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Standard Specification for Zirconium and Zirconium Alloy Strip, Sheet, and Plate¹

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1. Scope

1.1 This specification² covers five grades of zirconium strip, sheet, and plate.

1.2 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.

1.3 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:*³

E8 [Test Methods for Tension Testing of Metallic Materials](#)

E29 [Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications](#)

E290 [Test Methods for Bend Testing of Material for Ductility](#)

3. Terminology

3.1 *Definitions:*

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

3.2 *Lot Definition:*

3.2.1 *lot, 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.

3.3 *Forms:*

3.3.1 *strip, n*—a flat product, may be supplied in coil, less than 6 in. [150 mm] in width and from 0.005 in. [0.13 mm] to 0.188 in. [4.8 mm] in thickness.

3.3.2 *sheet, n*—a flat product 6 in. [150 mm] or more in width and from 0.005 in. [0.13 mm] to 0.188 in. [4.8 mm] in thickness.

3.3.3 *plate, n*—a flat product more than 0.188 [4.8] in. [4.8] in thickness.

4. Classification

4.1 The strip, sheet, or plate is to be furnished in five grades as follows:

4.1.1 *Grade R60700*—Low oxygen zirconium.

4.1.2 *Grade R60702*—Unalloyed zirconium.

4.1.3 *Grade R60704*—Zirconium-tin.

4.1.4 *Grade R60705*—Zirconium-niobium.

4.1.5 *Grade R60706*—Zirconium-niobium.

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² For ASME Boiler and Pressure Vessel Code applications, see related Specification SB-551 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.

5. Ordering Information

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

- 5.1.1 Standard designation and year of issue,
- 5.1.2 Quantity (weight or number of pieces),
- 5.1.3 Lot definition for continuous anneal, if applicable (3.2.1),
- 5.1.4 Form (3.3) and dimensions,
- 5.1.5 Grade (4.1),
- 5.1.6 Metallurgical condition, if not in the recrystallized annealed condition (6.3),
- 5.1.7 Chemical analysis of elements not listed (7.1.4),
- 5.1.8 Product analysis (7.1.3 and 7.3.1),
- 5.1.9 Tensile test temperature (8.1),
- 5.1.10 Material condition and finish (9.1-9.5),
- 5.1.11 Workmanship and appearance (11.1 and 11.3),
- 5.1.12 Purchaser inspection (15.1 and 15.2),
- 5.1.13 Rejection and referee (16.2),
- 5.1.14 Product marking, (18.1 and 18.1.1),
- 5.1.15 Packaging and package marking (19.1),
- 5.1.16 Additions to the specification and supplementary requirements, if required, and
- 5.1.17 Additional requirements for explosion cladding, if applicable (Supplementary Requirements S.1).

NOTE 1—A typical ordering description is as follows: 9000-lb [5000 kg] zirconium sheet, 0.098 in. [2.5 mm] by 12 in. [300 mm] by 144 in. [3.5 m], ASTM B551/B551M-07, Grade R60705.

6. Materials and Manufacture

6.1 Material covered by this specification shall be made from ingots that are produced by vacuum or plasma arc melting, vacuum electron-beam melting, a combination of these three methods or other melting processes conventionally used for reactive metals. All processes to be done in furnaces usually used for reactive metals.

6.2 The various mill products covered by this specification shall be formed with the conventional extrusion, forging, or rolling equipment normally found in primary ferrous and nonferrous plants.

6.3 The strip, sheet, and plate shall be supplied in the recrystallized annealed condition unless otherwise specified in the purchase order.

7. Chemical Composition

7.1 The material covered by this specification shall conform to the chemical composition requirements prescribed in Table 1.

7.1.1 The elements listed in Table 1 are intentional alloy additions or elements which are inherent to the manufacture of sponge, ingot or mill product.

7.1.2 Elements intentionally added to the melt must be identified, analyzed, and reported in the chemical analysis.

7.1.3 Elements other than those listed in Table 1 are deemed to be capable of occurring in the grades listed in Table 1 by and only by way of unregulated or unanalyzed scrap additions to the ingot melt. Therefore, product analysis for elements not listed in Table 1 shall not be required unless specified and shall be considered to be in excess of the intent of this specification.

