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Materials Standards for PM SELF-LUBRICATING BEARINGS

2010 EDITION

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Documents

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MPIF Standard 35

**Materials
Standards
for PM
Self-
Lubricating
Bearings***

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

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

*For PM components made by the metal injection molding (MIM) process, see MPIF Standard 35, "Materials Standards for Metal Injection Molded Parts".

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Materials Standards for PM Self-Lubricating Bearings

Issued 1965

Revised 1974, 1976, 1986, 1990, 1998 and 2010

Scope

MPIF Standard 35 is issued to provide the design and materials engineer with the information necessary for specifying powder metallurgy (PM) materials that have been developed by the PM parts manufacturing industry. This section of Standard 35 deals with self-lubricating bearings and bushings made by the powder metallurgy process. A bearing may be defined as a machine part in which another component such as a journal or rod turns or slides. A bushing is normally a removable cylinder used to control the size of an opening or to resist abrasion or to serve as a guide. This section does not apply to materials for PM structural, powder forged (PF) steel or metal injection molded (MIM) parts or products which are covered in separate sections of MPIF Standard 35. The same materials may appear in more than one section depending upon their common use, e.g., some bearing materials may also be used in structural applications and vice versa. Each section of this standard is divided into subsections based on the various types of PM materials in common commercial use within that section. Notes at the beginning of each subsection discuss the characteristics of that material. Users of this standard should make a determination as to the availability of any referenced material.

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Both the purchaser and the manufacturer should, in order to avoid possible misconceptions or misunderstandings, agree on the following conditions prior to the manufacture of a PM part: minimum strength value, grade selection, chemical composition, proof testing, typical property values and processes, that may affect the part application.

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MPIF Standard 35—2010

Materials Standards for PM Self-Lubricating Bearings

Explanatory Notes

Minimum Value Concept

The Metal Powder Industries Federation has adopted the concept of *minimum* values of properties for PM materials. These values such as oil content and radial crush strength may be used in designing for a PM bearing application. Composition, density, and in some cases, radial crush strength, also have maximum values listed. It is seen as an advantage of the process that equivalent properties can be developed by varying chemical composition, particle configuration, density and/or processing techniques.

The minimum value is the value that will be statistically exceeded by all bearings in a production lot as defined by the manufacturer and the purchaser. **The manufacturer and the purchaser should agree on the sampling plan.**

The purchaser should select and specify the combination of PM material and properties most suitable for a specific application. The data provided define values for listed materials and display minimum properties. 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 application be discussed with the PM manufacturer.

Utilization of MPIF Standard 35 to specify a PM bearing means that unless the purchaser and manufacturer have agreed otherwise, the material will have at least the minimum value specified in the Standard.

(See **PM Bearing Materials Properties** on pages 6–12).

Grade Selection

Before a particular grade of material can be selected, a careful analysis is required of the design of the bearing and its end use, including dimensional tolerances. In addition, the final property requirements of the finished bearing should be considered, e.g., density, porosity, compressive strength, corrosion resistance, wear resistance, oil content, oil type, surface finish and any other requirements pertinent to the application. It is recommended that all of the above aspects be subjects of discussion between the manufacturer and the purchaser prior to final grade selection.

In addition to the bearing materials standardized herein, there are other proprietary materials available for specific applications.

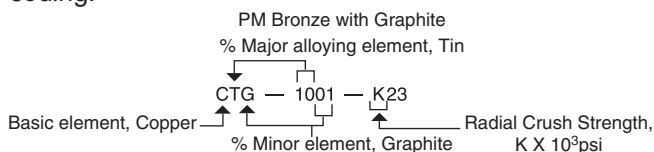
(See **Powder Metallurgy Design Manual** published by the Metal Powder Industries Federation for design recommendations and other information pertinent to the proper use of PM self-lubricating bearings.)

Nomenclature

The four digits following the prefix letter code refer to the composition of the material.

In nonferrous materials, the first two numbers in the four digit series designate the percentage of the major alloying constituent. The last two numbers of the four-digit series designate the percentage of the minor alloying constituent. The percentages of other minor elements excluded from the code are represented in the "Chemical Composition" that appears with each standard material.

Illustration of P/M nonferrous material designation coding:



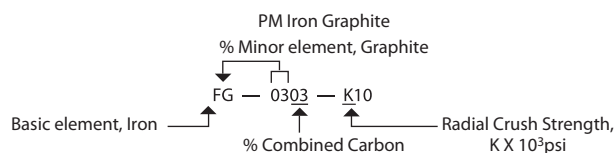
In ferrous materials, the major alloying elements (except combined carbon) are included in the prefix letter code. Other elements are excluded from the code but are represented in the "Chemical Composition" which appears with each standard material. The first two digits of the four-digit code indicate the percentage of the major alloying constituent present.

