



Space product assurance

**Processing and quality assurance
requirements for metallic powder
bed fusion technologies for space
applications**

Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering, product assurance and sustainability in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards. Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

This Standard has been prepared by the ECSS-Q-ST-70-80C Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

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Change log

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Introduction

This Standard specifies the processing and quality assurance requirements for the different types of Powder Bed Fusion (PBF) Additive Manufacturing processes for Metallic Materials for space flight applications. It can also be used for Additive Manufacturing activities on space related ground equipment and development activities for flight hardware. The Standard covers all Powder Bed Additive Manufacturing processes using Laser or Electron Beam as melting source.

This standard may be tailored for the specific characteristic and constraints of a space project in conformance with ECSS-S-ST-00.

1 Scope

This Standard defines requirements for processing and quality assurance of powder bed fusion technologies for space applications.

Within this standard a set of phases are specified, each to be followed when defining, verifying and manufacturing parts using metallic powder bed fusion technologies. In addition, requirements for operating and supervision personnel and equipment facilities are described.

This Standard does not aim to prescribe process parameters relevant to the fabrication using metallic powder bed fusion technologies.

Although this standard is developed for powder bed fusion based techniques, its principles can also be used as a reference for other metal-based and polymer-based processes. These include Wire Arc Additive Manufacturing (WAAM), Stereolithography (with metals), Binder Jetting, but also Selective Laser Sintering (SLS), Stereolithography (with polymers), Fused Deposition Modelling (FDM), and others.

Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revision of any of these publications do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

ECSS-S-ST-00-01	ECSS system – Glossary of terms
ECSS-E-ST-32	Space engineering - Structural general requirements
ECSS-Q-ST-10-09	Space product assurance - Nonconformance control system
ECSS-Q-ST-20	Space product assurance - Quality assurance
ECSS-Q-ST-70	Space product assurance - Materials, mechanical parts and processes
ECSS-Q-ST-70-15	Space product assurance - Non-destructive testing
ECSS-Q-ST-70-45	Space product assurance -Mechanical testing of metallic materials
EN 2003-009:2007	Aerospace series - Test methods - Titanium and titanium alloys - Part 009: Determination of surface contamination
EN ISO ASTM 52921:2016	Standard terminology for additive manufacturing - Coordinate systems and test methodologies
ISO 2859-1:1999	Sampling procedures for inspection by attributes, Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection
ISO ASTM 52941:2020	Additive manufacturing - System performance and reliability - Acceptance tests for laser metal powder-bed fusion machines for metallic materials for aerospace application
ISO ASTM 52942:2020	Additive manufacturing - Qualification principles - Qualifying machine operators of laser metal powder bed fusion machines and equipment used in aerospace applications

Terms, definitions and abbreviated terms

3.1 Terms from other standards

- a. For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply.
- b. For the purpose of this Standard, the terms and definitions from ECSS-E-ST-32 apply, in particular for the following term:
 1. structure

3.2 Terms specific to the present standard

3.2.1 as built

condition of a part or material sample that did not receive any treatment after completion of the AM build job

3.2.2 build job configuration

design of the part, its location, the number of the part(s) and witness specimens, in addition to supporting strategy in the build volume

3.2.3 build job

single complete operation of the powder bed fusion process to create objects in the powder bed

NOTE Multiple objects are commonly created during a build job.

[adopted from NASA MSFC 3717]

3.2.4 structural part

declaration by the design authority of an application to be structural or non-structural

NOTE The term “structural design” is defined in clause 3.2.44 of ECSS-E-ST-32 and can give some guidelines on how to declare an application structural or non-structural.

3.2.5 fatigue critical part

declaration by the design authority of a part to be fatigue critical or not

NOTE Typical cases are where fatigue loads are a significant factor in the design and verification process.

3.2.6 post process operations

action(s) performed after completion of the build job

3.2.7 powder lot

one quantity of powder manufactured in one continuous operation

3.2.8 powder batch

some quantity of a powder lot

NOTE When a large quantity of powder is procured (from the same powder lot), the powder lot is often split into different batches. Different batches can be blended, but they all originate from the same powder lot.

3.2.9 re-verification

repetition of a verification program or parts of it

NOTE The conditions are specified in clause 7.6.

3.2.10 end-to-end manufacturing process

process of producing AM parts, including any pre- and post-processing

3.2.11 overlap zone

part of the build volume of an AM machine, where sub-volumes of parts are built by two or more lasers or electron beams

3.2.12 evenly distributed in the build volume

distributed such that locations in the x-y plane, but also in z-direction up to the maximum height of the part to be built are covered

3.2.13 manufacturing supports

mechanical connections to limit parts distortion and to allow heat transfer during manufacturing

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms and symbols from ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
AM	additive manufacturing
AMP	additive manufacturing procedure
AMVP	additive manufacturing verification plan
AMVR	additive manufacturing verification report
AQL	acceptance quality level
ASTM	American Society for Testing and Materials

Abbreviation	Meaning
CDR	critical design review
CoC	certificate of compliance
DI	de-ionised
DRD	document requirements definition
E-PBF	Electron Beam Powder Bed Fusion
ECSS	European Cooperation for Space Standardization
EDS	energy-dispersive spectrometry
EIDP	end item data pack
ELI	extra low interstitials
FM	flight model
Ftu	ultimate tensile strength
Fty	yield strength
GSTP	general support technology program
HFP	hardware fabrication procedure
HIP	hot isostatic pressing
HP	hardware production
HPR	hardware production report
IPA	isopropyl alcohol
ISO	International Organisation for Standardisation
LBB	leak before burst
L-PBF	Laser Powder Bed Fusion
MMPDS	Metallic Materials Properties Development and Standardization
MOC	molecular contamination
mPBF	metal powder bed fusion
MPD	materials properties database
MRR	manufacturing readiness review
NCR	nonconformance report
NDT	non-destructive testing
OEM	original equipment manufacturer
PAC	particulate contamination
pAMP	preliminary additive manufacturing procedure
PBF	powder bed fusion
pHFP	preliminary hardware fabrication procedure
PMCR	preliminary manufacturing concept review
PVP	prototype verification plan

Abbreviation	Meaning
PVR	prototype verification report
RFA	request for approval
RFW	request for waiver
SEM	scanning electron microscope
SPC	statistical process control
X-Ray CT	x-ray computed tomography

3.4 Nomenclature

The following nomenclature applies throughout this document:

- a. The word “shall” is used in this Standard to express requirements. All the requirements are expressed with the word “shall”.
- b. The word “should” is used in this Standard to express recommendations. All the recommendations are expressed with the word “should”.

NOTE It is expected that, during tailoring, recommendations in this document are either converted into requirements or tailored out.

- c. The words “may” and “need not” are used in this Standard to express positive and negative permissions, respectively. All the positive permissions are expressed with the word “may”. All the negative permissions are expressed with the words “need not”.
- d. The word “can” is used in this Standard to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.

NOTE In ECSS “may” and “can” have completely different meanings: “may” is normative (permission), and “can” is descriptive.

- e. The present and past tenses are used in this Standard to express statements of fact, and therefore they imply descriptive text.

4.1 General

Producing parts through metallic Powder Bed Fusion technologies occurs frequently during the manufacture of parts for space applications.

This Standard specifies the necessary requirements to perform metallic Powder Bed Fusion processes for space applications (see Figure 4-1). Firstly, it is comprised of three phases, as they typically occur during the development of additively produced space hardware:

1. Within the AM definition phase, hardware requirements are reviewed and compared with AM manufacturing constraints, allowing for an early assessment of the feasibility of the envisaged AM project. At this stage, it is clarified, whether or not an existing, verified AMP is applicable for the intended application. If this is the case, the verification on specimen level in point 2 is not repeated, but the verification on part level is then the next step.
2. The aim of the verification phase is to verify the AM end-to-end process through a dedicated test campaign on specimen and part level. The verification on specimen-level results in the approved AMP. The HFP then summarises this two-stage verification on prototype-level and constitutes the basis for any hardware production. The intent of the AMP is to describe the intrinsic material properties and can therefore also be used for other designs.
3. In the hardware production phase, the hardware is produced according to the HFP. The success of manufacturing and inspection is described in the HPR.

Additive Manufacturing processes are considered critical (see the definition of a critical process in ECSS-Q-ST-70) and many factors are known to have a substantial influence on the properties of the final product. Therefore, after the here above described development phases, three clauses, namely clause 9 “AM operation and supervision personnel”, 10 “Equipment and facilities”, and 11 “Quality assurance” address the suitability of operating and supervision personnel, the applied equipment and facilities and define quality assurance requirements.

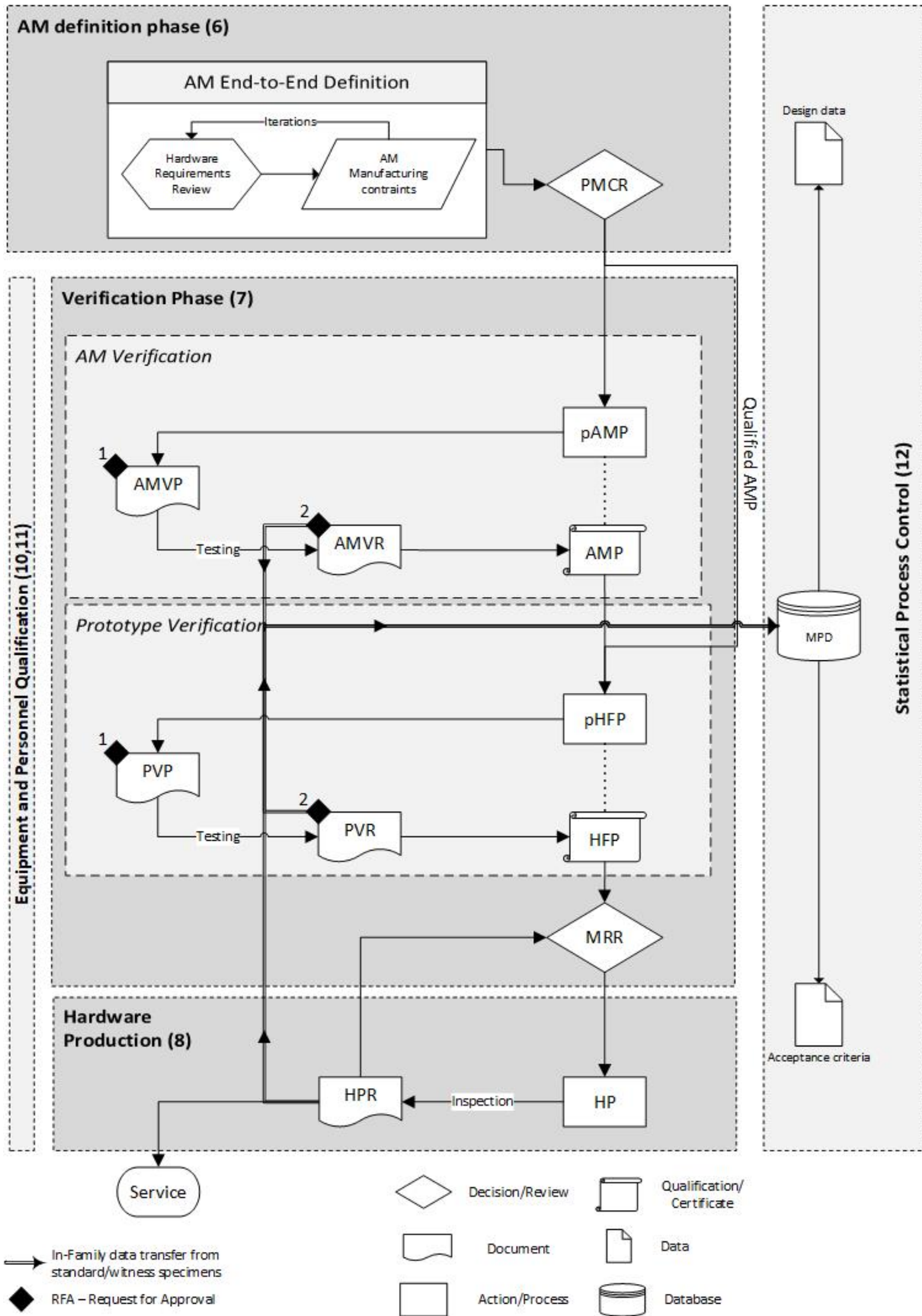


Figure 4-1: Flow chart showing the steps required to establish a verified metallic Powder Bed Fusion process and consequently to produce hardware

5 General

5.1 Referential axis definition

ECSS-Q-ST-70-80_1480001

- a. The standard axis shall be specified in accordance with EN ISO ASTM 52921:2016.

