ANNEX I – Specifications

rev. 2021-07-28

Content

I.1. Print Job

The equipment supplier is required to comply with the following print job specifications.

Sections marked by an (*) describe advisory values. The supplier is requested to communicate the actual values used.

Number of print jobs

Each participating supplier is invited to complete one mandatory print job for the evaluation, using "ETN Powder" provided by the ETN consortium.
A second optional print job could also be submitted in agreement with the ETN consortium.
Cf. *Powder specifications* below for more details.

Geometries

Each print job should include **all** the following components on one platform:

(a) Part – heat shield
- IP-free design of a high criticality application: heat shield (cf. fig. 1)
- STL file is provided
- Support-free component
- Components stacking allowed
- Dimensions: 72.1 x 58 x 27.4 mm
- Number: 13
  - 6 tensile tests taken from heat shields (2 orientations and 3 tests per orientation)
  - 4 bend test specimens (3 normal + 1 corroded)
  - 3 specimens for metallographic assessment
  - *Note:* information regarding maximum number of components that can be fitted on the build tray will be requested
- Location and orientation: free, build plan and layout to be communicated to ETN (STL file of the build envelope)

(b) Charpy impact test specimen
- Specimen dimensions: 55 x 10 x10 mm (printed specimens with 60 x 12 x 12mm)
- STL file is provided
- Number: 10 (2 orientations and 5 tests per orientation)
- Location and orientation: To be agreed with ETN
- Standard reference: ISO 148-1 :2016 Metallic materials – Charpy pendulum impact test – Part 1: Test method

(c) Tensile test specimen:
- Dimensions : ø12 x 110mm
- STL file is provided
- Number: 6 (2 orientations and 3 per orientation)
- Location:
  - in overlap zones [stitching areas or multi-laser]
  - other: To be agreed with ETN
- Orientation(s): To be agreed with ETN

(d) Cubes for Archimedes relative density measurements
- Dimensions: 10 x10 x 10mm
- STL file is provided
- Number: 10
- Location: To be agreed with ETN

(e) Powder capsule for powder monitoring
- STL file is provided
- Number: 1

Material

Nickel Alloy 718 powder for laser powder bed fusion

Powder specifications

Note: 2-step approach - each participating supplier is invited to complete two print jobs:

Compulsory

(1) ETN powder: print job with powder batch of Oerlikon MetcoAdd 718C (*link to datasheet*), complying with ASTM F3055-14a and provided by the ETN consortium, to be used as provided.

Optional

(2) print job with powder batch selected by the supplier and complying with the ETN powder specifications below, or most suitable powder according to the supplier

ETN powder specifications:

- Chemical composition: ASTM F3055 - 14a
- Particle size range: Gaussian curve with max. 3%vol. <5µm
- Particle morphology: gas atomized process ensuring spherical shape (no quantitative criteria – machine dependent) without significant satellites
- Flowability: no quantitative criteria (machine dependent)
- Relative humidity level at delivery: <10%rH
- Recycling: no

Layer thickness

Participating suppliers may select a layer thickness parameter of either 40 µm or 60 µm.

Post-processing

- No post-processing can be applied by the equipment supplier, i.e. no part machining, heat treatment, HIPping or surface treatment. The build platform shall be delivered in as-built conditions to ETN.
  Note: if the supplier generally relies on HIPping to improve the final quality of the product, they should inform ETN.
- A stress release heat treatment will then be applied according to ASTM F3055-class F and ASTM 2774E – S1750DP (cf. fig. 2). This process will be carried out by a 3rd party on behalf of the ETN Consortium (selected 3rd party for testing).

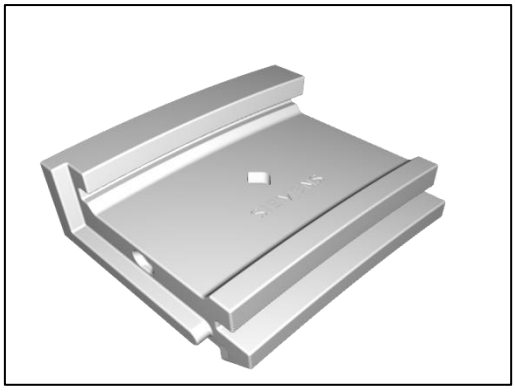

Figure 1 - Heat shield design, geometry (*a*)

