Co-funded by the Erasmus+ Programme of the European Union

Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

TOPIC 6: Additive Manufacturing Process Specification

David Wimpenny

FOR SAM PILOT ATTENDEES AND TRAINERS ONLY

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Topics covered include…

- What is the AM process specification
- Examples of AMPs

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Additive Manufacturing Process Specification (AMPS)

- Defines the entire end-to-end process which must be followed.
- Essential step in process certification for some applications
- Close link to standards
- AMPs is the fixed or frozen process which must be used for safety critical parts/sectors

AMPS gets into the detail of the process

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

AM Process Specification - Examples (Non-Exhaustive List)

- NASA 3717 for metallurgical control
- NASA 3716 for manufacture of spaceflight hardware
- ASTM F3303 Standard for Additive Manufacturing
- AMS 7003 Laser Powder Bed Process

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

AMPS Encompasses…(1)

- **Facility specification**; layout plan, people and material workflow and segregation, climate control for temperature and humidity
- **Environmental Health & Safety (EH&S) specification;** PPE measures, barriers/partitions, closed rooms, local exhaust ventilation, risk assessments and safe working practice, material COSHH…
- **People and skills specification;** approved users, roles and responsibilities, skills and training matrix
- **Equipment;** performance validation(Factory acceptance tests = FATS), installation, commissioning (Site acceptance tests =SATS), servicing, maintenance calibration for AM machine and other equipment used in the process

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

AMPS Encompasses…(2)

Co-funded by the Erasmus+ Programme of the European Union

- **Design data;** ID registers, version control, validation of fidelity.
- **Material/feedstock specification;** for metal powder the definition of alloy, form/shape, size range, size distribution, chemical weighting, interstitial content.
- **Specification of other consumables;** compressed air type, inert gas type, filter grade, alcohol cleaning grade, build plate specification and drawings
- **Operation specification;** Work instruction, guidelines, check sheets, route cards, manufacturing packs with control plans/process record sheets + process parameters

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

AMPS Encompasses…(3)

Co-funded by the Erasmus+ Programme of the European Union

- **KPVs and Process Window Control;** process variable measurement against necessary output criteria and fix setting/range by control plan

- **Inspection specification;** Part drawings and detailed inspection plans

Note: Where possible reference machine manufacturer instructions /manual. This avoids the need to duplicate this information, also ensures that the latest guidance is being used.

