Development of AWS D20.1/D20.1M, *Specification for Fabrication of Metal Components using Additive Manufacturing*

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AWS D20 COMMITTEE ON ADDITIVE MANUFACTURING

- **Charter:** Create a standard containing requirements for fabricating metal components using AM that, when adhered to, will result in the repeatable production of metal AM components that meet functional requirements

- **Result:** AWS D20.1/D20.1M:2019, *Specification for Fabrication of Metal Components using Additive Manufacturing*

AWS D20.1/D20.1M – PROCESSES COVERED

Table 1.1
Additive Manufacturing Processes

Process	Abbreviation
Laser Powder Bed Fusion	L-PBF
Electron Beam Powder Bed Fusion	EB-PBF
Laser Directed Energy Deposition	L-DED
Electron Beam Directed Energy Deposition	EB-DED
Plasma Arc Directed Energy Deposition	PA-DED
Gas Tungsten Arc Directed Energy Deposition	GTA-DED
Gas Metal Arc Directed Energy Deposition	GMA-DED

AWS D20.1/D20.1M - COMPONENT CLASSIFICATION

AWS D20.1 contains graded requirements for qualification and inspection based on the classification of the AM component. (1.4)

- **Class A** – Critical application. A component whose failure would cause significant danger to personnel, loss of control, loss of a system, loss of a major component, or an operating penalty.
- **Class B** – Semi-critical application. A component whose failure would reduce the overall strength of the equipment or system or preclude the intended functioning or use of equipment, but loss of the system or the endangerment of personnel would not occur.
- **Class C** – Noncritical application. A component whose failure would not affect the operation of the system or endanger personnel.

AWS D20.1/D20.1M:2019
CLAUSES

1 General Requirements

2 Normative References

3 Terms and Definitions

4 Design Requirements for Additively Manufactured Components

5 Additive Manufacturing Machine and Procedure Qualification

6 Additive Manufacturing Machine Operator Performance Qualification

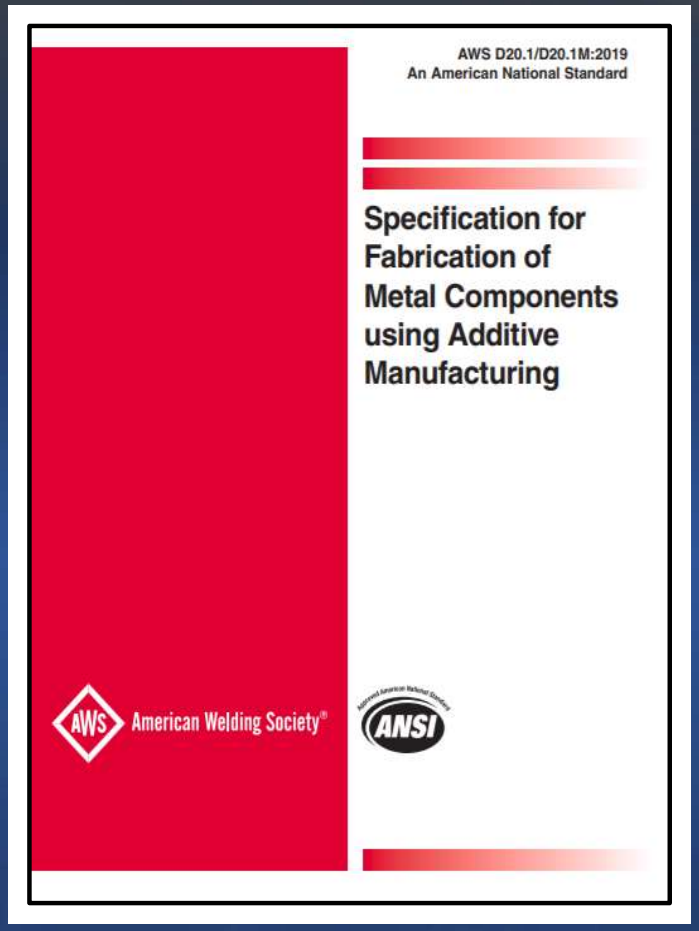
7 Fabrication

8 Inspection

AWS D20.1/D20.1M:2019
ANNEXES

A	Additive Manufacturing Qualification Records
B	Informative References
C	Examples of Standard Qualification Build Designs for Powder Bed Fusion
D	Suggested Format for Fabrication Records
E	Process Flowcharts for Producing Components using AWSD20.1/D20.1M
F	Requesting an Official Interpretation on an AWS Standard

