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Standard Specification for Additive Manufacturing – Finished Part Properties – Maraging Steel via Powder Bed Fusion[1]

This standard is issued under the fixed designation F3607; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers additive manufacturing of parts via full-melt laser beam powder bed fusion (PBF-LB) processing of maraging steel alloys. Parts made using this processing method are typically used in applications that require mechanical properties similar to wrought products, either as fabricated or heat treated. Products built to this specification may require additional post-processing in the form of machining, polishing, etc., to meet necessary surface finish and dimensional requirements.

1.2 Maraging steel (MS) is a class of precipitation hardened steel, where aging heat treatment is used to form precipitates and, consequently, achieve significantly increased hardness and strength. This specification focuses specifically on 300 grade maraging steel, which corresponds to UNS K93120 and EN1.2709. MS grade 300 has higher concentrations of cobalt and titanium than lower grades.

1.3 This specification is intended for the use of purchasers or producers, or both, of additively manufactured maraging steel parts for defining the requirements and ensuring part properties.

1.4 Users are advised to use this specification as a basis for obtaining parts that will meet the minimum acceptance requirements established and revised by consensus of committee members.

1.5 User requirements considered more stringent may be met by the addition to the purchase order of one or more supplementary requirements, which include, but are not limited to, those listed in Supplementary Requirements in Sections S1 to S3.

1.6 The values stated in SI units are to be regarded as standard. All units of measure included in this guide are accepted for use with the SI.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A262 Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels

A579/A579M Specification for Superstrength Alloy Steel Forgings

A1080/A1080M Practice for Hot Isostatic Pressing of Steel, Stainless Steel, and Related Alloy Castings

B213 Test Methods for Flow Rate of Metal Powders Using the Hall Flowmeter Funnel

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

B769 Test Method for Shear Testing of Aluminum Alloys

B855 Test Method for Volumetric Flow Rate of Metal Powders Using the Arnold Meter and Hall Flowmeter Funnel

B964 Test Methods for Flow Rate of Metal Powders Using the Carney Funnel

D3951 Practice for Commercial Packaging

E3 Guide for Preparation of Metallographic Specimens

E8/E8M Test Methods for Tension Testing of Metallic Materials

E9 Test Methods of Compression Testing of Metallic Materials at Room Temperature

E10 Test Method for Brinell Hardness of Metallic Materials

E18 Test Methods for Rockwell Hardness of Metallic Materials

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E23 Test Methods for Notched Bar Impact Testing of Metallic Materials
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E92 Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials
E140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness
E238 Test Method for Pin-Type Bearing Test of Metallic Materials
E353 Test Methods for Chemical Analysis of Stainless, Heat-Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys
E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness of Metallic Materials
E407 Practice for Microetching Metals and Alloys
E466 Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials
E606 Test Method for Strain-Controlled Fatigue Testing
E647 Test Method for Measurement of Fatigue Crack Growth Rates
E1417 Practice for Liquid Penetrant Testing
E1742 Practice for Radiographic Examination
E1820 Test Method for Measurement of Fracture Toughness
E2234 Practice for Sampling a Stream of Product by Attributes Indexed by AQL
E2762 Practice for Sampling a Stream of Product by Variables Indexed by AQL
F2924 Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion
F2971 Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing
F3122 Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes
G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

2.2 *ISO/ASTM Standards:*[2]

52900 Terminology for Additive Manufacturing – General Principles – Terminology
52901 Guide for Additive Manufacturing – General Principles – Requirements for Purchased AM Parts
52904 Additive Manufacturing – Process Characteristics and Performance – Practice for Metal Powder Bed Fusion Process to Meet Critical Applications
52921 Terminology for Additive Manufacturing – Coordinate Systems and Methodologies
52930 Additive manufacturing – Qualification principles – Installation, operation and performance (IQ/OQ/PQ) of PBF-LB equipment
52941 Additive manufacturing – System performance and reliability – Acceptance tests for laser metal powder-bed fusion machines for metallic materials for aerospace application
52942 Additive manufacturing – Qualification principles – Qualifying machine operators of laser metal powder bed fusion machines and equipment used in aerospace applications

2.3 *ASQ Standard:*[3]

ASQ C1 Specification of General Requirements for a Quality Program

2.4 *ISO Standards:*[4]

ISO 6506-1 Metallic materials – Brinell hardness test – Part 1: Test method
ISO 6507-1 Metallic materials – Vickers hardness test – Part 1: Test method
ISO 6508 Metallic materials – Rockwell hardness test – Part 1: Test method (scales A, B, C, D, E, F, G, H, K, N, T)
ISO 9001 Quality management system – Requirements
ISO 13485 Medical devices – Quality management systems – Requirements for regulatory purposes

2.5 *SAE Standards:*[5]

AMS 2759/3 Heat Treatment, Precipitation-Hardening Corrosion-Resistant, Maraging, and Secondary Hardening Steel Parts
AS 9100 Quality Management Systems – Requirements for Aviation, Space and Defense Organizations

2.6 *ASME Standard:*[6]

ASME B46.1 Surface Texture

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology relating to additive manufacturing in Terminology ISO/ASTM 52900 shall apply.

