



Standard Specification for Titanium and Titanium Ingots¹

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1. Scope*

1.1 This specification covers titanium and titanium alloy ingots as follows:

- 1.1.1 *Grade 1*—UNS R50250. Unalloyed titanium,
- 1.1.2 *Grade 2*—UNS R50400. Unalloyed titanium,
- 1.1.3 *Grade 3*—UNS R50550. Unalloyed titanium,
- 1.1.4 *Grade 4*—UNS R50700. Unalloyed titanium,
- 1.1.5 *Grade 5*—UNS R56400. Titanium alloy (6 % aluminum, 4 % vanadium),
- 1.1.6 *Grade 6*—UNS R54520. Titanium alloy (5 % aluminum, 2.5 % tin),
- 1.1.7 *Grade 7*—UNS R52400. Unalloyed titanium plus 0.12 to 0.25 % palladium,
- 1.1.8 *Grade 9*—UNS R56320. Titanium alloy (3 % aluminum, 2.5 % vanadium),
- 1.1.9 *Grade 11*—UNS R52250. Unalloyed titanium plus 0.12 to 0.25 % palladium,
- 1.1.10 *Grade 12*—UNS R53400. Titanium alloy (0.3 % molybdenum, 0.8 % nickel),
- 1.1.11 *Grade 13*—UNS R53413. Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
- 1.1.12 *Grade 14*—UNS R53414. Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
- 1.1.13 *Grade 15*—UNS R53415. Titanium alloy (0.5 % nickel, 0.05 % ruthenium),
- 1.1.14 *Grade 16*—UNS R52402. Unalloyed titanium plus 0.04 to 0.08 % palladium,
- 1.1.15 *Grade 17*—UNS R52252. Unalloyed titanium plus 0.04 to 0.08 % palladium,
- 1.1.16 *Grade 18*—UNS R56322. Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.04 to 0.08 % palladium,
- 1.1.17 *Grade 19*—UNS R58640. Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum),
- 1.1.18 *Grade 20*—UNS R58645. Titanium alloy (3 % aluminum, 8 % vanadium, 6 % chromium, 4 % zirconium, 4 % molybdenum) plus 0.04 to 0.08 % palladium,

- 1.1.19 *Grade 21*—UNS R58210. Titanium alloy (15 % molybdenum, 3 % aluminum, 2.7 % niobium, 0.25 % silicon),
- 1.1.20 *Grade 23*—UNS R56407. Titanium alloy (6 % aluminum, 4 % vanadium with extra low interstitials, ELI),
- 1.1.21 *Grade 24*—UNS R56405. Titanium alloy (6 % aluminum, 4 % vanadium) plus 0.4 to 0.8 % palladium,
- 1.1.22 *Grade 25*—UNS R56403. Titanium alloy (6 % aluminum, 4 % vanadium) plus 0.3 to 0.8 % nickel and 0.04 to 0.08 % palladium,
- 1.1.23 *Grade 26*—UNS R56404. Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
- 1.1.24 *Grade 27*—UNS R52254. Unalloyed titanium plus 0.08 to 0.14 % ruthenium,
- 1.1.25 *Grade 28*—UNS R56323. Titanium alloy (3 % aluminum, 2.5 % vanadium) plus 0.08 to 0.14 % ruthenium,
- 1.1.26 *Grade 29*—UNS R56404. Titanium alloy (6 % aluminum, 4 % vanadium, extra low interstitial elements, ELI) plus 0.08 to 0.14 % ruthenium,
- 1.1.27 *Grade 30*—UNS R53530. Titanium alloy (0.3 % cobalt, 0.05 % palladium),
- 1.1.28 *Grade 31*—UNS R53532. Titanium alloy (0.3 % cobalt, 0.05 % palladium),
- 1.1.29 *Grade 32*—UNS R55111. Titanium alloy (5 % aluminum, 1 % tin, 1 % zirconium, 1 % vanadium, 0.8 % molybdenum),
- 1.1.30 *Grade 33*—UNS R53442. Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),
- 1.1.31 *Grade 34*—UNS R53445. Titanium alloy (0.4 % nickel, 0.015 % palladium, 0.025 % ruthenium, 0.15 % chromium),
- 1.1.32 *Grade 35*—UNS R56340. Titanium alloy (4.5 % aluminum, 2 % molybdenum, 1.6 % vanadium, 0.5 % iron, 0.3 % silicon),
- 1.1.33 *Grade 36*—UNS R58450. Titanium alloy (45 % niobium),
- 1.1.34 *Grade 37*—UNS R52815. Titanium alloy (1.5 % aluminum), and
- 1.1.35 *Grade 38*—UNS R54250. Titanium alloy (4 % aluminum, 2.5 % vanadium, 1.5 % iron).