Combined carbon content in ferrous materials is designated by the last two numbers in the four-digit series. The ranges of carbon that are metallurgically combined are indicated in the coding systems below:

Carbon Ranges	Code Designation
0.0% - 0.3%	00
0.3% - 0.6%	05
0.6% - 0.9%	08

Carbon Ranges for Iron-Graphite Bearings	Code Designation
0.0% - 0.5%	03
0.5% - 1.0%	08

Illustration of PM ferrous material designation coding:



The two-digit suffix represents the minimum K strength, expressed in 10³ psi, that the user can expect from the PM material possessing that chemical composition. The letter K indicates a bearing grade material.

Examples of P/M Material Designation Coding

Material	Nominal Composition by Percent	Complete Code for Material, Composition and Minimum K x 10 ³ psi
PM Bronze	Cu-90, Sn-10	CT-1000-K26
PM graphited Bronze	Cu-86, Sn-10, G-4	CTG-1004-K10
PM Iron	All Fe	F-0000-K23
PM Iron-Copper	Fe-90, Cu-10	FC-1000-K40
PM Iron-Graphite	Fe-97.25 Graphite 2.5	FG-0303-K10
PM Diluted Bronze	Comb. Carbon 0.25 Fe-60, Cu-36, Sn-4	FCTG-3604-K16

Prefix Letter Code

A	Aluminum	FS	Iron Silicon
C	Copper	FX	Copper-Infiltrated
CT	Bronze		Iron or Steel
CNZ	Nickel-Silver	FY	Iron Phosphorus
CZ	Brass	G	Free graphite
F	Iron	M	Manganese
FC	Iron-Copper or Copper Steel	N	Nickel
FD	Diffusion-Alloyed Iron or Steel	P	Lead
FDCT	Diffusion-Alloyed Iron-Bronze	S	Silicon
FF	Soft-Magnetic Iron	SS	Stainless Steel
FL	Prealloyed Ferrous material except Stainless Steel		(prealloyed)
		T	Tin
FLD	Diffusion-Alloyed Steel (prealloyed base)	U	Sulfur
		Y	Phosphorus
FN	Iron-Nickel or Nickel Steel	Z	Zinc

Chemical Composition

The chemical composition of each material lists the principal elements by minimum and maximum percentage by mass percentage. "Other Elements" includes the total other elements by difference and is reported as a maximum percentage. These may include other minor elements added for specific purposes and the normal amount of extraneous constituents found in the individual ingredients.

The chemical composition specification for PM self-lubricating bearings describes the material in the as-sintered condition. An as-sintered part can be checked for chemical composition with no interference as long as the sampling procedure does not adversely affect results. In some instances, impregnants, whether for sizing or lubrication purposes, may be partially removed using Soxhlet extraction (ASTM B 963).

Parts that have been sized, tumbled, machined or impregnated may be contaminated with carbonaceous materials that must be removed prior to carbon determination. There is no known way to remove such interfering materials completely; thus an accurate carbon content should be measured on an as-sintered part. Combined carbon in iron can be measured by metallographic estimate of the area fraction of pearlite: 100% pearlite is equivalent to approximately 0.8% carbon.

Microstructure

The examination of the microstructure of a PM bearing can serve as a diagnostic tool and reveal the degree of sintering and other metallurgical information critical to the powder metallurgy process. Several observations common to most sintered materials are briefly described below.

In selecting a section of a PM part for microstructural analysis, an interior plane parallel to the pressing direction is preferred for mounting and polishing. Coarse and fine polishing should be continued until all of the pores are opened to view and the area fraction of porosity represents the density of the part. For example, an 80% dense bearing should show approximately 20% of its area as pores.

Low density materials such as those designed for self lubrication should be impregnated with mounting resin during preparation of the specimen for microstructural examination. This will help prevent distortion of the voids during machining or polishing. Sintered bearings are always first examined in the unetched condition. In an average sinter there will be very few or no original particle boundaries seen at 200X. Bearings should have their oil removed by Soxhlet extraction so that it will not interfere with microscopic examination. Examination of the unetched inside diameter surfaces should show surface porosity.

