Designation: B 351/B 351M – 02

Used in USDOE-NE standards

Standard Specification for Hot-Rolled and Cold-Finished Zirconium and Zirconium Alloy Bars, Rod, and Wire for Nuclear Application[1]

This standard is issued under the fixed designation B 351/B 351M; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers hot- and cold-finished zirconium and zirconium alloy bars, rod, and wire, other than those required for reforging, including rounds, squares, and shapes.

1.2 One unalloyed grade and three alloy grades for use in nuclear applications are described.

1.3 The products covered include the following sections and sizes:

Bars:	
Rounds, squares and hexagons	⅜ in. (9.5 mm) and over in diameter or size
Flats	¼ to 10 in. (6.4 to 250 mm) incl in width and ⅛ in. (3.2 mm) and over in thickness[A]
Rod:	
Rounds in coils for subsequent reworking	¼ to ¾ in. (6.4 to 19 mm) in diameter
Wire	less than ⅜ in. (9.5 mm) in diameter or size

[A] Thickness ⅛ in. (3.2 mm) to under 3/16 in. (4.8 m) can be cold-rolled strip as well as bar.

1.4 Unless a single unit is used, for example corrosion mass gain in mg/dm^2, the values stated in either inch-pound or SI units are to be regarded separately as standard. The values stated in each system are not exact equivalents; therefore each system must be used independently of the other. SI values cannot be mixed with inch-pound values.

1.5 The following precautionary 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]

B 350/B 350M Specification for Zirconium and Zirconium Alloy Ingots for Nuclear Application

E 8 Test Methods for Tension Testing of Metallic Materials

E 21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E 114 Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method

E 214 Practice for Immersed Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves

G 2/G 2M Test Method for Corrosion Testing of Products of Zirconium, Hafnium, and Their Alloys in Water at 680°F [360°C] or in Steam at 750°F [400°C]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *annealed*—denotes material that exhibits a recrystallized grain structure.

3.2 *Lot Definitions:*

3.2.1 *castings*—a lot shall consist of all castings produced from the same pour.

3.2.2 *ingot*—no definition required.

3.2.3 *rounds, flats, tubes, and wrought powder metallurgical products (single definition, common to nuclear and non-nuclear standards)*—a lot shall consist of a material of the same size, shape, condition, and finish produced from the same ingot or powder blend by the same reduction schedule and the same heat treatment parameters. Unless otherwise agreed between manufacturer and purchaser, a lot shall be limited to the product of an 8 h period for final continuous anneal, or to a single furnace load for final batch anneal.

3.2.4 *sponge*—a lot shall consist of a single blend produced at one time.

3.2.5 *weld fittings*—definition is to be mutually agreed upon between manufacturer and the purchaser.

4. Ordering Information

4.1 Purchase orders for material under this specification should include the following information as required to adequately describe the desired material:

4.1.1 Quantity (weight or number of pieces),

[1] This specification is under the jurisdiction of ASTM Committee B10 on Reactive and Refractory Metals and Alloys and is the direct responsibility of Subcommittee B10.02 on Zirconium and Hafnium.

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[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.

4.1.2 Name of material,
4.1.3 Condition (Section 6),
4.1.4 Finish (Section 14),
4.1.5 Cross section (round, square, etc.),
4.1.6 Form (bar, rod, wire),
4.1.7 Dimensions (size, thickness, width and length),
4.1.8 Grade (Table 1), and
4.1.9 ASTM designation and year of issue.

NOTE 1—A typical ordering description is as follows: 250 lb (100 kgs) zirconium alloy bar; hot rolled, annealed; mechanically descaled and pickled; ¾ in. (19 mm) by 4 in. (100 mm) by 144 in. (3.6 m), ASTM Specification B 351 - 01, Grade R60802.

4.2 In addition to the data specified in 4.1, the following options and points of agreement between the manufacturer and the purchaser should be specified on the purchase order as required:
4.2.1 Mechanical test temperature (see 8.1),
4.2.2 Tolerances (Section 10),
4.2.3 Workmanship standards (Section 13),
4.2.4 Special tests (Section 12),
4.2.5 Inspection (Section 16), and
4.2.6 Corrosion visual standards (Section 9).
4.2.7 Oxygen limits (see footnote A, Table 1).

