# AIPS
# Airbus Process Specification

## Additive Manufacturing
## Powder Bed Fusion of Metallic Materials



**Published and distributed by :**
**AIRBUS S.A.S.**
**ENGINEERING DIRECTORATE**
**31707 BLAGNAC Cedex**
**FRANCE**

**Contents**

## 1 Scope

This Airbus Process Specification defines the Engineering requirements for Additive Manufacturing - Metallic Powder Bed Fusion.

This specification does not give detailed instructions; these are given in the Airbus Process Instruction (AIPI) and the Work Instructions.

This specification shall not be used as an inspection document.

It shall be applied when mentioned in the relevant standard, material specification or Definition Dossier.

## 2 Normative References

This Airbus specification incorporates by dated or undated reference provisions from other publications. All normative references cited at the appropriate places in the text are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this Airbus specification only when incorporated in it by amendment of revision. For undated references, the latest issue of the publication referred to shall be applied.

| | |
|---|---|
| ISO11554 | Optics and photonics – Lasers and laser-related equipment – Test methods for laser beam power, energy and temporal characteristics |
| ISO14175 | Welding consumables – Gases and gas mixtures for fusion welding and allied processes |
| ISO14731 | Welding coordination — Tasks and responsibilities |
| ISO14744-1 | Welding - Acceptance inspection of electron beam welding machines - Part 1: Principles and acceptance conditions |
| ISO14744-2 | Welding - Acceptance inspection of electron beam welding machines - Part 2: Measurement of accelerating voltage characteristics |
| ISO14744-3 | Welding - Acceptance inspection of electron beam welding machines - Part 3: Measurement of beam current characteristics |
| ISO14744-4 | Welding - Acceptance inspection of electron beam welding machines - Part 4: Measurement of welding speed |
| ISO14744-6 | Welding - Acceptance inspection of electron beam welding machines - Part 6: Measurement of stability of spot position |
| ISO15607 | Specification and qualification of welding procedures for metallic materials - General rules |
| ISO15609-3/4 | Specification and qualification of welding procedures for metallic materials – Welding procedure specification |
| ISO/IEC17025 | Conformity assessment. General requirements for the competence of testing and calibration laboratories |
| ISO/DIS19828 | Welding for aerospace applications - Visual inspection of welds |
| ISO22827-2 | Acceptance tests for Nd:YAG laser beam welding machines - Machines with optical fibre delivery - Part 2: Moving mechanism |
| ISO/ASTM52900 | Additive manufacturing - General principles – Terminology |
| ISO/ASTM52921 | Standard terminology for additive manufacturing – Coordinate systems and test methodologies |
| EN2002-1 | Aerospace series – Metallic materials – Test methods – Part 1: Tensile testing at ambient temperature [1] |
| EN6072 | Aerospace series – Metallic materials – Test methods – Constant amplitude fatigue testing [1] |
| EN9103 | Aerospace series – Quality management systems – Variation management of key characteristics [1] |
| A1091 | Airbus Requirements for the Management of Hazardous Substances |
| ABS5874 | Metallic Powder - Titanium alloy Ti-6Al-4V Powder Sizes and Particle Size Distributions |

[1] Published as ASD Prestandard at the date of publication of this standard

| | |
|---|---|
| AIPS02-02-002 | Airbus Process Specification – Dry blasting |
| AIPS04-00-005 | Airbus Process Specification – Hot Isostatic Pressing for metallic Materials |
| AITM1-0012 | Airbus Test Method – Shear testing of metallic materials wrought products |
| AITM6-1001 | Airbus Test Method – For Inspection Processes – Penetrant inspection |
| AITM6-7002 | Airbus Test Method – For Inspection Processes – X- Radiographic Inspection General |
| AITM6-7005 | Airbus Test Method – For Inspection Processes – Radioscopic inspection of metallic materials by X- and gamma rays |
| AITM6-7006 | Airbus Test Method – For Inspection Processes – Computed tomography (CT) with X-rays (including planar X-ray tomography) |
| AITM6-7007 | Airbus Test Method – X-ray Inspection Using Digital Detector Arrays |
| AITM6-7008 | Airbus Test Method – Non Destructive Inspection of PBF (Powder Bed Fusion) Parts |
| ASTMB769 | Standard Test Method for Shear Testing of Aluminum Alloys [2] |
| ASTME8 | Standard Test Method for – Tension Testing of Metallic Materials [2] |
| ASTME9 | Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature [2] |
| ASTME111 | Standard Test Method for – Young's Modulus, Tangent Modulus and Chord Modulus [2] |
| ASTME238 | Standard Test Methods for Pin-Type Bearing Test of Metallic Materials [2] |
| ASTME399 | Standard Test Methods for Linear-Elastic Plane-Strain Fracture Toughness KIc of Metallic Materials [2] |
| ASTME647 | Standard Test Method for Measurement of Fatigue Crack Growth Rates [2] |
| DIN35224 | Welding for aerospace applications — Acceptance inspection of powder bed based laser beam machines for additive manufacturing |
| DIN35225 | Welding for aerospace applications – Qualification testing of operators for powder bed based laser beam machines for additive manufacturing |



[2] Published by: American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA

# 3 Definition, Applicability and Limitations

## 3.1 Definition

Powder Bed Fusion is the process of creating parts or adding material on existing parts by melting layer wise powders, molten by a Laser Beam or Electron Beam. For any definition or terminology use the definitions in accordance to ISO/ASTM52921 and ISO/ASTM52900.

| | |
|---|---|
| AIMS MS | Airbus Material Specification - Material Specification |
| AIMS TS | Airbus Material Specification - Technical Specification |
| AM | Additive Manufacturing |
| AM Batch | All parts produced in the same build cycle on one machine |
| APS | Additive Procedure Specification |
| Base Plate | Plate upon which powder is deposited and molten |
| Bobbling, quilting, swelling, slip defect | See AITM6-7008, Table 1 |
| BQ-WS | Build Quality Witness Specimen |
| CT | Computed Tomography |
| HIP | Hot Isostatic Pressing |
| HIP Batch | All parts heat treated in the same HIP cycle in one furnace |
| HT | Heat Treatment |
| HT Batch | All parts heat treated in the same heat treatment cycle in one furnace |
| KPP | Key Process Parameter |
| Powder Batch | Powder produced in the same atomization campaign from the same base material. |
| PC-WS | Production Chain Witness Specimen |
| PT | Penetrant Testing |
| RMS | Reference Manufacturing Shop |
| WS | Witness Specimen |

## 3.2 Acceptance Level

The acceptance levels are divided into A, B and C.

Their differences are based on different external and internal quality levels.

Depending on the classification each part will fall into one of the three grades.

Thus, the acceptance level of grade A, which depends on the production procedure and the type of material represents the best production results which can generally be reached under optimum conditions. The acceptance levels of grade B and grade C correspond to greater tolerances. In parallel to the acceptance level is also the definition of quality levels in use. A link between part classification, quality level and acceptance level is given by Table 1.

Note: Acceptance levels or quality levels shall be given on the drawing.

