



# Standard Specification for Titanium and Titanium Alloy Castings<sup>1</sup>

This standard is issued under the fixed designation B367; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense.*

## 1. Scope\*

1.1 This specification covers titanium and titanium alloy castings intended for general corrosion resistant and industrial applications, as follows:

- 1.1.1 *Grade C-2*—UNS R52550. Unalloyed titanium,
- 1.1.2 *Grade C-3*—UNS R52550. Unalloyed titanium,
- 1.1.3 *Grade C-5*—UNS R56400. Titanium alloy (6 % aluminum, 4 % vanadium),
- 1.1.4 *Grade C-7*—UNS R52700. Unalloyed titanium plus 0.12 to 0.25 % palladium,
- 1.1.5 *Grade C-8*—UNS R52700. Unalloyed titanium plus 0.12 to 0.25 % palladium,
- 1.1.6 *Grade C-9*—UNS R56320. Titanium alloy (3 % aluminum, 2.5 % vanadium),
- 1.1.7 *Grade C-12*—UNS R53400. Titanium alloy (0.3 % molybdenum, 0.8 % nickel),
- 1.1.8 *Grade C-16*—UNS R52402. Unalloyed titanium plus 0.04 to 0.08 % palladium,
- 1.1.9 *Grade C-17*—UNS R52252. Unalloyed titanium plus 0.04 to 0.08 % palladium, and
- 1.1.10 *Grade C-38*—UNS R54250. Titanium alloy (4 % aluminum, 2.5 % vanadium, 1.5 % iron).

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.

<sup>1</sup> This specification is under the jurisdiction of ASTM Committee B10 on Reactive and Refractory Metals and Alloys and is the direct responsibility of Subcommittee B10.01 on Titanium.

Current edition approved July 1, 2013. Published August 2013. Originally approved in 1961. Last previous edition approved in 2009 as B367 – 09. DOI: 10.1520/B0367-13.

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*:<sup>2</sup>

- A802/A802M Practice for Steel Castings, Surface Acceptance Standards, Visual Examination
- E8 Test Methods for Tension Testing of Metallic Materials
- E10 Test Method for Brinell Hardness of Metallic Materials
- E18 Test Methods for Rockwell Hardness of Metallic Materials
- E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E94 Guide for Radiographic Examination
- E142 Method for Controlling Quality of Radiographic Testing (Withdrawn 2000)<sup>3</sup>
- E165 Practice for Liquid Penetrant Examination for General Industry
- E446 Reference Radiographs for Steel Castings Up to 2 in. (50.8 mm) in Thickness
- E539 Test Method for Analysis of Titanium Alloys by X-Ray Fluorescence Spectrometry
- E1409 Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Technique
- E1447 Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by Inert Gas Fusion Thermal Conductivity/Infrared Detection Method
- E1941 Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis
- E2371 Test Method for Analysis of Titanium and Titanium Alloys by Direct Current Plasma and Inductively Coupled Plasma Atomic Emission Spectrometry (Performance-Based Test Methodology)

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> The last approved version of this historical standard is referenced on www.astm.org.

\*A Summary of Changes section appears at the end of this standard

## E2626 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 ¼ 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 ± 25°F (580 ± 14°C) for Grades C-2, C-3, C-7, C-8, C-12, C-16 and C-17, and 1200 ± 25°F (650 ± 14°C) for Grades C-5, C-6, C-9, C-18, and C-38. Time at temperature shall be a minimum of ½ h plus an additional ½ 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

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 E2626](#).

### 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 [A802/A802M](#) 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 a welding procedure and operators certified to 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.