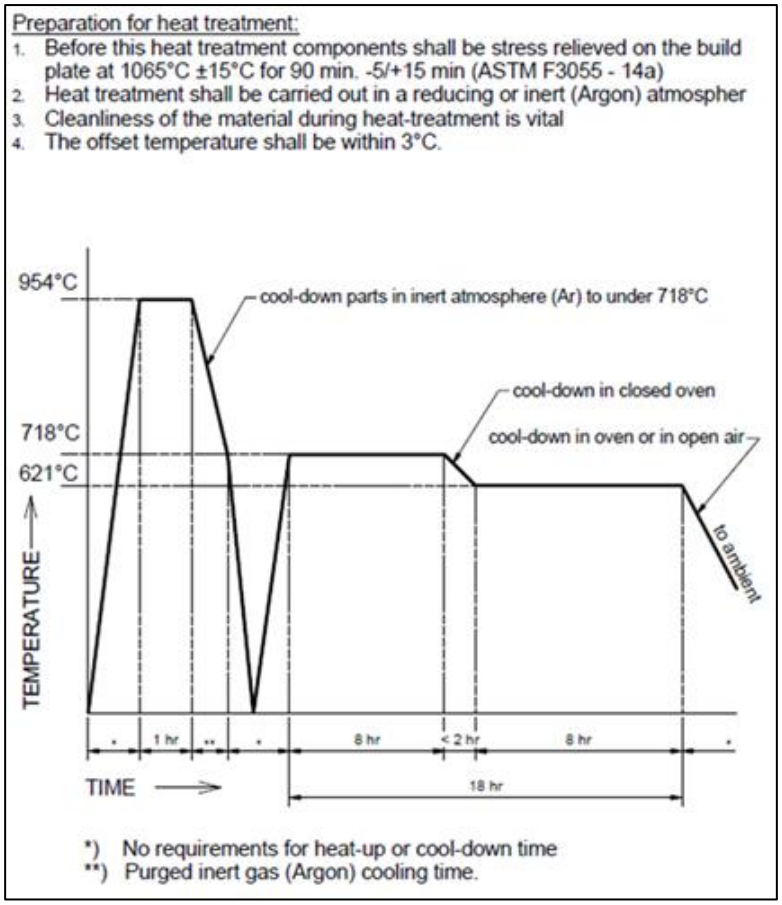

Figure 2 - Heat treatment for 3D printed Nickel Alloy 718, according to ASTM F3055-14a and AMS 2774E S1750DP

I.2. Print job log information

The equipment supplier is required to provide the following log information relating to the print job.

Log information

- Log print file listing all key print events, including but not limited to:
  - error messages;
  - O_2 content;
  - platform temperature;
  - all quality monitoring data that could be part of a QA/QC approach (layer control system/powder bed pictures, melt pool data...);
  - location & orientation of all specimen.
- Time
  - Preparation time, broken down by preparation steps
  - Effective print time (laser on – laser off)
  - Depowdering time of the specified components (cf. above)
- Supplier to clarify: standard output information

I.3. Equipment technical documentation

The equipment supplier is required to provide the following information:

Equipment

- Model
- Process basics
  - Machine handling including usability & preparation as well as change over time;
  - Ergonomics
  - Layer thickness options available
  - Re-coater times
  - Bulk parameters, contour parameters, powder utilization / losses
- Material portfolio
  - Variety of materials available for the machine
  - Availability of standard parameters sets per material
  - Allowed powder suppliers
- Build envelope
  - Dimensions
  - Maximum part size
  - Maximum number of test components – cf. Geometry (a) – that can be printed in this envelope at one print job (components stacking allowed)
  - Information regarding exclusion zones in relation to overlap of lasers
- Digital integration & data access
  - Standard interfaces & machine openness
  - List of influenceable variables
- Availability of quality monitoring system
- Number of power sources (multi-laser allowed)
- Cost range of one machine:
  - Hardware cost,
  - Maintenance cost,
  - Service costs,
  - Max running hours,
  - Guaranteed uptime.

Powder technical documentation

- Product Code
- Vendor's material common name
- Batch Number
- Production process and atomization gas
- Quantity (in kg)
- Chemical composition
- Particle size distribution (in vol.%, D10, D50, D90)
- Representative optical microscopy micrographs of
- Flowability (Hall Flow and static angle of repose)

I.4. Timeline

Timeline

Current timeline proposal, after collaboration agreements are signed:

Action	*Duration*	*Expected delivery*
NDA signature between all parties and ETN	4 weeks	August 2021
Parts production	6 weeks	October 2021
Testing program – carried out by independent laboratory	4 weeks	Early December 2021
Final report: results consolidation and documentation – carried out by the third-party coordinator	3 weeks	End December 2021
Communication of results	n.a.	January 2022

I.5. Standards References

F3055 - 14a	Standard Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion	link
ISO 148-1	Metallic materials – Charpy pendulum impact test – Part 1: Test method	link
AMS 2774E	Heat Treatment Wrought Nickel Alloy and Cobalt Alloy Parts	link

ANNEX II – Assessment Criteria

Content

II.1. Key Performance Indicators

The equipment evaluation will be based on the following KPIs defined by ETN.