3.1.2 Terminology relating to coordinate systems in Terminology ISO/ASTM 52921 shall apply.

3.1.3 Terminology relating to the ordering of additive manufacturing parts in ISO/ASTM 52901 shall apply.

3.1.4 Terminology in Specification F2924 shall apply.

4. Condition

4.1 Unless otherwise specified herein, all conditions shall meet the requirements in each section of this standard.

4.1.1 Condition SA parts shall be solution annealed in accordance with Section 15.

4.1.2 Condition HIP parts shall be hot isostatically pressed in accordance with Section 16.

4.1.3 Condition AGED parts shall be subject to an aging treatment in accordance with Section 15.

4.1.4 The purchaser may specify multiple conditions on the purchase order such as Condition SA/AGED or SA/HIP.

[3] Available from American Society for Quality (ASQ), 600 N. Plankinton Ave., Milwaukee, WI 53203, http://www.asq.org.

[4] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

[5] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, http://www.sae.org.

[6] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.

4.1.5 Condition AB parts indicate as built condition and shall not have any heat treatment applied.

4.2 Table 1 provides guidance on controls by condition.

5. Ordering Information

5.1 Parts shall be ordered in accordance with ISO/ASTM 52901 to a specified material condition.

5.2 Supplementary requirements such as those listed in the Supplementary Requirements section shall be stated on the purchase order.

6. Manufacturing Plan

6.1 Parts manufactured to this specification shall have a manufacturing plan in accordance with Practice ISO/ASTM 52904.

7. Feedstock and Powder Batches

7.1 Parts manufactured to this specification shall control feedstock and powder batches in accordance with Practice ISO/ASTM 52904.

7.1.1 The part manufacturer shall flow-down powder specifications to their powder vendor and have receiving procedures that ensure the powder meets the requirements in ISO/ASTM 52904.

7.1.2 Virgin and used powder may be mixed to produce parts. Used powder shall meet the requirements of Practice ISO/ASTM 52904.

7.1.3 In powder bed fusion machines, the feedstock should have a flow rate that is optimized for each process. The powder flow rate shall be measured in accordance with Test Methods B964, B213, or B855.

8. Machine Qualification

8.1 All machines producing parts shall be within acceptance limits defined in ISO/ASTM 52941.

8.2 Key process variables shall be determined in accordance with ISO/ASTM 52930.

8.3 When the process can meet the microstructure density requirements in Section 12, the process shall be fixed with no additional changes to key process variables under process controls in ISO/ASTM 52904.

8.4 Initial machine and material qualification shall consist of three builds each with a minimum of 16 tension test specimens and 4 density test specimens. Test specimen orientation shall be 12 in the Z direction, 2 in the X direction, 2 in the Y direction located within the XY build envelope intended for part production.

8.4.1 Tension test specimens shall meet the requirements in Section 13 after machining to Test Methods E8/E8M dimensions.

8.4.2 Density test specimens shall meet the requirements in Section 12.

8.4.3 Chemical composition shall meet the requirements in Section 11.

8.5 Upon successful completion of 8.4, the machine shall be considered qualified. Changes to the key process variables require re-qualification in accordance with Section 8.

9. Personnel Training Requirements

9.1 Build programmers and machine operators as defined in ISO/ASTM 52904 shall be trained in accordance with ISO/ASTM 52942 and ISO/ASTM 52904.

10. Process

10.1 Parts manufactured to this specification shall meet the requirements of ISO/ASTM 52904 for:

10.1.1 Control of machine operating system software,

10.1.2 Digital data configuration control, and

10.1.3 External (to the PBF-LB process) environment control.

10.2 Permissible parameter or process changes and extent of external intervention during the build cycle shall be identified in the manufacturing plan. All process changes shall be monitored and recorded. When agreed to by the purchaser, minor changes to the manufacturing plan may be made without requalification.

10.3 Post-processing operations may be used to achieve the desired shape, size, surface finish, or other part properties. The post-processing operations shall be agreed upon by the part supplier and purchaser.

11. Chemical Composition Evaluation

11.1 Chemical composition of as-built parts shall conform to the requirements specified in Table 2. Chemical compositions shall be determined in accordance with the methods in Test Methods E353.

