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Standard Specification for Additive Manufacturing Nickel Alloy (UNS N06625) with Powder Bed Fusion[1]

This standard is issued under the fixed designation F3056; 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 additively manufactured UNS N06625 components using full-melt powder bed fusion such as electron beam melting and laser melting. The components produced by these processes are used typically in applications that require mechanical properties similar to machined forgings and wrought products. Components manufactured to this specification are often, but not necessarily, post processed via machining, grinding, electrical discharge machining (EDM), polishing, and so forth to achieve desired surface finish and critical dimensions.

1.2 This specification is intended for the use of purchasers or producers, or both, of additively manufactured UNS N06625 components for defining the requirements and ensuring component properties.

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

1.4 User requirements considered more stringent may be met by the addition to the purchase order of one or more supplementary requirements, which may include, but are not limited to, those listed in Supplementary Requirements S1–S16.

1.5 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.6 *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.*

1.7 *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]

B213 Test Methods for Flow Rate of Metal Powders Using the Hall Flowmeter Funnel
B214 Test Method for Sieve Analysis of Metal Powders
B243 Terminology of Powder Metallurgy
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
B880 Specification for General Requirements for Chemical Check Analysis Limits for Nickel, Nickel Alloys and Cobalt Alloys
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
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E18 Test Methods for Rockwell Hardness of Metallic Materials
E21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials
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
E238 Test Method for Pin-Type Bearing Test of Metallic Materials

[1] This test method is under the jurisdiction of ASTM Committee F42 on Additive Manufacturing Technologies and is the direct responsibility of Subcommittee F42.05 on Materials and Processes.

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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.

E354 Test Methods for Chemical Analysis of High-Temperature, Electrical, Magnetic, and Other Similar Iron, Nickel, and Cobalt Alloys
E384 Test Method for Microindentation Hardness of Materials
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
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
E1417 Practice for Liquid Penetrant Testing
E1450 Test Method for Tension Testing of Structural Alloys in Liquid Helium
E1473 Test Methods for Chemical Analysis of Nickel, Cobalt and High-Temperature Alloys
E1820 Test Method for Measurement of Fracture Toughness
E1941 Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis
E2368 Practice for Strain Controlled Thermomechanical Fatigue Testing
F629 Practice for Radiography of Cast Metallic Surgical Implants
F2792 Terminology for Additive Manufacturing Technologies (Withdrawn 2015)[3]
F2924 Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion

2.2 *ISO/ASTM Standards:*[2]
52915 Specification for Additive Manufacturing File Format (AMF) Version 1.1
52921 Terminology for Additive Manufacturing—Coordinate Systems and Test Methodologies

2.3 *ASQ Standard:*[4]
ASQ C1 Specification of General Requirements for a Quality Program

2.4 *ISO Standards:*[5]
ISO 148-1 Metallic materials—Charpy pendulum impact test—Part 1: Test method
ISO 1099 Metallic materials—Fatigue testing—Axial force-controlled method
ISO 4545 Metallic materials—Knoop hardness test—Part 2: Verification and calibration of testing machines
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 6892-1 Metallic materials—Tensile testing at ambient temperature
ISO 6892-2 Metallic materials—Tensile testing—Part 2: Method of test at elevated temperature
ISO 9001 Quality management system—Requirements
ISO 9044 Industrial woven wire cloth—Technical requirements and testing
ISO 12108 Metallic materials—Fatigue testing—Fatigue crack growth method
ISO 12111 Metallic materials—Fatigue testing—Strain-controlled thermomechanical fatigue testing method
ISO 12135 Metallic materials—Unified method of test for the determination of quasistatic fracture toughness
ISO 12737 Metallic materials—Determination of plane-strain fracture toughness (withdrawn)
ISO 13485 Medical devices—Quality management systems—Requirements for regulatory purposes
ISO 19819 Metallic materials—Tensile testing in liquid helium

2.5 *Military Standard:*[6]
MIL-C-24615A Military Specification, Castings, Nickel-Chromium-Molybdenum, Columbium Alloy

2.6 *SAE Standards:*[7]
AMS 2269 Chemical Check Analysis Limits Nickel, Nickel Alloys, and Cobalt Alloys
AMS 5599 Nickel Alloy, Corrosion and Heat-Resistant, Sheet, Strip, and Plate 62Ni-21.5Cr-9.0Mo-3.7Cb (Nb) Solution Heat Treated
AMS 2774 Heat Treatment Wrought Nickel Alloy and Cobalt Alloy Parts
AS 9100 Quality Systems—Aerospace—Model for Quality Assurance in Design, Development, Production, Installation and Servicing

2.7 *ASME Standard:*[8]
ASME B46.1 Surface Texture

2.8 *NIST Standard:*[9]
IR 7847 (March 2012) CODEN:NTNOEF

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology relating to powder bed fusion in Specification F2924 shall apply.