Also contains: Commentary on the Specification for Fabrication of Metal Components using Additive Manufacturing



AWS D20.1/D20.1M
DESIGN REQUIREMENTS - CLAUSE 4

The Engineer is required to design and define component requirements to ensure compliance with all functional and system requirements. Responsibilities include:

- Develop or obtain appropriate material property requirements to satisfy the component design. (4.2)
- Design witness specimens for Class A and Class B PBF component builds. (4.3)
- Define component classification level, final dimensions, process restrictions, post-processing requirements, etc. (4.4)

AWS D20.1/D20.1M
MACHINE AND PROCEDURE QUALIFICATION – CLAUSE 5

As in the welding industry, qualification is achieved through the successful fabrication, inspection, and testing of material representative of the production component.

- Procedure Qualification Record (PQR) and Machine Qualification Record (MQR) required to document variables used during qualification builds. (5.1.1) Example records for each process provided in Annex A.
- Additive Manufacturing Procedure Specification (AMPS) must be qualified prior to fabrication of production components. Includes: AM process, component classification, build model file name, all applicable build platform, feedstock, machine, environment, build parameters, and post-processing information. (5.1.2)

AWS D20.1/D20.1M
MACHINE AND PROCEDURE QUALIFICATION

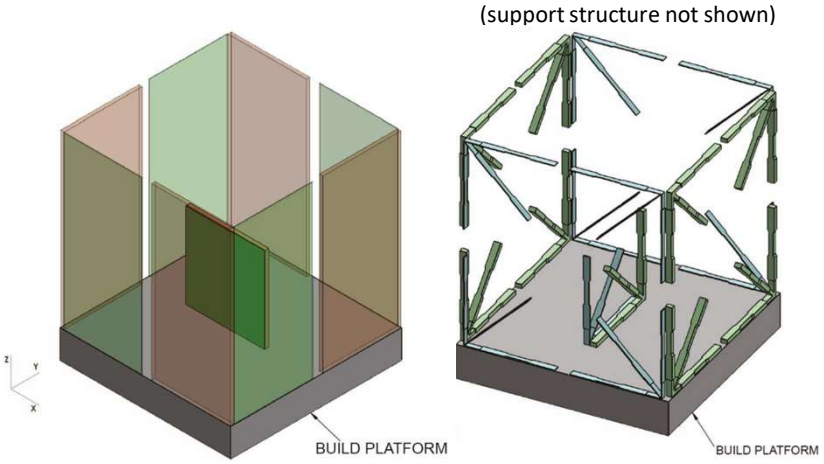
Table 5.1
Inspection and Testing Requirements for Machine and Procedure Qualification

Test Method		Powder Bed Fusion			Directed Energy Deposition		
		Class A	Class B	Class C	Class A	Class B	Class C
Machine Qualification Standard Qualification Build(s)	Visual Examination	Yes	Yes	—	Yes	Yes	—
	Dimensional Inspection	Yes	Yes	—	Yes	Yes	—
	Radiographic Examination	Yes	Yes	—	Yes	Yes	—
	Density Testing	Yes	Yes	—	Yes	Yes	—
	Tension Tests	54	54	—	9	9	—
	Metallographic Examination	Yes	Yes	—	Yes	Yes	—
Procedure Qualification Preproduction Test Build(s)	Visual Examination	Yes	Yes	Yes	Yes	Yes	Yes
	Dimensional Inspection	Yes	Yes	Yes	Yes	Yes	Yes
	Penetrant Testing	Yes	Yes	—	Yes	Yes	—
	Radiographic Examination	Yes	Yes	—	Yes	Yes	—
	Density Testing	Yes	Yes	Yes	Yes	Yes	Yes
	Tension Tests (Witness Specimens)	3	1	—	—	—	—
	Tension Tests (Component)	3	3	—	3	3	—
	Metallographic Examination	Yes	Yes	Yes	Yes	Yes	Yes
	Chemical Analysis	Yes	Yes	—	Yes	Yes	—

