SAE Aerospace
An SAE International Group

AEROSPACE MATERIAL SPECIFICATION

SAE AMS4992 REV. A

Issued 2002-10
Revised 2010-04

Superseding AMS4992

Castings, Structural Investment, Titanium Alloy 6Al - 4V Hot Isostatically Pressed

(Similar to UNS R56401)

RATIONALE

AMS4992A results from a Five Year Review and update of this specification.

1. SCOPE

1.1 Form

This specification covers titanium Ti 6Al-4V alloy in the form of investment castings.

1.2 Application

These castings have been used typically for structurally cast components requiring a combination of good strength-to-weight ratio and corrosion resistance, 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.

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.

AMS2175	Castings, Classification and Inspection of
AMS2249	Chemical Check Analysis Limits, Titanium and Titanium Alloys
AMS2694	Repair Welding of Aerospace Castings
AMS2750	Pyrometry
AMS2804	Identification, Castings

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
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/AMS4992A

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 600	Descaling and Cleaning Titanium and Titanium-Alloy Surfaces
ASTM E 8 / E 8M	Tension Testing of Metallic Materials
ASTM E 539	X-Ray Emission Spectrometric Analysis of 6AI-4V Titanium Alloy
ASTM E 1320	Reference Radiographs for Titanium Castings
ASTM E 1409	Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Technique
ASTM E 1417	Liquid Penetrant Testing
ASTM E 1447	Determination of Hydrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Thermal Conductivity/Infrared Detection Method
ASTM E 1742	Radiographic Examination
ASTM E 1941	Determination of Carbon in Refractory and Reactive Metals and Their Alloys
ASTM E 2371	Analysis of Titanium and Titanium Alloys by Atomic Emission Plasma Spectrometry

3. TECHNICAL REQUIREMENTS

3.1 Composition

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 nitrogen 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

Element	min	max
Aluminum	5.50	6.75
Vanadium	3.50	4.50
Iron	--	0.30
Oxygen	0.15	0.20
Carbon	--	0.10
Nitrogen	--	0.05 (500 ppm)
Hydrogen (3.1.2)	--	0.015 (150 ppm)
Yttrium (3.1.1)	--	0.005 (50 ppm)
Other Elements, each (3.1.1)	--	0.10
Other Elements, total (3.1.1)	--	0.40
Titanium	remainder	

3.1.1 Determination not required for routine acceptance.

3.1.2 For hydrogen analysis conducted in accordance with ASTM E 1447:

Sample size may be as large as 0.35 gram.

3.1.3 Check Analysis

Composition variations shall meet the applicable requirements of AMS2249.

3.2 Melting Practice

3.2.1 Castings and specimens shall be poured at the casting vendor's facility either from a remelt (See 8.2.3) of a master heat or directly from a master heat (See 3.2.2).

3.2.1.1 Remelt for Casting

The metal for castings and specimens shall be remelted and poured under inert gas pressure in accordance with 3.2.2.1, or under vacuum without loss of vacuum between melting and pouring.

3.2.1.2 If authorized by purchaser (See 8.2.4), portions of two or more qualified master heats of 3.2.3 may be remelted together and poured into castings using a procedure acceptable to purchaser.

3.2.1.3 Remelt for casting shall be performed using consumable electrode-practice or other method authorized by purchaser.

3.2.2 Master Heat Preparation

A master heat shall be prepared from any combination of elemental and revert materials which are melted and refined as necessary in a single furnace charge. Single or multiple melting shall be accomplished using consumable electrode, nonconsumable electrode, electron beam, or plasma arc practice(s).

3.2.2.1 The atmosphere for melting shall be vacuum or shall be argon and/or helium at an absolute pressure not higher than 1000 millimeters of mercury.

3.2.2.2 Revert (gates, sprues, risers, and rejected castings) may be used in the preparation of master heats; revert shall not be remelted directly, without refining, for pouring of castings. Melting of revert creates a new master heat.

3.2.2.3 Solidification of the master heat into pigs or ingots before remelting and pouring of castings is permitted.

3.2.2.4 The master heat source shall establish effective control procedures, including parameters for the critical variables that will consistently produce material suitable for remelting of castings, meeting the requirements of this specification. Control procedures shall be acceptable to purchaser and casting vendor.

3.2.3 Master Heat Qualification

Each master heat shall be qualified by chemical analysis and tensile specimens.

