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Standard Specification for Molybdenum and Molybdenum Alloy Bar, Rod, and Wire[1]

This standard is issued under the fixed designation B387/B387M; 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 (ε) indicates an editorial change since the last revision or reapproval.

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 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].

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.4 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.*

1.5 *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:*[2]

E8 Test Methods for Tension Testing of Metallic Materials [Metric] E0008_E0008M

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

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, 6.5 in. [165 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.

3.2 *Lot Definition:*

3.2.1 *for chemical composition, n*—the product of a single blend of powder or a single vacuum melted ingot.

3.2.2 *for mechanical property measurement, n*—the product manufactured from ingots sintered from either a single powder lot in a single sintering run in the same furnace or a single ingot, processed through the same processing equipment in a single uninterrupted run, using the same thermomechanical process to reach the same final size.

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),

[1] 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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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard

TABLE 1 Chemical Requirements

Element	Composition, %					
	Material Number					
	360	361	363	364	365	366
C	0.030 max	0.010 max	0.010–0.040	0.010–0.040	0.010 max	0.030 max
O, max	0.0020	0.0070	0.0030	0.050	0.0020	0.0025
N, max	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Fe, max	0.010	0.010	0.010	0.010	0.010	0.010
Ni, max	0.0020	0.005	0.0020	0.005	0.0020	0.002
Si, max	0.010	0.010	0.010	0.010	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

TABLE 2 Permissible Variations in Check Analysis

	Material No.	Check Analysis Limits, max or range, %	Permissible Variations in Check Analysis, %
C	361, 365	0.010	+0.002
	360, 366	0.030	+0.005
	363,364	0.010–0.040	±0.005
O	360, 365	0.0020	+10 % relative
	366	0.0025	+10 % relative
	363	0.0030	+10 % relative
	361	0.0070	+10 % relative
	364	0.050	+10 % relative
N	360, 361, 363, 364, 365, 366	0.0020	+0.0005
Fe	360, 361, 363, 364, 365, 366	0.010	+0.001
Ni	360, 363, 365, 366	0.002	+10 % relative
	361, 364	0.005	+10 % relative
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

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.

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 °F and 85 °F [18.3 °C 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 temperatures noted in Table 5 for a period of 30 min;

9.1.1 Acceptable atmospheres and purity requirements are:

9.1.1.1 Hydrogen (maximum dew point 0 °C).

TABLE 3 Mechanical Requirements for Round Bars and Rods[A]

Type	Temper[B]	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[D] (DPH), -10 kg, Vickers-10 kg
360, 361, 365	SR	0.020 to 0.125 [0.51 to 3.18], incl	85 [585]	65 [450]	15[C]	...
		over 0.125 to 0.406 [3.18 to 10.32]	75 [515]	55 [380]	15	...
		over 0.406 to 0.875 [10.32 to 22.2]	90 [620]	75 [515]	18	210 to 280
		over 0.875 to 1.125 [22.2 to 28.6]	85 [585]	70 [480]	15	210 to 270
		over 1.125 to 1.875 [28.6 to 47.6]	75 [515]	65 [450]	10	210 to 260
		over 1.875 to 2.875 [47.6 to 73.0]	70 [480]	60 [415]	10	210 to 250
		over 2.875 to 3.500 [73.0 to 88.9]	65 [450]	55 [380]	10	205 to 240
		over 3.500 to 6.50 [88.9 to 165]	65 [450]	55 [380]	5	180 to 240
363, 364	SR	0.188 to 0.875 [4.76 to 22.2], incl	115 [790]	100 [690]	18	260 to 320
		over 0.875 to 1.125 [22.2 to 28.6]	110 [760]	95 [655]	15	250 to 310
		over 1.125 to 1.875 [28.6 to 47.6]	100 [690]	85 [585]	10	245 to 300
		over 1.875 to 2.875 [47.6 to 73.0]	90 [620]	80 [550]	10	240 to 290
		over 2.875 to 3.500 [73.0 to 88.9]	85 [585]	75 [515]	5	235 to 285
		over 3.500 to 6.50 [88.9 to 165]	85 [585]	75 [515]	5	220 to 285
366	SR	0.188 to 0.875 [4.76 to 22.2], incl	95 [655]	80 [550]	2	240 to 300
		over 0.875 to 1.125 [22.2 to 28.6]	90 [620]	75 [515]	2	235 to 300
		over 1.125 to 1.875 [28.6 to 47.6]	85 [585]	70 [480]	2	230 to 290
		over 1.875 to 2.875 [47.6 to 73.0]	80 [550]	65 [450]	2	230 to 290
		over 2.875 to 3.500 [73.0 to 88.9]	75 [515]	60 [415]	2	225 to 290
		over 3.500 to 6.50 [88.9 to 165]	75 [515]	60 [415]	2	225 to 290
360	RX	Under 2 [50.8]	60 [415]	35 [240]	20	200 max
		2 to 6.50 [50.8 to 165]	55 [380]	25 [170]	20	200 max
363, 364	RX	Under 2 [50.8]	80 [550]	55 [380]	20	215 max
		2 to 6.50 [50.8 to 165]	75 [515]	45 [310]	10	215 max

[A] Mechanical properties of all bars, and rods other than round, shall be as agreed upon between the manufacturer and the purchaser.
[B] SR = stress-relieved; RX = essentially fully recrystallized.
[C] The gauge length is 10 in. [254 mm] for rods 0.020 in. to 0.125 in. [0.51 min to 3.18 min] in diameter only. All other elongation values are for 1-in. [25-mm] gauge lengths.
[D] In the case where the test sample thickness cannot support 10-kg load without causing "anvil effects," a lighter load may be used, but must be reported with the hardness results.

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

Diameter, in. (mm)	Permissible Variation, in. [mm]		
	Diameter		Out-of-Round
	+	−	
Descaled Rounds			
0.020 to 0.063 [0.51 to 1.59]	0.001 [0.03]	0.001 [0.03]	0.001 [0.03]
Over 0.063 to 0.125 [1.59 to 3.18]	0.002 [0.05]	0.002 [0.05]	0.002 [0.05]
Over 0.125 to 0.281 [3.18 to 7.14]	0.004 [0.10]	0.004 [0.10]	0.004 [0.10]
Over 0.281 to 0.625 [7.14 to 15.9]	0.008 [0.20]	0.008 [0.20]	0.010 [0.25]
Over 0.625 to 1.375 [15.9 to 34.9]	0.012 [0.30]	0.012 [0.30]	0.017 [0.43]
Over 1.375 to 2 [34.9 to 50.8]	0.018 [0.46]	0.018 [0.46]	0.023 [0.58]
Over 2 to 3.313 [508. to 84.1]	0.032 [0.81]	0.032 [0.81]	0.026 [0.66]
Over 3.313 to 4.750 [84.1 to 120.7]	0.040 [1.02]	0.040 [1.02]	0.028 [0.71]
Over 4.750 [120.7]	0.059 [1.50]	0.059 [1.50]	0.030 [0.76]
Machined or Centerless Ground Rounds			
0.016 to 0.750 [0.40 to 19.1]	0.003 [0.08]	0.003 [0.08]	—
>0.750 [>19.1]	0.010 [0.25]	0.010 [0.25]	—

9.1.1.2 Argon (maximum O content 5 ppm).
9.1.1.3 Helium (maximum O content 5 ppm).
9.1.1.4 Vacuum (maximum pressure 0.0133 Pa).
9.1.2 Nitrogen is not an acceptable atmosphere for annealing molybdenum or molybdenum alloys.