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Standard Specification for Molybdenum and Molybdenum Alloy Plate, Sheet, Strip, and Foil[1]

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1. Scope

1.1 This specification covers unalloyed molybdenum and molybdenum alloy plate, sheet, strip, and foil 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.

2. Referenced Documents

2.1 *ASTM Standards:*

E 8 Test Methods for Tension Testing of Metallic Materials[2]

E 345 Test Methods for Tension Testing of Metallic Foil[2]

3. Descriptions of Terms Specific to This Standard

3.1 *Plate*—Any product 3⁄16 in. or more in thickness.

3.2 *Sheet*—Any product 0.187 in. (4.75 mm) or less in thickness, to a minimum of 0.005 in. (0.13 mm) in thickness.

3.3 *Strip*—Any product 0.187 in. (4.75 mm) or less in thickness and less than 5 in. (127 mm) in width.

3.4 *Foil*—Any product less than 0.005 in. (0.13 mm) in thickness.

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 1),

4.1.2 Product form (Section 3),

4.1.3 Chemical requirements (Table 2 and Table 3),

4.1.4 Mechanical requirements (Section 7 and Table 1),

4.1.5 Softening temperature (Section 8),

4.1.6 Tolerances (Section 9, Table 4 and Fig. 1),

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 formed with the conventional extrusion, forging, or rolling 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 Molybdenum Alloy 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 2.

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 2 for the applicable type, 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 3.

7. Mechanical Properties

7.1 Material supplied under this specification shall conform

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[2] *Annual Book of ASTM Standards*, Vol 03.01.

TABLE 1 Mechanical Requirements

Type	Temper Condition[A]	Thickness, in. (mm)	Tensile[B] Strength, min, ksi (MPa)	Yield Strength 0.2 % Offset, min, ksi (MPa)	Elongation in 2 in. or 50 mm, min, %	Minimum Bend Radius
360, 361	SR	to 0.001 (0.025)	115 (795)	95 (655)	1	...
365		over 0.001 to 0.002 (0.025 to 0.05)	115 (795)	95 (655)	2	...
		over 0.002 to 0.003 (0.05 to 0.075)	115 (795)	95 (655)	3	...
		over 0.003 to 0.004 (0.075 to 0.1)	115 (795)	95 (655)	4	...
		0.005 to 0.010 (0.13 to 0.25)	110 (760)	90 (620)	5	2*t*[C]
		over 0.010 to 0.020 (0.25 to 0.5)	110 (760)	90 (620)	6	2*t*
		over 0.020 to 0.060 (0.5 to 1.5)	105 (725)	85 (585)	10	2*t*
		over 0.060 to 0.100 (1.5 to 2.5)	100 (690)	80 (550)	14	2*t*
		over 0.100 to 0.187 (2.5 to 4.75)	100 (690)	80 (550)	18	2*t*
		3⁄16to ½ (4.75 to 12.7)	100 (690)	80 (550)	10	...
		over ½ to 1 (12.7 to 25.4)	95 (655)	80 (550)	2[D]	...
		over 1 to 1½ (25.4 to 38)	95 (655)	80 (550)	1[D]	...
363, 364	SR	0.010 to 0.025 (0.25 to 0.635)	120 (830)	100 (690)	6	2*t*
		over 0.025 to 0.060 (0.635 to 1.5)	120 (830)	100 (690)	7	2*t*
		over 0.060 to 0.090 (1.5 to 2.3)	120 (830)	100 (690)	9	...
		over 0.090 to 0.187 (2.3 to 4.75)	120 (830)	100 (690)	10	...
		3⁄16 to ½ (4.75 to 12.7)	120 (830)	100 (690)	10	...
		over ½ to 1 (12.7 to 25.4)	110 (760)	95 (655)	10	...
		over 1 to 1½ (25.4 to 38)	100 (690)	85 (585)	8	...
360	RX	3⁄16 to 1½ (4.75 to 38)	55 (380)	25 (170)	20	...
363, 364	RX	3⁄16 to 1½(4.75 to 38)	75 (515)	45 (310)	10	...

[A] *SR* = stress-relieved. *RX* = essentially fully recrystallized.
[B] Both longitudinal and transverse tests between 65 and 85°F (18 and 29°C).
[C] Material thickness = *t*.
[D] Transverse elongation variable due to cross rolling limitations.

TABLE 2 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[A]	0.0015	0.0070	0.0030	0.030	0.0015	0.0025
N, max[A]	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

[A] Pending approved methods of analysis, deviations from these limits alone shall not be cause for rejection.

to the mechanical property requirements given in Table 1, when tested in the transverse direction to final working at test temperatures between 65 and 85°F (18 and 29°C).

7.2 Tension test specimens shall be prepared and tested in accordance with Test Methods E 8 or E 345 for foil. 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 (or mm/mm·min) to fracture.

7.3 For sheet and strip, the bend test specimens shall withstand being bent at a temperature between 65 and 85°F (18 and 29°C) through an angle of 90° or more without fracture. The bend shall be made on a radius equal to that shown in Table 3 for the applicable type. The bend test specimen shall be at least 0.5 in. (12.7 mm) wide and deburred. The speed of the ram shall be 5 to 10 in. (127 to 254 mm)/min.

TABLE 3 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	±0.005 ±0.002
O[A]	361 360, 363, 365, 366 364	0.0070 0.0030 0.030	+10 % relative +10 % relative +10 % relative
N[A]	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	±0.05
W	366	27.0–33.0	±1.0
Zr	363, 364	0.06–0.12	±0.02

[A] See Table 2, Footnote[A]