**Table 1: Part Classification - Acceptance level correlation**

<table>
<tr><th>Classification of parts</th><th>Quality level</th><th>Acceptance level</th></tr>
<tr><td>1</td><td rowspan="3">QL1</td><td rowspan="2">A</td></tr>
<tr><td>2.1</td></tr>
<tr><td>2.2</td><td>B</td></tr>
<tr><td>2.3</td><td>QL2</td><td rowspan="2">C</td></tr>
<tr><td>3</td><td>QL3</td></tr>
</table>

### 3.3 Applicability and Limitations

#### 3.3.1 Applicability

This Airbus specification is applicable when invoked by the drawing directly or through another document for the purpose given in the scope. When processing to AIPS01-04-020 is required, it shall be invoked on the drawing by the words "AM-Powder Bed Fusion". The ABS5874 shall also be part of the drawing

#### 3.3.2 Limitations

Powder Bed Fusion in accordance with this specification is limited to use metal powders defined in the ABS5874. The use of other powders needs to be authorized by the relevant Airbus Materials & Processes specialist. This AIPS is limited to produce parts with properties in accordance to materials specified by a Powder Bed Fusion related AIMS MS.

## 4 Engineering Requirements

Engineering requirements are minimum requirements specified by responsible engineering to ensure optimal performance of the manufacturing process.
All engineering requirements have to be met and controlled in production.
The maximum material thickness range is defined by the relevant AIMS MS. To cover needs on surface roughness, fatigue, distortion and for production an offset up to 2 mm on each surface above the limits of the AIMS MS is acceptable if shown in qualification that the material requirements are fulfilled.

### 4.1 New shop / additional material specification

Each new shop which will be qualified for the process and each qualified shop which wants to produce material against an additional material specification shall perform all tests as requested in chapter 0. All required tests and results shall be summarized in a report and fulfil the requirements of the relevant material specification. This report shall be added to the FPQ required for the first part produced against this material specification, independent of the part classification.

### 4.2 Additive manufacturing coordinator

AM Powder Bed Fusion is a special process, which requires the coordination of AM operations in order to establish confidence in welding fabrication and reliable performance in service. The tasks and responsibilities of people involved in AM-related activities (e. g. planning, executing, supervising and inspection) should be clearly defined. A shop specific AM coordinator with detailed knowledge about the processes and machines shall be responsible. All procedures and responsibilities of the AM coordinator shall be in line with the requirements as defined by the ISO 14731, if applicable.

### 4.3 Materials

#### 4.3.1 Base Plate

All materials which are in use shall be free of materials which can lead to a contamination during production like oil, grease, dirt and other powder particles from previous processes. The surface of the base plate shall have a reproducible quality (cleanliness, roughness, flatness). The surface quality needs to be mentioned in the APS for a specific production run. The base plate material shall be from the same alloy type as the used powder except if there are machine manufacturer requirements which shall be fulfilled too. If a different base plate material is in use then it needs to be secured that a contamination of the powder does not occur. The adjustment of the base plate in the build volume and relative to the recoater shall be described in a supplier specific work instruction.

#### 4.3.2 Powder

New powder needs to be in accordance to a powder specific AIMS MS. A reused powder will be influenced by the processing, depend on the re-use cycles and the completed builds and so a regular check of reused powders is required. It includes a check of the material composition which shall fulfil the composition of the final material AIMS MS, not of the powder specific AIMS MS; As a minimum all alloying elements which could change during processing, the flowability and grain size distribution shall be checked in production regularly.

Powders from different batches can be used and also blended before usage if a procedure is established and described by work instructions which guarantee that the powder after blending fulfils the required quality.

The flowability and particle size distribution of new, reused and blended powder shall be inline with the powder related AIMS MS.

### 4.4 Process Condition

The powder bed fusion process is covering fusion specific details and details of post process steps which are needed to get a final part in accordance with a standard drawing.

The typical main post processes are:

- Powder removal from base plate and part
- Heat treatment / Stress relieve
- Substructure removal
- Heat treatment
- Surface treatment

The detailed post processes are defined by and depend on the material and part specific requirements. The process condition requirements are outlined below.

#### 4.4.1 Production System

The whole production system, including the machine itself, powder storage equipment, powder removal areas, pre material and tools used in the production shall be free of moisture, oil and other dirt which could have a negative influence on the powder, atmosphere or process.
Before start of the melting process the power source, build volume atmosphere, gas flow and the base plate temperature of platforms with heating system in the production chamber have to reach constant conditions in line with APS.

#### 4.4.2 Powder layup quality

The maximum allowed layer thickness tolerance is ± 5 µm or below ± 10 % of the programmed layer thickness, whichever is bigger. The lay-up homogeneity of the powder layer shall be ensured in process.
A contamination of the powder by humidity or other dirt shall be avoided before, during and after processing. It includes the uploading, unloading of powder and removal of the part. Powder handling relevant procedures shall be described by supplier specific work instructions.

#### 4.4.3 Beam quality

The measurement of the beam related value(s) shall be performed before and after each change which is linked to the machine or parameter set and categorized as “midi” or “major” in Table 2. Before new parameters can be validated it needs to be shown that all APS relevant parameters are in line with the defined values for the key process parameters in the AIPI and in a stable mode with defined and secured tolerances.
Beam positioning and trajectory shall be in line with ISO22827-2, acceptance criteria B. The energy density and beam caustic depends on the used optical systems and lasers. So the values, energy density and roundness for a caustic ± 2 mm in and around the focus position, on minimum 7 planes (example: Focus position 0,0 mm / ± 0,6 mm / ± 1,2 mm / ± 2,0 mm) shall be measured for each power level used in production.
The energy distribution needs to be constant during the whole processing of an AM-Batch. It shall be regularly measured and contain, at minimum, all power levels which are in use during production and stated in the APS.
For electron beam based systems the beam quality measurement method shall be in accordance to the ISO14744-2, ISO14744-3 and ISO14744-6. Other procedures need to be agreed with the relevant materials and processes specialist.

#### 4.4.4 Temperature during Production

The local temperature in production can be influenced by the energy input of the beam, by the part size, active cooling systems or an additional heat source.
If during production a temperature could occur outside of the melt pool which can influence the material properties by the microstructure or evaporation of specific alloying elements a measurement system and/or procedure shall be established to detect it and/or avoid it.
If it is planned to use such a system or procedure in production a test program needs to be performed on top of the APS validation to secure the applicability for the generic production. The test description and all test results, including APS validation results shall be summarized in a report and sent to the responsible Airbus M&P for validation before using. Further tests could be required by M&P to accept the usage of the system or procedure.

