Standard Specification for Metal Injection Molded (MIM) Materials[1]

This standard is issued under the fixed designation B883; 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 ferrous metal injection molded materials fabricated by mixing elemental or pre-alloyed metal powders with binders, injecting into a mold, debinding, and sintering, with or without subsequent heat treatment.

1.2 This specification covers the following injection molded materials.

1.2.1 *Compositions:*

1.2.1.1 MIM-2200, low-alloy steel

1.2.1.2 MIM-2700, low-alloy steel

1.2.1.3 MIM-4605, low-alloy steel

1.2.1.4 MIM-4140, low-alloy steel

1.2.1.5 MIM-316L, austenitic stainless steel

1.2.1.6 MIM-17-4 PH, precipitation hardening stainless steel

1.2.1.7 MIM-420, ferritic stainless steel

1.2.1.8 MIM-430L, ferritic stainless steel

1.2.1.9 MIM-Cu, copper

1.3 Chemical composition limits are specified in Table 1.

1.4 With the exception of the values for density and the mass used to determine density, for which the use of the gram per cubic centimetre (g/cm^3) and gram (g) units is the long-standing industry practice, the values in inch-pound units are to be regarded as standard. The values given in parentheses or in separate tables are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.5 *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:*[2]

B243 Terminology of Powder Metallurgy

B311 Test Method for Density of Powder Metallurgy (PM) Materials Containing Less Than Two Percent Porosity

B933 Test Method for Microindentation Hardness of Powder Metallurgy (PM) Materials

B962 Test Methods for Density of Compacted or Sintered Powder Metallurgy (PM) Products Using Archimedes' Principle

E8 Test Methods for Tension Testing of Metallic Materials

E18 Test Methods for Rockwell Hardness of Metallic Materials

E228 Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer

E350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron

E415 Test Method for Analysis of Carbon and Low-Alloy Steel by Spark Atomic Emission Spectrometry

E1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Fusion Techniques

E1086 Test Method for Analysis of Austenitic Stainless Steel by Spark Atomic Emission Spectrometry

E1461 Test Method for Thermal Diffusivity by the Flash Method

E1621 Guide for Elemental Analysis by Wavelength Dispersive X-Ray Fluorescence Spectrometry

F1089 Test Method for Corrosion of Surgical Instruments

2.2 *MPIF Standards:*[3]

MPIF Standard 35 Materials Standards for Metal Injection Molded Parts

MPIF Standard 50 Method for Preparing and Evaluating Metal Injection Molded (MIM) Debound and Sintered/Heat Treated Tension Test Specimens

MPIF Standard 51 Method for Determination of Microindentation Hardness of Powder Metallurgy Materials

[1] This specification is under the jurisdiction of ASTM Committee B09 on Metal Powders and Metal Powder Products and is the direct responsibility of B09.11 on Near Full Density Powder Metallurgy Materials.

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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.

[3] Available from Metal Powder Industries Federation (MPIF), 105 College Rd. East, Princeton, NJ 08540-6692, http://www.mpif.org.

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

MPIF Standard 59 Method for Determination of Charpy Impact Energy of Unnotched Metal Injection Molded (MIM) Test Specimens
MPIF Standard 62 Method for Determination of the Corrosion Resistance of MIM Grades of Stainless Steel Immersed in 2 % Sulfuric Acid Solution
MPIF Standard 63 Method for Density Determination of Metal Injection Molded (MIM) Components (Gas Pycnometer)

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions of powder metallurgy terms can be found in Terminology B243. Additional descriptive information is available in the Related Material Section of Vol. 02.05 of the Annual Book of ASTM Standards.

