



# Standard Specification for Zirconium and Zirconium Alloy Strip, Sheet, and Plate<sup>1</sup>

This standard is issued under the fixed designation B 551/B 551M; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reappraisal.

## 1. Scope

1.1 This specification<sup>2</sup> covers five grades of zirconium strip, sheet, and plate.

1.2 Unless a single unit is used, for example corrosion mass gain in  $\text{mg}/\text{dm}^2$ , 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*:<sup>3</sup>

**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 290** 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*:

<sup>1</sup> 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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<sup>2</sup> For ASME Boiler and Pressure Vessel Code applications, see related Specification SB-551 in Section II of that Code.

<sup>3</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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 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, 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 B 551/B 550M-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.

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.

**TABLE 1 Chemical Requirements<sup>A</sup>**

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

<sup>A</sup> 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).

**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

## 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 [E 290](#).

## 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 cold-rolled, annealed, followed by a final light cold-rolled pass, generally on polished rolls
Sheet	hot-rolled hot-rolled, annealed cold-rolled, annealed cold-rolled, annealed, followed by a final light cold-rolled pass, generally on polished rolls
Plate	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  $\mu\text{in.}$  [0.8  $\mu\text{m}$ ] 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](#).

**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, % <sup>A</sup>	20	16	14	16	14
Bend test radius <sup>B</sup>	5T	5T	5T	3T	2.5T

<sup>A</sup> When a sub-size specimen is used, the gage length shall be as specified in Test Methods [E 8](#) for that specimen.

<sup>B</sup> 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.

**TABLE 4 Permissible Variations in Thickness of Hot-Rolled Zirconium Strip<sup>A</sup>**

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]

<sup>A</sup> Thickness measurements are taken at least ⅜ in. [10 mm] from edge.

10.5.3 Plate, **Table 20**.

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

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.

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 **E 29**.

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.

14.1.2 Care shall be exercised to ensure that the sample selected for testing is representative of the material and that it is not contaminated by the sampling procedure. If there is any question relating to the sampling technique or the analyses, the methods of sampling and analysis shall be as agreed upon between the purchaser and the manufacturer.

14.1.3 The utmost care must be used in sampling reactive metals for chemical analysis because of their great affinity for elements such as oxygen, nitrogen, and hydrogen. Therefore, in cutting samples for analysis, the operation should be carried out in a dust-free atmosphere. Chips should be collected from clean metal and tools should be clean and sharp. Samples for analysis should be stored in suitable containers.

14.2 *Test Methods*:

14.2.1 *Chemistry*:

14.2.1.1 Analyses shall be made using the manufacturer's standard methods.

14.2.1.2 The chemical composition enumerated in this specification shall in case of disagreement, be measured by methods mutually agreed upon by the manufacturer and the purchaser.

14.2.2 *Tension Tests*:

14.2.2.1 The room temperature tensile tests shall be conducted in accordance with Test Methods **E 8**. The yield strength shall be determined by the offset (0.2 %) 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 crosshead speed can be increased to approximately 0.05 in./in./min [mm/mm/min] to produce failure in approximately one additional minute.

14.2.2.2 Small size, 1-in. [25-mm] gage length specimens, proportional to the standard specimen, can be used

14.2.3 *Flatness*:

14.2.3.1 Flatness shall be determined in accordance with Eq 1 (see **Fig. 1**):

$$\text{Flatness, \%} = (H/L) \times 100 \quad (1)$$



**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  $\frac{3}{8}$  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]		
	$\frac{1}{16}$ [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<sup>A</sup>**

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]

<sup>A</sup> Thickness measurements are taken at least  $\frac{3}{8}$  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] <sup>A</sup>			
	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] <sup>B</sup>			
0.188 [4.7] 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]	...

<sup>A</sup> Thickness is measured along the longitudinal edges of the plate at least  $\frac{3}{8}$  in. [10 mm], but not more than 3 in. [75 mm] from the edge.

<sup>B</sup> 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].

where:

$H$  = maximum vertical distance between a flat reference surface and the lower surface of the sheet, and

$L$  = minimum horizontal distance between the highest point on the sheet and the point of contact with a flat reference surface. (Fig. 1 is included to illustrate the method for taking measurements for calculation of sheet flatness; however, a value of  $H$  less than  $\frac{1}{32}$  in. [0.8 mm] shall not be cause for rejection.)

## 15. Inspection

15.1 The manufacturer shall inspect the material covered by this specification prior to shipment and, on request, shall furnish the purchaser with certificates of test. 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 manufacturer. 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

**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]	¼ [1.6]	¼ [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 ¼ 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]

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 purchaser's inspection at the place of manufacture to be waived.

