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400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE MATERIAL SPECIFICATION

SAE AMS 4991B

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Superseding AMS 4991A

(R)

Titanium Alloy Castings, Investment
6Al - 4V
Hot Isostatic Pressed, Anneal Optional

UNS R56401

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 form 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 canceled and no superseding document has been specified, the last published issue of that document shall apply.

QUESTIONS REGARDING THIS DOCUMENT: (724) 772-7161 FAX: (724) 776-0243
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SAE WEB ADDRESS: http://www.sae.org

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 2694	Repair Welding of Aerospace Castings
AMS 2804	Identification, Castings

2.2 ASTM Publications:

Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM B 600	Descaling and Cleaning Titanium and Titanium Alloy Surfaces
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 1409	Determination of Oxygen in Titanium and Titanium Alloys by the Inert Gas Fusion Method
ASTM E 1417	Liquid Penetrant Examination
ASTM E 1447	Determination of Hydrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Thermal Conductivity Method
ASTM E 1742	Radiographic Examination

2.3 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-H-81200	Heat Treatment of Titanium and Titanium Alloys

3. TECHNICAL REQUIREMENTS:

3.1 Composition:

Castings shall conform to the percentages by weight shown in Table 1; oxygen shall be determined in accordance with ASTM E 1409, hydrogen in accordance with ASTM E 1447, and other elements by wet chemical methods in accordance with ASTM E 120, by spectrochemical methods, or by other analytical methods acceptable to 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 (3.1.2)	--	0.015	(150 ppm)
Yttrium (3.1.1)	--	0.005	(50 ppm)
Residual Elements, each (3.1.1)	--	0.10	
Residual 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 requirements of AMS 2249.

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.

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 8.2.5), 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 which are melted and refined as necessary in a single furnace charge. Single or multiple melting shall be accomplished using electron beam cold hearth melting or plasma arc are cold hearth melting 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 analysis and tensile specimens.

3.2.3.1 Specimens shall be either separately-cast, integrally-cast (See 8.2.6), or machined from a 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.

3.3.4 If welding is performed (See 3.9.1), castings shall be hot isostatically pressed and/or annealed after welding (See 3.9.2).

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 or ASTM E 8M (See 8.3) 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 and 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 8.5).

3.5 Thermal Processing:

Castings and representative specimens shall be hot isostatic 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). The provisions of MIL-H-81200 shall apply.

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 a 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 or ASTM E 8M (See 8.3) with the rate of strain maintained at 0.003 to 0.007 inch/inch per minute (0.003 to 0.007 mm/mm per minute) through the yield strength and then increased so as to produce failure in approximately one additional minute.

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 Nondesignated 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 inspection 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 misruns, are not acceptable. Any type of discontinuity appearing on opposite sides of a wall, and which 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 misruns.

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 Inch Linear	Maximum Discrete Discontinuity Length Inch Nonlinear	Maximum Cluster Length[1] 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 Millimeters Linear	Maximum Discrete Discontinuity Length Millimeters Nonlinear	Maximum Cluster Length[1] 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 as defined in Tables 6, 7, and 8.

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

3.7.3.2 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	Maximum Shrinkage Length, Inch Feature Thickness, Inch Up to 0.250 incl	Maximum Shrinkage Length, Inch Feature Thickness, Inch Over 0.250 to 0.500, incl	Maximum Shrinkage Length, Inch Feature Thickness, Inch Over 0.500 to 0.750, incl	Maximum Shrinkage Length, Inch Feature Thickness, Inch 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	Feature Thickness Millimeters	Up to 6.35 incl	Maximum Shrinkage Length, Millimeters Feature Thickness, Millimeters Over 6.35 to 12.70, incl	Maximum Shrinkage Length, Millimeters Feature Thickness, Millimeters Over 12.70 to 8.75, incl	Maximum Shrinkage Length, Millimeters Feature Thickness, Millimeters 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.

3.7.3.3 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 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 3.7.3.2 and 3.7.3.3 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.

3.7.3.5 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.