11.1.1 Analysis for elements not listed in Table 2 is not required to certify compliance with this specification.

TABLE 1 Guidance for Controls by Material Condition

Conditions	Thermal Post-Process	Manufacturing Plan Required	Powder Use Controlled	Powder Contamination Controlled	Post-Processing Controlled	Consolidated Material Chemistry Controlled	Microstructure Controlled	Mechanical Properties Controlled	Quality Program Required
AGED	Aging	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SA	Solution Annealed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HIP	Hot Isostatic Pressed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AB	none	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes

TABLE 2 Chemical Composition Requirements (wt. %) (Specification A579/A579M, grade 73)[A]

Material	As-built Material
Aluminum, Al	0.050–0.15 %
Boron, B	≤ 0.001 %
Carbon, C	≤ 0.030 %
Cobalt, Co	8.0–9.5 %
Iron, Fe	65.1–68.8 %
Manganese, Mn	≤ 0.10 %
Molybdenum, Mo	4.6–5.2 %
Nickel, Ni	18–19 %
Phosphorus, P	≤ 0.010 %
Silicon, Si	≤ 0.10 %
Sulfur, S	≤ 0.010 %
Titanium, Ti	0.50–0.80 %

[A] Other elements need not be reported unless the concentration level is greater than 0.1 % each, or 0.4 % total. Intentional elemental additions other than those specified in Table 1 are not permitted. All commercial metals contain small amounts of elements other than those which are specified. It is neither practical nor necessary to specify limits for unspecified elements, whether residual elements or trace elements that can be present. The producer is permitted to analyze for unspecified elements and is permitted to report such analyses. The presence of an unspecified element and the reporting of an analysis for that element shall not be a basis for rejection.

11.2 The chemical composition requirements in this specification are similar to those in Specification A579/A579M Type 7, Grade 73 or the UNS designation K93120 and EN1.2709.

12. Microstructure

12.1 Microstructural requirements and frequency of examinations shall be agreed upon by the supplier and purchaser in the as delivered condition. Specimen preparation shall be in accordance with Guide E3 and Practice E407.

12.2 Component density shall be measured in accordance with Test Method B311.

12.3 Explanations of relationships between processing and heat treatment conditions and microstructures are given in Appendix X1.

13. Mechanical Properties

13.1 Mechanical properties are highly dependent on the heat treatments applied to the part. The highest strengths and hardness result from aging at temperatures of 460 to 490 °C, while the best elongation at break characteristics tend to be achieved by high temperature aging at 600 °C, with some AB samples exhibiting similar ductility. More generally, aged specimens had better ductility than SA/AGED specimens due to the higher austenite content associated with the AGED condition. Stiffest properties are achieved by a combination of solution annealing and aging.

13.2 Tensile testing quality assurance specimens shall meet the minimum mechanical property requirements shown in Table 3.

13.3 Build platform coordinates and build platform location for test specimens shall be used in accordance with ISO/ASTM 52921.

TABLE 3 Minimum Tensile Requirements for as Delivered Condition[A]

Condition	Tensile Strength MPa (ksi), X, Y and Z Directions	Yield Strength MPa (ksi), X, Y and Z Directions	Elongation (%), X, Y and Z Directions
AB[B]	1050 (152)	800 (116)	10
SA[B]	1050 (152)	800 (116)	10
AGED[C]	1930 (280)	1895 (275)	2
SA/AGED[C]	1930 (280)	1895 (275)	2
HIP	not specified	not specified	not specified

[A] A gauge length corresponding to ISO 6892-1 may be used when agreed upon by the part supplier and purchaser.
[B] Mechanical properties were taken from research literature.
[C] Mechanical properties are consistent with Specification A579/A579M for Type 7, Grade 73 maraging steel.

13.4 Tension test specimens shall be prepared in accordance with Test Methods E8/E8M, either before or after thermal post-processing as agreed upon by the part supplier and purchaser.

NOTE 1—Guide F3122 provides guidance on evaluating mechanical properties. Tensile specimen geometry is often chosen to be representative of the produced part.

13.5 Specimens used for tension testing shall be machined from bulk deposition, machined from bars, or taken from near net shape specimens and built in the weakest orientation or highest variability orientation as determined during the machine and material qualification as agreed upon by the part supplier and purchaser.

NOTE 2—Mechanical properties of the test specimens may vary because of factors such as the location of the sample on the build platform, the test specimen orientation, and the number of parts on the build platform (related to delay time between beam exposures).

13.6 Tensile properties on test specimens shall conform to Table 3, as determined in accordance with Test Methods E8/E8M.

13.7 Reporting of tension tests results shall be in accordance with Practice F2971.

14. Supplementary Mechanical Properties

14.1 Hardness tests shall be performed in accordance with the requirements of Test Method E10, E18, or E92, or ISO 6506-1, 6507-1, or 6508 as agreed upon by the part supplier and purchaser.

14.2 Hardness specimens shall meet the minimum Vickers mechanical property requirements of 330 Hv for as-built specimens and 550 Hv for specimens aged at temperatures between 480 and 525°C for at least 3 h.

14.3 Hardness tests may be performed using Brinell, Rockwell C, or Vickers tests, then converted to different hardness scale, if needed, per Hardness Conversion Tables E140.

14.4 Static fracture toughness shall be tested in accordance with Test Method E399 or E1820. Dynamic fracture toughness shall be tested in accordance with Test Methods E23. Use of other relevant methods requires prior agreement between the part supplier and purchaser.