

Additively Manufactured Metallic Components for Use in the Petroleum and Natural Gas Industries

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Additively Manufactured Metallic Components for Use in the Petroleum and Natural Gas Industries

1 Scope

1.1 Purpose

This standard specifies requirements for qualification of the manufacturing process, production, marking, and documentation of additively manufactured metallic components used in the petroleum and natural gas industries when referenced by an applicable API equipment standard or otherwise specified as a requirement for conformance. The qualification process flowchart is shown in Figure 1.

1.2 Applicability

This standard applies to additively manufactured metallic components produced by powder bed fusion (PBF), directed energy deposition (DED), and binder jetting (BJT) processes.

1.3 Additive Manufacturing Specification Levels (AMSL)

This standard establishes requirements for three additive manufacturing specification levels (AMSL). These three AMSL designations—AMSL 1, AMSL 2, and AMSL 3—define increasing levels of additive manufacturing technical, quality, and qualification requirements.

NOTE An AMSL can be assigned to a component by a product specification or standard, the purchaser, or the manufacturer.

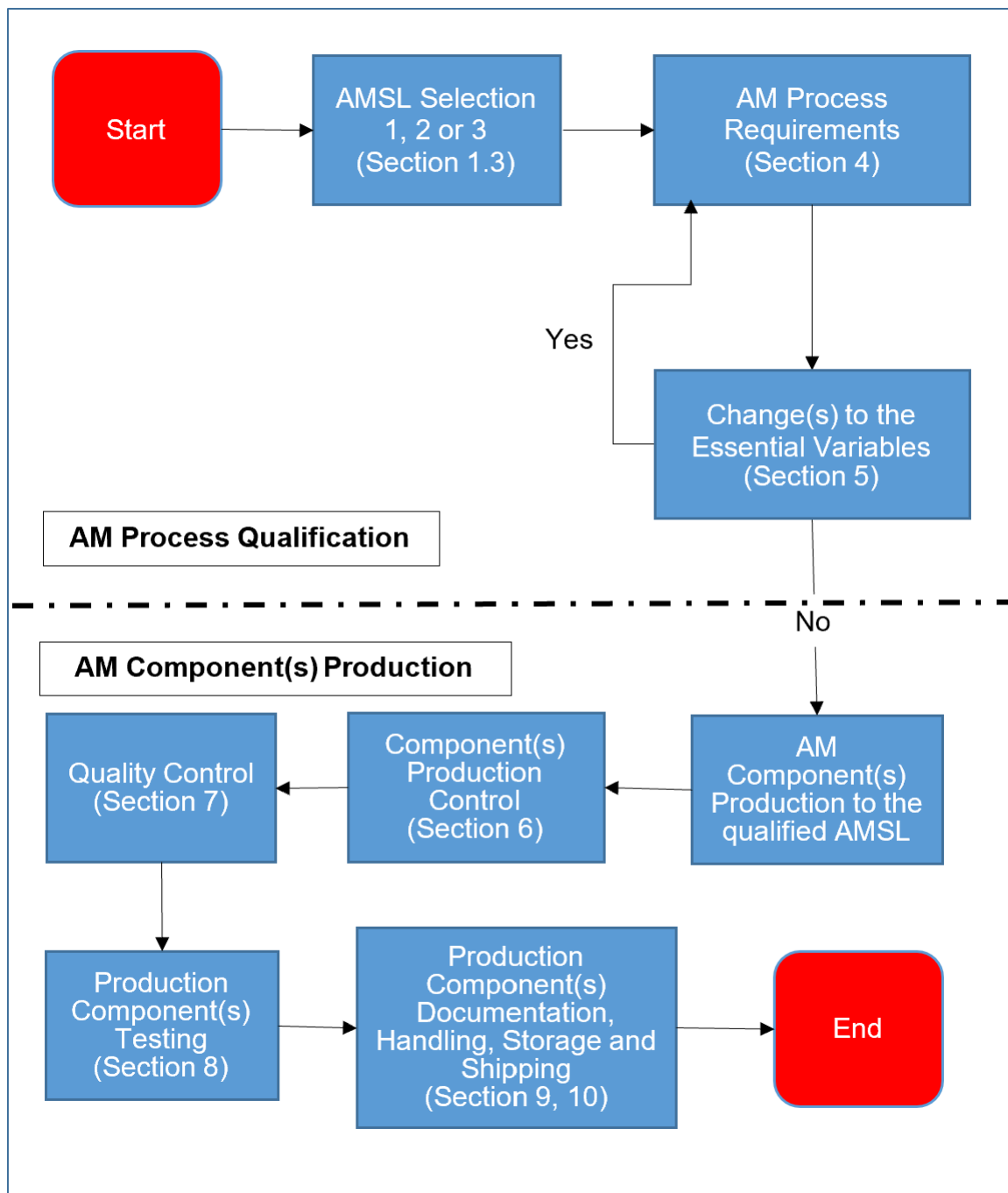


Figure 1—Qualification Process Flowchart

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Specification Q1, *Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry*

API 6A, *Specification for Wellhead and Tree Equipment*

ANSI¹ /ASQ Z1.4,² *Sampling Procedures and Tables for Inspection by Attributes*

ASTM A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

ASME³ BPVC, Section II—Materials, Part C—Specifications for Welding Rods, Electrodes, and Filler Metals

ASTM⁴ B294, *Standard Test Method for Hardness Testing of Cemented Carbides*

ASTM B311, *Standard Test Method for Density of Powder Metallurgy (PM) Materials Containing Less Than Two Percent Porosity*

ASTM B406, *Standard Test Method for Transverse Rupture Strength of Cemented Carbides*

ASTM B611, *Standard Test Method for Determining the High Stress Abrasion Resistance of Hard Materials*

ASTM B771, *Standard Test Method for Short Rod Fracture Toughness of Cemented Carbides*

ASTM B962, *Standard Test Methods for Density of Compacted or Sintered Powder Metallurgy (PM) Products Using Archimedes' Principle*

ASTM E8, *Standard Test Methods for Tension Testing of Metallic Materials*

ASTM E9, *Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature*

ASTM E10, *Standard Test Method for Brinell Hardness of Metallic Materials*