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

NASA AM Standards/Specs

Co-funded by the Erasmus+ Programme of the European Union

MEASUREMENT SYSTEM IDENTIFICATION METRIC/SI (ENGLISH) UNITS

National Aeronautics and Space Administration

MSFC-SPEC-3717
BASELINE
EFFECTIVE DATE: October 18, 2017

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

EM20

MSFC TECHNICAL STANDARD

SPECIFICATION FOR CONTROL AND QUALIFICATION OF LASER POWDER BED FUSION METALLURGICAL PROCESSES

Approved for Public Release; Distribution is Unlimited

CHECK THE MASTER LIST — VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

MSFC-SPEC-3717

Process

FEEDS INTO

MSFC-STD-3716

Part

MEASUREMENT SYSTEM IDENTIFICATION METRIC/SI (ENGLISH) UNITS

National Aeronautics and Space Administration

MSFC-STD-3716
BASELINE
EFFECTIVE DATE: October 18, 2017

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

EM20

MSFC TECHNICAL STANDARD

STANDARD FOR ADDITIVELY MANUFACTURED SPACEFLIGHT HARDWARE BY LASER POWDER BED FUSION IN METALS

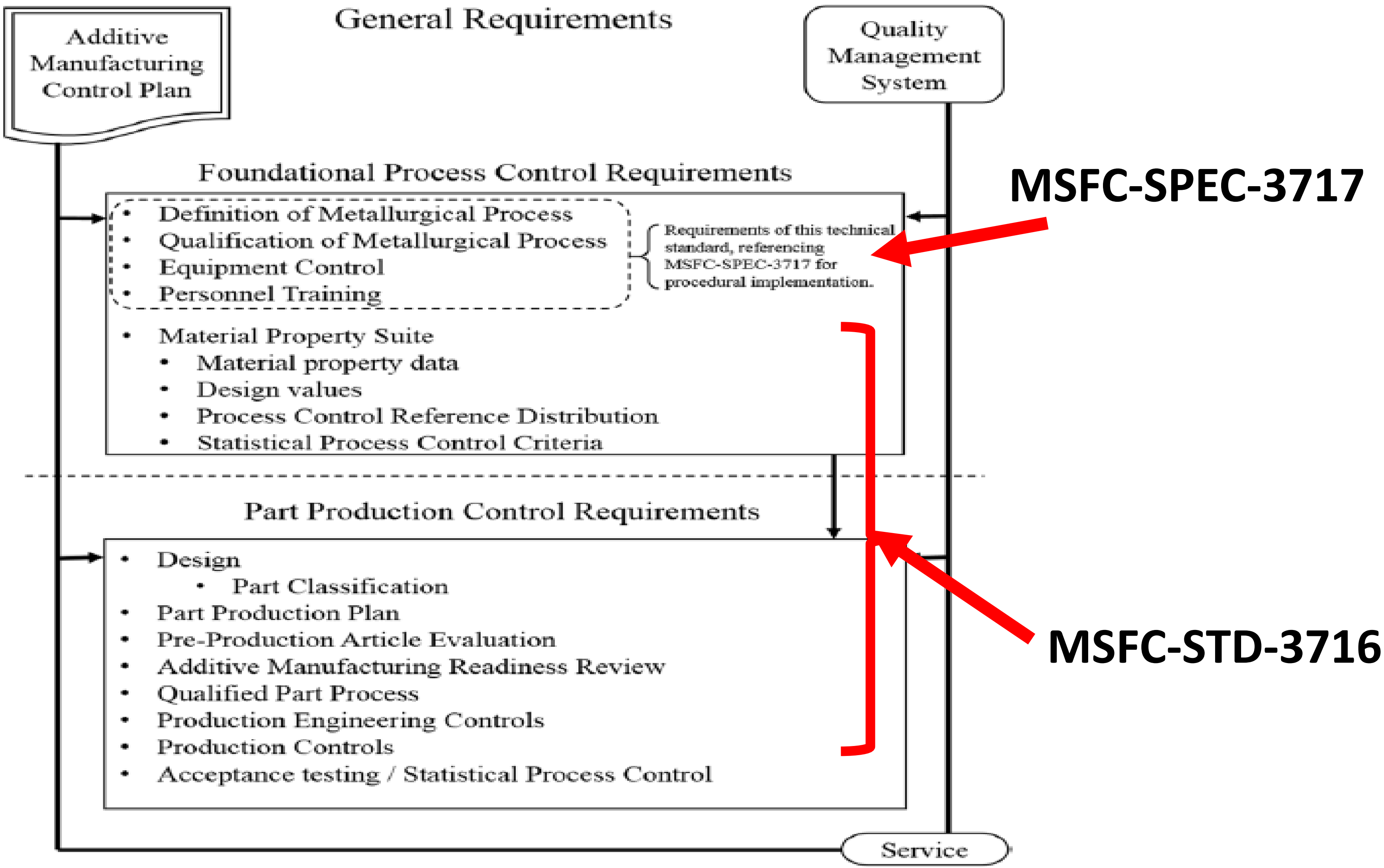
Approved for Public Release; Distribution is Unlimited

CHECK THE MASTER LIST — VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

MSFC-SPEC-3717 is an applicable document to **MSFC-STD-3716**.

It defines procedural requirements for **foundational aspects of process control** in L-PBF: definition and qualification of the L-PBF metallurgical process; maintenance, calibration, and qualification of L-PBF equipment and facilities; and training of personnel for L-PBF operations.

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Nasa Standard - MSFC-SPEC-3717

Co-funded by the Erasmus+ Programme of the European Union

SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

Title: Specification for Control and Qualification of Laser Powder Bed Fusion Metallurgical Processes	Document No.: MSFC-SPEC-3717	Revision: Baseline
	Effective Date: October 18, 2017	Page 4 of 58

MEASUREMENT SYSTEM IDENTIFICATION METRIC/SI (ENGLISH) UNITS

National Aeronautics and Space Administration

MSFC-SPEC-3717
BASELINE
EFFECTIVE DATE: October 18, 2017

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

EM20

MSFC TECHNICAL STANDARD

SPECIFICATION FOR CONTROL AND QUALIFICATION OF LASER POWDER BED FUSION METALLURGICAL PROCESSES

Approved for Public Release; Distribution is Unlimited

CHECK THE MASTER LIST — VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

You have been provided with a copy of this report

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Nasa Standard - MSFC-SPEC-3717

4.1.1 Powder Feedstock

4.1.1.1 Virgin Powder Requirements

[PCQR-2] A configuration controlled material specification used in all powder feedstock acquisition shall levy comprehensive requirements that ensure consistent performance in the L-PBF process and govern, at a minimum, the following aspects of virgin powder production and procurement:

a. Requiring powder producers and suppliers to operate under a QMS conforming to AS9100, or an equivalent approved by the CEO,
b. Specifying unambiguously the method of powder manufacture,
c. Specifying powder chemistry requirements, including acceptable methods of measurement and tolerance,
d. Specifying particle size distribution (PSD) requirements and the acceptable methods of powder sampling and determining the PSD, including explicit limits in weight percent on the quantity of coarse and fine particles outside the PSD range,
e. Specifying, at least qualitatively, the mean particle shape (powder morphology) and limits on satellite particles
f. Controlling the blending of powder heats into powder lots by requiring each blended powder heat individually meet all requirements of the feedstock specification
g. Prohibiting post-production additions to the powder lot for control of PSD or chemistry, (doping)
h. Providing requirements for powder cleanliness and contamination control,
i. Providing requirements for powder packaging, labeling, and environmental controls,

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Nasa Standard - MSFC-SPEC-3717

Co-funded by the Erasmus+ Programme of the European Union

4.1.3 Thermal Processing

[PCQR-6] The thermal process for the candidate metallurgical process shall be defined with all steps needed to manage microstructural evolution from the as-built state to the final microstructure, including a mandatory hot isostatic pressing (HIP) step for application of the metallurgical process to Class A parts.