#### 4.4.5 Build Volume Atmosphere

To avoid contamination of the powder or the part by gases or humidity in process a shielding gas atmosphere or a vacuum is required. It shall be there from the start of the production process including possible preheating and cooling phase down to minimum 150° C. The gas for shielding shall be in accordance to the ISO14175 with purity equal or better than 99,995 %. The shielding gas atmosphere shall have no negative influence on the material properties. Independent of this the maximum oxygen content in the build volume atmosphere during production shall be below 0,2 %. The vacuum system shall be feasible to reach a vacuum below $5x10^{-5}$ mbar. This shall be controlled on a regular basis to guarantee the effectiveness of the vacuum chamber. In production the use of Helium with purity equal or better than 99,995 % is acceptable. By using Helium the vacuum shall be below $4x10^{-3}$ mbar during production. In production a discoloration of the material is not allowed. Sensors need to be there to control the shielding gas atmosphere in a proper way to guarantee sufficient shielding in each area of the build volume during the whole of the processing. The main gas flow parameter needs to be stated in the APS.

#### 4.4.6 Powder removal

After the fusion process the part is enclosed by loose powder or powder which is semi sintered. This powder shall be removed before further processing. A contamination of the powder by the cleaning process is not allowed.
Dry blasting in according to AIPS02-02-002 is also allowed provided that a surface removal before penetrant inspection is performed which removes the blasting material and possible smearing effects completely. Parts shall not be distorted after dry blasting. The blasting parameters (pressure, abrasive diameter, etc.) shall be selected depending on the thickness and configuration of the part in order to avoid distortion. If the removed powder shall be recycled and reused in the fusion process then the blasting material shall be in line with the relevant additive manufacturing powder specific AIMS.

#### 4.4.7 Heat Treatment

Unless otherwise defined by the drawing, parts shall be heat treated at the temperatures, times and pressure defined in the relevant material specification. The heat treatment process shall be performed in accordance to the relevant heat treatment AIPS.
alloys and especially titanium alloys can be reactive during the fusion process and heat treatment at elevated temperatures particularly with elements such as oxygen, nitrogen, hydrogen and carbon. Reactions with these elements can result in the formation of a brittle surface layer which has a detrimental effect on the mechanical performance of the parts.
The surface shall be treated as stated in the relevant heat treatment AIPS after each production step which could impact the surface contamination, except when a complete removal of the contaminated surfaces on the final part is guaranteed.
The stress relieve shall be performed in line with the material specific AIMS MS.

#### 4.4.8 Part removal from build plate and substructures

Depending on the part geometry, build chamber temperature and the used build parameter stresses can occur in the part which can led to effects such as distortion or cracks. To reduce such effects a substructure will be built in between part and base plate. In addition to these stresses are part related areas there which need to be supported by substructures to be buildable.
The substructures need to be removed after fusion, powder removal and the normally performed stress relieve.
Only qualified mechanical and/or (electro-) chemical post processes shall be used for the substructure removal. The local production needs to decide which process or process combination will be used to remove the substructure. The performed removal process shall have no impact on the part geometry or material properties. The workflow shall be fixed and validated about the first part qualification (FPQ). All removal process related requirements, as stated by the relevant AIPS, need to be fulfilled except separate surface roughness requirements. Removal processes which can lead to a smearing or have the risk to close defects like pores or cracks shall be performed after penetrant inspection, except if it is demonstrated by smearing test that this risk is covered. The smearing test shall be performed in accordance to the relevant AITM. If no AITM exist a supplier specific procedure shall be established and accepted during the FPQ-process for the first part where the procedure will be used.

### 4.4.9 Heat treatment - Hot Isostatic Pressing (HIP)

The HIP process is described in the AIPS04-00-005 and can be required by the relevant material AIMS and/or inside of this process as a post processing step. Other HIP procedures may be applied, provided that they are captured as part of the frozen manufacturing route for a frozen supplier and authorised by Airbus Materials & Processes as part of the process qualification.
The HIP process is mandatory

- if requested by relevant AIMS MS,
- to remove lack of fusions after production as a post processing step,
- to guarantee a stress relieve.

HIP is not mandatory

- if it is not required by the AIMS MS and other methods, provided that online monitoring in process or offline NDT can give the right evidence that there are no lacks of fusions in the material.
- if the stress relieve is realized by another heat treatment or test which gives the evidence that no stress relieve is required.
- The freedom of “lack of fusions” needs to be shown by tests and statistical analysis.

### 4.4.10 Surface treatment

The surface of the parts after fusion, powder removal and part removal from substructures is undefined. That means the surface quality varies depending on used powder particle size, particle distribution of the powder, fusion parameter, layer thickness and orientation of each surface in production. Due to this the parts are not useable for production without a surface treatment.
A surface treatment processes which can lead to a smearing or has the risk to close defects like pores or cracks shall be performed after penetrant inspection except if it is demonstrated by smearing tests that this risk is covered.
Surface treatments to smooth and/or clean the surface shall be performed by a qualified mechanical and/or (electro-) chemical process or process chain. If not stated on the drawing the local production organization needs to decide which process or process chain is being applied to fulfil the surface quality requirements. The workflow shall be fixed and validated by the first part qualification (FPQ). All surface smoothing process related requirements for the used processes, as stated by the relevant AIPS, need to be fulfilled except surface roughness requirements.
The removal rate on the surface depends on the surface quality after fusion and the chosen surface treatment process or process chain. So the removal rate shall be considered in the design for manufacturing by a material offset on the surface if necessary.
The surface treatment process or process chain shall guarantee that all surfaces of a part are free from loose and partial molten particles as well as contaminations such as grease, oil, scale, tarnish/temper colour or alpha case.
The surface treatment process or process chain shall guarantee that penetrant inspection in accordance to AITM6-1001 is possible to be performed on all surfaces independent of size, geometry and classification of the part.

## 4.5 Other Requirements

### 4.5.1 Personnel and Equipment

Personnel requirements shall be established by the Local Quality Assurance Authority and shall be in accordance with DIN35225. It shall contain a general overview about all design and production chain steps to produce a part and give a detailed understanding about the specific material, machine and process aspects of the additive manufacturing technology. Laser beam machines shall be checked in according to DIN35224 and Electron beam machines in according to ISO14744-1 and ISO14744-4.

Positioning and trajectory shall be in line with ISO22827-2 for laser and electron beam machines, with the acceptance criteria B as mentioned in Table 2 of the ISO22827-2.

Personnel who perform the visual control of the parts shall fulfil chapter 7 of the ISO/DIS19828.

### 4.5.2 Retention

Retention of log files, “.stl” files, specimen and inspection reports shall be held as per Airbus retention policy.
Safeguards to ensure traceability of the digital files, including design history of the components shall be defined.
Also the software to slice the part for a specific machine set up shall be stored. It needs to be guaranteed that for each part all production relevant parameters are known and stored.

### 4.5.3 Shop floor/ Facilities conditions

All powder fusion and related processing equipment shall be located in a non-greasy, temperature and humidity controlled atmosphere. The environmental conditions set by the machine manufacturers shall be respected all the time. The shop floor conditions shall not allow contamination of the part(s) or the powder with external substances, tooling or re-used powder particles.

### 4.5.4 Additive Manufacturing Procedure Specification (APS).

For each new build cycle an APS is required. The amount of testing to validate a new APS or an existing APS depends on the change categories “Minor”, “Midi” or “Major”. Major changes will result in a new APS. The categorization of a change is captured by Table 2.