3.1.2 Terminology relating to additive manufacturing in Terminology F2792 shall apply.

[3] The last approved version of this historical standard is referenced on www.astm.org.
[4] Available from American Society for Quality (ASQ), 600 N. Plankinton Ave., Milwaukee, WI 53203, http://www.asq.org.
[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.
[6] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://dodssp.daps.dla.mil.
[7] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.
[8] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.
[9] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

3.1.3 Terminology relating to coordinate systems in Terminology 52921 shall apply.

3.1.4 Terminology relating to powder metallurgy in Terminology B243 shall apply.

4. Classification

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

4.1.1 Class A components shall be stress relieved or annealed per Section 12.

4.1.2 Class B components shall be annealed per Section 12.

4.1.3 Class C components shall be hot isostatically pressed per Section 13.

4.1.4 Class D—Not Used.

4.1.5 For Class E components, all thermal post processing shall be optional.

4.1.6 Class F—Not Used.

5. Ordering Information

5.1 Orders for components compliant with this specification shall include the following to describe the requirements adequately:

5.1.1 This specification designation,

5.1.2 Description or part number of product desired,

5.1.3 Quantity of product desired,

5.1.4 Classification,

5.1.5 SI or SAE units,

5.1.5.1 *Discussion*—The STL file format used by many powder bed fusion machines does not contain units of measurement as metadata. When only STL files are provided by the purchaser, ordering information should specify the units of the component along with the electronic data file. More information about data files can be found in ISO/ASTM 52915.

5.1.6 Dimensions and tolerances (Section 14),

5.1.7 Mechanical properties (Section 11),

5.1.8 Methods for chemical analysis (Section 9),

5.1.9 Sampling methods (Section S16),

5.1.10 Post-processing sequence of operations,

5.1.11 Thermal processing,

5.1.12 Allowable porosity (Section S8),

5.1.13 Component marking such as labeling the serial or lot number in the CAD file prior to the build cycle, or product tagging,

5.1.14 Packaging,

5.1.15 Certification,

5.1.16 Disposition of rejected material (Section 15), and

5.1.17 Other supplementary requirements.

6. Manufacturing Plan

6.1 Class A, B, C, and E components manufactured to this specification shall have a manufacturing plan that includes, but is not limited to, the following:

6.1.1 A machine, manufacturing control system, and qualification procedure as agreed between component supplier and purchaser;

NOTE 1—Qualification procedures typically require qualification build cycles in which mechanical property test specimens are prepared and measured in accordance with Section 11 or other applicable standards. Location, orientation on the build platform, number of test specimens for each machine qualification build cycle, and relationship between specimen test results and component quality shall be agreed upon between component supplier and purchaser.

6.1.2 Feedstock that meets the requirements of Section 7;

6.1.3 The machine identification, including machine software version, manufacturing control system version (if automated), build chamber environment, machine conditioning, and calibration information of the qualified machine;

6.1.4 Predetermined process as substantiated by the qualification procedure;

6.1.5 Safeguards to ensure traceability of the digital files, including design history of the components;

6.1.6 All the steps necessary to start the build process, including build platform selection, machine cleaning, and powder handling;

6.1.7 The requirements for approving machine operators;

6.1.8 Logging of machine build data files, upper and lower limits of the parameters affecting component quality and other process validation controls;

6.1.9 The number of components per build cycle, their orientation and location on the build platform, and support structures, if required;

6.1.10 Process steps including, but not limited to, Section 8;

6.1.11 Post-processing procedure, including sequence of the post-processing steps and the specifications for each step;

6.1.12 Thermal processing including stress relieve, furnace anneal, hot isostatic pressing, and heat treat; and

6.1.13 Inspection requirements as agreed between the purchaser and component supplier, including any supplementary requirements.

7. Feedstock

7.1 The feedstock for this specification shall be metal powder, as defined in ASTM B243, that has the powder type, size distribution, shape, tap density, and flow rate acceptable for the process as determined by the component supplier.

7.2 The metal powder shall be free from detrimental amounts of inclusions and impurities and its chemical composition shall be adequate to yield, after processing, the final material chemistry listed in Table 1.

