AEROSPACE MATERIAL SPECIFICATION

AMS4993™ REV. G

Issued 1982-01
Revised 2023-11

Superseding AMS4993F

Titanium Alloy, Blended Powder Compacts, Sintered
6Al - 4V
(Composition similar to UNS R56400)

RATIONALE

AMS4993G result from a Five-Year Review and update of the specification with changes to prohibit unauthorized exceptions (see 3.6, 4.5.1, 5.1.1, and 8.4), relocate Definitions (see 2.4), update Applicable Documents (see Section 2, 3.1.4, and 3.5.3), Surface Roughness (see 3.5.3), and Ordering Information (see 8.6), and allow use of the immediate prior specification revision (see 8.5).

1. SCOPE

1.1 Form

This specification covers a titanium alloy in the form of compacts produced by pressing and sintering a blend of elemental titanium powder and aluminum-vanadium alloy powder (see 8.6).

1.2 Application

These compacts have been used typically for light weight nuts (B-nuts) used for connecting fluid lines to fittings and to equipment, and for other small high-quantity miscellaneous hardware, but usage is not limited to such applications.

1.2.1 Certain processing procedures and service conditions may cause these products to become subject to stress-corrosion cracking; ARP982 recommends practices to minimize such conditions.

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.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS2249 Chemical Check Analysis Limits, Titanium and Titanium Alloys

AMS2644 Inspection Material, Penetrant

ARP982	Minimizing Stress-Corrosion Cracking in Wrought Titanium Alloy Products
AS7766	Terms Used in Aerospace Metals Specifications

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 B311	Density of Powder Metallurgy (PM) Materials Containing Less Than Two Percent Porosity
ASTM E8/E8M	Tension Testing of Metallic Materials
ASTM E539	Analysis of Titanium Alloys by Wavelength Dispersive X-Ray Fluorescence Spectrometry
ASTM E1409	Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by Insert Gas Fusion.
ASTM E1417/E1417M	Liquid Penetrant Testing
ASTM E1447	Determination of Hydrogen in Reactive Metals and Reactive Metal Alloys by Inert Gas Fusion with Detection by Thermal Conductivity or Infrared Detection
ASTM E1742/E1742M	Radiographic Examination
ASTM E1941	Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis
ASTM E2371	Analysis of Titanium and Titanium Alloys by Direct Current Plasma and Inductively Coupled Atomic Emission Plasma Spectrometry (Performance-Base Test Methodology)
ASTM E2994	Analysis of Titanium and Titanium Alloys by Spark Atomic Emission Spectrometry and Glow Discharge Atomic Emission Spectrometry (Performance-Based Method)

2.3 ASME Publications

Available from ASME, P.O. Box 2900, 22 Law Drive, Fairfield, NJ 07007-2900, Tel: 800-843-2763 (U.S./Canada), 001-800-843-2763 (Mexico), 973-882-1170 (outside North America), www.asme.org.

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

2.4 Definitions

Terms used in AMS are defined in AS7766.

3. TECHNICAL REQUIREMENTS

3.1 Composition

Shall be that resulting from blending elemental titanium powder as in 3.1.3 and aluminum-vanadium alloy powder as in 3.1.4 and shall conform to the percentages by weight shown in Table 1, after pressing and sintering. Carbon shall be determined in accordance with ASTM E1941, hydrogen in accordance with ASTM E1447, oxygen and nitrogen in accordance with ASTM E1409, and other elements in accordance with ASTM E539, ASTM E2371, or ASTM E2994. Other analytical methods may be used if acceptable to the purchaser.

Table 1 - Composition

Element	Min	Max	
Aluminum (3.1.1)	5.50	6.75	
Vanadium (3.1.1)	3.50	4.50	
Iron	--	0.30	
Oxygen	--	0.30	
Sodium	--	0.15	
Chlorine	--	0.15	
Carbon	--	0.10	
Silicon	--	0.05	
Nitrogen	--	0.05	(500 ppm)
Hydrogen	--	0.01	(100 ppm)
Other Elements, each	--	0.10	
Other Elements, total	--	0.40	
Titanium	remainder		

3.1.1 The difference in aluminum concentration and vanadium concentration among three different locations in a lot of blended powder shall be not greater than 0.4%.

3.1.2 Check Analysis

Compositional variations shall meet the applicable requirements of AMS2249.

