



AEROSPACE MATERIAL SPECIFICATION

AMS4991

REV. E

Issued 1980-07
Revised 2014-04

Superseding AMS4991D

Titanium Alloy Castings, Investment
6Al - 4V
Hot Isostatic Pressed, Anneal Optional
(Composition similar to UNS R56401)

RATIONALE

AMS4991E results from a Five Year Review and update of this specification that aligns hydrogen sample mass with ASTM E 1447 and standardizes reporting requirements.

1. SCOPE

1.1 Form

This specification covers a titanium alloy in the forms of investment castings having four grades of permissible discontinuities.

1.2 Application

These castings have been used typically for parts of intricate design requiring a combination of good strength-to-weight ratio, creep and fatigue properties, and corrosion resistance up to 750 °F (399 °C), but usage is not limited to such applications.

1.3 Classification

Quality grades A, B, C, and D are defined in 3.7. If a specific grade is not specified (See 8.2.1), Grade C or better shall be supplied.

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.

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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.

AMS2249 Chemical Check Analysis Limits, Titanium and Titanium Alloys

AMS2750 Pyrometry

AMS2694 Repair Welding of Aerospace Castings

AMS2804 Identification, Castings

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 Analysis of Titanium Alloys by X-Ray Fluorescence Spectrometry

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 by Combustion Analysis

ASTM E 2371 Analysis of Titanium and Titanium Alloys by Direct Current Plasma and Inductively Coupled Atomic Emission 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 (See 8.2.2 and 8.2.3).

TABLE 1 - COMPOSITION

Element	min	max
Aluminum	5.50	6.75
Vanadium	3.50	4.50
Iron	--	0.30
Oxygen	--	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 vendor's facility either from a remelt (See 8.2.4) of a master heat or directly from a master heat (See 3.2.3).

3.2.1.1 Remelt for Casting

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 8.2.5), 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 that 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 practices.

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.

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 evaluation of chemical and tensile specimens.

3.2.3.1 Specimens shall be either separately-cast, integrally-cast (See 8.2.6), or machined-from-casting, and shall conform to 3.2.1.

3.2.3.2 If specimens are separately-cast, vendor shall have a written procedure acceptable to purchaser. Control factors of 4.4.2.2 shall apply.

3.2.3.3 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 Castings shall be hot isostatically pressed.

3.3.2 A separate annealing operation may be performed, but is not required.

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

3.4 Test Specimens

3.4.1 Chemical Analysis Specimens

Shall be of any convenient size and shape.

3.4.2 Tensile Specimens

Shall be of standard proportions in accordance with ASTM E 8 / E 8M with 0.250 inch (6.35 mm) diameter at the reduced parallel gage section.

3.4.2.1 Separately-cast and integrally-cast specimens may be either cast to size or cast oversize and subsequently machined to 0.250 inch (6.35 mm) diameter.

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

3.4.2.2 When integrally-cast specimens and specimens machined from castings are specified, specimen size and location shall be agreed upon by purchaser and vendor (See 8.2.7 and 8.4).

3.5 Thermal Processing

Castings and representative specimens shall be hot isostatically pressed in accordance with 3.5.1, unless alternative cycle parameters are specified by customer. When performed, 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 of 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 (See 4.3.1) at a temperature within the range of 1300 to 1550 °F (704 to 843 °C), hold at the selected temperature within ± 25 °F (± 14 °C) for 2 to 4 hours, cool in the furnace to below 1000 °F (538 °C). Pyrometry shall be in accordance with AMS2750

3.6 Properties

Castings and representative tensile specimens shall conform to the following requirements; conformance of separately cast tensile specimens to the requirements of 3.6.1.1 shall be used for acceptance of castings except when purchaser specifies that integrally-cast specimens to the requirements of 3.6.1.1 or specimens machined-from-casting to the requirements of 3.6.1.2 shall apply.

