AEROSPACE MATERIAL SPECIFICATION

AMS4991™	REV. G

Issued 1980-07
Reaffirmed 1994-04
Revised 2023-05

Superseding AMS4991F

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

RATIONALE

AMS4991G results from a Five-Year Review and update of this specification with changes to update general agreement language related to prohibiting unauthorized exceptions (8.4), relocate definitions (2.3), update applicable documents (Section 2), thermal processing (3.5), and allow the use of the immediate prior specification revision (8.3).

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 2.3.1), 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 +1 724-776-4970 (outside USA), www.sae.org.

AMS2249 Chemical Check Analysis Limits, Titanium and Titanium Alloys

AMS2694 In-Process Welding of Castings

AMS2750 Pyrometry

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 AMS are clarified in AS7766 and as follows:

2.3.1 “Specified”

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

2.3.2 “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.

2.3.3 “Purchaser”

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

2.3.4 “Melt”

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

2.3.5 “Authorized by the Purchaser”

Requires prior written approval from the purchaser.

2.3.6 “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 of the producer. The casting drawing may identify a specific location for the attachment of each integrally cast specimen.

2.3.7 “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.

2.3.8 “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 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”

The producer records that 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.

2.3.11 “Discontinuities”

Includes negative surface conditions such as depressions or voids and subsurface conditions such as less-dense and more-dense foreign material, gas holes, or shrinkage for which specific limits are defined herein.

2.3.12 “Discrete Discontinuity”

A well-defined individual recess, cavity, or inclusion.

2.3.13 “Linear Discontinuity”

A discontinuity whose ratio of length to average width is greater than three.

2.3.14 “Length”

The diameter of a circle encompassing the limits of the discontinuity, weld deposited material, or blended area.

2.3.15 “Cluster”

Two or more discrete discontinuities (see 2.3.12) separated by less than three times the length of the largest adjacent discontinuity.

2.3.16 “Cracks”

Sharp, narrow breaks or fissure lines in which material separation has occurred. Separated faces may still be in contact.

2.3.17 “Square”

A rectangular figure whose four sides are equal to the specified dimension. The square shall be superimposed on the part so as to incorporate the maximum number of discontinuities.

2.3.18 “Finished Thickness”

The thickness after final finishing operations, measured as the shortest distance between the two opposite surfaces of the feature being considered.

2.3.19 “Background Discontinuities”

Small, scattered, subsurface discontinuities, such as shrink cavities, porosity, more-dense or less-dense foreign material, and gas holes, appearing over extended areas of the casting.

2.3.20 “Final Finishing”

Finishing, including machining, that produces the contour indicated by the symbol “*f*” or on the drawing or a phantom line contour on the drawing that represents a surface produced at final assembly.

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 (see 2.3.2 and 2.3.3).

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 producer's facility either from a remelt (see 2.3.4) 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 the purchaser (see 2.3.5), 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 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 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 mm 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 the purchaser and casting producer.

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 2.3.6), or machined-from-casting, and shall conform to 3.2.1.

3.2.3.2 If specimens are separately cast, the producer shall have a written procedure acceptable to the 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 producer 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 E8/E8M 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 the purchaser and producer (see 2.3.7 and 8.5).

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 the customer. When performed, 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 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 the 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 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 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 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

3.7.1 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.

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 E1417 or other method specified by the 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 the purchaser and producer.

3.7.1.4 Discontinuities for which specific limits are not defined herein, such as hot tears, cracks (see 2.3.16), 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 (see 2.3.17).

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 (see 2.3.12) and clustered (see 2.3.15) negative discontinuities shall not exceed those specified in Table 5 (see 2.3.14).

Table 5A - Negative surface discontinuity limits, inch/pound units

Area Grade	Maximum Number of Discontinuities (see 2.3.11)	Maximum Discrete Discontinuity Length Inches Linear (see 2.3.13)	Maximum Discrete Discontinuity Length Inches Nonlinear	Maximum Cluster Length[1] Inches
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 2.3.11)	Maximum Discrete Discontinuity Length Millimeters Linear (see 2.3.13)	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 (see 2.3.20) 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 the purchaser and as necessary to ensure maintenance of satisfactory quality.

3.7.3.1 Radiographic examination shall be conducted in accordance with ASTM E1742 or other method specified by the purchaser.