**Table 2: APS validation specimens**

| **Norm (values)** | **Specimen norm type and final size / [mm] (in line with qualification)** | **Specimen Orientation** | **Required APS validation tests** | | |
|---|---|---|---|---|---|
| | | | **Major changes** | **Midi changes** | **Minor changes** |
| See chapter 7.3 | Build Quality WS | ZY | Additional testing [b] | No change | No change |
| Tensile EN2002-1 /ASTME8 ($R_m$ / $R_{p0,2}$ / A5) | Type 4 Ø6, M10, L = 70 | X | 5 | 5 | 0 |
| | | Y | | 0 | |
| | | Z | | 5 | |
| | | 45° ZX | | 0 | |
| | | 45° XY | | 5 | |
| Axial Fatigue EN6072 | Type FCE 12,5 A $K_t$=1,035 | Z | 10 | 0 | 0 |
| | | X | | | |
| Fatigue Crack Growth ASTME647 | CT W40 B20 R=0,1 | X-Z | 2 | 0 | 0 |
| | | 45°XY-45°YX | | | |
| | | X-Y | | | |
| Fracture Toughness ASTME399 | CT W20 B10 $K_{1c}$ | X-Z | 2 | 2 | 0 |
| | | 45°XY-45°YX | | | |
| | | X-Y | | | |
| Bearing Stress ASTME238 ($F_{bru}$, /$F_{bry}$) | e/D = 2,0 / Ø6 | ZX | 3 | 2 | 0 |
| | | XZ | | 0 | |
| Compression Proof Stress AITM1-0012 / ASTME9 ($R_{0,2c}$) | 25 x Ø13 | Z | 3 | 2 | 0 |
| | | X | | 0 | |
| Shear ASTMB769 /AITM1-0012 (shear strength) | 28,5 x Ø8 | Z | 3 | 2 | 0 |
| | | X | | 0 | |
| Metallographic /Table 8 | - | | 2 per AM batch [a] | None [a] | 0 |
| (digital) X-Ray or CT Table 8 | - | | All after HIP | | |
| PT /Table 8 | | | | | |
| Visual /Table 8 | | | | | |
| Chemical Composition Table 8 | | | 2 per AM batch [a] | None [a] | None |

[a] Depend on the build temperature additional tests are required (see 4.4.4). If parts with functional classification 2.1 and 1 inside of the build then the tests need to be done by a cut out in the thickest area at 1 part of each part number.

[b] The build quality WS for the full height build shall be checked against systematic indications such as line porosity or high surface near porosity in the clamping areas by CT with 30 µm resolution. No systematic indications are acceptable

The APS need to be in line with the AIPI. An APS shall be stored for the life time of the part and available upon request from Airbus or during an Audit. The APS for the actual build jobs in production shall be known by and reachable for the operators.

**Table 3: APS Re-validation specimens**

| Norm | Specimen Norm type and final size (in line with qualification) / [mm] | Specimen Orientation | Number of Specimens |
|---|---|---|---|
| Tensile<br>EN2002-1 /ASTME8<br>($R_m$ /$R_{p0,2}$ /A5) | Type 4<br>Ø6, M10, L = 70 | Z | 6 |
| | | 45° XY | |
| | | X | |
| Fatigue Crack Growth<br>ASTME647 | CT W40 B20<br>R=0,1 | X-Z | 1 |
| Fracture Toughness<br>ASTME399 | CT W20 B10<br>$K_{1c}$ | X-Z | 1 |
| | | X-Y | |
| Metallographic /Table 8 | - | | All after HIP in final machined condition |
| (digital) X-Ray or CT<br>Table 8 | | | |
| PT /Table 8 | | | |
| Visual /Table 8 | | | |
| Chemical composition<br>Table 8 | | | One per batch |

The local AM coordinator shall validate the APS, following the principles as described by the ISO15607. The APS shall as a minimum contain all detailed machine/programming/process specific information required to make an AM-part and not stated by other documents, in line with the ISO15609-3/4. All additive manufacturing shall be carried out against validated APS.

In all cases, all the APS validation tests and inspections defined shall be carried out by considering the requirements as stated in Table 6. Only the number of AM batches built over the full build chamber height can be reduced from 3 down to 1 and the minimum number of AM batches can be reduced from 10 down to 3. The acceptance criteria for validation of the APS are related to the requirements of the relevant AIMS MS, acceptance level A.

**Table 4: Characterisation of changes for APS validation**

| No | Change | Categories | To be tested on |
|---|---|---|---|
| 1 | Part positioning | Minor a | Part |
| 2 | Part orientation (if acceptable by AIMS) | | |
| 3 | Sub structure | | |
| 4 | Add or remove parts in a specific build job | | |
| 5 | Base plate surface (change of pre-treatment influence) | Minor | |

(continued)

**Table 4: Characterisation of changes for APS validation (concluded)**

| No | Change | Categories | To be tested on |
|---|---|---|---|
| 6 | KPP and shielding gas guiding system | Major | Specimen |
| 7 | Machine software<br>(Software not influenced by the machine user) | Major b | |
| 8 | Parameter software<br>(software to add parameters or to transform parameters defined by the machine user) | | |
| 9 | After maintenance (no change of machine parameters/laser) | Midi | |
| 10 | Powder supplier (same specification) | | |
| 11 | Powder specification (same alloy) | Requalification | |
| 12 | Change of machine or machine type | Major | |
| 13 | Recoater type/material (no further change of machine) | Midi | |
| 14 | (Partial) modification of the build chamber, the machine or gas flow which can influence the shielding gas and atmosphere | Major | Specimens |
| 15 | Movement of machine | | |

[a] Midi if the production temperature is in a range which could have an impact on microstructure and chemical composition (see 4.4.4).
[b] If evidence can be provided that the mechanical performance of the part can't be affected then this becomes a minor change.

The required tests for validation of the APS shall be in accordance with the same specification and geometry as used for the qualification. The amount of specimens and their orientation are defined in Table 2. The evaluation of the test results shall be performed as done for qualification and shall reach the same level as reached in qualification.
A re-validation of the APS needs to be performed every 6 months by an AM batch built over the full build chamber height. Minimum 1 or 1/3, whichever is bigger, of each specimen type as defined in Table 3 needs to be in the upper 1/3. The specimens shall have the same build position as they had during APS validation. The results need to be on the same level as reached during qualification.

### 4.5.5 Use of different alloys in production

A regular change of the alloys in production on a machine is forbidden. The environmental conditions and local procedures shall ensure that a cross contamination of the powder is avoided in all production steps.
If a change of Powder was done then the first 5 AM batches need to be checked in detail:

- CT of each PC-WS with Voxel of 10 µm -> Free of foreign material inclusions.
- 2 Powder samples (minimum 1000 mm³) out of each of the 5 batches need to be check with CT with Voxel of 10 µm -> Free of foreign particles

### 4.5.6 Restart

A restart of the machine during production after an automated or manual machine stop as a result of a possible repair is acceptable if:

- The restart is also captured by the witness specimens.
- It is stopped before the start or after finishing of melting a layer.
- No visible layer shift is observed on the final part.
- Atmosphere conditions are stable during the stop.
- The distance between last layer position and focus position is below 0,5 times of the layer thickness.
- There are no changes of machine or laser parameters.
- The affected area is checked 100% by PT and (digital) X-Ray or CT and fulfil the requirements of acceptance level A.