5. Materials and Manufacture

5.1 Materials covered by this specification shall be produced by multiple vacuum melting in arc furnaces, electron beam melting, or other melting processes conventionally used for reactive metals; all processes to be done in furnaces usually used for reactive metals.

6. Condition

6.1 Grades R60001, R60802, and R60804 furnished under this specification shall be in the annealed condition unless otherwise specified.

6.2 Grade R60901 in sizes under 1 in. (25 mm) in minimum dimension furnished under this specification shall be in the cold-worked condition unless otherwise specified. Sizes 1 in. (25 mm) and over in minimum dimension shall be furnished in the annealed condition unless otherwise specified.

7. Chemical Composition

7.1 The material shall conform to the requirements for chemical composition as prescribed in Table 1.

7.2 The manufacturer's ingot analysis made in accordance with Specification B 350/B 350M shall be considered the chemical analysis for material produced to this specification except for hydrogen, oxygen, and nitrogen content, which shall be determined on the finished product. Alternatively, the manufacturer may sample an intermediate or final size during processing with the same frequency and in the same positions relative to the ingot, as specified in Specification B 350/

TABLE 1 Chemical Requirements

Element	Composition, Weight %			
	UNS R60001	UNS R60802	UNS R60804	UNS R60901
Tin	. . .	1.20–1.70	1.20–1.70	. . .
Iron	. . .	0.07–0.20	0.18–0.24	. . .
Chromium	. . .	0.05–0.15	0.07–0.13	. . .
Nickel	. . .	0.03–0.08	. . .	. . .
Niobium (columbium)	. . .	. . .	. . .	2.40–2.80
Oxygen	[A]	[A]	[A]	0.09–0.15
Iron + chromium + nickel	. . .	0.18–0.38	. . .	. . .
Iron + chromium	. . .	. . .	0.28–0.37	. . .
Maximum Impurities, Weight %				
Aluminum	0.0075	0.0075	0.0075	0.0075
Boron	0.00005	0.00005	0.00005	0.00005
Cadmium	0.00005	0.00005	0.00005	0.00005
Calcium	...	0.0030	0.0030	...
Carbon	0.027	0.027	0.027	0.027
Chromium	0.020	. . .	. . .	0.020
Cobalt	0.0020	0.0020	0.0020	0.0020
Copper	0.0050	0.0050	0.0050	0.0050
Hafnium	0.010	0.010	0.010	0.010
Hydrogen	0.0025	0.0025	0.0025	0.0025
Iron	0.150	. . .	. . .	0.150
Magnesium	0.0020	0.0020	0.0020	0.0020
Manganese	0.0050	0.0050	0.0050	0.0050
Molybdenum	0.0050	0.0050	0.0050	0.0050
Nickel	0.0070	. . .	0.0070	0.0070
Niobium	...	0.0100	0.0100	...
Nitrogen	0.0080	0.0080	0.0080	0.0080
Phosphorus	. . .	. . .	. . .	0.0020
Silicon	0.0120	0.0120	0.0120	0.0120
Tin	0.0050	. . .	. . .	0.010
Tungsten	0.010	0.010	0.010	0.010
Titanium	0.0050	0.0050	0.0050	0.0050
Uranium (total)	0.00035	0.00035	0.00035	0.00035

[A] When so specified in the purchase order, oxygen shall be determined and reported. Maximum, minimum, or both, permissible values should be specified in the purchase order.

B 350M, to determine the composition, except for hydrogen, oxygen, and nitrogen, which shall be determined on the finished product.

7.3 Analysis shall be made using the manufacturer's standard methods. In the event of disagreement as to the chemical composition of the metal, methods of chemical analysis for reference purposes shall be determined by a mutually acceptable laboratory.

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

7.5 *Number of Tests*—Two random samples for each 4000 lb (1800 kg) or fraction thereof shall be analyzed for hydrogen, nitrogen, and oxygen.