ECSS-Q-ST-70-80_1480002

- b. The gas flow over the powder bed as well as the recoating direction shall be specified, using the referential axis definition.

ECSS-Q-ST-70-80_1480003

- c. The Z-axis shall be perpendicular to the build platform, as specified in Figure 5-1.

ECSS-Q-ST-70-80_1480004

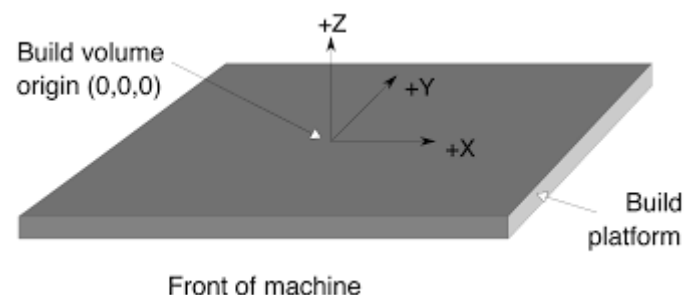
- d. The X-axis shall be perpendicular to the z axis and parallel to the front side of the machine.

ECSS-Q-ST-70-80_1480005

- e. The positive direction shall be left to right, as specified in Figure 5-1.

ECSS-Q-ST-70-80_1480006

- f. The positive Y-axis shall be perpendicular to the Z and X-axis front to back.



ECSS-Q-ST-70-80_1480007

Figure 5-1 Definition of coordinate system [source: EN ISO ASTM 52921:2016]

5.2 Safety classification of AM parts

5.2.1 Overview

Additively manufactured parts for space applications are classified into four classes according to their function and requirements using safety categories (see clause 5.2.2).

Different considerations are made for the classification.

For example, loaded parts subjected to a maximum Von Mises stress $> 50\%$ of the yield strength (F_{ty} in tensile) or $> 25\%$ of the ultimate strength (F_{tu} in tensile) of the material, or if in human spaceflight and subjected to fracture control, are likely considered structural in this context.

Another example is pressurized hardware designed primarily for the storage of pressurized fluid with an energy level greater than or equal to 19310 Joule, or with an internal pressure greater than or equal to 0,69 MPa, or which can create a hazard (if released) are also likely considered structural. Items with an energy level below 19310 Joule can still be considered as structural, unless for instance verified as Leak Before Burst (LBB), to mitigate the risk of catastrophic rupture (see ECSS-E-ST-32-01), although those are sometimes still considered safety critical, even if not fracture critical.

5.2.2 Definition of AM safety classes

5.2.2.1 Safety Class 1.1 parts

Are considered critical and structural. Failure of a Class 1.1 part results in a loss of spacecraft, major components, loss of life, or loss of control of the spacecraft.

5.2.2.2 Safety Class 1.2 parts

Are critical, but non-structural. Failure of a Class 1.2 part results in loss of spacecraft, major components, loss of life, or loss of control of the spacecraft.

5.2.2.3 Safety Class 2 parts

Are non-critical but structural. Their failure can reduce the efficiency of the system but not cause the loss of the spacecraft.

5.2.2.4 Safety Class 3 parts

Are non-critical and non-structural and are contained so that failure does not affect other flight elements. These parts require minimal integrity verification, the controls are mainly visual.

5.2.3 Requirement

ECSS-Q-ST-70-80_1480008

- a. The customer and the design authority shall agree on a safety class for the intended product, as specified in Table 5-1.

ECSS-Q-ST-70-80_1480220

Table 5-1: Safety classes

	Structural	Non-structural
Critical	Class 1.1	Class 1.2
Non-critical	Class 2	Class 3

5.3 Multiple laser systems

ECSS-Q-ST-70-80_1480009

- a. If AM systems with multiple lasers are used, means to test the overlap zone(s) of lasers shall be implemented.

ECSS-Q-ST-70-80_1480010

- b. If AM machines with multiple interacting lasers are used, all laser interaction areas, including the overlap zone(s) shall be assessed by testing.

NOTE The intention is to build test specimens, which are built by two lasers to assess the interface zone of these.

5.4 Family of parts

5.4.1 Overview

The intention of this clause is to allow for design modifications, of a previously verified design, which are not expected to have an impact on the manufacturing stability nor on the final properties of the part without going through a full verification.

5.4.2 Requirements

ECSS-Q-ST-70-80_1480011

- a. If design modifications are performed on parts which have previously been verified in compliance with requirement 7.5.4a, the supplier may propose to re-use the PVR of the initial design, to create a new HFP.

ECSS-Q-ST-70-80_1480012

- b. The new HFP, specified in requirement 5.4.2a, which then does not undergo full verification, shall be submitted to the customer for approval.

5.5 Acceptance criteria

ECSS-Q-ST-70-80_1480013

- a. Acceptance criteria for all tests shall be specified prior to entering the prototype verification phase.

AM definition phase

6.1 Overview

The aim of the AM definition phase is to converge to a preliminary manufacturing concept, allowing for an early assessment of the envisaged AM project. Conducting a feasibility study before starting the AM definition phase intends to help identifying critical aspects at an early stage.

6.2 Input for AM definition phase

6.2.1 Overview

Requirements are defined in order to be able to converge to a preliminary manufacturing concept.

Requirements can refer to: mission and purpose of the part, functionality, applicable safety class, geometry of the part, interface location, thermal and mechanical loading, acceptance criteria for defects, cleanliness aspects, surface conditions, inspectability, etc.

Changes or additions of basic requirements at a later stage of the project can drastically reduce the performance of a part or in worst case require a complete redesign potentially leading to higher cost and effort in the subsequent phases. The design can be developed through co-engineering meetings between the customer, the supplier, and its major partners for post-processing.

This can include the addition of material to ease e.g. milling, which is removed before delivery, but can impact the surface finish. Areas for marking and the associated technique(s) can also be discussed during these meetings.

6.2.2 Requirement

ECSS-Q-ST-70-80_1480014

- a. AM manufacturing constraints shall be iterated with requirements, which are applicable to the part to be built, to converge to an AM end-to-end process.

NOTE 1 AM manufacturing constraints can refer to: design allowables of the MPD, safety class, build volume, feature sizes (e.g. thin walled structures) maximum buildable overhang, availability of feedstock, post processing constraints (e.g. accessibility, clamping), the

removal strategy for powder and manufacturing supports.

NOTE 2 Cleanliness requirements which also address cleanability of the part, can significantly influence the design.

NOTE 3 Violated AM design constraints in the AM definition phase can lead to a complete redesign or in worst case to abandonment of the AM concept and to higher cost and effort in the verification phase.

6.3 Preliminary Manufacturing Concept Review (PMCR)

ECSS-Q-ST-70-80_1480015

- a. As a result from the AM definition phase, a Preliminary Manufacturing Concept Review (PMCR) shall be performed.

ECSS-Q-ST-70-80_1480016

- b. The minimum content of the PMCR shall be in accordance with the DRD from Annex A.

ECSS-Q-ST-70-80_1480017

- c. If the customer declares the PMCR successful, the supplier shall proceed with further development.

Verification phase

7.1 Overview

The aim of this phase is to verify the AM end-to-end process through a dedicated test campaign. First, the preliminary Additive Manufacturing Procedure (pAMP) is established, defining acceptable powder characteristics, AM machine operation parameters, AM machine processing window(s), post processing parameters (e.g. pressure and working distance for jet blasting or heat treatment parameters), and NDT techniques. These parameters are then verified through rather low-cost tests (e.g. density cubes and tensile tests). Once the result of these are acceptable, the pAMP is established.

After having established the pAMP, it is verified on specimen level (AMP), and on prototype level (HFP). The main principle is that preliminary procedures (pAMP and pHFP) are converted to verified procedures (AMP and HFP) through dedicated test campaigns (AMVP and PVP). This logic is also shown in Figure 4-1.

7.2 Establishment of pAMP

7.2.1 Feedstock

ECSS-Q-ST-70-80_1480018

- a. The powder procurement specification shall be specified in conformance with clause 13.2.

7.2.2 Establishment of work processing windows including post processing

ECSS-Q-ST-70-80_1480019

- a. The supplier shall specify a set of AM processing parameter ranges suitable for the selected alloy, design features, and supporting structure.

NOTE Examples of design features that can be foreseen are overhangs.

ECSS-Q-ST-70-80_1480020

- b. The supplier shall specify a set of processing parameters for post-processing operations.

NOTE The post build operations are established in an early stage of the part design and printing

definition as they can have an impact on its resulting features in terms of functionality, performances, appearance and safety.

ECSS-Q-ST-70-80_1480021

- c. The supplier shall provide evidence of the general suitability of the AM and post processing parameters through testing in accordance with Table 7-1.

ECSS-Q-ST-70-80_1480022

- d. The pre-verification phase need not be repeated for machines of the same model, for which a valid AMP exists.

ECSS-Q-ST-70-80_1480023

Table 7-1: Pre-verification test matrix

Test definition	Quantity	Characteristics / criteria
Tensile	At least 3 specimens each in x or y, and z direction, 9 in total	See clause 12.5.2
Density	At least 3 specimens	See clause 12.4
Metallography	At least 3 specimens	To be done in accordance with clause 12.5.1 with the exception of requirement 12.5.1.2 (analysis of melt pool depth)
Customised tests	To be specified, if requested by the customer	-

7.2.3 Preliminary Additive Manufacturing Procedure (pAMP)

ECSS-Q-ST-70-80_1480024

- a. A Preliminary Additive Manufacturing Procedure shall be established in accordance with DRD in Annex B.

NOTE The AMP is valid for one machine (one serial number, as per Annex B).

ECSS-Q-ST-70-80_1480025

- b. If a verified AMP is available, the verification may be limited to the new design, in compliance with clause 7.5.

NOTE The intent of the AMP is to describe the intrinsic material properties achieved with a defined end-to-end-manufacturing process. Often, this parameter set is applicable for many geometries. Therefore, the AMP can be used for a variety of different part designs.

7.3 Verification on specimen- (AMP), and prototype-level (HFP)

ECSS-Q-ST-70-80_1480026

- a. The AM verification phase shall be split into two phases:
 - 1. AM verification on metallurgical and mechanical standard test specimens, in compliance with clause 7.4, and
 - 2. AM verification on prototypes: in compliance with clause 7.5.

ECSS-Q-ST-70-80_1480027

- b. The build job configuration of the prototypes shall be frozen for class 1.1, 1.2 and class 2 parts.

ECSS-Q-ST-70-80_1480028

- c. The build job configuration may be changed for class 3 parts pending approval of the customer.

ECSS-Q-ST-70-80_1480029

- d. Any hardware that is built during the verification phase shall be manufactured in compliance with a previously specified pAMP.

ECSS-Q-ST-70-80_1480030

- e. A-basis design allowables shall be calculated for static tensile properties in accordance with ECSS-E-ST-32 clause 4.5.8.

NOTE 1 Calculating A-basis design allowables is done before setting the witness sample threshold to ensure that it is sufficiently above these design values.