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

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

7.2.1 The ingot shall be sampled in sufficient places along the side wall so that the top sample is within 5 in. [125 mm] of the top face. A minimum of three samples per ingot is required.

TABLE 1 Chemical Requirements^A

Element	Composition, %				
	Grades				
	R60700	R60702	R60704	R60705	R60706
Zirconium + hafnium, min	99.2	99.2	97.5	95.5	95.5
Hafnium, max	4.5	4.5	4.5	4.5	4.5
Iron + chromium	0.2 max	0.2 max	0.2 to 0.4	0.2 max	0.2 max
Tin	...	...	1.0 to 2.0	...	...
Hydrogen, max	0.005	0.005	0.005	0.005	0.005
Nitrogen, max	0.025	0.025	0.025	0.025	0.025
Carbon, max	0.05	0.05	0.05	0.05	0.05
Niobium	...	...	...	2.0 to 3.0	2.0 to 3.0
Oxygen, max	0.10	0.16	0.18	0.18	0.16

^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 (see 7.1.1).

7.2.2 These samples shall be analyzed for the alloying and impurity elements given in Table 1.

7.2.3 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 7.2.1 to determine the composition, except for hydrogen and nitrogen, which shall be determined on the finished product.

7.3 Check Analysis:

7.3.1 Check analysis is an analysis made by the purchaser or the manufacturer of the metal after it has been processed into finished mill forms, and is either for the purpose of verifying the composition of a heat or lot or to determine variations in the composition within a heat or lot. Acceptance or rejection of a lot of material may be made by the purchaser on the basis of this check analysis. When requested by the purchaser and stated in the purchase order, a product check analysis for any elements listed in Table 1 shall be made on the finished product.

7.3.2 Check analysis limits shall be as specified in Table 2. These limits are the amounts an individual result for a given element may vary under or over the specified limits shown in Table 1.

7.3.3 Check analysis tolerances do not broaden the specified heat analysis requirements but cover variations between laboratories in the measurement of chemical content.

7.3.4 The manufacturer shall not ship material that is outside the limits specified in Table 1 for the applicable grade.

8. Mechanical Properties

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

8.2 For strip and sheet, the bend test specimen shall stand being bent at ambient temperature through an angle of 105° without fracture in the outside of the bent portion. The bend shall be made around a mandrel having a radius equal to that shown in Table 3 for the applicable grade. Bend testing shall be performed in accordance with Test Methods E290.

9. Condition and Finish

9.1 Sheet, strip, or plate shall be furnished in one of the following conditions as designated on the purchase order:

Form	Condition
Strip	hot-rolled
	hot-rolled, annealed
	cold-rolled
	cold-rolled, annealed
Sheet	cold-rolled, annealed, followed by a final light cold-rolled pass, generally on polished rolls
	hot-rolled
	hot-rolled, annealed
	cold-rolled, annealed
Plate	cold-rolled, annealed, followed by a final light cold-rolled pass, generally on polished rolls
	hot-rolled
	hot-rolled, annealed
	hot-rolled

9.2 Hot-rolled sheet, strip, or plate shall be furnished with one of the following finishes as designated in the purchase order:

- 9.2.1 Not descaled,
- 9.2.2 Mechanically descaled,
- 9.2.3 Mechanically descaled and pickled,
- 9.2.4 As-ground.

TABLE 2 Permissible Variation in Check 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

	Grades				
	R60700	R60702	R60704	R60705	R60706
Tensile strength, min, ksi [MPa]	...	55 [380]	60 [415]	80 [550]	74 [510]
Yield strength, min, ksi [MPa]	...	30 [205]	35 [240]	55 [380]	50 [345]
Tensile strength, max, ksi [MPa]	55 [380]	...	...	...	...
Yield strength, max, ksi [MPa]	44 [305]	...	...	...	...
Elongation in 2 in. or 50 mm, min, % ^A	20	16	14	16	14
Bend test radius ^B	5T	5T	5T	3T	2.5T

^A When a sub-size specimen is used, the gage length shall be as specified in Test Methods E8 for that specimen.

^B T equals the thickness of the bend test specimen. Bend tests are not applicable to material over 0.187 in. [4.8 mm] in thickness.