### 4.6 Key Characteristics

Key Characteristics according to EN9103 are defined by responsible engineering based on a risk analysis for parts manufactured by this process. Key characteristics shall be defined on product level and if necessary also on process level.

**Table 5: Key Characteristics**

| Product Key Characteristic | | | Process Key Characteristic | | |
|---|---|---|---|---|---|
| No. | Designation | Requirement Limit | Sub.-No. | Designation | Requirement/ Limit |
| 1 | Material Properties | Material Specific AIMS MS | 1.1 | Beam quality [a] (power stability, focus and caustic form/size/Z-position/energy density) | See process instructions |
| | | | 1.2 | A: Powder layer quality -homogeneity surface | |
| | | | | B: Powder layer quality - thickness | |
| | | | 1.3 | Beam positioning and beam speed | |
| | | | 1.4 | Powder quality | See powder specific AIMS MS and material specific AIMS MS |
| | | | 1.5 | Temperature over the production time and on each relevant area of the part in production [b] | Below temperature which reached during qualification or APS validation |
| | | | 1.6 | Atmosphere of production environment (humidity/temperature) | No contamination by humidity possible |
| | | | 1.7 | Atmosphere of build volume (humidity/vacuum/shielding gas quality/gas flow quality/pressure) | No influences on the material properties and surfaces (temper colour) |

[a] For each APS relevant power value.
[b] Only if the temperature will be in a range that it can influence the microstructure and/or it can have an influence on the material composition.

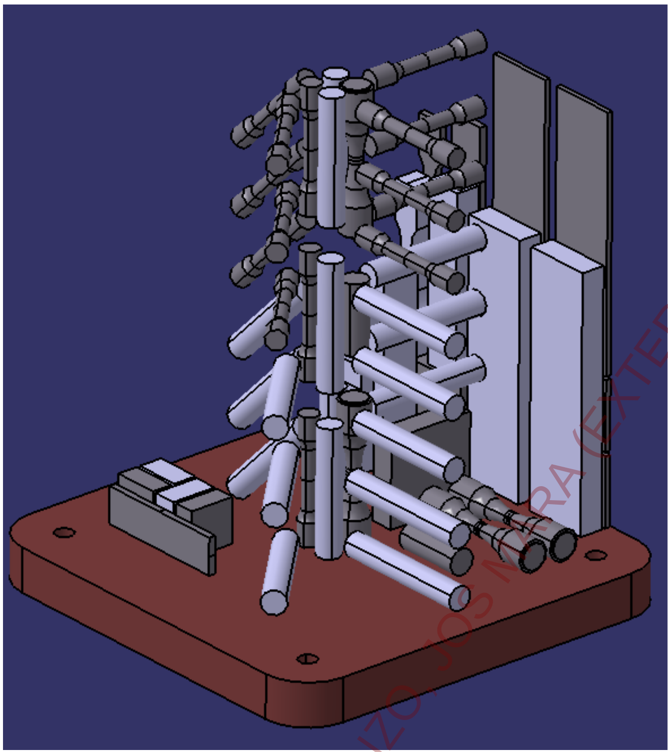
Key Characteristics shall be subject to variation control by the production organization according to EN9103. Key Characteristics do not relieve the production organization from meeting all engineering requirements defined in this document.
All values need to be measured with equipment, calibrated in accordance to ISO/IEC17025. The laser relevant measurements shall be performed in accordance to ISO11554. If a calibration against these standards is not possible then it needs to be secured that all relevant APS values are measureable in a regular and reproducible way. A complete readjustment of all AM-machine parameters needs to be secured and described by local work instructions.
The measurement frequency for Sub.-No. 1.1 and 1.3 has to start with minimum 1 per week for all values. The frequency of control may be progressively reduced after the APS is established and statistics are available which show the stability of the parameters down to one every month. This reduction needs to be authorized by Quality Department. Sub.-No. 1.2 A, 1.5, 1.6 have to be monitored for each build job, 1.2 B every 6 months and 1.4 on the powder reuse cycles as mentioned in the relevant chapters before. A link between all values and the produced batch shall be guaranteed and stored.

## 5 Technical Qualification

### 5.1 Engineering Requirements for Technical Qualification

As a general rule, the qualification requirements defined below shall be followed if technical qualification of the process in a manufacturing shop other than the RMS is required. In certain cases, the Airbus Materials & Processes specialist may authorize changes to the qualification requirements, e.g. base materials, test piece configurations or the number of test specimens required. In such cases, the revised requirements will be detailed in the qualification test program.

Based on the requirements in Table 6 a possible AM batch could look like the illustration in Figure 1. Alternative AM Batch designs are acceptable if the requirements of Table 6 are fulfilled.



:

**Figure 1: AM Batch design example which consider the production requirements for the specimens**

### 5.1.1 Specimen production requirements

The test specimen shall be representative for the machine/supplier specific production and therefore the requirements as stated in the following table shall be considered.

**Table 6: Specimen production requirements**

| To be considered | Remarks |
|---|---|
| Full size of the build volume needs to be reflected by the specimens. | Specimens in all positions near to the outer limits on left, right, front, back and top of the planned build volume need to be produced.<br>Minimum 3 AM Batches shall have the full build height.<br>Minimum 2 or 10% of each specimen type need to be produced on the upper 3$^{rd}$ of the build volume. |
| Temperatures during production (see 4.4.4) | Minimum one additional build shall be performed and specimens extracted which can give the confidence that no unexpected high temperature has occurred which could have an effect on the microstructure or material evaporation will occur during production. |
| Minimum 10 different AM batches | All Specimen types need to represent the 10 AM batches. If the number of specimens is below 10, each specimen shall be in one batch and as a minimum the first and 10$^{th}$ batch needs to be represented. |
| Maximum thickness range of the relevant AIMS need to be considered | Minimum one or 25% of each specimen type, whichever is bigger, shall be produced out of the thickest material as allowed by the relevant AIMS plus an offset of 2 mm on each side.<br>Example: An AIMS is applicable for material up to 12 mm and the specimen is the tensile type 4 specimen in the Z direction.<br>- 25% of 24 Specimens is 6 Specimens<br>- AIMS is applicable for material with a thickness of 12 mm<br>=> 6 tensile type 4 specimens build in Z-direction need to be produced out of material with a thickness of 12 mm + 2 mm + 2 mm = 16 mm |

(continued)