4. Ordering Information

4.1 Orders for parts conforming to this specification may include the following:

4.1.1 ASTM designation,

4.1.2 Alloy composition including carbon content (see Table 1),

4.1.3 Heat treatment condition and hardness (see Tables 2-5),

4.1.4 Functional or mechanical property testing (see 7.3 – 7.7 and Tables 2-5),

4.1.5 Corrosion resistance testing (see 8.1 – 8.1.4 and Table 6),

4.1.6 Thermal conductivity testing (see 9.1–9.2 and Table 7 and Table 8),

4.1.7 Thermal expansion testing (see 10.1–10.2 and Table 9 and Table 10),

4.1.8 Purchaser or purchaser's representative desire to witness the inspection and testing of material prior to shipment (see 12.2),

4.1.9 Requirement for certification of material and a report of test results (see 14.1),

4.1.10 Requirement for full or partial chemical analysis (see Section 6), and

4.1.11 Other special requirements as mutually agreed.

5. Materials and Manufacture

5.1 Parts shall be made by injection molding mixtures of metal powder with binders, debinding, and sintering, with or without subsequent heat treatment. The material shall conform to the designations in 1.2.1 and meet the chemical composition specified in Table 1.

6. Chemical Composition

6.1 Metal injection molded material shall conform to the chemical requirements prescribed in Table 1.

6.2 Chemical analysis for the elements copper, chromium, molybdenum, and nickel shall be determined in accordance with Test Methods E415 (preferred method), E350, E1086, E1621, Inductively Coupled Plasma–Atomic Emission Spectrometry (ICP-AES), Atomic Absorption (AA), or any such method as shall be agreed upon between buyer and seller. Analysis of the element carbon shall be determined in accordance with Test Methods E1019, via optical emission spectroscopy, or other method agreed upon between the purchaser and seller.

7. Mechanical and Physical Property Requirements

7.1 The preferred method of verifying the acceptable performance of a finished part is a qualification test to be performed on an actual part. The specific test should be determined following consideration of the function of the part, and should be agreed upon between manufacturer and purchaser.

7.2 Mandatory and typical mechanical properties of materials covered by this specification are shown in Tables 2-10.

7.3 *Tensile Properties:*

7.3.1 The tensile properties of MIM materials shall be measured using test specimens prepared and evaluated in accordance with MPIF Standard 50.

7.3.2 *Tensile Test Method*—When requested in the purchase order, tensile specimens shall be prepared and processed along with production parts. Tensile specimens shall be tested in accordance with Test Methods E8. Yield strength shall be determined by the 0.2% offset method. MPIF Standard 50 governs the manufacture of the test bars, while Test Methods E8 governs the testing procedure.

7.4 *Impact Energy Properties:*

7.4.1 Typical impact energy properties of materials covered by this specification are shown in Tables 2-5.

7.4.2 The impact energy properties of MIM materials shall be measured using test specimens prepared and evaluated in accordance with MPIF Standard 59.

7.4.3 *Impact Energy Test Method*—When requested in the purchase order, impact energy specimens shall be prepared and processed along with production parts.

7.5 *Density:*

7.5.1 The density of MIM materials shall be measured in accordance with Test Method B311 or MPIF Standard 63. If a test specimen gains mass when immersed in water, it shall be tested in accordance with Test Method B962.

7.6 *Apparent Hardness*—The apparent hardness of MIM materials shall be measured in accordance with Test Methods E18.

7.7 *Microindentation Hardness*—The microindentation hardness of MIM materials shall be measured in accordance with Test Method B933 or MPIF Standard 51.

8. Corrosion Resistance Requirements

8.1 *Corrosion Resistance:*

8.1.1 The preferred method of verifying the acceptable performance of a finished part is a qualification test to be performed on an actual part. The specific test should be determined following consideration of the function of the part, and should be agreed upon between manufacturer and purchaser.

8.1.2 Typical corrosion resistance of materials covered by this specification is shown in Table 6.

8.1.3 The corrosion resistance of MIM materials shall be measured using test specimens prepared in accordance with MPIF Standard 59.

8.1.4 *Corrosion Resistance Test Method*—When requested in the purchase order, corrosion resistance specimens shall be prepared and processed along with production parts. MPIF Standard 59 governs the manufacture of specimens, but Test Method F1089 governs corrosion resistance testing for copper sulfate and boiling water. MPIF Standard 62 governs corrosion resistance testing for sulfuric acid.