9.3 Cold-rolled sheet or strip shall be furnished with one of the following finishes as designated in the purchase order:

9.3.1 Bright cold-rolled,

9.3.2 Ground 32 $\mu\text{in.}$ [0.8 μm] rms or better, or

9.3.3 Pickled.

9.4 *Hot-Rolled Strip*—The following types of edges can be furnished on hot-rolled strip when specified in the purchase order:

9.4.1 Mill edge,

9.4.2 Split edge, or

9.4.3 Sheared edge.

9.5 *Cold-Rolled Strip*—A slit edge is normally furnished on cold-rolled strip. A machined edge is available for weld preparation when specified in the purchase order.

9.6 *Sheet and Plate*—Both hot- and cold-rolled sheet and plate are furnished with a sheared edge.

10. Permissible Variations in Dimensions and Weights

10.1 *Thickness*—The variations in thickness of strip, sheet, and plate are given in the following tables:

10.1.1 Hot-rolled strip, Table 4.

10.1.2 Cold-rolled strip, Table 5.

10.1.3 Hot- and cold-rolled sheet, Table 6.

10.1.4 Plate, Table 7.

10.2 *Width*—The variations in width are given in the following tables:

10.2.1 Hot-rolled strip, Table 8.

10.2.2 Cold-rolled strip, Table 9.

10.2.3 Hot- and cold-rolled sheet, Table 10.

10.2.4 Plate, Table 11.

10.3 *Length*—The variations in length are given in the following tables:

10.3.1 Hot- and cold-rolled strip, Table 12.

10.3.2 Hot- and cold-rolled sheet, Table 13.

10.3.3 Plate, Table 11.

10.4 *Crown Tolerances*—The variations in crown tolerances are given in the following tables:

10.4.1 Hot-rolled strip, Table 14.

10.4.2 Cold-rolled strip, Table 15.

10.4.3 Hot-rolled sheet, Table 16.

10.4.4 Cold-rolled sheet, Table 17.

10.5 *Camber Tolerances*—The variations in camber tolerances are given in the following tables.

10.5.1 Hot- and cold-rolled strip, Table 18.

10.5.2 Hot- and cold-rolled sheet, Table 19.

10.5.3 Plate, Table 20.

10.6 *Diameter*—The variation in diameter tolerance for circular plates is given in Table 21.

TABLE 4 Permissible Variations in Thickness of Hot-Rolled Zirconium Strip^A

Specified Width, in. [mm]	Variation from Specified Thickness for Widths Given, Over and Under, in [mm]	
	0.083–0.118 [2.1–3.0]	Over 0.118–0.188 [3.0–4.78]
To 3½ [90], incl	0.005 [0.13]	0.006 [0.15]
Over 3½ [90] –6 [150], incl	0.006 [0.15]	0.007 [0.18]

^A Thickness measurements are taken at least ¼ in. [10 mm] from edge.

TABLE 5 Permissible Variations in Thickness of Cold-Rolled Zirconium Strip

NOTE 1—For thickness under 0.010 in. [0.25 mm] in width to 6 in. [150 mm] a tolerance of $\pm 10\%$ of the thickness shall apply.

NOTE 2—Thickness measurements shall be taken $\frac{3}{16}$ in. [10 mm] in from edge of the strip, except on widths less than 1 in. [2.5 mm] where the tolerances are applicable for measurements at all locations.

Specified Thickness, in. [mm]	Permissible Variations in Thickness, for Widths Given, \pm in. [mm]		
	$\frac{3}{16}$ [4.8] to 1 [25], excl	1 [25] to 3 [75], excl	3 [75] to 6 in. [150], excl
0.188–0.160 [4.78–4.06], incl	0.002 [0.05]	0.003 [0.08]	0.004 [0.10]
0.160–0.100 [4.05–2.52], incl	0.002 [0.05]	0.002 [0.05]	0.003 [0.08]
0.099–0.069 [2.51–1.75], incl	0.002 [0.05]	0.002 [0.05]	0.003 [0.08]
0.068–0.050 [1.74–1.27], incl	0.002 [0.05]	0.002 [0.05]	0.003 [0.08]
0.049–0.040 [1.26–1.01], incl	0.002 [0.05]	0.002 [0.05]	0.0025 [0.07]
0.039–0.035 [0.99–0.90], incl	0.002 [0.05]	0.002 [0.05]	0.0025 [0.06]
0.034–0.029 [0.87–0.73], incl	0.0015 [0.04]	0.0015 [0.04]	0.002 [0.05]
0.028–0.026 [0.72–0.66], incl	0.001 [0.025]	0.0015 [0.04]	0.0015 [0.04]
0.025–0.020 [0.65–0.51], incl	0.001 [0.025]	0.001 [0.025]	0.0015 [0.04]
0.019 [0.50] and under	0.001 [0.025]	0.001 [0.025]	0.001 [0.025]