AWS D20.1/D20.1M
PBF MACHINE QUALIFICATION

PBF machine qualification requires a “standard qualification build” with 54 tension test specimens (minimum), representative of the component in the following ways:

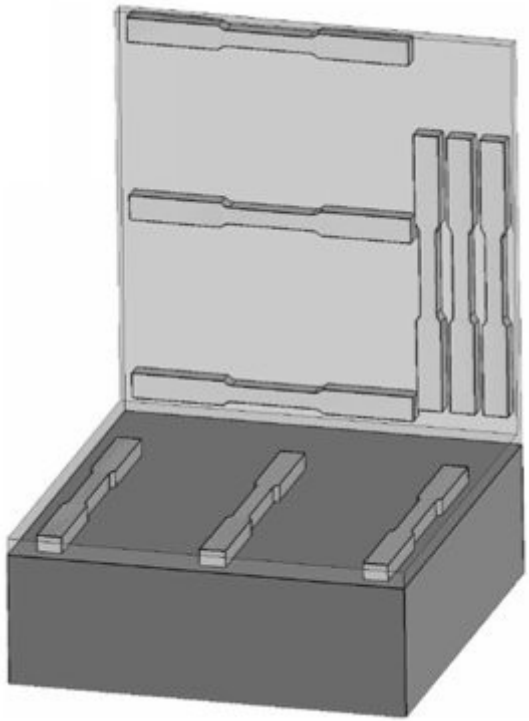
- Thick and thin specimens shall be fabricated to represent a range of component feature geometries. (5.2.1.1)
- Specimen orientations shall include tensile axis within the X-Y plane, along the Z-axis, and at 45° from the Z-axis. (5.2.1.2)
- Specimens shall encompass the build volume to be used during component fabrication. (5.2.1.2)
- Dimensional inspection features shall be included in the build. (5.2.1.1)



AWS D20.1/D20.1M
DED MACHINE QUALIFICATION

DED machine qualification requires a “standard qualification build” from which a minimum of 9 tension test specimens can be removed.

- The build shall provide material with heat sink conditions representative of the component, with vertical and horizontal plane conditions at a minimum. (5.2.2.1)
- Dimensional inspection features shall be included in the build. (5.2.2.1)
- Three additional tension test specimens required across interface for components with integrated build platform. (5.2.3.2)



AWS D20.1/D20.1M
AM PROCEDURE QUALIFICATION

For PBF and DED components, AM procedure qualification requires fabrication and testing of a “preproduction test build,” which shall:

- Be fabricated from the same build file as will be used for the production component (i.e., shall have identical geometry to the production component, including witness specimens). (5.2.3)
- Undergo the same post-processing steps (e.g., surface finishing, thermal processing) as will be used for the production component. (5.2.3)
- Be fabricated using the same parameters as will be used for the production component, aside from changes within qualified limits. (5.2.3)

