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AMERICAN SOCIETY FOR TESTING AND MATERIALS  
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## Standard Specification for Molybdenum and Molybdenum Alloy Bar, Rod, and Wire<sup>1</sup>

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<sup>e1</sup> NOTE—Keywords were added editorially in June 1995.

### 1. Scope

1.1 This specification covers unalloyed molybdenum and molybdenum alloy bar, rod, and wire as follows:

1.1.1 *Molybdenum 360* Unalloyed vacuum arc-cast molybdenum.

1.1.2 *Molybdenum 361* Unalloyed powder metallurgy molybdenum.

1.1.3 *Molybdenum Alloy 363* Vacuum arc-cast molybdenum ± 0.5 % titanium ± 0.1 % zirconium (TZM) alloy.

1.1.4 *Molybdenum Alloy 364* Powder metallurgy molybdenum ± 0.5 % titanium ± 0.1 % zirconium (TZM) alloy.

1.1.5 *Molybdenum 365* Unalloyed vacuum arc-cast molybdenum, low carbon.

1.1.6 *Molybdenum Alloy 366* Vacuum arc-cast molybdenum, 30 % tungsten alloy.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are provided for information purposes only.

### 2. Referenced Documents

#### 2.1 ASTM Standards:

E 8 Test Methods for Tension Testing of Metallic Materials<sup>2</sup>  
F 289 Specification for Molybdenum Wire and Rod for Electronic Applications<sup>3</sup>

### 3. Terminology

#### 3.1 Definitions of Terms Specific to This Standard:

3.1.1 *bar and rod* Any straight product with a round, rectangular, hexagonal, or octagonal solid cross section, 4 in. (101.6 mm) in diameter or less, or of equivalent cross-sectional area.

3.1.2 *wire* Any product furnished in coils or on spools or reels.

NOTE 1—This specification covers wire no smaller than 0.020 in. (0.51 mm) in diameter or of equivalent cross-sectional area. Specification F 289 covers diameters up to 0.020 in.

<sup>1</sup> This specification is under the jurisdiction of ASTM Committee B-10 on Reactive and Refractory Metals and Alloys and is the direct responsibility of Subcommittee B10.04 on Molybdenum and Tungsten.

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<sup>2</sup> *Annual Book of ASTM Standards*, Vol 03.01.

<sup>3</sup> *Annual Book of ASTM Standards*, Vol 10.04.

### 4. Ordering Information

4.1 Orders for material under this specification shall include the following information as applicable:

4.1.1 Material number and temper designation (Section 1 and Table 3),

4.1.2 Product form (Section 3),

4.1.3 Chemical requirements (Table 1 and Table 2),

4.1.4 Mechanical requirements (Section 7),

4.1.5 Softening temperature (Section 8),

4.1.6 Tolerances (Section 9 and Table 4),

4.1.7 Workmanship and quality level requirements (Section 10),

4.1.8 Packaging (Section 16),

4.1.9 Marking (Section 15),

4.1.10 Certification and reports (Section 14), and

4.1.11 Disposition of rejected material (Section 13).

### 5. Materials and Manufacture

5.1 The various molybdenum mill products covered by this specification shall be manufactured with the conventional extrusion, forging, swaging, rolling, and drawing equipment normally found in primary ferrous and nonferrous plants. The ingot metal for Molybdenum 360 and 365 and Molybdenum Alloys 363 and 366 is vacuum arc-melted in furnaces of a type suitable for reactive, refractory metals, and for Molybdenum 361 and 364 the metal is consolidated by powder metallurgy methods.

### 6. Chemical Composition

6.1 The molybdenum and molybdenum alloy ingots and billets for conversion to finished products covered by this specification shall conform to the requirements of the chemical composition prescribed in Table 1.

#### 6.2 Check Analysis:

6.2.1 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.

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

6.2.3 The manufacturer shall not ship material that is outside the limits specified in Table 1 for the applicable type,

**TABLE 1 Chemical Requirements**

Element	Composition, %					
	Material Number					
	360	361	363	364	365	366
C	0.030 max	0.010 max	0.010±0.030	0.010±0.040	0.010 max	0.030 max
O, max <sup>A</sup>	0.0015	0.0070	0.0030	0.030	0.0015	0.0025
N, max <sup>A</sup>	0.002	0.002	0.002	0.002	0.002	0.002
Fe, max	0.010	0.010	0.010	0.010	0.010	0.010
Ni, max	0.002	0.005	0.002	0.005	0.002	0.002
Si, max	0.010	0.010	0.010	0.005	0.010	0.010
Ti	...	...	0.40±0.55	0.40±0.55	...	...
W	...	...	...	...	...	27±33
Zr	...	...	0.06±0.12	0.06±0.12	...	...
Mo	balance	balance	balance	balance	balance	balance

<sup>A</sup>Pending approved methods of analysis, deviations from these limits alone shall not be cause for rejection.

