Designation: B 353 – 01$^{\epsilon 1}$

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 B 353; 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—Tin content in UNS R60901 and UNS R60904 in Table 1 was editorially corrected in February 2002.

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 B 811.

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 2.

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

2. Referenced Documents

2.1 *ASTM Standards:*

B 350 Specification for Zirconium and Zirconium Alloy Ingots for Nuclear Application[2]

B 811 Specification for Wrought Zirconium Alloy Seamless Tubes for Nuclear Reactor Fuel Cladding[2]

E 8 Test Methods for Tension Testing of Metallic Materials[3]

E 21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials[3]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[4]

E 112 Test Methods for Determining the Average Grain Size[3]

G 2 Test Method for Corrosion Testing of Products of Zirconium, Hafnium, and Their Alloys in Water at 680°F or in Steam at 750°F[5]

G 2M Test Method for Corrosion Testing of Products of Zirconium, Hafnium and Their Alloys in Water at 633K or in Steam at 673K [Metric][5]

2.2 *ANSI Standard:*

ANSI B46.1 Surface Texture (Surface Roughness)[6]

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.

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

3.1.3.2 *ingot*—no definition required.

3.1.3.3 *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.

[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] *Annual Book of ASTM Standards,* Vol 02.04.

[3] *Annual Book of ASTM Standards,* Vol 03.01.

[4] *Annual Book of ASTM Standards,* Vol 14.02.

[5] *Annual Book of ASTM Standards,* Vol 03.02.

[6] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

TABLE 1 Chemical Requirements

Element	Composition, Weight %				
	UNS R60001	UNS R60802	UNS R60804	UNS R60901	UNS R60904
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	2.50–2.80
Oxygen	[A]	[A]	[A]	0.09–0.15	[A]
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	0.0075
Boron	0.00005	0.00005	0.00005	0.00005	0.00005
Cadmium	0.00005	0.00005	0.00005	0.00005	0.00005
Calcium	...	0.0030	0.0030	...	...
Carbon	0.027	0.027	0.027	0.027	0.027
Chromium	0.020	...	...	0.020	0.020
Cobalt	0.0020	0.0020	0.0020	0.0020	0.0020
Copper	0.0050	0.0050	0.0050	0.0050	0.0050
Hafnium	0.010	0.010	0.010	0.010	0.010
Hydrogen	0.0025	0.0025	0.0025	0.0025	0.0010
Iron	0.150	...	...	0.150	0.150
Magnesium	0.0020	0.0020	0.0020	0.0020	0.0020
Manganese	0.0050	0.0050	0.0050	0.0050	0.0050
Molybdenum	0.0050	0.0050	0.0050	0.0050	0.0050
Nickel	0.0070	...	0.0070	0.0070	0.0070
Niobium	...	0.0100	0.0100	...	...
Nitrogen	0.0080	0.0080	0.0080	0.0080	0.0080
Phosphorus	...	...	...	0.0020	0.0020
Silicon	0.0120	0.0120	0.0120	0.0120	0.012
Tin	0.0050	...	...	0.010	0.010
Tungsten	0.010	0.010	0.010	0.010	0.010
Titanium	0.0050	0.0050	0.0050	0.0050	0.0050
Uranium (total)	0.00035	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.

TABLE 2 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

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

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

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."

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 2), and name of material,

4.1.3 Condition (recrystallized or stress relieved),

4.1.4 Dimensions, length, and tolerance,

4.1.5 Method of manufacture (seamless or welded),

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),

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.), and

4.1.9 Mutually agreed-upon inspection standards in accordance with 8.2, 9.2, 9.4, 9.5, 10.1.1.2, 10.1.2.2, and 10.1.2.3.

NOTE 1—A typical order description may read as follows: 1000 pieces of seamless zirconium-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 B 353-XX. 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 6),

4.2.3 Specimen temperature(s) during mechanical testing (Section 7),

4.2.4 Method of determining yield strength if other than 0.2 % offset method (Section 7),

4.2.5 Initial gage length of mechanical test samples for determining elongation after rupture (Table 3, Footnote *D*),

4.2.6 Tensile property requirements for conditions or temperatures not listed in Table 3 (Section 7),

4.2.7 Location of the inside diameter plugs in elevated temperature short-time tension test, when specified (see Table 3, Footnote *D*, and Paragraph 7.1.3),

4.2.8 Burst properties (Paragraph 7.2),

4.2.9 Post burst test measurement technique (Annex A1),

4.2.10 Sample condition and visual standards for corrosion test when specified (Section 9),

4.2.11 Hydride orientation test procedure, measurement technique, magnification of photomicrograph, and limiting values for *Fn* (Section 11 and Annex A2),

4.2.12 General test requirements and test plan for samples (Section 13),

4.2.13 Hydrostatic test requirements (Section 12),

4.2.14 Contractile strain ratio acceptance criteria, when specified (Paragraph 7.3 and Annex A4),

4.2.15 Retest sampling plan and requirements (Section 14),

4.2.16 Quantity variance (Section 16),

4.2.17 Certificate of test (Section 18), and

4.2.18 Special packing instructions (Section 19).

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 1. 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. Chemical Composition

6.1 The material shall conform to the requirements for chemical composition prescribed in Table 1. The purchaser shall specify the grade desired.