NOTE 2 An example on how design allowables can be calculated for a normally distributed population is given in MMPDS chapter 9.4. This meets the intent of calculating A-basis design allowables, considering the requested number of samples in Table 7-2.

ECSS-Q-ST-70-80_1480031

- f. Other approaches than calculating A-basis design allowables specified in requirement 7.3e may be proposed by the supplier, to be agreed with the customer.

NOTE Other approaches can be the calculation of B-basis design allowables together with additional justification.

ECSS-Q-ST-70-80_1480032

- g. At the end of the verification phase, the acceptance criteria for material properties for the witness samples to be produced in the hardware production phase, shall be agreed by the supplier and the customer.

7.4 Additive Manufacturing Verification Plan (AMVP)

7.4.1 Overview

ECSS-Q-ST-70-80_1480033

- a. The supplier shall define an Additive Manufacturing Verification Plan (AMVP) in compliance with Annex C, which allows establishing design allowables for all design driving load types, environments, and failure modes.

ECSS-Q-ST-70-80_1480034

- b. The AMVP specified in 7.4.1a shall be agreed with the customer.

7.4.2 Safety class 1.1, 1.2, and class 2

ECSS-Q-ST-70-80_1480035

- a. The AMVP for class 1.1, 1.2 and class 2 parts shall include as a minimum the tests listed in Table 7-2.

ECSS-Q-ST-70-80_1480036

- b. For class 1.2 parts, fatigue, and CT scanning need not be performed.

ECSS-Q-ST-70-80_1480037

- c. The design authority shall declare a part to be fatigue critical or not.

ECSS-Q-ST-70-80_1480038

- d. The justification for fatigue criticality from 7.4.2c shall be included in the respective structural analysis report.

ECSS-Q-ST-70-80_1480039

Table 7-2: Test methods for class 1.1, 1.2, and class 2 parts

Test definition	Characteristics/criteria	Comment
Visual inspection	See clause 12.3	On all produced specimens
Metallography	See clause 12.5.1	6 microsections from specimens evenly distributed in the build volume, covering the full height
Tensile testing	See clause 12.5.2	At least 2 build jobs with 10 valid specimens each (population of minimum 20), evenly distributed in the build volume, from the direction showing the lowest strength values. The supplier is free to build the total number of specimens through a higher number of build jobs.

Test definition	Characteristics/criteria	Comment
Fatigue testing (not required for class 1.2)	See clause 12.5.3	For non-fatigue critical hardware: One build job with 12 specimens evenly distributed on the build plate, to create one Wohler curve. For fatigue critical hardware: Two build jobs with 12 specimens each, evenly distributed on the build plate, to create one Wohler curve with 24 data points (testing at least 4 load levels with 6 specimens each) shall be generated. For both cases, the supplier is free to build the total number of specimens through a higher number of build jobs.
X-Ray CT	See requirements 12.3g and 12.3h	On fatigue specimens (grip section can be excluded)
Powder testing	See clause 13.1	The powder properties shall be determined if non-virgin powder is used. If virgin powder with a validated CoC is used, no powder testing is required.
Customised Tests	To be specified, if requested by the customer.	-
<p>NOTE Examples for customised tests are tensile testing with small diameters or thickness to represent thin-walled sections on a part, compression tests for stability sensitive designs, or fatigue crack growth and fracture toughness, tests for fracture control implementation, or tests at high and/or low temperatures. Hardness testing can be useful, if differences in microstructure need to be assessed.</p>		

7.4.3 Safety class 3

ECSS-Q-ST-70-80_1480040

- a. A full height blank shall be built, covering the full height of the build job.

ECSS-Q-ST-70-80_1480041

- b. From the bar(s) built in 7.4.3a, 3 samples for micro sectioning shall be extracted.

ECSS-Q-ST-70-80_1480042

- c. Those samples shall be subjected to visual inspection, metallography, or specific application tests specified by the customer.

ECSS-Q-ST-70-80_1480043

- d. The supplier may test 3 tensile specimens evenly distributed in the build volume instead of the requirements 7.4.3a, 7.4.3b and 7.4.3c.

7.4.4 Reporting

ECSS-Q-ST-70-80_1480044

- a. If all tests were conducted successfully, the pAMP shall become the AMP.

ECSS-Q-ST-70-80_1480045

- b. All test results generated through the AMVP shall be reported in the Additive Manufacturing Verification Report (AMVR) in conformance with the DRD in Annex D.

ECSS-Q-ST-70-80_1480046

- c. All test results shall be incorporated in a Materials Properties Database (MPD), as specified in clause 11.3.1.

NOTE The materials database is used to calculate design allowables and can give relevant insight in the repetitiveness of an AM process. The data is not intended to be publicly shared.

7.5 Prototype verification Plan (PVP)

7.5.1 General

ECSS-Q-ST-70-80_1480047

- a. The supplier shall define a model philosophy in line with the project's approach for the relevant subsystem.

NOTE A Protoflight approach can be an effective way to develop AM hardware, especially for items which are not fatigue critical or safe life potential fracture critical items.

ECSS-Q-ST-70-80_1480048

- b. The supplier shall specify a preliminary Hardware Fabrication Procedure in conformance with the DRD in Annex E.

ECSS-Q-ST-70-80_1480049

- c. The supplier shall specify a Prototype Verification Plan (PVP) in conformance with the DRD in Annex G.

ECSS-Q-ST-70-80_1480050

- d. All prototypes, or test specimens shall be produced in accordance with the preliminary Hardware Fabrication Procedure (pHFP), including all manufacturing steps and post build operations.

7.5.2 Safety classes 1.1, 1.2, and 2

ECSS-Q-ST-70-80_1480051

- a. A prototype shall be built and tested for every new part design.

NOTE Testing of prototypes is done for manufacturing validation.

ECSS-Q-ST-70-80_1480052

- b. Prototypes and witness samples shall be tested as specified in Table 7-3.

ECSS-Q-ST-70-80_1480053

- c. A minimum number of 3 valid tensile test results from witness specimens shall be produced.

NOTE It is good practice to plan for a suitable number of spares.

ECSS-Q-ST-70-80_1480054

- d. A Powder capture sample shall be produced to satisfy the requirement in clause 12.2.

ECSS-Q-ST-70-80_1480055

- e. If X-Ray CT is not technically feasible, customised and destructive tests may be required.

ECSS-Q-ST-70-80_1480056

Table 7-3: Test methods for prototypes, and witness samples for safety classes 1.1, 1.2, and 2

Test definition	Reference	Test object
Dimensional control	According to drawings	All prototypes, and witness specimens.
Visual inspection	See clause 12.3	100 %, on all prototypes, and witness specimens, or as far as possible as permitted by the geometrical complexity
Tensile witness specimens	See clause 12.5.2	3 valid specimens, evenly distributed in the build volume.
X-Ray CT	See requirement 12.3g and 12.3h	100 %, on all prototypes.
Density testing	See clause 12.4	2 full height blanks. From one, three single sections are extracted. The second one is kept in case a specific volume needs to be assessed.
Metallography	See clause 12.5.1	To be performed on one of the two full height blanks.

Test definition	Reference	Test object
Powder testing	See clause 13.1	The powder properties shall be determined if non-virgin powder is used. If virgin powder with a validated CoC is used, no powder testing is required.
Powder capture sample	See clause 12.2	Testing is only done in case of a non-conformance.
Customised Tests	To be specified, if requested by the customer.	-
<p>NOTE 1 Depending on the requirements for the part, some additional tests can be performed on specific samples: roughness, screws junctions characterizations, pressure test, leak test, particulate contamination, hardness tests and microstructural assessments on selected locations of the produced prototype.</p> <p>NOTE 2 Parts produced with powder bed based methods are prone to show adhering particles on the surface, which can lead to particulate contamination. This occurrence is particularly pronounced for parts produced with electron beam based machines. Cleanliness is usually addressed in the equipment PA requirements.</p>		

7.5.3 Safety class 3

ECSS-Q-ST-70-80_1480057

- a. Tests shall be performed in compliance with the Table 7-4.

ECSS-Q-ST-70-80_1480058

- b. Density testing, as required in Table 7-4 may be replaced by tensile testing of 3 specimens.

ECSS-Q-ST-70-80_1480059

Table 7-4: Test methods for prototypes, and witness specimens for safety class 3

Test definition	Reference	Test object
Dimensional control	According to drawings	All prototypes, and witness specimens.
Visual inspection	See clause 12.3	100 %, on all prototypes, and witness specimens, or as far as possible as permitted by the geometrical complexity.
Density testing	See clause 12.4	2 full height blanks. From one, three single sections are extracted. The second one is kept in case a specific volume needs to be assessed.
Powder capture sample	See clause 12.2	Testing is only done in case of a non-conformance.
Customised Tests	To be specified, if requested by the customer.	-

7.5.4 Reporting

ECSS-Q-ST-70-80_1480060

- a. The pHFP shall become the HFP after all tests were conducted successfully.

ECSS-Q-ST-70-80_1480061

- b. All test results generated through the PVP shall be reported in the Prototype Verification Report (PVR) in accordance with Annex H.

ECSS-Q-ST-70-80_1480062

- c. The test results of the witness specimens shall be incorporated in a Materials Properties Database (MPD), in accordance with clause 11.3.1.

7.6 Re- verification of AM machines

7.6.1 Overview

Re-verification is necessary, if modifications on an existing and verified machine are performed.

7.6.2 Requirements

ECSS-Q-ST-70-80_1480063

- a. All tests in the AMVP shall be repeated, if major software or hardware updates were performed which can impact the processing parameters.

ECSS-Q-ST-70-80_1480064

- b. For safety class 1.1, 1.2, and 2, all tests in Table 7-2, with the exception of customised tests and fatigue tests, shall be repeated, if:
 1. A machine was re-located;
 2. Essential components were replaced, repaired, or altered;
 3. Minor software updates were performed which do not impact the processing parameters;
 4. The AM machine has not been operated for 6 months or more.

NOTE 1 Essential components can be the laser or the scanner head, or any other part which is crucial to reach the required laser beam quality. A non-essential component could be a recoater blade, which is considered to be a consumable.

NOTE 2 Software affected by these requirements is any, which can affect the processing parameters of the AM machine.

7.7 Machine pause

7.7.1 Overview

A machine pause is a stop of beam with no other associated phenomenon such as a stop of heating system, power outage, collision of recoater with the part, or loss of inert atmosphere.

7.7.2 Requirements

ECSS-Q-ST-70-80_1480065

- a. No unplanned process interruption shall be accepted during the verification phase.

NOTE An unplanned process interruption can be triggered by a stop of heating system, power outage, collision of recoater with the part, loss of inert atmosphere, scheduled or un scheduled maintenance, etc.

ECSS-Q-ST-70-80_1480066

- b. Unplanned process interruptions may be acceptable upon customer agreement during the verification phase, if the elapsed time is less than the elapsed time between two consecutive layers.

ECSS-Q-ST-70-80_1480067

- c. If a machine pause is planned to occur during the hardware production phase, dedicated tests to characterise the properties of the interface zone shall be included in the AMVP.

ECSS-Q-ST-70-80_1480068

- d. For planned machine pauses, a procedure for re-start shall be established by the supplier and agreed with the customer.

ECSS-Q-ST-70-80_1480069

- e. The recommendations of the OEM regarding machine restart shall be followed.

7.8 Repair

ECSS-Q-ST-70-80_1480070

- a. No repair of the manufactured part(s) or specimens shall be permitted during the verification phase.

7.9 Manufacturing supports

ECSS-Q-ST-70-80_1480071

- a. Prototypes or standard test samples shall be free of any residues of supports, if the prototypes or test samples are tested without subsequent machining.

7.10 Parts cleaning

ECSS-Q-ST-70-80_1480072

- a. Cleaning processes shall be applied so that the parts comply with cleanliness requirements of the equipment.

