Designation: B353 – 12 (Reapproved 2022)ε1

Standard Specification for Wrought Zirconium and Zirconium Alloy Seamless and Welded Tubes for Nuclear Service (Except Nuclear Fuel Cladding)[1]

This standard is issued under the fixed designation B353; 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.

ε[1] NOTE—Editorial changes made to Table 5 in April 2022.

1. Scope

1.1 This specification covers seamless and welded wrought zirconium and zirconium-alloy tubes for nuclear application. Nuclear fuel cladding is covered in Specification B811.

1.2 Five grades of reactor grade zirconium and zirconium alloys suitable for nuclear application are described.

1.2.1 The present UNS numbers designated for the five grades are given in Table 1.

1.3 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.

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

B350/B350M Specification for Zirconium and Zirconium Alloy Ingots for Nuclear Application

B811 Specification for Wrought Zirconium Alloy Seamless Tubes for Nuclear Reactor Fuel Cladding

E8 Test Methods for Tension Testing of Metallic Materials [Metric] E0008_E0008M

E21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials

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

E112 Test Methods for Determining Average Grain Size

G2/G2M 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 *dimensions, n*—tube dimensions are outside diameter, inside diameter, and wall thickness. Only two of these parameters may be specified in addition to length, except minimum wall may be specified with outside and inside diameter. In each case, ovality and wall thickness variation (WTV) may be specified as additional requirements (see 3.1.5 and 3.1.6).

3.1.2 *hydride orientation fraction, Fn, n*—the ratio of hydride platelets oriented in the radial direction to the total hydride platelets in the field examined.

3.1.3 *Lot Definitions:*

3.1.3.1 *tubes, n*—a lot shall consist of a material of the same size, shape, condition, and finish produced from the same ingot

[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.

TABLE 1 ASTM and UNS Number Designations for Reactor Grade Zirconium and Zirconium Alloys

Grade	UNS Number
Reactor-grade zirconium	R60001
Zirconium-tin alloy	R60802
Zirconium-tin alloy	R60804
Zirconium-niobium alloy	R60901
Zirconium-niobium alloy	R60904

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.

3.1.4 *mill finish tubes, n*—tubes that have received all finishing operations subsequent to final anneal, which potentially affects tube mechanical, dimensional, or surface condition. These operations include, but are not limited to, pickling, cleaning, outer and inner surface abrasive conditioning, and straightening.

3.1.5 *ovality, n*—the difference between the maximum and minimum diameter, either outer or inner, as determined at any one transverse cross section of the tube.

3.1.6 *wall thickness variation (WTV), n*—the difference between maximum and minimum wall thickness measured at any one transverse cross section of the tube.

3.1.6.1 *Discussion*—Measurement of ovality and WTV made by a helical scan with a pitch not exceeding 0.25 in. (6.5 mm) shall be considered as equivalent to "at any one cross section of the tube."

3.1.7 *recrystallized, n*—fully annealed condition.

3.1.8 *stress relieved, n*—annealed to remove residual stresses without recrystallization.

4. Ordering Information

4.1 Purchase orders for material covered in this specification should include the following information to describe adequately the desired material:

4.1.1 Quantity,

4.1.2 Grade (see Table 1), and UNS Number,

4.1.3 Condition (recrystallized or stress relieved) (Section 6),

4.1.4 Dimensions, length, and tolerance (see Table 2 with Notes),

4.1.5 Method of manufacture (seamless or welded) (Section 5),

4.1.6 ASTM designation and year of issue,

4.1.7 Surface finish on the inside (ID) and the outside (OD) surfaces (Ra (in micro-inches or micrometres), unless otherwise stated) (6.3),

4.1.8 Surface condition on the inside (ID) and outside (OD) surfaces (as pickled, abraded, etc.), and ends (as-saw cut, machined/chamfered, sheared, etc.) (6.2), and

4.1.9 Mutually agreed-upon inspection standards in accordance with 9.2, 10.2, 10.4, 10.5, 11.1.1.2, 11.1.2.2, and 11.1.2.3.

NOTE 1—A typical order description may read as follows: 1000 pieces of seamless zirconium-tin alloy tube OD abraded and ID pickled, Grade R60804, recrystallized, ¾ in. outside diameter by 0.035 in. wall by 10-ft lengths in accordance with ASTM B353-07. Surface finish to be__ OD, __ ID.

