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SPECIFICATION FOR TITANIUM AND TITANIUM ALLOY CASTINGS



SB-367

(Identical with ASTM Specification B367-09 except Supplementary Requirement S6 (Tension Test) is mandatory, and welders, welding operators, and welding procedures for para. 10 shall be in accordance with Section IX.)

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1. Scope

1.1 This specification covers titanium and titanium alloy castings intended for general corrosion resistant and industrial applications.

1.2 This specification is intended for use of purchasers and/or producers of reactive metal castings for defining the requirements and assuring the properties of castings for unique corrosion-resistant applications, that is, not for commodity items which must meet all potential purchasers' requirements.

1.2.1 Users are advised to use the specification as a basis for obtaining castings which will meet minimum acceptance requirements established and revised by consensus of the members of the committee.

1.2.2 User requirements considered more stringent may be met by the addition to the purchase order of one or more supplementary requirements, which may include, but are not limited to, those listed in Sections S1 through S8.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

2. Referenced Documents

2.1 ASTM Standards:

- A 802/A 802M Practice for Steel Castings, Surface Acceptance Standards, Visual Examination
- E 8 Test Methods for Tension Testing of Metallic Materials
- E 10 Test Method for Brinell Hardness of Metallic Materials
- E 18 Test Methods for Rockwell Hardness of Metallic Materials
- E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 94 Guide for Radiographic Examination

E 142 Test Method for Controlling Quality of Radiographic Testing

E 165 Test Method for Liquid Penetrant Examination

E 446 Reference Radiographs for Steel Castings Up to 2 in. [51 mm] in Thickness

E 539 Test Method for X-Ray Fluorescence Spectrometric Analysis of 6Al-4V Titanium Alloy

E 1409 Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Technique

E 1447 Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by Inert Gas Fusion Thermal Conductivity/Infrared Detection Method

E 1941 Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys

E 2371 Test Method for Analysis of Titanium and Titanium Alloys by Atomic Emission Plasma Spectrometry

E 2626 Guide for Spectrometric Analysis of Reactive and Refractory Metals

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *lot, n* — shall consist of all castings of the same design produced from the same pour.

3.1.2 *pour, n* — shall consist of all material melted and cast at one time.

4. Ordering Information

4.1 Orders for castings to this specification shall include the following as required, to describe the requirements adequately:

4.1.1 Description of the castings by pattern number or drawing. Dimensional tolerances shall be included on the casting drawing,

4.1.2 Quantity,

4.1.3 Grade designation (see Table 1),

4.1.4 Options in the specification, and

4.1.5 Supplementary requirements desired, including the standards of acceptance.

5. Materials and Manufacture

5.1 Materials for this specification shall be melted by conventional processes used for reactive metals. Typical methods include the consumable electrode and induction-slag, plasma arc, induction-skull, and electron beam melting processes.

6. Chemical Composition

6.1 *Pour Analysis* — An analysis of each pour shall be made by the producer from a sample such as a casting or test bar that is representative of the pour. The chemical composition determined shall conform to the requirements specified for the relevant grade in Table 1.

6.1.1 The elements listed in Table 1 are intentional alloy additions or elements which are inherent to the manufacture of titanium sponge, ingot or mill product.

6.1.1.1 Elements other than those listed in Table 1 are deemed to be capable of occurring in the grades listed in Table 1 by and only by way of unregulated or unanalyzed scrap additions to the ingot melt. Therefore product analysis for elements not listed in Table 1 shall not be required unless specified and shall be considered to be in excess of the intent of this specification.

6.1.2 Elements intentionally added to the melt must be identified, analyzed, and reported in the chemical analysis.

6.2 When agreed upon by the producer and the purchaser and requested by the purchaser in his written purchase order, chemical analysis shall be completed for specific residual elements not listed in this specification.

6.3 *Product Analysis* — Product analysis tolerances do not broaden the specified heat analysis requirements, but cover variations between laboratories in the measurement of chemical content. The producer shall not ship material which is outside the limits specified in Table 1 for the applicable grade. Product analysis limits shall be as specified in Table 2.

6.4 *Sampling* — Samples for chemical analysis may be made by the purchaser on a representative casting from any lot. Due to the possibility of oxygen or other interstitial contamination, samples for oxygen, carbon, hydrogen, and nitrogen analysis shall be taken no closer than $\frac{1}{4}$ in. (6.3 mm) to a cast surface except that castings too thin for this shall be analyzed on representative material. The

chemical composition determined shall conform to the analysis in Table 1 within the check analysis variations shown in Table 2 or shall be subject to rejection by the purchaser.