3.7.3.2 If ASTM E1320 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 (see 2.3.20)

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 Inches[1]	Feature Thickness Inches	Maximum Shrinkage Length, Inches Feature Thickness, Inches Up to 0.250, incl	Maximum Shrinkage Length, Inches Feature Thickness, Inches Over 0.250 to 0.500, incl	Maximum Shrinkage Length, Inches Feature Thickness, Inches Over 0.500 to 0.750, incl	Maximum Shrinkage Length, Inches Feature Thickness, Inches 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	Maximum Shrinkage Length, 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.

3.7.3.4.2 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 Tables 6 and 7 discontinuities is not less than permitted by Table 6.

3.7.3.4.4 Background Discontinuities

Size and number of background discontinuities (see 2.3.19) 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.

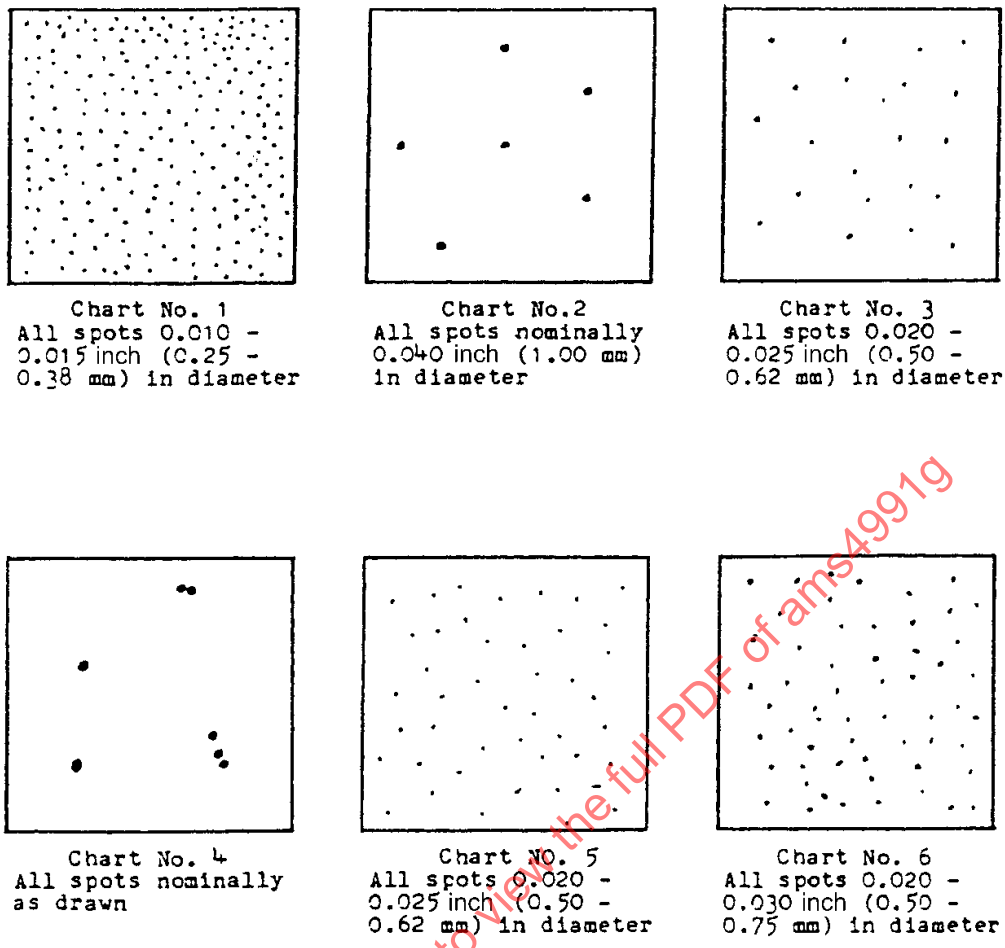

Figure 1 - Background porosity

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

3.7.3.4.5 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 Inches	Minimum Specified Feature Thickness Millimeters	Blend Depth Limit[1] Below Minimum Specified Thickness Inches	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	Not below minimum
	0.100 and Over	2.70 and Over	specified thickness	specified thickness
			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 inches (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 the purchaser.

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

3.9.2 Unless otherwise specified by the 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.

3.10 Exceptions

Any exceptions shall be authorized by the purchaser and reported as in 4.5.4.

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. Results of such tests shall be reported to the purchaser as required by 4.5. The 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 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 with 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) or selected by the producer (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 2.3.8) 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 the 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 the purchaser, the producer shall include in the report of 4.5 a description of the origin of the specimen that was tested.