**Table 6: Specimen production requirements (concluded)**

| To be considered | Remarks |
|---|---|
| Multiple Laser | Requirement for each AM batch:<br>Minimum one specimen of each WS type need to be produced for each Laser usage combination which shall be used in production:<br>A: Laser 1 or 2 => 1 specimen of each WS type<br>B: Laser 1 and 2 in separate sections => 2 of each WS type<br>C: Laser 1 and 2 in parallel in all sections => 1 of each WS type<br>D: Laser 1 and 2 in parallel and separate sections => 3 of each WS type<br><br>All specimen types need to be produced with each Laser usage combination which shall be used in production. A minimum of 25% of each defined specimen type shall be produced with each laser combination. If the possible laser usage combination is above 4 than the number of each specimen type needs to be increased. ¼ of each specimen type as listed in Table 7 shall be produced with each possible laser combination.<br>Example: 6 laser usage combinations possible => Amount of specimens is increasing by 50% (6 laser usage combinations x 25 % = 150 %). |

### 5.1.2 Qualification Tests

The qualification shall be performed with 1 alloy, in accordance to 1 powder specification and 1 final material related specification. All specimens shall be produced with 1 machine parameter set as stated in the APS. Each build job shall be captured by an APS which describes all important details for the specific production run.

**Table 7: Qualification Test Specimens**

| Specification | Specimen type and final size (mm) | Specimen Orientation | Number of specimens |
|---|---|---|---|
| See chapter 7.3 [c] | Build Quality WS | Z-Y | see Table 6 |
| See chapter 7.3 | Production Chain WS | Z | see Table 6 |
| Tensile [d]<br>EN2002-1 /ASTME8<br>($R_m$ / $R_{p0,2}$ / A5) | Type 2<br>91 x 15 x 2 | Z-X | 6 |
| | | Z-Y | |
| | | 45° XY-Z | |
| | | Y-Z | |
| Tensile<br>EN2002-1 /ASTME8<br>($R_m$ / $R_{p0,2}$ / A5) | Type 4<br>Ø6, M10, L = 70 | X | 24 |
| | | Y | |
| | | Z | |
| | | 45° ZX | |
| | | 45° XY | |
| Elastic modulus<br>ASTME111 | | X | 4 |
| | | Y | |
| | | Z | |
| | | 45° ZX | |
| | | 45° XY | |
| Axial Fatigue<br>EN6072 | Mini T Type / $K_t$=2.3<br>100x20x2 / Ø6,35 | ZX | 20 |
| | | YZ | |
| | Type FCE 12,5 A<br>$K_t$=1.035 | X | 20 |
| | | Y | |
| | | Z | |
| | | 45° ZX | 10 |
| | | 45° XY | |
| Fatigue Crack Growth<br>ASTME647 | CT W40 B20<br>R=0,1 | X-Z | 2 |
| | | 45°XY-45°YX | |
| | | X-Y | |
| | | 45°ZX-45°XZ | |

(continued)

**Table 7: Qualification Test Specimens (Concluded)**

| Specification | Specimen type and final size [mm] | Specimen Orientation | Number of specimens |
|---|---|---|---|
| Fracture Toughness ASTME399 | CT W20 B10 $K_{1c}$ | X-Z | 3 |
| | | 45°XY-45°YX X-Y | |
| | | 45°ZX-45°XZ | |
| Bearing Stress ASTME238 ($F_{bru}$, /$F_{bry}$) | e/D = 1,5 /Ø6 | Z-X | 6 |
| | | X-Z | |
| | e/D = 2,0 /Ø6 | Z-X | 6 |
| | | X-Z | |
| | | 45°XY-Z | 4 |
| Compression Proof Stress AITM1-0012 /ASTME9 ($R_{0,2c}$) | 25 x Ø13 | X | 4 |
| | | Z | |
| | | 45° XY | |
| Shear AITM 1-0012 /ASTMB769 (shear strength) | 28,5 x Ø8 | X | 4 |
| | | Z | |
| | | 45° XY | |
| Metallographic / Table 8 | - | | 2 per AM batch [b] |
| (digital) X-Ray / Table 8 | | | All before and after HIP |
| Computer Tomography Table 8 | | | Minimum 2 or 10% of specimens from each AM batch before and after HIP [a, c] |
| PT / Table 8 | - | | All |
| Visual / Table 8 | | | |
| Chemical Composition Table 8 | | | One per AM batch [b] |

[a] Each specimen type shall be checked a minimum of 2 times in the qualification
[b] Additional tests are possible depend on build temperature (see 4.4.4)
[c] The production chain WS out of 2 batches shall be checked against systematic indications like line porosity or high surface near porosity in the clamping areas by CT with 30 µm resolution. No systematic failures are acceptable.
[d] Thickness offset max. 0,5 mm per side

### 5.1.3 Testing and Inspection of Qualification Test Pieces

The test pieces shall be inspected in accordance with Table 8, acceptance, level A. If HIP is applied the CT and/or (digital) X-Ray shall be performed before and after Hipping. All other none destructive inspections shall be carried out in the final machined part conditions.

**Table 8: Testing and Inspection of Qualification Test Pieces**

| Testing / Inspection | Test Method/Specification | Acceptance Criteria |
|---|---|---|
| **Non Destructive testing** | | |
| Visual | - | See Annex A |
| PT | AITM6-1001 | |
| (digital) X-Ray or CT | AITM6-7002<br>AITM6-7005<br>AITM6-7006<br>AITM6-7007 | |
| **Destructive Testing** | | |
| Mechanical Testing | In accordance to relevant AIMS TS | See material related AIMS MS |
| Metallographic | | |
| Chemical Composition | | |

In the case of qualification test pieces, the Qualification Body may request additional tests to be carried out. In such cases, all details of the tests, together with the requirements to be met shall be quoted in the Qualification Test Program. The specimen types are defined by the relevant AIMS TS. If the type is not defined by the AIMS TS see Table 7 column 1 and 2.
The minimum number of specimens is defined by Table 7, column 4. All mechanical tests shall be performed with machined surfaces. The specimens shall fulfil the requirements of the relevant AIMS MS on a statistical basis.

For static properties the evaluation of a T99 value is required and for dynamic properties a comparison versus the Airbus database by M&P, used to set the specification is required.

Therefore all mechanical test values, including the witness specimen values shall be summarized and given to Airbus material and process specialists for the final evaluation.

During qualification the powder quality needs to be checked. The powder shall fulfil the requirements as stated in 4.3.1. This needs to be shown during qualification by testing the powder in accordance with the relevant powder and material AIMS before each new AM batch and after the last AM batch.

## 6 First Part Qualification

Introducing new structural components or changes into serial production using special manufacturing processes require a decision from Responsible Engineering on a First Part Qualification (FPQ), according to the relevant Airbus procedure.
Main objective of an FPQ is to prove, that the inner quality of a structural part / component meets the requirements defined in the Definition Dossier, taking into account materials, key parameters of the manufacturing process and tooling.

## 7 Series Production Inspection

The shop shall perform the following series production inspections under serial conditions.

### 7.1 Powder

New, reused or blended powder shall be checked according established control plan against

- Flowability
- Particle size distribution
- Chemistry (minimum material specific contaminations and alloy changes out of the process)

Local procedures shall be established to secure that a general moisture contamination of the powder cannot occur. In production a powder surface moisture measurement is required.