15.2 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 to not interfere unnecessarily with the operation of the works.

## 16. Rejection and Referee

16.1 Material not conforming to the specification or to authorized modifications shall be subject to rejection by the purchaser.

16.2 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.

16.3 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.

## 17. Certification

17.1 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.

## 18. Product Marking

18.1 *Identification*—Unless otherwise specified, each plate, sheet, and strip shall be marked in the respective location indicated below, with the number of this specification, heat number, manufacturer's identification, and the nominal thickness. The characters shall be not less than ⅜ in. [9.52 mm] in height, shall be applied using a suitable marking fluid, and shall be capable of being removed with a hot alkaline cleaning solution without rubbing. The marking shall have no deleterious effect on the material or its performance. The characters shall be sufficiently stable to withstand ordinary handling

18.1.1 Plate, flat sheet, and flat strip over 6 in. [150 mm] in width shall be marked in lengthwise rows of characters recurring at intervals not greater than 3 in. [75 mm], the rows being spaced not more than 1 in. [40 mm] apart and alternatively staggered. Heat numbers shall occur at least three times across the width of the material and at intervals not greater than 2 ft [0.6 m] along the length. As an option, when permitted by the purchaser, each plate, sheet, or cut length strip may be marked in at least one corner with the number of this specification, heat number, manufacturer's identification, and the nominal thickness in inches or millimetres as required.

18.1.2 Flat strip 6 in. [150 mm] and under in width shall be marked near one end.

18.1.3 Coiled sheet and strip shall be marked near the outside end of the coil.

## 19. Packaging and Package Marking

19.1 Unless otherwise specified, material purchased under this specification may be packaged for shipment either by boxing, crating, single boarding, burlapping, or with no protection in accordance with the manufacturer's standard practice.

19.2 All material shall be packaged in such a manner as to assure safe delivery to its destination when properly transported by any common carrier.

19.3 The package shall be so marked as to indicate the nature of any special handling required.

19.4 Each bundle, box, or coil shall be legibly and conspicuously marked or tagged with the following information:

- 19.4.1 Purchase order or contract number,
- 19.4.2 Name of material,

**TABLE 11 Permissible Variations in Width and Length of Rectangular, Sheared Zirconium Plate**

NOTE 1—The permissible variation under the specified width and length is ¼ in. [6.4 mm]

NOTE 2—Rectangular plates over 1 in. [25 mm] in thickness are not commonly sheared, and are machined or otherwise cut to length and width or produced in the size as-rolled, uncropped.

