



Standard Specification for Seamless and Welded Zirconium and Zirconium Alloy Tubes¹

This standard is issued under the fixed designation B 523/B 523M; 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 specification² covers three grades of zirconium and zirconium alloy seamless and welded tubes.

1.2 Unless a single unit is used, for example corrosion mass gain in mg/dm², 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.

1.3 The following precautionary caveat pertains only to the test methods portion 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:³

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

B 551/B 551M Specification for Zirconium and Zirconium Alloy Strip, Sheet, and Plate

B 614 Practice for Descaling and Cleaning Zirconium and Zirconium Alloy Surfaces

E 8 Test Methods for Tension Testing of Metallic Materials

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

E 213 Practice for Ultrasonic Examination of Metal Pipe and Tubing

E 426 Practice for Electromagnetic (Eddy-Current) Examination of Seamless and Welded Tubular Products, Austenitic Stainless Steel and Similar Alloys

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *annealed, n*—for purposes of this specification “annealed” denotes material that exhibits a recrystallized grain structure.

3.2 Lot Definitions:

3.2.1 *tubes, n*—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.

4. Classification

4.1 The tubes are furnished in three grades as follows:

4.1.1 *Grade R60702*—Unalloyed zirconium.

4.1.2 *Grade R60704*—Zirconium-tin alloy.

4.1.3 *Grade R60705*—Zirconium-niobium alloy.

5. Ordering Information

5.1 Orders for material under this specification should include the following information:

5.1.1 Quantity (weight or number of pieces, or both),

5.1.2 Name of material (zirconium seamless or welded tube),

5.1.3 Dimensions (diameter, wall thickness as either average or minimum, lengths),

5.1.4 ASTM designation and year of issue,

5.1.5 Grade number (see 4.1), and

5.1.6 Additions to the specification, if required. See 6.3.1, 7.3, 10.1, 12.7.3, 14.1, and 15.1 for additional optional requirements for the purchase order.

NOTE 1—A typical ordering description is as follows: 1000 pieces of seamless zirconium tubes, 2 in. [50 mm] in outside diameter by 0.06 in. [1.5 mm] in average wall thickness by 10 ft [3 m] in length, vacuum annealed, ASTM B 523/B 523M - 01, Grade R60702.

¹ This specification is under the jurisdiction of ASTM Committee B10 and is the direct responsibility of Subcommittee B10.02 on Zirconium and Hafnium.

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² For ASME Boiler and Pressure Vessel Code Applications, see related Specification SB-523 in Section II of that Code.

³ 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.

6. Materials and Manufacture

6.1 Seamless tube shall be made by any seamless method that will yield a product meeting the requirements of this specification.

6.2 Welded tube shall be made from sheet or strip meeting the requirements of Specification **B 551/B 551M** by an automatic arc-welding process or other method of welding that will yield a product meeting the requirements of this specification. Filler metal shall not be used. Welded tubing shall be supplied as follows:

6.2.1 As welded, or

6.2.2 As welded and further reduced.

6.2.3 Welds in grade R60705 shall be stress relief annealed within 14 days after welding to prevent delayed hydride cracking. The heat treatment shall be done as follows:

6.2.3.1 The stress-relieving treatment shall consist of holding the fitting at a minimum temperature of 1100°F [600°C] for not less than ½ h/in. [25 mm] of the maximum thickness in a nonreducing atmosphere. The minimum time at this temperature is 15 min. All stress-relieved parts shall be cleaned subsequently and shall be free of oxide scale contamination (see Practice **B 614**).

6.3 The tube shall be furnished annealed.

6.3.1 Purchaser shall specify one of the following:

(a) annealed in air

(b) annealed in vacuum

7. Chemical Composition

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

7.2 The manufacturer's ingot analysis shall be considered the chemical analysis for tubing, except for hydrogen and nitrogen, which shall be determined on the finished product.

7.3 When requested by the purchaser and stated in the purchase order, a product analysis for any elements listed in **Table 1** shall be made on the finished product.

7.3.1 The manufacturer's analysis shall be considered as verified if the check analysis confirms the manufacturer's reported values within the tolerances prescribed in **Table 2**.