ASTM E18, *Standard Test Methods for Rockwell Hardness of Metallic Materials*

ASTM E23, *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E92, *Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials*

ASTM E140, *Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness*

ASTM E228, *Standard Test Method for Linear Thermal Expansion of Solid Materials with a Push-Rod Dilatometer*

ASTM E384, *Standard Test Method for Microindentation Hardness of Materials*

ASTM E1461, *Standard Test Method for Thermal Diffusivity by the Flash Method*

ASTM G65, *Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus*

ASNT⁵ SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*

¹ American National Standards Institute, 1899 L Street, NW, Washington, DC 20036, www.ansi.org.

² American Society for Quality, 600 North Plankinton Avenue, Milwaukee, Wisconsin 53203, www.asq.org.

³ American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016, www.asme.org.

⁴ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

⁵ American Society for Nondestructive Testing, PO Box 28518, 1711 Arlingate Lane, Columbus, Ohio 43228, www.asnt.org.

EN⁶ 10204, *Metallic products — Types of inspection documents*

ISO⁷ 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

ISO 6506, *Metallic materials — Brinell hardness test (parts 1 through 4)*

ISO 6507, *parts 1 through 4, Metallic materials — Vickers hardness test (parts 1 through 4)*

ISO 6508, *parts 1 through 3, Metallic materials — Rockwell hardness test (parts 1 through 3)*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

ISO 9001, *Quality management systems — Requirements*

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 18265, *Metallic materials — Conversion of hardness values*

ISO 28079, *Hardmetals — Palmqvist toughness test*

ISO/ASTM 52900, *Additive manufacturing — General principles — Terminology*

ISO/ASTM 52921, *Standard Terminology for Additive Manufacturing — Coordinate Systems and Test Methodologies*

ISO 80000-1, *Quantities and units — Part 1: General*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the terms and definitions given in ISO/ASTM 52900 and the following apply. Where identical terms and definitions are given, the terms and definitions provided in this specification supersede the terms and definitions contained in ISO/ASTM 52900.

3.1.1

acceptance number

The acceptance number is the maximum number of defects or defective units in the sample that will permit acceptance lot or batch.

3.1.2

binder

Liquid bonding agent or glue used in the binder jetting process for holding metal particles together.