[Rationale: This MSFC Specification requires post-build thermal processes to evolve part microstructure toward a uniform and orderly state to mitigate risks, known and unknown, associated with material performance due to the complex as-built microstructure from the L-PBF process.]

A typical L-PBF thermal process includes stress relief, HIP, and post-HIP heat treatments appropriate to the alloy, such as annealing or a solution treatment and aging cycle.

Stress relief thermal cycles are not mandatory for a L-PBF metallurgical process. HIP is mandatory for all L-PBF metallurgical processes that are used to produce Class A parts per MSFC-STD-3716, thus use restrictions for the metallurgical process are needed when HIP is not included in the thermal process. HIP conditions are chosen to provide a time and temperature appropriate to fully homogenize and recrystallize the as-built microstructure as well as to close the majority of microporosity present from the build process. Further heat treatment following HIP is performed as required to achieve the proper final microstructure for the alloy.

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

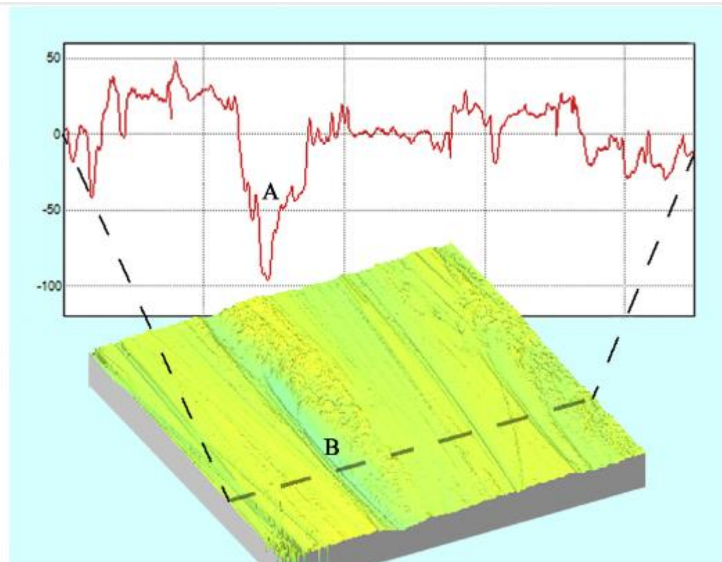
4.2.4 Surface Texture and Detail Resolution Metrics (Reference Parts)

[PCQR-17] Surface texture and detail resolution capability of the L-PBF process shall be evaluated using Reference Part(s) from a minimum of two locations in the build area:

a. The near center of the build area,
b. The furthest location for beam reach or other location identified with reduced build quality.

[Rationale: Rendering capability of the L-PBF process is commonly not uniform across the build area due to influences such as laser incidence angle. These two evaluation locations are intended to bound the process capability.]

This MSFC Specification does not levy specific quality metrics for surface texture and detail resolution for purposes of qualifying a metallurgical process. The Master QMP should be



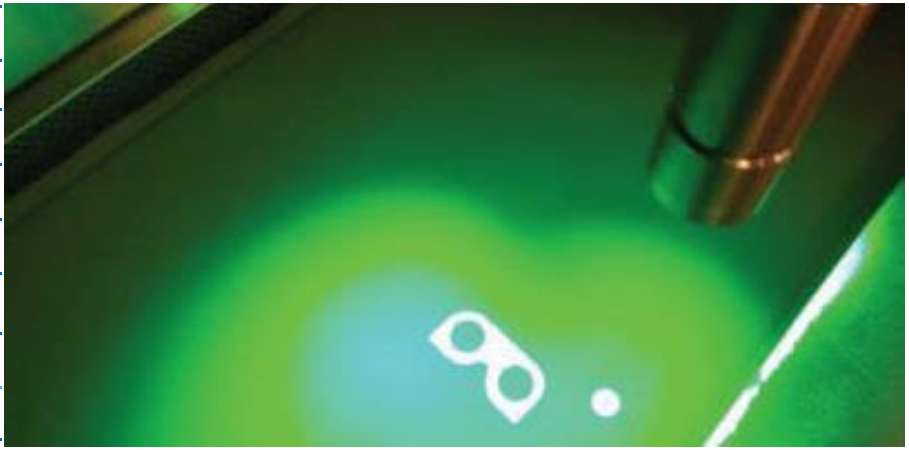
Precision Engineering 46 (2016) 34–47Contents lists available at ScienceDirectPrecision Engineeringjo ur nal homep age: www.elsevier.com/

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

4.5 Equipment and Facility Process Control

[PCQR-23] The equipment control requirements of this section shall be in place and verifiable through the QMS of the L-PBF Process Vendor prior to production of L-PBF parts under auspices of MSFC-STD-3716.