TABLE 1 Chemical Requirements^A

Element	Composition, %		
	UNS Grade Designation		
	R60702	R60704	R60705
Zirconium + hafnium, min ^B	99.2	97.5	95.5
Hafnium, max	4.5	4.5	4.5
Iron + chromium	0.2 max	0.2 to 0.4	0.2 max
Tin	...	1.0 to 2.0	...
Hydrogen, max	0.005	0.005	0.005
Nitrogen, max	0.025	0.025	0.025
Carbon, max	0.05	0.05	0.05
Niobium	2.0 to 3.0
Oxygen, max	0.16	0.18	0.18

^A By agreement between the purchaser and the manufacturer, analysis may be required and limits established for elements and compounds not specified in the table of chemical composition.

^B The value for zirconium + hafnium, min, is a warranted but not a measured value.

TABLE 2 Permissible Variation in Product Analysis Between Different Laboratories

Element	Permissible Variation in Product Analysis, %
Hydrogen	0.002
Nitrogen	0.01
Carbon	0.01
Hafnium	0.1
Iron + chromium	0.025
Tin	0.05
Niobium	0.05
Oxygen	0.02

TABLE 3 Tensile Requirements

	UNS Grade Designation		
	R60702	R60704	R60705
Tensile strength, min, ksi [MPa]	55 [380]	60 [415]	80 [550]
Yield strength, min, ksi [MPa]	30 [205]	35 [240]	55 [380]
Elongation in 2 in. or 50 mm, min, %	16	14	16

8. Tensile Requirements

8.1 The material, as represented by the test specimens, shall conform to the tensile properties prescribed in **Table 3**.

9. Permissible Variation in Dimensions

9.1 *Diameter*—At any point (cross section) along the length of the tube, the variation in outside diameter shall not exceed those prescribed in **Table 4**.

9.2 *Length*—When tubes are ordered cut to length, the length shall be not less than that specified, but a variation of ⅛ in. [3.2 mm] will be permitted on tube up to 10 ft [3 m], inclusive. For lengths over 10 ft, an additional over-tolerance of ⅛ in. [3.2 mm] for each 10 ft [3 m] or fraction thereof shall be permissible up to ½ in. [13 mm], maximum.

9.3 *Straightness*—The tube shall be free of bends or kinks and the maximum uniform bow shall not exceed the values shown in **Table 5**.

9.4 *Squareness of Cut*—The angle of cut of the end of any tube up to 1½ in. [40 mm] in outside diameter may depart from square not more than 0.016 in./in. [mm/mm].

10. Workmanship and Quality Level Requirements

10.1 The finished tube shall be clean and free of foreign material, shall have smooth ends, free of burrs, and shall be free of injurious external and internal imperfections in accordance with standards of acceptability agreed upon between the manufacturer and the purchaser. Minor defects may be removed provided the dimensional tolerances of **Table 4** are not exceeded.

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**.

TABLE 4 Permissible Variations in Outside Dimensions Based on Individual Measurements

Outside Diameter, in. [mm]	Diameter Tolerance, in. [mm] ^{A,B}	Permissible Variations ^C in Wall Thickness, t, %
Under 1 [25], excl	±0.004 [±0.100]	10
Over 1 to 1½ [25 to 40], incl	±0.005 [±0.125]	10
Over 1½ to 2 [40 to 50], incl	±0.006 [±0.150]	10
Over 2 to 2½ [50 to 65], incl	±0.007 [±0.180]	10
Over 2½ to 3½ [65 to 90], incl	±0.010 [±0.250]	10

^A These permissible variations in outside diameter apply only to tubes as finished at the mill before subsequent swaging, expanding, bending, polishing, or other fabricating operations.

^B Ovality is the maximum and minimum outside diameter of a tube measured at any one cross section. If the measurement is made with a ring gage, the following formula shall apply: Ovality = specified OD tube + diameter tolerance +0.002 in. [.05 mm] (length of ring gage, 1 in. [25 mm] × specified tube OD).