9. Thermal Conductivity Requirements

9.1 Mandatory and typical thermal conductivity values for MIM-Cu are shown in Table 7 and Table 8.

9.2 The thermal conductivity of MIM materials shall be measured in accordance with Test Method E1461.

10. Thermal Expansion Coefficient

10.1 The typical coefficients of thermal expansion for MIM-Cu material are shown in Table 9 and Table 10.

10.2 The coefficient of thermal expansion for MIM-Cu was determined in accordance with Test Method E228. A push-rod dilatometer was used for the tests, using a 1.8 °F/min (1 °C/min) heating rate in air atmosphere. The average coefficient of thermal expansion was determined at room temperature [68 °F (20 °C)] up to a series of temperatures.

11. Sampling

11.1 *Testing*—The manufacturer and purchaser shall mutually agree upon the number of specimens to represent the lot for qualification, chemical, mechanical, or corrosion resistance property testing.

12. Inspection

12.1 Inspection of the parts supplied under this specification shall be the responsibility of the manufacturer or a mutually agreed upon third party.

12.2 If the purchaser desires that a representative witness the inspection and testing of the material prior to shipment, such a requirement shall be part of the purchase order.

13. Rejection

13.1 Parts that fail to conform to the requirements of this specification may be rejected. Rejection should be reported to the manufacturer or supplier promptly and in writing.

14. Certification

14.1 When specified in the purchase order, a manufacturer's certification shall be furnished to the purchaser that the parts were manufactured, samples tested, and inspected in accordance with this specification and found to meet its requirements. When specified in the purchase order, a report of the test results shall be furnished.

15. Keywords

15.1 coefficient of thermal expansion; corrosion resistance; low-alloy steels; mechanical properties; metal injection molded parts; metal injection molded steels; metal injection molding (MIM); metal powders; MIM; PIM; powder injection molding; sintered steels; stainless steels; thermal conductivity; unnotched Charpy impact energy

TABLE 1 Chemical Composition Requirements For Metal Injection Molded Materials (weight %)

Material Designation		Fe	Ni	Cr	Co	Mo	C	Cu	Si	Mn	Nb + Ta	V	Other
MIM-2200	Min.	Bal.	1.5	-	-	-	-	-	-	-	-	-	-
	Max.	Bal.	2.5	-	-	0.5	0.1	-	1.0	-	-	-	1.0
MIM-2700	Min.	Bal.	6.5	-	-	-	-	-	-	-	-	-	-
	Max.	Bal.	8.5	-	-	0.5	0.1	-	1.0	-	-	-	1.0
MIM-4605	Min.	Bal.	1.5	-	-	0.2	0.4	-	-	-	-	-	-
	Max.	Bal.	2.5	-	-	0.5	0.6	-	1.0	-	-	-	1.0
MIM-4140	Min.	Bal.	-	0.8	-	0.2	0.3	-	-	-	-	-	-
	Max.	Bal.	-	1.2	-	0.3	0.5	-	0.6	1.0	-	-	1.0
MIM-316L	Min.	Bal.	10	16	-	2	-	-	-	-	-	-	-
	Max.	Bal.	14	18	-	3	0.03	-	1.0	2.0	-	-	1.0
MIM-420	Min.	Bal.	-	12	-	-	0.15	-	-	-	-	-	-
	Max.	Bal.	-	14	-	-	0.4	-	1.0	1.0	-	-	1.0
MIM-430L	Min.	Bal.	-	16	-	-	-	-	-	-	-	-	-
	Max.	Bal.	-	18	-	-	0.05	-	1.0	1.0	-	-	1.0
MIM-17-4PH	Min.	Bal.	3	15.5	-	-	-	3	-	-	0.15	-	-
	Max.	Bal.	5	17.5	-	-	0.07	5	1.0	1.0	0.45	-	1.0
MIM-Cu	Min.	-	-	-	-	-	-	99.8	-	-	-	-	-
	Max.	-	-	-	-	-	-	100.0	-	-	-	-	0.2[A]

[A]Excluding silver.