7. Heat Treatment

7.1 Unless otherwise specified in the contract, all castings will be supplied in the as-cast condition except when post-weld heat treatment is required.

7.2 If post-weld heat treatment is required, it shall consist of a stress relief performed at $1075 \pm 25^\circ\text{F}$ ($580 \pm 14^\circ\text{C}$) for Grades C-2, C-3, C-7, C-8, C-12, C-16 and C-17, and $1200 \pm 25^\circ\text{F}$ ($650 \pm 14^\circ\text{C}$) for Grades C-5, C-6, C-9, C-18, and C-38. Time at temperature shall be a minimum of $\frac{1}{2}$ h plus an additional $\frac{1}{2}$ h at temperature per inch of thickness for section sizes greater than 1 in. (25 mm). After heat treatment, the castings should be cooled in air or in the furnace to ambient temperature unless otherwise agreed upon between the purchaser and producer.

8. Methods of Chemical Analysis and Tension Test

8.1 The chemical analysis shall normally be conducted using the ASTM standard test methods referenced in 2.1. Other industry standard methods may be used where the ASTM test methods in 2.1 do not adequately cover the elements in the material or by agreement between the producer and purchaser. Alternate techniques are discussed in Guide E 2626.

8.2 Tension testing in accordance with Supplementary Requirement S6 is mandatory.

9. Workmanship, Finish, and Appearance

9.1 All castings shall be made in a workman-like manner and shall conform to the dimensions in drawings furnished by the purchaser before manufacturing is started. If the pattern is supplied by the purchaser, the dimensions of the casting shall be as predicted by the pattern.

9.2 The surface of the casting shall be free of adhering mold material, scale, cracks, and hot tears as determined by visual examination. Other surface discontinuities shall meet the visual acceptance standards specified in the order. Practice A 802/A 802M or other visual standards may be used to define acceptable surface discontinuities and finish. Unacceptable surface discontinuities shall be removed and their removal verified by visual examination of the resultant cavities.

10. Repair by Welding

10.1 If repairs are required, these shall be made using welders, welding operators, and welding procedures qualified in accordance with Section IX of the ASME Boiler

TABLE 2
CHECK ANALYSIS TOLERANCES

Element	Maximum or Range, Weight%	Permissible Variation in Check Analysis
Nitrogen	0.05	+0.02
Carbon	0.10	+0.02
Hydrogen	0.015	+0.003
Iron	1.2–1.8	±0.20
Iron	0.50	+0.15
	0.40	+0.08
	0.25	+0.05
	0.20	+0.04
Oxygen	0.25	+0.05
	0.20	+0.04
Aluminum	2.5–6.75	±0.40
Vanadium	2.0–4.5	±0.15
Tin	2.0–3.0	±0.15
Palladium	0.04–0.25	±0.02
Molybdenum	0.2–0.4	±0.04
Nickel	0.3–0.9	±0.05
Other (each)	0.10	+0.02

and Pressure Vessel Code and certified to the quality requirements established by the producer. The procedures developed shall be consistent with standard practices recommended for reactive metal alloys. The producer shall maintain documentation on procedure and welder qualifications. Procedure modifications or special arrangements shall be as agreed upon between the producer and the purchaser.

10.2 The composition of the deposited weld metal shall be within the chemical requirements for each grade established in Table 1.

10.2.1 Unalloyed titanium Grades C-2 and C-3, and low-alloy Grades C-12, C-7, C-8, C-16, and C-17 castings shall be stress-relieved if the repair is considered capable of adding stresses that will interfere with the purpose for which the castings are intended. The decision for stress relieving shall be made by the producer, unless otherwise agreed upon. The stress-relief cycle shall be in accordance with 7.2 followed by air or furnace cooling to room temperature, or as agreed upon between the purchaser and the producer.

10.2.2 Grade C-5 (Ti-6Al-4V), Grade C-6 (Ti-5Al-2.5Sn), Grade C-9, Grade C-18, and C-38 castings shall be stress-relieved after weld repair, if the weld defect or excavation is through a wall or exceeds 1 in.³ (16.4 cm³) of deposited metal. All welds on Grade C-12 (Ti-.3Mo-.8Ni) castings shall be stress-relieved after weld repair. The stress-relief cycle shall be in accordance with 7.2.