7.3 Powder blends are allowed unless otherwise specified between the component supplier and component purchaser, as

TABLE 1 Composition (wt %)

Element	min	max
Carbon	–	0.10
Manganese	–	0.50
Silicon	–	0.50
Phosphorus	–	0.015
Sulfur	–	0.015
Chromium	20.00	23.00
Cobalt	–	1.00
Molybdenum	8.00	10.00
Niobium	3.15	4.15
Titanium	–	0.40
Aluminum	–	0.40
Iron	–	5.00
Nickel	remainder	

long as all powder used to create the powder blend meets the requirements in Table 1 and lot numbers are documented and maintained.

7.4 Used powder is allowed. The proportion of virgin powder to used powder shall be recorded and reported for each production run. The maximum number of times used powder can be used as well as the number of times any portion of a powder lot can be processed in the build chamber should be agreed upon between component supplier and purchaser for Class A, B, and C. There are no limits on the number of build cycles for used powder for Class E components. After a build cycle, any remaining used powder may be blended with virgin powder to maintain a powder quantity large enough for next build cycle. The chemical composition of used powders shall be analyzed regularly, as agreed upon between component supplier and purchaser. Powder not conforming to Table 1 or 7.7 shall not be further processed in the machine to manufacture Class A, B, and C components.

7.4.1 All used powder shall be sieved with a sieve having a mesh size appropriate for removing any agglomerates or contaminants from the build cycle.

7.5 All powder sieves used to manufacture Class A, B, and C components shall have a certificate of conformance that they were manufactured to ISO 9044 or all powder sieving shall be in conformance with Specification E11.

7.6 Sieve analysis of used powder or powder lots during incoming inspection or in-process inspection shall be made in accordance with Test Method B214 or as agreed between component supplier and purchaser.

7.7 The maximum percentage of any element in Table 1 may be increased for virgin powder, used powder and powder blends when agreed upon between component supplier and purchaser. When component supplier and purchaser agree to an increase in the maximum percentage of any element, 9.2 shall apply.

7.8 Any powder lot or powder blend containing any used powder shall be considered used powder.

8. Process

8.1 Processing shall be conducted per applicable standards or as agreed upon between component supplier and purchaser according to an approved manufacturing plan as described in Section 6.

8.1.1 Test specimens for quality assurance may be required to be built and tested in accordance with Section 11 with each build cycle or before and after a production run as agreed upon between the component supplier and purchaser.

NOTE 2—In addition to tension test specimens, fatigue test specimens may be required by the purchaser to be built with the components at the beginning and end of each production run. Fatigue testing is described in Supplementary Requirement S6.

8.2 Permissible parameter, process changes and extent of external intervention during the build cycle shall be identified in the manufacturing plan. All process changes shall be continuously monitored and recorded. When agreed to by the purchaser, minor changes to the manufacturing plan are permissible without machine requalification.

8.3 Condition and finish of the components shall be agreed upon between the component supplier and purchaser.

8.4 Post-processing operations may be used to achieve the desired shape, size, surface finish, or other component properties. The post-processing operations shall be agreed upon between the component supplier and purchaser for Class A, B, and C components.

9. Chemical Composition

9.1 Except for Class E, as built components shall conform to the percentages by weight shown in Table 1. Carbon, Sulfur, Nitrogen, and Oxygen shall be determined in accordance with Test Methods E1019 and other elements in accordance with Test Methods E354. Chemical composition shall be determined by Test Methods E1473, E1019, or E1941, or combination thereof, as appropriate. Other analytical methods may be used if agreed upon by the component supplier and purchaser.

9.2 Chemical check analysis limits shall be in accordance with AMS 2269 or Specification B880 and Table 2. Chemical check analysis tolerances do not broaden the limits in Table 1, but cover variations between laboratories in the measurement of chemical content. The supplier shall not ship components that are outside the limits specified in Table 1.

9.3 The chemical composition requirements in this specification for UNS N06625 components are the same as specification AMS 5599 for wrought alloy.

10. Microstructure

10.1 The microstructural requirements and frequency of examinations shall be mutually agreed upon by the supplier and purchaser. Specimen preparation shall be in accordance with Guide E3 and Practice E407.

11. Mechanical Properties

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

11.2 Tension test specimens shall be prepared in accordance with ISO/ASTM E8/E8M either before or after thermal processing as agreed upon by component supplier and purchaser.

