



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

This standard is issued under the fixed designation B 776; 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 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 and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

**E 8** Test Methods for Tension Testing of Metallic Materials

**E 21** Test Methods for Elevated Temperature Tension Tests of Metallic Materials

**E 29** Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

## 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 ingot or powder blend 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 0.188 in. (4.8 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),

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<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.

- 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: twenty-eight pieces hafnium plate, annealed; mechanically descaled and pickled; 0.158 by 6.000 in. thick by 18-in. long lengths; Grade R1; ASTM B 776 – 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 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 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 compliance only when specified in the purchase order. When

**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

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 E 29.

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:

**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 ⅜ in. (10 mm) from edge.

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

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

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

**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>			
0.188 to 0.375 (4.7 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).

**TABLE 8 Permissible Variations in Width of Hot-Rolled Hafnium Strip**

Specified Width, in. (mm)	Permissible Variations in Width, in. (mm)					
	Mill Edge		Slit Edge		Sheared Edge	
	+	-	+	-	+	-
$3\frac{1}{2}$ (90) and under	$\frac{1}{8}$ (3.2)	0 (0)	$\frac{1}{32}$ (0.8)	$\frac{1}{32}$ (0.8)	$\frac{1}{16}$ (1.6)	$\frac{1}{16}$ (1.6)
over $3\frac{1}{2}$ to 6 (90 to 150), incl	$\frac{3}{16}$ (4.8)	$\frac{1}{8}$ (3.2)	$\frac{1}{32}$ (0.8)	$\frac{1}{32}$ (0.8)	...	0 (0)



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

Specified Thickness, in. (mm)	Permissible Variations in Thickness, $\pm$ , for Widths Given, in. (mm)	
	Under 1/2 (12)	1/2 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 Hafnium Sheet**

Specified Width, in. (mm) for Thickness Under 3/16 in. (4.8 mm)	Permissible Variations in Width, in. (mm)
6 to 24 (150 to 600), excl	+1/8, -0 (+3.2, -0)
24 to 48 (600 to 1200), excl	+1/8, -0 (+3.2, -0)
48 (1200) and over	+3/16, -0 (+4.8, -0)

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.

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

13.4 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.

### 14. Number of Tests, Retests and Rework

14.1 *Number of Tests:*

14.1.1 Two chemistry tests for hydrogen and nitrogen content shall be made from each lot of finished product.

14.1.2 Two tension tests shall be made from each lot, one in the longitudinal and one in the transverse direction at each of the required temperatures.

14.2 *Retests:*

14.2.1 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.

14.2.2 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.

14.2.3 If the results for the retest fail to conform to the specification, the material will be rejected in accordance with Section 17.

14.3 *Rework:*

14.3.1 If the results of the final sheet, strip, or plate inspections are not in conformance with the requirements of this specification, the lot may be reworked at the option of the manufacturer. The lot shall be acceptable if the results of all tests, after reworking, conform to this specification.

## 15. Sampling and Test Methods

15.1 *Sampling:*

15.1.1 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 and shall be representative of the finished product.

15.1.2 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 analysis shall be as agreed upon between the purchaser and the manufacturer.

15.1.3 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.

15.2 *Test Methods:*

15.2.1 *Chemistry:*

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

15.2.1.2 The chemical composition enumerated in this specification shall in case of disagreement, be determined in accordance with the methods approved for referee purposes by ASTM International. Where such methods are not available, methods of analysis as mutually agreed upon by the manufacturer and the purchaser shall be employed.

15.2.2 *Tension Tests:*

15.2.2.1 The room temperature tensile tests shall be conducted in accordance with Test Methods E 8 and elevated temperature tensile tests in accordance with Test Methods E 21. 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.