3.6.1 Room Temperature Tensile Properties

Shall be as specified in 3.6.1.1 or 3.6.1.2, 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 Separately-Cast or Cut from Integrally-Cast Coupons

Shall be as shown in Table 2.

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	6%

3.6.1.2 Machined-from-Casting Specimens

3.6.1.2.1 Machined-from-Casting Specimens from Designated Areas

Shall be as shown in Table 3.

TABLE 3 - MINIMUM TENSILE PROPERTIES

Property	Value
Tensile Strength	130 ksi (896 MPa)
Yield Strength at 0.2% Offset	120 ksi (827 MPa)
Elongation in 4D	6%

3.6.1.2.2 Machined-from-Casting Specimens from Non-designated Areas

Shall be as shown in Table 4.

TABLE 4 - MINIMUM TENSILE PROPERTIES

Property	Value
Tensile Strength	127 ksi (876 MPa)
Yield Strength at 0.2% Offset	110 ksi (758 MPa)
Elongation in 4D	4.5%

3.6.2 Surface Contamination

Castings shall be free of any oxygen-rich layer, such as alpha case, compounds such as residue from halogenated solvents and 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

3.7.1 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.

3.7.1.1 Castings shall have smooth surfaces and shall be cleaned sufficiently to permit nondestructive inspection. Metallic shot or grit shall not be used for final cleaning.

3.7.1.2 When specified, additional nondestructive testing shall be performed as follows:

3.7.1.2.1 Fluorescent penetrant testing in accordance with ASTM E 1417 or other method specified by purchaser.

3.7.1.3 Acceptance standards other than those specified herein for radiographic, fluorescent penetrant, visual, surface contamination, and other inspections shall be as agreed upon by purchaser and vendor.

3.7.1.4 Discontinuities for which specific limits are not defined herein, such as hot tears, cracks, cold shuts, and miss runs, are not acceptable. Any type of discontinuity appearing on opposite sides of a wall, and that is interconnected, is not acceptable.

3.7.2 Visual and, If Specified, Fluorescent Penetrant Inspection

3.7.2.1 Positive (Raised) Material on Cast Surfaces

Shall be acceptable as follows:

3.7.2.1.1 Nodules

Three nodules, 0.020 inch (0.51 mm) and under in height above the parent surface and 0.020 inch (0.51 mm) and under in length, are permissible in a 1-inch (25-mm) square; or one nodule, 0.020 inch (0.51 mm) and under in height and 0.150 inch (3.81 mm) and under in length, in a 2-inch (51-mm) square.

3.7.2.1.2 Parting Lines and Gating Material

Positive material less than 0.015 inch (0.38 mm) in height, in the form of parting lines, gates, risers, or material due to wax welds.

3.7.2.1.3 Areas to be Final Finished

Positive material less than 0.060 inch (1.52 mm) in height in areas to be finish machined.

3.7.2.2 Flowlines

Flowlines on cast surfaces are acceptable as follows:

3.7.2.2.1 Flowlines shall have well-rounded contours.

3.7.2.2.2 The width of the flowline shall be equal to, or greater than, twice the depth of the flowline below the parent surface.

3.7.2.2.3 Flowlines shall not be associated with cold shuts or miss runs.

3.7.2.2.4 In Grade A areas, flowlines are not permitted.

3.7.2.2.5 In Grade B, C, and D areas, flowlines 0.005 inch (0.13 mm) and under in depth below the parent surface are permissible without length or number restriction.

3.7.2.2.6 In Grade C and D areas, flowlines 0.010 inch (0.25 mm) and under in depth below the parent surface are permissible provided that not more than two such flowlines exist in a 1-inch (25-mm) square and that the flowlines are 0.250 inch (6.35 mm) and under in length.

3.7.2.3 Permissible Negative Surface Discontinuities

Size and quantity of discrete and clustered negative discontinuities shall not exceed those specified in Table 5.