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each

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

system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.3 *The following caveat pertains only to the test method portions of this specification: This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*²

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E178 Practice for Dealing With Outlying Observations

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 Inert Gas Fusion

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)

E2626 Guide for Spectrometric Analysis of Reactive and Refractory Metals

3. Terminology

3.1 *Lot Definitions:*

3.2 *ingot, n*—a quantity of metal cast into a shape suitable for subsequent processing to various mill products.

4. Ordering Information

4.1 Orders for material under this specification shall include the following information as required to describe adequately the desired material:

4.1.1 Grade number (1.1),

4.1.2 Nominal weight in the unit system regarded as standard (inch-pound or SI),

4.1.3 Nominal size (width and gauge or diameter, length) in the unit system regarded as standard (inch-pound or SI),

4.1.4 ASTM designation and year of issue.

4.2 Orders for material under this specification may include (at the discretion of the purchaser) the following additional information:

4.2.1 Method of manufacture (5.1),

4.2.2 Surface condition (7.1 and 7.2),

4.2.3 Product analysis (6.2),

4.2.4 Additional chemical analysis (6.1.3),

4.2.5 Requirements for purchaser inspection/witness (11.1), and

4.2.6 Packaging (Section 15).

5. Materials and Manufacture

5.1 Materials covered by this specification are produced by one of the following methods:

5.1.1 double vacuum arc melting,

5.1.2 triple vacuum arc melting,

5.1.3 electron beam cold hearth melting followed by vacuum arc melting,

5.1.4 plasma arc cold hearth melting followed by vacuum arc melting,

5.1.5 electron beam cold hearth melting,

5.1.6 plasma arc cold hearth melting or

5.1.7 other melting process as agreed upon by the purchaser and producer.

5.2 The melting method used to produce the ingot shall be reported to the purchaser on the certification.

5.3 The melting method shall be at the discretion of the producer, unless specified in the purchase order.

6. Chemical Composition

6.1 The chemistry of titanium and titanium alloy ingot covered by this specification shall conform to the requirements for the specified grade as prescribed in Table 1.

6.1.1 The elements listed for each grade in Table 1 are intentional alloy additions or elements that are inherent to the manufacture of titanium sponge or ingot.

6.1.2 Elements intentionally added to the melt, including additions made via revert additions, must be identified, analyzed and reported in the chemical analysis. Elements not listed in Table 1 for the specified grade shall not be required.

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

6.2 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 other methods acceptable to the purchaser. Alternate techniques are discussed in Guide E2626.

6.3 *Product Check Analysis*—Product check analysis is an analysis made by or for the purchaser for the purpose of verifying the composition of the ingot. The check analysis tolerances reflect the variation between laboratories in the measurement of chemical composition. The permissible variation in the product check analysis from the specified range is as prescribed in Table 2.

7. Condition

7.1 *Surface Finish*—The surface finish shall be at the discretion of the producer, unless specified in the purchase order.

² 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.