NOTE Particulate contamination (PAC) can e.g. occur due to particles adhering to the part's surface. Molecular contamination (MOC) can e.g. include residues of cutting fluids for milling or turning.

7.11 Documentation

ECSS-Q-ST-70-80_1480073

- a. The AMVP and the PVP shall be incorporated in the first issue of the RFA in accordance with Annex D of ECSS-Q-ST-70.

NOTE See also Figure 4-1.

ECSS-Q-ST-70-80_1480074

- b. The AMVR and the PVR shall be incorporated in the second issue of the RFA in accordance with Annex D of ECSS-Q-ST-70.

NOTE See also Figure 4-1.

7.12 Manufacturing Readiness Review (MRR)

ECSS-Q-ST-70-80_1480075

- a. The MRR shall be performed in compliance with ECSS-Q-ST-20.

ECSS-Q-ST-70-80_1480076

- b. The results of the verification testing, AMVR and PVR, and the HFP shall be presented at MRR.

ECSS-Q-ST-70-80_1480077

- c. The second issue of the RFA shall only be approved after having successfully performed the MRR.

ECSS-Q-ST-70-80_1480078

- d. During the MRR, it shall be confirmed to the customer that build job configuration is under configuration control.

Hardware production

8.1 Overview

The aim of this phase is to produce the intended hardware according to the previously defined HFP, and to validate it through non-destructive, mechanical, or functional tests, as well as through witness specimens.

8.2 Requirements for hardware production

8.2.1 General

ECSS-Q-ST-70-80_1480079

- a. Hardware production shall be done in compliance with the Hardware Fabrication Procedure (HFP) from the DRD in Annex E.

ECSS-Q-ST-70-80_1480080

- b. The supplier shall produce and test the witness specimens according to Table 8-1.

ECSS-Q-ST-70-80_1480081

Table 8-1: Overview of witness samples to be produced with hardware

Test object	Safety Class 1.1	Safety Class 1.2	Safety Class 2	Safety Class 3
Tensile test specimens	3	3	3	3 tensile specimens or 1 full height blank
Full height blanks	2	2	1	
Powder Capture Sample	1	1	1	-

8.2.2 Process interruption

ECSS-Q-ST-70-80_1480082

- a. If an unplanned process interruption occurs during the hardware production phase, the manufacturer may continue the manufacturing.

ECSS-Q-ST-70-80_1480083

- b. In case of an unplanned process interruption specified in requirement 8.2.2a, a major nonconformance shall be raised.

8.2.3 Manufacture of hardware and witness samples

8.2.3.1 Overview

Witness samples produced with hardware provide a reference of the material properties within the produced build job. An overview of the different witness samples and test methods is given in Table 8-1.

8.2.3.2 Standard tensile test specimens

ECSS-Q-ST-70-80_1480084

- a. Samples to provide validation of material shall be built as test pieces and undergo all post processing steps as specified in the HFP.

ECSS-Q-ST-70-80_1480085

- b. The shape and orientation of the specimens shall be determined in compliance with clause 12.5.2.

ECSS-Q-ST-70-80_1480086

- c. The tensile specimens shall be evenly distributed in the build volume.

ECSS-Q-ST-70-80_1480087

- d. In case overlapping areas are present in the part, the arrangement of the specimens shall cover all combinations of lasers for multi laser systems including overlapping areas.

NOTE It is best practice to place the tensile test specimen such that the maximum height of the FM is in the gauge length.

ECSS-Q-ST-70-80_1480088

- e. A minimum number of 3 valid tensile test results shall be produced for all safety class 1.1, 1.2, and 2.

NOTE It is good practice to plan for a suitable number of spares.

8.2.3.3 Full height blanks

ECSS-Q-ST-70-80_1480089

- a. The full height blanks shall undergo the same post processing steps as defined in the HFP for the part.

ECSS-Q-ST-70-80_1480090

- b. The full height test blanks shall reach at least the same height as the part.

8.2.3.4 Powder capture sample

ECSS-Q-ST-70-80_1480091

- a. Powder capture samples shall be produced in compliance with clause 12.2.

8.3 Testing of witness samples

8.3.1 Tensile testing

ECSS-Q-ST-70-80_1480092

- a. All tensile tests shall be performed in compliance with clause 12.5.2.

ECSS-Q-ST-70-80_1480093

- b. The yield strength, tensile strength, elastic modulus, and elongation at break of each individual tensile test shall all be within the ranges specified in the PVP.

8.3.2 Full height blanks

8.3.2.1 Safety class 1.1 and 1.2

ECSS-Q-ST-70-80_1480094

- a. The density shall be measured on the full height blanks in compliance with clause 12.4.

ECSS-Q-ST-70-80_1480095

- b. The second full height blank shall be stored and only be tested, if needed for a failure investigation.

NOTE These are necessary to provide material for inspection if a build interruption occurs. One full height blank can be inspected at the height of the process interruption to assess its impact on the as-built microstructure.

ECSS-Q-ST-70-80_1480096

- c. Metallography shall be performed for class 1.1 and 1.2 parts on the full height blanks in accordance with clause 12.5.1.1.

ECSS-Q-ST-70-80_1480097

- d. The chemical composition including light elements shall be assessed on the full height blanks for class 1.1 and 1.2 parts.

NOTE 1 If during the AM-pre-verification phase, a feedstock and recycling study demonstrates negligible change in composition within the specified limits, then chemical composition specimens are expected to be less critical.

NOTE 2 For feedstock/process combinations which show, for example, a continuous increase in O content or a continuous decrease in Mg content to a specified limit, then, determining the chemical composition can be done in all builds and analysed before part release.

8.3.2.2 Safety class 2 and 3

ECSS-Q-ST-70-80_1480098

- a. The density shall be measured in compliance with clause 12.4.

8.3.3 Powder capture sample

ECSS-Q-ST-70-80_1480099

- a. The powder capture sample shall be removed from the baseplate before any heat treatment or HIP process.

ECSS-Q-ST-70-80_1480100

- b. The powder capture sample shall be stored and only be tested in accordance with clause 13.1, if needed for a failure investigation.

ECSS-Q-ST-70-80_1480101

- c. The powder capture sample specified in 8.3.3b, may be analysed immediately to avoid storing.

8.4 Inspection of hardware

8.4.1 Non-destructive techniques

ECSS-Q-ST-70-80_1480102

- a. The supplier shall implement at least the non-destructive tests in accordance with Table 8-2.

NOTE If the part is under fracture control, more NDT can be needed, to satisfy ECSS-E-ST-32-01. For NDT see ECSS-Q-ST-70-15.

ECSS-Q-ST-70-80_1480103

- b. The NDT methods in Table 8-2 shall be carried out in accordance with clause 12.3.

ECSS-Q-ST-70-80_1480104

- c. The part shall be accepted if the found indications are in compliance with the acceptance criteria specified in the PVP.

ECSS-Q-ST-70-80_1480221

Table 8-2: Overview of non-destructive tests for AM hardware

Test definition	Safety Class 1.1	Safety Class 1.2	Safety Class 2	Safety Class 3
X-Ray CT	100 %	100 %	-	-
Visual inspection	100 %, or as far as possible as permitted by the geometrical complexity of the part	100 %, or as far as possible as permitted by the geometrical complexity of the part	100 %, or as far as possible as permitted by the geometrical complexity of the part	100 %, or as far as possible as permitted by the geometrical complexity of the part
Dimensional control	100 %	100 %	100 %	Sampling according to ISO 2859-1:1999 sensitivity level II, AQL 0.65
Functional test or proof test	If no X-Ray technique is technically feasible or useful	If no X-Ray technique is technically feasible or useful	-	-

ECSS-Q-ST-70-80_1480105

- d. If required in Table 8-2 for the respective safety class, X-Ray CT testing shall be performed after the last heat- or HIP-treatment.

ECSS-Q-ST-70-80_1480106

- e. The X-Ray CT Testing, specified in 8.4.1d, may be performed before a final machining step.

ECSS-Q-ST-70-80_1480107

- f. If required in Table 8-2 for the respective safety class, visual inspection, dimensional control, and functional tests shall be performed after the last post-processing step.

NOTE It is best practice to perform selected NDT techniques after each manufacturing step to mitigate the production risk in addition to the tests in requirement 8.4.1d and f.

ECSS-Q-ST-70-80_1480108

- g. For class 1.1 and 1.2 parts, functional tests may be performed instead of X-Ray techniques if these are technically not feasible.

NOTE Examples of parts that cannot be inspected with X-Ray techniques include ones that cannot be penetrated due to their size, thickness, or the material's density.

ECSS-Q-ST-70-80_1480109

- h. X-Ray CT may be replaced by 2D X-Ray inspection if agreed with the customer.

8.5 Reporting

ECSS-Q-ST-70-80_1480110

- a. All test results of clause 8.3 and 8.4 shall be reported in the Hardware Production Report (HPR) in conformance with the DRD in Annex F.

AM operation and supervision personnel

9.1 Overview

The aim of this clause is to ensure the suitability of operating and supervision personnel.

NOTE It is best practice that the positions described in clauses 9.2-9.4 are not held by one person only to avoid a single point of failure.

9.2 AM supervisor

ECSS-Q-ST-70-80_1480111

- a. The appointment of the AM supervisor shall be reported to the customer.

ECSS-Q-ST-70-80_1480112

- b. The manufacturer shall employ an Additive Manufacturing supervisor who is responsible for the following tasks:
1. Facility and equipment maintenance,
 2. Health and safety,
 3. The AMP,
 4. Build job configuration.

NOTE 1 The AM supervisor does not necessarily have to personally perform the tasks listed in requirement 9.2b, but is expected to supervise and record these tasks.

NOTE 2 Facility and equipment maintenance also includes software maintenance of the AM equipment.

9.3 Qualification and certification of AM operators

9.3.1 Laser based Powder Bed Fusion processes

ECSS-Q-ST-70-80_1480113

- a. Only operators holding a valid qualification test certificate for Laser Powder Bed Fusion (L-PBF) in compliance to ISO ASTM 52942:2020 shall perform operations on such equipment.

9.3.2 Electron Beam based Powder Bed Fusion processes

ECSS-Q-ST-70-80_1480114

- a. The supplier shall define a training and test program for qualifying machine operators of electron beam metal powder bed fusion machines and equipment.

NOTE At the time of issuing this standard, no dedicated standard for qualifying E-PBF operators was available. ISO ASTM 52942:2020 was developed for laser beam based machines, but can be used as reference when meaningfully applied.

ECSS-Q-ST-70-80_1480115

- b. Only operators holding a valid qualification test certificate in accordance with requirement 9.3.2a shall perform operations on electron beam based powder bed fusion equipment.

9.4 Qualification and certification of personnel for NDT

ECSS-Q-ST-70-80_1480116

- a. Personnel performing Non-Destructive Testing on additively manufactured parts shall be trained and certified in accordance with ECSS-Q-ST-70-15.

9.5 Safety of Personnel

ECSS-Q-ST-70-80_1480117

- a. National regulations applicable for operators of metal powder bed fusion equipment shall be applied.

ECSS-Q-ST-70-80_1480118

- b. If such national regulations are not available, the supplier shall implement safety measures for personnel by himself.

10 Equipment and facilities

10.1 Overview

The aim of this clause is to ensure the suitability of the applied equipment and the used facilities.

10.2 Conditions for facilities

ECSS-Q-ST-70-80_1480119

- a. The temperature of the room where the AM machine is operated shall always be between 20 °C and 25 °C with a maximum relative humidity of 50 %, if powders are exposed to this environment.

10.3 Laser based equipment calibration

ECSS-Q-ST-70-80_1480120

- a. The acceptance inspection shall be performed in accordance with to ISO ASTM 52941:2020.

10.4 Electron beam based equipment calibration

ECSS-Q-ST-70-80_1480121

- a. The acceptance inspection shall be performed in accordance with OEM specification.