3.2.3.1 Separately cast specimens may be used for qualification of master heats only. Master heats may also be qualified using integrally-cast specimens (See 8.2.5) or specimens machined from a casting and shall conform to 3.2.1.

3.2.3.2 The acceptance tests of 4.2.1 may be used to satisfy the qualification requirements of 3.2.3.

3.3 Condition

3.3.1 All castings shall be hot isostatically pressed.

3.3.2 A separate annealing operation may be performed, at the vendor's option, but it is not required unless specified by the purchaser.

3.3.3 The vendor shall record the type of thermal processing performed as a control factor of 4.4.2.2.

3.3.4 If welding is performed (See 3.7.4.1), castings shall be hot isostatically pressed and/or annealed after welding (See 3.7.4.2).

3.4 Test Specimens

3.4.1 Chemical Analysis Specimens

Shall be of any convenient size and shape.

3.4.2 Tensile Specimens

Sample material shall be of sufficient size to permit the preparation of round tensile specimens of 0.250 inch (6.35 mm) diameter conforming to ASTM E 8 / E 8M with a gage length of 1 inch (25.4 mm). When agreed upon by purchaser and vendor (See 8.2.6), specimens may be of different size, or may be flat, rectangular, or cast-to-size (See 8.5 and 8.6).

3.4.2.1 Integrally-Cast Specimens

Shall be prepared from sample material attached to castings and tested for tensile property determination as specified in Table 2. Unless otherwise specified by purchaser, the following shall apply:

3.4.2.1.1 Sample material quantity(s), location(s), and thickness(es) shall be agreed upon by purchaser and vendor (See 8.4). Additional sample material may be added for retesting or for foundry purposes, at the option of the foundry.

3.4.2.1.2 Sample material shall remain attached to the casting until completion of hot isostatic pressing and heat treatment. When acceptable to purchaser, sample material may be removed to accommodate straightening or other processing, in which case each removed sample shall be identified for traceability and processed with casting(s) through all subsequent operations.

3.4.2.2 Specimens Machined from Castings

Shall be excised and tested for tensile property determination as specified in Table 2. The quantity(s) and location(s) shall be as agreed upon by purchaser and vendor (See 8.4).

3.4.3 After machining and chemical cleaning, tensile specimens shall be free of oxygen-rich layer, such as alpha case, or other surface contamination.

3.5 Thermal Processing

Castings and representative tensile specimens shall be hot isostatically pressed in accordance with 3.5.1. When performed (See 3.3.2), annealing shall be in accordance with 3.5.2.

3.5.1 Hot Isostatic Press

Process in inert atmosphere at not less than 14.5 ksi (100 MPa) within the range 1650 to 1750 °F (899 to 954 °C), hold at the selected temperature within ±25 °F (±14 °C) degrees for 2 to 4 hours, and cool under inert atmosphere in the autoclave to below 800 °F (427 °C).

3.5.2 Anneal

Process in vacuum or inert atmosphere at a temperature within the range 1300 to 1550 °F (704 to 843 °C), hold at the selected temperature within ±25 °F (±14 °C) degrees for 2 to 4 hours, and cool in the furnace to below 1000 °F (538 °C). Pyrometry shall be in accordance with AMS2750.

3.6 Properties

Castings and representative specimens shall conform to the following requirements;

3.6.1 Room Temperature Tensile Properties

Shall be as specified in 3.6.1.1, determined in accordance with ASTM E 8 / E 8M with the rate of strain set at 0.005 inch/inch/minute (0.005 mm/mm/minute) and maintained within a tolerance of ±0.002 inch/inch/minute (0.002 mm/mm/minute) through the 0.2% offset yield strain.

3.6.1.1 Integrally Cast and Specimens Machined from a Casting

Shall be as shown in Table 2.

TABLE 2 - MINIMUM ROOM TEMPERATURE TENSILE PROPERTIES

Property	Cross Section Thickness		
	Less than 0.500 inch (Less than 12.7 mm)	0.500 to 1.500 inches, incl (12.7 to 38.1 mm, incl)	Over 1.500 to 4.000 inches (Over 38.1 to 101.6 mm)
Tensile Strength	125 ksi (861.8 MPa)	123 ksi (848.1 MPa)	120 ksi (827.4MPa)
Yield Strength at 0.2% Offset	112 ksi (772.2 MPa)	112 ksi (772.2 MPa)	110 ksi (758.4MPa)
Elongation in 4D (%)	5	4	3

3.6.1.2 When authorized by purchaser, room temperature tensile properties may be determined using separately-cast specimens, in which case sampling and testing frequency by master heat or lot shall be specified by purchaser (See 8.4).