TABLE 6 Permissible Variations in Thickness of Hot- and Cold-Rolled Zirconium Sheet^A

Specified Thickness, in. [mm]	Hot-Rolled	Cold-Rolled
	Permissible Variations in Thickness, \pm in. [mm]	Permissible Variations in Thickness, \pm in. [mm]
0.146 to 0.188 [3.70 to 4.76], excl	0.014 [0.35]	0.007 [0.18]
0.131 to 0.145 [3.32 to 3.69]	0.012 [0.30]	0.006 [0.15]
0.115 to 0.130 [2.92 to 3.31]	0.010 [0.25]	0.005 [0.13]
0.099 to 0.114 [2.50 to 2.91]	0.009 [0.23]	0.0045 [0.11]
0.084 to 0.098 [2.13 to 2.49]	0.008 [0.20]	0.004 [0.10]
0.073 to 0.083 [1.85 to 2.12]	0.007 [0.18]	0.0035 [0.09]
0.059 to 0.072 [1.49 to 1.84]	0.006 [0.15]	0.003 [0.08]
0.041 to 0.058 [1.04 to 1.48]	0.005 [0.13]	0.0025 [0.07]
0.027 to 0.040 [0.68 to 1.03]	0.004 [0.10]	0.002 [0.05]
0.017 to 0.026 [0.43 to 0.67]	0.003 [0.08]	0.0015 [0.4]
0.008 to 0.016 [0.20 to 0.42]	0.002 [0.05]	0.001 [0.03]
0.006 to 0.007 [0.14 to 0.19]	0.0015 [0.04]	0.0008 [0.02]
0.005 [0.13] or less	0.001 [0.025]	0.0005 [0.01]

^A Thickness measurements are taken at least $\frac{3}{16}$ in. [10 mm] in from edge. Tolerances do not include crown.

TABLE 7 Permissible Variations in Thickness of Zirconium Plate

Specified Thickness, in. [mm]	Width, in. [mm] ^A			
	To 84 [2130], incl	Over 84 [2130] to 120 [3050], incl	Over 120 [3050] to 144 [3660], incl	Over 144 [3660]
	Tolerances Over Specified Thickness, in. [mm] ^B			
0.188 [4.7] to 0.375 [9.5], excl	0.045 [1.14]	0.050 [1.27]	...	...
0.125 [3.2] to 0.375 [9.5], excl	0.045 [1.14]	0.050 [1.27]	...	...
0.375 [9.5] to 0.75 [19], excl	0.055 [1.40]	0.060 [1.52]	0.075 [1.90]	0.090 [2.29]
0.75 [19] to 1.0 [25], excl	0.060 [1.52]	0.065 [1.65]	0.085 [2.16]	0.100 [2.54]
1.0 [25] to 2.0 [50], excl	0.070 [1.78]	0.075 [1.90]	0.095 [2.41]	0.115 [2.92]
2.0 [50] to 3.0 [75], excl	0.125 [3.18]	0.150 [3.81]	0.175 [4.44]	0.200 [5.08]
3.0 [75] to 4.0 [100], excl	0.175 [4.44]	0.210 [5.33]	0.245 [6.22]	0.280 [7.11]
4.0 [100] to 6.0 [150], excl	0.250 [6.35]	0.300 [7.62]	0.350 [8.89]	0.400 [10.16]
6.0 [150] to 8.0 [200], excl	0.350 [8.89]	0.420 [10.67]	0.490 [12.45]	0.560 [14.22]
8.0 [200] to 10.0 [250], incl	0.450 [11.43]	0.540 [13.72]	0.630 [16.00]	...