Specified Length, in. [m]	Specified Width, in. [m]	Permissible Variations Over Specified Dimension, for Thickness Given, in. [mm]					
		Under ⅜ in. [9.5 mm]		⅜ – ⅝ in. [9.5–16 mm], excl		⅝ in. [16 mm] and Over	
		Width	Length	Width	Length	Width	Length
Under 120 [3.0]	Under 60 [1.5]	⅜ [9.5]	½ [13]	⅞ [11]	⅝ [16]	½ [13]	¾ [20]
	60–84 [1.5–2.1], excl	⅞ [11]	⅝ [16]	½ [13]	1 1/16 [18]	⅝ [16]	⅞ [22]
	84–108 [2.1–2.74], excl	½ [13]	¾ [20]	⅝ [16]	⅞ [22]	⅝ [9.5]	1 [25]
	108 [2.74] or over	⅝ [16]	⅞ [22]	¾ [20]	1 [25]	⅞ [22]	1 1/8 [29]
120–240 [3.0–6.0], excl	Under 60 [1.5]	⅜ [9.5]	⅝ [16]	½ [13]	⅞ [22]	⅝ [16]	1 [25]
	60–84 [1.5–2.1], excl	½ [13]	¾ [20]	⅝ [16]	⅞ [22]	¾ [20]	1 [25]
	84–108 [2.1–2.74], excl	⅞ [14]	⅞ [22]	1 1/16 [18]	1 5/16 [24]	1 3/16 [21]	1 1/8 [29]
	108 [2.74] or over	⅝ [16]	1 [25]	¾ [20]	1 1/8 [29]	⅞ [22]	1 1/4 [32]
240–360 [6.0–9.0], excl	Under 60 [1.5]	⅜ [9.5]	1 [25]	½ [13]	1 1/8 [29]	⅝ [16]	1 1/4 [32]
	60–84 [1.5–2.1] excl	½ [13]	1 [25]	⅝ [16]	1 1/8 [29]	¾ [20]	1 3/4 [32]
	84–108 [2.1–2.74], excl	⅞ [14]	1 [25]	1 1/16 [18]	1 1/8 [29]	⅞ [22]	1 3/8 [35]
	108 [2.74] or over	1 1/16 [18]	1 1/8 [29]	⅞ [22]	1 1/4 [32]	1 [25]	1 3/8 [35]
360–480 [9.0–12.0], excl	Under 60 [1.5]	⅞ [11]	1 1/8 [29]	½ [13]	1 1/4 [32]	⅝ [16]	1 1/2 [38]
	60–84 [1.5–2.1], excl	½ [13]	1 1/4 [32]	⅝ [16]	1 3/8 [35]	¾ [20]	1 1/2 [38]
	84–108 [2.1–2.74], excl	⅞ [14]	1 1/4 [32]	¾ [20]	1 3/8 [35]	⅞ [22]	1 1/2 [38]
	108 [2.74] or over	¾ [20]	1 3/8 [35]	⅞ [22]	1 1/2 [38]	1 [25]	1 5/8 [41]
480–600 [12.0–15.0], excl	Under 60 [1.5]	⅞ [11]	1 1/4 [32]	½ [13]	1 1/2 [38]	⅝ [16]	1 5/8 [41]
	60–84 [1.5–2.1], excl	½ [13]	1 3/8 [35]	⅝ [16]	1 1/2 [38]	¾ [20]	1 5/8 [41]
	84–108 [2.1–2.74], excl	⅝ [16]	1 3/8 [35]	¾ [20]	1 1/2 [38]	⅞ [22]	1 5/8 [41]
	108 [2.74] or over	¾ [20]	1 1/2 [38]	⅞ [22]	1 5/8 [41]	1 [25]	1 3/4 [45]
600 [15.0] or over	Under 60 [1.5]	½ [13]	1 3/4 [45]	⅝ [16]	1 7/8 [48]	⅝ [16]	1 7/8 [48]
	60–84 [1.5–2.1], excl	⅝ [16]	1 3/4 [45]	¾ [20]	1 7/8 [48]	⅞ [22]	1 7/8 [48]
	84–108 [2.1–2.74], excl	⅝ [16]	1 3/4 [45]	¾ [20]	1 7/8 [48]	⅞ [22]	1 7/8 [48]
	108 [2.74] or over	⅞ [22]	1 3/4 [45]	1 [25]	2 [50]	1 1/8 [29]	2 1/4 [57]

**TABLE 12 Permissible Variations in Length of Hot- and Cold-Rolled Zirconium Strip**

Specified Length, ft [m]	Permissible Variations in Length, in. [mm]
To 5 [1.5], incl	+⅜, – 0 [+ 9.5, –0]
Over 5–10 [1.5–3], incl	+½, – 0 [+13, –0]
Over 10–20 [3–6.1], incl	+⅝, – 0 [+16, –0]

**TABLE 13 Permissible Variations in Length of Hot- and Cold-Rolled Zirconium Sheet**

Specified Length, ft [m]	Permissible Variations in Length, in. [mm]
To 5 [1.5], incl	+⅜, – 0 [+9.5, –0]
Over 5 [1.5]–10 [3], incl	+½, – 0 [+13, –0]
Over 10 [3]–15 [4.6], incl	+1, –0 [+25, –0]

**TABLE 14 Crown Tolerances for Hot-Rolled Zirconium Strip**

Specified Width, in. [mm]	Permissible Variation in Thickness from Edge to Center of Strip, for Widths Given, in. [mm]
To 3 1/2 [90], incl	0.003 [0.08]
Over 3 1/2 –6 [90–150], incl	0.004 [0.10]

**TABLE 15 Crown Tolerances for Cold-Rolled Zirconium Strip**

Specified Thickness, in. [mm]	Tolerance by which the Thickness at Middle of Strip may be Greater than at the Edges, for Width to 6 in. [150 mm], in. [mm]
0.005 [.13]–0.010 [.25], incl	0.0008 [.02]
Over 0.010 [.25]–0.025 [.64], incl	0.001 [0.25]
Over 0.025 [.64]–0.065 [1.65], incl	0.0015 [.04]
Over 0.065 [1.65]–0.188 [4.8], excl	0.002 [.05]

- 19.4.3 Grade,
- 19.4.4 Size,
- 19.4.5 Lot, heat, or ingot number,
- 19.4.6 Condition (see Section 9),
- 19.4.7 Gross, net and tare weights, and

