AEROSPACE MATERIAL SPECIFICATION

AMS4994	REV. A

Issued 1992-07
Revised 2006-03
Reaffirmed 2015-03

Superseding AMS4994

Titanium Alloy Powdered Metal Products
6Al - 4V
Hot Isostatically Pressed, Annealed

(Composition similar to UNS R56400)

RATIONALE

AMS4994A has been reaffirmed to comply with the SAE five-year review policy.

1. SCOPE:

1.1 Form:

This specification covers powdered metal products consolidated by hot isostatic pressing (HIP) of titanium alloy powder compacts.

1.2 Application:

These products have been used typically for complex-shaped powdered metal products made to near net shape dimensions with properties similar to wrought products, but usage is not limited to such applications.

2. APPLICABLE DOCUMENTS:

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue 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.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
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SAE WEB ADDRESS: **http://www.sae.org**

SAE values your input. To provide feedback on this Technical Report, please visit
http://www.sae.org/technical/standards/AMS4994A

2.1 SAE Publications:

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AMS 2249	Chemical Check Analysis Limits, Titanium and Titanium Alloys
AMS 2750	Pyrometry
AMS-STD-2154	Inspection, Ultrasonic, Wrought Metals, Process For
AMS 4998	Titanium Alloy Powder, 6Al - 4V, Premium Quality

2.2 ASTM Publications:

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM B 311	Density Determination for Powder Metallurgy Materials Containing Less than Two Percent Porosity
ASTM E 8	Tension Testing of Metallic Materials
ASTM E 8M	Tension Testing of Metallic Materials (Metric)
ASTM E 399	Plane-Strain Fracture Toughness of Metallic Materials
ASTM E 539	Standard Test Method for X-Ray Emission Spectrometric Analysis of 6Al-4V Titanium Alloy
ASTM E 1409	Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Technique
ASTM E 1417	Liquid Penetrant Examination
ASTM E 1447	Determination of Hydrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Thermal Conductivity Method
ASTM E 1742	Radiographic Examination
ASTM E 1941	Standard Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys
ASTM E 2371	Standard Test Method for Analysis of Titanium and Titanium Alloys by Atomic Emission Plasma Spectrometry

2.3 ANSI Publications:

Available from ANSI American National Standards Institute, 25 West 43rd Street, New York, NY 10036, Tel: 212-642-4900, www.ansi.org.

ANSI B46.1	Surface Texture

3. TECHNICAL REQUIREMENTS:

3.1 Powder:

The powder used to make products shall conform to AMS 4998 and shall be derived from prealloyed stock. Comminuted hydrided stock is not permitted.

3.2 Composition:

Parts shall conform to the percentages by weight shown in Table 1; carbon shall be determined in accordance with ASTM E 1941, hydrogen in accordance with ASTM E 1447, oxygen and notrogen in accordance with ASTM E 1409, , and other elements in accordance with ASTM E 539 or ASTM E 2371. Other analytical methods may be used if acceptable to the purchaser.

TABLE 1 - Composition

Elements	min	max
Aluminum	5.50	6.75
Vanadium	3.50	4.50
Oxygen	0.13	0.20
Iron	--	0.30
Carbon	--	0.10
Tin (3.2.1)	--	0.10
Molybdenum (3.2.1)	--	0.10
Copper (3.2.1)	--	0.10
Manganese (3.2.1)	--	0.10
Zirconium	--	0.10
Nitrogen	--	0.05
Hydrogen	--	0.0125 (125 ppm)
Yttrium (3.2.2)	--	0.0050 (50 ppm)
Other Elements, each (3.2.2)	--	0.10
Other Elements, total (3.2.2)	--	0.30
Titanium	remainder	

3.2.1 The combined contents of tin, molybdenum, copper, and manganese shall not exceed 0.20%.

3.2.2 Determination not required for routine acceptance.

3.2.3 Check Analysis: Composition variations shall meet the applicable requirements of AMS 2249.

3.3 Condition:

Annealed.

3.4 Heat Treatment:

Powdered metal products shall be annealed by heating under vacuum or in argon and/or helium to a temperature within the range 1275 to 1600 °F (691 to 871 °C), holding at the selected temperature within ±25 °F (±14 °C) for four hours ± 0.25 and furnace cooling under vacuum or in argon and/or helium. Pyrometry shall be in accordance with AMS 2750.

3.5 Consolidation Process:

3.5.1 Powder shall be compacted in a single gas-hot-isostatic-pressing (HIP) cycle. Pressing parameters of time, temperature, and pressure shall be selected to provide parts that conform to the requirements of 3.6.

3.5.2 All consolidation shall be performed below 1750 °F (954 °C).

3.5.3 When metal containers are used to hold the powder during consolidation, all evidence of the metal container shall be removed mechanically or chemically before annealing.

3.6 Properties:

Powdered metal products shall conform to the following requirements:

3.6.1 Thermally-Induced Porosity (TIP): The degree of TIP in consolidated parts shall not exceed 0.3% or other value agreed upon by the purchaser and vendor, determined as in 3.6.1.1.

3.6.1.1 A sample weighing 0.01 to 0.1 pound (4.5 to 45.5 grams) shall be cut from an annealed compact. The sample density shall be determined in accordance with ASTM B 311. The sample shall then be heated in a vacuum at 2200 to 2300 °F (1204 to 1260 °C) and 10-3 Torr maximum pressure for not less than two hours. No backfilling shall be permitted and vacuum shall be held until temperature falls below 700 °F (371 °C). The percent change in density expressed as the difference in density divided by the final density and multiplied by 100 shall be defined as the degree of TIP.

