Designation: F3554 – 22

# Standard Specification for Additive Manufacturing – Finished Part Properties – Grade 4340 (UNS G43400) via Laser Beam Powder Bed Fusion for Transportation Applications[1]

This standard is issued under the fixed designation F3554; 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 manufactured via laser beam powder bed fusion (PBF-LB) processing of Grade 4340 (UNS G43400) used in transportation applications, including automotive applications. Parts made using this processing method require heat treatment to achieve maximum strength and are typically used in applications that require mechanical properties similar to wrought Grade 4340 (UNS G43400) products. Products built to this specification may require additional post-processing in the form of machining, polishing etc. to meet necessary surface finish and dimensional tolerances.

1.2 This specification describes the required facility, training, equipment, and processing requirements necessary to support the production of parts with properties and associated quality metrics outlined in a part classification structure.

1.3 This specification is intended for the use of purchasers or producers, or both, of PBF-LB Grade 4340 (UNS G43400) parts for defining the requirements based on classification methodology. These requirements shall be agreed upon by the part supplier and purchaser.

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 additional requirements in the purchase order.

1.6 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.7 *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]

B822 Test Method for Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering

D3951 Practice for Commercial Packaging

E3 Guide for Preparation of Metallographic Specimens

E8/E8M Test Methods for Tension Testing of Metallic Materials

E10 Test Method for Brinell Hardness of Metallic Materials

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E407 Practice for Microetching Metals and Alloys

E112 Test Methods for Determining Average Grain Size

E1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Inert Gas Fusion Techniques

E1245 Practice for Determining the Inclusion or Second-Phase Constituent Content of Metals by Automatic Image Analysis

E1417 Practice for Liquid Penetrant Testing

E1479 Practice for Describing and Specifying Inductively Coupled Plasma Atomic Emission Spectrometers

E1742 Practice for Radiographic Examination

E2234 Practice for Sampling a Stream of Product by Attributes Indexed by AQL

E2594 Test Method for Analysis of Nickel Alloys by Inductively Coupled Plasma Atomic Emission Spectrometry (Performance-Based)

E2762 Practice for Sampling a Stream of Product by Variables Indexed by AQL

F2971 Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing

[1] This specification is under the jurisdiction of ASTM Committee F42 on Additive Manufacturing Technologies and is the direct responsibility of Subcommittee F42.07 on Applications.

Current edition approved Oct. 1, 2022. Published November 2022. DOI: 10.1520/F3554-22.

[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.

F3122 Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes
F3301 Additive Manufacturing – Post Processing Methods – Standard Specification for Thermal Post-Processing Metal Parts Made Via Powder Bed Fusion

2.2 *ISO/ASTM Standards:*[2]
52900 Additive manufacturing — General principles — Fundamentals and vocabulary
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 Test Methodologies
52930 Additive manufacturing — Qualification principles — Installation, operation, and performance (IQ/OQ/PQ) of PBFLB 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 metal laser powder bed fusion machines and equipment used in aerospace applications

2.3 *ISO Standards:*[3]
ISO 9001 Quality management system — Requirements
ISO 9044 Industrial woven wire cloth — Technical requirements and testing
ISO 9712 Non-destructive testing — Qualification and certification of NDT personnel
ISO 16949 Quality management systems — Particular requirements for the application of ISO 9001:2008 for automotive production and relevant service part organizations

2.4 *SAE Standards:*[4]
AS 9100 Quality Management Systems – Requirements for Aviation, Space and Defense Organizations
AMS 2175 Castings, Classification, and Inspection of

2.5 *ASME Standards:*[5]
ASME B46.1 Surface Texture

2.6 *National Aerospace Standards:*[6]
NAS410 National Aerospace Standard Certification & Qualification of Non-destructive Test Personnel

2.7 *ANSI/ASNT:*[7]
CP189 Standard for Qualification and Certification of Non-destructive Testing Personnel

## 3. Terminology

3.1 *Definitions of Terms:*

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

3.1.2 Part positioning and orientation related to coordinate systems in ISO/ASTM 52921 shall apply.

## 4. Classification

4.1 All parts made to this specification shall be given a classification A, B, C, D, according to the annex.

## 5. Condition

5.1 All Conditions shall meet the requirements in each section of this standard and conform to Specification F3301.

5.1.1 Condition SR, parts shall be stress relieved.

5.1.2 Condition Q/T, parts shall be quenched and tempered.

5.1.3 Condition HIP, parts shall be processed by hot isostatic pressing.

5.2 The purchaser may specify multiple conditions on the purchase order such as Condition SR/HIP.

5.2.1 Class A parts shall be delivered in condition HIP and Q/T.

5.2.2 Class B parts shall be delivered in condition Q/T.

5.2.3 Class C parts shall be delivered in condition SR.

5.2.4 Class D parts shall be delivered in condition as agreed upon between supplier and purchaser.

## 6. Ordering Information

6.1 Parts shall be ordered in accordance with ISO/ASTM 52901 and include the specified condition(s) and classification in accordance with this specification.

