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

This standard is issued under the fixed designation B551/B551M; 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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal. ~~ε1 Note—An editorial change was made in Tables 10 and 12 in February 2006.~~

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~~ [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 of Terms Specific to This Standard:~~

~~3.1 Definitions:~~

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

~~3.2 Lot Definitions:~~

~~3.2.1 castings Lot Definition:~~

~~3.2.1.1 lot, n—a lot shall consist of all castings produced from the same pour.~~

~~3.2.2 ingot—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—no definition required.~~

~~3.3.2 rounds, flats, tubes, and wrought powder metallurgical products (single definition, common to nuclear and non-nuclear standards)—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 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.~~

~~3.3.2.4 sponge—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.~~

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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.

3.3.3 *plate, n*—a lot shall consist of a single blend produced at one time.

3.2.5 *weld fittings, n*—definition is to be mutually agreed upon between manufacturer and the purchaser. —a flat product more than 0.188 in. [4.8 mm] 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.

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);

5.1.2 Name of material (zirconium strip, sheet, or plate);

5.1.3 Grade number (see Section 4)

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 ASTM designation and year of issue,

5.1.5 Finish and appearance (Section 10), and

5.1.6 Additions to the specification and supplementary requirements, if required:

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 B 551-01; B551/B551M-07, Grade R60705.

6. Materials and Manufacture

6.1 The strip, sheet, and plate covered by this specification shall be formed with conventional forging and rolling equipment found in primary ferrous and nonferrous metal plants.

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).

~~6.2 The strip, sheet, and plate shall be supplied in the recrystallized annealed condition.~~

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 shall conform to the requirements as to chemical composition prescribed in~~

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.

~~7.3 When requested by the purchaser and stated in the purchase order, a product analysis for any elements listed in~~

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.

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.

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

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

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 E-8 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.

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.

9. Permissible Variations in Dimensions

9.1 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:

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

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.

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 μin. [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:

- 9.1.1 Hot- and cold-rolled sheet, 10.1.1 Hot-rolled strip, Table 4.
- 9.1.2 Hot-rolled strip,
- 10.1.2 Cold-rolled strip, Table 5.
- 9.1.3 Cold-rolled strip,

TABLE 19 4 Permissible Variations in Weight and Thickness of Hot- and Cold-Rolled Zirconium Sheet^A

Specified Width, in. [mm]	Any item of 5 sheets or less or any item estimated to weigh 20.0 lb [8.3 kg] or less, may actually weigh as much as 10% over	Over the estimated weight 0.118–0.188 [3.0–4.78]
Any item of more than 5 sheets and estimated to weigh more than 200 lb [100 kg] may actually weigh as much as 7½% over the estimated weight	0.005 [0.13]	0.006 [0.15]
To 3½ [90], incl	0.005 [0.13]	0.006 [0.15]
There is no under tolerance in weight for zirconium sheets, under tolerance being restricted by the permissible thickness variations	Only random (or mill size) sheets may be ordered on a square foot [meter] basis, and the number of square feet	Only random (or mill size) sheets may be ordered by as much as 5% [meter] shipped may exceed the number ordered by as much as 5%
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.

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

9.1.4 Plate,

10.1.4 Plate, Table 7.

9.2 Width and Length—The variation in width and length are given in the following tables:

9.2.1 Hot- and cold-rolled sheet,

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

10.2.1 Hot-rolled strip, Table 8.

9.2.2 Hot-rolled strip, Tables 9 and

TABLE 4 6 Permissible Variations in Thickness of Hot- and Cold-Rolled Zirconium Sheet^A