TABLE 2 Check Analysis Tolerances

Check Analysis Tolerances (wt %)	
Element	Permissible Variation in Check Analysis
Carbon	±0.01
Manganese	±0.03
Silicon	±0.03
Phosphorus	±0.005
Sulfur	±0.003
Chromium	±0.25
Cobalt	±0.03
Molybdenum	±0.15
Niobium	±0.15
Aluminum	±0.05
Titanium	±0.03
Iron	±0.07
Nickel	±0.45

11.3 In accordance to with ISO/ASTM 52921, specimens used for tension testing shall be machined from bulk deposition, machined from bars or taken from near net shape specimens and built in *X*, *Y*, *Z*, or other orientations as agreed with purchaser.

NOTE 3—Mechanical properties of the test specimens may vary because of the location of the sample on the build platform and the test specimen orientation. Whether or not the test specimens are near net shape or machined from larger blocks is a matter of preference.

11.4 Tensile properties on test specimens shall conform to Table 3, as determined in accordance with Test Methods E8/E8M at a strain rate of 0.003 to 0.007 mm/mm/min through yield and then the crosshead speed may be increased so as to produce failure in approximately one additional minute.

12. Thermal Processing

12.1 When required, Class A components shall be stress relieved or annealed as agreed between component supplier and purchaser. Stress relief is optional for all other classifications.

NOTE 4—Stress relief is typically performed while the components are attached to the build platform. AMS 2774 provides stress relief guidance. Some residual stress may remain depending on the stress relief processing. Components manufactured on some powder bed fusion machines may not require a stress relief procedure. Components processed to 12.1 may require further thermal processing.

12.2 Class B components shall be annealed per AMS 2774. Other classifications may be annealed as agreed between component supplier and purchaser.

12.3 Class C components shall be stress relieved and removed from the platform, hot isostatically pressed (HIP) per Section 13 and then annealed per AMS 2774.

12.4 Class D—Classification not used.

12.5 Class F—Classification not used.

13. Hot Isostatic Pressing

13.1 HIP is required for Class C components and optional for all other classifications.

13.1.1 Process components under inert atmosphere at not less than 100 MPa within the range of 1120 to 1175 °C; hold at the selected temperature within ±15 °C for 240 min ± 60 min and cool under inert atmosphere to below 425 °C, or to parameters as agreed upon between the component supplier and purchaser.

14. Dimensions and Permissible Variations

14.1 Tolerances on as-built components shall be agreed upon by the component supplier and purchaser.

14.2 As-built components may be machined to meet dimensional requirements.

14.3 Component repair by welding shall be approved by the purchaser.

15. Retests

15.1 If the results of any chemical or mechanical property test or any inspection method, including S1–S15, on a component are not in conformance with the requirements of this specification, the component may be retested at the option of the manufacturer.

15.1.1 The frequency of the retest will be double the initial number of tests. If the results of the retest conform to the requirement, then the retest values will become the test values for certification.

15.2 All test results including the original test results and the conforming retest results shall be reported to the purchaser.

15.3 If any of the results for the retest fail to conform to this specification, the material shall be rejected in accordance with Section 17.

16. Inspection

16.1 Inspection criteria shall be agreed upon by the component supplier and purchaser.

17. Rejection

17.1 Components not conforming to this specification, or modifications to this specification that are not authorized by the purchaser, will be subject to rejection.

17.2 All rejected components shall be quarantined and reported to the component purchaser.

18. Certification

18.1 A certificate, including a complete test report, shall be provided by the component supplier at the time of shipment stating that the components were manufactured and tested in accordance with this specification.

18.2 If the component supplier and purchaser are one and the same, equivalent internal documentation shall be acceptable in lieu of certification.

TABLE 3 Minimum Tensile Properties[A,B]

Room Temperature Classification	Tensile Strength MPa X and Y Directions	Tensile Strength MPa Z Direction	Yield Strength at 0.2% Offset MPa X and Y Directions	Yield Strength at 0.2% Offset MPa Z Direction	Elongation in 5 cm or 4D (%) X and Y Direction	Elongation in 5 cm or 4D (%) Z Direction	Reduced Area X and Y Direction	Reduced Area Z Direction
A, B, C E	485 no requirement	485 no requirement	275 no requirement	275 no requirement	30 no requirement	30 no requirement	30 no requirement	30 no requirement

[A] A gauge length corresponding to ISO 6892 may be used when agreed upon between supplier and purchaser (5.65 times the square root of S0, where S0 is the original cross-sectional area).
[B] Mechanical properties conform to MIL-C-24615A Grade B.