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

6.3 The ingot analysis made in accordance with Specification B 350 shall be considered the chemical analysis for material produced to this specification except for oxygen,

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 E 8 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 E 8. 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 E 8.

[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 E 8 and E 8M 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 E 21 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.

hydrogen, and nitrogen content which shall be determined on the finished product. Alternatively, the material may be sampled at 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 to determine the composition, except for hydrogen, oxygen, and nitrogen, which shall be determined on the final product.

6.4 *Product Analysis*—Product analysis is an analysis made 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 specification range is as listed in Table 4 .

TABLE 4 Permissible Variations in Product Analysis

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

6.4.1 *Number of Tests*—Two samples for each 4000 lb (1800 kg) or fraction thereof of the product shall be analyzed for hydrogen, nitrogen and oxygen. The location of the samples may be random, or as agreed between the manufacturer and purchaser.

7. Mechanical Properties

7.1 *Tensile Properties*

7.1.1 The tensile properties of the material shall be determined at one or more of the following temperatures as agreed upon between the manufacturer and purchaser: at room temperature, at 572°F (300°C), at another agreed-upon temperature, or at a combination thereof.

7.1.2 For tensile tests carried out at room temperature, the properties shall conform to the limits listed in Table 3. For tensile tests carried out at other temperatures, the properties shall conform to the values listed in Table 3 for that temperature, or, for conditions not listed in Table 3, the properties shall conform to those agreed upon between the manufacturer and purchaser.

7.1.3 The tension test shall be conducted in accordance with Test Methods E 8 or E 21. Yield strength shall be determined by the 0.2 % offset method. The tensile properties shall be determined using a strain rate of 0.003 to 0.007 in./in. · min (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. · min (mm/mm · min) to failure. When an elevated temperature tension test is specified, the positioning of inside diameter plugs shall be mutually agreed upon between the manufacturer and the purchaser.

7.1.4 *Number of Tests*—For each lot, two samples for each 4000 lb (1800 kg) or fraction thereof shall be tested for tensile properties. The location of the samples may be random or as agreed between the manufacturer and purchaser.

7.2 *Burst Properties*:

7.2.1 Burst testing, when specified, shall be performed at room temperature on finished tubing. The burst properties shall conform to the values agreed upon between the manufacturer and purchaser.

NOTE 2—In setting values for burst properties, cognizance should be taken of the variability of this test. Standard deviations of 4.4 % were encountered in the ASTM round robin in tubing with diameter approximately 0.4 in. (10 mm) used to confirm the recommended procedure.

7.2.2 The room temperature burst test shall be conducted in accordance with Annex A1.

7.2.3 *Number of Tests*—For each lot, two samples for each 4000 lb (1800 kg) or fraction thereof shall be tested for tensile properties. The location of the samples may be random or as agreed between the manufacturer and purchaser.

7.3 *Contractile Strain Ratio (CSR)*:

7.3.1 When so specified by the purchaser, the contractile strain ratio (CSR) shall be determined at room temperature and shall conform to limits that are to be mutually agreed upon between the manufacturer and purchaser.

NOTE 3—Contractile strain ratio testing was the subject of a 1993 round robin conducted by ASTM Subcommittee B10.02 using specimens with diameter approximately 0.4 in. (10 mm). The variability was relatively large and should be considered in setting specific limits. The following two-sigma limits were determined as an estimate of the test precision: ± 0.16 for samples with a CSR of 1.68, and ± 0.22 for samples with a CSR of 2.53.

7.3.2 Contractile strain ratio testing shall be conducted in accordance with Annex A4.

7.3.3 *Number of Tests*—For each lot, two samples for each 4000 lb (1800 kg) or fraction thereof shall be tested for CSR properties. The location of the samples may be random or as agreed between the manufacturer and purchaser.

8. Grain Size

8.1 The average grain size of recrystallized tubes shall be equal to ASTM micrograin Size No. 7 or finer when determined in accordance with Test Methods E 112. The test shall be performed on a longitudinal section.