AWS D20.1/D20.1M
QUALIFICATION LIMITS

Table 5.2
Qualification Variables for Powder Bed Fusion Processes

Qualification Variables for Powder Bed Fusion	PBF L	PBF EB
5.4.1 Build Design		
(1) Build model. Any change to the build model.	P	P
(2) Component classification. Any increase in component classification (i.e., from Class C to Class B or Class A, or from Class B to Class A).	Q	Q
5.4.2 Material		
(1) Feedstock specification and classification. Any change in feedstock specification or classification (e.g. group, type, or class), form, or feedstock manufacturing process.	Q	Q
(2) Powder composition. (sampling per 7.4.2.3) Any change beyond the specified tolerances established by the Engineer and Contractor for the powder specification in terms of chemical composition.	Q	Q
(3) Particle size distribution. (sampling per 7.4.2.3) Any change beyond the specified tolerances established by the Engineer and Contractor for the powder specification in terms of particle size distribution.	Q	Q
(4) Rheological performance. (sampling per 7.4.2.3) Any change beyond the specified tolerances established by the Engineer and Contractor for the powder specification in terms of rheological performance.	Q	Q
(5) Build platform material specification and classification. Any change in build platform material specification or classification (e.g. group, type, and/or class) or form.	P	P
(6) Build platform thickness. A change in build platform thickness by ±10%.	P	P

AWS D20.1 lists all qualification variables for PBF (Table 5.2) and DED (Table 5.3) processes, along with the changes to each variable that require requalification of the AM machine (M), AM procedure (P), or both (Q).

Sections include Build Design, Material, Machine, Environment, Heat Source Characteristics, Deposition Characteristics, and Post-Processing.

AWS D20.1/D20.1M
MACHINE OPERATOR PERFORMANCE QUALIFICATION – CLAUSE 6

AM machine operators must be capable of repeatedly fabricating acceptable AM components. Qualification is achieved through training, practical examination, and a completion of a demonstration build (6.3).

Training topics include (6.3.2.1):

- Feedstock material storage, safety, and setup.
- Cleaning requirements and environmental controls.
- Machine calibration, preventative maintenance, and safety.
- Loading of qualified build parameters.
- Running and monitoring AM build cycles.
- Recording AM build cycle data.
- Common build defects, their causes, and means of prevention.
- Recovery from planned and unplanned build interruptions.

AWS D20.1/D20.1M
FABRICATION OF AM PARTS - CLAUSE 7

Clause 7 identifies various fabrication controls requirements

- Digital control plan (7.2)
- Preproduction maintenance checklist (7.3)
- Equipment calibration control plan (7.3.1)
- Identification and traceability controls (7.4.1)
- Cleaning (7.4.2.1)
- Build platform dimensions (thickness, surface finish, parallelism) (7.4.2.2)
- Feedstock specification and powder recycling (7.4.2.3)
- Feedstock change plan (7.4.2.4)
- Preheat and interpass temperature controls (7.5)
- Contamination control (7.6.1)
- Gas specification (7.6.2)

AWS D20.1/D20.1M
FABRICATION OF AM PARTS

Clause 7 identifies various fabrication controls requirements

- Use of qualified AMPS (7.7)
- Planned and unplanned build interruptions (7.8)
- In-process adjustments or modifications (7.9, 7.13)
- Witness specimens (7.10)
- Component identification (7.11)
- Build acceptance (7.12)
- Post-build processing (7.14)
- Records requirements (7.15)

AWS D20.1/D20.1M
INSPECTION OF AM PARTS – CLAUSE 8

Clause 8 contains inspection, testing, and acceptance requirements for qualification builds, production components, and witness specimens:

- Qualification of inspection personnel. (8.1)
- Nondestructive examination (NDE) requirements and acceptance:
  - Visual examination (8.2.1), dimensional examination (8.2.2), penetrant testing (PT) (8.2.3), magnetic particle testing (MT) (8.2.4), radiographic testing (RT) (8.2.5), density testing (8.2.6)
- Destructive evaluation requirements and acceptance:
  - Tension testing (8.3.1), metallographic examination (8.3.2), chemical analysis (8.3.3)

CONCLUSIONS

- AWS D20.1/D20.1M:2019 provides comprehensive design, qualification, fabrication, and inspection requirements for metal components using PBF and DED AM processes.
- Extensive testing and evaluation are required to ensure that AM parts will be produced with acceptable, repeatable properties.
- Potential material variability related to build orientation, thickness, and surface roughness demonstrates the importance of testing material representative of component features.
- Standardized test article builds using representative material provide a repeatable means for detecting quality concerns and sources of microstructural and mechanical property variability.