TABLE 5A - NEGATIVE SURFACE DISCONTINUITY LIMITS, INCH/POUND UNITS

Area Grade	Maximum Number of Discontinuities (See 8.2.11)	Maximum Discrete Discontinuity Length	Maximum Discrete Discontinuity Length	Maximum Cluster Length ¹
		Inch Linear	Inch Nonlinear	Inch
A	4 discrete discontinuities in a 1-inch square	None Allowed	0.015	None Allowed
B	4 discrete discontinuities in a 1-inch square	None Allowed	0.020	--
	One cluster in a 2-inch square	None Allowed	0.010 ⁽²⁾	0.125
C	8 discrete discontinuities in a 1-inch square	0.020 One max	0.030	--
	One cluster in a 2-inch square	0.010	0.030 ⁽²⁾	0.375
D	8 discrete discontinuities in a 1-inch square	0.045 Two max	0.040	--

¹ Clusters shall be nonlinear. An area of shrinkage appearing on a finished surface may be considered a cluster.

² One discrete nonlinear discontinuity is permitted within the cluster.

TABLE 5B - NEGATIVE SURFACE DISCONTINUITY LIMITS, SI UNITS

Area Grade	Maximum Number of Discontinuities (See 8.2.11)	Maximum Discrete Discontinuity Length	Maximum Discrete Discontinuity Length	Maximum Cluster Length ¹
		Millimeters Linear	Millimeters Nonlinear	Millimeters
A	4 discrete discontinuities in a 25-mm square	None Allowed	0.38	None Allowed
B	4 discrete discontinuities in a 25-mm square	None Allowed	0.51	--
	One cluster in a 50-mm square	None Allowed	0.25 ⁽²⁾	3.0
C	8 discrete discontinuities in a 25-mm square	0.51 One max	0.75	--
	One cluster in a 50-mm square	0.25	0.75 ⁽²⁾	9.5
D	8 discrete discontinuities in a 25-mm square	1.14 Two max	1.02	--

¹ Clusters shall be nonlinear. An area of shrinkage appearing on a finished surface may be considered a cluster.

² One discrete nonlinear discontinuity is permitted within the cluster.

3.7.2.4 Negative (Depressed) Discontinuities on Cast or Finished Surfaces

Shall be acceptable as follows:

3.7.2.4.1 Discontinuities that will be removed by final finishing operations are permissible.

3.7.2.4.2 In Grade C or D areas, an unlimited number of discrete discontinuities 0.020 inch (0.51 mm) and under in length and separated by at least 0.100 inch (2.50 mm) are permissible if the subsurface portions of these discontinuities are in accordance with limitations specified in 3.7.3.

3.7.3 Radiographic Quality

Castings shall be produced under radiographic control. This control shall consist of 100% radiographic examination of every casting of each part number until foundry manufacturing controls, in accordance with 4.4.2, have been established. Additional radiography of production castings shall be conducted in accordance with the frequency of inspection specified by purchaser and as necessary to ensure maintenance of satisfactory quality.

3.7.3.1 Radiographic examination shall be conducted in accordance with ASTM E 1742 or other method specified by purchaser.

3.7.3.2 If ASTM E 1320 is not used to specify radiographic acceptance standards (casting grade), then the acceptance criteria of 3.7.3.4 shall apply.

3.7.3.3 Areas to be Final Finished

Discontinuities that will be removed by final finishing operations are acceptable.

3.7.3.4 Radiographic Acceptance Standards

3.7.3.4.1 Shrinkage

Shall be in accordance with Table 6.