15.2.2.2 Small size, 1-in. (25-mm) gauge length specimens, proportional to the standard specimen, can be used.

**TABLE 11 Permissible Variations in Width and Length of Rectangular, Sheared Hafnium 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 to ⅝ in. (9.5 to 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 to 84 (1.5 to 2.1), excl	⅞ (11)	⅝ (16)	½ (13)	⅞ (16)	⅝ (16)	⅞ (22)
	84 to 108 (2.1 to 2.74), excl	½ (13)	¾ (20)	⅝ (16)	⅞ (22)	⅜ (9.5)	1 (25)
	108 (2.74) or over	⅝ (16)	⅞ (22)	¾ (20)	1 (25)	⅞ (22)	1½ (29)
120 to 240 (3.0 to 6.0), excl	Under 60 (1.5)	⅜ (9.5)	⅝ (16)	½ (13)	⅞ (22)	⅝ (16)	1 (25)
	60 to 84 (1.5 to 2.1), excl	½ (13)	¾ (20)	⅝ (16)	⅞ (22)	¾ (20)	1 (25)
	84 to 108 (2.1 to 2.74), excl	⅞ (14)	⅞ (22)	⅞ (18)	⅞ (24)	⅞ (21)	1½ (29)
	108 (2.74) or over	⅝ (16)	1 (25)	¾ (20)	1½ (29)	⅞ (22)	1¼ (32)
240 to 360 (6.0 to 9.0), excl	Under 60 (1.5)	⅜ (9.5)	1(25)	½ (13)	1½ (29)	⅝ (16)	1¼ (32)
	60 to 84 (1.5 to 2.1), excl	½ (13)	1 (25)	⅝ (16)	1½ (29)	¾ (20)	1¾ (32)
	84 to 108 (2.1 to 2.74), excl	⅞ (14)	1 (25)	⅞ (18)	1½ (29)	⅞ (22)	1¾ (35)
	108 (2.74) or over	⅞ (18)	1½ (29)	⅞ (22)	1¼ (32)	1 (25)	1¾ (35)
360 to 480 (9.0 to 12.0), excl	Under 60 (1.5)	⅞ (11)	1½ (29)	½ (13)	1¼ (32)	⅝ (16)	1½ (38)
	60 to 84 (1.5 to 2.1), excl	½ (13)	1¼ (32)	⅝ (16)	1¾ (35)	¾ (20)	1½ (38)
	84 to 108 (2.1 to 2.74), excl	⅞ (14)	1¼ (32)	¾ (20)	1¾ (35)	⅞ (22)	1½ (38)
	108 (2.74) or over	¾ (20)	1¾ (35)	⅞ (22)	1½ (38)	1 (25)	1¾ (41)
480 to 600 (12.0 to 15.0), excl	Under 60 (1.5)	⅞ (11)	1¼ (32)	½ (13)	1½ (38)	⅝ (16)	1½ (41)
	60 to 84 (1.5 to 2.1), excl	½ (13)	1¾ (35)	⅝ (16)	1½ (38)	¾ (20)	1½ (41)
	84 to 108 (2.1 to 2.74), excl	⅝ (16)	1¾ (35)	¾ (20)	1½ (38)	⅞ (22)	1½ (41)
	108 (2.74) or over	¾ (20)	1½ (38)	⅞ (22)	1½ (41)	1 (25)	1¾ (45)
600 (15.0) or over	Under 60 (1.5)	½ (13)	1¾ (45)	⅝ (16)	1¾ (48)	⅝ (16)	1¾ (48)
	60 to 84 (1.5 to 2.1), excl	⅝ (16)	1¾ (45)	¾ (20)	1¾ (48)	⅞ (22)	1¾ (48)
	84 to 108 (2.1 to 2.74), excl	⅝ (16)	1¾ (45)	¾ (20)	1¾ (48)	⅞ (22)	1¾ (48)
	108 (2.74) or over	⅞ (22)	1¾ (45)	1 (25)	2 (50)	1½ (29)	2¼ (57)

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

Specified Length, ft (m)	Permissible Variations in Length, in. (mm)
To 5 (1.5), incl	+ ⅜, - 0 (+9.5, -0)
Over 5 to 10 (1.5 to 3), incl	+ ½, - 0 (+13, -0)
Over 10 to 20 (3 to 6.1), incl	+⅝, - 0 (+16, -0)

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

Specified Length, ft (m)	Permissible Variations in Length, in. (mm)
To 5 (1.5), incl	+ ⅜, - 0 (+9.5, -0)
Over 5 to 10 (1.5 to 3), incl	+ ½, - 0 (+13, -0)
Over 10 to 15 (3 to 4.6), incl	+1, -0 (+25, -0)

### 15.2.3 Flatness:

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

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

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

Specified Width, in. (mm)	Permissible Variations in Thickness from Edge to Center of Strip, for Widths Given, in. (mm)
To 3½ (90), incl	0.003 (0.08)
Over 3½ to 6 (90 to 150), incl	0.004 (0.10)

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 ⅓ in. (0.8 mm) shall not be cause for rejection.)