3.6.2 Surface Contamination

Castings shall be free of any oxygen-rich layer (such as alpha case), compounds or residue from halogenated solvents, quenchants, or other surface contamination.

3.6.2.1 Cleaning shall be performed in accordance with ASTM B 600 or other method(s) acceptable to purchaser.

3.6.2.2 After cleaning, and prior to any subsequent processing involving temperatures over 500 °F (260 °C), castings shall be handled in a manner to preclude surface contamination. Handling with clean, dry, white cotton gloves is recommended.

3.7 Quality

Castings, as received by purchaser, shall be uniform in quality and condition, sound, and free from foreign materials and from imperfections detrimental to usage of the castings. Castings shall be free of cracks, laps, hot tears, and cold shuts and free of scale and other process induced surface contamination that which would obscure defects.

3.7.1 Castings shall be produced under radiographic control. This control shall consist of radiographic examination of each casting part number until foundry manufacturing controls, in accordance with 4.4.2, have been established. Additional radiography shall be conducted in accordance with the frequency of inspection specified by purchaser and as necessary to ensure continued maintenance of internal quality.

3.7.1.1 Radiographic examination shall be conducted in accordance with ASTM E 1742 or other method specified by purchaser (See 8.2.7).

3.7.2 When specified, castings shall be subjected to fluorescent penetrant testing in accordance with ASTM E 1417 or other method specified by purchaser.

3.7.3 Acceptance standards for radiographic, fluorescent penetrant, visual, surface contamination and other inspections shall be as agreed upon by purchaser and vendor.

3.7.3.1 AMS2175 may be used to specify frequency of inspection (casting class).

3.7.3.2 ASTM E 1320 may be used to specify radiographic standards (casting grade).

3.7.4 Castings shall not be peened, plugged, impregnated, or welded unless authorized by purchaser.

3.7.4.1 When authorized by purchaser, in-process welding in accordance with AMS2694 or other welding program acceptable to purchaser may be used.

3.7.4.2 Unless otherwise specified by purchaser, castings shall be hot isostatically pressed and/or annealed after welding.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The vendor of castings shall supply all samples for vendor'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 conform to specified requirements.

4.2 Classification of Tests

4.2.1 Acceptance Tests

Composition (3.1), tensile properties (3.6.1), surface contamination (3.6.2), and quality requirements (3.7) are acceptance tests and shall be performed as specified in 4.3.

4.2.2 Periodic Tests

Radiographic soundness (3.7.1) is a periodic test and shall be performed at a frequency selected by the vendor unless frequency of testing is specified by purchaser.

4.2.3 Preproduction Tests

All technical requirements are preproduction tests and shall be performed on sample castings (4.3.2), when a change in control factors (4.4.2.2) occurs, and when purchaser deems confirmatory testing to be required.

4.3 Sampling and Testing

Shall be in accordance with the following:

4.3.1 One chemical analysis specimen in accordance with 3.4.1 from each master heat or a casting from each master heat shall be tested for conformance to Table 1.

4.3.1.1 Except as specified in 4.3.1.2, hydrogen determination shall be on each lot (See 8.2.8) if chemical cleaning (See 8.2.9) is performed after thermal processing, if final anneal heat treatment is performed under inert atmosphere, or if castings are delivered in the hot isostatically pressed condition without subsequent vacuum anneal heat treatment.

4.3.1.2 Hydrogen determination is permitted on each master heat if final anneal heat treatment is performed in vacuum, and if no further chemical cleaning is performed after vacuum anneal heat treatment.

4.3.2 One preproduction casting in accordance with 4.4 shall be tested to the requirements of the casting drawing and to all technical requirements.

4.3.2.1 Dimensional inspection sample quantity shall be as specified by purchaser.

4.3.3 Tensile tests shall be conducted to determine conformance with 3.6.1. Sampling and test frequency is dependent upon the type and origin of specimen specified by purchaser (See 3.6 and 8.4) or selected by vendor (See 4.3.3.3).

4.3.3.1 For integrally-cast specimens in the representative condition of 3.5, at least two specimens from each lot (See 8.2.8) shall be randomly selected and tested for conformance with 3.6.1.1.

4.3.3.2 For specimens machined from a casting, one or more castings in the representative condition of 3.5 shall be randomly selected from each lot (See 8.2.8) and tested at each location shown on the engineering drawing for conformance with 3.6.