3.1.3

build

See “build cycle” in ISO/ASTM 52900.

3.1.4

by agreement

Agreed between manufacturer and purchaser.

⁶ European Committee for Standardization, Rue de la Science 23, B – 1040 Brussels, Belgium, www.cen.eu.

⁷ International Organization for Standardization, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, www.iso.org.

3.1.5**certificate of conformance**

A document containing the statement by the additive manufacturer certifying that the component(s) meets the requirements of this standard.

3.1.6**cleaner**

A liquid cleaning agent used in the binder jetting process to maintain the quality of the print head jets (removing excess binder).

3.1.7**component build file**

A file that defines the geometry, arrangement of the components, witness specimens, and support structures, as applicable, that will be built by a piece of printing equipment. This file will be converted to printing instructions.

3.1.8**hard metal**

Material manufactured with binder jetting that typically combines a softer metallic phase and harder ceramic phase to create a harder wear-resistant material. The harder phase can either be incorporated in the green stage or introduced in situ.

3.1.9**live setter**

A setter made from the same material as the finished part.

3.1.10**metallic**

A material that contains metal elements as the majority of the composition (by weight or by atomic percentage).

3.1.11**on-site**

The additive manufacturer's facility.

3.1.12**printing equipment**

See "AM Machine" in ISO/ASTM 52900.

3.1.13**procedure**

An organization's documented method for performing an activity under controlled conditions to achieve conformity to specified requirements.

3.1.14**process consumables**

Material inputs to the additive manufacturing process that are specified in accordance with the component being manufactured (e.g., feedstock, binder, substrate, gas) as applicable to the process used.

3.1.15**production lot**

All components of the same build with the same thermal post-processing.

3.1.16**removable components**

Items that are removed or replaced as part of the manufacturing process (e.g., build platform, recoater blade).

3.1.17**scaling strategy**

Adjusting the component size by a percentage in the x, y, and z dimensions of a part to accommodate the anisotropic effects in printing that occur during the sintering of the material in the binder jetting process.

3.1.18**serviceable components**

Items that are removed/replaced/cleaned as part of a maintenance event (e.g., filters, lenses, laser).

3.1.19**setter**

A fixture used in the furnace to control unwanted distortion caused by gravity of the part during sintering.

3.1.20**substrate**

The surface onto which the initial layer of feedstock is deposited. This may be a build platform (e.g., for powder bed fusion), a surface that becomes an integral portion of the component, or a surface of an existing component (e.g., for DED).

3.2 Acronyms and Abbreviations

For purposes of this standard, the following abbreviations apply.

AM	additive manufacturing
AMF	additive manufacturing file format
AMSL	additive manufacturing specification level
BJT	binder jetting
CAD	computer-aided design
CT	computed tomography
CVN	Charpy V-notch
DED	directed energy deposition
DPD	digital product definition
EB	electron beam
HIP	hot isostatic pressing
IGES	initial graphics exchange specification
LB	laser beam
NDE	nondestructive examination
MPS	manufacturing process specification
OEM	original equipment manufacturer
PBF	powder bed fusion
QMS	quality management system
STEP	standard for the exchange of product model data
STL	standard triangle language
3MF	3-D manufacturing format

4 Requirements for the Additive Manufacturing Process

4.1 General

This standard gives the requirements for three additive manufacturing specification levels (AMSL). The AMSLs are numbered in increasing levels of severity from 1 to 3 to reflect increasing technical, quality, and qualification criteria. This section describes the conditions that, when met, allow the additive manufacturing process to receive the appropriate AMSL classification.

When additively manufactured metallic components are ordered to an API product specification or API product standard, the API product specification or API product standard shall take precedence over this standard as long as the requirements of the API product specification or API product standard meet or exceed the minimum requirements set forth in this standard.

4.2 Additive Manufacturer Requirements

4.2.1 General

For all AMSLs, the additive manufacturer shall implement and maintain required controls to ensure products and services meet specified requirements and shall conform with the requirements of 4.2 and its subsections.

4.2.2 Additive Manufacturer Quality Management System (QMS)

The additive manufacturer shall establish, document, implement, and maintain, at all times, a QMS and associated processes. The QMS shall be in conformance with either API Specification Q1 or ISO 9001.

