Designation: B386/B386M – 19

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

This standard is issued under the fixed designation 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 ribbon 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 Units—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.

1.2.1 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

3. Terminology

3.1 *Definitions of Terms Specific to This 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.

[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.

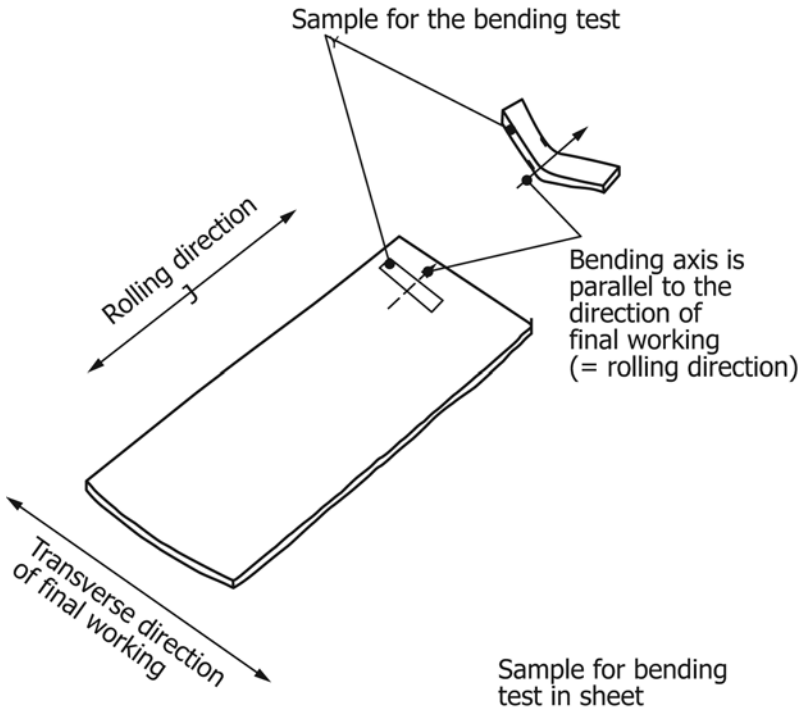

FIG. 1 Sample for Bending Test

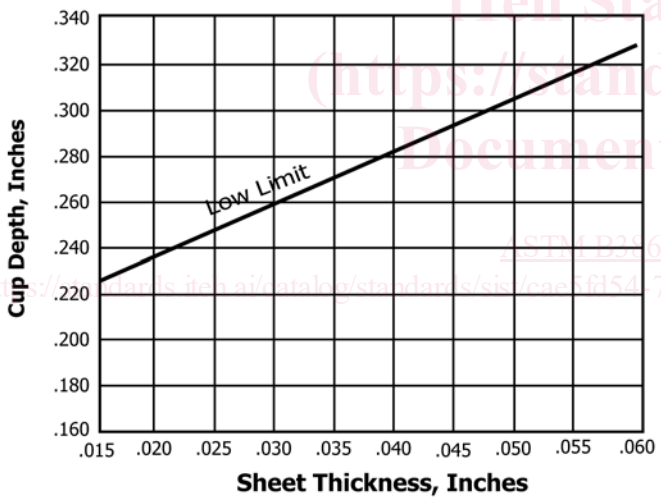

FIG. 2 Ball Punch Deformation Requirements for Drawing Grade Sheet

3.1.2 *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*—product 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*—product less than 0.187 in. [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.

3.1.9 *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*—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.

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 (Sections 1 and 3),

4.1.2 Product form and grade (Section 3),

4.1.3 Chemical requirements (Section 6, Table 1, and Table 2),

4.1.4 Mechanical requirements (Section 8, Table 3, Fig. 1, and Fig. 2),

4.1.5 Thermal stability (Section 9 and Table 4),

4.1.6 Tolerances (Section 10, Table 5 and Fig. 3),

4.1.7 Workmanship, finish, and appearance (Section 11),

4.1.8 Sampling (Section 12),

4.1.9 Rejection and disposition of rejected material (Section 13),

4.1.10 Certification and reports (Section 14),

4.1.11 Marking (Section 15), and

4.1.12 Packaging and package marking (Section 16)

5. Materials and Manufacture

5.1 The various molybdenum mill products covered by this specification shall be 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 are vacuum arc-melted in furnaces of a type suitable for reactive, refractory metals. Molybdenum 361 and Molybdenum Alloy 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 1.

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.

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
	360, 364	0.010–0.040	±0.005
	360, 365	0.0020	+10 % relative
	361	0.0070	+10 % relative
	363	0.0030	+10 % relative
	364	0.050	+10 % relative
	366	0.0025	+10 % relative
N	360, 361, 363, 364, 365, 366	0.0020	+0.0005
Fe	360, 361, 363, 364, 365, 366	0.010	+10 % relative
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

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, 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.

6.5.3 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 direction perpendicular to the final rolling direction (transverse direction) at test temperatures between 65 and 85°F [18 and 29°C]. Product that is too narrow to allow a

TABLE 1 Chemical Requirements

NOTE 1—By agreement between purchaser and supplier, analysis may be required and limits established for elements or compounds not specified in the table of chemical composition.

Element	Composition, wt. %					
	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	0.0020	0.0070	0.0030	0.050	0.0020	0.0025
N, max	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