

MPIF STANDARD 35
2016 Edition

Materials Standards for
**Metal
Injection
Molded Parts**

Published by Metal Powder Industries Federation



Documents

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Materials Standards for Metal Injection Molded Parts*

*See MPIF Standard 35,
*Materials Standards for PM
Structural Parts* for structural
parts made by the powder
metallurgy (PM) process.

*See MPIF Standard 35,
*Materials Standards for PM
Self-Lubricating Bearings* for
bearings and bushings made by
the PM process.

*See MPIF Standard 35,
*Materials Standards for P/F
Steel Parts* for steel
components made by the
powder forging (PF) process.

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Materials Standards for Metal Injection Molded Parts

Issued 1993
Revised 2000, 2007 and 2016

Scope

MPIF Standard 35 is issued to provide the design and materials engineer with the information necessary for specifying powder metal (PM) materials that have been developed by the PM parts manufacturing industry. This section of Standard 35 deals with products manufactured by Metal Injection Molding (MIM). It does not apply to conventional PM structural materials, PM self-lubricating bearings or powder forged (PF) materials which are covered in separate editions of MPIF Standard 35. Each section of this standard is divided into subsections based on the various types of MIM materials in common commercial use within that section. Notes at the beginning of each subsection discuss the characteristics of that material. The same materials may appear in more than one section of the standard depending upon their common use, e.g., some low-alloy or stainless steel materials may also be used in soft-magnetic applications.

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Both the purchaser and manufacturer should, in order to avoid possible misconceptions or misunderstandings, agree on the following conditions prior to the manufacture of a MIM component: material selection, chemical composition, minimum property values and any other processes, that may affect the part application.

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105 College Road East
Princeton, New Jersey 08540-6692 U.S.A.
Tel: (609) 452-7700
Fax: (609) 987-8523
E-mail: info@mpif.org
Website: mpif.org



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MPIF Standard 35—2016

Materials Standards for Metal Injection Molded Parts

Explanatory Notes and Definitions

Minimum Value Concept

The Metal Powder Industries Federation has adopted the concept of minimum property values for metal injection molded (MIM) materials. These values may be used to determine the material best suited to the particular application as it is manufactured by the metal injection molding (MIM) process.

As an aid to the user in selecting materials, in addition to minimum property values, typical values for other properties are listed. This makes it possible for the user to select and specify the exact MIM material and properties most suitable for a specific application. The data provided define minimum values for listed materials and display typical properties achieved under commercial manufacturing procedures. Enhanced mechanical properties and other improvements in performance characteristics may be attained through more complex processing. *To select a material optimum in both properties and cost effectiveness, it is essential that the part application be discussed with the MIM parts manufacturer.*

Minimum Mechanical Property Values

The minimum mechanical property values for MIM materials are expressed in terms of yield strength (0.2% offset method), ultimate tensile strength and percent elongation for all materials in the as-sintered and/or heat treated conditions. MIM materials exhibit properties similar to wrought materials because they are processed to near full density.

The tensile properties utilized for establishing this Standard were obtained from tensile specimens prepared specifically for evaluating MIM materials. Tensile properties of test specimens machined from commercial parts or from non-standard MIM test specimens, may vary from those obtained from specimens prepared according to MPIF Standard 50. (See *MPIF Standard 50* for additional details)

Minimum Magnetic Property Values

The minimum magnetic property values for MIM materials are expressed in terms of part density, maximum permeability, maximum coercive force and magnetic saturation. The specified minimum magnetic saturation is measured with an applied field of 25 oersteds. All magnetic test data reported are for DC testing only.

The magnetic properties utilized for establishing this Standard were obtained from specimens prepared and tested in accordance with ASTM A773.

Minimum Controlled-Expansion Property Values

A minimum density level is expressed for the MIM controlled-expansion alloys due to their use in electronics applications to provide hermetic seals with materials such as glasses and ceramics.

Practical Methods of Demonstrating Part Performance

For structural parts, the practical method of demonstrating minimum values is through the use of a static or dynamic proof test by the manufacturer and the purchaser using the first production lot of parts and a mutually agreed upon method of stressing the part. For example, from the design of a given part, it is agreed that the breaking load should be greater than a given force. If that force is exceeded in proof tests, the minimum strength is demonstrated. The first lot of parts can also be tested in service and demonstrated to be acceptable. The static or dynamic load to fracture is determined separately and these data are statistically analyzed to determine a minimum breaking force for future production lots. Exceeding that minimum force on future lots is proof that the specified strength has been met.