**TABLE 2 Permissible Variations in Check Analysis**

	Material No.	Check Analysis Limits, max or range, %	Permissible Variations in Check Analysis, %
C	360, 363, 364, 366, 361, 365	0.010±0.040 0.010	60.005 60.002
O <sup>A</sup>	361 360, 363, 365, 366 364	0.0070 0.0030 0.030	+10 % relative +10 % relative +10 % relative
N <sup>A</sup>	361, 364, 365 360, 363, 366	0.0020 0.0010	+0.0005 + 0.0005
Fe	360, 361, 363, 364, 365, 366	0.010	+0.001
Ni	360, 361, 363, 364, 365, 366	0.005	+0.0005
Si	360, 361, 363, 364, 365, 366	0.010	+0.002
Ti	363, 364	0.40±0.55	60.05
W	366	27.0±33.0	61.0
Zr	363, 364	0.06±0.12	60.02

<sup>A</sup>See Table 1, Footnote A.

with the exception of oxygen and nitrogen, whose percentage may vary with the method of fabrication.

6.2.4 Check analysis limits shall be as specified in Table 2.

## 7. Mechanical Properties

7.1 Material supplied under this specification shall conform to the mechanical property requirements given in Table 3 when tested in the longitudinal direction of working at test temperatures between 65 and 85°F (18.3 and 29.4°C).

7.2 Tension test specimens shall be prepared and tested in accordance with Test Methods E 8. Tensile properties shall be determined using a strain rate of 0.002 to 0.005 in./in. min (or mm/mm min) through 0.6 % offset and 0.02 to 0.05 in./in. min to fracture.

## 8. Softening Temperature

8.1 If specified, the material supplied under this specification shall have mechanical properties not lower than those shown in Table 3 after reheating in a protective atmosphere to the following temperatures for a period of 30 min;

Molybdenum Type	°F	°C
360	1650	900
361	1650	900
363	2100	1150
364	2100	1150
365	1650	900
366	2000	1100

## 9. Permissible Variations in Dimensions

9.1 Diameter, and out-of-round tolerances on molybdenum and molybdenum alloy products covered by this specification shall be as specified in Table 4.

9.2 Length and straightness tolerances and limitations shall be as follows:

9.2.1 Cut lengths, 6<sup>1</sup>/<sub>4</sub> in. (6.35 mm).

9.2.2 Straightness, maximum deviation of 0.050 in./ft (1.27 mm/305 mm) in any length.

9.3 Permissible variations in dimensions for wire, square, or rectangular bars, and hexagonal or octagonal rods, shall be as agreed upon between the manufacturer and the purchaser.

## 10. Workmanship, Finish, and Appearance

10.1 Molybdenum and molybdenum alloy bar, rod, and wire shall be free of injurious external and internal imperfections of a nature that will interfere with the purpose for which it is intended.

10.2 Material may be finished as forged, rolled, swaged, or drawn (black), as cleaned, as machined, or as ground.

10.3 The manufacturer shall be permitted to remove surface imperfections provided such removal does not reduce the dimension below the minimum permitted by the tolerance for the dimension specified.

## 11. Sampling

11.1 Care shall be exercised to ensure that the sample selected for testing is representative of the material and form and is not contaminated by the sampling procedure.

## 12. Methods of Chemical Analysis

12.1 The chemical composition enumerated in this specification shall, in case of disagreement, be determined in accordance with the test methods approved for referee purposes by ASTM.<sup>4</sup> Where such test methods are not available, methods of analysis as mutually agreed upon between the manufacturer and the purchaser shall be employed.

## 13. Rejection

13.1 Material not conforming to this specification or to authorized modifications shall be subject to rejection. Unless

<sup>4</sup> Reference should be made to the *Annual Book of ASTM Standards*, Vol 03.05.