3.1.3 Titanium Powder Composition

Shall conform to the percentages by weight shown in Table 2, determined as in 3.1.

Table 2 - Titanium powder composition

Element	Min	Max	
Iron	--	0.20	
Oxygen	--	0.20	
Sodium	--	0.20	
Chlorine	--	0.20	
Carbon	--	0.06	
Silicon	--	0.05	
Nitrogen	--	0.03	(300 ppm)
Hydrogen	--	0.015	(150 ppm)
Other Elements, each	--	0.10	
Other Elements, total	--	0.40	
Titanium	remainder		

3.1.4 Alloying Powder Composition

Shall conform to the percentages by weight shown in Table 3, determined by analytical methods acceptable to the purchaser.

Table 3 - Alloy powder composition

Element	Min	Max
Aluminum	56	64
Vanadium	38	42
Other Elements, total	--	3.0

3.2 Condition

As sintered at not lower than 2100 °F (1149 °C).

3.3 Powder Lot Control

The titanium 6Al-4V powder shall be blended in lots by a suitable process in a noncontaminating facility. A powder lot shall be all powder produced as a single mixture in one production blend of titanium powder and aluminum-vanadium alloy powder.

3.3.1 Whenever a production run of sintered compacts does not require an entire lot of blended powder, the powder used shall be identified as a sub lot. The identity of sub lots in a basic powder lot shall be maintained.

3.3.2 Unused portions of qualified powder lots not of sufficient size for a production run of sintered compacts may be added to, and blended with, titanium and aluminum-vanadium alloy powders in the production of a new powder lot. In that event, the requirements of Table 1 shall apply to the final powder lot.

3.4 Properties

Sintered compacts shall conform to the following requirements:

3.4.1 Tensile Properties

Shall be as shown in Table 4, determined in accordance with ASTM E8/E8M on specimens, of the same powder lot, sintered with the parts represented.

Table 4 - Minimum tensile properties

Property	Value	
Tensile Strength	130 ksi	(896 MPa)
Yield Strength at 0.2% Offset	120 ksi	(827 MPa)
Elongation in 4D	10%	
Reduction in Area	10%	

3.4.2 Proof Test

Sintered compacts shall pass a proof or failure test conducted by a procedure developed by the manufacturer and for which a correlation with the tensile properties of 3.4.1 has been established for each configuration and size of sintered compact.

3.4.3 Density

Shall be not lower than 0.157 pound per cubic inch (4346 kg/m^3), determined in accordance with ASTM B311 or other method agreed upon by the purchaser and producer.

3.4.4 Microstructure

The microstructure of the compacts shall be alpha and beta phases. The alpha phase may have different shapes such as acicular or lamellar, plate-like, equiaxed, serrated, or Widmanstätten (basketweave). A continuous network of alpha in prior beta grain boundaries is acceptable. In additon, the microstructure shall be homogeneous and free from inclusions, alloy segregation, laminations, and alpha case. Compacts shall also be free from interconnecting voids, porosity in excess of 0.010 inch (0.25 mm) in maximum dimension, and linear porosity in excess of 0.006 inch (0.15 mm) in maximum dimension.

3.4.4.1 Microstructure and porosity shall be determined by metallographic examination at 100 to 500X magnification except 400 to 500X magnification shall be used for alpha case, after suitably polishing, or polishing and etching, as appropriate. Adjacent pores shall be treated as a single pore if they are closer to each other than the largest pore maximum dimension. Porosity whose length is more than three times its width shall be considered linear porosity.

3.5 Quality

Sintered compacts, as received by the purchaser, shall be uniform in quality and condition, clean, and free of defects such as cracks, seams, grooves, laminations, pits, inclusions, and surface oxidation and from other imperfections detrimental to their usage.

3.5.1 Sintered compacts shall be free from cracks, porosity, and other surface imperfections, determined by fluorescent penetrant inspection in accordance with ASTM E1417/E1417M using AMS2644 Type 1 Level 3 penetrant.

3.5.2 Sintered compacts shall be free from low- and high-density inclusions and inhomogeneity, determined by radiographic inspection in accordance with ASTM E1742/E1742M.

3.5.3 Average Roughness (Ra) of sintered compacts shall not exceed 125 µin (3.2 µm), determined in accordance with ASME B46.1.

