

MPIF STANDARD
35

Materials Standards

for

METAL INJECTION MOLDED PARTS

2000 edition



Documents

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Materials Standards for Metal Injection Molded Parts*

*For structural parts made by the powder metallurgy (P/M) process, see MPIF Standard 35, "Materials Standards for P/M Structural Parts."

*For bearings and bushings made by the P/M process, see MPIF Standard 35, "Materials Standards for P/M Self-Lubricating Bearings."

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

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Materials Standards for Metal Injection Molded Parts

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Scope

MPIF Standard 35 is issued to provide the design and materials engineer with the information necessary for specifying powder metal (P/M) materials which have been developed by the P/M parts manufacturing industry. This section of Standard 35 deals with products manufactured by Metal Injection Molding (MIM). It does not apply to conventional P/M structural materials, self-lubricating bearings or powder forged (P/F) 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 use of any MPIF Standard is entirely voluntary. MPIF Standards are issued and adopted in the public interest. They are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper material for his particular product. Existence of MPIF Standards does not in any respect preclude any member or non-member of the Federation from manufacturing or selling products which use materials or testing procedures not included in this Standard. Other materials which are not covered in this Standard may be commercially available.

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MPIF Standards are subject to periodic review and may be revised. Users are cautioned to refer to the latest edition.

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, chemistry, minimum property values and any other processes, which may affect the part application.

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MPIF Standard 35

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. (See MPIF Standard 50 for additional details on MIM tensile test specimens.) 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.

Minimum Magnetic Property Values

The minimum magnetic property values for MIM materials are expressed in terms of part density, maximum permeability 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 A 773.

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 beginning on page 6.)

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.

Chemistry

The chemistry 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 chemistry 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. Microhardness values shown as Rockwell C were converted from 100 g load (0.981 N) Knoop microhardness 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 pur-

chaser and producer.

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/cm³). MIM materials generally contain less than 5% porosity, so impregnation is not applicable. (See MPIF Standard 42 for additional details.)

A method commonly used is as follows:

$$D = \frac{A \rho_w}{A - C + E}$$

Where:

D = density, in grams per cubic centimeter

A = mass of the specimen in air, in grams

C = mass of the specimen in water, in grams

E = mass (tare) of the suspending wire or basket, in water, in grams

ρ_w = density of water at test temperature, in grams per cubic centimeter

Note 1: Masses A, C & E shall be determined to within 1 milligram.

Note 2: The effect of the surface tension of water in weighing the test sample should be minimized with the addition of a wetting agent to the water in the amount of 0.1%.

Note 3: Water density is determined as follows:

Effect of Temperature on Water Density			
Temperature °C	ρ_w g/cm ³	Temperature °F	ρ_w g/cm ³ *
15	0.9990	60	0.9990
16	0.9989	62	0.9988
17	0.9988	64	0.9986
18	0.9986	66	0.9984
19	0.9984	68	0.9982
20	0.9982	70	0.9980
21	0.9980	72	0.9977
22	0.9978	74	0.9974
23	0.9975	76	0.9972
24	0.9973	78	0.9969
25	0.9970	80	0.9966
26	0.9968	82	0.9963
27	0.9965	84	0.9959
28	0.9962	86	0.9956
29	0.9959	*Interpolated from °C data	
30	0.9956		

NOTE: The °C values of ρ_w shown are taken from, "Metrological Handbook 145, Quality Assurance for Measurements", 1990, NIST, P 9.10., and represent the values in air at one atmosphere pressure. (See MPIF Standard 42 for additional details.)

Another method of density determination may be by gas pycnometer as agreed upon between buyer and seller.

Ultimate Tensile Strength

Ultimate tensile strength, expressed in 10³ 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 10³ 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.

Young's Modulus

Young's modulus, expressed in 10⁶ psi (GPa), is the ratio of normal stress to corresponding strain for tensile or compressive stresses below the proportional limit of the material. Data were measured by the use of resonant frequency testing.

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.)

Macrohardness (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. Following is a recommended procedure for measuring the apparent hardness of a MIM material:

- Specify a region for evaluation.
- Remove any burrs that might affect the indentation hardness reading by coming in contact with the indenter or support surfaces.
- Obtain a minimum of five hardness readings.
- Average the readings.
- Report the average results to the nearest whole number.

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.)

Microhardness

Microhardness is determined by microhardness testers utilizing Knoop (HK) or Vickers (HV) indentors. Microhardness measurements are convertible to equivalent Rockwell hardness values for comparisons with other materials. (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 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 dm²) per day factor, in units of

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

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 F 1089 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 F 1089 for additional details.)

Soft Magnetic Properties

The magnetic data presented in this standard were developed in accordance with ASTM Standard A 773.

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 kilogauss (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})

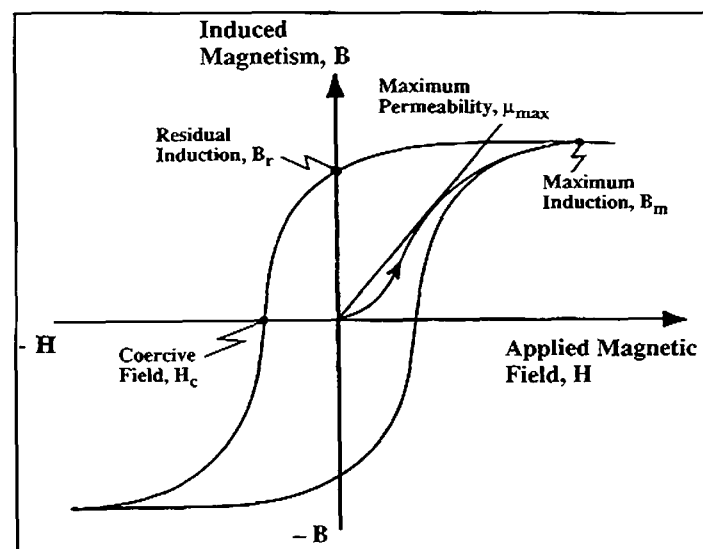
The slope of the line from the origin to the knee of the initial B-H magnetization curve. This parameter is dimensionless.

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 Lall, Metal Powder Industries Federation, 1992, p.11.

SI Units

Data were measured in English units and converted to SI Units in accordance with ASTM Standard Practice E 380.

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 B 883 Metal Injection Molded (MIM)
Ferrous Structural Parts

Additional MIM material properties are under development. Data will be published in subsequent editions of this Standard.