For parts that require minimum magnetic characteristics, the practical method of demonstrating acceptable magnetic properties is through the use of a magnetic proof test. For example, from the design of a given part, it is agreed that the magnetic force generated by the part when a specified magnetic field is applied should be greater than a mutually agreed upon value between the parties concerned. If that force is exceeded in proof tests, the minimum magnetic performance is demonstrated. Exceeding this minimum value on future lots is proof that the specific magnetic properties have been met.

Utilization of MPIF Standard 35 to specify a MIM material means that unless the purchaser and manufacturer have agreed otherwise, the material will have the minimum value specified in the Standard. (See Material Properties section.)

Typical Values

For each MIM material listed, a set of typical values is shown for properties, e.g., density, hardness, elongation, etc., some or all of which may be important for a specific application. Typical values are shown for properties, e.g., elongation, hardness, coercive field, etc., some or all of which may be important for a specific application. The property data were compiled from test specimens processed by individual MIM producers.

The typical values are listed for general guidance only. They should not be considered minimum values. While achievable through normal manufacturing processing, they may vary somewhat depending upon the area of the component chosen for evaluation, or the specific manufacturing process utilized. Those properties listed under the “typical value section” for each material which are required by the purchaser should be thoroughly discussed with the MIM parts manufacturer before establishing the specification. Required property values, other than those expressed as minimum should be separately specified for each MIM part, based on its intended use.

Chemical Composition

The chemical composition of each material lists its principal elements and allowable ranges.

Mechanical Properties

Mechanical property data indicate the minimum and typical properties that may be expected from test specimens conforming to the density and chemical composition criteria listed. It should be understood that mechanical properties used in this standard were derived from individual test specimens prepared specifically for material evaluation and sintered under commercial production conditions.

Hardness values of heat treated specimens are given first as apparent hardness and second, when available, as equivalent particle or matrix hardness values. Residual porosity found in MIM components will slightly affect the apparent hardness readings. Microindentation hardness values shown as Rockwell C were converted from 100 g load (0.981 N) Knoop microindentation hardness measurements.

Heat Treatment

MIM materials may be heat treated to increase strength, hardness and wear resistance. The percentages of carbon, alloying elements and residual porosity determine the degree of hardening possible. Tempering or stress relief is required after quenching for optimum strength and durability. Ferrous MIM parts processed with little or no final carbon may be surface carburized for increased surface hardness while retaining core toughness. Martensitic and precipitation hardening stainless steels may also be heat treated for increased hardness and strength.

Most MIM materials respond well to normal wrought heat treating practices and procedures. It is recommended that the heat-treatment procedures for any MIM material be established in cooperation with the MIM part manufacturer to achieve the desired balance of final properties in the finished part.

Surface Finish

The overall finish and surface reflectivity of MIM materials depends on density, tool condition, particle size and secondary operations. Effective surface smoothness of as-sintered MIM components is usually better than an investment cast surface. Surface finish can be further improved by secondary operations such as coining, honing, burnishing or grinding. The surface finish requirements and methods of determination must be established by mutual agreement between purchaser and producer. (See *MPIF Standard 58* for additional details.)

Microstructure

MIM materials generally contain less than 5% porosity, approaching the density of wrought materials. The examination of the microstructure of a MIM part can serve as a diagnostic tool and reveal the degree of sintering and other metallurgical information critical to the metal injection molding process. There are several observations common to most sintered MIM materials, as briefly described below. Comments on specific materials will be found in the subsections devoted to those particular materials.

Sintered parts are normally examined first in the unetched condition. With a proper sinter, there will be no original particle boundaries seen at 200X. Small, uniformly distributed, well rounded discrete pores lead to higher strength, ductility and impact resistance.

MIM Material Designation

The Metal Injection Molding Association has chosen to use the designation system similar to AISI-SAE where applicable. These designations were chosen because MIM parts are likely to be used as replacements for wrought products already in service. When specifying a material made by the MIM process, it should be so designated with a “MIM” prefix to the material grade. For example, a part fabricated from Type 316L stainless steel by MIM would be designated as “MIM-316L”.

Material Selection

Before a particular material can be selected, a careful analysis is required of the design of the part and its end use. In addition, the final property requirements of the finished part should be agreed upon by the manufacturer and the purchaser of the MIM part. Issues such as static and dynamic loading, wear resistance, machinability and corrosion resistance may also be specified.

Grade Selection

For certain magnetic materials, the material designation will specify the material as either “Grade 1” or “Grade 2”. The Grade 1 material, as compared with Grade 2, will exhibit improved magnetic characteristics. The difference between a Grade 1 and Grade 2 material can usually be found in the material’s microstructure, with a high density, large grain size and low amounts of interstitials (carbon, oxygen, nitrogen, etc.) all contributing to improved magnetic properties.