8.2 If specified, the grain size in the welded and heat affected zones of welded tubes shall be examined in sections that are transverse to the weld. The grain sizes in the weld and heat affected zones shall be smaller than those found in the corresponding regions of a standard that is acceptable to the manufacturer and purchaser.

8.3 *Number of Samples*—For each lot, the grain size shall be determined for two samples for each 4000 lb (1800 kg) or fraction thereof. The location of the samples may be random or as agreed between the manufacturer and purchaser.

9. Corrosion Properties

9.1 When specified, a corrosion test in steam at 750°F (400°C) and 1500 psi (10.3 MPa) may be performed on Grades R60802, R60804, R60901, and R60904. If specified, the test may be performed in water at 680°F (360°C). The tests shall be

conducted in accordance with Test Methods G 2 or G 2M.

9.2 When specified in the purchase order, the samples may be tested in a mill finished condition. In this case, visual acceptance standards shall be agreed upon between the manufacturer and the purchaser and the mass gain limits of 9.5.1, 9.5.2, or 9.6 shall apply.

9.3 *Number of samples*—For each lot, the specified corrosion test shall be carried out on two samples for each 4000 lb (1800 kg) or fraction thereof. The location of the samples may be random, or as agreed between the manufacturer and purchaser.

9.4 *Post-test Examination*—After the test, all specimens shall be examined for color, lustre, surface irregularities, and corrosion products, and compared against visual standards previously agreed upon between the purchaser and the manufacturer. The mass gain shall be determined using the method prescribed in Test Methods G 2 or G 2M.

9.5 *Acceptance Criteria for Steam Test*:

9.5.1 *Grades UNS R60802 and UNS R60804*—The specimens shall have a continuous black oxide film and be free of white and brown corrosion product in excess of the standards. The specimens shall exhibit a mass gain of not more than 22 mg/dm^2 in a 72-h test or 38 mg/dm^2 in a 336-h test.

9.5.2 *Grades UNS R60901 and UNS R60904*—The specimens shall have a continuous uniform dark gray oxide film, and shall exhibit a mass gain of not more than 35 mg/dm^2 in a 72-h test, or 60 mg/dm^2 in a 336-h test.

9.5.3 If the mass gain of a specimen from any lot exceeds the 72-h test limits, the manufacturer has two options: (*1*) Continue the corrosion test on the lot that failed the test to a total of 336 h with the same specimens at the same prescribed temperature and pressure, or (*2*) Resample the lot that failed for twice the original number of specimens and conduct a 336-h corrosion test. In either case, if the specimens from the lot being retested pass the 336-h test requirements (mass gain and visual), the lot shall be acceptable.

9.6 *Acceptance Criteria for Water Test*—The acceptance criteria for the water corrosion test shall be agreed upon between the manufacturer and purchaser.

10. Inspection

10.1 The manufacturer shall inspect the entire length of the mill finished tubes covered by this specification, prior to shipment, for dimensions, outer and inner surfaces, straightness, and surface and internal flaws as follows:

10.1.1 *Surface and Internal Flaw Inspection*:

10.1.1.1 *Ultrasonic Inspection Test Methods*—Each tube shall be inspected by the ultrasonic test method in accordance with Annex A3.

10.1.1.2 *Ultrasonic Reference Standard*—The test equipment shall be calibrated with an artificially defected standard tube of the same nominal material, diameter, wall thickness, surface finish, fabrication process, and final thermal treatment as the lot being tested. The standard shall contain not less than four defects oriented as follows: (*1*) outer tube surface, parallel to tube axis; (*2*) outer tube surface, transverse to tube axis; (*3*) inner tube surface, parallel to tube axis; and (*4*) inner tube surface, transverse to tube axis. The defects shall be notches with a depth to be agreed upon between the manufacturer and purchaser. The minimum dimensions of the artificial defect shall be 0.0015 in. (0.038 mm) deep and 0.065 in. (1.65 mm) long.

10.1.1.3 *Rejection*—Any tube showing an ultrasonic indication equal to or greater than the standard in 10.1.1.2 shall be rejected.

10.1.2 *Outer and Inner Surfaces, Visual Inspection*:

10.1.2.1 *Test Method*—Each tube shall be inspected over its entire length. The outside surface shall be inspected under a minimum light intensity of 100 fc (1100 lux). The inner surface shall be inspected from each end against a suitable light background.

10.1.2.2 *Acceptance Criteria*—The tubes shall not contain oxides, cracks, seams, slivers, blisters, pits, laps, foreign particles, or scratches exceeding the mutually agreed-upon inspection standard.