TABLE 2 Mandatory and Typical Mechanical and Physical Properties of Metal Injection Molded Low-Alloy Steels[A]
Inch-Pound Units

Material Designation	Minimum Mandatory Values Tensile Properties			Typical Values Tensile Properties			Elastic Constants		Density	Typical Values Hardness		Unnotched Charpy Impact Energy[B]
	Ultimate Strength	Yield Strength	Elongation in 1 in.	Ultimate Strength	Yield Strength	Elongation in 1 in.	Young's Modulus	Poisson's Ratio		Macro (apparent)	Micro (converted)[C]	ft-lbf
	10^3 psi	10^3 psi	%	10^3 psi	10^3 psi	%	10^6psi		g/cm^3	Rockwell		
MIM-2200 (as-sintered)	37	16	20	42	18	40	28	0.28	7.6	45 HRB	N/D	100
MIM-2700 (as-sintered)	55	30	20	60	37	26	28	0.28	7.6	69 HRB	N/D	130
MIM-4605 (as-sintered)	55	25	11	64	30	15	29	0.28	7.5	62 HRB	N/D	50
MIM-4605[D] (quenched and tempered)	215	190	≤1	240	215	2	29.5	0.28	7.5	48 HRC	55 HRC	40
MIM-4140 (quenched and tempered)	200	155	3	240	180	5	29.5	0.28	7.5	46 HRC	N/D	55

[A] Reprinted by permission from MPIF Standard 35, "Materials Standard for Metal Injection Molded Parts," 2007, Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540-6692.
[B] MPIF Standard 59 specimens are 0.197 × 0.394 × 2.155 in. The results were not normalized to 0.394 × 0.394 × 2.165 in. since this would have resulted in higher impact energy values.
[C] N/D indicates a value was not determined for the purpose of this standard.
[D] These data were measured on test bars tempered for 1 h at 350°F.

TABLE 3 Mandatory and Typical Mechanical and Physical Properties of Metal Injection Molded Low-Alloy Steels[A]
SI Units

Material Designation	Minimum Mandatory Values Tensile Properties			Typical Values Tensile Properties			Elastic Constants		Density	Typical Values Hardness		Unnotched Charpy Impact Energy[B]
	Ultimate Strength	Yield Strength	Elongation in 25.4 mm	Ultimate Strength	Yield Strength	Elongation in 25.4 mm	Young's Modulus	Poisson's Ratio		Macro (apparent)	Micro (converted)[C]	J
	MPa	MPa	%	MPa	MPa	%	GPa		g/cm^3	Rockwell		
MIM-2200 (as-sintered)	255	110	20	290	125	40	190	0.28	7.65	45 HRB	N/D	135
MIM-2700 (as-sintered)	380	205	20	415	255	26	190	0.28	7.6	69 HRB	N/D	175
MIM-4605 (as-sintered)	380	170	11	440	205	15	200	0.28	7.5	62 HRB	N/D	70
MIM-4605[D] (quenched and tempered)	1480	1310	<1	1655	1480	2	205	0.28	7.5	48 HRC	55 HRC	55
MIM-4140 (quenched and tempered)	1380	1070	3	1650	1240	5	205	0.28	7.5	46 HRC	N/D	75

[A] Reprinted by permission from MPIF Standard 35, "Materials Standards for Metal Injection Molded Parts," 2007, Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540–6692. SI values converted from inch-pound units in Table 2.
[B] MPIF Standard 59 specimens are 5 × 10 × 55 mm. The results were not normalized to 10 × 10 × 55 mm since this would have resulted in higher impact energy values.
[C] N/D indicates a value was not determined for the purpose of this standard.
[D] These data were measured on test bars tempered for 1 h at 177°C.

