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Standard Specification for Molybdenum and Molybdenum Alloy Plate, Sheet, Strip, Foil, and FoilRibbon¹

This standard is issued under the fixed designation ~~B386~~B386/B386M; 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 plate, sheet, strip, foil, and foilRibbon 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.

1.1.7 *Drawing Grade*—A drawing grade is defined, which may be specified as a separate requirement by the purchaser.

1.2 ~~The Units~~—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values given stated in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard—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.

1.2.1 The ball punch deformation test called for in 8.4 is a test that is specified in the inch-pound system, and original test results used to produce Fig. 2 were all obtained using inch-pound measurements. For this reason, the graph of minimum required cup height as a function of sheet thickness has been retained in its original inch-pound system. The graphical data has been scanned and a straight line fitted to the scan data. The equation of this line is included in both inch-pound and SI units.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 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](#)

[E92 Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials](#)

[E345 Test Methods of Tension Testing of Metallic Foil](#)

[E384 Test Method for Microindentation Hardness of Materials](#)

[E643 Test Method for Ball Punch Deformation of Metallic Sheet Material](#)

[E1941 Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis](#)

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.

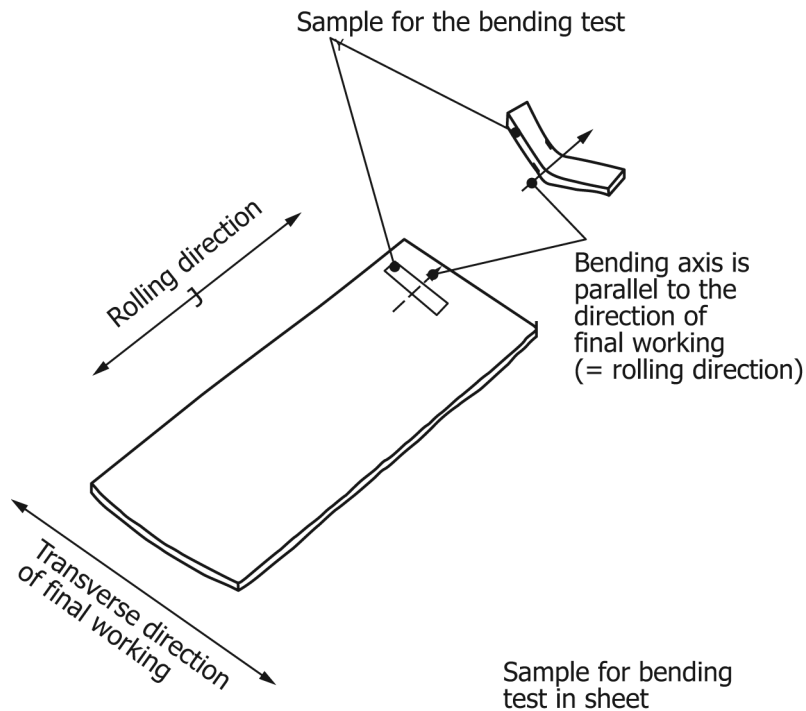


FIG. 1 Sample for Bending Test

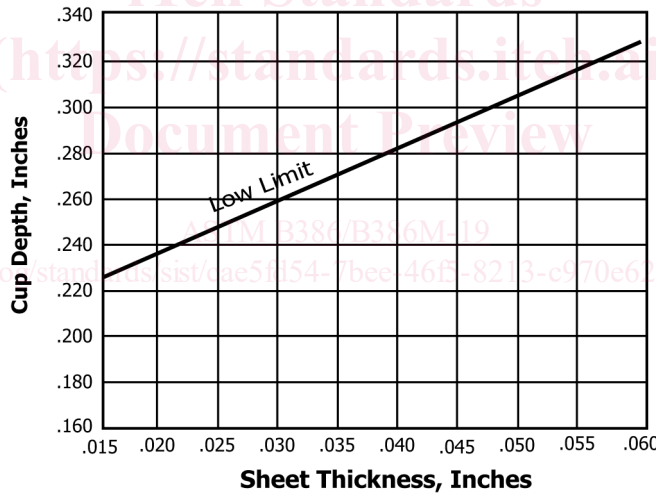


FIG. 2 Ball Punch Deformation Requirements for Drawing Grade Sheet

3. Terminology

3.1 *Definitions of Terms Specific to This Standard: Standard* (Note that definitions reflect varying nomenclature from producer to producer, and are not necessarily exclusive, for example, sheet/ribbon/strip; foil/ribbon/strip):

3.1.1 *drawing grade, n*—sheet having thickness from 0.015 in. [0.38 mm] to 0.060 in. [1.52 mm], intended for applications which require drawability.