3.6.2 Tensile Properties: Shall be as specified in Table 2, determined in accordance with ASTM E 8 or ASTM E 8M.

TABLE 2 - Minimum Tensile Properties

Property	Value
Tensile Strength	130 ksi (896 MPa)
Yield Strength at 0.2% Offset	120 ksi (827 MPa)
Elongation in 4D or 2 Inches (50.8 mm)	10%
Reduction of Area*	25%
*For cylindrical specimens only	

3.6.2.1 Requirements for products from which tensile specimens cannot be obtained due to size limits shall be as agreed upon by purchaser and vendor.

3.6.3 Fracture Toughness: When specified, the minimum plane strain fracture toughness shall be 65 ksi $\sqrt{\text{inch}}$ (71 MPa $\sqrt{\text{m}}$) for any orientation, determined in accordance with ASTM E 399. Location and orientation of specimens shall be as specified on the engineering drawing; if not specified, location and orientation are optional.

3.6.4 Microstructure: The microstructure of finished products in any region shall be homogeneous and free of inclusions and voids and shall exhibit equiaxed alpha in a transformed beta matrix or equiaxed alpha and elongated alpha in a transformed beta matrix. Continuous alpha along prior beta boundaries or other evidence of beta region exposure, a surface layer of predominantly alpha phase (alpha case), and/or evidence of prior particle boundaries are not acceptable. Examinations shall be made on etched samples at up to 250X magnification. Edges and corners shall be examined to show consolidation and absence of contamination.

3.6.5 Radiographic Inspection: Shall be in accordance with ASTM E 1742, Quality Level 2, and shall shown no evidence of any high- or low-density inclusions.

3.6.6 Ultrasonic Inspection: When specified, shall be in accordance with AMS-STD-2154, acceptance Class AA. Inspection type, PM standard blocks, and other inspection parameters shall be as agreed upon by purchaser and vendor.

3.6.7 Penetrant Inspection: Product shall be inspected in accordance with ASTM E 1417, Type 1, method optional, sensitivity Level 2. Products with any of the following conditions are not acceptable:

Linear indications (length = 3 x width).
Rounded indications 1/32 inch (0.8 mm) and larger.
More than 10 porosity indications in any 1 square inch (645 mm^2) area.

3.6.8 Texture: Surface texture shall be 125 microinches (3.18 µm) or smoother determined in accordance with ANSI B46.1.

3.7 Quality:

Powdered metal products, as received by purchaser, shall be uniform in quality and condition, sound, and free of foreign materials and imperfections detrimental to usage of the parts.

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection:

The supplier of products shall provide all samples for supplier's tests and shall be responsible for the performance of all required tests. Purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the product conforms to specified requirements.

4.2 Classification of Tests:

Tests for all technical requirements are acceptance tests and preproduction tests and shall be performed prior to or on the initial shipment of product to a purchaser, on each lot, when a change in material and/or processing requires reapproval as in 4.4, and when purchaser deems confirmatory testing to be required.

4.3 Sampling and Testing:

Shall be as follows; a lot shall be all products of a single design, produced from the same powder lot or blend, compacted in the same consolidation cycle, post compaction heat treated in the same furnace load, and presented for supplier's inspection at one time:

4.3.1 For Acceptance Tests: Specimens shall be taken from products, prolongations, or material adjacent to the product. Results from the following tests shall be forwarded to purchaser before or with any shipment of product:

4.3.1.1 One sample from each lot for composition (3.2), thermally induced porosity (3.6.1), fracture toughness (3.6.3) when specified, microstructure (3.6.4), and surface texture (3.6.8).

4.3.1.2 Two samples from each lot for tensile properties (3.6.2).

4.3.1.3 Each product in each lot for radiographic inspection (3.6.5), ultrasonic inspection (3.6.6) when specified, and penetrant inspection (3.6.7).

4.3.2 For Preproduction Tests: Specimens may be taken from sacrificial powdered metal products, products instrumented for temperature monitoring, and material adjacent to products such as fill tubes. In some cases products shall be augmented with a prolongation specifically for specimens. Prolongation design and any controls on specimen location and orientation shall be specified on the drawing. Prior to the initial shipment of any product, the supplier shall forward to purchaser the results of a process preproduction program consisting of the following tests and any other tests specified on the drawing or purchase order.

4.3.2.1 One sample from each of two products for composition (3.2) and thermally induced porosity (3.6.1).

4.3.2.2 One sample from one product and five samples from products or prolongations for tensile properties (3.6.2).

4.3.2.3 One sample from one product and two samples from products or prolongations for fracture toughness (3.6.3).

4.3.2.4 Two samples from each of three products or prolongations for microstructure (3.6.4).

4.3.2.5 Each product for radiographic inspection (3.6.5), ultrasonic inspection (3.6.6) when required, and penetrant inspection (3.6.7).

4.3.2.6 One sample from each of three products for surface texture inspection (3.6.8).

4.4 Approval:

4.4.1 The supplier of powdered metal products shall establish a written process description of manufacture and inspection for each product number prior to and during preproduction. The description shall include control factors and parameters that provide products meeting the requirements of this specification. Control factors considered proprietary by vendor may be assigned codes within the process description. Each variation in such control factors shall be assigned a modified code designation. The vendor shall maintain a complete record of all proprietary factors and codes. These factors shall include, but are not limited to, the following:

Type and source of powder
Compaction concept
Mold design (fill tube location)
Compaction parameters and sequence, type of gas, times, temperatures, pressures
Post compaction cleaning and annealing methods and annealing parameters
Sequence of all chemical and/or heat treatments
Inspection procedures, standards, parameters