^C When minimum wall tubes are ordered, tolerances are all plus and shall be double the values shown.

TABLE 5 Straightness

Length, ft [m]	Maximum Curvature Depth of Arc
Over 3 to 6 [0.9 to 1.85], incl	⅛ in. [3.2 mm]
Over 6 to 8 [1.8 to 2.5], incl	⅜ in. [5 mm]
Over 8 to 10 [2.5 to 3.0], incl	¼ in. [6.4 mm]
Over 10 [3.0]	¼ in./any 10 ft [2.1 mm/m]

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. Number of Tests and Retests

12.1 One longitudinal tension test, see 13.1, shall be made from each lot.

12.2 One chemistry test, see 7.2 and 13.8, for hydrogen and nitrogen shall be made from each lot of finished product.

12.3 One flare test, see 13.6, shall be made from each lot.

12.4 One reverse flattening test, see 13.7, shall be made from each lot of welded tubing.

12.5 *Welded Tubes:*

12.5.1 Welded tubes shall be nondestructively tested using the following procedures:

12.5.1.1 Eddy Current Test, see 13.2.

12.5.1.2 Ultrasonic Test, see 13.3.

12.5.1.3 Hydrostatic Test, see 13.4, or pneumatic test, see 13.5.

12.6 *Seamless Tubes:*

12.6.1 Seamless tubes shall be nondestructively tested using the following procedures:

12.6.1.1 Ultrasonic Test, see 13.3.

12.6.1.2 Eddy Current Test, see 13.2 using the drilled hole standard, or hydrostatic test, see 13.4, or pneumatic test, see 13.5.

12.7 *Retests:*

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

12.7.2 If the results of any tests of any lot do not conform to the requirements specified, retests shall be made on additional tubes of double the original number from the same lot, each of which shall conform to the requirements specified.

12.7.3 Retesting after failure of initial retests may be done only with the approval of the purchaser.

13. Test Methods

13.1 *Tension Tests*—Conduct the tension test in accordance with Test Methods E 8. Determine the yield strength by the offset (0.2 %) method. Determine the tensile properties 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.

13.2 *Eddy Current Testing:*

13.2.1 Perform the nondestructive electric test in accordance with Practices E 213 or E 426, or a purchaser-approved procedure.

13.2.1.1 The calibration tube shall contain, at the option of the producer, any one of the following discontinuities to establish a minimum sensitivity level for rejection. Place the discontinuity in the parent metal.

(a) *Drilled Hole*—Drill a hole not larger than 0.031 in. [0.8 mm] in diameter radially and completely through the tube wall, taking care to avoid distortion of the tube while drilling.

(b) *Transverse Tangential Notch*—Using a round tool or file with a 0.25-in. [6.4 mm] diameter, file or mill a notch tangential to the surface and transverse to the longitudinal axis of the tube. The notch shall have a depth not exceeding 12.5 % of the specified wall thickness of the tube or 0.004 in. [0.10 mm], whichever is greater.

(c) *Longitudinal Notch*—Machine a notch 0.031 in [0.8 mm] or less in width in a radial plane parallel to the material axis on the outside of the tube to have a depth not exceeding 12.5 % of the specified wall thickness of the material or 0.004 in. [0.10 mm], whichever is greater. The length of the notch shall be compatible with the testing method.

13.3 *Ultrasonic Testing:*

13.3.1 For ultrasonic testing, the longitudinal calibration reference notches shall be at the option of the manufacturer, and be any one of the three common notch shapes in accordance with Practice E 213. The depth of the notch shall not exceed 12.5 % of the specified wall thickness of the material or 0.004 in. [0.10 mm], whichever is greater.

13.3.2 Set aside any tubes showing an indication in excess of that obtained from the calibration standard and subject them to rework, retest, or rejection. A tube, therefore, set aside may be further examined for confirmation of the presence of a defect and may be resubmitted for inspection by the same

technique if no defect is found. Any tube may also be resubmitted for inspection if reworked so as to remove the defect within the specified diameter and wall thickness tolerances as prescribe in **Table 4**.