3.1.2 *foil, n*—product less than 0.005 in. [0.13 mm] in thickness; foil is typically rolled dominantly in one direction.

3.1.3 *lot, n*—for chemical composition, the ingots obtained from a single blend of powder, sintered together under the same conditions, or the ingots obtained from a single vacuum-melted ingot.

3.1.4 *lot, n*—for mechanical property measurement, 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.

3.1.5 *plate, n*—any product $\frac{3}{4}$ 0.187 in. [4.75 mm] or more in thickness. Depending upon starting ingot thickness and finished plate thickness, Plate may be rolled unidirectionally (in a single direction), or cross-rolled (rolled in different directions).

3.1.6 *recrystallized (RX), adj*—the microstructural condition of product annealed after final rolling to obtain an essentially fully recrystallized microstructure consisting of equiaxed or nearly equiaxed grains.

3.1.7 *ribbon, n*—product less than 0.02 in [0.51 mm] in thickness, coiled and mainly rolled unidirectionally.

3.1.8 *sheet, n*—any product less than 0.187 in. (4.75 mm) or less [4.75 mm] in thickness, to a minimum of 0.005 in. (0.13 mm) in thickness. Sheet is usually rolled mainly in one direction, and depending upon thickness may be produced as individual flat pieces or in coils.

3.1.2.1 *standard grade, n*—sheet ordered without additional requirements imposed for applications which require drawing to make a product.

3.1.2.2 *drawing grade, n*—sheet having thickness between 0.015 in. (0.38 mm) and 0.060 in. (1.52 mm), intended for applications which require drawing of the sheet to make a product.

3.1.9 *standard grade, n*—sheet ordered without additional requirements imposed for drawability.

3.1.10 *stress relieved (SR), adj*—the microstructural condition of product annealed after final rolling to improve ductility. This condition may contain a small fraction of recrystallized grains.

3.1.11 *strip, n*—any product 0.187 in. (4.75 mm) or less in thickness and less sheet product less than 5 in. (127 mm) in width. Strip may be produced on a mill that rolls to the width specified, or may be cut from wider sheets.

3.1.4 *foil, n*—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 (Sections 1 and Table 13),

4.1.2 Product form and grade (Section 3),

4.1.3 Chemical requirements (Section 6, Table 21, and Table 32),

4.1.4 Mechanical requirements (Section 78, Table 3 and, Table 1 Fig. 1, and Fig. 2),

4.1.5 Softening temperature Thermal stability (Section 89 and Table 4),

4.1.6 Tolerances (Section 910, Table 45 and Fig. 13),

4.1.7 Workmanship and quality level requirements Workmanship, finish, and appearance (Section 1011),

4.1.8 Packaging Sampling (Section 1612),

4.1.9 Marking Rejection and disposition of rejected material (Section 1513),

4.1.10 Certification and reports (Section 14), and

4.1.11 Marking (Section 15), and

4.1.12 Disposition of rejected material Packaging and package marking (Section 1316):

5. Materials and Manufacture

5.1 The various molybdenum mill products covered by this specification shall be formed processed 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 are vacuum arc-melted in furnaces of a type suitable for reactive, refractory metals and for metals. Molybdenum 361 and Molybdenum Alloy 364, the metal is 364 are 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 21.

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

6.3 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.

6.4 The chemical composition enumerated in this specification shall in case of disagreement, be determined in accordance with methods of analysis mutually agreed upon by the manufacturer and the purchaser.

6.5 *Check Analysis:*

6.5.1 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.