10.1.2.3 The finished tubes shall be visibly free of all grease, oil, residual lubricants, and other extraneous materials, as determined by mutually agreed-upon standards.

10.1.3 *Straightness*:

10.1.3.1 *Test Method*—Each tube shall be inspected for straightness by rolling on a surface plate and observing for the maximum deflection (bow) in the vertical plane between two points of contact, or by another method acceptable to the purchaser.

10.1.3.2 *Acceptance Criteria*—The tubes shall be free of bends or kinks, and the maximum bow of lengths up to 10 ft (3.0 m) shall not exceed 1 part in 1200. For lengths greater than 10 ft, the maximum bow shall not exceed 1 part in 800.

10.1.4 *Dimensional Inspection*:

10.1.4.1 *Test Method*—Each tube shall be inspected over its entire length by using a method agreed upon between the manufacturer and purchaser.

10.1.4.2 *Acceptance Criteria*—The tubes shall meet the dimensional requirements of Table 5.

10.1.5 *Length*—When tubing is ordered cut to length, the usable length shall be not less than that specified; but a variation of 0.125 in. (3.0 mm) will be permitted for lengths up to 6 ft (2.0 m). In lengths over 6 ft (2.0 m), a variation of 0.25 in. (6 mm) will be permissible.

10.1.6 *Purchaser Inspection*:

10.1.6.1 The manufacturer shall inspect tubes covered by this specification prior to shipment and, on request, shall furnish the purchaser with certificates of test. If so specified on the purchase order, the purchaser or his representative may witness the testing and inspection of the tubes 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 is not present at the time agreed upon for the testing and if no new date is agreed upon, the manufacturer shall consider the requirement for purchaser's inspection at place of manufacture to be waived.

10.1.6.2 When the inspector representing the purchaser appears at the appointed time and place, the manufacturer shall afford him all reasonable facilities to see that the material is being furnished in accordance with this specification. This

TABLE 5 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

inspection shall be so conducted as not to interfere unnecessarily with production operations.

11. Hydride Orientation

11.1 Hydride orientation, *Fn*, when specified, shall be determined on finished tubing and shall conform to the values agreed upon between the manufacturer and the purchaser.

11.2 *Number of Samples*—For each lot, the hydride orientation shall be determined for two samples for each 4000 lb (1800 kg) or fraction thereof. The location of the samples may be random or as agreed between the manufacturer and purchaser.

11.3 The hydride orientation shall be determined in accordance with Annex A2.

12. Hydrostatic Test

12.1 When so specified in the purchase order, each tube 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. The pressure shall be determined by the equation:

$$P = 2St/D \tag{1}$$

where:
P = minimum hydrostatic test pressure (psi or MPa),
S = allowable fiber stress of one half of the minimum yield strength (psi or MPa),
t = wall thickness (in. or mm), and
D = outside diameter (in. or mm).

12.2 The maximum hydrostatic test pressure shall not exceed 2500 psi (17.0 MPa) for size 3 in. (75 mm) and under, or 4000 psi (28 MPa) for sizes over 3 in. (75 mm). Hydrostatic pressure shall be maintained for not less than 15 s.

13. Number of Tests

13.1 *Sampling*—Samples shall be taken for each of the tests specified in 13.2. The minimum sampling frequency shall be in accordance with the number of samples given in the appropriate paragraphs.

13.2 Each sample chosen in accordance with 13.1 shall be tested as follows: (*1*) product chemistry (Section 6), (*2*) tension test, at a temperature and using specimens as mutually agreed upon (Section 7.1), (*3*) burst test when specified (Section 7.2), (*4*) grain size (Section 8), (*5*) corrosion test when specified (Section 9), and (*6*) hydride orientation when specified and as mutually agreed upon (Section 11).

14. Retest

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

14.2 If the results of the tube inspection of a lot are not in conformance with the requirements of this specification, the lot may be reworked at the option of the manufacturer, providing the rework steps are within the previously approved specifications and procedures used for the original fabrication. Deviations must be approved by the purchaser.

14.3 If the result of any test in Section 13.2 does not meet the specification requirements, retests shall be performed on twice as many samples as originally tested for the characteristic, or using retest procedures mutually agreed upon between the manufacturer and the purchaser.

14.3.1 All test results including the original test results shall be reported to the purchaser. Retest results shall be indicated with the suffix "*R*".

14.3.2 Only one set of retests is permitted and all retest results shall conform to the specification requirements for the retested characteristic. Following a failed test, 100 % testing is not considered to be a retest.

15. Significance of Numerical Limits

15.1 For the purpose of determining compliance with the specified limits of property requirements, an observed value or a calculated value shall be rounded in accordance with the rounding method of Practice E 29.