[Rationale: Controlled part production can only occur once equipment and facility controls are in place and enforced.]



4.6.1 Training Program

[PCQR-45] An active operator training program shall be defined, maintained, and implemented to meet the following objectives:

a. Provide a consistent framework for training and certification requirements
b. Provide clear delineations of abilities and responsibilities associated with granted certifications
c. Provide operators with all necessary skills, knowledge, and experience to execute the responsibilities of their certification safely and reliably
d. Provide for operator evaluations that demonstrate adequacy in skills, knowledge, and experience to grant certifications to personnel, ensuring only properly trained and experienced personnel have appropriate certifications
e. Incorporate content regarding the importance, purpose, and use of the QMS for all certifications.

[Rationale: Operator certifications are only meaningful if granted from a properly structured and adequate training program.]

The CEO and L-PBF Process Vendors are jointly responsible for the adequacy of the implemented training program.

There is currently no openly defined system for operator certifications in AM technologies. The intent of this requirement is to ensure appropriate depth in the knowledge and skills of the AM workforce involved in the production of aerospace parts per these MSFC Technical Standards. Programs are developing within the industry and if suitable may be used in lieu of an internally structured program.

https://www.google.com/url?sa=i&url=https%3A%2F%2Ftwitter.com

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

NASA Standard -MSFC-STD-3716

Co-funded by the Erasmus+ Programme of the European Union

..provides a framework for implementation of L-PBF AM parts into spaceflight applications requiring high reliability…

MEASUREMENT SYSTEM IDENTIFICATION METRIC/SI (ENGLISH) UNITS

National Aeronautics and Space Administration

MSFC-STD-3716
BASELINE
EFFECTIVE DATE: October 18, 2017

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

EM20

MSFC TECHNICAL STANDARD

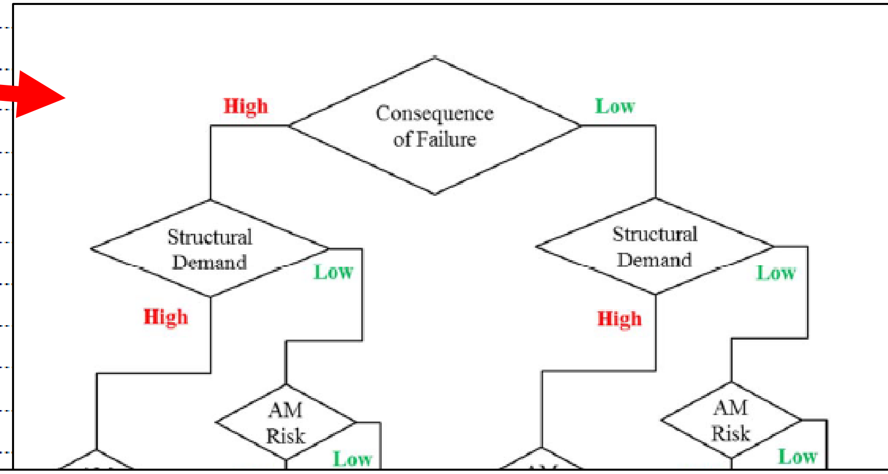
STANDARD FOR ADDITIVELY MANUFACTURED SPACEFLIGHT HARDWARE BY LASER POWDER BED FUSION IN METALS

Approved for Public Release; Distribution is Unlimited

CHECK THE MASTER LIST — VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

You have been provided with a copy of this report

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



2.1.2 *Safety Class 1*

Class 1 parts are considered critical. Failure of a Class 1 part results in a loss of spacecraft, major components, loss of life, or loss of control of the spacecraft.

2.1.3 *Safety Class 2*

Class 2 parts are non-critical but structural and are considered as their failure can reduce the efficiency of the system but not cause the loss of the spacecraft.

2.1.4 *Safety Class 3*

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.

This project has been funded with sup
Commission cannot be held responsible for any use which may be made of the information contained therein.

