



Designation: B776 – 12 (Reapproved 2019)

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

This standard is issued under the fixed designation B776; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This specification covers two grades of wrought hafnium and hafnium alloy strip, sheet, and plate as follows:

- 1.1.1 Grade R1 for nuclear applications, and
- 1.1.2 Grade R3 for commercial applications.

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

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

- 2.1 *ASTM Standards*:<sup>2</sup>
  - E8/E8M Test Methods for Tension Testing of Metallic Materials
  - E21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials
  - E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

<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.

Current edition approved April 1, 2019. Published May 2019. Originally approved in 1987. Last previous edition approved in 2012 as B776 – 12. DOI: 10.1520/B0776-12R19.

<sup>2</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. Terminology

### 3.1 Lot Definition:

3.1.1 *lot, n*—a lot shall consist of a material of the same size, shape, condition, and finish produced from the same ingot by the same reduction schedule and the same heat treatment parameters. Unless otherwise agreed upon 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.

### 3.2 Forms:

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

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

3.2.3 *plate, n*—a flat product more than 0.125 in. (3.2 mm) in thickness.

## 4. Classification

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

- 4.1.1 Grade R1 (Nuclear)—Unalloyed.
- 4.1.2 Grade R3 (Commercial)—Unalloyed.

## 5. Ordering Information

5.1 Purchase orders for materials under this specification shall include the following information as applicable:

- 5.1.1 Quantity (weight or number of pieces),
- 5.1.2 Form (3.2) and dimensions,
- 5.1.3 Grade (4.1),
- 5.1.4 Lot definition for continuous anneal, if applicable (3.1),
- 5.1.5 Metallurgical condition, if not in the recrystallized annealed condition (6.3),
- 5.1.6 Chemical analysis of elements not listed (7.1.3),
- 5.1.7 Product analysis (7.1.1.1 and 7.1.3),
- 5.1.8 Tensile test temperatures (8.1),
- 5.1.9 Mechanical properties, for Grade R3 (8.1),
- 5.1.10 Corrosion properties and testing, (9.1 and 9.1.3),
- 5.1.11 Material condition and finish (12.1 – 12.5),
- 5.1.12 Workmanship standards and methods of inspection (Section 13),

- 5.1.13 Purchaser inspection (16.1),
- 5.1.14 Rejection and referee (17.2),
- 5.1.15 Certification report (Section 18),
- 5.1.16 Product marking (Section 19), and
- 5.1.17 Packaging and package marking (Section 20).

NOTE 1—A typical ordering description is as follows: 28 pieces hafnium plate, annealed; mechanically descaled and pickled; 0.158 by 6.000 in. thick by 18-in. long lengths; Grade R1; ASTM B776 – 07.

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

## 7. Chemical Composition

7.1 The grades of R1 and R3 metal 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.

7.1.1.1 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

**TABLE 2 Check Analyses Limits**

Element	Variations Under Min. or Over Max. %
Hydrogen	0.002
Nitrogen	0.01
Carbon	0.01
Zirconium	0.02
Iron and Chromium	0.025
Tin	0.05
Niobium	0.05
Oxygen	0.02

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.

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

7.1.3 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, except for certain cases where tests on product are required, as specified in 14.1.1.

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 and the distance between samples or between the bottom face and a sample does not exceed one ingot diameter. 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 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.

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 Grade R1 shall conform to the requirements prescribed in Table 3 for room temperature mechanical properties. Elevated temperature properties shall be used to determine

**TABLE 1 Chemical Requirements**

Elements	Composition, Weight	
	Grade R1	Grade R3
Aluminum	0.010	0.050
Carbon	0.015	0.025
Chromium	0.010	0.050
Copper	0.010	...
Hydrogen	0.0025	0.0050
Iron	0.050	0.0750
Molybdenum	0.0020	...
Nickel	0.0050	...
Niobium	0.010	...
Nitrogen	0.010	0.015
Oxygen	0.040	0.130
Silicon	0.010	0.050
Tantalum	0.020	...
Tin	0.0050	...
Titanium	0.010	0.050
Tungsten	0.0150	0.0150
Uranium	0.0010	...
Vanadium	0.0050	...
Zirconium	<sup>A</sup>	<sup>A</sup>
Hafnium	balance	balance

<sup>A</sup> Zirconium shall be reported. Acceptable levels shall be established by mutual agreement between purchaser and producer.