10.2.3 Hot isostatic pressing (HIP) may be substituted for required thermal treatment provided all requirements for that treatment are met, and temperatures detrimental to the material properties are not reached.

11. Referee Test and Analysis

11.1 In the event of disagreement between the manufacturer and the purchaser on the conformance of the material to the requirements of this specification, a mutually acceptable referee shall perform the tests in question using the ASTM standard methods in 2.1. The referee's testing shall be used in determining conformance of the material to this specification.

12. Inspection

12.1 The producer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Foundry inspection by the purchaser shall not interfere unnecessarily with the producer's operations.

12.2 If the results of any chemical or mechanical property test lot are not in conformance with the requirements of this specification, the lot may be retested at the option of the producer. The frequency of the retest will double the initial number of tests. If the results of the retest conform to the specification, then the retest values will become the test values for certification. Only original conforming test results or the conforming retest results shall be reported to the purchaser. If the results for the retest fail to conform to the specification, the material will be rejected in accordance with Section 13.

12.3 For purposes of determining conformance with the specifications contained herein, an observed or a calculated value shall be rounded off to the nearest unit in the last right-hand significant digit used in expressing the limiting value. This is in accordance with the round-off method of Practice E 29.

13. Rejection

13.1 Any rejection based on test reports shall be reported to the producer within 60 days from the receipt of the test reports by the purchaser.

13.2 Material that shows unacceptable discontinuities as determined by the acceptance standards specified on the order, subsequent to acceptance at the producer's works, may be rejected, and the producer shall be notified within 60 days, or as otherwise agreed upon.

13.3 In the event of disagreement between the producer and the purchaser on the conformance of the material to the requirements of this specification, a mutually acceptable referee shall perform the tests in question. The referee's testing shall be used in determining the conformance of the material to this specification.

14. Certification

14.1 The manufacturer shall supply at least one copy of the report certifying that the material supplied has been manufactured, inspected, sampled, and tested in accordance with the requirements of this specification and that the results of chemical analysis, tensile, and other tests meet the requirements of this specification for the grade specified. The report shall include results of all chemical analysis, tensile tests, and all other tests required by the specification.

15. Product Marking

15.1 Unless otherwise specified, the following shall apply.

15.1.1 Castings shall be marked for material identification with this designation and grade symbol, that is, C-2, C-3, C-5, C-6, C-7, C-8, C-9, C-12, C-16, C-17, C-18,

or C-38 if size permits. Marking shall be in such position as not to impair the function of the casting.

15.1.2 The producer's name or identification mark and the pattern number shall be cast or stamped using low stress stamps on all castings. Small size castings may be such that marking must be limited consistent with the available area.

15.1.3 The marking of lot numbers on individual castings shall be agreed upon by the producer and the purchaser.

15.1.4 Marking shall be in such a position as not to injure the usefulness of the casting.

16. Keywords

16.1 castings; corrosion resistant; titanium; titanium alloys

SUPPLEMENTARY REQUIREMENTS

Supplementary Requirement S6 is mandatory. Other supplementary requirements shall be applied only when specified by the purchaser. Details of the supplementary requirements shall be agreed upon by the producer and purchaser. The specified tests shall be performed by the producer prior to shipment of the castings.

S1. Radiographic Examination

S1.1 When specified in the purchase order, castings shall be examined for internal discontinuities by means of X rays or gamma rays. Inspection procedure shall be in accordance with the Guide E 94 and Test Method E 142. Types and degrees of discontinuities considered shall be judged by the Reference Radiographs E 446. Extent of examination and the basis for acceptance shall be agreed upon by the producer and the purchaser. A specification that may be used as a basis for such agreement is described as follows.

S1.2 Extent of Examination:

S1.2.1 Category I — The castings shall be 100% inspected radiographically and film sent or made available for purchaser examination.

S1.2.2 Category II — Critical areas of all castings shall be radiographically inspected to ensure that casting quality is sufficient to meet customer needs. The film record need not be maintained.

S1.2.3 Category III — Sample castings shall be radiographed in accordance with an agreed upon schedule. When discontinuities exceed the acceptance limits, all castings in the lot shall be examined according to Category II.