6.2 Supplementary requirements shall be stated on the purchase order.

## 7. Manufacturing Plan

7.1 All classification of parts manufactured to this specification shall have a manufacturing plan in accordance with ISO/ASTM 52904.

## 8. Feedstock and Powder Batches

8.1 Classifications A, B, C of parts manufactured to this specification shall use pre-alloyed powder and control powder batches in accordance with ISO/ASTM 52904.

8.1.1 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.

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

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

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

[6] Available from Aerospace Industries Association (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209, http://www.aia-aerospace.org.

[7] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org and American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.

8.1.2 Virgin and used powder may be mixed to produce parts for all classifications. Used powder shall meet the requirements of ISO/ASTM 52904.

8.1.3 For Class A part production, the process for sieving used feedstock shall maintain the powder specification in 8.1.1.

8.1.4 For Class A part production, the supplier shall provide objective evidence that changing the alloy type in the PBF-LB machine does not cause part contamination.

## 9. Machine Qualification (Class A, B, C)

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

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

9.3 When the process can meet the microstructure density requirements in Section 13, the process shall be fixed with no additional changes to key process variables under process controls in ISO/ASTM 52904.

9.4 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.

9.4.1 Tension test specimens shall meet the requirements in Section 14 after machining to Test Method E8/E8M dimensions

9.4.2 Density test specimens shall meet the requirements in Section 13 when processed with only hatch scanning.

9.4.3 Chemical composition shall meet the requirements in Section 12.

9.5 Upon successful completion of 9.4, the machine shall be considered qualified. Changes to the key process variables require re-qualification in accordance with Section 9.

9.6 Class D parts are exempt from machine qualification.

## 10. Personnel Training Requirements (Class A, B, C)

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

## 11. Process (Class A, B, C)

11.1 Process shall be agreed upon by the part supplier and purchaser.

11.2 All classifications of parts manufactured to this specification shall meet the requirements of ISO/ASTM 52904 for:

11.2.1 Control of machine operating system software.

11.2.2 Digital data configuration control.

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

11.3 Permissible parameter or process changes and extent of external intervention during the build cycle shall be identified in the manufacturing plan.

11.3.1 This requires a new first article inspection (FAI) for Class A and B.

11.3.2 All process changes shall be monitored and recorded. When agreed to by the purchaser, minor changes to the manufacturing plan may be made without re-qualification, for example, change of operation sequences.

11.4 Post processing operations may be used to achieve the desired shape, size, surface finish or other part properties.

## 12. Chemical Composition Evaluation

12.1 As built chemical composition of parts shall conform to the requirements specified in Table 1. Methods and practices relating to as built chemical analysis required by this specification shall be in accordance with Practice E1479. Test Method E1019 shall be used to measure carbon, nitrogen, and sulfur. Remaining elements shall be measured in accordance with Test Method E2594. Other analytical methods may be used if agreed upon by the part supplier and purchaser.

12.1.1 Analysis for elements not listed in Table 1 is not required to certify compliance with this specification.

12.2 Chemical check (product) analysis limits shall be as shown in Table 2. Chemical check analysis tolerances do not broaden the requirements in Table 1 for the powder or part supplier but cover variations between laboratories in the measurement of chemical content. The part supplier shall not certify parts to this specification if the part chemistry is outside the requirements specified in Table 1.

12.3 The chemical composition requirements in this specification for as built product conforms to Grade 4340 (UNS G43400) except sulfur and phosphorus are limited to 0.01 mass fraction % to prevent embrittlement and cracking.

12.4 Limits for elements not specified in Table 1 and Table 2 for the material ordered may be established by agreement between the part supplier and purchaser.

**TABLE 1 Chemical Composition Requirements (mass fraction %)[A,B,C]**

| Material | Carbon | Manganese | Silicon | Phosphorus, max | Sulfur, max | Chromium | Nickel | Molybdenum | Other Elements, max each[B] | Other Elements, max total[B] |
|---|---|---|---|---|---|---|---|---|---|---|
| As built Material | 0.38 – 0.43 | 0.65 – 0.90 | 0.15 – 0.350 | 0.01 | 0.01 | 0.70 – 0.90 | 1.65 – 2.0 | 0.20 – 0.30 | 0.10 | 0.40 |

[A] The percentage of iron content by difference is not required to be determined or certified.
[B] 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.
[C] Phosphorus and sulfur concentrations numbers are reduced from Grade 4340 (UNS G43400).