**TABLE 3 Grade 1 Mechanical Properties**

Sample Direction	Condition	Test Temperature	Tensile Strength, min ksi (MPa)	Yield Strength, min ksi (MPa)	Elongation, (min %) in 2 in. (50 mm)
Longitudinal	annealed	RT	58 (400)	22 (151)	20
Longitudinal	annealed	600 °F (315 °C)	25 (172)	11 (76)	25
Transverse	annealed	RT	45 (310)	25 (172)	20
Transverse	annealed	600 °F (315 °C)	23 (158)	14 (96)	30

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

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

<sup>A</sup> Thickness measurements are taken at least ¾ in. (10 mm) from edge.

compliance only when specified in the purchase order. When required by the purchaser, Grade R3 mechanical properties shall conform to the limits specified in the purchase order.

**9. Corrosion Properties**

9.1 When required by the purchaser and stated in the purchase order, the following corrosion testing shall be performed:

9.1.1 Two samples chosen at random from each lot shall be corrosion tested in water at 680 °F (360 °C), 2690 psi (18.5 MPa) for 672 + 8 – 0 h using the manufacturer’s standard procedure.

9.1.2 *Grade R1*—Coupons shall exhibit a weight gain of not more than 10 mg/dm<sup>2</sup>.

9.1.3 Grade R3 will be tested for information only, if required by purchase order.

**10. Significance of Numerical Limits**

10.1 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 righthand place of figures of the specified limit
Tensile strength and yield strength	nearest 1000 psi (10 MPa)
Elongation	nearest 1 %

**11. Permissible Variations in Dimensions and Weights**

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

- 11.1.1 Hot-rolled strip, [Table 4](#).
- 11.1.2 Cold-rolled strip, [Table 5](#).
- 11.1.3 Hot- and cold-rolled sheet, [Table 6](#).

11.1.4 Plate, [Table 7](#).

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

- 11.2.1 Hot-rolled strip, [Table 8](#).
- 11.2.2 Cold-rolled strip, [Table 9](#).
- 11.2.3 Hot- and cold-rolled sheet, [Table 10](#).
- 11.2.4 Plate, [Table 11](#).

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

- 11.3.1 Hot- and cold-rolled strip, [Table 12](#).
- 11.3.2 Hot- and cold-rolled sheet, [Table 13](#).
- 11.3.3 Plate, [Table 11](#).

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

- 11.4.1 Hot-rolled strip, [Table 14](#).
- 11.4.2 Cold-rolled strip, [Table 15](#).
- 11.4.3 Hot-rolled sheet, [Table 16](#).
- 11.4.4 Cold-rolled sheet, [Table 17](#).

11.5 *Camber Tolerances*—The variations in camber tolerances are given in the following tables:

- 11.5.1 Hot- and cold-rolled strip, [Table 18](#).
- 11.5.2 Hot- and cold-rolled sheet, [Table 19](#).
- 11.5.3 Plate, [Table 20](#).

11.6 *Diameter*—The variation in diameter tolerance for circular plates is given in [Table 21](#).

11.7 *Flatness*—The permissible variation from a flat surface for plate is given in [Table 22](#).

11.8 *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 %.

**12. Condition and Finish**

12.1 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
Sheet	cold-rolled, annealed
	cold-rolled, annealed, followed by a final light cold-rolled pass, generally on polished rolls.
	hot-rolled
Plate	hot-rolled, annealed
	cold-rolled, annealed
	cold-rolled, annealed, followed by a final light cold-rolled pass, generally on polished rolls.