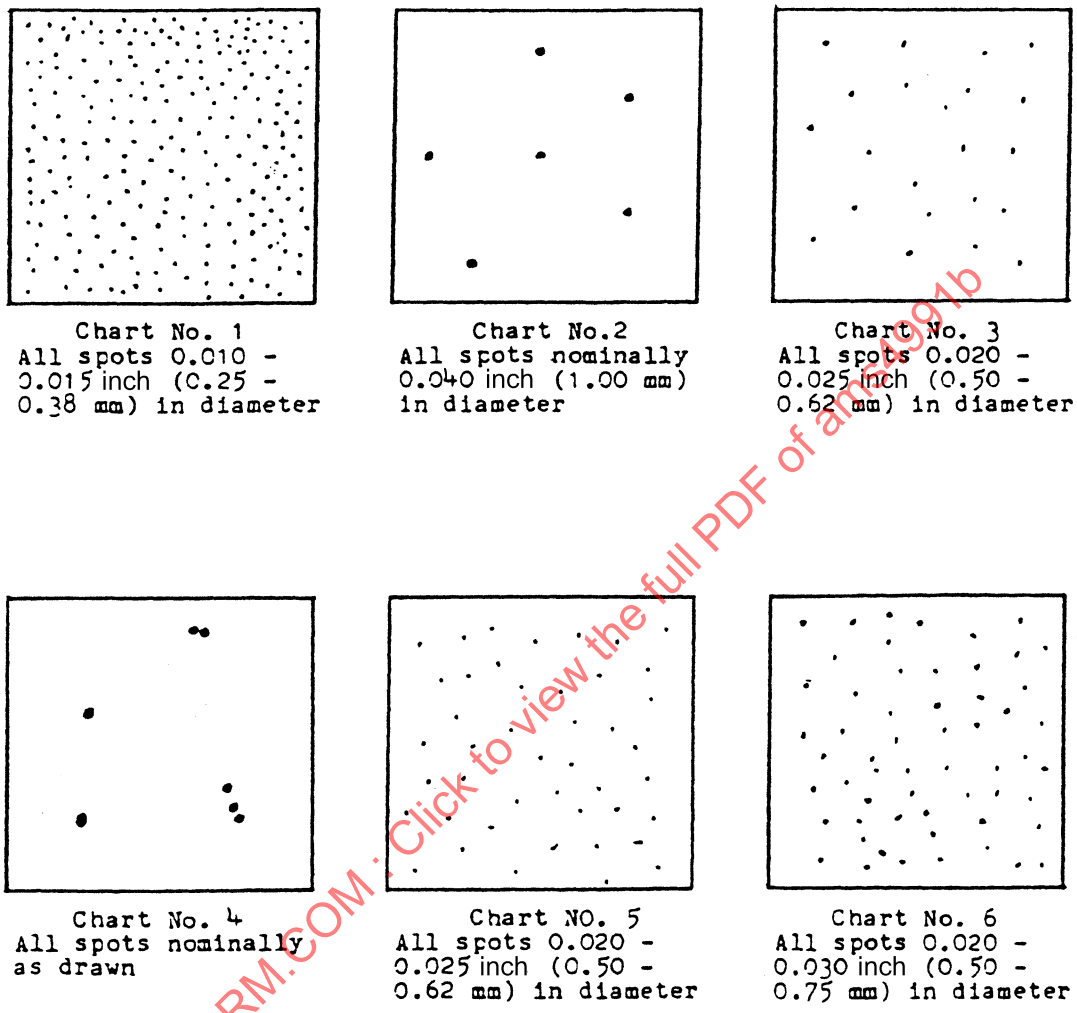

FIGURE 1 - Background Porosity

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

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

3.7.3.7 Areas to be Final Finished: Discontinuities which will be removed by final finishing operations are acceptable.

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

[1]Areas blended below minimum specified thickness shall be not greater than 1 square inch (645 mm^2) 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 AMS 2694 or other welding program acceptable to purchaser may be used.

3.9.2 Unless otherwise specified by purchaser, castings shall be hot isostatically pressed and/or annealed after welding. Castings which are hot isostatically pressed prior to welding need not be hot isostatically pressed again after welding but then must be annealed.

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 Composition (3.1), tensile properties (3.6.1), surface contamination (3.6.2), surface finish (3.7.1.1) and visual (and fluorescent penetrant, if specified) inspection (3.7.2) 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.

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 if 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 or more specimens 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 or more specimens from each lot shall be randomly selected and tested for conformance to 3.6.1.1.