**TABLE 3 Mechanical Requirements for Round Bars and Rods<sup>A</sup>**

Type	Temper <sup>B</sup>	Diameter, in. (mm)	Tensile Strength, min, ksi (MPa)	Yield Strength, 0.2 % Off-set, min, ksi (MPa)	Elongation in 1 in. (50 mm) min, %	Diamond Pyramid Hardness (DPH), Vickers-10 kg
360, 361, 365	SR	0.020 to <sup>1</sup> ϕ <sub>8</sub> (0.51 to 3.18), incl	85 (585)	65 (450)	15 <sup>C</sup>	...
		over <sup>1</sup> ϕ <sub>8</sub> to <sup>13</sup> ϕ <sub>32</sub> (3.18 to 10.32)	75 (515)	55 (380)	15	...
		over <sup>13</sup> ϕ <sub>32</sub> to <sup>7</sup> ϕ <sub>8</sub> (10.32 to 22.2)	90 (620)	75 (515)	18	230 to 280
		over <sup>7</sup> ϕ <sub>8</sub> to <sup>1</sup> ϕ <sub>8</sub> (22.2 to 28.6)	85 (585)	70 (480)	15	225 to 270
		over <sup>1</sup> ϕ <sub>8</sub> to <sup>17</sup> ϕ <sub>8</sub> (28.6 to 47.6)	75 (515)	65 (450)	10	215 to 260
		over <sup>17</sup> ϕ <sub>8</sub> to <sup>27</sup> ϕ <sub>8</sub> (47.6 to 73.0)	70 (480)	60 (415)	10	210 to 250
		over <sup>27</sup> ϕ <sub>8</sub> to <sup>31</sup> ϕ <sub>2</sub> (73.0 to 88.9)	65 (450)	55 (380)	10	205 to 240
363, 364	SR	<sup>3</sup> ϕ <sub>16</sub> to <sup>7</sup> ϕ <sub>8</sub> (4.76 to 22.2), incl	115 (790)	100 (690)	18	260 to 320
		over <sup>7</sup> ϕ <sub>8</sub> to <sup>1</sup> ϕ <sub>8</sub> (22.2 to 28.6)	110 (760)	95 (655)	15	250 to 310
		over <sup>1</sup> ϕ <sub>8</sub> to <sup>17</sup> ϕ <sub>8</sub> (28.6 to 47.6)	100 (690)	85 (585)	10	245 to 300
		over <sup>17</sup> ϕ <sub>8</sub> to <sup>27</sup> ϕ <sub>8</sub> (47.6 to 73.0)	90 (620)	80 (550)	10	240 to 290
		over <sup>27</sup> ϕ <sub>8</sub> to <sup>31</sup> ϕ <sub>2</sub> (73.0 to 88.9)	85 (585)	75 (515)	5	235 to 285
366	SR	<sup>3</sup> ϕ <sub>16</sub> to <sup>7</sup> ϕ <sub>8</sub> (4.76 to 22.2), incl	95 (655)	80 (550)	5	240 to 300
		over <sup>7</sup> ϕ <sub>8</sub> to <sup>1</sup> ϕ <sub>8</sub> (22.2 to 28.6)	90 (620)	75 (515)	4	235 to 300
		over <sup>1</sup> ϕ <sub>8</sub> to <sup>17</sup> ϕ <sub>8</sub> (28.6 to 47.6)	85 (585)	70 (480)	3	230 to 290
		over <sup>17</sup> ϕ <sub>8</sub> to <sup>27</sup> ϕ <sub>8</sub> (47.6 to 73.0)	80 (550)	65 (450)	3	230 to 290
		over <sup>27</sup> ϕ <sub>8</sub> to <sup>31</sup> ϕ <sub>2</sub> (73.0 to 88.9)	75 (515)	60 (415)	2	225 to 290
360	RX	Under 2 (50.8)	60 (415)	35 (240)	20	200 max
		2 to <sup>31</sup> ϕ <sub>2</sub> (50.8 to 88.9)	55 (380)	25 (170)	20	200 max
363, 364	RX	Under 2 (50.8)	80 (550)	55 (380)	20	215 max
		2 to <sup>31</sup> ϕ <sub>2</sub> (50.8 to 88.9)	75 (515)	45 (310)	10	215 max

<sup>A</sup>Mechanical properties of all bars, and rods other than round, shall be as agreed upon between the manufacturer and the purchaser.

<sup>B</sup>SR 5 stress-relieved; RX 5 essentially fully recrystallized.

<sup>C</sup>The gage length is 10 in. (254 mm) for rods 0.020 to <sup>1</sup>ϕ<sub>8</sub> in. (0.51 to 3.18 min) in diameter only. All other elongation values are for 1-in. (25-mm) gage lengths.