10.4.1 Frequency

ECSS-Q-ST-70-80_1480122

- a. Beam calibration shall be performed in the following cases:
 1. Scheduled in maintenance program,
 2. Machine has been moved,
 3. Differences have been observed between parts,
 4. Changes of machine hardware have been done.

ECSS-Q-ST-70-80_1480123

- b. Beam calibration shall ensure that the spot quality is equal over the entire build area.

10.4.2 Calibration protocol description

ECSS-Q-ST-70-80_1480124

- a. Automatic calibration procedure shall be performed in accordance with OEM equipment handbook.

ECSS-Q-ST-70-80_1480125

- b. Verification of calibration shall be performed as follows:
 - 1. Building of OEM verification plate, which achieve a beam test pattern.
 - 2. Check the beam calibration plate status with visual inspection, which allows evaluation of:
 - (a) Dimensional accuracy of bead
 - (b) Beam alignment
 - (c) Focus offset
 - (d) Electron beam deflection system
 - 3. Building of OEM reference part in order to finalise evaluation of:
 - (a) Dimensional accuracy of shape
 - (b) Material properties

10.5 Maintenance and repair

10.5.1 Maintenance of laser based machines

ECSS-Q-ST-70-80_1480126

- a. As a minimum, maintenance shall be carried out as described in the OEM equipment handbook.

ECSS-Q-ST-70-80_1480127

- b. In the absence of clear OEM instructions, maintenance activities shall include:
 - 1. After each build
 - (a) Visual inspection of the system,
 - (b) Check of laser-protection glass in the process chamber door and process chamber cover (contamination, scratches, penetration, etc.),
 - (c) Clean laser glass,

- (d) Check recoater condition,
- (e) Check gas circulation filter and change if necessary,
- 2. Weekly
 - (a) Check of safety equipment (emergency stop, etc.),
 - (b) Visual check and, if polluted, cleaning of gas outlet valve,
 - (c) Check filter on personal protection for impurities and clean or replace if polluted,
 - (d) Check filter on cooling unit and clean or replace if polluted,
 - (e) Check coolant filling level and fill it if level is low,
 - (f) Check cooling water for impurities,
 - (g) Check DI cartridge on cooling unit and clean or replace if necessary.
- 3. Monthly
 - (a) Clean areas behind removable inner walls, if they are present,
 - (b) Testing emergency shutdown, emergency stop,
 - (c) Check the sieving equipment for damage
- 4. Half-yearly
 - (a) Change cooling water.
- 5. Annually
 - (a) Check fire extinguisher,
 - (b) Check, clean and calibrate optical systems,
 - (c) Clean gas circulation pipes,
 - (d) Check mechanical drives, guides and bearings,
 - (e) Check seals,
 - (f) Inspect air dryer and filters.

ECSS-Q-ST-70-80_1480128

- c. All maintenance records shall be noted in an equipment log book, either digitally or on paper.

10.5.2 Maintenance of electron beam based machines

ECSS-Q-ST-70-80_1480129

- a. As a minimum, maintenance shall be carried out as described in OEM equipment handbook.

- b. Maintenance activities shall include:
1. After each build
 - (a) Check log and analyse results from build done,
 - (b) Visual inspection of the system,
 - (c) Vacuum clean the powder basin centre area with clean vacuum cleaner,
 - (d) Check the chamber interior for metallisation and clean if polluted,
 - (e) Check or change protections foils of beam column, chamber,
 - (f) Check or change observation window protection glass,
 - (g) Vacuum clean the chamber from loose particles with dirty vacuum cleaner,
 - (h) Remove tank and sandblast cake in dedicated sandblaster,
 - (i) Sieve powder contents in sandblaster and clean vacuum cleaner,
 - (j) Fill hoppers with sieved powder,
 - (k) Clean seals and door,
 - (l) Close the chamber and start vacuum.
 2. Before a build
 - (a) Check that the rake is properly attached and the condition of rake teeth,
 - (b) Check amount of powder according to height of next job,
 - (c) Check or trim the powder dispatcher in accordance with OEM equipment handbook.
 3. Weekly
 - (a) Check of safety equipment,
 - (b) Check filter on personal protection for impurities and clean or replace if polluted,
 - (c) Clean floor of laboratory.
 4. Monthly
 - (a) Clean areas: Cabinet, computer, behind the side walls,
 - (b) Check coolant filling level and fill it if level is low,
 - (c) Check Helium filling level and fill it if level is low,
 - (d) Testing emergency shutdown, emergency stop,
 - (e) Check / clean the sieving equipment for damage.
 5. Yearly
 - (a) Check fire extinguisher,
 - (b) Inspect air dryer and filters,
 - (c) Inspect sandblaster and change filters.

6. A – Maintenance: See OEM handbook for frequency
 - (a) Check electron beam unit: cathode, top column, sensors,
 - (b) Check vacuum chamber,
 - (c) Check camera system,
 - (d) Check mechanical drives, guides and bearings,
 - (e) Check / adjust powder dispatcher system,
 - (f) Check seals.
7. B – Maintenance: See OEM handbook for frequency
 - (a) Change cathode,
 - (b) Check electron beam unit: top column, sensors,
 - (c) Check vacuum chamber,
 - (d) Check camera system,
 - (e) Check mechanical drives, guides and bearings,
 - (f) Change rake arm,
 - (g) Check / adjust powder dispatcher system,
 - (h) Check / adjust build tank and table,
 - (i) Check seals.

NOTE Safety equipment can refer to devices which trigger e.g. emergency stops, etc.

ECSS-Q-ST-70-80_1480131

- c. All maintenance records shall be noted in an equipment log book, either digital or paper.

10.5.3 Repair

ECSS-Q-ST-70-80_1480132

- a. All repairs shall be noted in an equipment log book.

ECSS-Q-ST-70-80_1480133

- b. After each repair, follow-up actions shall be performed as specified in the OEM handbook.

ECSS-Q-ST-70-80_1480134

- c. In case of doubt, the follow-up action shall be mutually agreed with the OEM.

10.6 Materials and consumables

10.6.1 Management of powder

ECSS-Q-ST-70-80_1480135

- a. The manufacturer shall produce a Powder Management Plan in conformance with DRD in Annex I for approval by the customer.

ECSS-Q-ST-70-80_1480136

- b. For safety class 1.1, class 1.2 and 2, only alloys of the same family shall be processed in the same build chamber due to the risk of cross-contamination.

NOTE 1 Examples of families of alloys commonly used by the space industry are:

- Nickel based alloys as IN 718, IN 625, and Hastelloy X
- Aluminium alloys as AlSi10Mg, AlSi7Mg0.6, AA8009, and Scalmalloy®
- Ferritic stainless steels and martensitic stainless steels
- Austenitic stainless steels and Nickel containing iron alloys as INVAR®
- Titanium alloys containing more than 85 weight-% titanium as Ti-6Al-4V

NOTE 2 Austenitic stainless steels are not considered to be of the same family of ferritic or martensitic stainless steels.

10.6.2 Tooling and features

ECSS-Q-ST-70-80_1480137

- a. Bottles, funnels, sieves and hand tools shall be dedicated to one family of alloys

ECSS-Q-ST-70-80_1480138

- b. Cleaning of solid surfaces of tools or any other manufacturing equipment shall be carried out with a wipe and IPA.

10.6.3 Gases

ECSS-Q-ST-70-80_1480139

- a. The purity of argon shall be at least 99,998 %.

ECSS-Q-ST-70-80_1480140

- b. The purity of nitrogen shall be at least 99,998 %.

ECSS-Q-ST-70-80_1480141

- c. Nitrogen shall not be used with Ti-alloys.

10.6.4 Cleaning of machines

ECSS-Q-ST-70-80_1480142

- a. In addition to cleaning of mPBF machines in line with maintenance schedules, cleaning of the powder path shall be carried out after completion of the maximum number of validated powder recycles.

11 Quality assurance

11.1 Configuration control

ECSS-Q-ST-70-80_1480143

- a. The AMP and the HFP shall be under configuration control.

11.2 Maintenance of AM procedure

11.2.1 Overview

The basic principle is that as soon an AMP or a HFP has been verified, no modification is permitted without customer agreement. Changes of these procedures may require partial or complete re-verification.

11.2.2 Requirements

ECSS-Q-ST-70-80_1480144

- a. Every modification of a verified AMP or HFP shall be agreed between supplier and customer and the documents updated accordingly.

11.3 Statistical Process Control

11.3.1 Materials Properties Database (MPD)

ECSS-Q-ST-70-80_1480145

- a. A MPD shall be populated with data, generated from one AMP.

NOTE Data from witness specimens which have been produced according to an AMP can also be included in the MPD. An example of a MPD is given in Annex K.

ECSS-Q-ST-70-80_1480146

- b. Data shall only be included in the MPD, if it is produced with a verified AMP.

ECSS-Q-ST-70-80_1480147

- c. Data shall only be included, if it is considered to be “in family” of the existing material property suite.

ECSS-Q-ST-70-80_1480148

- d. A dataset shall only be considered “in family” with an existing materials property suite, if the deviation of the arithmetic average of the yield and tensile strength does not exceed three standard deviations.

NOTE Typically, the “in family” criterion is only applied for static mechanical properties.

11.4 Quality control

11.4.1 Reference and witness samples

ECSS-Q-ST-70-80_1480149

- a. Witness samples shall be stored in conformance with life duration of the mission upon customer request.

11.4.2 Documentation of manufacturing

ECSS-Q-ST-70-80_1480150

- a. Traceability shall be ensured through a shop traveller.

NOTE The shop traveller can include the dates of the different manufacturing steps including post operations, the powder batch number, the powder level in machine before start, confirmation of compliance with AMP through operator’s signature, etc.

ECSS-Q-ST-70-80_1480151

- b. All data shall be available for review.

11.4.3 Anomalies and non-conformances occurring during the AM process

ECSS-Q-ST-70-80_1480152

- a. In case of anomalies occurring during the AM process, a nonconformance report in compliance with ECSS-Q-ST-10-09 shall be raised.

NOTE A deviation from the qualified range of one or more process parameters can be considered as anomalies.

11.5 Auditing

ECSS-Q-ST-70-80_1480153

- a. A supplier process audit shall be performed for new suppliers prior to the start of the pre-verification phase.

ECSS-Q-ST-70-80_1480154

- b. Suppliers may be re-audited if major changes to the end-to-end manufacturing process are made.

NOTE An example of an audit check list is proposed in Annex J.

11.6 End Item Data Pack

ECSS-Q-ST-70-80_1480155

- a. The EIDP shall be created in compliance with Annex B of ECSS-Q-ST-20.

Testing of AM materials and parts

12.1 Overview

The aim of this clause is to detail several non-destructive and destructive testing methods which are called up through the above requirements.

12.2 Powder capture sample

12.2.1 Overview

Powder capture samples provide a useful historic reference to a powder used in a build. They can also provide an indication of any powder contamination issue occurring before or during the build.

A powder capture sample can be an mPBF container built during the mPBF which intrinsically contains powder as-supplied to the build chamber and any contaminants generated during the build.

Equally, it can be a powder sampling tool, which is inserted into the bed, collects a sample and is then withdrawn.

12.2.2 Requirement

ECSS-Q-ST-70-80_1480156

- a. Powder capture samples shall contain sufficient powder for any likely retrospective tests.

12.3 NDT for AM

ECSS-Q-ST-70-80_1480157

- a. The selection of NDT techniques shall be performed in the AM definition phase and implemented in accordance with ECSS-Q-ST-70-15.

NOTE ASTM E3166:2020 “Standard Guide for Non-destructive Examination of Metal Additively Manufactured Aerospace Parts After Build” can be used complementary for examining AM parts.

ECSS-Q-ST-70-80_1480158

- b. Visual inspection shall be performed in compliance with ECSS-Q-ST-70-15.