TABLE 6A - SHRINKAGE LIMITS, INCH/POUND UNITS

Area Grade	Maximum Number in 1-Inch Square	Minimum Separation Inch ¹	Feature Thickness Inch	Up to 0.250 incl	Maximum Shrinkage Length, Inch Feature Thickness, Inch	Maximum Shrinkage Length, Inch Feature Thickness, Inch	Maximum Shrinkage Length, Inch Feature Thickness, Inch
					Over 0.250 to 0.500, incl	Over 0.500 to 0.750, incl	Over 0.750
A	3	0.500	Up to 0.500, incl	0.050	0.070	0.120	0.150
		0.200	Over 0.500	0.050	0.070	0.120	0.150
B	3	0.200	Up to 0.500, incl	0.120	0.160	0.200	0.220
		0.120	Over 0.500	0.120	0.160	0.200	0.220
C	5	0.100	All	0.190	0.200	0.220	0.250
D	7	0.100	All	0.250	0.250	0.270	0.300

¹ Discrete areas of shrinkage separated by less than the amount shown in Table 6 shall be considered as one discrete discontinuity.

TABLE 6B - SHRINKAGE LIMITS, SI UNITS

Area Grade	Maximum Number in 25-mm Square	Minimum Separation Millimeters ¹	Feature Thickness Millimeters	Up to 6.35 incl	Maximum Shrinkage Length, Millimeters Feature Thickness, Millimeters	Maximum Shrinkage Length, Millimeters Feature Thickness, Millimeters	Maximum Shrinkage Length, Millimeters Feature Thickness, Millimeters
					Over 6.35 to 12.70, incl	Over 12.70 to 19.05, incl	Over 19.05
A	3	12.70	Up to 12.70, incl	1.27	1.78	3.05	3.81
		5.08	Over 12.70	1.27	1.78	3.05	3.81
B	3	5.08	Up to 12.70, incl	3.05	4.06	5.08	5.59
		3.05	Over 12.70	3.05	4.06	5.08	5.59
C	5	2.54	All	4.83	5.08	5.56	6.35
D	7	2.54	All	6.35	6.35	6.86	7.62

¹ Discrete areas of shrinkage separated by less than the amount shown in Table 6 shall be considered as one discrete discontinuity.

3.7.3.4.2 Gas Holes and More-Dense or Less-Dense Foreign Material

Shall be in accordance with Table 7.

TABLE 7 - GAS HOLES AND FOREIGN MATERIAL LIMITS

Area Grade	Maximum Number in a 1-inch (25-mm) Square	Minimum Separation ¹	Maximum Length ²
A	3	0.250 inch (6.35 mm)	1/8 section thickness
B	6	3 times the largest dimension of the larger discontinuity	1/4 section thickness for 0.060 inch (1.52 mm) and under wall; 3/8 section thickness for wall over 0.060 inch (1.52 mm)
C	9	2 times the largest dimension of the larger discontinuity	1/2 section thickness
D	12	2 times the largest dimension of the larger discontinuity	1/2 section thickness

¹ Discrete gas holes and foreign material discontinuities separated by less than the amount shown in Table 7 shall be considered as one discrete discontinuity.

² The maximum discontinuity lengths in Table 7 are based on feature section thickness on the casting drawing, for which high-low limit dimensions are shown, or can otherwise be determined. If the casting drawing indicates that a feature will be finish machined, but the final thickness cannot be determined from the dimensions shown or otherwise determined then the maximum discontinuity length permitted is one-half that shown in Table 7 with no change in number and separation requirements.

3.7.3.4.3 Combinations of Different Types of Defects in the Same Area

Discrete discontinuities permitted by Tables 6 and 7 may exist in the same area provided that a) all requirements of 3.7.3.4.1 and 3.7.3.4.2 are met, b) the total number of discrete discontinuities is not greater than permitted by Table 6, and c) the minimum spacing between Table 6 and Table 7 discontinuities is not less than permitted by Table 6.

3.7.3.4.4 Background Discontinuities

Size and number of background discontinuities shall not exceed, and the spacing shall be not less than, that indicated by any of the reference charts (See Figure 1) specified in Table 8.

