NCAMP-DRAM

National Center for Advanced Material Performance
Rapid Advanced Material Performance

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NCAMP-DRAM Additive Material Specification

This specification is generated and maintained in accordance with NCAMP-DRAM Standard Operating Procedures

Standard Specification for Additive Manufacturing Laser Powder Bed Fusion Titanium-6 Aluminum-4 Vanadium (Grade 5)

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Revision Table:

Revision	Date	Description of Changes	Author
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Abbreviations and Acronyms

ASTM	American Society for Testing and Materials
CEA	Cognizant Engineering Authority
EBSD	Electron Backscatter Diffraction
HIP	Hot Isostatic Press
L-PBF	Laser Powder Bed Fusion
LCF	Low Cycle Fatigue
OQ	Operational Qualification
PQ	Performance Qualification
PCD	Process Control Document
TDP	Technical Data Package
Ti-6Al-4V	Titanium-6 Aluminum-4 Vanadium
VSR	Vacuum Stress Relief

1. Scope

The purpose of this document is to provide material characteristics and properties of Additively Manufactured (AM) Ti-6Al-4V alloy material. This material specification shall encompass material characteristics produced via Laser Powder Bed Fusion (L-PBF).

1.1. Application

The material described in this document is intended to be used in a variety of end-use applications across multiple industries, provided that the material characteristics and properties meet the requirements of such application.

1.2. Classifications

The classifications listed in Table 1 below represent heat treatments. This specification applies to all classes unless otherwise specified. Minimum fatigue requirements for Class C materials shall be as specified in section 5.

Table 1: Material Classifications

Class A	Vacuum Stress Relief (VSR) and Hot Isostatic Press (HIP)
Class B	Vacuum Stress Relief (VSR) Only
Class C	Vacuum Stress Relief (VSR) and Fatigue Testing Required

2. Applicable Documents

The following documents are used as reference materials for this program (see Table 2). The user shall use the most recent revision of these documents unless a specific document revision is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

Table 2: List of Applicable Documents

Document No.	Document Title
AMS7003	Laser Powder Bed Fusion Process
ND-ME 001	Standard Specification for Additive Manufacturing Laser Powder Bed Fusion Operational Qualification
AMS7015	Titanium 6-Aluminum 4-Vanadium Powder for Additive Manufacturing
AMS2249	Chemical Check Analysis Limits, Titanium and Titanium Alloys
AMS7002	Process Requirements for Production of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts
AMS7028	Titanium Alloy, Ti-6Al-4V, Hot Isostatically Pressed (Low Temperature, High Pressure), Produced by Laser Powder Bed Fusion
AMS2801	Heat Treatment of Titanium Alloy Parts

AS1814	Terminology for Titanium Microstructures
ASTM B311	Standard Test Method for Density of Powder Metallurgy (PM) Materials Containing Less Than Two Percent Porosity
ASTM E8/E8M	Tension Testing of Metallic Materials
ASTM E3	Standard Guide for Preparation of Metallographic Specimens
ASTM E18	Standard Test Methods for Rockwell Hardness of Metallic Materials
ASTM E2627	Standard Practice for Determining Average Grain Size Using Electron Backscatter Diffraction (EBSD) in Fully Recrystallized Polycrystalline Materials
ASTM E606/E606M-21	Standard Test Method for Strain-Controlled Fatigue Testing
ASTM E407	Standard Practice for Microetching Metals and Alloys

Note: Newest revision of document shall apply.

3. General Requirements

3.1. Processing Information

All additive manufacturing processes shall be in accordance with AMS7003 and accompanied by process control documentation (PCD) approved by the cognizant engineering authority (CEA). After approval, processes shall be considered fixed, and any changes shall be substantiated and authorized by the CEA. PCDs shall satisfy requirements and define key process variables of an applicable process specification. For parts produced using the L-PBF process, feedstock shall comply with AMS7015 Class A requirements.

3.2. Order of Operations

After build completion, additional processes may be required to meet part requirements. Those processes shall be applied in the following order according to the respective classes stated in section 1.2 as shown in Table 3 below:

Table 3: Order of Operations

Class A	Class B	Class C
1. Powder Removal	1. Powder Removal	1. Powder Removal
2. Vacuum Stress Relief	2. Vacuum Stress Relief	2. Vacuum Stress Relief
3. Build Plate and Support Removal	3. Build Plate and Support Removal	3. Build Plate and Support Removal
4. Hot Isostatic Press	4. Final Machining	
5. Final Machining		

3.3. Heat Treatments

Heat treatment furnaces, temperature recording, other equipment, and working zone temperature surveys shall be in accordance with AMS2801 however the heat treatment temperatures are as defined below. Any interrupted cycle may be resumed.

3.3.1. Class A

A completed Class A heat treatment includes VSR and HIP cycles as defined in the subsections below. All parts and components shall be post-processed in the order defined in section 3.2.

3.3.1.1. Vacuum Stress Relief

VSR shall be performed at 1292°F ± 14°F (700°C ± 8°C) for 1 hour in vacuum. Cooling shall take place at 30°F (17°C) per minute to 599°F (315°C). Cooling below 599°F (315°C) can then be cooled at any rate in air.

3.3.1.2. Hot Isostatic Pressing

HIP shall be performed at 1499°F ± 25°F (815°C ± 14°C) for a minimum of 2 hours + 30 minutes and at a pressure of 28.3 ksi ± 0.7 ksi (195 ± 5 MPa). Cooling shall take place at 30°F (17°C) per minute in an inert atmosphere until the workpiece is below 797°F (425°C). Cooling below 797°F (425°C) can then be cooled at any rate.

3.3.2. Class B and C

A completed Class B or C heat treatment only includes VSR as defined in section 3.3.1.1.