### 7.2 Part

All parts shall be inspected in accordance with Table 9.

**Table 9: Inspection Methods and Test Frequency**

| Acceptance level | Inspection method | Frequency per AM Batch (start / minimum) | Acceptance criteria |
|---|---|---|---|
| A | (digital) X-Ray or CT | 100 % | See Annex A |
| | PT | | |
| | Visual | | |
| B | (digital) X-Ray or CT | 100 % [a] / 20 % | |
| | PT | | |
| | Visual | 100 % | |
| C | (digital) X-Ray or CT | 100 % [a] | |
| | PT | 100 % [a] / 20 % | |
| | Visual | 100 % | |

[a] The frequency of inspection may be progressively reduced after the additive manufacturing process is established, and extensive statistics are available for a part. This modification shall be validated by the quality department.

### 7.3 Witness test specimens

Witness test specimens shall accompany the used process parameter for a build job and be representative for the maximum height produced in the build. They shall be positioned

- At the maximum distance between beam positioning mirror and beam focus used for the specific build
- in the coldest area of a build job on the side where the shielding gas flow ends
- as near to the part as possible

The condition of the BQ-WS before testing is including stress relieve and without HIP. This specimen shall deliver a fast first feedback about the build quality.
The test shall be performed in accordance to EN2002-1 or ASTME8. The BQ-WS specimen design shall be in accordance to Figure B.1-left and the clamping device shall be in accordance to Figure B.2.

The PC-WS (Figure B.2-right) delivers a direct link to the final part quality. It shall be tested in the same final condition as the part, including all heat treatment steps.

Size of the production chain specimen (ZYX): Zx6x6 $mm^3$

An artificial cuboid with a size of 2x2x20 $mm^3$ shall be produced inside of the specimen.

**Table 10: Testing of the witness tests specimens**

| Specimen | Tests | Requirements |
|---|---|---|
| Build Quality (BQ) | Tensile | 100% of the minimum yield strength value reached in qualification |
| Production Chain (PC) | (digital) X-Ray [a] or CT [a] | See Annex A<br>(Acceptance level A) |
| | PT | See Annex A<br>(Acceptance level A) |
| | Visual Inspection | Outer deformation of the WS visible in artificial unmolten cuboid area (HIP performed) [b] |
| | Metallographic [a] | Micro structure and grain size in line with AIMS MS |

[a] For builds containing parts classified as class 2.1 and 1
[b] If HIP is part of the process chain

The test shall consist of the configuration and method of evaluation as given in Table 10. If the PC WS fails in NDT except for the metallographic checks all parts out of the build job shall be checked by NDT. If the PC WS fails metallographic checks a concession is required.
The test results shall be stored, statistical analysed and compared with the statistical analysed level as reached during qualification. The specimens themselves shall be stored for a minimum of 3 month after testing.
The minimum quantity of witness specimens is defined in Table 6. The quantity and configuration of witness test specimens may be changed with prior agreement from the Airbus Materials & Processes specialist.

### 7.4 Acceptance Criteria

In all cases, the additive manufactured part must satisfy the acceptance criteria defined in Annex A.

## 8 Rework

Not applicable.

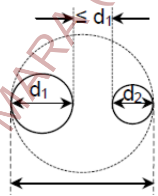
## 9 Environment, Health and Safety

The manufacturing process shall be in line with Airbus Health and Safety and eco-efficiency policies.
Compliance with A1091 shall be ensured for all materials, substances and/or articles implemented during process.
In particular, targeted substances according to A1091 shall not be used, if a safer alternative is available.

Uses made of all substances involved in the process shall be documented in Safety Data Sheet as required by REACh regulation (Registration Evaluation and Authorization of Chemicals).

# Annex A
## (Normative)
## Acceptance Criteria

**Table A.1: Internal Acceptance Criteria**

<table>
<tr><th rowspan="2">Description of Imperfection or Defect</th><th colspan="3">Acceptance level after HIP and for parts without HIP</th></tr>
<tr><th>A</th><th>B</th><th>C</th></tr>
<tr><td>Cracks</td><td colspan="3">Not Permitted</td></tr>
<tr><td rowspan="2">Gas porosities and less dense inclusion</td><td colspan="2">< 200 µm</td><td>< 500 µm</td></tr>
<tr><td colspan="3">No line porosity is acceptable [a]<br><br>Where the distance (ΔL) between two individual porosity is ≤ $d_1$ (where $d_1$ is the size of larger pore) they shall be considered as a single pore<br><br></td></tr>
<tr><td>Solid inclusion [b]</td><td colspan="2">< 150 µm and 1 inclusion<br>< 200 µm per 25 $cm^3$ is allowed<br>Inclusions located at a distance shorter than 1/3 thickness or 2 mm from the surface whatever is the lower are not allowed</td><td>< 300 µm and<br>1 inclusion below 500 µm per 25 $cm^3$ is allowed</td></tr>
<tr><td>Lack of Fusion [c]</td><td colspan="3">Not Permitted</td></tr>
<tr><td colspan="4">[a] For Acceptance level A and B all indications below 150 µm will not be considered and for acceptance level C all indications below 300 µm will not be considered.<br>[b] The volume of 25 $cm^3$ is linked to the volume of the final part. Example: Part volume is 80 $cm^3$ => 80 $cm^3$/25 $cm^3$ => a maximum of 3 Inclusions are acceptable.<br>[c] Defects between molten powder layers => Measurement in layup direction required</td></tr>
</table>

## Annex A
## (Normative)
## Acceptance Criteria

**Table A.2: External Acceptance Criteria**

| Description of Imperfection or Defect | Acceptance level | | |
|---|---|---|---|
| | A | B | C |
| Cracks | Not permitted | | |
| Surface pores | Not permitted | < 100 µm and 3 pores < 200 µm per 25 mm² are allowed | < 300 µm and 2 pores < 500 µm per 25 mm² are allowed |
| Slip defect | Not permitted | Acceptable if (digital) X-ray or CT performed and no sharp edges remaining in final conditions | |
| Temper colour | Not permitted | | |
| Bobbling | Allowed provided removed by finishing/machining | | |
| Quilting | | | |
| Swelling | | | |
| Surface quality | Free of loose and partly molten powder particles | | |
| | $R_a$ [b] < 3,2 µm | | $R_z$ [a, c] < 5 µm x t [d] |

[a] Rz measured in Z direction by including a minimum of 100 layers

[b] Roughness requirement for machined surfaces. Roughness requirements for un-machined surfaces shall be stated on the drawing.

[c] $R_z$ can be increased by half of the thickness above the minimum size allowed by the drawing.

Example:

Minimum size on a part: $2^{\pm 0,2}$ mm

If the final size is 2 mm - 0,2 mm = 1,8 mm then is the acceptable $R_z$ = 5 µm x 2 = <u>10 µm</u>.