TABLE 1 Chemical Requirements

Chemical Composition (Weight %)^{A,B,C,D}

Grade	UNS Number	C max	O range or max	N max	H max ^E	Fe range or max	Al	V	Pd	Ru	Ni	Mo	Cr	Co	Zr	Nb	Sn	Si	Other Elements max, each	Other Elements max, total
1	R50250	0.08	0.18	0.03	0.003	0.20	...	...	...	...	...	...	...	...	...	...	...	...	0.1	0.4
2	R50400	0.08	0.25	0.03	0.003	0.30	...	...	...	...	...	...	...	...	...	...	...	...	0.1	0.4
3	R50550	0.08	0.35	0.05	0.003	0.30	...	...	...	...	...	...	...	...	...	...	...	...	0.1	0.4
4	R50700	0.08	0.40	0.05	0.003	0.50	...	...	...	...	...	...	...	...	...	...	...	...	0.1	0.4
5	R56400	0.08	0.20	0.05	0.003	0.40	5.5-6.75	3.5-4.5	...	...	...	...	...	...	...	...	...	...	0.1	0.4
6	R54520	0.08	0.20	0.03	0.003	0.50	4.0-6.0	...	...	...	...	...	...	...	...	...	2.0-3.0	...	0.1	0.4
7	R52400	0.08	0.25	0.03	0.003	0.30	...	...	0.12-0.25	...	...	...	...	...	...	...	...	...	0.1	0.4
9	R56320	0.08	0.15	0.03	0.003	0.25	2.5-3.5	2.0-3.0	...	...	...	...	...	...	...	...	...	...	0.1	0.4
11	R52250	0.08	0.18	0.03	0.003	0.20	...	...	0.12-0.25	...	...	...	...	...	...	...	...	...	0.1	0.4
12	R53400	0.08	0.25	0.03	0.003	0.30	...	...	...	...	0.6-0.9	0.2-0.4	...	...	...	...	...	...	0.1	0.4
13	R53413	0.08	0.10	0.03	0.003	0.20	...	...	...	0.04-0.06	0.4-0.6	...	...	...	...	...	...	...	0.1	0.4
14	R53414	0.08	0.15	0.03	0.003	0.30	...	...	...	0.04-0.06	0.4-0.6	...	...	...	...	...	...	...	0.1	0.4
15	R53415	0.08	0.25	0.05	0.003	0.30	...	...	...	0.04-0.06	0.4-0.6	...	...	...	...	...	...	...	0.1	0.4
16	R52402	0.08	0.25	0.03	0.003	0.30	...	...	0.04-0.08	...	...	...	...	...	...	...	...	...	0.1	0.4
17	R52252	0.08	0.18	0.03	0.003	0.20	...	...	0.08	...	...	...	...	...	...	...	...	...	0.1	0.4
18	R56322	0.08	0.15	0.03	0.003	0.25	2.5-3.5	2.0-3.0	0.04-0.08	...	...	...	...	...	...	...	...	...	0.1	0.4
19	R58640	0.05	0.12	0.03	0.003	0.30	3.5-4.0	7.5-8.5	...	...	...	3.5-4.5	5.5-6.5	...	3.5-4.5	...	...	...	0.15	0.4
20	R58645	0.05	0.12	0.03	0.003	0.30	3.0-4.0	7.5-8.5	0.04-0.08	...	...	3.5-4.5	5.5-6.5	...	3.5-4.5	...	...	...	0.15	0.4
21	R58210	0.05	0.17	0.03	0.003	0.40	2.5-3.5	8.5	...	...	...	14.0-16.0	...	...	...	2.2-3.2	0.15-0.25	...	0.1	0.4
23	R56407	0.08	0.13	0.03	0.003	0.25	5.5-6.5	3.5-4.5	...	...	...	...	...	...	...	...	...	...	0.1	0.4
24	R56405	0.08	0.20	0.05	0.003	0.40	5.5-6.75	3.5-4.5	0.04-0.08	...	...	...	...	...	...	...	...	...	0.1	0.4
25	R56403	0.08	0.20	0.05	0.003	0.40	5.5-6.75	4.5	0.08	...	0.3-0.8	...	...	...	...	...	...	...	0.1	0.4
26	R52404	0.08	0.25	0.03	0.003	0.30	...	...	...	0.08-0.14	...	...	...	...	...	...	...	...	0.1	0.4
27	R52254	0.08	0.18	0.03	0.003	0.20	...	...	...	0.08-0.14	...	...	...	...	...	...	...	...	0.1	0.4
28	R56323	0.08	0.15	0.03	0.003	0.25	2.5-3.5	2.0-3.0	...	0.08-0.14	...	...	...	...	...	...	...	...	0.1	0.4
29	R56404	0.08	0.13	0.03	0.003	0.25	5.5-6.5	3.5-4.5	...	0.08-0.14	...	...	...	...	...	...	...	...	0.1	0.4
30	R53530	0.08	0.25	0.03	0.003	0.30	...	...	0.04-0.08	...	...	...	...	0.20-0.80	...	...	...	...	0.1	0.4
31	R53532	0.08	0.35	0.05	0.003	0.30	...	...	0.04-0.08	...	...	...	...	0.20-0.80	...	...	...	...	0.1	0.4