Process basics - Machine handling incl. usability & preparation as well as change over time; - Ergonomics, layer thickness, re-coater times, bulk parameters, contour parameters, powder utilization / losses
Material portfolio - Variety of materials including standard parameter sets available for machine; - Single source vs. multiple suppliers
Build Envelope - in x/y/z determining maximal part size, that can be fitted on the build tray and productivity (maximum number of parts that can be printed in this envelope at one print job)
Digital integration & data access - standard interfaces & machine openness / influenceable variables
Quality - Manufactured part: observed defects, geometry, microstructure & mechanical performance
Productivity - Simulation & experiment in terms of time & costs per part (e.g., maximum number of parts that can be printed in the envelope at one print job, incl. with components stacking)
Transferability - of frozen build parameter sets from one machine to other of same type, same supplier, same technology
Costs - Cost for printed part, CapEx & OpEx

II.2. Testing program

Test methods shall comply with ASTM F3055-14a and additional references listed under II.3

The testing scope will involve a mixed approach covering three levels of testing:

1. Build Process Qualification Testing : Machine + material + parameters
2. Production Testing : test specimens included in the print job, printed together with the test component(s)
3. Part Qualification Testing.

Mechanical Testing		
Testing	***Comment***	***Geometry***
Tensile testing at room temperature	- Longitudinal and transversal direction extracted from the component - Yield strength, ultimate tensile strength, elongation and Young modulus - Based on 6 tensile test specimens (2 orientations and 3 tests per orientation) and 6 tensile tests taken from heat shield (2 orientations and 3 tests per orientation)	From heat shield and tensile specimens
Bend testing	- Longitudinal and transversal direction extracted from the component - Identification of defect or crack indication presenting a critical size of 3mm after testing - Based on 3 specimens (10mm thickness) taken from a heat shield	From heat shield
Bend test after corrosion test	- ASTM A262 Practice B – "The Streicher Test" for corrosion test only, no bend test afterwards (one test)	From heat shield
Charpy impact testing at room temperature	- Spread in absorbed energies over the platform - Based on 10 Charpy impact test specimens (2 orientations and 5 tests per orientation)	From Charpy impact test specimen
Hardness measurement at room temperature	- Measurements in bulk area and close to surface (fill contours) - Spreadability along track lines (bulk and sub-surface areas) - Based on 16 measurements	From heat shield
Archimedes relative density measurements	- Based on measurements on 10 cubes, incl. cutting of cubes from bars	From witness bars
Powder capsule characterisation	- Chemical composition (incl. Trace elements) - Particle size distribution by laser scattering - Particle morphology by image analysis via scanning electron microscopy - Flowability: Hall flow, static angle of repose, dynamic angle of repose, tap density and compacity curve	From powder capsule

Metallurgical analysis and NDT		
Testing	***Comment***	***Geometry***
Destructive examination by optical microscopy	Metallographic examination of the constitution and structure: - Microstructure bulk material - Microstructure sub-surface - Cracking at connections points - Porosity assessment (size, distribution, morphology and location): bulk and sub-surface porosities, and specific locations such as interface between part and support structures connection to platform - Grain size - Scanning track assessment	From heat shield
Destructive examination by scanning electron microscopy	- Microstructure bulk material - Microstructure sub-surface - Statistics on pores (morphology and location)	From heat shield

Surface / Volumetric NDT	- Number, location and size of surface-breaking flaws [red dye penetrant]
	- Number, location and size of sub-surface flaws [ultrasonic & eddy current]
	- Geometrical deviation from CAD model [CT scanning]
	  o Thin wall features
	  o Down-facing surface quality
	  o Overall distortion
	- Roughness Ra & Sa on various face orientations
		From heat shield

II.3. Standards References

F3049 - 14	Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes	link
F3055 - 14a	Standard Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion	link
ISO / ASTM52904 - 19	Additive Manufacturing – Process Characteristics and Performance: Practice for Metal Powder Bed Fusion Process to Meet Critical Applications	link
F2971 - 13	Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing	link
F3122 - 14	Standard Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes	link
ISO / ASTM52907 - 19	Additive manufacturing — Feedstock materials — Methods to characterize metallic powders	link
ASTM A262 - 15	Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels	link

Note

As the standard F3055 - 14a only provides the minimum tensile properties of PBF Nickel Alloy 718 at room temperature, the Special Metals datasheet for conventionally produced Inconel 718 will be referred to for guidance or information on targeted mechanical requirements not covered by F3055 - 14a. [link]