If the final size is 2 mm - 0,1 mm = 1,9 mm (0,1 mm thicker as minimum allowed by the tolerance) then there is a thickness reserve per side of 0,1 mm / 2 = 0,05 mm which can be used to increase the $R_z$ value.

By this the acceptable $R_z$ value for the 1,9 mm part can be calculated to:

$R_z$ = 5 µm x t + thickness reserve/2 = 5 µm x 2 + 0,1 mm /2 = <u>60 µm</u>

[d] t = Value of the nominal thickness in the thinnest area of a part.

Example:

Thinnest area = 5 ±0,2 mm => t = 5

**Annex B**
**(Normative)**
**Witness Specimen Design**

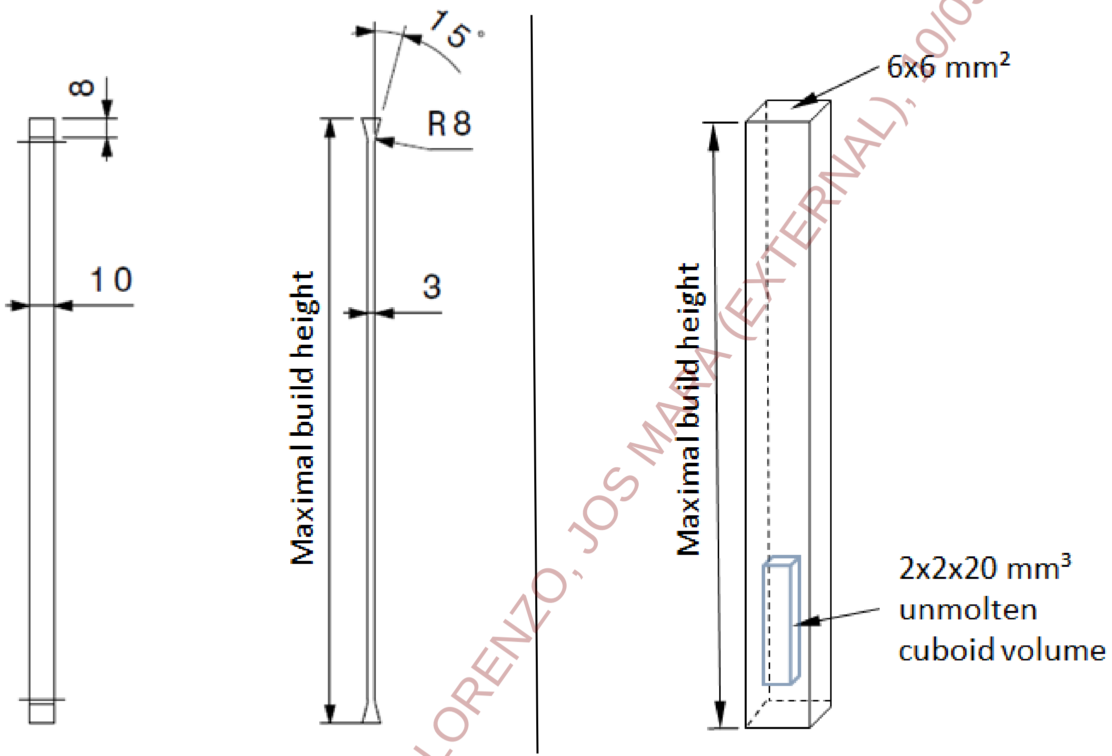



**Figure B.1: "Build Quality" witness specimen (left) and "Production Chain" witness specimen (right)**

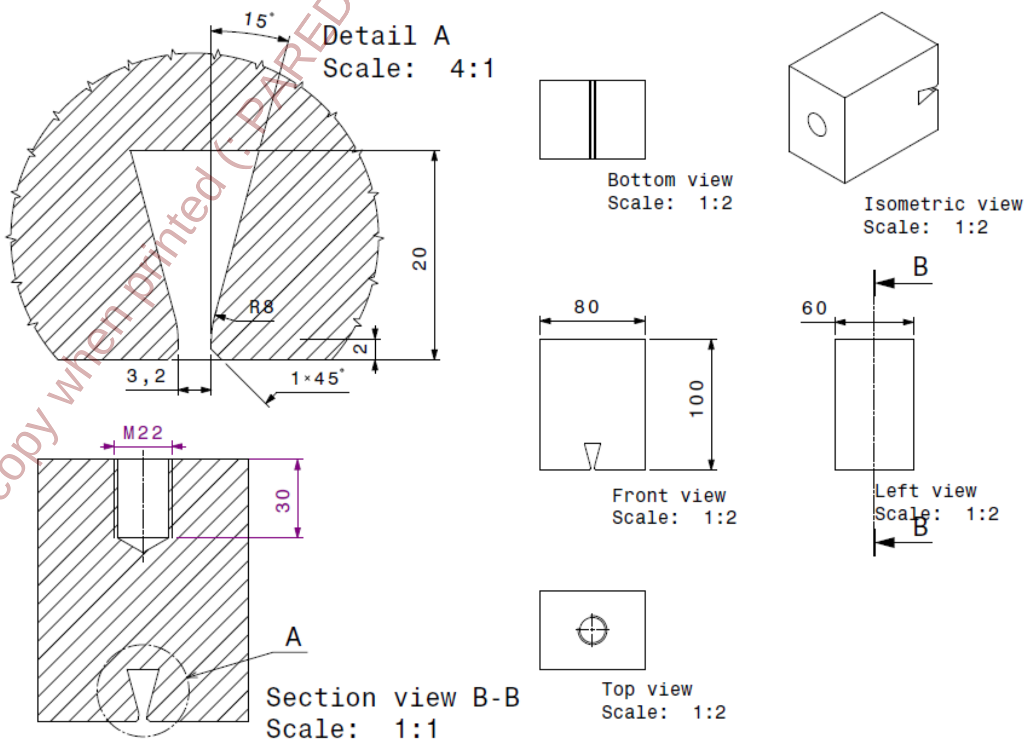



**Figure B.2: Design of the clamping device to test the "Build Quality" witness specimen**

## RECORD OF REVISIONS

| Issue | Clause modified | Description of modification |
|---|---|---|
| 1<br>11/15 | - | New standard. |
| 2<br>11/17 | Title | Change of title “Additive Manufacturing - Power Bed Fusion” to “Additive Manufacturing - Powder Bed Fusion of Metallic Materials” |
| | General | Update of all chapters against wording except chapter 9. |
| | §4.1 | Sub-chapter added |
| | §4.2 | Sub-chapter added |
| | §4.4.8 | Sub-chapter added |
| | §4.4.10 | Sub-chapter added |
| | §4.5 | Sub-chapter added |
| | §4.5.2 | Sub-chapter added |
| | §4.5.5 | Sub-chapter added |
| | §4.6 | Key characteristics and its test frequencies updated |
| | §8 | “Rework not applicable” added |
| | Table 3 | Table added |
| | Table 4 | Table added |
| | Table A.1 | Table updated |
| | Table A.2 | Table updated |
| | Annex B | Annex added |
| | | |