TABLE III. Witness specimen quantities for stand-alone acceptance

Class	A1	A2	A3	A4	B1	B2	B3	B4
Tensile	6	6	6	6	6	6	6	6
FH Contingency	1	1	1	1	1	1	-	-
Metallography	2	2	1	1	1	1	-	-
Chemistry	1	1	-	-	-	-	-	-
HCF	2	2	2	2	2	-	-	-
Low Margin Point	A/R	A/R	-	-	-	-	-	-
Witness sub-article	A/R	-	A/R	-	A/R	-	-	-
Witness article	1 for 6	-	-	-	-	-	-	-
CQMP	A/R	A/R	A/R	A/R	A/R	A/R	-	-

Notes:
FH Contingency = Full-height contingency specimen
A/R = As required when specified in the PPP/QPP

TABLE IV. Witness specimen acceptance methods for stand-alone acceptance

Class	A1	A2	A3	A4	B1	B2	B3	B4
Tensile	PCRD	PCRD	PCRD	PCRD	PCRD	PCRD	PCRD	PCRD
FH Contingency	A/N	A/N	A/N	A/N	A/N	A/N	-	-
Metallography	Comp	Comp	Comp	Comp	Comp	Comp	-	-
Chemistry	A/S	A/S	-	-	-	-	-	-
HCF	PCRD	PCRD	PCRD	PCRD	PCRD	-	-	-
Low Margin Point	DV Min	DV Min	-	-	-	-	-	-
Witness sub-article	Comp	-	Comp	-	Comp	-	-	-
Witness article	Comp	-	-	-	-	-	-	-
CQMP	A/S	A/S	A/S	A/S	A/S	A/S	-	-

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

6.2.8.1 Part Model Integrity

[AMR-36] A methodology for verifying the integrity of part models throughout all stages of the digital part definition associated with the L-PBF process shall be documented and enforced through the AMCP.

[Rationale: To ensure the certified design intent is reflected in the part, the integrity of the part design must be verified at the original CAD, then maintained throughout the process of geometry conversion to render a complete build file for the L-PBF part.]

Just as standard processes exist to confirm part drawings properly specify final part configuration prior to release, a similar process is required to check the integrity of solid models and any associated information containing design intent. Design integrity must be maintained throughout the AM-related manipulations of the post-design electronic data such as error-free creation of stereolithography (STL) files with proper resolution, and generation of L-PBF platform-specific slice files.

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

6.2.12.2 As-Built Part Inspections

[AMR-41] Immediately upon build completion and removal from the powder bed, all parts shall receive, at minimum, full visual inspection for any indications of build anomalies prior to processes that may alter the as-built state of the part, such as bead or grit blasting, with all anomalies recorded in detail in the QMS.

[Rationale: Many indicators of L-PBF process quality are best evaluated prior to further part processing, including many indicators, such as coloration or support damage, that may be eliminated during further part processing.]

Build anomalies include, but are not limited to, witness lines on the part surface (see definition), unusual discoloration, laminar defects such as cracks or tears, separation of part from support structures, and geometric distortion.

At this time, the L-PBF machine should receive an inspection for any anomalies. Any damage or nicks in the edge of the recoater blade should be noted.

High quality photographs to document the as-built part inspection process is recommended, particularly unusual observations or anomalies.

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

6.2.14.7 Certification of Compliance Records

[AMR-58] The production engineering record shall contain a list of all records needed to establish part compliance with the requirements of the QPP, with all such records maintained within the QMS.

[Rationale: For proper L-PBF part traceability, it is important that the production engineering record unambiguously define what records are required to establish the complete production data package for the part. Without such accounting, data packages for parts may go incomplete, resulting in parts with insufficient quality rationale.]

In accordance with NRRS 1441.1, NASA Records Retention Schedules, contract and QMS requirements, all part records are archived for the prescribed period and remain fully traceable, including those provided by external vendors for operations such as heat treating, machining, or inspection. All witness specimen test results and records as well as non-conformance documentation are included in the certification of compliance records for the part. When complete, it is recommended that a final, summarized certification of conformance record be generated demonstrating all requirements have been met, all non-conformances resolved, and that the part is fit for service.

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

7.3 Fatigue

[AMR-61] As required for structural assessment, or at customer discretion, the MPS for any given L-PBF product shall include fatigue properties developed in accordance with the following policies:

a. The process for developing design fatigue curves from the test data is described as part of the MUA substantiating the MPS methodology per section 5.4 of the main body;

b. Fatigue initiation life properties are developed in the form of stress-life or strain-life curves;

c. All fatigue design curves are labeled with their basis, e.g., typical or bounding;

d. Fatigue properties are subject to the lot requirements of section 5.4.2.1 of the main body;