**TABLE 2 Check Analysis Limits (Tolerances) (mass fraction %)**

| Element | Permissible Variation in Check Analysis |
|---|---|
| Carbon | ±0.02 |
| Manganese | ±0.03 |
| Silicon | ±0.05 |
| Phosphorus | ±0.005 |
| Sulfur | ±0.005 |
| Chromium | ±0.03 |
| Nickel | ±0.03 |
| Molybdenum | ±0.03 |
| Other Elements, each | ±0.001 |

12.5 Results of supplementary element analysis shall be reported on the certification.

## 13. Microstructure of PBF-LB Grade 4340 (UNS G43400)

13.1 For Class A parts, density in the as built condition shall be ≥99.7 % with an even distribution of pores as measured in accordance with Practice E1245 with a microscopic field of view approximately 9.0 $mm^2$ and 25X to 50X magnification. Measurements shall be taken in plane with and normal to the build platform on each sample.

13.2 For Class B parts, density in the as built condition shall be ≥99.5 % when measured in accordance with 13.1.

13.3 For Class A and B parts, the grains shall be equiaxed and have a grain size of 5 or finer in accordance with Test Method E112.

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

## 14. Mechanical Properties of PBF-LB Grade 4340 (UNS G43400)

14.1 For Class A, B, C parts, a minimum of four tension test specimens shall be processed in each build cycle and tested at room temperature to meet the minimum mechanical property requirements shown in Table 3.

14.1.1 A minimum of three test specimens shall be tested and reported. Additional test specimen(s) can be saved for future evaluation.

**TABLE 3 Minimum Mechanical Property Requirements for as Delivered Condition for Grade 4340 (UNS G43400)[A,B]**

| Classification | Tensile Strength MPa [ksi] X, Y and Z Directions | Yield Strength at 0.2 % Offset MPa [ksi] X, Y and Z Directions | Elongation in 50 mm [2 in.] or 4D (%) X, Y and Z Direction | Reduced Area (%) X, Y and Z Direction |
|---|---|---|---|---|
| Class A, B, C | 1860 (270) | 1480 (215) | 6 | 10 |
| D | No Requirement | No Requirement | No Requirement | No Requirement |

[A] A gauge length corresponding to ISO 6892 may be used when agreed upon between supplier and purchaser.

[B] The specification minimums tensile properties in this table were derived from sufficient quantity to produce statistically valid minimum values, produced, and tested at the U.S. Army DEVCOM AC under a qualified process.

14.1.2 For Class C parts, test specimens, in accordance with 14.1.1, may be produced before and after a production run instead of per build cycle.

14.1.3 Class D parts do not require mechanical testing. See Table 3.

14.2 Build platform coordinates and orientation for test specimens shall be recorded in accordance with ISO/ASTM 52921.

14.3 Tension test specimens shall be prepared in accordance with Test Method E8/E8M, in the condition of the delivered part.

NOTE 1—Guide F3122 provides guidance on evaluating mechanical properties.

14.4 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, or both, as determined during the machine and material qualification.

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, the number of parts on the build platform (delay time between beam exposures) and surface finish. Whether or not the test specimens are near net shape or machined is to be agreed upon by the part supplier and purchaser.

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

14.6 Reporting of tension tests results shall be in accordance with Specification F2971.

14.7 Hardness testing shall be performed on Class A, B, and C quality assurance specimens in accordance with Test Method E10. Delivered product shall have a minimum hardness of 51 HRC. When agreed upon between parts producer and purchaser, hardness test may be substituted for tension tests as specified in 14.1. All hardness testing shall be conducted in the as delivered condition.

## 15. Dimensions and Permissible Variations

15.1 Tolerances on as built parts shall meet the engineering requirements and be agreed upon by the part supplier and purchaser.

15.2 As built parts may be machined to meet dimensional requirements.

15.3 Part repairs performed by welding shall be approved by purchaser before delivery of the part.

## 16. Re-Tests

16.1 If the results of any chemical or mechanical property test or any inspection method, on a part or test specimen are not in conformance with the requirements of this specification, the part or test specimen may be retested at the option of the part supplier.

16.1.1 If there is a failure for any test, and additional test specimens are available, then a retest with twice as many samples may be conducted. If the results of the re-test conform to the requirement, then the re-test values may be used to support part acceptance.