TABLE 1 Continued
Chemical Composition (Weight %)^{A,B,C,D}

Grade	UNS Number	C max	O range or max	N max	H max ^E	Fe range or max	Al	V	Pd	Ru	Ni	Mo	Cr	Co	Zr	Nb	Sn	Si	Other Elements max, each	Other Elements max, total
32	R55111	0.08	0.11	0.03	0.003	0.25	4.5-5.5	0.6-1.4	...	...	...	0.6-1.2	...	...	0.6-1.4	...	0.6-1.4	0.06-0.14	0.1	0.4
33	R53442	0.08	0.25	0.03	0.003	0.30	...	...	0.01-0.02	0.02-0.04	0.35-0.55	...	0.1-0.2	...	...	...	...	...	0.1	0.4
34	R53445	0.08	0.35	0.05	0.003	0.30	...	...	0.01-0.02	0.02-0.04	0.35-0.55	...	0.1-0.2	...	...	...	...	...	0.1	0.4
35	R56340	0.08	0.25	0.05	0.003	0.20-0.80	4.0-5.0	1.1-2.1	...	...	...	1.5-2.5	...	...	...	...	...	0.20-0.40	0.1	0.4
36	R58450	0.04	0.16	0.03	0.001	0.03	...	...	...	...	...	...	...	...	...	42.0-47.0	...	...	0.1	0.4
37	R52815	0.08	0.25	0.03	0.003	0.30	1.0-2.0	...	...	...	...	...	...	...	...	...	...	...	0.1	0.4
38	R54250	0.08	0.20-0.30	0.03	0.003	1.2-1.8	3.5-4.5	2.0-3.0	...	...	...	...	...	...	...	...	...	...	0.1	0.4

^A At minimum, the analysis of samples from the top and bottom of the ingot shall be completed and reported for all elements listed for the respective grade in this table.

^B The percentage of titanium is determined by difference.

^C 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 but not added intentionally. 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.

^D The purchaser may, in the written purchase order, request analysis for specific elements not listed in this specification.

^E Lower hydrogen may be obtained by negotiation with the manufacturer.

TABLE 2 Permissible Variations in Product Analysis

Element	Product Analysis Limits,	Permissible Variation in
	Max or Range, (%)	Product Analysis
Aluminum	0.5 to 2.5	±0.20
Aluminum	2.5 to 6.75	±0.40
Carbon	0.10	±0.02
Chromium	0.1 to 0.2	±0.02
Chromium	5.5 to 6.5	±0.30
Cobalt	0.2 to 0.8	±0.05
Hydrogen	0.02	±0.002
Iron	0.80	±0.15
Iron	1.2 to 1.8	±0.20
Molybdenum	0.2 to 0.4	±0.03
Molybdenum	0.6 to 1.2	±0.15
Molybdenum	1.5 to 4.5	±0.20
Molybdenum	14.0 to 16.0	±0.50
Nickel	0.3 to 0.9	±0.05
Niobium	2.2 to 3.2	±0.15
Niobium	>30	±0.50
Nitrogen	0.05	±0.02
Oxygen	0.30	±0.03
Oxygen	0.31 to 0.40	±0.04
Palladium	0.01 to 0.02	±0.002
Palladium	0.04 to 0.08	±0.005
Palladium	0.12 to 0.25	±0.02
Ruthenium	0.02 to 0.04	±0.005
Ruthenium	0.04 to 0.06	±0.005
Ruthenium	0.08 to 0.14	±0.01
Silicon	0.06 to 0.40	±0.02
Tin	0.62 to 3.0	±0.15
Vanadium	0.6 to 4.5	±0.15
Vanadium	7.5 to 8.5	±0.40
Zirconium	0.6 to 1.4	±0.15
Zirconium	3.5 to 4.5	±0.20
Other Element ^A (each)	0.15	±0.02

^A Other elements are present in a metal or an alloy in small quantities and are inherent to the manufacturing process but not added intentionally. 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.

7.2 When specified, the ingots shall be conditioned on the surface to standards agreed upon between the manufacturer and the purchaser.

7.3 Titanium and titanium alloy ingots shall be free of imperfections that would be deemed injurious by the standards of acceptability agreed upon between the purchaser and the manufacturer.

7.3.1 The manufacturer shall be permitted to remove minor surface imperfections. Surface imperfections may be removed up to 1 in. (25 mm) deep from the ingot surface. Areas adjacent to the imperfection shall be blended smoothly into the ingot surface at a slope not less than 3:1.

8. Retest

8.1 If any sample or specimen exhibits obvious contamination, improper preparation, or flaws disqualifying it as a representative sample, it shall be discarded and a new sample or specimen substituted.

8.2 If the results of any test are not in conformance with the requirements of this specification, the original sample from the ingot may be retested or the ingot may be re-sampled and tested.

8.2.1 If the original ingot sample is retested, the frequency of the retest will be at least double the initial number of tests. The retests will be compared to the original value to determine if the original value is an outlier in accordance with Practice E178. If it is an outlier the retest values will be averaged and the averaged retest values reported. If it is not an outlier all the values will be averaged and the averages of all of the tests become the test value reported. If the averaged value reported conforms to the specification, then they become the test values for certification.

