



# Standard Specification for Molybdenum and Molybdenum Alloy Bar, Rod, and Wire<sup>1</sup>

This standard is issued under the fixed designation B387; 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 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 standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

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>

- [E8 Test Methods for Tension Testing of Metallic Materials](#)
- [E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications](#)
- [E2626 Guide for Spectrometric Analysis of Reactive and Refractory Metals](#)

<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 B10.04 on Molybdenum and Tungsten.

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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.

## F289 Specification for Molybdenum Wire and Rod for Electronic Applications

## 3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *bar and rod, n*—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, n*—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 F289 covers diameters up to 0.020 in. (0.51 mm).

## 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 Metallurgical condition (Section 7),
- 4.1.5 Mechanical requirements (Section 8),
- 4.1.6 Thermal stability (Section 9),
- 4.1.7 Tolerances (Section 10 and Section 11 and Table 4),
- 4.1.8 Workmanship and quality level requirements (Section 12),
- 4.1.9 Disposition of rejected material (Section 14),
- 4.1.10 Certification and reports (Section 15),
- 4.1.11 Marking (Section 16), and
- 4.1.12 Packaging (Section 17).

## 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. For Molybdenum 361 and 364 the metal is consolidated by powder metallurgy methods.

**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	±0.005
		0.010	±0.002
O <sup>A</sup>	361	0.0070	+10 % relative
	360, 363, 365, 366	0.0030	+10 % relative
	364	0.030	+10 % relative
N <sup>A</sup>	361, 364, 365	0.0020	+0.0005
	360, 363, 366	0.0010	+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	±0.05
W	366	27.0–33.0	±1.0
Zr	363, 364	0.06–0.12	±0.02

<sup>A</sup> See Table 1, Footnote A. Negative variations in check analysis are permitted.

## 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 Heat Analysis:

6.2.1 Heat analysis is made by the manufacturer of the metal on a representative sample of powder from a single powder blend in the case of material made from pressed and sintered powder billets, or on a representative sample of a cast ingot or intermediate product from that ingot in the case of material made from cast ingot.

6.2.2 Heat analysis shall be as specified in Table 1.

6.2.3 The manufacturer shall not ship material that is outside the limits specified in Table 1 for the applicable type, with the exception of oxygen and nitrogen, whose percentage may vary with the method of fabrication.

### 6.3 Check Analysis:

6.3.1 Check analysis is made by the purchaser or the manufacturer of the metal after it has been processed into finished mill forms, and is either to verify the heat analysis of a heat or lot, or to determine variations in composition within a heat or lot.

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

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

## 7. Metallurgical Condition

7.1 Products shall be furnished in the wrought and stress relieved condition unless otherwise stated on the purchase order.

## 8. Mechanical Properties

8.1 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).

## 9. Thermal Stability

9.1 If specified on the purchase order, 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

## 10. Significance of Numerical Limits

10.1 For the purpose of determining compliance with the specified property requirements listed in Tables 1–4, an observed calculated value shall be rounded as indicated in the following table, in accordance with the rounding methods of Practice E29.

Property	Rounded Unit for Observed or Calculated Values
Chemical composition and tolerances (when expressed in decimals)	Nearest unit in the last right-hand place of figures of the specified limit
Tensile strength and yield strength	Nearest 1000 psi (MPa)
Elongation	Nearest 1 %

