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INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE MATERIAL SPECIFICATION

SAE AMS 4994

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Reaffirmed AUG 2000

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

UNS R56400

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 following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 2249	Chemical Check Analysis Limits, Titanium and Titanium Alloys
AMS 2750	Pyrometry
AMS 4998	Titanium Alloy Powder, 6Al - 4V, Premium Quality

QUESTIONS REGARDING THIS DOCUMENT: (724) 772-7161 FAX: (724) 776-0243
TO PLACE A DOCUMENT ORDER: (724) 776-4970 FAX: (724) 776-0790
SAE WEB ADDRESS: http://www.sae.org

2.2 ASTM Publications:

Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM B 311	Density of Cemented Carbides
ASTM E 8	Tension Testing of Metallic Materials
ASTM E 8M	Tension Testing of Metallic Materials (Metric)
ASTM E 120	Chemical Analysis of Titanium and Titanium Alloys
ASTM E 399	Plane-Strain Fracture Toughness of Metallic Materials

2.3 U.S. Government Publications:

Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-453	Inspection, Radiographic
MIL-STD-2154	Inspection, Ultrasonic, Wrought Metals, Process for
MIL-STD-6866	Inspection, Liquid Penetrant
MIL-STD-2073-1	DOD Materiel, Procedures for Development and Application of Packaging Requirements

2.4 ANSI Publications:

Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

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, determined, after all thermal and chemical processing, by wet chemical methods in accordance with ASTM E 120, by spectrochemical methods, or by other analytical methods acceptable to 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 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 B311. 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 MIL-STD-453, 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 MIL-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 MIL-STD-6866, 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 performing all required tests. Purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the product conforms to the requirements of this specification.

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.

4.2.1 For direct U.S. Military procurement, substantiating test data and, when requested, preproduction test material shall be submitted to the cognizant agency as directed by the procuring activity, contracting officer, or request for procurement.

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

4.4.2 Prior to the initial shipment of products of a particular design, the supplier shall submit results of preproduction tests and, when requested, a copy of the process description for approval by the cognizant engineering organization.

4.4.3 The supplier shall not change the process description and shall make no significant change to materials, processes, or controls referenced in the process description, unless the change is approved by the cognizant engineering organization. A significant change is one which in the judgment of the cognizant engineering organization, could affect the properties or performance of the product.

4.5 Reports:

4.5.1 Prior to the initial shipment of product, the supplier shall forward to purchaser the results of a completed preproduction program for approval. The report shall include the results of tests required in 4.3.2 and the process description and codes required in 4.4.1.

4.5.2 The supplier of product shall furnish with each shipment a report showing the results of all tests to determine conformance to the requirements of 4.3.1. This report shall include the purchase order number, part number, lot number, AMS 4994, and quantity.

4.6 Resampling and Retesting:

If any sample representing the lot in tests 3.2, 3.6.1, or 3.6.2 fails to meet the specified requirements, disposition of the lot may be based on the results of testing three additional samples for each original nonconforming specimen. Failure of any retest results to meet specified requirements shall be cause for rejection of the lot represented. Results of all tests shall be reported.