TABLE 4 Mandatory and Typical Mechanical and Physical Properties of Metal Injection Molded Stainless Steels[A]
Inch-Pound Units

Material Designation	Minimum Mandatory Values Tensile Properties			Typical Values Tensile Properties			Elastic Constants		Density	Typical Values Hardness		Unnotched Charpy Impact Energy[B]
	Ultimate Strength	Yield Strength	Elongation in 1 in.	Ultimate Strength	Yield Strength	Elongation in 1 in.	Young's Modulus	Poisson's Ratio		Macro (apparent)	Micro (converted)[C]	ft-lbf
	10^3 psi	10^3 psi	%	10^3 psi	10^3 psi	%	10^{10} psi		g/cm^3	Rockwell		
MIM-316L (as-sintered)	65	20	40	75	25	50	28	0.28	7.6	67 HRB	.N/D	140
MIM-420[D] (heat treated)	180	[E]	[F]	200	174	<1	28	0.30	7.4	44 HRC	50 HRC	30
MIMI-430L (as-sintered)	50	30	20	60	35	25	30	0.29	7.5	65 HRB	N/D	110
MIM-17-4 PH (as-sintered)	115	94	4	130	106	6	28	0.29	7.5	27 HRC	.N/D	100
MIM-17-4 PH[G] (heat treated)	155	140	4	172	158	6	28	0.29	7.5	33 HRC	40 HRC	100

[A] Reprinted by permission from MPIF Standard 35, "Materials Standards for Metal Injection Molded Parts," 2007, Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540-6692.
[B] MPIF Standard 59 specimens are 0.197 × 0.394 × 2.165 in. The results were not normalized to 0.394 × 0.394 × 2.165 in. since this would have resulted in higher impact energy values.
[C] N ⁄D indicates a value was not determined for the purpose of this standard.
[D] Heat treated MIM-420 parts were austenitized and tempered at 400°F (204°C) for a minimum of 1 hour.
[E] Heat Treated MIM-420 may not show any yield point based on a 0.2 % offset.
[F] There may be no measurable elongation for the MIM-420 heat treated material.
[G] These data were measured on test bars aged at 900°F (heat treated to H900).

TABLE 5 Mandatory and Typical Mechanical and Physical Properties of Metal Injection Molded Stainless Steels[A]
SI Units

Material Designation	Minimum Mandatory Values Tensile Properties			Typical Values Tensile Properties			Elastic Constants		Density	Typical Values Hardness		Unnotched Charpy Impact Energy[B]
	Ultimate Strength	Yield Strength	Elongation in 25.4 mm	Ultimate Strength	Yield Strength	Elongation in 25.4 mm	Young's Modulus	Poisson's Ratio		Macro (apparent)	Micro (converted)[C]	J
	MPa	MPa	%	MPa	MPa	%	GPa		g/cm^3	Rockwell		
MIM-316L	450	140	40	520	175	50	190	0.28	7.6	67 HRB	N/D	190
MIM-420[D] (heat treated)	1240	[E]	[F]	1380	1200	<1	190	0.30	7.4	44 HRC	50 HRC	40
MIM-430L	345	205	20	415	240	25	210	0.29	7.5	65 HRB	N/D	[E]
MIM-17-4 PH	795	650	4	900	730	6	190	0.29	7.5	27 HRC	N/D	70
MIM-17-4 PH[G] (heat treated)	1070	965	4	1185	1090	6	190	0.29	7.5	33 HRC	40 HRC	[E]

[A] Reprinted by permission from MPIF Standard 35, "Materials Standards for Metal Injection Molded Parts," 2007 Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540-6692. SI values converted from inch-pound units in Table 4.
[B] MPIF Standard 59 specimens are 5 × 10 × 55 mm. The results were not normalized to 10 × 10 × 55 mm since this would have resulted in higher impact energy values.
[C] N ⁄D indicates a value was not determined for the purpose of this standard.
[D] Heat treated MIM-420 parts were austenitized and tempered at 400°F (204°C) for a minimum of 1 hour.
[E] Heat Treated MIM-420 may not show any yield point based on a 0.2 % offset.
[F] There may be no measurable elongation for the MIM-420 heat treated material.
[G] These data were measured on test bars aged at 482°C (heat treated to H900).