A careful analysis of the design and function of the part should determine what grade material is required for a given application. It is recommended that a discussion of the required magnetic performance take place between the manufacturer and the purchaser before the final grade selection.

Density

Density is expressed in grams per cubic centimeter (g/cm^3) and may be determined by various standardized methods. Some common methods of MIM density determination include:

MPIF Standard 54: This method is generally used for products that contain less than 2% porosity (impermeable PM). It is based on the principle of water displacement.

MPIF Standard 63: This method comprises use of a gas pycnometer. Any open porosity will not be included as part of measured volume. The density obtained by the gas pycnometer method will typically be higher than the density obtained by water displacement.

MPIF Standard 42: This method is generally used for PM products having surface-connected porosity and is based on the use of Archimedes’ principle. MIM materials generally contain less than 5% porosity, so impregnation is not applicable.

Ultimate Tensile Strength

Ultimate tensile strength, expressed in 10^3 psi (MPa) is the ability of a test specimen to resist fracture when a pulling force is applied in a direction parallel to its longitudinal axis. It is equal to the maximum load divided by the original cross-sectional area. (See *MPIF Standard 50* for additional details.)

Yield Strength

Yield Strength, expressed in 10^3 psi, is the load at which a material exhibits a 0.2% offset from proportionality on a stress-strain tension curve divided by the original cross-sectional area. (See *MPIF Standard 50* for additional details.)

Elongation

Elongation (plastic), expressed as a percentage of the original gage length (typically 1.0 in. [25.4mm]), is based on measuring the increase in gage length after fracture, providing the fracture takes place within the gage length.

Elongation can also be measured with a break-away extensometer on the tensile specimen. The recorded stress strain-curve displays total elongation (elastic and plastic). The elastic strain at the 0.2% yield strength must be subtracted from the total elongation to give the plastic elongation. (See *MPIF Standard 59* for additional details.)

Elastic Constants

Data for the elastic constants in this standard were generated from resonant frequency testing. An equation relating the three elastic constants is:

$$\nu = \frac{E}{2G} - 1$$

Young’s Modulus (E)

Young’s modulus, expressed in 10^6 psi (GPa), is the ratio of normal stress to corresponding strain for tensile or compressive stresses below the proportional limit of the material.

Shear Modulus (G)

Shear modulus, expressed in 10^6 psi (GPa), is the ratio of shear stress to corresponding shear strain below the proportional limit of the material.

Poisson’s Ratio (ν)

Poisson’s ratio is the absolute value of the ratio of transverse strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material.

Impact Energy

Impact energy, measured in foot-pounds-force (Joules), is a measure of the energy absorbed in fracturing a specimen in a single blow. An unnotched 5 mm X 10 mm cross-section Charpy specimen was used to establish the MIM impact energy values. (See *MPIF Standard 59* for additional details.)

Macroindentation Hardness (Apparent)

The hardness value of a MIM part when using a conventional indentation hardness tester is referred to as “apparent hardness” because it represents a combination of matrix hardness plus effect of residual porosity. The effect of residual porosity on hardness values is minor for MIM parts. Apparent hardness measures the resistance to indentation.

The manufacturer and the purchaser should agree on the hardness, the measuring procedure, and the hardness scale for each part tested. (See *MPIF Standard 43* for additional details.)

Microindentation Hardness

Microindentation hardness is determined by utilizing Knoop (HK) or Vickers (HV) indentors with a microindentation hardness tester. It measures the true hardness of the structure by eliminating the effect of porosity, and thus is a measure of resistance to abrasive and adhesive wear. Microindentation hardness measurements are convertible to equivalent Rockwell hardness values for comparison with other materials.

A description of the microstructure must be reported. The specimen shall be polished to reveal the porosity and lightly etched to view the phases in the microstructure and to determine where to place the hardness indentation. If the indenter strikes an undisclosed pore, the diamond mark will exhibit curved edges and the reading must be discarded. Since the data tend to be scattered compared with pore-free material, it is recommended that a minimum of 5 indentations be made, anomalous readings discarded, and an average taken of the remainder. (See *MPIF Standard 51* for additional details.)

Corrosion Resistance

Three media and test methods were used to rate the resistance of the MIM stainless steel alloys to corrosion.