In 90-10 copper-tin bronze bearings, the structure should be alpha bronze with no tin-rich phases at 200–400X magnification. In iron-copper bearings, the copper should have melted and flowed into the surrounding small pores. With 5% to 10% copper, the copper will be visible as melted regions. With 2% copper or less, free copper is generally not present. Bearings should show a minimum of original particle boundaries. The microstructure of "diluted" bronze combines the appearances of iron and bronze structures.

Iron-graphite material should exhibit either free graphite in its microstructure or a free graphite/combined carbon mixture, depending upon manufacturing process. To preserve graphite for metallographic examination, rough grind on 400 and 600 grit SiC paper, then polish for 2-6 minutes with moderate pressure, 250 rpm lap, one micrometer grit diamond on a short-napped cloth.

Oil Impregnation

The controlled, interconnected pore structure in low density PM parts or bearings permits their impregnation with lubricating oil. This provides self-lubricating properties. When friction heats the part, the oil expands and flows to the bearing surface. In operation, the oil is "pumped" from the bearing as the shaft rotates. On cooling, the oil returns into the metal's pores by capillary action. Conventional PM bearings can absorb from 10 to 30% by volume of oil. Impregnation is achieved by vacuum techniques or by soaking the parts in heated oil. Properly manufactured PM bearings will have the open pores 90% filled with oil (minimum). Packaging

and atmospheric conditions may affect oil retention over time. If “dry-to-touch” bearings are specified, the oil content must meet the specification requirement after any procedure to remove surface oil. For further details, see the Engineering Information Section of this standard.

Porosity

Porosity is the percentage of void volume in a bearing. It is the complement of density. A bearing that is 85% of pore-free density will have 15% porosity. Porosity in bearings is present as a network of interconnected pores that extend to the surface, like a sponge. Interconnected porosity is important to the performance of self-lubricating bearings and is part of the specification for those types of materials.

It shall be calculated as follows:

$$P = \left(\frac{B-A}{B-(C-E)\rho_o} \times 100 \right) \rho_w$$

Where:

- P = interconnected porosity in volume percent
- ρ_o = density of as-received oil at the temperature of test, in g/cm³
- ρ_w = density of water at the immersion temperatures, g/cm³
- A = mass of oil-free specimen, in air, in grams
- B = mass of fully oil-impregnated specimen, in grams
- C = mass of fully oil-impregnated specimen and test specimen support immersed in water, in grams
- E = mass of test specimen support in water, in grams

Note 1. All weighings are made by analytical balance.

Note 2. The effect of the surface tension of water in weighing the test sample should be minimized by the addition of a wetting agent to the distilled or deionized water.

Note 3. The specimen mass should be at least 1 gram.

Note 4. See MPIF Standard 57 for the specific test method details.

Oil Content by Volume, As Received

Oil content (P_1) represents the volume percent of oil that fills the porosity of the as-received bearing.

It shall be calculated as follows:

$$P_1 = \left(\frac{J-A}{B-(C-E)\rho_o} \times 100 \right) \rho_w$$

Where:

- P_1 = oil content of the as-received bearing, in volume percent
- J = mass of the as-received, oil-impregnated specimen in air, in grams
- A = mass of oil-free specimen in air, in grams

B = mass of the fully oil-impregnated specimen in air, in grams

C = mass of the fully oil-impregnated specimen suspended and immersed in water, in grams

E = mass of test specimen support in water, in grams

ρ_o = density of as-received oil at the temperature of test, in g/cm³

ρ_w = density of distilled water at the temperature of test

Note 1. All weighings are made by analytical balance.

Note 2. The effect of the surface tension of water in weighing the test specimen should be minimized by the addition of a wetting agent to the distilled or deionized water.

Note 3. The specimen mass should be at least 1 gram.

Note 4. See MPIF Standard 57 for the specific test method details.

Oil Impregnation Efficiency

The impregnation efficiency, I_E , defined as the % of open porosity filled with oil, is calculated as:

$$I_E = P_1 / P \times 100$$

Where:

- I_E = oil-impregnation efficiency
- P_1 = oil content of the as-received bearing in volume %
- P = interconnected porosity in volume %

Density

Density is expressed in grams per cubic centimeter (g/cm³). “Dry density” is the mass per unit volume of an unimpregnated PM bearing. “Wet density” is the mass per unit volume of a PM bearing impregnated with oil or other non-metallic materials. Typically, density of structural components is reported on a dry unimpregnated basis and density of bearings on a fully impregnated basis. See MPIF Standard 57 for additional details.