## 11. Permissible Variations in Dimensions

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

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

<sup>C</sup> The gage length is 10 in. (254 mm) for rods 0.020 to 1/8 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 1/16 (0.51 to 1.59)	0.001 (0.02)	0.001 (0.02)	0.001 (0.02)
Over 1/16 to 9/32 (1.59 to 7.14)	0.002 (0.05)	0.002 (0.05)	0.004 (0.10)
Over 9/32 to 13/32 (7.14 to 10.32)	0.010 (0.25)	0.005 (0.13)	0.008 (0.20)
Over 13/32 to 5/8 (10.32 to 15.9)	0.010 (0.25)	0.005 (0.13)	0.012 (0.30)
Over 5/8 to 7/8 (15.9 to 22.2)	0.015 (0.38)	0.005 (0.13)	0.015 (0.38)
Over 7/8 to 1 (22.2 to 25.4)	0.020 (0.51)	0.005 (0.13)	0.015 (0.38)
Over 1 to 1 3/8 (25.4 to 34.9)	0.020 (0.51)	0.010 (0.25)	0.018 (0.46)
Over 1 3/8 to 1 1/2 (34.9 to 38.1)	0.020 (0.51)	0.015 (0.38)	0.020 (0.51)
Over 1 1/2 to 1 7/8 (38.1 to 41.3)	0.025 (0.64)	0.015 (0.38)	0.020 (0.51)
Over 1 7/8 to 2 (41.3 to 50.8)	0.030 (0.76)	0.020 (0.51)	0.025 (0.64)
Over 2 to 2 1/2 (50.8 to 63.5)	0.032 (0.81)	0.032 (0.81)	0.025 (0.64)
Over 2 1/2 to 3 1/4 (63.5 to 82.6)	0.032 (0.81)	0.032 (0.81)	0.027 (0.69)
Over 3 1/4 to 3 1/2 (82.6 to 88.9)	0.045 (1.14)	0.045 (1.14)	0.040 (1.02)
<b>Centerless Ground Rounds</b>			
1/16 to 1/2 (1.58 to 12.7)	0.002 (0.05)	0.002 (0.05)	...
Over 1/2 (12.7)	0.003 (0.08)	0.003 (0.08)	...

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

11.2.1 Cut lengths,  $\pm 1/4$  in. (6.35 mm).

11.2.2 Straightness, maximum deviation of 0.050 in./ft (4.17 mm/m) in any length.

11.3 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.

## 12. Workmanship, Finish, and Appearance

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

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

12.3 Material may be finished as forged, rolled, swaged, or drawn (black), as cleaned, as machined, or as ground. The finish to be supplied for any product shall be agreed upon between the manufacturer and the purchaser.

12.4 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.

### 13. Sampling and Test Methods

#### 13.1 *Sampling:*

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

13.1.2 Samples for mechanical testing shall be taken from the finished material after all metallurgical processing is completed. Samples may be taken prior to final inspection, and shall be representative of the finished product.

#### 13.2 *Chemical Analysis:*

13.2.1 Analysis may be made using the manufacturer's standard methods. If there is any question relating to the sampling technique or the analysis of the sample, the methods of sampling and analysis shall be as agreed upon between the purchaser and the manufacturer.

13.2.2 Guide [E2626](#) can provide guidance regarding appropriate analytical techniques.

#### 13.3 *Mechanical Testing:*

13.3.1 Tension test specimens shall be prepared and tested in accordance with Test Methods [E8](#). Tensile properties shall be determined using a strain rate of 0.002 to 0.005 in./in.·min (or mm/mm·min) for sufficient strain to accurately determine a 0.2 % offset yield strength value, and 0.02 to 0.05 in./in.·min (or mm/mm·min) to fracture.

### 14. Rejection and Referee

14.1 Material not conforming to this specification or to authorized modifications may be rejected. Rejection for failure of the material to meet the requirements of this specification shall be reported to the manufacturer within 30 calendar days from the receipt of the material by the purchaser.

14.2 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.

14.3 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.

### 15. Certification

15.1 The manufacturer shall supply at least one copy of the report certifying that the material supplied has been manufactured, inspected, sampled, and tested in accordance with the requirements of this specification and that the results of chemical analysis, mechanical, and other tests meet the requirements of this specification for the appropriate grade specified. The report shall include results of all chemical analysis and mechanical and other tests required by the specification

15.2 The report shall include the purchase order number, heat or powder lot number, this specification number, material type and temper, and quantity and number of items covered by shipment.

### 16. Product Marking

16.1 Each bar, rod, bundle, box, coil, or spool shall be legibly and conspicuously marked or tagged with the number of this specification, heat or lot number, manufacturer's identification, type, temper, and nominal size. The characters shall be not less than  $\frac{3}{8}$  in. (9.52 mm) in height.

16.2 All markings must withstand ordinary handling, and shall be capable of removal with standard cleaning solvents. The marking shall have no deleterious effect on the material or its performance.

### 17. Packaging and Package Marking

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

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

17.3 The package shall be marked to indicate the nature of any special handling required.

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

17.4.1 Purchase order or contract number,

17.4.2 Name of material,

17.4.3 Grade,

17.4.4 Size,

17.4.5 Lot, heat, or ingot number,

17.4.6 Temper,

17.4.7 Gross, net and tare weights, and

17.4.8 This ASTM specification number.

### 18. Keywords

18.1 molybdenum; molybdenum alloy bar; molybdenum alloy rod; molybdenum alloy wire ; molybdenum bar; molybdenum rod; molybdenum wire

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