Sulfuric Acid Testing - Standard 5 mm X 10 mm X 55 mm test specimens were immersed in a 2% sulfuric acid solution at room temperature ($72^{\circ}\text{F} \pm 4^{\circ}\text{F}$ [$22^{\circ}\text{C} \pm 2^{\circ}\text{C}$]) for 1,000 hours. Two replicates were tested. The loss in mass for each was determined and then converted into a mass loss per surface area (in dm^2) per day factor, in units of

$$\frac{\text{g}}{(\text{dm}^2) (\text{day})}$$

(See *MPIF Standard 62* for additional details.)

Copper Sulfate Testing - The copper sulfate test consists of mixing 22.5 ml of distilled water with 1 g cupric sulfate crystals and 2.5 g sulfuric acid. Specimens are immersed in this solution for 6 minutes at a temperature between 63° and 67°F (17° and 19°C). Specimens that show no visual signs of copper plating are classified as passing this test. (See ASTM F1089 for additional details.)

Boiling Water Testing - The boiling water test consists of immersing the specimen in boiling, distilled water for 30 minutes. After 30 minutes, the heat source is shut off and the specimen remains in the water for 3 hours. The specimen is then removed and left to dry for 2 hours. Specimens that show no visual corrosion are classified as passing this test. (See ASTM F1089 for additional details.)

Soft-Magnetic Properties

The magnetic data presented in this standard were developed in accordance with ASTM Standard A773.

Magnetizing Field (H)

The magnetic field applied to a test specimen, measured in oersteds (Oe) or amperes/metre (A/m).

Induction (B)

The measured magnetic field generated in a test specimen due to an applied magnetic field, measured in kilo- gauss (kG) or tesla (T).

Maximum Induction (B_m)

The maximum value of induction in a DC hysteresis loop. This value depends on the magnetizing field applied. Data are reported at magnetizing fields of 25 Oe and 500 Oe, (1,990 A/m and 39,800 A/m), in units of kilogauss (kG) or tesla (T).

Maximum Permeability (μ_{max})

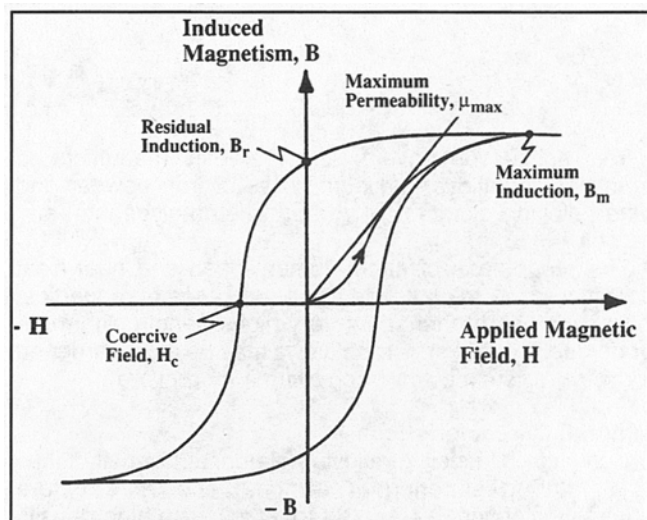
The slope of the line from the origin to the knee of the initial B-H magnetization curve. This parameter is dimensionless.

Coercive Field (H_c)

The DC magnetizing field required to restore the magnetic induction to zero after the material has been symmetrically, cyclically magnetized, measured in Oe (A/m).

Residual Induction (B_r)

The retained magnetism in the specimen after the applied field has been reduced to zero Oe (A/m). This is reported in kG or T.



Idealized Magnetic Hysteresis Curve

Reference: *Soft Magnetism, Fundamentals for Powder Metallurgy and Metal Injection Molding*, Chaman Lal, Metal Powder Industries Federation, 1992, p.11.

Thermal Properties

Coefficient of Thermal Expansion (CTE)

The fractional increase in the length per unit rise in temperature at constant pressure.

Thermal Conductivity

The rate of heat flow, under steady state conditions, through a unit area, per unit temperature gradient in the direction perpendicular to the area. Thermal conductivity was determined in accordance with ASTM E1461, thermal flash method.

SI Units

Data were determined in inch-pound units and converted to SI units in accordance with IEEE/ASTM SI 10.

Referenced MPIF Standards

The test method standards referenced in this document are published by MPIF and are available in the latest edition of *Standard Test Methods for Metal Powders and Powder Metallurgy Products*.