19.4.8 Standard specification number.

## 20. Keywords

20.1 plate; sheet; strip; zirconium; zirconium alloy

**TABLE 16 Crown Tolerances for Hot-Rolled Zirconium Sheet**

Specified Width, in. [mm]	Permissible Variation in Thickness from Edge to Center of Strip, for Widths Given, in. [mm]
6–12 [150–300], incl	0.004 [0.10]
Over 12–18 [300–460], incl	0.006 [0.15]
Over 18–24 [460–500], excl	0.008 [0.20]

**TABLE 17 Crown Tolerances for Cold-Rolled Zirconium Sheet**

Specified Thickness, in. [mm]	Tolerance by Which the Thickness at Middle of Strip may be Greater than at the Edges, for Widths Given, in. [mm]	
	6 [150] to 12 [300], incl	Over 12 [300] to 24 [600], incl
0.005 [.13]–0.010 [.25], incl	0.001 [.025]	0.0015 [.04]
Over 0.010 [.25]–0.025 [.64], incl	0.0015 [.04]	0.002 [.05]
Over 0.025 [.64]–0.065 [1.65], incl	0.002 [.05]	0.0025 [.06]
Over 0.065 [1.65]– $\frac{3}{16}$ [4.8], excl	0.0025 [.06]	0.003 [.08]

**TABLE 18 Camber Tolerance for Hot- and Cold-Rolled Zirconium Strip<sup>A</sup>**

Specified Width, in. [mm]	Tolerance, per Unit Length of any 8 ft [2.4 m], in. [mm]
To 1½ [38], incl	$\frac{1}{8}$ [3.2]
Over 1½ –6 [38–150], incl	$\frac{3}{32}$ [2.4]

<sup>A</sup> Camber is the greatest deviation of a side edge from a straight line, the measurement being taken on the concave side with a straightedge.

**TABLE 19 Camber Tolerances for Hot- and Cold-Rolled Zirconium Sheet<sup>A</sup>**

Specified Width, in. [mm]	Tolerance per Unit Length of any 8 ft [24 m], in. [mm]
6–36 [600–900], incl	$\frac{1}{8}$ [3.2]
Over 36 [900]	$\frac{3}{32}$ [2.4]

<sup>A</sup> Camber is the greatest deviation of a side edge from a straight line, the measurement being taken on the concave side with a straightedge.

**TABLE 20 Camber Tolerances for Zirconium Plates<sup>A</sup>**

Tolerance:	$\frac{1}{8}$ in. [3.2 mm] × (number of feet of length/5) (number of metres/1.5)
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<sup>A</sup> Camber is the greatest deviation of a side edge from a straight line. The measurement is taken by placing a straightedge on the concave side and measuring the greatest distance between the plate edge and the straightedge.



**TABLE 21 Diameter Tolerances for Circular Zirconium Plates**

Specified Diameter, in. [m]	Tolerance Over Specified Diameter for Given Diameter and Thickness (No Tolerance Under), in. [mm]		
	To 3/8 [9.5], incl, in Thickness	3/8 to 5/8 [9.5-16] excl, in Thickness	5/8 [16] and Over in Thickness <sup>A</sup>
To 60 [1.5], excl	1/4 [6.4]	3/8 [9.5]	1/2 [13]
60-84 [1.5-2.1], incl	5/16 [8.0]	7/16 [11]	9/16 [14]
84-108 [2.1-2.8], excl	3/8 [9.5]	1/2 [13]	5/8 [16]
108-130 [2.8-3.3], incl	7/16 [11]	9/16 [14]	11/16 [17.5]

<sup>A</sup> Circular plates over 5/8 in. [16 mm] in thickness are not commonly sheared and are machined or otherwise cut.