TABLE 1 Chemical Requirements

Composition, Weight Percent<sup>A,B,C,D,E</sup>

Grade	UNS Carbon Number	Oxygen max.	Nitrogen max.	Hydrogen max.	Iron range or max.	Aluminum	Vanadium	Palladium	Ruthenium	Nickel	Molybdenum	Chromium	Cobalt	Zirconium	Niobium	Tin	Silicon	Other Elements, max. each	Other Elements, max. total
C-2	R52550	0.10	0.40	0.05	0.015	—	—	—	—	—	—	—	—	—	—	—	—	0.1	0.4
C-3	R52550	0.10	0.40	0.05	0.015	—	—	—	—	—	—	—	—	—	—	—	—	0.1	0.4
C-5	R56400	0.10	0.25	0.05	0.015	5.5-6.75	3.5-4.5	—	—	—	—	—	—	—	—	—	—	0.1	0.4
C-6	R54520	0.10	0.20	0.05	0.015	4.0-6.0	—	—	—	—	—	—	—	—	—	2.0-3.0	—	0.1	0.4
C-7	R52700	0.10	0.40	0.05	0.015	—	—	0.12-0.25	—	—	—	—	—	—	—	—	—	0.1	0.4
C-8	R52700	0.10	0.40	0.05	0.015	—	—	0.12-0.25	—	—	—	—	—	—	—	—	—	0.1	0.4
C-9	R56320	0.10	0.20	0.05	0.015	2.5-3.5	2.0-3.0	—	—	—	—	—	—	—	—	—	—	—	—
C-12	R53400	0.10	0.25	0.05	0.015	—	—	—	—	0.6-0.9	0.2-0.4	—	—	—	—	—	—	0.1	0.4
C-16	R52402	0.10	0.18	0.03	0.015	—	—	0.04-0.08	—	—	—	—	—	—	—	—	—	0.1	0.4
C-17	R52252	0.10	0.20	0.03	0.015	—	—	0.04-0.08	—	—	—	—	—	—	—	—	—	0.1	0.4
C-18	R58465	0.08	0.20	0.03	0.015	2.5-3.5	2.0-3.0	0.04-0.08	—	—	—	—	—	—	—	—	—	0.1	0.4
C-38	R54250	0.08	0.20-0.30	0.03	0.015	3.5-4.5	2.0-3.0	—	—	—	—	—	—	—	—	—	—	0.1	0.4

<sup>A</sup> At minimum, one pour analysis shall be completed and reported for all elements listed for the respective grade in this table.  
<sup>B</sup> If the casting is subjected to thermal or chemical processing following the pour, final product hydrogen shall be reported in lieu of pour hydrogen. Lower hydrogen may be obtained by negotiation with the manufacturer.  
<sup>C</sup> Single values are maximum. The percentage of titanium is determined by difference.  
<sup>D</sup> Other elements need not be reported unless the concentration level is greater than 0.1 % each, or 0.4 % total. Other elements may not be added intentionally. Other elements may be present in titanium or titanium alloys in small quantities and are inherent to the manufacturing process. In titanium these elements typically include aluminum, vanadium, tin, chromium, molybdenum, niobium, zirconium, hafnium, bismuth, ruthenium, palladium, yttrium, copper, silicon, cobalt, tantalum, nickel, boron, manganese, and tungsten.  
<sup>E</sup> The purchaser may, in the written purchase order, request analysis for specific elements not listed in this specification.

**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
	2.5–6.75	±0.40
Aluminum	2.0–4.5	±0.15
Vanadium	2.0–3.0	±0.15
Tin	0.04–0.25	±0.02
Palladium	0.2–0.4	±0.04
Molybdenum	0.3–0.9	±0.05
Nickel	0.10	+0.02
Other (each)		

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.<sup>3</sup> (16.4 cm<sup>3</sup>) 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 E29](#).

## 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 the ASTM designation number (Specification B367) 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 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 E94 and Test Method E142. Types and degrees of discontinuities considered shall be judged by the Reference Radiographs E446. 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 E446 is described as follows:

<i>Category A</i>	gas porosity	severity level 2
<i>Category B</i>	sand and slag inclusions	severity level 2
<i>Category C</i>	shrinkage CA	severity level 2
<i>Category C</i>	shrinkage CB	severity level 2
<i>Category C</i>	shrinkage CC	severity level 2
<i>Category C</i>	shrinkage CD	severity level 2
<i>Category D</i>	crack	none permitted
<i>Category E</i>	hot tear	none permitted
<i>Category F</i>	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 E165. 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.

**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 <sup>A</sup>	Rockwell Hardness, max <sup>A</sup>
C-2	210	B96
C-3	235	C24
C-5	365	C39
C-6	335	C36
C-7	210	B96
C-8	235	C24
C-9	365	C39
C-12	235	C24
C-16	210	B96
C-17	235	C24
C-18	365	C39
C-38	365	C39

<sup>A</sup> Average of three tests.

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 E8. 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 E10 or E18.

## SUMMARY OF CHANGES

Committee B10 has identified the location of selected changes to this standard since the last issue (B367-09) that may impact the use of this standard. (Approved July 1, 2013.)

(1) Added Grades included under Scope and UNS Numbers under Scope and in Table 1.

*ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.*

*This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.*

*This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the ASTM website (www.astm.org/COPYRIGHT/).*