



AEROSPACE MATERIAL SPECIFICATION

AMS4992™**REV. D**Issued 2002-10
Revised 2023-08

Superseding AMS4992C

Casting, Structural Investment, Titanium Alloy 6Al - 4V
Hot Isostatically Pressed
(Composition similar to UNS R56401)

RATIONALE

AMS4992D results from a Five-Year Review and update of this specification with changes to update general agreement language related to unauthorized exceptions (8.6), relocate Definitions (2.3), update Applicable Documents (Section 2), Thermal Processing (3.5), and allow the use of the immediate prior specification revision (8.5).

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 +1 724-776-4970 (outside USA), www.sae.org.

AMS2175	Castings, Classification and Inspection of
AMS2249	Chemical Check Analysis Limits, Titanium and Titanium Alloys
AMS2694	In-Process Welding of Castings
AMS2750	Pyrometry

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SAE WEB ADDRESS:

For more information on this standard, visit
<https://www.sae.org/standards/content/AMS4992D>

AMS2804 Identification, Castings

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 B600 Descaling and Cleaning Titanium and Titanium-Alloy Surfaces

ASTM E8/E8M Tension Testing of Metallic Materials

ASTM E539 Analysis of Titanium Alloys by Wavelength Dispersive X-Ray Fluorescence Spectrometry

ASTM E1320 Reference Radiographs for Titanium Castings

ASTM E1409 Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by Inert Gas Fusion

ASTM E1417 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 Spectrometry

ASTM E1742 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 Spectrometry (Performance-Based 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 Definitions

Terms used in this AMS are clarified in AS7766 and as follows:

2.3.1 ACCEPTABLE TO THE PURCHASER

Does not require prior written approval from the purchaser but allows the producer to make a decision and the purchaser the right to disapprove the decision.

2.3.2 PURCHASER

The cognizant engineering organization responsible for casting design and fitness for use, or the designee of this engineering organization.

2.3.3 REMELT

All castings poured from a single furnace charge. Also referred to as melt, submelt, heat, or subheat.

2.3.4 AUTHORIZED BY THE PURCHASER

Requires prior written approval from the purchaser.

2.3.5 INTEGRALLY CAST SPECIMEN

An attached specimen that is cast in the mold and remains with the casting lot through the completion of all hot isostatic pressing and annealing operation(s) required by the producer. The casting drawing may identify a specific location for the attachment of each integrally cast specimen.

2.3.6 AGREED UPON BY THE PURCHASER AND PRODUCER

Requires concurrence of both the purchaser and producer; such concurrence is typically documented by way of the casting drawing, purchase order, or other engineering documentation.

2.3.7 SPECIFIED

Requires documented instruction from the purchaser through casting drawing, purchase order, specification, or other engineering documentation.

2.3.8 LOT

For room temperature tensile testing, a lot shall consist of all castings of the same part number, poured from a single master heat in one or more consecutive remelts through a furnace campaign of no longer than 12 hours and processed in a batch through each hot isostatic pressing and anneal treatment, as applicable. For hydrogen testing, a lot shall consist of all castings processed as a batch through hot isostatic pressing only, or through final anneal heat treat in inert atmosphere. For visual and nondestructive testing, an inspection lot shall consist of castings of the same part number, manufactured under the same process control parameters of 4.4.2.2.

2.3.9 CHEMICAL CLEANING

Includes processing using nitric, hydrofluoric, or nitric/hydrofluoric acid solutions where material removal exceeds 0.0004 inch (0.010 mm). This will typically exclude pickling prior to fluorescent penetrant inspection.

2.3.10 CONDITIONS OF MANUFACTURE AND INSPECTION

Producer records which document completion and conformance to the producer's procedures for control factors of 4.4.2.2, including traceability to master heat, thermal batch, sampling, and testing.

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 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	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	--	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 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 producer's facility either from a remelt (see 2.3.3) 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 the purchaser (see 2.3.4), 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 the purchaser.

3.2.1.3 Remelt for casting shall be performed using consumable electrode-practice or other method authorized by the 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 mm mercury (Hg).

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 the purchaser and casting producer.

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 2.3.5) 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 producer's option, but it is not required unless specified by the purchaser.

3.3.3 The producer 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 E8/E8M with a gage length of 1 inch (25.4 mm). When agreed upon by the purchaser and producer (see 2.3.6), specimens may be of different size, or may be flat, rectangular, or cast-to-size (see 8.3 and 8.4).

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 the purchaser, the following shall apply:

3.4.2.1.1 Sample material quantity(s), location(s), and thickness(es) shall be agreed upon by the purchaser and producer (see 8.7). 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 the 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 the purchaser and producer (see 8.7).

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. Lot (see 2.3.8) hydrogen determination is required after thermal processing per 4.3.1 if final anneal heat treatment is performed under inert atmosphere or if no vacuum anneal heat treatment is performed after hot isostatic pressing.

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) 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) 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 E8/E8M with the rate of strain set at 0.005 in/in/min (0.005 mm/mm/min) and maintained within a tolerance of ± 0.002 in/in/min (± 0.002 mm/mm/min) 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 (827.4 MPa)
Yield Strength at 0.2% Offset	112 ksi (772.2 MPa)	112 ksi (772.2 MPa)	110 ksi (758.4 MPa)
Elongation in 4D (%)	5	4	3

3.6.1.2 When authorized by the 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 the purchaser (see 8.7).

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 B600 or other method(s) acceptable to the 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 the 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 the purchaser and as necessary to ensure continued maintenance of internal quality.

3.7.1.1 Radiographic examination shall be conducted in accordance with ASTM E1742 or other method specified by the purchaser (see 2.3.7).

3.7.2 When specified, castings shall be subjected to fluorescent penetrant testing in accordance with ASTM E1417 or other method specified by the purchaser.

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

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

3.7.3.2 ASTM E1320 may be used to specify radiographic standards (casting grade).

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

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

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

3.8 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 castings 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 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 producer unless frequency of testing is specified by the 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 the 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 2.3.8) if chemical cleaning (see 2.3.9) 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 the 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 the purchaser (see 3.6 and 8.7) or selected by the producer (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 2.3.8) 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 2.3.8) and tested at each location shown on the engineering drawing for conformance with 3.6.
- 4.3.3.3 When acceptable to the 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 the purchaser, the producer 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 the purchaser and producer.
- 4.3.4 Castings shall be inspected in accordance with 3.7 to the methods, frequency, and acceptance standards specified by the 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 the purchaser.
- 4.3.6 Alternative sampling plans may be submitted to the purchaser for approval based on evidence of past satisfactory performance. The 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 the purchaser before castings for production use are supplied, unless such approval is waived by the purchaser.
- 4.4.2 For each casting part number, the producer 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, the producer shall submit a statement of the proposed change for the purchaser's reapproval. When requested, the producer shall also submit test specimens and/or sample castings to the purchaser for reapproval.
- 4.4.2.1 Production castings produced prior to receipt of the purchaser's approval shall be at the producer's risk.