13.4 *Hydrostatic Test*:

13.4.1 Each tube, so tested, shall withstand, without showing bulges, leaks, or other defects, an internal hydrostatic pressure that will produce in the tube wall a stress of 50 % of the minimum specified yield strength at room temperature, except as restricted by **13.4.2**. Determine the hydrostatic pressure as follows:

$$P = 2St/D \quad (1)$$

where:

- P = minimum hydrostatic test pressure, psi [MPa],
- S = allowable fiber stress of one half the minimum yield strength, psi [MPa],
- t = wall thickness, in. [mm], and
- D = outside diameter, in. [mm].

13.4.2 The maximum hydrostatic test pressure shall not exceed 2500 psi [17.2 MPa] for sizes 3 in. [75 mm] and under, or 2800 psi [19.3 MPa] for sizes over 3 in. [75 mm]. Maintain the hydrostatic pressure for not less than 5 s. When requested by the purchaser and so stated in the order, test the tube in sizes 14 in. [350 mm] in diameter and smaller, to one and one half times the specified working pressure, provided the fiber stress corresponding to those test pressures does not exceed one half the minimum specified yield strength of the material as determined by the equation given in **13.4.1**. When one and one half times the working pressure exceeds 2800 psi [19.3 MPa], the hydrostatic test pressure shall be a matter of agreement between the manufacturer and the purchaser.

13.5 *Pneumatic Test*—Each tube so tested shall withstand an internal air pressure of 150 psi [1.0 MPa], minimum, for 5 s, minimum, without showing evidence of leakage. Use the test method that permits easy visual detection of any leakage, such as by placing the tube under water or by using the pressure differential method. Any evidence of leakage shall be cause for rejection of that tube.

13.6 *Flare Test*—A section of the annealed tube, approximately 4 in. [100 mm] in length, shall be capable of being flared without cracking visible to the unaided eye. Make the flare with a tool having a 60° included angle until the specified outside diameter has been increased by 15 %.

NOTE 2—Samples of tube supplied in tempers other than annealed may be annealed before testing.

13.7 *Reverse Flattening Test*—Subject welded tube to a reverse flattening test in accordance with Test Methods and Definitions **A 370**. Open and flatten a section of the tube approximately 4 in. [100 mm] long that is slit longitudinally 90° either side of the weld with the weld at the point of maximum bend. No cracking is permitted

13.8 *Chemical Tests*—Conduct the chemical analysis by the standard techniques normally used by the manufacturer.

14. Inspection

14.1 The manufacturer shall inspect the material covered by this specification prior to shipment. If so specified in 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 his purchase order which tests he desires to witness. The manufacturer shall give ample notice to the purchaser as to the time and place of the designated tests. If the purchaser's representative does not present himself at the time agreed upon for the testing, the manufacturer shall consider the requirement for the purchaser's inspection at the place of manufacture to be waived.

14.2 The manufacturer shall afford the inspector representing the purchaser, without charge, all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. This inspection shall be so conducted as not to interfere unnecessarily with the operation of the works.

15. Rejection

15.1 Rejection for failure of the material to meet the requirements of this specification shall be reported to the manufacturer. 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.

16. Certification

16.1 A producer or supplier shall furnish the purchaser with a certificate that the material was manufactured, sampled, tested, and inspected in accordance with this specification and has been found to meet the requirements. The certificate shall include a report of the test results.

17. Referee

17.1 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. The results of the referee's testing shall be used in determining conformance of the material to this specification.

18. Product Marking

18.1 Each length of tube ½ in. [13 mm] and larger in outside diameter, manufactured in accordance with this specification shall be marked legibly, either by stenciling, stamping, or rolling, with the manufacturer's private identifying mark, the ASTM designation, method of manufacture, the grade, and heat number. On smaller than ½ in. [13 mm] in outside diameter tubing that is bundled, the same information may be stamped legibly on a metal tag securely attached to each bundle.

19. Packaging and Package Marking

19.1 The tube shall be packaged in such a manner as to assure safe delivery to its destination when properly transported by common carrier.

20. Keywords

20.1 tubes; tubing; zirconium; zirconium alloy

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