TABLE 6 Typical Corrosion Resistance Properties of Metal Injection Molded Stainless Steels[A]
SI Units

Material Designation	Typical Values H_2SO_4[B] g/dm^2/day	Typical Values $CuSO_4$	Boil Test in H_2O
MIM-316L (as-sintered)	<0.005	Pass	Pass
MIM-430L (as-sintered)	[C]	[C]	[C]
MIM-17-4 PH (as-sintered)	<0.005	Pass	Pass
MIM-17-4 PH[D] (heat treated)	<0.005	Pass	Pass

[A] Reprinted by permission from MPIF Standard 35, "Materials Standards for Metal Injection Molded Parts," 2007 Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540-6692.
[B] MPIF Standard 59 test specimens were tested in 2 % H_2SO_4 for 1000 h at 22°C ± 2°C. These test specimens were tested in accordance with MPIF Standard 62.
[C] Additional data will appear in subsequent editions of this specification.
[D] These data were measured on test bars aged at 482°C (heat treated to H900).

TABLE 7 Mandatory and Typical Thermal Conductivity Properties of Metal Injection Molded Copper[A]
Inch-Pound Units

Material Designation	Minimum Values		Typical Values				
	Density	Thermal Conductivity (at 77°F)	Density	Thermal Conductivity (at 77°F)	UTS	Tensile Properties Yield (0.2%)	Elongation (in 1 in.)
	g/cm³	Btu•ft/(h•ft²•°F)	g/cm³	Btu•ft/(h•ft²•°F)	10³ psi	10³ psi	%
MIM-Cu (as-sintered)	8.50	190	8.75	208	30	10	30

[A]Reprinted by permission from MPIF Standard 35, "Materials Standards for Metal Injection Molded Parts," April 2012 release, Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540–6692.

TABLE 8 Mandatory and Typical Thermal Conductivity Properties of Metal Injection Molded Copper[A]
SI Units

Material Designation	Minimum Values		Typical Values				
	Density	Thermal Conductivity (at 25°C)	Density	Thermal Conductivity (at 25°C)	UTS	Tensile Properties Yield (0.2%)	Elongation (in 1 in.)
	g/cm³	W/(m•K)	g/cm³	W/(m•K)	MPa	MPa	%
MIM-Cu (as-sintered)	8.50	330	8.75	360	207	69	30

[A]Reprinted by permission from MPIF Standard 35, "Materials Standards for Metal Injection Molded Parts," April 2012 release, Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540–6692.

TABLE 9 Typical Coefficient of Thermal Expansion of Metal Injection Molded Copper[A]
Inch-Pound Units

Material Designation	From 68 °F to:	Average CTE (x10⁻⁶/°F)
MIM-Cu (as-sintered)	100 °F	8.7
	150 °F	8.9
	200 °F	9.1
	250 °F	9.3
	300 °F	9.4

[A]Reprinted by permission from MPIF Standard 35, "Materials Standards for Metal Injection Molded Parts," April 2012 release, Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540–6692.

TABLE 10 Typical Coefficient of Thermal Expansion of Metal Injection Molded Copper[A]
SI Units

Material Designation	From 20 °C to:	Average CTE (x10⁻⁶/°C)
MIM-Cu (as-sintered)	38 °C	15.7
	66 °C	16.0
	93 °C	16.4
	121 °C	16.7
	149 °C	16.9

[A]Reprinted by permission from MPIF Standard 35, "Materials Standards for Metal Injection Molded Parts," April 2012 release, Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540–6692.

SUMMARY OF CHANGES

Committee B09 has identified the location of selected changes to this standard since the last issue (B883-10$^{\varepsilon 1}$) that may impact the use of this standard.

(1) Added a statement of units—1.4.
(2) Added a new material—MIM-Cu—to subsection 1.2.1.9
(3) Added a new section on thermal conductivity requirements, Section 9.
(4) Added a new section on coefficient of thermal expansion, Section 10.
(5) Included chemical composition limits for MIM-Cu in Table 1.
(6) Added new tables for thermal conductivity and coefficient of thermal expansion for MIM-Cu, Tables 7-10.