Specified Thickness, in. [mm]	Hot-Rolled Permissible Variations in Thickness, ± in. [mm]	Cold-Rolled Permissible Variations in Thickness, ± in. [mm]
0.146 – 0.1875, excl [3.7 – 4.8]	0.014 [0.35]	
0.146 to 0.188 [3.70 to 4.76], excl	0.014 [0.35]	0.007 [0.18]
0.131 – 0.145 [3.31 – 3.69]	0.012 [0.30]	
0.131 to 0.145 [3.32 to 3.69]	0.012 [0.30]	0.006 [0.15]
0.115 – 0.130 [2.91 – 3.30]	0.010 [0.25]	
0.115 to 0.130 [2.92 to 3.31]	0.010 [0.25]	0.005 [0.13]
0.099 – 0.114 [2.51 – 2.90]	0.009 [0.23]	
0.099 to 0.114 [2.50 to 2.91]	0.009 [0.23]	0.0045 [0.11]
0.084 – 0.098 [2.12 – 2.50]	0.008 [0.20]	
0.084 to 0.098 [2.13 to 2.49]	0.008 [0.20]	0.004 [0.10]
0.073 – 0.083 [1.84 – 2.11]	0.007 [0.18]	
0.073 to 0.083 [1.85 to 2.12]	0.007 [0.18]	0.0035 [0.09]
0.059 – 0.072 [1.49 – 1.83]	0.006 [0.15]	
0.059 to 0.072 [1.49 to 1.84]	0.006 [0.15]	0.003 [0.08]
0.041 – 0.058 [1.04 – 1.48]	0.005 [0.13]	
0.041 to 0.058 [1.04 to 1.48]	0.005 [0.13]	0.0025 [0.07]
0.027 – 0.040 [0.67 – 1.03]	0.004 [0.10]	
0.027 to 0.040 [0.68 to 1.03]	0.004 [0.10]	0.002 [0.05]
0.017 – 0.026 [0.42 – 0.66]	0.003 [0.08]	
0.017 to 0.026 [0.43 to 0.67]	0.003 [0.08]	0.0015 [0.4]
0.008 – 0.016 [0.19 – 0.41]	0.002 [0.05]	
0.008 to 0.016 [0.20 to 0.42]	0.002 [0.05]	0.001 [0.03]
0.006 – 0.007 [0.15 – 0.18]	0.0015 [0.04]	
0.006 to 0.007 [0.14 to 0.19]	0.0015 [0.04]	0.0008 [0.02]
0.005 [0.13]	0.001 [0.025]	
0.005 [0.13] or less	0.001 [0.025]	0.0005 [0.01]

^A Thickness measurements are taken at least ¼ in. [9.5–10 mm] in from edge. Tolerances do not include crown.

TABLE 20 7 Permissible Variations From a Flat Surface for Annealed Zirconium Plate—inch [mm]

NOTE 1—Variations in flatness apply to plates up to 15 ft [4.6 m] in length, or to any 15 ft [4.6 m] of longer plates.

NOTE 2—If the longer dimension is under 36 in. [1 m], the variation is not greater than 3/4 in. [6.4 mm].

NOTE 3—The shorter dimension specified is considered the width and the variation in flatness across the width does not exceed the tabular amount for that dimension.

NOTE 4—The maximum deviation from a flat surface does not customarily exceed the tabular tolerance for the longer dimension specified.