4. Requirements

All requirements apply after heat treatment.

4.1. Chemical Composition

All parts and components produced in accordance with this specification under any classification shall have a chemical composition that complies with AMS7028. The chemical composition requirements can be found in AMS7028 Table 1.

Composition variations shall comply with the check analysis requirements in AMS2249.

4.2. Tensile Properties

4.2.1. Build Cycle Release Specimen Requirements

Test specimens and parts shall be manufactured and heat treated in the same cycle. The diameter of these witness specimen blanks shall be built to a 0.6 inch thickness or diameter. Testing specimens shall be machined in accordance with their applicable standard after being heat treated to desired class in accordance with section 3.3. A sufficient number of specimens should be built in the event a second specimen is needed.

4.2.2. Minimum Property Requirements

Specimens either extracted from parts or machined from near net test coupons shall adhere to ASTM E8/E8M standard using round Small Size Specimen 3 (0.25-inch diameter and 1 inch gauge length). The roughness average (Ra) of machined specimens shall be 63 µin or better. Testing shall start at an initial strain of 0.005in/in/min. After yielding, a secondary speed of 0.1in/in/min shall be engaged. Specimens built in other orientations shall also meet or exceed the requirements set out in Table 4. The minimum tensile requirements below apply to all material classes specified in section 1.2.

Table 4: Minimum Tensile Requirements

Test Temperature	Ultimate Tensile Strength (ksi)	0.2% Yield Strength (ksi)	Elongation, %
Room Temperature	149	135	11

4.3. Microstructure

Photomicrographs of parts or specimens shall be taken in accordance with ASTM E3 and ASTM E407 at a magnification of 50x minimum. The microstructure inspection plane shall be parallel to the build direction (ZX plane). The microstructure shall be composed of alpha (α) laths within prior beta (β) grains and intergranular β, as defined in AS1814. No visible cracks, or inclusions shall be present on test specimens. Photomicrographs shall be provided in a high-resolution digital format.

4.4. Alpha Case

No Alpha case allowed.

4.5. Density

The density of parts and specimens shall meet the minimum requirement of 0.158 lb/in³ measured in accordance with ASTM B311.

4.6. Hardness

The parts and specimens shall also achieve a minimum average Rockwell C Hardness of 35. The hardness measurements shall be determined in accordance with ASTM E18.

4.7. Porosity

A test specimen or part processed in accordance with section 3.2 shall meet porosity requirements. Porosity area fraction shall be measured across the entire region (average area fraction). The maximum single defect size, for voids, non-melted particles, pores, etc., shall not exceed 0.055 inch (1.4 mm).

5. Operational Qualification Requirements

Operational Qualification (OQ) testing requirements are defined within ND-ME 001, *Standard Specification for Additive Manufacturing Laser Powder Bed Fusion Operational Qualification*. Applicable OQ tests for each material class are listed in Table 5.

Table 5: OQ Tests Required for each Material Class

Material Class	4.1 Chemistry	4.2.2 Tensile	4.3 Microstructure	4.6 Porosity	5.1 & 5.2 Fatigue
A	X	X	X	X	
B	X	X	X	X	
C	X	X	X	X	X

It is important to note that fatigue testing is not required for build cycle release. It is only required for OQ.

5.1. Fatigue Specimen Requirements

Test specimens shall be manufactured and heat treated in accordance with Class C requirements as outlined in section 3.2. The fatigue specimens and parts shall be manufactured and heat treated in the same cycle, and surfaces shall be left in the as-printed condition. A sufficient number of specimens should be built in the event a second specimen is needed.

5.2. Fatigue Requirements

The as-printed fatigue specimens manufactured shall adhere to ASTM E606 standards with a gauge length of 0.5 inches. Low Cycle Fatigue (LCF) testing shall be carried out at an R-ratio of 0 and at the specified alternating stress levels in Table 6. Specimens shall be strain controlled at a frequency of 0.5 Hz for the first 24 hours before switching over to load control. The runout for LCF testing shall be set at 2 million cycles. Specimens built in all orientations shall meet or exceed the requirements set out in Table 6.

Table 6: Class C Minimum Fatigue Requirements

Test Temperature	Surface Condition	Single Amplitude Alternating Stress (ksi)	Number of Cycles
RTA	As-Printed	26	110,400
		41	14,800

6. Verification

6.1. Testing

The producer shall be responsible for performing all required tests. Composition (see 4.1), Tension (see 4.2), microstructure (see 4.3), density (see 4.4), hardness (see 4.6), and porosity (see 4.7) testing shall be performed in the final heat-treated condition for each build cycle.

6.2. Reporting

6.2.1. Certificate of Test

A certificate of test shall be provided for all builds displaying test results of all required tests and analyses. The test shall verify compliance with this specification. The certificate of test shall contain the following information in addition to numerical results:

- Specification number and associated class
- Producer’s name
- L-PBF Machine make and model
- Lot number
- Serial number for each part and/or specimen traceable to build number, powder lot, and heat treatment.
- Test method performed

6.2.2. Heat Treatment Certificates

Certificates for heat treatment shall be furnished to verify all heat treatments adhere to this specification.

7. Rejections

Any specimens or parts that fail to meet this specification, or approved modifications authorized by the CEA, may be rejected.

8. Delivery

8.1. Markings and Identification

Parts and components shall have proper identification associated with a technical data package (TDP) or testing plan.

8.2. Packaging

All components shall be packaged in a manner that ensures they remain free from contamination, and any potential damage or loss during storage, handling, or shipping can be effectively mitigated. Packaging of shipment shall follow commercial rules and safety practices to ensure carrier acceptance and safe delivery.