8. Mechanical Properties

8.1 The material shall conform to the requirements prescribed in Table 3 for room temperature mechanical properties. Elevated temperature properties shall be used to determine compliance only when specified in the purchase order.

8.2 The yield strength shall be determined by the offset (0.2 % method) as prescribed in Test Methods E 8.

8.3 The tensile properties shall be determined using a strain rate of 0.003 to 0.007 in./in. (mm/mm)/min through the yield strength. After the yield strength has been exceeded, the cross head speed may be increased to approximately 0.05 in./in. (mm/mm)/min to failure.

8.4 Requirements for mechanical properties do not apply to wire.

8.5 The tensile properties enumerated in this specification shall be determined in accordance with Test Methods E 8 or E 21.

8.6 *Number of Tests*—Two random samples for each 4000 lb (1800 kg) or fraction thereof shall be tested for mechanical properties in the longitudinal direction.

9. Corrosion Properties

9.1 Two samples chosen at random from each 4000 lb (1800 kg, a hard conversion) or fraction thereof shall be corrosion tested in steam at 750°F (400°C), 1500 psi (10.3 MPa), for 72 h or 336 h at the option of the manufacturer in accordance with Test Method G 2/G 2M.

9.2 *Acceptance Criterion*:

9.2.1 *Grades R60802 and R60804*—All coupons thus tested shall exhibit a continuous, black, lustrous oxide film and be free of white or brown corrosion product in excess of standards previously agreed upon between manufacturer and purchaser. Coupons shall exhibit a weight gain of not more than 22 mg/dm^2 in a 72-h test or 38 mg/dm^2 in a 336-h test.

9.2.2 *Grade R60901*—All coupons shall exhibit a continuous, uniform, dark gray oxide film. Coupons shall exhibit a weight gain of not more than 35 mg/dm^2 in a 72-h test or 60 mg/dm^2 in a 336-h test.

TABLE 2 Permissible Variations in Product Analysis

Alloying Elements	Permissible Variation from the Specified Range (Table 1), %
Tin	0.050
Iron	0.020
Chromium	0.010
Nickel	0.010
Iron + chromium	0.020
Iron + chromium + nickel	0.020
Niobium	0.050
Oxygen	0.020
Each Impurity Element	20 ppm or 20 % of the specified limit, whichever is smaller

10. Permissible Variations in Dimensions

10.1 Bars, rod, and wire shall conform to the dimensional requirements for the specified product as prescribed in Tables 5-10.

11. Significance of Numerical Limits

11.1 For the purpose of determining compliance with the specified limits for requirements of the properties listed in the following table, an observed value or a calculated value shall be rounded as indicated in accordance with the rounding methods of Practice E 29.

Property	Rounded Unit for Observed or Calculated Value
Chemical composition, and tolerances (when expressed as decimals)	nearest unit in the last right-hand place of figures of the specified limit
Tensile strength and yield strength	nearest 1000 psi (10 MPa)
Elongation	nearest 1 %

12. Special Tests

12.1 *Ultrasonic Inspection*:

12.1.1 In lieu of the ultrasonic test of the ingot as specified in Specification B 350/B 350M, the manufacturer may alternatively perform ultrasonic inspection at an intermediate size in accordance with Practices E 114 or E 214, with the approval of the purchaser.

12.1.2 Unless otherwise approved by the purchaser, the reference standard shall consist of a 0.06 in. (1.5 mm) flat bottom hole drilled perpendicular to the longitudinal product axis to a depth of 0.5 in. (13 mm).

12.1.3 Any defect reflections greater than the indication from the reference standard should be rejected.

12.2 Additional tests may be specified in the purchase order. The test method and standards shall be agreed upon in advance between manufacturer and purchaser.

13. Workmanship and Appearance

13.1 Bars, rod, or wire shall be free of cracks, seams, slivers, blisters, burrs, and other injurious imperfections in accordance with standards of acceptability agreed upon between the manufacturer and the purchaser.

14. Finish

14.1 Bars or rod in the hot-finished condition shall be furnished with one of the following finishes as designated in the purchase order:

14.1.1 Not descaled,