8.2.2 The manufacturer may resample the ingot at the non-conforming location(s) in a different area at the same axial location. The frequency of the resample will be at least double the initial number of tests. If the results of the resample conform to the specification, then the resample values become the test values for certification.

8.3 The manufacturer may scalp or crop the ingot to remove nonconforming material then sample the remaining ingot position(s). The ingot shall be acceptable if all results of the tests on the ingot conform to this specification.

9. Sampling

9.1 Samples for chemical analyses shall be representative of the material being tested. The utmost care must be used in sampling titanium for chemical analysis because of its great affinity for elements such as oxygen, nitrogen, and hydrogen. Therefore in cutting samples for analysis, the operation should be carried out insofar as possible in a dust-free atmosphere. Chips should be collected from clean metal and tools should be clean and sharp. Samples for analysis should be stored in suitable containers.

9.2 The ingot shall be sampled at a minimum of two locations; top and bottom. The top sample shall be within 12 in. (300 mm) of the top face. The bottom sample shall be within 12 in. (300 mm) of the bottom face.

10. Significance of Numerical Limits

10.1 For purposes of determining compliance with the specified limits for requirements of the properties listed in Table 1 and Table 2, an observed value or a calculated value shall be rounded as indicated in accordance with the rounding method of Practice E29.

11. Inspection

11.1 The manufacturer shall inspect the material covered by this specification prior to shipment. If so specified on the purchase order, the purchaser or his representative may witness the testing and inspection of the material at the place of manufacture. In such cases, the purchaser shall state in the purchase order those tests that are to be witnessed. The manufacturer shall give ample notice to the purchaser as to the time and place of the designated tests. If the purchaser's representative is not present at the time agreed upon for the testing, the manufacturer shall consider the requirement for purchaser's inspection at place of manufacture to be waived.

11.2 The manufacturer shall afford the inspector representing the purchaser, without charge, all reasonable facilities to

satisfy the purchaser that the material is being furnished in accordance with this specification. This inspection shall be conducted so as not to interfere unnecessarily with the operation of the works.

12. Rejection

12.1 Rejection for failure of the material to meet this specification shall be reported to the manufacturer within 60 calendar days from the receipt of the material by the purchaser. Unless otherwise specified, rejected material may be returned to the manufacturer at the manufacturer's expense, unless the purchaser receives, within three weeks of the notice of rejection, other instructions for disposition.

13. Referee

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

14. Certification

14.1 A manufacturer's certification shall be furnished to the purchaser. The certification will state that the material was manufactured, sampled, tested and inspected in accordance with the specification and has been found to meet the requirements. The manufacturer shall include the melt method(s) used to produce the ingot on the certification. A report of the test

results (determined in accordance with Section 9 and Section 8) shall be included with the certification.

15. Packaging and Marking

15.1 Each ingot shall be steel stamped on the top with the manufacturer's ingot number.

15.2 Ingots shall be packaged in such a manner as to assure safe delivery to their destination when properly transported by any common carrier.

15.3 If ingots are packaged in a box, each box shall be legibly and conspicuously marked or tagged with the following information (at a minimum):

15.3.1 Order or contract number,

15.3.2 Grade,

15.3.3 Ingot number,

15.3.4 Net weight and

15.3.5 ASTM specification number.

15.4 If ingots are not packaged as part of a box, each ingot shall be legibly and conspicuously marked with the following (at a minimum):

15.4.1 Ingot number,

15.4.2 Grade, and

15.4.3 Net weight.

15.5 The purchaser may specify additional markings or packaging requirements as part of the order requirements.

16. Keywords

16.1 ingot; titanium; titanium alloy

APPENDIX

(Nonmandatory Information)

X1. MELT METHODS

X1.1 The purpose of this specification is to define requirements for titanium ingot (cylindrical) or slab (rectilinear). Titanium producers use a range of melt methods and processes to produce the ingot or slab. The most widely used methods (to the best ability of the committee) have been itemized in 5.1.1 through 5.1.6.

X1.2 Not all of the methods have been captured in 5.1.1 through 5.1.6.

X1.3 Not all of the methods listed in 5.1.1 through 5.1.6 have been successfully used to manufacture all of the alloys in the scope of this specification. A discussion on the appropriate melt method for each grade produced is beyond the scope of this specification.

SUMMARY OF CHANGES

Committee B10 has identified the location of selected changes to this standard since the last issue (B977-11) that may impact the use of this standard. (Approved July 1, 2013.)

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

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