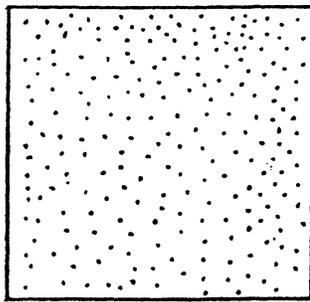


Chart No. 1
All spots 0.010 -
0.015 inch (0.25 -
0.38 mm) in diameter

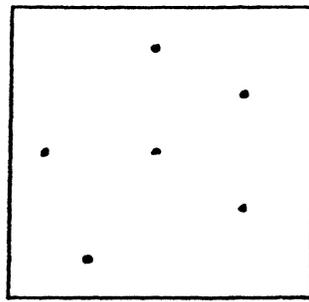


Chart No. 2
All spots nominally
0.040 inch (1.00 mm)
in diameter

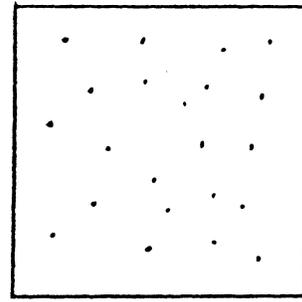


Chart No. 3
All spots 0.020 -
0.025 inch (0.50 -
0.62 mm) in diameter

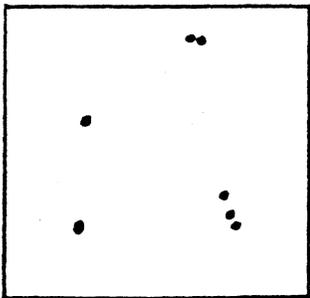


Chart No. 4
All spots nominally
as drawn

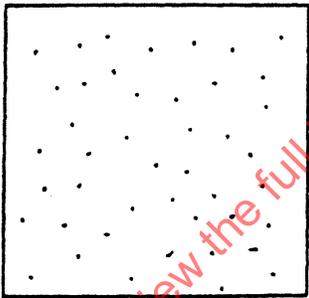


Chart NO. 5
All spots 0.020 -
0.025 inch (0.50 -
0.62 mm) in diameter

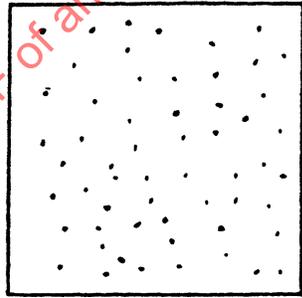


Chart No. 6
All spots 0.020 -
0.030 inch (0.50 -
0.75 mm) in diameter

FIGURE 1 - BACKGROUND POROSITY

TABLE 8 - BACKGROUND DISCONTINUITY LIMITS

Area Code	Standard Chart Number (See Figure 1)	Table 6 Discontinuities Permissible	Table 7 Discontinuities Permissible	Spacing Between Table 6, Table 7, and Background Discontinuities
A	No Background Discontinuities Permitted	Yes	Yes	--
B	1	Yes	Yes	None Required
B	2	Yes	Yes	See Table 6
B	3	Yes	Yes	None Required
B	4	One discrete	No	None Required
C & D	4	Yes	Yes	See Table 6
C & D	5	Yes	Yes	None Required
C & D	6	Yes	Yes	See Table 6

3.7.3.4.5 Other Indications

Indications due to grain orientation, diffraction pattern, variations in material density, or ghost lines are acceptable in all areas.

3.8 Blending

Blending of cast surfaces is acceptable as specified in Table 9 and 3.8.1 and 3.8.2.

TABLE 9 - SURFACE BLENDING LIMITS

Area Grade	Minimum Specified Feature Thickness	Minimum Specified Feature Thickness	Blend Depth Limit ¹ Below Minimum Specified Thickness	Blend Depth Limit ¹ Below Minimum Specified Thickness
	Inch	Millimeters	Inch	Millimeters
A and B	Up to 0.100, excl 0.100 and Over	Up to 2.70, excl 2.70 and Over	Not below minimum specified thickness 0.005	Not below minimum specified thickness 0.13
C and D	Up to 0.100, excl 0.100 and Over	Up to 2.70, excl 2.70 and Over	0.010 0.020	0.25 0.51

¹ Areas blended below minimum specified thickness shall be not greater than 1 square inch (645 mm²) in area.