ECSS-Q-ST-70-80_1480159

- c. Visual inspection shall be performed after completion of the build job and after separation from the build plate.

NOTE It is best practice to carry out the visual inspection with a magnification of 10x or higher. The aim of the visual inspection is to locate any superficial anomalies. This can include cavities, discolouration, contamination, cracks, lack of fusion, and as far as this can be detected with the applied magnification.

ECSS-Q-ST-70-80_1480160

- d. Dye penetrant inspection shall be performed if specified by the customer.

ECSS-Q-ST-70-80_1480161

- e. Dye penetrant inspection shall be carried out with sensitivity level 2 in accordance with AMS 2644, unless otherwise specified by the customer or necessary for implementation of for example fracture control.

NOTE For example, fracture control requirements can ask for a higher sensitivity level than 2 or even a different technique.

ECSS-Q-ST-70-80_1480162

- f. The dye of the selected method shall be cleanable in full.

NOTE AM parts are expected to have relatively high surface roughness, which makes dye penetrant inspection challenging to apply. Jet-, vapour-, and bead-blasting can close surface-cracks and it is therefore best practice to apply an etch before dye penetrant inspection.

ECSS-Q-ST-70-80_1480163

- g. X-Ray CT shall be applied to detect internal defects in accordance with ASTM E 1570 and ASTM E 1441 unless otherwise specified.

NOTE Typical internal defects for mPBF processes are pores, lack of fusion, cracks, or inclusions. X-Ray CT can also provide the porosity level, the defect's size, shape, and location.

ECSS-Q-ST-70-80_1480164

- h. For X-Ray CT, the voxel size shall be adapted to the smallest acceptable defect size.

NOTE It is best practise to adjust the resolution such that the smallest acceptable defect size can be detected with at least two voxels. Other important parameters include the contrast to noise ratio, the focal spot size, the reference samples for detection of smallest defect size, etc.

ECSS-Q-ST-70-80_1480165

- i. In cases where the acceptance criteria for inner defects cannot be verified with NDT techniques, the supplier shall propose and justify an alternative method to assess these.

NOTE Alternative methods can include process monitoring techniques or proof testing.

12.4 Density testing

12.4.1 Overview

State of the art AM processes can show some porosity in the form of lack of fusion-like defects and/or pores. The relative density of AM material is therefore a crucial factor to judge its “health”, and it is often measured with “full height blanks”. A full height blank is a free-standing specimen that stretches from the base plate to the maximum height of the part to be built and can have a circular (typically \varnothing 10 mm) or a rectangular (typically 10x10 mm²) cross section.

12.4.2 Requirements

ECSS-Q-ST-70-80_1480166

- a. Density specimens produced together with a part shall not be positioned farther away from the actual part than 20 mm in x or y direction.

ECSS-Q-ST-70-80_1480167

- b. At least one sample shall be positioned at the side where the gas is extracted from the build chamber and tested.

NOTE Techniques for density measurement include Archimedes (EN ISO 3369:2010 or ASTM B 962:2017), X-ray CT, and quantitative metallography.

12.5 Destructive testing

12.5.1 Metallography

12.5.1.1 General Metallography

ECSS-Q-ST-70-80_1480168

- a. Microsections shall be made normal to the Z-axis, in accordance with clause 5.1, to evaluate bulk material and parallel to the Z-axis, for the assessment of melt pool characteristics.

ECSS-Q-ST-70-80_1480169

- b. The microstructure shall be demonstrated free of unacceptable defects when evaluated with metallurgical cross-sections at a minimum magnification of 50x and an area of evaluation $\geq 1\text{cm}^2$.

NOTE 1 Detrimental defects can include foreign particle inclusions, or pores, lack of fusion or cracks, exceeding defined acceptance criteria.

NOTE 2 The basic concept of microstructural investigations for AM material was adopted from NASA MSFC-SPEC-3717.

ECSS-Q-ST-70-80_1480170

- c. In case of utilising more than one beam, it shall be demonstrated that this results in consistent mechanical properties throughout the build area, including the regions where beams overlap.

NOTE "beams" includes laser and electron beams.

ECSS-Q-ST-70-80_1480171

- d. Grain size and morphology shall be assessed qualitatively through metallography.

ECSS-Q-ST-70-80_1480172

- e. For class 1.1 and 1.2, the chemical composition shall be determined.

ECSS-Q-ST-70-80_1480173

- f. The presence of any alpha case layer on the surface of titanium alloys shall be determined in compliance with EN 2003-009:2007.

ECSS-Q-ST-70-80_1480174

- g. For parts in compliance with safety class 1.2 and class 3, alpha case on Ti-6Al-4V may be accepted without measurement, if the stresses with applicable margins are below 100 MPa.

NOTE Thick alpha case layers can release particles, which needs to be avoided.

ECSS-Q-ST-70-80_1480175

- h. No alpha case shall be accepted for any safety class and Ti-6Al-4V, if stresses with applicable margin above 100 MPa, unless technically justified and agreed by the customer.

12.5.1.2 Top and bottom layer melt pool assessment**ECSS-Q-ST-70-80_1480176**

- a. The assessment shall include blanks from the bottom of the build and the top of the build for the characterisation of the top layer melt pool.

ECSS-Q-ST-70-80_1480177

- b. The top surface layer of each blank shall be sectioned parallel to the Z-axis for the assessment of the melt pool of this layer.

ECSS-Q-ST-70-80_1480178

- c. Any cosmetic or smoothing pass shall be omitted during the manufacture of these samples.

NOTE Top layer melt pool blanks are useful for the inspection of the geometry and macrostructure of melt tracks. Therefore a top (surface) layer from the bottom of the build is compared with a top (surface) layer at the top of the build in order to confirm laser and optics performance at the beginning and end of the build, and to validate against material produced during different builds. Please note that some mPBF equipment nominally apply a cosmetic or smoothing pass on top surfaces. The melt pool assessment is intended to show the typical process result without this cosmetic or smoothing pass.

ECSS-Q-ST-70-80_1480179

- d. To evaluate the repeatability of the machine, the arithmetic average of the depth of a full melt pool (d_F) to layer thickness (t_L), and the depth of the overlap (d_O) to layer thickness (t_L), shall be calculated from at least 10 melt pools from the top and the bottom of the build.

NOTE 1 The concept of investigating the top layer melt pool, including the approach of melt pool measurements, as also shown in Figure 12-1 were adopted from NASA MSFC-SPEC-3717.

NOTE 2 The measurements taken during top surface Melt Pool evaluation are used to check repeatability of the machine using a defined set of parameters, see Figure 12-1. t_L = defined nominal layer thickness, d_F = depth of full melt pool, d_O = depth of overlap (between adjacent

melt pools). There is no acceptance criteria; this measurement sets the baseline for the performance of the individual machine and parameter set.

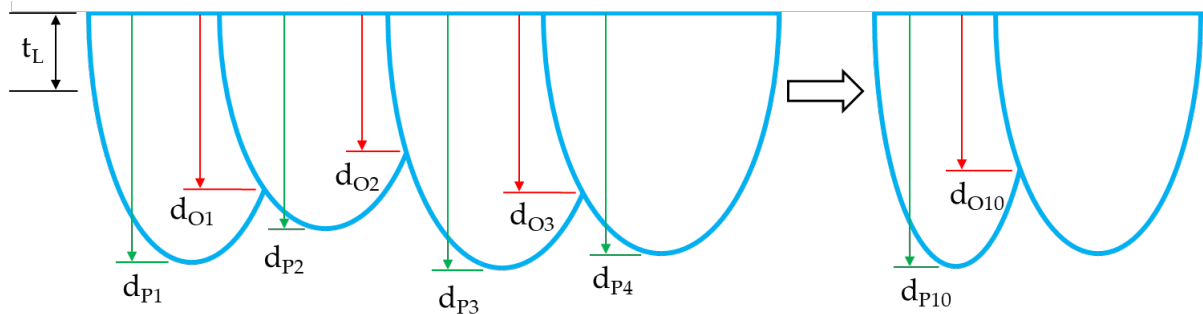


Figure 12-1: Melt pool measurement concept [Image and concept: adopted from NASA MSFC-SPEC-3717]

12.5.2 Tensile testing

ECSS-Q-ST-70-80_1480180

- a. The direction showing the lowest strength values, determined within the pre-verification phase, shall be tested.

NOTE 1 The direction showing the lowest strength values is often Z (vertical).

NOTE 2 Additional justification that the tested samples represent the worst case properties at critical locations can be provided by, for example metallurgical and hardness investigations of flight representative hardware.

ECSS-Q-ST-70-80_1480181

- b. The tensile tests shall be performed in accordance with ECSS-Q-ST-70-45.

NOTE Values of the elastic modulus can vary to some extent if determined through tensile testing, and it can be necessary to define wider ranges for the acceptance criteria.

ECSS-Q-ST-70-80_1480182

- c. The surface condition of the tensile specimens shall be proposed by the supplier and agreed with the customer.

ECSS-Q-ST-70-80_1480183

- d. The elongation at break shall be above 8 % for Ti-6Al-4V.

NOTE 1 A martensitic microstructure is usually achieved when producing Ti-6Al-4V materials through

Laser Powder Bed Fusion processes. Heat treatments can alter this to an α - β microstructure. Titanium martensite generally affects the mechanical properties such that strength values would increase and toughness or ductility values would decrease. It is therefore strongly recommended to apply heat treatments (e.g. at about 800 °C) to transform martensite into an α - β microstructure.

NOTE 2 Other alpha-beta titanium alloys may exhibit similar challenges regarding heat treatments on secondary mechanical properties and it is therefore recommended to consider this effect.

12.5.3 Fatigue testing

12.5.3.1 Overview

Parts produced with Laser Powder Bed Fusion processes generally exhibit a rather high surface roughness, have residual stresses, and a varying microstructure throughout the build height. These features are known to have an effect on the fatigue performance.

12.5.3.2 Requirements

ECSS-Q-ST-70-80_1480184

- a. The fatigue tests shall be performed in accordance with ECSS-Q-ST-70-45.

ECSS-Q-ST-70-80_1480185

- b. The orientation of the fatigue specimens shall be proposed by the supplier for acceptance by the customer.

ECSS-Q-ST-70-80_1480186

- c. The surface condition of the fatigue specimens shall be proposed by the supplier and accepted by the customer.

NOTE 1 It is best practice to test the fatigue specimens in a representative surface condition, according to the end to end manufacturing process, defined in the AMP.

NOTE 2 Surface treatments can include jet blasting, electro polishing, and plasma polishing or similar processes.

ECSS-Q-ST-70-80_1480187

- d. The load ratio (R) shall be representative of the final application.

NOTE In many cases, a stress ratio of -1 is representative of space applications, especially when the dominant load is caused by vibration.

13 Powders

13.1 Testing of powders

ECSS-Q-ST-70-80_1480188

- a. With a test method proposed by the supplier and agreed with the customer, testing of powders shall include as a minimum:
1. Chemical composition, including light elements,
 2. Particle size distribution,
 3. Density in both apparent and tapped conditions, and
 4. Flow properties.

NOTE 1 For requirement 13.1a1: light elements can include carbon, hydrogen, oxygen, and nitrogen.

NOTE 2 For requirement 13.1a1: the chemical composition can be determined by energy-dispersive spectrometry (EDS) as per ISO 22309:2011 or ASTM E1508 or by atomic emission spectrometry for Aluminium alloys as per ASTM E3061:2017 and for titanium alloys as per ASTM E 2371:2013.

NOTE 3 For requirement 13.1a1: determination of hydrogen in titanium alloys can be done by inert gas fusion as per ASTM E 1447:2016. Determination of carbon in refractory and reactive metals can be done by combustion analysis as per ASTM E 1941:2016. Determination of oxygen in titanium alloys can be done by reduction-extraction methods as per ISO 4491-4:2019. Oxygen and nitrogen in titanium alloys can be determined by inert gas fusion as per ASTM E 1409:2013.