## 16. Inspection

16.1 The manufacturer shall inspect the material covered by this specification prior to shipment. If so specified in the

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

Specified Thickness, in. (mm)	Tolerance by Which the Thickness at Middle of Strip may be Greater than at Edges, for Widths to 6 in. (150 mm), in. (mm)
0.005 to 0.010 (.13 to .25), incl	0.0008 (.02)
Over 0.010 to 0.025 (.25 to .64), incl	0.001 (.025)
Over 0.025 to 0.065 (.64 to 1.65), incl	0.0015 (.04)
Over 0.065 to 0.188 (1.65 to 4.8), excl	0.002 (.05)

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

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

purchase order, the purchaser or his representative may witness the testing and inspection of the material at the place of manufacture. In such cases the purchaser shall state in his purchase order which tests he desires to witness. The manufacturer shall give ample notice to the purchaser as to the time and place of designated test. 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.

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

### 17. Rejection and Referee

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

17.2 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.

17.3 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.

### 18. Certification

18.1 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. When specified in the purchase order or contract, the certificate shall include a report of the test results.

### 19. Product Marking

19.1 When specified, each plate, sheet, and strip shall be marked with the number of this specification, type, temper, lot number, manufacturer's identification, nominal thickness in inches, and gross, net, and tare weights. Characters shall be not less than  $\frac{3}{8}$  in. (9.5 mm) in height, applied with a suitable marking fluid and capable of being removed without rubbing. The markings or their removal shall have no deleterious effect on the material or its performance. The characters shall be sufficiently stable to withstand ordinary handling.

19.2 When specified, plate and flat sheet shall be marked in lengthwise rows of characters recurring at intervals not greater than 2 ft (0.6 m), the rows spaced not more than 3 in. (76 mm) apart and alternately staggered.

19.3 When specified, coiled strip and sheet shall be marked near the outside of the coil.

### 20. Packaging and Package Marking

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

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

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

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

- 20.4.1 Purchase order or contract number,
- 20.4.2 Name of material,
- 20.4.3 Grade,
- 20.4.4 Size,
- 20.4.5 Lot, heat, or ingot number,
- 20.4.6 Condition,
- 20.4.7 Gross, net and tare weights, and
- 20.4.8 ASTM specification number.

### 21. Keywords

21.1 foil; hafnium; hafnium alloy; hafnium drawing grade sheet; hafnium nuclear applications; hafnium plate; hafnium sheet; hafnium strip

**TABLE 17 Crown Tolerances for Cold-Rolled Hafnium 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 to 12 (150 to 300), incl	Over 12 to 24 (300 to 600), incl
0.005 to 0.010 (.13 to .25), incl	0.001 (.025)	0.0015 (.04)
Over 0.010 to 0.025 (.25 to .64), incl	0.0015 (.04)	0.002 (.05)
Over 0.025 to 0.065 (.64 to 1.65), incl	0.002 (.05)	0.0025 (.06)
Over 0.065 to $\frac{3}{16}$ (1.65 to 4.8), excl	0.0025 (.06)	0.003 (.08)

**TABLE 18 Camber Tolerance for Hot- and Cold-Rolled Hafnium 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 to 6 (38 to 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 Hafnium Sheet<sup>A</sup>**

Specified Width, in. (mm)	Tolerance per Unit Length of any 8 (24), in. (mm)
6 to 36 (600 to 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 Hafnium 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 being taken on the concave side with a straightedge.