**TABLE 4 Permissible Variations in Diameter and Limits of Tolerance Out-of-Round for Rolled, Forged, Extruded, Swaged, or Drawn Rounds (Descaled)**

Diameter, in. (mm)	Permissible Variation, in. (mm)		
	Diameter		Out-of-Round
	+	-	
0.020 to <sup>1</sup> ϕ <sub>16</sub> (0.51 to 1.59)	0.001 (0.02)	0.001 (0.02)	0.001 (0.02)
Over <sup>1</sup> ϕ <sub>16</sub> to <sup>9</sup> ϕ <sub>32</sub> (1.59 to 7.14)	0.002 (0.05)	0.002 (0.05)	0.004 (0.10)
Over <sup>9</sup> ϕ <sub>32</sub> to <sup>13</sup> ϕ <sub>32</sub> (7.14 to 10.32)	0.010 (0.25)	0.005 (0.13)	0.008 (0.20)
Over <sup>13</sup> ϕ <sub>32</sub> to <sup>5</sup> ϕ <sub>8</sub> (10.32 to 15.9)	0.010 (0.25)	0.005 (0.13)	0.012 (0.30)
Over <sup>5</sup> ϕ <sub>8</sub> to <sup>7</sup> ϕ <sub>8</sub> (15.9 to 22.2)	0.015 (0.38)	0.005 (0.13)	0.015 (0.38)
Over <sup>7</sup> ϕ <sub>8</sub> to 1 (22.2 to 25.4)	0.020 (0.51)	0.005 (0.13)	0.015 (0.38)
Over 1 to <sup>13</sup> ϕ <sub>8</sub> (25.4 to 34.9)	0.020 (0.51)	0.010 (0.25)	0.018 (0.46)
Over <sup>13</sup> ϕ <sub>8</sub> to <sup>1</sup> ϕ <sub>2</sub> (34.9 to 38.1)	0.020 (0.51)	0.015 (0.38)	0.020 (0.51)
Over <sup>1</sup> ϕ <sub>2</sub> to <sup>5</sup> ϕ <sub>8</sub> (38.1 to 41.3)	0.025 (0.64)	0.015 (0.38)	0.020 (0.51)
Over <sup>5</sup> ϕ <sub>8</sub> to 2 (41.3 to 50.8)	0.030 (0.76)	0.020 (0.51)	0.025 (0.64)
Over 2 to <sup>21</sup> ϕ <sub>2</sub> (50.8 to 63.5)	0.032 (0.81)	0.032 (0.81)	0.025 (0.64)
Over <sup>21</sup> ϕ <sub>2</sub> to <sup>31</sup> ϕ <sub>4</sub> (63.5 to 82.6)	0.032 (0.81)	0.032 (0.81)	0.027 (0.69)
Over <sup>31</sup> ϕ <sub>4</sub> to <sup>31</sup> ϕ <sub>2</sub> (82.6 to 88.9)	0.045 (1.14)	0.045 (1.14)	0.040 (1.02)
Centerless Ground Rounds			
<sup>1</sup> ϕ <sub>16</sub> to <sup>1</sup> ϕ <sub>2</sub> (1.58 to 12.7)	0.002 (0.05)	0.002 (0.05)	...
Over <sup>1</sup> ϕ <sub>2</sub> (12.7)	0.003 (0.08)	0.003 (0.08)	...

otherwise speci®ed, rejected material may be returned to the manufacturer at the manufacturer's expense unless the purchaser receives, within three weeks of notice of rejection, other instructions for disposition.

#### 14. Certi®cation

14.1 If requested, the manufacturer shall supply at least three copies of a report of the chemical analysis of each heat (Types 360, 363, 365, and 366) or powder metallurgy product from the powder lot (Types 361 and 364) represented in the shipment, and reports of the result of tests of each size of each

heat or powder lot to determine properties required in Sections 7.1 and 8.

14.2 The report shall include the purchase order number, heat number, this speci®cation number, and quantity and number of items covered by shipment.

#### 15. Product Marking

15.1 Each bar, rod, bundle, box, coil, or spool shall be legibly and conspicuously marked or tagged with the number of this speci®cation, heat or lot number, manufacturer's identi®cation, type, temper, and nominal size.

**16. Packaging and Package Marking**

16.1 Unless otherwise specified, material purchased under this specification must be packaged by box or other suitable protective containers and should be so marked as to indicate the nature of any special handling required.

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**17. Keywords**

17.1 molybdenum; molybdenum alloy bar; molybdenum alloy rod; molybdenum alloy wire

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