A method commonly used is as follows:

$$D_{\text{dry}} = \frac{A\rho_w}{B-C+E}$$

$$D_{\text{wet}} = \frac{B\rho_w}{B-C+E}$$

Where:

- D = density, in grams per cubic centimeter
- A = mass of the oil-free specimen in air, in grams
- B = mass of the fully oil-impregnated sample in air, in grams
- C = mass of the fully oil-impregnated specimen suspended and immersed in water, in grams

E = mass (tare) of suspending wire or basket in water, in grams, and
 ρ_w = density of distilled water at the temperature of test

Note 1. All weighings are made by analytical balance.

Note 2. The effect of the surface tension of water in weighing the test specimen should be minimized by the addition of a wetting agent to the distilled or deionized water.

Note 3. The specimen mass should be at least 1 gram.

Note 4. See MPIF Standard 57 for the specific test method details.

Radial Crush Strength

The radial crush strength, "K", of a bearing shall be calculated as follows:

$$K = \frac{P(D - t)}{Lt^2}$$

Where:

K = radial crush strength, in 10^3 psi (MPa)
 P = radial crushing force, in pounds force (N)
 D = outside diameter of bearing, in inches (mm)
 t = wall thickness of bearing, in inches (mm)
 L = bearing length, in inches (mm)

Note 1. This equation becomes invalid when the wall thickness of a bearing is greater than 30% of its outside diameter.

Note 2. See **PM Bearing Material Properties** on pages 6–12 for "K", radial crush strength.

The actual radial crushing force shall be determined by compressing the test bearing between two flat surfaces; the direction of the load being normal to the longitudinal axis of the bearing. The point at which the load drops due to the first crack shall determine the crushing force. This test shall be applied to plain cylindrical bearings. Flanged bearings shall be tested by cutting off the flange and compressing the two sections separately.

Spherical bearings shall be machined to plain cylindrical shape. Each section shall meet the minimum strength requirements established in this Standard. This is demonstrated by comparing the measured crushing force with the value calculated, using the "K" strength given in the respective minimum property tables. See MPIF Standard 55 for additional details.

Storage

Oil-impregnated bearings shall be stored in non-absorbent containers to prevent oil loss. They should also be protected from dirt and dust. The purchaser and manufacturer should agree on finished surface condition.

The use of chlorinated solvents to remove oil or to clean bearing surfaces prior to oil-impregnation is not recommended. Solvent residuals tend to form a weak acid that can cause shaft wear. See MPIF Standard 58 for additional details.

Surface Finish

A very smooth finish may be desirable where surface finish affects the function of a bearing; however due to the porous nature of PM parts, normal cone stylus measurements with tracer type instruments will not measure the true finish of the surface. This is because the interconnected surface porosity is deeper than surface irregularities in the metal.

The purchaser and manufacturer should agree on a surface finish specification and method of measurement without ignoring the effect of the surface finish of the mating shaft.

SI Units (See page 26)

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

Comparable Standards

Standards for powder metallurgy self-lubricating bearings have been issued by both ASTM and ISO. The ASTM standards use similar compositions and density ranges as this MPIF standard. The ISO standard provides information on bearing materials using dry density specifications.

ASTM B 438	Standard Specification for Bronze-Base Powder Metallurgy (PM) Bearings (Oil-Impregnated)
ASTM B 439	Standard Specification for Iron-Base Powder Metallurgy (PM) Bearings (Oil-Impregnated)
ISO 5755	Sintered Metal Materials-Specifications Tables 1 & 2: Materials for bearings

Bronze Bearings

Low graphite bearing material contains 10% tin and up to 0.3% graphite. The bronze provides corrosion resistance. At 6.4 g/cm³ density, this material is adequate to ensure some ductility and also resist shock loading. The material can be staked. Bearings of this material are used in fractional horsepower motors, business machines, farm implements, hardware, machine tools, etc. At higher density (6.8 g/cm³), it is even more ductile and will support higher loads. At the higher density the bearings hold less oil and the material is used in lower speed applications. Because of their strength, such materials are often used as a combination structural part and bearing.

A medium graphite bearing material contains graphite in amounts of 0.5 to 1.8%. These bearings will operate under heavy loads and high speeds and under moderately abrasive conditions.

Bronze bearings containing more than 3% graphite run very quietly. They tend to require less field lubrication and operate at somewhat higher temperatures. They are often used in oscillatory or intermittent modes.