4.2 In addition to the information in 4.1, the following points of agreement between the manufacturer and purchaser should be specified in the purchase order as required:

4.2.1 Filler metal requirements for welded tubes (Paragraph 5.4),

4.2.2 Oxygen concentration limits in R60001, R60802, R60804, and R60904 (Section 7),

TABLE 2 Permissible Variations in Diameter, Wall Thickness, and Ovality Measured at Any Location

NOTE 1—The tolerances in this table are applicable to only two of the three following dimensions: outside diameter, inside diameter, and wall thickness.

NOTE 2—The manufacturer should be consulted for applicable tolerances in small tubes (less than 0.187 in. (5 mm) in diameter) or tubes with wall thickness less than 0.010 in. (0.25 mm).

NOTE 3—A wider variation of ±12.5 % of wall thickness is permitted for extra-thick walled tubes having wall thicknesses of 0.75 in. (19 mm) (or greater) or inside diameter 60 % (or less) of the outside diameter.

NOTE 4—Ovality is the difference between maximum and minimum outside diameters measured at any one cross section.

NOTE 5—In tubes with nominal wall thickness less than 3 % of nominal outside diameter, the ovality tolerance is twice the tolerance shown for outside or inside diameter (columns 3 and 4), but the average outside or inside diameter must fall within the tolerance given in columns 3 and 4 of the table.

NOTE 6—The manufacturer should be consulted for ovality tolerances in tubes with wall thickness less than 2 % of nominal outside diameter.

Nominal Outside Diameter		Variation in Diameter Outside or Inside		Ovality See Note 5		Variation in Wall Thickness
in.	mm	in.	mm	in.	mm	%
0.187–0.625, excl	5–16, excl	±0.002	±0.05	0.004	0.10	±10
0.625–1.000, excl	16–25, excl	±0.0025	±0.06	0.005	0.12	±10
1.000–2.000, excl	25–50, excl	±0.004	±0.10	0.008	0.20	±10
2.000–3.000, excl	50–75, excl	±0.005	±0.13	0.010	0.26	±10
3.000–4.000, excl	75–100, excl	±0.007	±0.18	0.014	0.36	±10
4.000–5.000, excl	100–125, excl	±0.010	±0.25	0.020	0.50	±10
5.000–6.000, excl	125–150, excl	±0.015	±0.40	0.030	0.80	±10
6.000–8.000, excl	150–200, excl	±0.020	±0.50	0.040	1.00	±10

4.2.3 Specimen temperature(s) during mechanical testing (Section 8 and Table 3, Footnote *C*),

4.2.4 Method of determining yield strength if other than 0.2 % offset method (Section 8),

4.2.5 Tensile property requirements for conditions or temperatures not listed in Table 3 (Section 8),

4.2.6 Location of the inside diameter plugs in elevated temperature short-time tension test, (see Table 3, Footnote *D*, and Paragraph 8.1.3),

4.2.7 Burst properties (Paragraph 8.2),

4.2.8 Post burst test measurement technique (Annex A1),

4.2.9 Sample condition and visual standards for corrosion test (Section 10),

4.2.10 Hydride orientation test procedure, measurement technique, magnification of photomicrograph, and limiting values for *Fn* (Section 12 and Annex A2),

4.2.11 For hydride orientation, angle theta (θ) for determining radial platelets (Section 12 and Annex A2).

4.2.12 General test requirements and test plan for samples (Section 14),

4.2.13 Hydrostatic test requirements (Section 13),

4.2.14 Contractile strain ratio acceptance criteria (Paragraph 8.3 and Annex A4),

4.2.15 Retest sampling plan and requirements (Section 15),

4.2.16 Quantity variance (Section 17),

4.2.17 Certificate of test (Section 19), and

4.2.18 Special packing instructions (Section 20).

5. Materials and Manufacture

5.1 Material covered by this specification shall be made from ingots produced by multiple vacuum arc melting, electron beam melting or other melting processes conventionally used for reactive metals; all melting is to be carried out in furnaces usually used for reactive metals.

5.2 The tubes shall be made by a process approved by the purchaser.

5.3 Seamless tubes may be made by any method that will yield a seamless product that meets the requirements of this specification. One such method is extrusion of billets with subsequent cold working, by drawing, swaging, or rocking, with intermediate anneals until the final dimensions are reached.