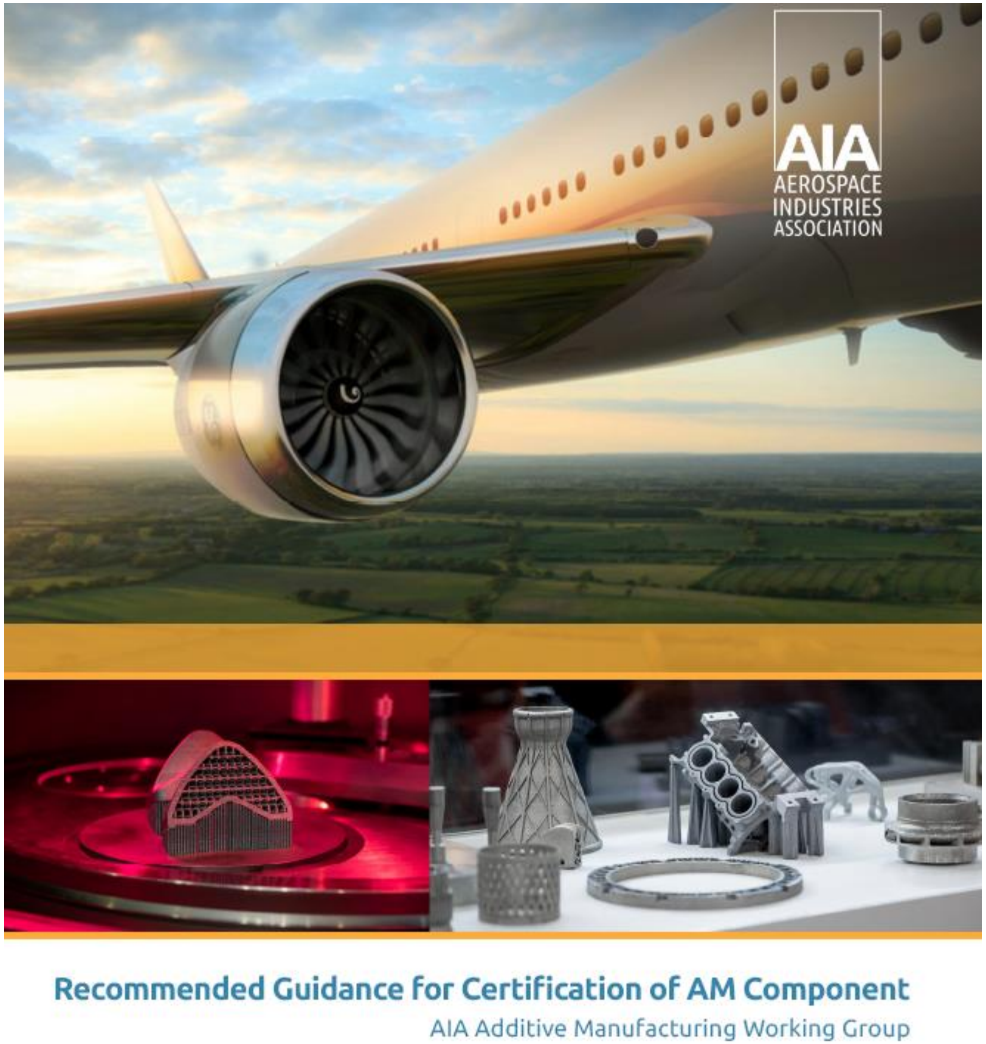
e. Ten or more tests are used to define a fatigue curve for a given condition and, for HCF, a minimum of four tests are within 10% of the stress defined as the fatigue limit; (See the definition of fatigue limit for this MSFC Technical Standard.)

f. If the MPS fatigue design curves are applied to Class A parts with cycle counts $\geq 10^8$, fatigue test data are acquired to substantiate the design curve in this regime, except for Class B parts, where an analytical methodology for predicting such fatigue limits may be employed when properly documented;

g. Effects of surface textures rendered by the L-PBF process, and surface improvement treatments, are included in the fatigue design curves of the MPS as follows:

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Recommended Guidance for Certification of AM Components
AIA Additive Manufacturing Working Group



You have been provided with a copy of this report

Recommended Guidance for Certification of AM Components
AIA Additive Manufacturing Working Group

Co-funded by the Erasmus+ Programme of the European Union

https://www.aia-aerospace.org/wp-content/uploads/2020/02/AIA-Additive-Manufacturing-Best-Practices-Report-Final-Feb2020.pdf

You have been provided with a copy of this report

Disclaimer ..FAA has participated however, conclusions stated within this report do not necessarily represent the views of the FAA.

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

Process Control Documents

Infrastructure

- Facility Control Plan
- Operator Training and Qualification Plan
- Work Instruction Plan
- Software Configuration Control Plan

Machine Qualification Plans

- Key Process Variable (KPV) Plan
- Machine Configuration Plan
- Preventative Maintenance Plan
- Machine Calibration Plan
- Machine Requalification Plan

Feedstock Control Plan

- Feedstock Lot Control Plan
- Feedstock Handling Plan
- Powder Feedstock Re-use Plan
- Machine and Material Alloy Change
- Contamination Avoidance Plan

Part Production Plans

- Engineering Requirements Plan
- Manufacturing Part Definition Plan
- Machine Parameters Plan
- Build Interruption Plan
- Quality Control Plan
- In-Process Monitoring Inspection Plan
- Record Keeping Plan

Post-Process Plans

- Powder Removal Plan
- Stress Relief Plan
- Hot Isostatic Press (HIP) Plan
- Heat Treatment Plan
- Build Plate Removal Plan
- Support Removal Plan
- Surface Enhancement Plan

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Sources of information

- National/international standards
- Sector specific guidelines
- Other sources…….