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



TABLE 1 Mechanical Requirements Mechanical Requirements, When Tested Between 65 and 85°F [18 and 29°C]

Type	Temper Condition ^d	Thickness, in. (mm)[mm]	Tensile ^a Strength, min, ksi (MPa)[MPa]	Yield ^a Strength 0.2 % Offset, min, ksi (MPa)[MPa]	Elonga- ^a tion in 2" in. or 50[50 mm;mm], min, -%	Minimum Bend Ra- dius
360, 361, 365	SR	to 0.001 (0.025)	115 (795)	-95 (655)	-4	...
		360, 361, 365	SR	to 0.001 [0.025]	115 [790]	95 [660]
				over 0.001 to 0.002 (0.025 to 0.05)	115 (795)	-95 (655)
				over 0.001 to 0.002 [0.025 to 0.051]	115 [790]	95 [660]
				over 0.002 to 0.003 (0.05 to 0.075)	115 (795)	-95 (655)
				over 0.002 to 0.003 [0.051 to 0.076]	115 [790]	95 [660]
				over 0.003 to 0.004 (0.075 to 0.1)	115 (795)	-95 (655)
				over 0.003 to 0.005 [0.076 to 0.127]	115 [790]	95 [660]
				0.005 to 0.010 (0.13 to 0.25)	110 (760)	-90 (620)
				over 0.005 to 0.010 [0.127 to 0.254]	110 [760]	90 [620]
				110 (760)	-90 (620)	6
	over 0.010 to 0.020 (0.25 to 0.5)					
	110 [760]		90 [620]	6	2t	
over 0.010 to 0.020 [0.254 to 0.508]						
over 0.020 to 0.060 (0.5 to 1.5)	105 (725)	-85 (585)	10	2t		
over 0.020 to 0.060 [0.508 to 1.524]	105 [720]	85 [590]	10	2t		
over 0.060 to 0.100 (1.5 to 2.5)	100 (690)	-80 (550)	14	2t		
over 0.060 to 0.100 [1.524 to 2.540]	100 [690]	80 [550]	12	2t		
over 0.100 to 0.187 (2.5 to 4.75)	100 (690)	-80 (550)	18	2t		
over 0.100 to 0.187 [2.540 to 4.750]	100 [690]	80 [550]	15	2t		
3/4 to 1 1/2 (4.75 to 12.7)	100 (690)	-80 (550)	10	...		
over 1/2 to 1 (12.7 to 25.4)	-95 (655)	-80 (550)	-2 ^d	...		
over 1 to 1 1/2 (25.4 to 38)	-95 (655)	-80 (550)	-1 ^d	...		
over 0.187 to 0.500 [4.750 to 12.700]	100 [690]	80 [550]	10	...		
over 0.500 to 1.000 [12.700 to 25.400]	95 [660]	80 [550]	2	...		
over 1.000 to 1.500 [25.4 to 38.100]	95 [660]	80 [550]	1	...		
363, 364	SR	0.010 to 0.025 (0.25 to 0.635)	120 (830)	100 (690)	-6	2t
363, 364	SR	0.010 to 0.025 [0.254 to 0.635]	120 [830]	100 [690]	6	2t
		over 0.025 to 0.060 (0.635 to 1.5)	120 (830)	100 (690)	-7	2t
		over 0.025 to 0.060 [0.635 to 1.524]	120 [830]	100 [690]	7	2t
		over 0.060 to 0.090 (1.5 to 2.3)	120 (830)	100 (690)	-9	...
		over 0.060 to 0.090 [1.524 to 2.286]	120 [830]	100 [690]	9	...
		over 0.090 to 0.187 (2.3 to 4.75)	120 (830)	100 (690)	10	...
		over 0.090 to 0.187 [2.286 to 4.750]	120 [830]	100 [690]	10	...
		3/4 to 1 1/2 (4.75 to 12.7)	120 (830)	100 (690)	10	...
		over 1/2 to 1 (12.7 to 25.4)	110 (760)	-95 (655)	10	...
		over 1 to 1 1/2 (25.4 to 38)	100 (690)	-85 (585)	10	...
		over 0.187 to 0.500 [4.750 to 12.700]	120 [830]	100 [690]	10	...
		over 0.500 to 1.000 [12.700 to 25.400]	110 [760]	95 [660]	10	...
		over 1.000 to 1.500 [25.400 to 38.100]	100 [690]	85 [590]	7	...

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