2 eye chart at approximately 400 mm;
- b) Visus 0,8 at approximately 400 mm;
- c) Eye sight requirements of EN 4179/NAS 410 or ISO 18490.

NOTE The results of the 3 near vision testing methods are not fully comparable.

Colour perception shall be examined by a suitable method, e.g. the Ishihara test.

Near vision shall be tested to these requirements at least every 2 years. Colour perception shall be tested to these requirements at least every 6 years.

4.4 Theoretical test

The theoretical test shall include the content given in [Annex A](#).

The theoretical knowledge shall be as a minimum proven in a multiple choice test. The test shall contain a minimum of 20 questions. At least 80 % of the questions shall be answered correctly.

4.5 Practical test

The practical test shall include the content given in [Annex B](#).

For proving the practical skills, the operator shall demonstrate the necessary process steps on a laser metal powder bed based fusion machine and shall set up the machine according to a (preliminary) additive manufacturing procedure specification (PAPS or APS).

NOTE See [Annex D](#) for an example of an APS.

The advanced skills listed in [Annex B](#) shall be given on the qualification test certificate when trained and successfully tested.

5 Qualification test certificate

The examiner or examining body shall certify that the operator for laser metal powder bed fusion machine has successfully passed all tests.

If the operator for a laser metal powder bed fusion machine failed to pass one of the tests according to [4.3](#), [4.4](#) and/or [4.5](#), no qualification test certificate shall be issued.

The certificate shall contain as a minimum the following:

- a) name;
- b) date of birth or unique identifier, e.g. employee number;
- c) machine model (machine manufacturer and the specific machine type) of the machine(s) used for the practical assessment;
- d) material group(s) addressed in the theoretical test;
- e) if applicable, the trained and tested advanced skills (according to [Annex B](#));
- f) corrective lenses, if required to pass the vision acuity test according to [4.3](#);
- g) date of issue of the certificate;
- h) expiration date for period of validity;
- i) name and signature of the examiner.

The certificate shall be issued under the responsibility of the examiner or examining body. A suggested certificate format is provided in [Annex C](#).

6 Validity of testing

6.1 General

The qualification test certificate is valid only for the machine model, powder material(s) and skills which had been assessed.

6.2 Period of validity

The qualification test certificate is valid for a period of 2 years. The operator qualification test certificate shall be renewed every 2 years, according to [6.3](#).

The certificate expires by the end of the respective month when the practical test was taken.

Requalification shall be carried out during the period of validity at any time when:

- a) there is reason to assume that the operator does not fulfil the requirements of the qualification;
- b) the operator has not been working for more than 6 months on the machine model of the qualification;
- c) unsatisfactory results occur on representative parts, which are related to the setup of the machine according to a procedure specification.

6.3 Requalification test

For the requalification test, the same requirements as for the initial qualification tests apply.

The theoretical assessment may be adapted to the operator's professional experience.

The practical assessment may be performed during production.

Successful requalification assessment shall be continuously recorded into qualification test certificate.

6.4 Supplementary test

A supplementary test shall be carried out to add additional machine model(s), powder material(s) and advanced skills to the qualification test certificate. The content of the theoretical and practical assessment can be limited to the additional variables.

A supplementary test does not affect the validity of the initial qualification test certificate.

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Annex A (normative)

Content of the theoretical assessment

The theoretical assessment shall include as a minimum the following aspects:

- a) working safety:
 - related to the machine model;
 - powder (toxic powder, risk of fire and explosion, handling, personal protective equipment, quarantines);
 - process atmosphere (argon, nitrogen, vacuum, safety systems);
 - auxiliaries (e. g. cleaning agent);
- b) equipment and processes:
 - basic process fundamentals including advantages and disadvantages of the process, fields of application;
 - process parameters;
 - fundamental equipment knowledge;
 - machine functions;
 - maintenance according to the machine manufacturers/company specific instructions;
 - qualification procedure for the machine;
 - measures for process assurance (power stability, beam geometry, beam position);
 - machine setup (cleaning, tidiness, build platform);
 - handling of powder (approval, storage, contamination);
 - powder lot traceability;
 - interferences and their negative effects;
 - post processing operations.
- c) Scope and period of validity of the qualification test certificate:
 - scope;
 - period of validity and re-testing.

Annex B (normative)

Content of the practical assessment

The practical assessment shall comprise the following as minimum:

- a) fit and setup of the Laser Powder Bed Fusion (L-PBF) system:
 - verifying the machine setup (e.g. control system, scanning head, beam power supply, gas supply, cooling system, cleaning and changing components);
 - preparing (handling, sieving) and verifying the build platform and powder (feedstock);
 - performing file loading and build jobs specification verification based on the APS (includes inserting/verifying process parameters if needed);
 - verifying beam parameters and conditions (e.g. power stability, geometry, focal point positioning);
 - performing build layout, if applicable;
 - following health, safety and environment procedures for the fit and setup of the L-PBF system;
 - preparing the machine for the build job;
 - following and completing work documentation;
- b) monitoring and managing the manufacturing of parts:
 - if applicable, ensuring that the layers are manufactured according to the quality requirements (i.e. first layers and periodically);
 - reporting issues and implementing corrective or preventive actions as advised;
 - removing the build platform from the machine;
 - removing the powder from the powder bed and from the parts;
 - following health, safety and environment procedures;
 - performing a specified basic check of the as-built parts (no NDT inspection);
- c) preparing L-PBF parts for post processing:
 - if applicable, providing information from process monitoring data about critical areas for extended testing (e.g. powder bed monitoring, build anomalies);
 - parts cleaning;
 - transfer parts for post processing operations;
 - following health, safety and environment procedures;
- d) maintenance of the L-PBF system:
 - implementing equipment maintenance routines (+ software);
 - cleaning and replacing materials components (e.g. powder bed, cleaning agent, filters, cover glass);

- reporting problems;
 - following health, safety and environment procedures;
- e) advanced skills, if performed by the machine operator:
- power measurement;
 - beam geometry determination;
 - beam positioning.

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Annex C (informative)

Example of qualification test certificate for operators of laser metal powder bed fusion machines

(The user of this form is allowed to copy this present form.)

Examiner/examining body or company

Certification of operator qualification of laser metal powder bed fusion machines for additive manufacturing of metallic parts in accordance with ISO/ASTM 52942

Qualification test certificate No.: _____ Operator identity No.: _____

Surname, first name: _____

Date of birth: _____

Fabricator and location: _____

has on xx-yy-zzzz successfully passed the qualification test for operators of laser metal powder bed fusion machines for additive manufacturing of metallic parts in accordance with ISO/ASTM 52942.

Details of the test

Machine manufacturer and models: _____

Material group(s): _____

Corrective lenses required: Yes No

Description of the assessed advanced skills or any limitations, if applicable:

This certificate will expire on yyyy-mm [end of month of issuing the test certificate + 2 years], unless renewed by notation on the reverse side after passing a repeat test.

Place and date of issue: _____

Examiner/ Examining body

Qualification 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:
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:
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Changes to preceding qualification test certificate:

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