5.4 Unless otherwise agreed upon between the manufacturer and purchaser, welded tubing shall be made from flat-rolled products by an automatic or semiautomatic welding process with no addition of filler metal in the welding operation. Other methods of welding, such as the addition of filler metal or hand welding, may be employed if approved by the purchaser and tested by methods agreed upon between the manufacturer and the purchaser. If filler wire is used, it must meet the chemical requirements of the appropriate grade as shown in Table 4. Welded tube is normally cold reduced to the desired dimensions by such methods as drawing, swaging, or rocking. The manufacturer must prevent contamination during welding by use of proper precautions.

6. Condition and Finish

6.1 *Metallurgical Condition:*

6.1.1 Grade R60001 product shall be in the recrystallized condition unless otherwise specified in the purchase order.

6.1.2 Grades R60802, R60804, R60901, and R60904 product can be furnished in the recrystallized condition or cold-worked and stress-relieved condition, as specified in the purchase order.

6.2 Tubes shall be furnished with one of the following finishes as designated in the purchase order:

6.2.1 As cold reduced,

TABLE 3 Minimum Tensile Properties of Tubing Tested in the Longitudinal Direction[A,B,C,D,E,F]

Material Condition	Test Temperature[C,F]		Minimum Ultimate Tensile Strength		Minimum 0.2 % Yield Strength		Minimum Elongation, %
	°F	(°C)	psi	(MPa)	psi	(MPa)	
R60001	RT	RT	42 000	(290)	20 000	(140)	25
Recrystallized	572	(300)	[B]	[B]	[B]	[B]	[B]
R60802, R60804	RT	RT	60 000	(415)	35 000	(240)	20
Recrystallized	572	(300)	[B]	[B]	[B]	[B]	[B]
R60802, R60804	RT	(RT)	[B]	[B]	[B]	[B]	[B]
Cold-worked and Stress-relieved	572	(300)	[B]	[B]	[B]	[B]	[B]
R60901, R60904	RT	(RT)	65 000	(450)	45 000	(310)	20
Recrystallized	572	(300)	[B]	[B]	[B]	[B]	[B]
R60901, R60904	RT	(RT)	103 000	(710)	70 000	(485)	12
Cold-worked and Stress-relieved	572	(300)	69 500	(480)	48 000	(330)	12

[A] The strength of zirconium alloys is a function of their metallurgical condition, alloy content, and impurity level, especially oxygen. The strength values listed above are for alloys that contain oxygen concentrations in the range 900 to 1400 ppm. For alloys with other oxygen concentrations, the tensile properties are to be agreed upon between the manufacturer and the purchaser.

[B] To be agreed upon between the manufacturer and the purchaser.

[C] The tensile test is to be carried out at one or more of the temperatures listed in Table 3 (or at another temperature) as agreed upon between the manufacturer and purchaser. If one of the above temperatures is selected, the minimum properties shall be as listed for that temperature. If a different temperature is selected, the minimum properties shall be agreed upon between the manufacturer and purchaser.

[D] Paragraph 6.9.1 in Test Methods E8 allows small diameter tubes to be tested as full size tubular sections with snug-fitting metal plugs inserted into the ends of the tube to permit proper gripping by the test machine jaws, as shown in Fig. 11 in Test Methods E8. Specimens for the testing of large diameter tubes are cut from the wall of the tube and are to satisfy the requirements of Figs. 12 and 13 in Test Methods E8.

[E] The properties in this table apply to tubes 0.125 in. (3.2 mm) outside diameter and larger, and 0.015 in. (0.38 mm) wall and thicker. Mechanical properties of tubes outside these limits are to be agreed upon between the manufacturer and purchaser.

[F] "RT" represents room temperature; Note 4 in Test Methods E8 and E8M indicates that RT shall be considered to be 50 to 100 °F (10 to 38 °C) unless otherwise specified. Paragraph 9.4.4 in Test Methods E21 states that for the duration of the test, the difference between the indicated temperature and the nominal test temperature is not to exceed ±5 °F (3 °C) for tests at 1800 °F (1000 °C) and lower, and ±10 °F (6 °C) for tests at higher temperatures.