Material	Material Designation Code	Chemical Composition, %			MINIMUM VALUES (A)			Density, D _{wet} (A) (B) g/cm ³	
					Radial Crush Strength, K		Oil Content, P ₁ (F)		
		Element	Min.	Max.	10 ³ psi	MPa	Volume %	Min.	Max.
Bronze (Low Graphite)	CT-1000-K19	Copper Tin Graphite Other (G)	Bal. 9.5 0 0	Bal. 10.5 0.3 2.0	19	130	24 (H)	6.0	6.4
	CT-1000-K26	Copper Tin Graphite Other (G)	Bal. 9.5 0 0	Bal. 10.5 0.3 2.0	26	180	19	6.4	6.8
	CT-1000-K37	Copper Tin Graphite Other (G)	Bal. 9.5 0 0	Bal. 10.5 0.3 2.0	37	260	12	6.8	7.2
	CT-1000-K40	Copper Tin Graphite Other (G)	Bal. 9.5 0 0	Bal. 10.5 0.3 2.0	40	280	9	7.2	7.6
Bronze (Medium Graphite)	CTG-1001-K17	Copper Tin Graphite Other (G)	Bal. 9.5 0.5 0	Bal. 10.5 1.8 2.0	17	120	22 (I)	6.0	6.4
	CTG-1001-K23	Copper Tin Graphite Other (G)	Bal. 9.5 0.5 0	Bal. 10.5 1.8 2.0	23	160	17	6.4	6.8
	CTG-1001-K30	Copper Tin Graphite Other (G)	Bal. 9.5 0.5 0	Bal. 10.5 1.8 2.0	30	210	9	6.8	7.2
	CTG-1001-K34	Copper Tin Graphite Other (G)	Bal. 9.5 0.5 0	Bal. 10.5 1.8 2.0	34	230	7	7.2	7.6
Bronze (High Graphite)	CTG-1004-K10	Copper Tin Graphite Other (G)	Bal. 9.2 2.5 0	Bal. 10.2 5.0 2.0	10	70	11 (J)	5.8	6.2
	CTG-1004-K15	Copper Tin Graphite Other (G)	Bal. 9.2 2.5 0	Bal. 10.2 5.0 2.0	15	100	(E)	6.2	6.6

(A) These data are based on material in the finished condition.

(B) Oil-impregnated. Assumes an oil density of 0.875 g/cm³.

(E) At maximum graphite (5%) and density (6.6 g/cm³), this material will contain only a trace of oil. At 3% graphite and 6.2-6.6 g/cm³ density, it will contain 8% min. oil content.

(F) Minimum oil content will decrease with increasing density. Those shown are valid at the upper-limit of the density given.

(G) Iron 1% max.

(H) For an oil content of 27% min., density range will be 5.8-6.2 g/cm³, K will be 15,000 psi min. (105 MPa).

(I) For an oil content of 25% min., density range will be 5.8-6.2 g/cm³, K will be 13,000 psi min. (90 MPa).

(J) At 3% graphite, it will contain 14% min. oil content.

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Approved: 1986 Revised: 1998, 2010

Diffusion-Alloyed Iron-Bronze Bearings

The diffusion-alloyed iron-bronze compositions provide a bearing material with greater iron content than the conventional premixed diluted bronze bearings. Diffusion-alloyed iron-bronze bearings have lower raw material cost and improved radial crush strength compared with the conventional premixed bronze (90-10) bearings.

Material	Material Designation Code	Chemical Composition, % (L)			MINIMUM VALUES (A)			Density, D_{wet} (A) (B) g/cm ³	
					Radial Crush Strength, K		Oil Content, P_1		
		Element	Min.	Max.	10 ³ psi	MPa	Volume %	Min.	Max.
Diffusion-Alloyed Iron-Bronze	FDCT-1802-K18	Iron	Bal.	Bal.	22	150	24	5.6	6.0
		Copper	17.0	19.0					
		Tin	1.5	2.5					
		Carbon	0	0.1					
		Other	0	1.0					
	FDCT-1802-K28	Iron	Bal.	Bal.	31	215	19	6.0	6.4
		Copper	17.0	19.0					
		Tin	1.5	2.5					
		Carbon	0	0.1					
	FDCT-1802-K38	Iron	Bal.	Bal.	39	270	13	6.4	6.8
		Copper	17.0	19.0					
		Tin	1.5	2.5					
		Carbon	0	0.1					
		Other	0	1.0					

(A) These data are based on material in the finished condition.

(B) Oil-impregnated. Assumes an oil density of 0.875 g/cm³.

(L) These compositions have no added graphite.