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

- 12.2.1 Not descaled,
- 12.2.2 Mechanically descaled, or
- 12.2.3 Mechanically descaled and pickled.

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

- 12.3.1 Cold-rolled,
- 12.3.2 Ground 32 µin. (0.8 µm) rms or better, or

**TABLE 5 Permissible Variations in Thickness of Cold-Rolled Hafnium Strip**

NOTE 1—For thickness under 0.010 in. (0.25 mm) and 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. (25 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)		
	$\frac{3}{16}$ to 1 (4.8 to 25), excl	1 to 3 (25 to 75), excl	3 to 6 (75 to 150), excl
0.188 to 0.160 (4.78 to 4.06), incl	0.002 (0.05)	0.003 (0.08)	0.004 (0.10)
0.160 to 0.100 (4.05 to 2.52), incl	0.002 (0.05)	0.002 (0.05)	0.003 (0.08)
0.099 to 0.069 (2.51 to 1.75), incl	0.002 (0.05)	0.002 (0.05)	0.003 (0.08)
0.068 to 0.050 (1.74 to 1.27), incl	0.002 (0.05)	0.002 (0.05)	0.003 (0.08)
0.049 to 0.040 (1.26 to 1.01), incl	0.002 (0.05)	0.002 (0.05)	0.0025 (0.07)
0.039 to 0.035 (1.00 to 0.88), incl	0.002 (0.05)	0.002 (0.05)	0.0025 (0.07)
0.034 to 0.029 (0.87 to 0.73), incl	0.0015 (0.04)	0.015 (0.04)	0.002 (0.05)
0.028 to 0.026 (0.72 to 0.66), incl	0.001 (0.025)	0.015 (0.04)	0.0015 (0.04)
0.025 to 0.020 (0.65 to 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 Hafnium 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 (0.04)
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) from edge. Tolerances do not include crown.

**TABLE 7 Permissible Variations in Thickness for Hafnium Plate**

Specified Thickness, in. (mm)	Width, in. (mm) <sup>A</sup>			
	To 84 (2130), incl	Over 84 to 120 (2130 to 3050), incl	Over 120 to 144 (3050 to 3660), incl	Over 144 (3660)
	Tolerances Over Specified Thickness, in. (mm) <sup>B</sup>			
0.125 to 0.375 (3.2 to 9.5), excl	0.045 (1.14)	0.050 (1.27)	...	...
0.375 to 0.75 (9.5 to 19), excl	0.055 (1.40)	0.060 (1.52)	0.075 (1.90)	0.090 (2.29)
0.75 to 1.0 (19 to 25), excl	0.060 (1.52)	0.065 (1.65)	0.085 (2.16)	0.100 (2.54)
1.0 to 2.0 (25 to 50), excl	0.070 (1.78)	0.075 (1.90)	0.095 (2.41)	0.115 (2.92)
2.0 to 3.0 (50 to 75), excl	0.125 (3.18)	0.150 (3.81)	0.175 (4.44)	0.200 (5.08)
3.0 to 4.0 (75 to 100), excl	0.175 (4.44)	0.210 (5.33)	0.245 (6.22)	0.280 (7.11)
4.0 to 6.0 (100 to 150), excl	0.250 (6.35)	0.300 (7.62)	0.350 (8.89)	0.400 (10.16)
6.0 to 8.0 (150 to 200), excl	0.350 (8.89)	0.420 (10.67)	0.490 (12.45)	0.560 (14.22)
8.0 to 10.0 (200 to 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. (0.25 mm).

12.3.3 Pickled.

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

- 12.4.1 Mill edge,
- 12.4.2 Slit edge, and
- 12.4.3 Sheared edge.

12.5 *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.

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

**13. Workmanship and Appearance**

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

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