^A Thickness is measured along the longitudinal edges of the plate at least $\frac{3}{16}$ in. [10 mm], but not more than 3 in. [75 mm] from the edge.

^B For circles, the over thickness tolerances in this table apply to the diameter of the circle corresponding to the width ranges shown. For plates of irregular shape, the over thickness tolerances apply to the greatest width corresponding to the width ranges shown. For plates up to 10 in. [250 mm], incl. in thickness, the tolerance under the specified thickness is 0.01 in. [0.25mm].

10.7 *Flatness*—The permissible variation from a flat surface for plate is given in Table 22.

10.8 *Weight*—The actual shipping weight of any one item of an ordered thickness and width in any finish may exceed estimated weight by as much as 10 %.

11. Workmanship and Appearance

11.1 Cracks, seams, slivers, blisters, burrs, and other injurious imperfections shall not exceed standards of acceptability agreed upon by the manufacturer and the purchaser.

11.2 The finished strip, sheet, or plate shall be visibly free of oxide, grease, oil, residual lubricants, and other extraneous materials.

TABLE 8 Permissible Variations in Width of Hot-Rolled Zirconium Strip

Specified Width, in. [mm]	Permissible Variation in Width, in. [mm]					
	Mill Edge		Slit Edge		Sheared Edge	
	+	-	+	-	+	-
3½ [90] and under	⅛ [3.2]	0 [0]	½ [0.8]	½ [0.8]	⅛ [1.6]	⅛ [1.6]
Over 3½ [90] – 6 [150], incl	⅜ [4.8]	⅛ [3.2]	½ [0.8]	½ [0.8]	...	0 [0]

TABLE 9 Permissible Variations in Width of Cold-Rolled Zirconium Strip (Slit Edge)

Specified Thickness, in. [mm]	Permissible Variations in Thickness, plus and minus, for Widths Given, in. [mm]	
	Under ½ [12]	½ to 6 [12 to 152], incl
0.188 to 0.161 [4.76 to 4.08], incl	...	0.016 [0.41]
0.160 to 0.100 [4.07 to 2.53], incl	0.010 [0.25]	0.010 [0.25]
0.099 to 0.069 [2.52 to 1.74], incl	0.008 [0.20]	0.008 [0.20]
0.068 [1.73] and under	0.005 [0.13]	0.005 [0.13]

TABLE 10 Permissible Variations in Width of Hot- and Cold-Rolled Zirconium Sheet

Specified Width, in. [mm] for Thickness Under ⅜ in. [4.8 mm]	Permissible Variations in Width, in. [mm]
6–24 [150–600], excl	+⅛, –0 [+3.2, –0]
24–48 [600–1200], excl	+⅛, –0 [+3.2, –0]
48 and over [1200]	+⅜, –0 [+4.8, –0]

11.3 Methods of testing for these defects and standards of acceptability shall be as agreed upon between the manufacturer and the purchaser.

11.4 The manufacturer shall be permitted to remove surface imperfections provided such removal does not reduce the dimensions below the minimum permitted by the tolerances for that dimension.

12. Significance of Numerical Limits

12.1 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 E29.

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 %

13. Number of Tests and Retests

13.1 One longitudinal tension shall be made from each lot (see 14.2).

13.2 One chemistry test for hydrogen and nitrogen content shall be made from each lot of finished product (see 14.1).

13.3 Two bend tests, one in the longitudinal and one in the transverse direction, shall be made from each lot (see 8.2).

13.4 *Retests:*

13.4.1 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.

13.4.2 If the results of any chemical or mechanical property test lot are not in conformance with the requirements of this specification, the lot may be retested at the option of the manufacturer. Retests shall be made on double the original number of samples from the same lot. Both retest values shall conform to the requirements specified. These acceptable retest values will become the test values for certification.

13.4.3 If the results for the retest fail to conform to the specification, the material will be rejected in accordance with Section 16. Retesting after failure of initial retests may be done only with the approval of the purchaser.

14. Sampling and Test Methods

14.1 *Sampling:*

14.1.1 Samples for chemical and mechanical testing shall be taken from the finished material after all metallurgical processing to determine conformity to this specification. The samples may be taken prior to final inspection and minor surface conditioning by abrasion and pickling shall be representative of the finished product.