**TABLE 22 Permissible Variations From a Flat Surface for Annealed Zirconium Plate-inch [mm]**

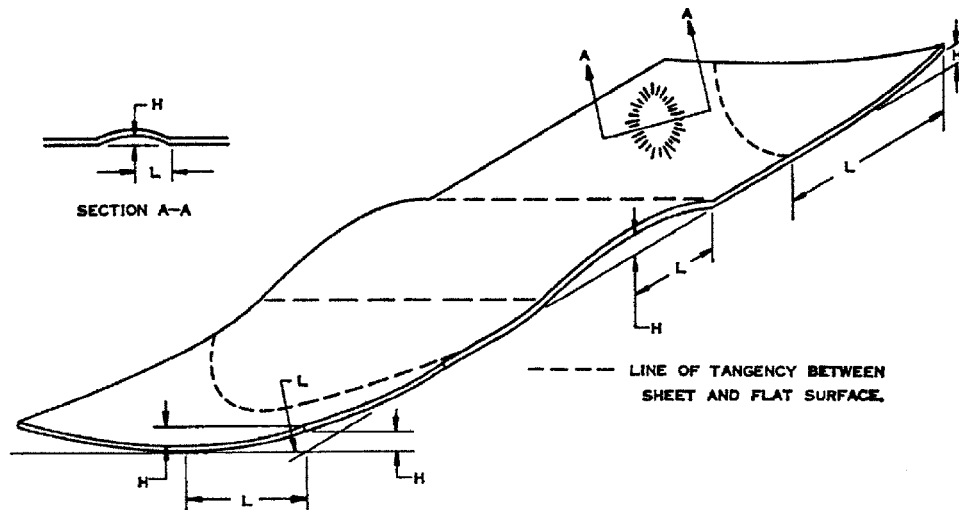
NOTE 1—Variations in flatness apply to plates up to 15 ft [4.6 m] in length, or to any 15 ft [4.6 m] of longer plates.

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

NOTE 4—The maximum deviation from a flat surface is measured in accordance with 14.2.3 and Fig. 1.

Specified Thickness, in. [mm]	Permissible Variations in Flatness, for Widths Given, Plus and Minus, in. [mm]								
	48 in. [1.2 m] or Under	48 [1.2 m]-60 [1.5 m], excl	60 [1.5]-72 [1.8 m], excl	72 [1.8]-84 [2.1 m], excl	84 [2.1]-96 [2.4 m], excl	96 [2.4 m]-108 [2.74 m], excl	108 [2.74]-120 [3.05 m], excl	120 [3.05]-144 [3.7 m], excl	144 [3.7 m] and Over
1/8 [3.2]-1/4 [6.4], excl	3/4 [20]	1 1/16 [27]	1 1/4 [32]	1 3/8 [35]	1 5/8 [41]	1 5/8 [41]	...	...	...
1/4 [6.4]-3/8 [9.5], excl	1 1/16 [17.5]	3/4 [20]	1 5/16 [24]	1 1/2 [28.6]	1 3/8 [35]	1 7/16 [36.5]	1 9/16 [40]	1 7/8 [48]	...
3/8 [9.5]-1/2 [13], excl	1/2 [13]	9/16 [14]	1 1/16 [17.5]	3/4 [20]	1 5/16 [24]	1 1/8 [28.6]	1 1/4 [32]	1 7/16 [36.5]	1 3/4 [45]
1/2 [13]-3/4 [20], excl	1/2 [13]	9/16 [14]	5/8 [16]	5/8 [16]	3/4 [20.6]	1 1/8 [28.6]	1 1/8 [28.6]	1 1/8 [28.6]	1 3/8 [35]
3/4 [20]-1 [25], excl	1/2 [13]	9/16 [14]	5/8 [16]	5/8 [16]	3/4 [20]	1 3/16 [30]	1 5/16 [24]	1 [25]	1 1/8 [28.6]
1 [25]-1 1/2 [38], excl	1/2 [13]	9/16 [14]	9/16 [14]	9/16 [14]	1 1/16 [17.5]	1 1/16 [17.5]	1 1/16 [17.5]	3/4 [20]	1 [25]
1 1/2 [39]-4 [100], excl	3/16 [4.8]	5/16 [8]	3/8 [9.5]	7/16 [11]	1/2 [13]	9/16 [14]	5/8 [16]	3/4 [20]	7/8 [22]
4 [100]-6 [150], excl	1/4 [6.4]	3/8 [9.5]	1/2 [13]	9/16 [14]	5/8 [16]	3/4 [20]	7/8 [22]	1 [25]	1 1/8 [28.6]



Flatness Deviation, % = (H/L) × 100.

H = maximum distance between flat surface and lower surface of sheet.

L = minimum distance between highest point on sheet and point of contact with flat surface.

**FIG. 1 Plate and Sheet Flatness Measurement Method**

**SUPPLEMENTARY REQUIREMENTS****S.1 Additional Requirements for Material to be Used for Explosion Cladding**

S1.1 These requirements apply exclusively for sheet and plate to be used for explosion cladding.

S1.2 These requirements apply only to Grades R60700 and R60702 and only in thicknesses ranging from 0.078 in. [2 mm] to 0.78 in. [20 mm] inclusive.

S1.3 Additional flatness requirements:

S1.3.1 The permissible variation in flatness for zirconium material grades R60700 and R60702 for explosion cladding applications shall be ½ that of the limits in **Table 22**. Localized flatness variations shall not exceed 0.12 in. [3 mm] in 39 in. [1 m], as measured using a straight edge placed (balanced) at any location on the plate surface.

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