NOTE 4 For requirement 13.1a1: increased oxygen content can lead to reduced ductility of IN 718 at elevated temperatures. It is best practice to limit the oxygen content in the base material more strictly than this is done for conventional materials.

NOTE 5 For requirement 13.1a2: particle size distribution can be analyzed by sieve analysis as per ISO 4497:2020 or ASTM B214:2016, by laser diffraction in compliance with ISO 13320:2020 or

ASTM B822:2017 or by image analysis in compliance with ISO 13322:2014.

NOTE 6 For requirement 13.1a3: the apparent density can be determined according to ISO 3923-1:2018 or ASTM B212:2017 (Funnel Method). The tap density can be determined according to ISO 3953:2011 or ASTM B527.

NOTE 7 For requirement 13.1a3: testing for porosity in powder particles is not required, but it can be performed by helium pycnometry in compliance with ASTM B923:2020, or through X-Ray CT scanning.

NOTE 8 For requirement 13.1a4: flow properties can be determined through the Hall Flowmeter test in compliance with ASTM B213:2020, ASTM B 964:2016, or ISO 4490:2018 and tap density as per ASTM B527:2020. Alternatively, "angle of repose" tests according to ISO 4324:1977 can also be used.

NOTE 9 For requirement 13.1a4: it is best practice to determine powder particle morphology and satellite build-up with an SEM as complementary information.

NOTE 10 Aluminium powders are known to pick up moisture, which can degrade flow properties or lead to significant gas porosity in the final AM part. It is best practice to control the humidity level in areas where AM powder is handled or stored. The test can be performed using one of the following methods: capacitive titration (Karl-Fischer) according to ISO 760:1978 or ASTM E203:2016, thermogravimetric according to ASTM E1131:2020, or with a humidity sensor.

13.2 Procurement

ECSS-Q-ST-70-80_1480189

- a. The procurement specification shall include limits of properties specified in 13.1a.

ECSS-Q-ST-70-80_1480190

- b. The chemical composition shall be in compliance with national or international standards if these are available.

NOTE Examples include: ASTM F3001:2014 for Ti6Al4V ELI, ASTM F2924:2014 for Ti6Al4V, ASTM F3318:2018 for AlSi10Mg, ASTM F3055:2014 for nickel alloy 718, ASTM

F3184:2016 for SS316, ASTM F3056:2014 for nickel alloy 625.

ECSS-Q-ST-70-80_1480191

- c. The certificate of conformance (CoC) shall include measurement values for the properties specified in 13.1a.

ECSS-Q-ST-70-80_1480192

- d. The CoC shall clearly indicate whether the powder meets the procurement specification.

ECSS-Q-ST-70-80_1480193

- e. When delivered from the supplier, all powder shall be in a sealed powder container with a witness tag between the lid and container to prove it has not been opened.

13.3 Safe Handling

ECSS-Q-ST-70-80_1480194

- a. Powders shall be handled in line with national or European occupational health regulations.

NOTE AM Powders require careful handling. They can be flammable and hazardous and pose a danger to health if handled incorrectly.

13.4 Storage

ECSS-Q-ST-70-80_1480195

- a. The container shall be labelled with the contents, the batch number, and the date of storage beginning.

ECSS-Q-ST-70-80_1480196

- b. Powder, containers shall be stored in humidity and temperature controlled area.

ECSS-Q-ST-70-80_1480197

- c. Powders shall be stored in compliance with national or European occupational health regulations.

13.5 Loading

ECSS-Q-ST-70-80_1480198

- a. Loading of powder shall follow machine-specific instructions.

13.6 Recycling

ECSS-Q-ST-70-80_1480199

- a. The use of recycled powder shall be permitted once a validation of mPBF recycled powder is demonstrated to show properties within the limits specified in clause 13.2a.

NOTE 1 Efficient production using mPBF processes can require recycling of powder. Recycled powder arises from excess powder removed by the recoater arm and un-fused powder from a build process.

NOTE 2 This applies to mPBF equipment with and without automated powder re-cycling systems.

NOTE 3 It is common practice to submit a powder lot to a number of recycling operations, which is considered a maximum and then re-test the properties defined in 13.1a. If the powder meets the acceptance criteria of this clause, every recycling step in between can also be considered acceptable.

ECSS-Q-ST-70-80_1480200

- b. Any powder batch containing used powder shall be considered recycled powder.

13.7 Blending

ECSS-Q-ST-70-80_1480201

- a. For class 1.1, 1.2, and 2 parts, no blending of powder lots shall be permitted.

NOTE Mixing of powder lots is not permitted as traceability of powders is then lost. Opposed to this, mixing of powder batches is permitted.

ECSS-Q-ST-70-80_1480202

- b. For class 3 parts, powders may be mixed, if it can be demonstrated that the blend has properties in accordance with requirements from clause 13.1a.

13.8 Disposal

ECSS-Q-ST-70-80_1480203

- a. Powders shall be disposed in compliance with national or European occupational health regulations.

Annex A (normative)

Preliminary Manufacturing Concept Review (PMCR) - DRD

A.1 DRD identification

A.1.1 Requirement identification and source document

This DRD is called from ECSS-Q-ST-70-80, requirement 6.3b.

A.1.2 Purpose and objective

The aim of the AM definition phase is to converge to a preliminary manufacturing concept, allowing for an early assessment of the envisaged AM project. Conducting a feasibility study before starting the AM definition phase intends to help identifying critical aspects at an early stage. The PMCR is the formal review where the conclusions of this feasibility study are documented and presented.

A.2 Expected response

A.2.1 Scope and content

ECSS-Q-ST-70-80_1480204

- a. The supplier shall present the preliminary manufacturing concept, including as a minimum:
 1. An overview of all applicable, application-specific requirements
 2. The safety class
 3. The selected AM end to end manufacturing process
 4. Design allowables from a MPD (if available)
 5. AMP (if available and verifiable)

A.2.2 Special remarks

None.

Annex B (normative)

Additive Manufacturing Procedure (AMP) - DRD

B.1 DRD identification

B.1.1 Requirement identification and source document

This DRD is called from the requirement 7.2.3a.

B.1.2 Purpose and objective

The purpose of the AM Procedure is to ensure that all relevant information relating to the production of each AM part, including pre-and post-processing, is documented in sufficient detail such that repeatability of the AM end to end process is given.

B.2 Expected response

B.2.1 Scope and content

ECSS-Q-ST-70-80_1480205

- a. The AMP shall contain the following information:
 1. A flow chart, detailing all performed operations and their sequence from design up to final cleaning and controls, indicating the responsible stakeholder(s)
 2. General information
 - (a) Date, issue and revision number,
 - (b) Powder,
 - (c) AM process,
 - (d) Reference to the test report in compliance with Annex D.
 3. Equipment and facilities
 - (a) Referential axis definition in compliance with clause 5.1,
 - (b) Identification of the equipment, model and serial number, used to perform all processes,
 - (c) Machine management system software,
 - (d) Reference to procedures of all applied processes.
 4. Reference to powder management plan in compliance with Annex I.

5. Reference to AM process parameter set
6. Shielding gas
 - (a) Shield gas identification and purity,
 - (b) Shield gas flow rate and direction,
 - (c) Level of oxygen during the build,
 - (d) Beginning, ending and duration of the shielding gas.
7. Level of vacuum
8. In case of pre-heating is applied, the temperature, and the time at temperature
9. Base plate
 - (a) Alloy type of base plate,
 - (b) Thickness of base plate,
 - (c) Base plate temperature.
10. Type of recoater (blade, material of blade, roller, or other)
 - NOTE 1 to item 3.(d): This includes e.g. preparatory processes, the AM process, surface treatment, heat treatment, non-destructive testing, marking and, cleaning.
 - NOTE 2 to item 9.(b): The baseplate serves several purposes. One of them is to provide stiffness to counter-act bending forces due to the accumulation of residual stresses during the build process. High-strength materials and parts with high-volume cross sections may require thicker plates than materials with lower strength or filigree designs.
 - NOTE 3 to item 10.: A cryptographic hash can be useful to unambiguously identify digital files as reference to AM process parameter set.

B.2.2 Additional requirements for various AM processes

ECSS-Q-ST-70-80_1480206

- a. In addition to the requirements specified in B.2.1, the AMP for Electron Beam based Powder Bed Fusion processes shall contain as a minimum, the following information
 1. Equipment:
 - (a) Model and make,
 - (b) Electron gun type.
 2. Manufacturers' or measured values for the beam quality parameters.

- b. In addition to the requirements specified in B.2.1, the AMP for Laser based Powder Bed Fusion processes shall contain as a minimum, the following information:
 - 1. Equipment:
 - (a) Type of energy source, model and make.

B.2.3 Special remarks

None.

Annex C (normative)

AM verification plan (AMVP) - DRD

C.1 DRD identification

C.1.1 Requirement identification and source document

This DRD is called from ECSS-Q-ST-70-80, requirement 7.4.1a.

C.1.2 Purpose and objective

The AM verification plan is used to ensure that all relevant information related to the verification testing is documented in sufficient detail for the customer to agree on the implementation of the test programme.

C.2 Expected response

C.2.1 Scope and content

ECSS-Q-ST-70-80_1480208

- a. For Safety Class 1.1, 1.2, and 2: Powder characteristics (CoC or test results) including chemical composition, flow rate, and size distribution shall be annexed to this AMVP.

ECSS-Q-ST-70-80_1480209

- b. The AM verification plan shall include the following information:
 - 1. Tensile tests: sample type, surface finishing, criteria of acceptance
 - 2. Fatigue tests: sample type, surface finishing, levels of stress for Woehler curve, stress ratio and criteria of acceptance
 - 3. CT scan: strategy and criteria of acceptance
 - 4. Cleanliness: method and criteria of acceptance
 - 5. Specific tests: description, applicable specification and criteria of acceptance

ECSS-Q-ST-70-80_1480210

- c. The pAMP shall be attached to the AM verification plan.

C.2.2 Special remarks

None.

Annex D (normative)

AM Verification Report (AMVR) – DRD

D.1 DRD identification

D.1.1 Requirement identification and source document

This DRD is called from ECSS-Q-ST-70-80, requirement 7.4.4b.

D.1.2 Purpose and objective

The purpose of the Additive Manufacturing verification report is to ensure that all relevant information related to the results of the verification testing is documented in sufficient detail for the customer to agree on the verification.

D.2 Expected response

D.2.1 Scope and content

ECSS-Q-ST-70-80_1480211

- a. The verification test report shall include the following information:
1. Reference to AMP
 2. Quantity and shape of samples
 3. Short tests description
 4. Test results
 5. Analysis of results
 6. Acceptance criteria for witness specimens
 7. Conclusion: verification PASS or FAIL

D.2.2 Special remarks

None.

Annex E (normative)

Hardware Fabrication Procedure (HFP) - DRD

E.1 DRD identification

E.1.1 Requirement identification and source document

This DRD is called from the requirement 7.5.1b and 8.2.1a.

E.1.2 Purpose and objective

The purpose of the Hardware Fabrication Procedure is to define the conditions how the Additive Manufacturing Hardware has to be produced.

E.2 Expected response

E.2.1 Scope and content

ECSS-Q-ST-70-80_1480212

- a. The Hardware Fabrication Procedure (HFP) shall contain the following information:
1. Reference to AMP
 2. Safety Class (1.1, 1.2, 2 or 3), as agreed between the design authority and the customer
 3. The build job configuration
 4. Reference to Prototype Verification Report
 5. List of witness tests in accordance with clauses 8.2.3, 8.3, and 8.4

E.2.2 Special remarks

None.