S1.3 Basis for Acceptance:

S1.3.1 The maximum severity level for each specific type of discontinuity shall be agreed upon by the purchaser and producer. A specification which may be used as a basis for such agreement, using Reference Radiographs E 446 is described as follows:

Category A	gas porosity	severity level 2
Category B	sand and slag inclusions	severity level 2
Category C	shrinkage CA	severity level 2
Category C	shrinkage CB	severity level 2
Category C	shrinkage CC	severity level 2
Category C	shrinkage CD	severity level 2
Category D	crack	none permitted
Category E	hot tear	none permitted
Category F	insert	none permitted

S2. Liquid Penetrant Examination

S2.1 The castings shall be examined for surface discontinuities by means of liquid penetrant examination. The

examination shall be in accordance with Test Method E 165. Areas to be inspected, methods and types of liquid penetrants to be used, developing procedure, and basis for acceptance shall be agreed upon between the producer and the purchaser.

S3. Examination of Weld Preparation

S3.1 Cavities prepared for welding due to surface discontinuities, such as cracks, open porosity, etc. shall be examined by means of liquid penetrant examination in order to verify removal of such discontinuities.

S3.2 Weld repairs that are made to eliminate discontinuities that are detected by radiography shall be re-radiographed to verify that unacceptable discontinuities have been removed.

S5. Hot Isostatic Pressing (HIP)

S5.1 Hot isostatic pressing (HIP) shall be used to improve as-cast quality when required. Temperature, time at temperature, and atmosphere shall be as agreed upon between the producer and the purchaser.

S5.2 Castings for which HIP is not required may be hot isostatic pressed by the producer in accordance with the requirements of 7.2.

S5.3 HIP may be substituted for required thermal treatment provided all requirements for that treatment are met and temperatures detrimental to the material properties are not reached.

S6. Tension Test

S6.1 Tensile properties shall be determined on material representing each pour. Properties shall be determined in the as-cast condition unless otherwise specified in the purchase order. The results shall conform to the requirements specified in Table S6-1.

S6.2 Test bars may be obtained from special test blocks cast for that purpose or cut from castings processed with a lot.

S6.3 Tensile tests shall be made in accordance with the requirements of Test Methods E 8. Tensile properties

shall be determined using a strain rate of 0.003 to 0.007 in./in./min (0.003 to 0.007 mm/mm/min) through the yield strength.

S6.4 If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted from the same pour.

S7. Prior Approval of Major Weld Repairs

S7.1 Major weld repairs as defined and agreed upon between the producer and the purchaser shall be subject to the prior approval of the purchaser.

S8. Hardness Test

S8.1 Hardness shall be determined on material representing each lot. Hardness shall be determined in the as-cast condition unless otherwise specified in the purchase order. The results shall conform to the requirements specified in Table S8-1.

S8.2 Hardness shall be determined on a sample cast for that purpose, or on a casting randomly selected from a lot. If a casting is used for a hardness sample, indentations shall be made in a surface that will not be subsequently machined. Hardness values reported shall be representative of the base metal of the castings and not of any surface contamination due to mold-metal interactions.

S8.3 Hardness tests shall be made in accordance with the requirements of Test Methods E 10 or E 18.

**TABLE S6-1
TENSILE REQUIREMENTS**

Grade	Tensile Strength, min, ksi (MPa)	Yield Strength 0.2% Offset, min, ksi (MPa)	Elongation in 1-in. Gage Length, min, %
C-2	50 (345)	40 (275)	15
C-3	65 (450)	55 (380)	12
C-5	130 (895)	120 (825)	6
C-6	115 (795)	105 (725)	8
C-7	50 (345)	40 (275)	15
C-8	65 (450)	55 (380)	12
C-9	90 (620)	70 (483)	10
C-12	70 (483)	50 (345)	8
C-16	50 (345)	40 (275)	15
C-17	35 (240)	25 (170)	20
C-18	90 (620)	70 (483)	10
C-38	130 (895)	115 (794)	8

**TABLE S8-1
HARDNESS REQUIREMENTS**

Grade	Brinell Hardness, max (A)	Rockwell Hardness, max (A)
C-2	210	B 96
C-3	235	C 24
C-5	365	C 39
C-6	335	C 36
C-7	210	B 96
C-8	235	C 24
C-9	365	C 39
C-12	235	C 24
C-16	210	B 96
C-17	235	C 24
C-18	365	C 39
C-38	365	C 39

NOTE:

(A) Average of three tests.