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Standard Specification for Additive Manufacturing – Finished Part Properties – Standard Specification for Niobium-Hafnium Alloy UNS R04295 via Laser Beam Powder Bed Fusion for Spaceflight Applications[1]

This standard is issued under the fixed designation F3635; 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 niobium-hafnium alloy used in spaceflight applications. Parts made using this processing method are typically used in applications that require mechanical properties like wrought 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 is intended for the use of purchasers or producers, or both, of PBF-LB R04295 parts for defining the requirements based on classification methodology. These requirements shall be agreed upon by the part supplier and purchaser.

1.3 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.

1.4 User requirements considered more stringent may be met by the addition to the purchase order.

1.5 *Units*—The values stated in SI units are to be regarded as the standard. Other units are included only for informational purposes.

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]

D3951 Practice for Commercial Packaging
E3 Guide for Preparation of Metallographic Specimens
E8/E8M Test Methods for Tension Testing of Metallic Materials
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E112 Test Methods for Determining Average Grain Size
E367 Test Methods for Chemical Analysis of Ferroniobium
E407 Practice for Microetching Metals and Alloys
E1245 Practice for Determining the Inclusion or Second-Phase Constituent Content of Metals by Automatic Image Analysis
E1417 Practice for Liquid Penetrant Testing
E1447 Test Method for Determination of Hydrogen in Reactive Metals and Reactive Metal Alloys by Inert Gas Fusion with Detection by Thermal Conductivity or Infrared Spectrometry
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
E2626 Guide for Spectrometric Analysis of Reactive and Refractory Metals (Withdrawn 2017)[3]
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.

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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.

[3] The last approved version of this historical standard is referenced on www.astm.org.

F3122 Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes

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

52915 Specification for Additive Manufacturing File Format (AMF) Version 1.2

52921 Terminology for Additive Manufacturing-Coordinate Systems and Test 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 metal laser powder bed fusion machines and equipment used in aerospace applications

2.3 *ISO Standards:*[4]

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

2.4 *SAE Standards:*[5]

AMS2175 Castings, Classification, and Inspection of

AS9100 Quality Management Systems — Requirements for Aviation, Space and Defense Organizations

2.5 *ASME Standard:*[6]

ASME B46.1 Surface Texture (Roughness, Waviness, Lay)

2.6 *NASA Standard:*

NASA STD–6030 Additive Manufacturing Requirements for Spaceflight Systems

2.7 *National Aerospace Standard:*

NAS410 National Aerospace Standard Certification & Qualification of Non-destructive Test Personnel

2.8 *ANSI / ASNT Standard:*

CP189 ASTN Standard for Qualification and Certification of Nondestructive Testing Personnel

3. Terminology

3.1 *Definitions:*

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 NASA STD–6030.

5. Condition

5.1 All conditions shall meet the requirements in each section of this standard.

5.1.1 Condition ANN parts shall be annealed. Anneal for 60 ± 15 min at 1093 ± 15°C.

5.1.2 Condition HIP parts shall be hot isostatically pressed. Process components under inert atmosphere at not less than 100 MPa within the range of 1575 to 1625°C; hold at the selected temperature within ±15°C for 120 ± 30 min and cool under inert atmosphere to below 425°C, or to parameters as agreed upon between the component supplier and purchaser.

5.1.3 Condition OPT parts all thermal post processing shall be optional.

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

5.2.1 Class A, B, C parts shall be delivered in the ANN condition.

5.2.2 Class A parts shall be processed by Hot Isostatic Pressing (HIP) and HIP shall be optional for all other classifications.

5.2.3 Class D parts (As described in NASA STD–6030 Table 22) shall be delivered in condition as agreed upon between supplier and purchaser.

NOTE 1—HIP can introduce significant contamination risk to UNS R04295 alloy due to other parts outgassing in coach HIP cycles. Nadcap accreditation is recommended for HIP vendors.

6. Ordering Information

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

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

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.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.

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

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

8.1.5 Blending of powder lots is permitted. Powder blends with more than 2 powder lots, shall require powder sample capsules to be processed in the build cycles. The number and location of powder capsules shall be determined by part manufacturer. The powder in the capsules shall meet the requirements in this section.

NOTE 2—Examples of capsules sizes can be found in the document link here. NIST Advanced Manufacturing Series 100-17.

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 Z direction, 2 in X direction, and 2 in 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 Parameter or process changes 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 delivered (except for coatings) 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 Methods E367, or a combination thereof, as appropriate. Hydrogen shall be measured in accordance with Test Method E1447. 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.

12.1.2 Alternative analytical methods may be used if agreed upon by the part supplier and purchaser (refer to Guide E2626).

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 conform to UNS R04295.

12.4 Limits for elements not specified in Table 1 and Table 2 for the material ordered may be established between the part

TABLE 1 Chemical Composition Requirements (wt. %)[A]

Material	Carbon max.	Oxygen max.	Nitrogen max.	Hydrogen max.	Hafnium	Titanium	Zirconium max.	Tungsten max.	Tantalum max.	Other Elements, max. each[B]	Other Elements, max. total[B]
As Delivered Material	0.015	0.060	0.010	0.0015	9.00-11.00	0.70-1.30	0.70	0.50	0.50	0.10	0.40

[A] The percentage of niobium 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 may analyze for unspecified elements and 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.