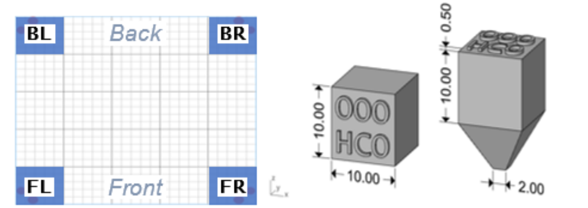


Figure 1. At the UK's National Centre for Additive Manufacturing, we put a block in every each corner of our metal powder bed fusion builds - see plan view of the build chamber on the left with corners labelled back left (BL), back right (BR), front left (FL) and front right (FR). The geometry of the block is also shown - plan view (middle) and side view (right). It is a 10 mm cube with an inverted pyramid below it. The letters on top are a unique identifier that are used to trace them back to the build and location on the bed. The blocks are removed from the build plate and tested to monitor the performance of the machine.

This process is mandatory at the National Centre for all M-PBF machine builds, with the exception of the following scenarios:

- For parameter development builds, or when a standard material melt-theme does not exist
- On externally prepared builds files which do not permit internal additions and alterations
- When the addition of cubes is physically impossible, due to the geometry of primary parts e.g. for large-spanning primary parts which cover the entire surface of the build platform

KHUB-AM-0007-Selecting buying commissioning an MPBF system-v2.0

Guide -

Considerations when Selecting, Commissioning and Maintaining a Metal Powder Bed Fusion System

November 2020

- Validation of process capability - where you identify a candidate machine and process parameters to achieve the required build quality
- Installation and commissioning
- Maintenance, servicing and upgrades
- Measurement of M-PBF Machines

KNOWLEDGEHUB

http://knowledgehub.the-mtc.org/knowledge-hub/

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Case study

You have been provided with a copy of this report

Inspiring Great British Manufacturing

Report Title: **D1 - Guidance on Validation of the Electron Beam Powder Bed Fusion Process for Aerospace**

Version Number: 1.0

Project Title: 32296-12-11 DRAMA Metron Process Validation Support Package

Prepared For: Metron Advanced Equipment Ltd.

Author: Nick Cruchley

Thank you to Metron allowing this information to be shared with you

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Definitions of terminology used in within the context of production of components for the aerospace industry

Term	Quoted Definition	Definition Source	Reference
Certification	"A procedure by which a third party gives written assurance that a product, process or service conforms to a specified requirement."	MAASAG Paper 124 Issue 1	(Lunt, et al., 2018)
Qualification	"The demonstration that the product, process or service conforms to a specified requirement."	MAASAG Paper 124 Issue 1	(Lunt, et al., 2018)
Validation	"Activities performed to demonstrate that a product is capable of meeting the requirements for the specified application or intended use." Note: Validation can also apply to a manufacturing process.	SABRe Supplier Management System Requirements Definition	(Rolls-Royce, 2019)
Verification	"Verification uses objective evidence to confirm that specified requirements have been met."	SABRe Supplier Management System Requirements Definition	(Rolls-Royce, 2019)

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Product Design & Development	Requirements capture	Product design	Review design for manufacturability and assembly		
Process Design & Development	Establish process flow	Identify process operating windows	Establish process capability – geometry	Establish process capability – material properties 32296-12-11 D1 & D2	Process control plan 32296-12-11 D1
Machine Qualification	Machine installation qualification	Machine operation qualification	Machine performance qualification		
Product & Process Validation	Process validation	Product Validation			
Quality Control	Quality control plan				

Description of the stages of new production introduction from design to qualified process and product

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Airworthiness Regulations

- **CAA/ EASA:** the regulatory bodies which oversee the safety of the aerospace sector
- **Design Organisation:** "responsible for the design of products, parts and appliances or for changes or repairs" …… likes of Boeing, Airbus, Rolls-Royce, GE Aviation and Pratt and Whitney.
- **Production Organisation:** "responsible for the manufacture of products, parts and appliances" … must demonstrate its capability in accordance with Annex 1 (Part 21), Subpart J of the regulation (European Union, 2012)… must (amongst other things) have agreement in place with Design Organisation; demonstrate a robust Quality System; and have a nominated independent owner of quality management.
- Obtaining these approvals **can take years**….includes visits from National Aviation Authority (the CAA for the UK) and so the lead time can, in part, depend upon the availability of the National Aviation Authority

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Subcontracting

- Design Organisation or Production Organisation can subcontract to another company but legal responsibility for the airworthiness of the products remains with them (ie you can not subcontract the responsibility)

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Working to standards

- AS9100D = aerospace industry QMS standard
- Nadcap (National Aerospace and Defense Contractors Accreditation Program)= for special processes. such as heat treatment, coating, mechanical testing.