Specified Thickness, in. [mm]	Permissible Variations in Flatness, for Widths Given, Plus and Minus, in. [mm] ^A			
	4 To 8 in. [1.27 to 203 mm]—excl	4 Over 84 in. [2134 to 2130 mm]—excl	6 Over 120 in. [3048 to 3048 mm]—excl	72 Over 1.8 m [4572 to 4572 m]—excl
3/16 [4.8] to 1/4 [6.4], excl	[20]	1/16 [2.7]	1/4 [32]	1/8 [3.2]
0.188 [4.7] to 0.375 [9.5], excl	0.045 [1.14]	0.050 [1.27]	1/4 [32]	1/8 [3.2]
6.4 [163] to 9.5 [241], excl	[17.5]	[20]	[24]	[24]
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]
1/8 [3.2] to 1/4 [6.4], excl	1/16 [2.7]	1/16 [2.7]	1/16 [2.7]	1/16 [2.7]
0.75 [19] to 1.0 [25], excl	0.060 [1.52]	0.065 [1.65]	0.085 [2.16]	0.100 [2.54]
9.5 [241] to 13 [330], excl	[13]	[14]	[17.5]	[20]
1.0 [25] to 2.0 [50], excl	0.070 [1.78]	0.075 [1.90]	0.095 [2.41]	0
13 [330] to 20 [508], excl	[13]	[14]	[16]	[16]
2.0 [50] to 3.0 [75], excl	0.125 [3.18]	0.150 [3.81]	0.175 [4.44]	[16]
20 [508] to 25 [635], excl	[13]	[14]	[16]	[16]
3.0 [75] to 4.0 [100], excl	0.175 [4.44]	0.210 [5.33]	0.245 [6.22]	[16]
1 [25] to 1 [38], excl	[13]	[14]	[14]	[14]
4.0 [100] to 6.0 [150], excl	0.250 [6.35]	0.300 [7.62]	0.350 [8.89]	0.4
1 1/2 [38] to 4 [100], excl	[4.8]	[8]	[9.5]	[11]
6.0 [150] to 8.0 [200], excl	0.350 [8.89]	0.420 [10.67]	0.490 [12.45]	[11]
4 [100] to 6 [150], excl	[6.4]	[9.5]	[13]	[14]
8.0 [200] to 10.0 [250], incl	0.450 [11.43]	0.540 [13.72]	0.630 [16.00]	[14]

^A Thickness is measured along the longitudinal edges of the plate at least 3/8 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. [0.25 mm].

TABLE 5 8 Permissible Variations in Thickness of Hot-Rolled Zirconium Strip

Specified Width, in. [mm]	Permissible Variation in Width, in. [mm]			
	Mill Edge	Mill Edge	Variation from Specified Thickness for Width	Widths Given, Over and Under, in. [mm]
0.187–0.118, incl	0.119–0.083, incl	0.006 [0.15]	0.005 [0.13]+	—
+	–0.083, incl	–	–	–
	To 3 1/2 incl	–	–	–
Over 3 1/2–12, incl	0.007 1/8 [0.18]	0.006 [0.15]	Over 12–1 1/2 8, incl	0.008 1/32 [0.20]
3 1/2 [90] and under	1/8 [3.2]	0 [0]	1/32 [0.8]	1/32 [0.8]
Over 18–24, incl	0.010 3/16 [0.25]	1/4 [3.2]	1/32 [0.8]	1/32 [0.8]
Over 3 1/2 [90]–6 [150], incl	3/16 [4.8]	1/8 [3.2]	1/32 [0.8]	1/32 [0.8]

^A Thickness measurements shall be taken 3/8 in. [9.5 mm] from edge. Tolerances do not include crown.

10.2.2 Cold-rolled strip, Table 9 10.

9.2.3 Cold-rolled strip, Tables 11 and 10

TABLE 10 9 Permissible Variations in Length Width of Hot and Cold-Rolled Zirconium Strip (Slit Edge)

Specified Length Thickness, in. [mm]	Permissible Variations in Length, plus and minus, for Widths Given, in. [mm]	
	To 5, incl	Over 5, excl
Over 5–10, incl [1.5–3]	± 1/2 [12.7], ...	± 3/8 [9.5] to 1/2 [12.7]
0.188 to 0.161 [4.76 to 4.08], incl	...	0 [0] to 1/16 [1.6]
Over 10–20, incl [3–6.4]	± 5/8 [15.9], ...	0.010 [0.25]
0.160 to 0.100 [4.07 to 2.53], incl	...	0.010 [0.25]
0.099 to 0.06, incl	...	0.008 [0.20]
0.099 to 0.069 [2.52 to 1.74], incl	...	0.008 [0.20]
0.068 [1.73] and under	0.005 [0.13]	0.005 [0.13]