Std. 42	Density of Compacted or Sintered Powder Metallurgy (PM) Products
Std. 43	Apparent Hardness of Powder Metallurgy Products
Std. 50	Preparing and Evaluating Metal Injection Molded (MIM) Sintered/Heat Treated Tension Test Specimens
Std. 51	Microindentation Hardness of Powder Metallurgy Materials
Std. 54	Density of Impermeable Powder Metallurgy (PM) Materials
Std. 58	Surface Finish of Powder Metallurgy (PM) Products
Std. 59	Charpy Impact Energy of Unnotched Metal Injection Molded (MIM) Test Specimens
Std. 62	Corrosion Resistance of MIM Grades of Stainless Steel Immersed in 2% Sulfuric Acid Solution
Std. 63	Density Determination of Metal Injection Molded (MIM) Components (Gas Pycnometer)

Comparable Standard

Standards for metal injection molded parts have been issued by ASTM. The ASTM standard was adapted from MPIF Standard 35 and uses the MPIF MIM nomenclature system.

ASTM B883 Standard Specification for Metal Injection Molded (MIM) Materials

Additional MIM materials and property data are under development. When available, data will be published in subsequent editions of this Standard.

New, approved materials and property data may be posted periodically on the MPIF website. Between published editions, go to mpif.org to access data that will appear in the next printed edition of this standard.

Low-Alloy Steels

This subsection covers MIM materials manufactured from both prealloys and admixtures of iron powder and other alloying elements such as nickel, molybdenum, and carbon.

The proportions of each element used and heat treat conditions may be varied to achieve a range of properties. Alloys may be hardened for very high strength with moderate ductility. Lower carbon alloys may be case hardened for wear resistance while achieving a tough core.

Material Characteristics

Complete diffusion of alloying elements normally takes place during sintering. The homogeneous structure imparts exceptional strength properties. The high density attained through MIM processing also gives these materials good ductility.

Application

Low-alloy steels are generally used for structural applications, especially when carburized. They are specified for applications where high strength and hardness are necessary.

Microstructure

Residual pores should be small, discrete, well distributed and rounded. The microstructure will vary with composition and heat treatment.

Material Designation Code	Chemical Composition, % — Low-Alloy Steels						
	Fe	Ni	Mo	C	Cr	Si (max)	Mn (max)
MIM-2200 ⁽¹⁾	Bal.	1.5 – 2.5	0.5 max	0.1 max	—	1.0	—
MIM-2700	Bal.	6.5 – 8.5	0.5 max	0.1 max	—	1.0	—
MIM-4140	Bal.	—	0.2 – 0.3	0.3 – 0.5	0.8 – 1.2	0.6	1.0
MIM-4605 ⁽²⁾	Bal.	1.5 – 2.5	0.2 – 0.5	0.4 – 0.6	—	1.0	—

Other Elements: Total may not exceed 1.0% combined.

(1) Formerly designated as MIM-4600

(2) Formerly designated MIM-4650 with the addition of a minimum 0.2% Mo.

To select a material optimum in both properties and cost effectiveness, it is essential that the part application be discussed with the MIM parts manufacturer. (See **Explanatory Notes: Minimum Value Concept**.) Both the purchaser and manufacturer should, in order to avoid possible misconceptions or misunderstandings, agree on the following conditions prior to the manufacture of a MIM component: material selection, chemical composition, minimum property values and any other processes, that may affect the application.

Low-Alloy Steels

MIM Material Properties – Inch-Pound Units

MINIMUM VALUES			TYPICAL VALUES								
Material Designation Code (condition)	Tensile Properties			Tensile Properties			Elastic Constants		Unnotched Charpy Impact Energy (A)	Hardness	
	Ultimate Strength	Yield Strength	Elongation	Ultimate Strength	Yield Strength	Elongation	Young's Modulus	Poisson's Ratio		Macro-indentation (apparent)	Micro-indentation (converted)
	10 ³ psi	10 ³ psi	(in 1 inch)						10 ³ psi		
MIM-2200 (as-sintered)	37	16	20	42	18	40	28.0	0.28	100	45 HRB	N/D
MIM-2700 (as-sintered)	55	30	20	60	37	26	28.0	0.28	130	69HRB	N/D
MIM-4140 (quenched & tempered)	200	155	3	240	180	5	29.5	0.28	55	46 HRC	N/D
MIM-4605 (as-sintered)	55	25	11	64	30	15	29.0	0.28	50	62 HRB	N/D
MIM-4605 (quenched & tempered)	215	190	<1	240	215	2	29.5	0.28	40	48HRC	55 HRC

NOTES:

(A) Impact energy values derived from an un-notched 5 mm x 10 mm cross-section Charpy specimen (see MPIF Standard 59).

N/D Not determined for the purposes of this standard.