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Guidance for Aerospace Process Control

- Guidance on the processes and requirements for the introduction of new products to aerospace is freely available in the form of: Rolls-Royce SABRe 3 Production Part Approval Process (Rolls-Royce, 2015)

and

- SAE Requirements for Advanced Product Quality Planning and Production Part Approval Process (SAE International, 2016).

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Table 2: Reviewed documents referencing to specific EB-PBF process tasks

	Reviewed Documents										
	NADCAP Audit Criteria For Laser and Electron Beam Metallic Powder Bed Additive Manufacturing	MASAAG Paper 124 Guidance Note On the Qualification and Certification of Additive Manufactured Parts for Military Aviation	AIA - Recommended Guidance for Certification of AM components	FAA Job Aid for Evaluating Additive Manufacturing Facilities and Processes	NASA MSFC-STD-3717 Specification For Control and Qualification of Laser Powder Bed Fusion Metallurgical Processes	ASTM F2924 Standard Specification for Additive Manufacturing Titanium-6 Aluminium-4 Vanadium with Powder Bed Fusion	ASTM F3049 Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes	ASTM F3301 Standard for Additive Manufacturing – Post Processing Methods – Standard Specification for Thermal Post-Processing Metal Parts Made Via Powder Bed Fusion	ASTM F3303 Standard for Additive Manufacturing – Process Characteristics and Performance: Practice for Metal Powder Bed Fusion Process to Meet Critical Applications	AMS 2801B Heat Treatment of Titanium Alloy Parts	AMS7003 Laser Powder Bed Fusion Process
Powder specification	X		X		X	X			X		
Powder Receipt	X			X							
Powder handling	X	X		X	X						
Powder Storage	X	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		X
Powder blending		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		X
Powder recycling		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Powder testing		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Key process variables		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		X
Machine operation	X	X	X						X		
Build Monitoring		X		X							
Build pauses	X	X			X						X
Machine maintenance	X	X		X	X				X		X
Support removal	X		X								
Thermal post processing	X	X	X		X	X		X		X	
Surface Finishing		X									
Machining											
Inspection	X	X	X	X							

Guide to applicable standards is given in Metron report

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

4.1 Powder

4.1.1 Specification

The sources reviewed containing information on the specification of powder being procured and for continual testing is displayed in Table 2. Based on the information reviewed the MTC suggests that Metron's processes must include the following:

- Powder suppliers are to hold AS9100 or an equivalent accreditation
- A clear powder specification is used when procuring powder feedstock including acceptable limits, methods of sampling, methods of testing and acceptable testing tolerances on the following metrics:
  - Chemistry
  - Particle size distribution (PSD)
  - Powder morphology (at least qualit
  - Flowability
  - Contamination requirements
- In addition to this the powder specification
  - Explicitly state the powder manufacturing method (incl. atomising gas)
  - Place controls on the blending of powder heats into powder lots (i.e. requiring each blended heat to meet the feedstock specification)
  - State the requirements for feedstock packaging (incl. environmental controls) that by design explicitly prevent moisture from entering.

Note: Multiple standards (ASTM F3303) explicitly prohibit the placing of desiccants or other materials in contact with the feedstock materials.

- A certificate of conformance (CoC) to the supplied specification
  - Identifiers of powder heat and blended lot with date and location of production allowing traceability back to the specific heat.
- Powder should be verified against this specification prior to use

A lot of detail is given in Metron report

4.1.7 Testing

The sources reviewed provided little guidance on the procedures and methods for powder testing, however, ASTM F3049-14 can provide some guidance on this. Together with this standard the MTC recommends following the test standards for verifying the powder feedstock metrics displayed in the table below.

Table 3: Test standards governing the relevant metallic powder test methods employed for the suggested material purchasing specification

Property	Test	Governing standard
		ASTM B215
		ASTM B214
	hod	ASTM B822
	ons only**	ASTM B243
		ASTM E1447
	s	ASTM E1941
composition	Inductively Coupled Plasma Atomic Emission Spectrometry	ASTM E2371
	Wavelength Dispersive X-ray fluorescence	ASTM E539
Flowability	Hall flow	ASTM B213 & B855
	Carney flow	ASTM B964
Contamination	N/a	No current governing standard or commonly accepted test method
Density	Hall flow	ASTM B212
	Carney flow	ASTM B417
	Scott volumeter	ASTM B329
	Arnold meter	ASTM B703
	Tap Density	ASTM B527
	Skeletal density	ASTM B923

* Non standardised light scattering methods may be applicable

** Only defines definitions of powder shapes – no standard for qualification of powder morphology currently exists

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Please review

- NASA MSFC-SPEC-3717
- NASA MSFC-STD-3716
- AIA manufacturing best practice guide
- Metron case study

Look at the similarities and differences between the space (NASA) and aerospace approaches

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the
Erasmus+ Programme
of the European Union

www.skills4am.eu

Thank you & Questions

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the
Erasmus+ Programme
of the European Union