3.8.1 Blended areas shall be smooth with no radius less than 0.25 inch (6 mm) except that an internal blended radius equal to the minimum internal radius specified on the drawing is permissible on the curved surface represented by that radius.

3.8.2 Blended areas shall be separated by distances equal to, or greater than, the length of the largest adjacent blended area or 1 inch (25 mm), whichever is less. Blended areas separated by less than 1 inch (25 mm) shall be considered as one blended area.

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

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

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

3.9.3 Castings that are hot isostatically pressed before welding need not be hot isostatically pressed 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. Results of such tests shall be reported to the purchaser as required by 4.5. 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

4.2.1 Acceptance Tests

Composition (3.1), tensile properties (3.6.1), surface contamination (3.6.2), visual (and fluorescent penetrant, if specified) inspection (3.7.2), and the applicable requirements of quality are acceptance tests and shall be performed as specified in 4.3.

4.2.2 Periodic Tests

Radiographic soundness (3.7.3) is a periodic test and shall be performed at a frequency 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 with 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) or selected by vendor (See 4.3.3.4).

4.3.3.1 For separately-cast specimens in the representative condition of 3.5, one specimen from each lot (See 8.2.8) shall be tested for conformance to 3.6.1.1.

4.3.3.2 For integrally-cast specimens in the representative condition of 3.5, two specimens from each lot shall be randomly selected and tested for conformance to 3.6.1.1.

4.3.3.3 For specimens machined-from-casting, one casting in the representative condition of 3.5 shall be randomly selected from each lot and tested at each location shown on the engineering drawing for conformance with 3.6.1.2 for designated and/or non-designated areas.

4.3.3.3.1 If designated areas are evaluated, the non-designated areas need not be tested.

4.3.3.4 When acceptable to purchaser, specimens machined-from-casting may be used in lieu of both separately-cast and integrally-cast specimens, and integrally-cast specimens may be used in lieu of separately-cast specimens. In each case, the resultant properties must conform to the requirements of 3.6.1 for that origin and type of specimen.

4.3.3.4.1 When specimens are selected for test as in 4.3.3.4 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.

4.3.3.5 When casting size, section thickness, gating method, or other factors do not permit conformance to 4.3.3.2 or 4.3.3.3, 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 herein, and as 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 purchaser.

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 in 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 the vendor's risk.

4.4.2.2 Control factors for producing castings and separately cast specimens include, but are not limited to, the following factors: Supplier's procedures shall identify tolerances, ranges, and/or control limits, as applicable. Control factors for separately-cast specimens must generally represent but need not be identical to, those factors used for castings:

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 risers

Mold refractory formulation including prime and backup materials

Grain refinement methods, if applicable

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)

Hot isostatic processing (HIP) cycles

Annealing heat treatment cycle(s), if applicable

Straightening procedures, if applicable

In-process welding of castings when permitted by purchaser

Final inspection methods

Location of specimens machined from casting, if applicable.

4.4.2.2.1 Any of the above control factors that parameters are considered proprietary by the 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 producer of castings shall furnish with each shipment a certification document declaring that castings have been processed, tested, and inspected as specified and that the results of the inspections and tests conform to requirements.

4.5.1 Unless otherwise specified, vendor shall furnish test report(s) showing the results of tests and inspections conducted in accordance with 4.2 and 4.3.

4.5.1.1 Chemical analysis determinations, property test data, and the results of any retests conducted shall be expressed numerically to reflect actual quantitative test values.

4.5.1.2 Inspection and preproduction results shall be reported at the frequency specified by, and in a format acceptable to purchaser.

4.5.1.3 Nonconformances shall be documented and approved by purchaser in accordance with purchaser's material review requirements.