4.3.3.3 When acceptable to purchaser, specimens machined from a casting may be used in lieu of integrally-cast specimens. In each case, the resultant properties must conform to the requirements of 3.6.1.1 for that source.

4.3.3.3.1 When specimens are selected for test as in 4.3.3.3 from an origin other than that specified by purchaser, vendor shall include in the report of 4.5, a description of the origin of the specimen that was tested.

4.3.3.4 When casting size, section thickness, gating method, or other factors do not permit conformance to 4.3.3.1 or 4.3.3.2, the sampling and testing shall be agreed upon by purchaser and vendor.

4.3.4 Castings shall be inspected in accordance with 3.7 to the methods, frequency, and acceptance standards specified by purchaser.

4.3.5 Freedom from surface contamination shall be evaluated on a casting or representative specimen from each lot after completion of all thermal treatments, or by evaluation of castings or representative specimens taken individually from each hot isostatic press, and anneal if applicable, process batch.

4.3.5.1 Techniques used for metallographic examination shall be acceptable to purchaser.

4.3.6 Alternative sampling plans may be submitted to purchaser for approval based on evidence of past satisfactory performance. Purchaser approval is required prior to implementation of alternative sampling plans.

4.4 Approval

4.4.1 Sample casting(s) from new or reworked master patterns produced under the casting procedure of 4.4.2 shall be approved by purchaser before castings for production use are supplied, unless such approval is waived by purchaser.

4.4.2 For each casting part number, vendor shall establish parameters for process control factors that will consistently produce castings and test specimens meeting the requirements of the casting drawing and this specification. These parameters shall constitute the approved casting procedure and shall be used for production of subsequent castings and test specimens. If necessary to make any change to these parameters, vendor shall submit a statement of the proposed change for purchaser reapproval. When requested, vendor shall also submit test specimens and/or sample castings to purchaser for reapproval.

4.4.2.1 Production castings produced prior to receipt of purchaser's approval shall be at vendor's risk.

4.4.2.2 Control factors for producing castings include, but are not limited to, the following factors. Supplier's procedures shall identify tolerances, ranges, and/or control limits, as applicable.

Master heat metal source
Composition of ceramic cores, if used
Arrangement and number of patterns in the mold (including integrally-cast specimens, if applicable)
Size, shape, and location of gates and sprues
Mold refractory formulation, including prime and backup materials
Mold backup material (weight, thickness, or number of dips)
Type of furnace, atmosphere control, and charging and melting practices
Mold preheat and metal pouring temperatures
Solidification and cooling procedures
Cleaning operations (mechanical and chemical/electrochemical)
Annealing heat treatment, if applicable
Hot isostatic pressing treatment
Straightening procedures, if applicable
Final inspection methods
Location of specimens integrally cast or machined from a casting, if applicable

4.4.2.2.1 Any of the above control factors for which parameters are considered proprietary by vendor may be assigned a code designation. Each variation in such parameters shall be assigned a modified code designation.

4.4.2.2.1.1 Unless otherwise agreed upon by purchaser and vendor, purchaser shall be entitled to review proprietary control factor details and coding at vendor's facility.

4.5 Reports

The vendor shall provide a copy of the original material manufacturer’s report (material certification), including: producer name, product form, mill produced size, and country where the metal was melted (i.e., final melt in the case of metal processed by multiple melting operations).The vendor of castings shall furnish with each shipment a report showing the results of tests to determine conformance to the technical requirements. This report shall include the purchase order number, master heat identification, heat treat/HIP lot identification, AMS4992A, part number, quantity, and source of tensile property specimens (See 4.3.3.3.1).

4.6 Resampling and Retesting

If results of a valid test fail to meet specified requirements, two additional specimens in accordance with 4.3 from the same master heat or lot, as applicable, shall be tested for each non-conforming characteristic. Results of each additional test, and the average of the results of all tests (original and retests), shall meet specified requirements; otherwise, the master heat or lot shall be rejected.

Results of all tests shall be reported.

4.6.1 A test may be declared invalid if failure is due to improper specimen preparation, test equipment malfunction, improper test procedure, or the presence of random process defects, such as an inclusion, in a tensile specimen. Results of all tests shall be reported.

5. PREPARATION FOR DELIVERY

5.1 Identification

Unless otherwise specified by purchaser, individual castings shall be identified in accordance with AMS2804.