3.6 Exceptions

Any exceptions shall be authorized by the purchaser and reported as in 4.5.1

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The producer of sintered compacts shall supply all samples for the producer's tests and shall be responsible for the performance of all required tests. The purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the sintered compacts conform to specified requirements.

4.2 Classification of Tests

4.2.1 Acceptance Tests

The following requirements are acceptance tests and shall be performed as specified in 4.2.1.1 and 4.2.1.2:

4.2.1.1 Powder Lot

On each powder lot prior to use for production of sintered compacts:

4.2.1.1.1 Composition (see 3.1).

4.2.1.1.2 Blend uniformity check analysis on aluminum and vanadium contents (see 3.1.1).

4.2.1.1.3 Tensile properties (see 3.4.1).

4.2.1.1.4 Density (see 3.4.3).

4.2.1.1.5 Microstructure (see 3.4.4).

4.2.1.2 Part Lot

On each lot of sintered compacts from each sinter run:

4.2.1.2.1 Composition (see 3.1).

4.2.1.2.2 Tensile properties (see 3.4.1).

4.2.1.2.3 Proof test (see 3.4.2), density (see 3.4.3), and quality (see 3.5).

4.2.1.2.4 Microstructure (see 3.4.4).

4.2.2 Preproduction Tests

All technical requirements are preproduction tests and shall be performed prior to or on the first-article shipment of sintered compacts to a purchaser, when a change in ingredients and/or processing requires approval by the cognizant engineering organization (see 4.4.2), and when the purchaser deems confirmatory testing to be required.

4.3 Sampling and Testing

Shall be in accordance with 4.3.1 and 4.3.2. A powder lot shall be all powder blended from the same batches of titanium and aluminum-vanadium powders in a single blending operation; a lot of sintered compacts shall be all sintered compacts of the same configuration produced from one powder lot in one production run using the same equipment and processing procedures in one sinter furnace load and presented for the producer's inspection at one time.

4.3.1 For Acceptance Tests

4.3.1.1 Powder Lot

4.3.1.1.1 One pressed and sintered test specimen for composition.

4.3.1.1.2 Three pressed and sintered specimens taken from three different locations in the blend for aluminum and vanadium uniformity checks.

4.3.1.1.3 Twelve pressed and sintered test specimens for tensile properties and density.

4.3.1.1.4 Two pressed and sintered test specimens for microstructure.

4.3.1.2 Part Lot

4.3.1.2.1 One sintered compact for composition.

4.3.1.2.2 One pressed and sintered test specimen for tensile properties.

4.3.1.2.3 Sintered compacts as specified in Table 5, selected at random from the lot, for proof tests, density, and quality.

Table 5 - Sampling for proof test, density, and quality

Number of Inspection Units in the Lot	Proof Test (3.4.2) and Density (3.4.3)	Quality (3.5)
Up to 99	2	4
100 to 299	3	6
300 to 599	4	8
600 to 999	5	10
1000 to 1499	6	12
1500 to 1999	7	14
2000 to 2999	8	16
3000 to 3999	9	18
4000 to 5999	10	20
6000 to 10000	12	24
Over 10000	15	30

4.3.1.2.4 One sintered compact for microstructure.

4.3.2 For Preproduction Tests

As agreed upon by the purchaser and producer (see 8.6).

4.4 Approval

4.4.1 The producer of compacts 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 the producer may be assigned codes within the process description. Each variation in such control factors shall be assigned a modified code designation. The producer shall maintain a complete record of all proprietary factors and codes. These control factors shall include, but are not limited to, the following:

Powder source(s)
Blending method
Powder storage, identification, and handling procedures
Compaction sequence and parameters, including atmosphere, time, temperature, and pressure
Type of sintering furnace
Furnace calibration and leak-up rate
Size of furnace charge
Sintering sequence and parameters, including atmosphere, time, and temperature
Material on which the pressed compacts rest during sintering
Whether re-sintering is permitted
Cleaning procedures and parameters
Inspection procedures, parameters, and standards

4.4.2 Prior to the initial shipment of compacts of a particular design, the supplier shall submit results of preproduction tests and, when requested, a copy of the process description for approval. Proof or failure test procedure (see 3.4.2), correlation with tensile properties, and acceptance limits shall be approved 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 that, in the judgment of the cognizant engineering organization, could affect the properties or performance of the compacts.