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

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

<sup>A</sup> Circular plates over  $\frac{5}{8}$  (16 mm) in thickness are not commonly sheared and are machined or otherwise cut.



**TABLE 22 Permissible Variations from a Flat Surface for Annealed Hafnium Plate, inch (mm)**

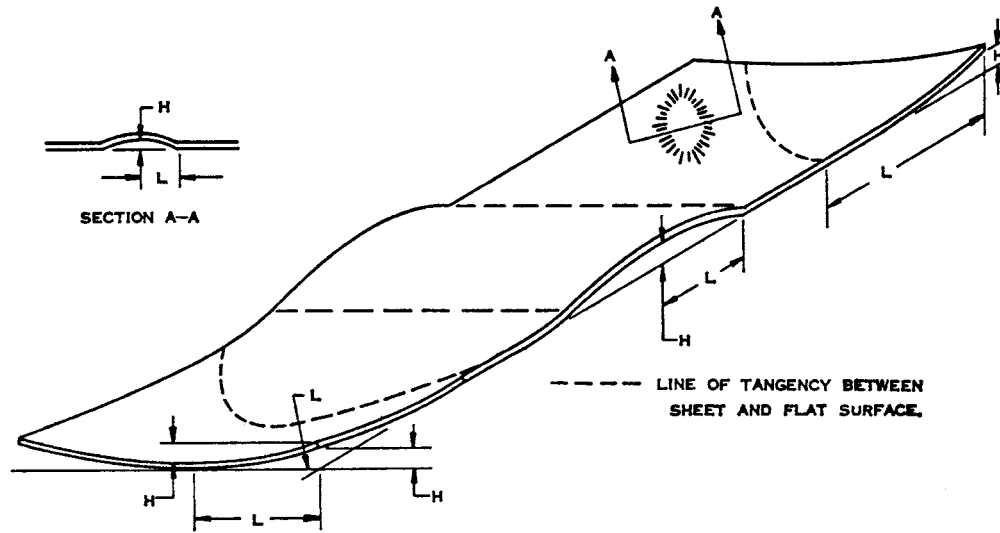
NOTE 1—Variations in flatness apply to plates up to 15 ft in (4.6 m) length, or to any 15 ft (4.6 m) of longer plates.

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 dimension.

NOTE 4—The maximum deviation from a flat surface is measured in accordance with 15.2.3.1 and Fig. 1.

Specified Thickness, in. (mm)	Permissible Variations in Flatness, for Widths Given, ±, in. (mm)								
	48 (1.2) or Under	48 to 60 (1.2 to 1.5), excl	60 to 72 (1.5 to 1.8), excl	72 to 84 (1.8 to 2.1), excl	84 to 96 (2.1 to 2.4), excl	96 to 108 (2.4 to 2.74), excl	108 to 120 (2.74 to 3.05), excl	120 to 144 (3.05 to 3.7), excl	144 (3.7) and Over
1/8 to 1/4 (3.2 to 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 to 3/8 (6.4 to 9.5), excl	1 1/16 (17.5)	3/4 (20)	15/16 (24)	1 1/8 (28.6)	1 3/8 (35)	1 7/16 (36.5)	1 9/16 (40)	1 7/8 (48)	...
3/8 to 1/2 (9.5 to 13), excl	1/2 (13)	9/16 (14)	1 1/16 (17.5)	3/4 (20)	15/16 (24)	1 1/8 (28.6)	1 1/4 (32)	1 7/16 (36.5)	1 3/4 (45)
1/2 to 3/4 (13 to 20), excl	1/2 (13)	9/16 (14)	5/8 (16)	5/8 (16)	13/16 (20.6)	1 1/8 (28.6)	1 1/8 (28.6)	1 1/8 (28.6)	1 3/8 (35)
3/4 to 1 (20 to 25), excl	1/2 (13)	9/16 (14)	5/8 (16)	5/8 (16)	3/4 (20)	1 1/16 (30)	1 5/16 (24)	1 (25)	1 1/8 (28.6)
1 to 1 1/2 (25 to 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 to 4 (39 to 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 to 6 (100 to 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, % =  $(H/L) \times 100$

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**

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