Annex F (normative)

Hardware Production Report (HPR) - DRD

F.1 DRD identification

F.1.1 Requirement identification and source document

This DRD is called from the requirement 8.5a.

F.1.2 Purpose and objective

The purpose of the Hardware Production Report is to report the any results of performed tests on witness specimens and performed NDT.

F.2 Expected response

F.2.1 Scope and content

ECSS-Q-ST-70-80_1480213

- a. The Hardware Production Report (HPR) shall contain the following information:
1. Reference to HFP
 2. Witness specimens test results
 3. NDT results
 4. Reference to the shop traveller
 5. Reference to Non-Conformance Reports (NCRs)
 6. Reference to Requests for Waivers (RFWs)

F.2.2 Special remarks

None.

Annex G (normative)

Prototype Verification Plan (PVP) - DRD

G.1 DRD identification

G.1.1 Requirement identification and source document

This DRD is called from ECSS-Q-ST-70-80, requirement 7.5.1c.

G.1.2 Purpose and objective

The prototype verification plan is used to ensure that all relevant information is documented in sufficient detail for the customer to agree on the implementation of the test programme.

G.2 Expected response

G.2.1 Scope and content

ECSS-Q-ST-70-80_1480214

- a. The prototype verification plan shall include the following information:
1. NDT: strategy and criteria of acceptance
 2. Cleanliness inspection: method and criteria of acceptance
 3. Specific tests: description, applicable specification and criteria of acceptance
 4. Safety Class (1.1, 1.2, 2 or 3), as agreed between the design authority and the customer

NOTE To item 3: This can include e.g.: destructive testing, mechanical testing, functional testing, and thermo-elastic distortion.

ECSS-Q-ST-70-80_1480215

- b. The AMP shall be attached to the PVP.

ECSS-Q-ST-70-80_1480216

- c. The PVP shall be submitted for approval by the design authority.

G.2.2 Special remarks

None.

Annex H (normative)

Prototype Verification Report (PVR) - DRD

H.1 DRD identification

H.1.1 Requirement identification and source document

This DRD is called from ECSS-Q-ST-70-80, requirement 7.5.4b.

H.1.2 Purpose and objective

The purpose of the PVR is to document all relevant results of the verification testing in sufficient detail such that the customer can judge whether it has passed or failed.

H.2 Expected response

H.2.1 Scope and content

ECSS-Q-ST-70-80_1480217

- a. The verification test report shall include the following information:
1. Reference to AMP
 2. Quantity and shape of samples
 3. Quantity and shape of prototypes
 4. Short tests description
 5. Test results
 6. Analysis of results
 7. Conclusion: verification PASS or FAIL

H.2.2 Special remarks

None.

Annex I (normative)

Powder Management Plan (PMP) - DRD

I.1 DRD identification

I.1.1 Requirement identification and source document

This DRD is called from ECSS-Q-ST-70-80, requirement 10.6.1a.

I.1.2 Purpose and objective

The purpose of the Powder Management Plan (PMP) is to ensure that powders are procured in sufficient quality and it shall also define safe handling, storage, loading into AM machines, recycling, blending, and disposal.

I.2 Expected response

I.2.1 Scope and content

ECSS-Q-ST-70-80_1480218

- a. The powder management plan shall specify how powders are
1. Tested,
 2. Procured,
 3. Safely handled,
 4. Stored,
 5. Loaded,
 6. Recycled,
 7. Blended, and
 8. Disposed.

NOTE The detailed requirements are specified in clause 13.

I.2.2 Special remarks

ECSS-Q-ST-70-80_1480219

- a. The test results shall be made available upon request.

Annex J (informative) Template for auditing

Example of template for auditing is given in Table J-1.

Table J-1: Audit template

	TOPIC / QUESTION	Associated requirement	Refer to	ANSWER	Associated document	Actions
General	Company presentation					
Perimeter /Restriction	Which processes are audited?		Introduction/ AMP			
	Which standards are used?	Clause 2	Normative references			
	Which raw material/alloy/powder(s) is/are used?					
	Which equipment model(s) and number(s) are used?	Clause 5.3	Multiple Laser Systems			
	Multiple Laser System?	Clause 7.7	Machine pause management			
	Machine pause(s) planned?					
	Which design software is used?					
Which parts are to be manufactured?	Clause 5.2	Family of parts				

	TOPIC / QUESTION	Associated requirement	Refer to	ANSWER	Associated document	Actions
	Which powder/equipment is used? Which safety class is applied? Is the concept of family of parts applied?	Clause 5.4	Safety classes			
Specification	Review of purchase specification & Contract					
Verification	Is the AM definition phase well understood? Any deviations to requirements → RFDs?	Clause 6 Annex A	AM definition phase PMCR			
	Is the AM verification phase well understood? Any deviations to requirements → RFDs?	Clause 7 Annex B Annex C Annex D Annex E Annex F Annex G Annex H	AM verification phase AM procedure AMVP & AMVR PVP & PVR			
Inputs and manufacturing documents	Are the internal AM procedures for the intrinsic process parameters compliant to Annex B?	Annex B	AM Procedure			
	Is a specific manufacturing procedure available (including a flow chart) to produce parts identified in this project?	Clause 8 Annex E	Hardware fabrication procedure Hardware production control Hardware production			
	Which processes and tests, or inspections are sub contracted?					

	TOPIC / QUESTION	Associated requirement	Refer to	ANSWER	Associated document	Actions
Environment	How are the tools, used to produce these parts, controlled?					
	Is the environment and the equipment sufficient to guarantee the customer requirements?					
	How are software and its changes managed?					
	What post process treatments are used?					
	How are these processes documented? (e.g.: part removal, mechanical, thermal, surface treatment, etc.)					
	How are oxygen / gas levels managed in the machines?					
	How is test and inspection equipment managed? (for controls, tests, dimensional measurement, etc.)					
	How is cleanliness after all post process operations managed?					
	Has an AM supervisor been appointed?	Clause 9.2	AM supervisor			
Personnel	How are AM operators trained?	Clause 9.3	AM operators			
	How are AM inspectors trained?	Clause 9.4	AM inspectors			
	What is the validity period of the certificates?					
	What are the conditions for maintaining the certification?					
	Are the training and certificates managed internally or externally?					

	TOPIC / QUESTION	Associated requirement	Refer to	ANSWER	Associated document	Actions
	Is a skills matrix available and is there redundancy for AM operators and AM inspectors?					
	Are the conditions for facilities understood and met?	Clause 10.2	Conditions for facilities			
Equipment and facilities	Are the requirements for Laser Beam calibration understood and met?	Clause 10.3	Laser Beam calibration			
	Are the requirements for electron beam calibration understood and met?	Clause 10.4	EB calibration			
	Are the requirements for maintenance and repair (laser based machine) understood and met?	Clause 10.5.1 Clause 10.5.3 Clause 7.6	Maintenance and Repair (laser based machine) Re-Verification			
	Are the requirements for maintenance and repair (EB based machine) understood and met?	Clause 10.5.2 Clause 10.5.3 Clause 7.6	Maintenance and Repair (EB based machine) Re-verification			
	Are the requirements for cleaning the machine understood and met? (e.g.: How is a change of powder in the machine performed?)	Clause 10.6.4	Cleaning of machine			
Materials and Consumables	Which powder properties are tested and how is this done?	Clause 10.6.1 Annex 13.1	Management of powders Testing			
	Is a CoC available for raw material / purchasing specification?	Clause 10.6.1 Clause 13.2	Management of powders Procurement			
	How is the incoming inspection performed?	Clause 10.6.1 Clause 13.1	Management of powders Testing			
	How is powder traceability managed?					

	TOPIC / QUESTION	Associated requirement	Refer to	ANSWER	Associated document	Actions
	How is the recycling of powders managed?	Clause 10.6.1 Clause 13.6	Management of powders Recycling			
	How is the powder quality ensured after several recycling steps?	Clause 10.6.1 Clause 13.7	Management of powders Blending			
	How are the powder storage conditions managed? (e.g.: protection against humidity and oxidation, etc.)	Clause 10.6.1 Clause 13.4	Management of powders Storage			
	Is there a drying process for powder before production? If yes, how is it managed?					
	Are the requirements for gas management understood and met?	Clause 10.6.3	Gases			
	Are the requirements for tooling understood and met?	Clause 10.6.2	Tooling			
Non-destructive testing	Are the requirements for NDI and density understood and can they be met?	Clause 12.3 and 12.4	NDI & density			
Destructive testing	Are the requirements or recommendations for Destructive testing understood?	Clause 12.5	Destructive testing			

	TOPIC / QUESTION	Associated requirement	Refer to	ANSWER	Associated document	Actions
Quality assurance & Manufacturing	Industrial documentation	Clause 11.2 Clause 11.4.1 Clause 11.4.2 Clause 11.6 Annex B	Maintenance of AMP Witness sample Documentation of manufacturing EIDP AM procedure			
	Are the requirements for SPC understood and met?	Clause 11.3	SPC			
	Process Monitoring NC and delays management	Clause 11.4.3				

J.1.2 Special remarks

None.

Annex K (informative) Example of a Materials Properties Database (MPD)

Example of Materials Properties Database (MPD) is given in Table K-1.

Table K-1: Example of a Materials Properties Database

	Mechanical properties					
AMP reference	UTS	YS (or PS)	Elongation	Young's Modulus E	Other	Density

Bibliography

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ECSS-E-ST-32-01	Space engineering - Fracture control
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ASTM B213:2020	Standard Test Methods for Flow Rate of Metal Powders Using the Hall Flowmeter Funnel
ASTM B214:2016	Standard Test Method for Sieve Analysis of Metal Powders
ASTM B527:2020	Standard Test Method for Determination of Tap Density of Metallic Powders and Compounds
ASTM B822:2017	Standard Test Method for Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering
ASTM B923:2020	Standard Test Method for Metal Powder Skeletal Density by Helium or Nitrogen Pycnometry
ASTM B962:2017	Standard Test Methods for Density of Compacted or Sintered Powder Metallurgy (PM) Products Using Archimedes' Principle.
ASTM B964:2016	Standard Test Methods for Flow Rate of Metal Powders Using the Carney Funnel
ASTM E203:2016	Standard Test Method for Water Using Volumetric Karl Fischer Titration
ASTM E1131:2020	Standard Test Method for Compositional Analysis by Thermogravimetry
ASTM E1409:2013	Standard Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by Inert Gas Fusion
ASTM E1447:2016	Standard Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by Inert Gas Fusion Thermal Conductivity/Infrared Detection Method
ASTM E1508:2019	Standard Guide for Quantitative Analysis by Energy-Dispersive Spectroscopy
ASTM E1941:2016	Standard Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis
ASTM E2371:2013	Standard Test Method for Analysis of Titanium and Titanium Alloys by Direct Current Plasma and

	Inductively Coupled Plasma Atomic Emission Spectrometry (Performance-Based Test Methodology)
ASTM E3061:2017	Standard Test Method for Analysis of Aluminum and Aluminum Alloys by Inductively Coupled Plasma Atomic Emission Spectrometry (Performance Based Method)
ASTM E3166:2020	Standard Guide for Nondestructive Examination of Metal Additively Manufactured Aerospace Parts After Build
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ISO 760:1978	Determination of water - Karl Fischer method (General method)
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ISO 3953:2011	Metallic powders - Determination of tap density
ISO 4324:1977	Surface active agents - Powders and granules - Measurement of the angle of repose
ISO 4490:2018	Metallic powders - Determination of flow rate by means of a calibrated funnel (Hall flowmeter)
ISO 4491-4:2019	Metallic powders - Determination of oxygen content by reduction methods - Part 4: Total oxygen by reduction-extraction
ISO 4497:2020	Metallic powders - Determination of particle size by dry sieving
ISO 13320:2020	Particle size analysis - Laser diffraction methods
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MMPDS-14:2019	Metallic Materials Properties Development and Standardisation