4.2.3 Quality Control Procedures

All quality control activities shall be controlled by the additive manufacturer's documented procedures, which include appropriate methodology and acceptance criteria.

NDE procedures shall be detailed regarding the requirements of all applicable nationally or internationally recognized standards specified by the additive manufacturer. All NDE procedures shall be approved by a Level III examiner qualified in accordance with ASNT SNT-TC-1A or ISO 9712 in the specified discipline.

4.2.4 Technical Review Requirements

The additive manufacturer shall maintain procedure(s) to ensure that technical requirements are reviewed prior to acceptance of the order.

The additive manufacturer shall maintain records of this review, including:

- applicable purchaser or governing design and/or construction specifications/standards;
- deviations from governing design and/or construction specifications/standards;
- material specifications;
- acceptance criteria;
- qualification of procedures;
- qualification of personnel;
- qualification of printing equipment;

- outsourced services;
- inspection and testing requirements, including third-party verification;
- identification and traceability;
- post-processing requirements.

4.2.5 Personnel Training and Competency Requirements

Personnel shall be competent to carry out assigned tasks and responsibilities based on the appropriate education, training, skills, and experience needed to meet product and purchase order requirements. The additive manufacturer shall maintain a written procedure that defines personnel competency and identifies training and qualification requirements.

The additive manufacturer shall identify:

- knowledge and training necessary to address specific requirements;
- qualifications required for personnel performing processes that require validation;
- method(s) used to verify the competency of personnel.

The additive manufacturer shall maintain evidence of conformity to the above requirements.

4.2.6 Non-destructive Examination Personnel Requirements

Personnel performing NDE shall be qualified in accordance with the additive manufacturer's documented training program that is based on the requirements specified in the following:

- ISO 9712; or
- ASNT SNT-TC-1A; or
- a national or international standard that is equivalent to ISO 9712 or ASNT SNT-TC-1A.

NDE Level I or Level II personnel shall be qualified by NDE Level III personnel in the specified discipline.

4.2.7 Inspection Personnel Requirements

Personnel performing visual inspection for acceptance shall take and pass an annual vision examination in accordance with the additive manufacturer's documented procedure that is based on the requirements specified in the following:

- ISO 9712; or
- ASNT SNT-TC-1A; or
- a national or international standard that is equivalent to ISO 9712 or ASNT SNT-TC-1A.

4.2.8 Other Personnel Requirements

All other personnel performing measurements, inspections, or tests for acceptance shall be qualified in accordance with the additive manufacturer's documented procedures and requirements.

4.2.9 Facility Requirements

The additive manufacturer shall have on-site equipment and personnel to perform the required processes needed to produce the components under the scope of this standard as identified below:

- equipment to perform required printing activities (excluding post-processing activities);
- storage and usage of the process consumables and equipment in accordance with the requirements of this standard;
- appropriate handling and lifting equipment (as applicable);
- inspection and test equipment (as applicable).

4.2.10 Monitoring and Measuring Equipment Requirements

Instruments used to measure and control critical process variables during the additive manufacturing process, including all post-processing activities, shall be serviced and calibrated in accordance with written specifications.

Equipment used to inspect, test, or examine material or other equipment shall be identified, controlled, calibrated, and adjusted at specified intervals in accordance with documented instructions, and consistent with nationally or internationally recognized standards, to maintain the accuracy required by this standard.

4.3 Feedstock Requirements

4.3.1 Feedstock Suppliers

The feedstock supplier shall maintain a quality management system that, at a minimum, conforms to ISO 9001.

4.3.2 Feedstock Material

4.3.2.1 General

The additive manufacturer shall maintain feedstock specifications that include, at a minimum, the requirements listed in the subsections below.

4.3.2.2 Powder Feedstock

Virgin powder feedstock requirements shall be defined by powder specifications. Testing methodologies shall be defined and in accordance with internationally recognized standards or specifications (e.g., ISO/ASTM 52907). At a minimum, the feedstock specification shall address:

- alloy and/or grade designation;
- chemical composition;
- particle size distribution;
- density;
- flow properties;
- method of powder manufacture;
- storage, preservation, and handling requirements;
- certification requirements.