

MPIF STANDARD 35-PF
2017 Edition

Materials Standards for

PF
Steel
Parts

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Materials Standards for PF Steel 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 Metal
Injection Molded Parts* for PM
components made by the
metal injection molding (MIM)
process.

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Materials Standards for PF Steel 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 metallurgy (PM) materials that have been developed by the PM parts manufacturing industry. This section of Standard 35 deals with products manufactured by powder forging (PF). It does not apply to materials for conventional PM structural, self-lubricating bearings or metal injection molded (MIM) products, 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 PF 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 producer should, in order to avoid possible misconceptions or misunderstandings, agree on the following conditions prior to the manufacture of a PF component: material selection, chemical composition and alloying method, proof testing, typical property values and processes, which may affect the part application.

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MPIF Standard 35-PF

2017 Edition

Materials Standards for PF Steel Parts

Explanatory Notes and Definitions

Introduction

Fully dense powder metallurgy (PM) products are produced by a variety of processes including powder forging (PF) and hot isostatic pressing (HIP). The powder forging process is an extension of the more conventional press and sinter process. A porous preform is hot forged using a single blow. Forging is carried out in a heated, totally enclosed die; limited flash is generated. This PF process contrasts with the forging of wrought steels where multiple blows often are necessary to form the part from bar stock and considerable material is wasted as flash.

There are two basic forms of powder forging:

1. hot upset powder forging—hot densification of a PM preform by forging where there is a significant amount of lateral material flow.
2. hot repress powder forging—hot densification of a PM preform by forging where the material flow is mainly in the direction of forging.

In hot upset PF the extensive unconstrained lateral flow of material results in a combination of normal and shear stresses around the pores. The pores become flattened and elongated in the direction of lateral flow, breaking up any residual oxide films and creating strong metallurgical bonds across former pore boundaries. This enhances dynamic properties such as fracture toughness and fatigue strength. In hot repress PF there is much less lateral flow. As densification proceeds the stress state approaches a pure hydrostatic condition. Typically the pores flatten without much lateral movement or sliding. This decreased movement reduces the tendency to break up residual oxide films and may result in lower ductility and toughness, compared with a hot upset processed product.

Typical Value

For each material listed in this standard a set of typical mechanical property values are provided, including tensile properties, compressive yield strength, fatigue limit and hardness. These mechanical properties were based on laboratory studies where the test specimens were sectioned from PF samples. **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 on the area of the component chosen for evaluation or the specific manufacturing process utilized.

Chemical Composition

The chemical composition of each material lists the principal elements by minimum and maximum weight percent. If required, a sample for chemical analysis shall be taken from the core area of the component. For spectroscopic analysis, the sample shall consist of a single solid piece carefully cut using a cutting fluid to prevent overheating. Samples for oxygen analysis should be cut using a low speed precision cut-off wheel. After cutting, wash the piece with a suitable low-residue solvent to remove the cutting fluid and dry with filtered compressed air. For carbon and wet chemical analysis, remove drillings, chips or solid pieces without the use of water, oil, or other lubricant, and with care to prevent overheating.

(See MPIF Standards 66 and 67 for additional details.)

Mechanical Properties

Mechanical property data provide the typical properties that can be expected from test specimens conforming to the density and chemical composition requirements listed in this standard. The properties listed herein were derived from individual test specimens machined from PF material samples, prepared under commercial practices specifically for material evaluation.

The preferred method for verifying the acceptable performance of a finished part is for the producer and purchaser to agree upon a qualification test to be performed on the actual part. The specific test should be determined following consideration of the function of the part. An example would be measuring the force needed to break teeth off a gear, using a prescribed test fixture.

Where the part configuration permits, standard mechanical property test specimens may be machined from the part in the condition in which it is to be used. (Remove test specimens from parts to be used in the quenched and tempered condition after heat treatment of the part to ensure the microstructure is representative of the actual part.) The applicable part drawing or purchase order shall designate the location from which the mechanical property test specimens are to be removed and the type of specimen to be tested.

Heat Treatment

PF steel parts react to heat treatment in the same manner as wrought steels. Similar processes are used including annealing, normalizing, quench hardening and case hardening. Two heat treat processes are used in this standard – a normalized condition (cool typically from 1550 °F [843 °C] in still air) and a quench plus temper condition (oil quench typically from 1550 °F [843 °C] and temper at selected temperatures to achieve a desired hardness, unless otherwise noted).

Microstructure

The examination of the microstructure of a PF steel part can serve as a diagnostic or quality control tool by revealing metallurgical information critical to the powder forging process. Five microstructural criteria are provided to assist the producer and purchaser in assessing the quality of the product. Limits for each condition and designated critical regions for evaluation should be agreed upon by the purchaser and producer.

1. Surface-finger oxide penetration – the maximum depth of penetration of surface-finger oxides from the finished product surface, determined in accordance with ASTM B797.
2. Interparticle oxide networks – the extent of any interparticle oxide network in each designated critical region of the PF part, determined in accordance with ASTM B797.
3. Decarburization depth – the maximum depth of complete decarburization (only ferrite present) on the surface of a PF part, or, the depth of total decarburization (total decarburization = complete decarburization + partial decarburization), the depth at which core carbon is reached, in accordance with ASTM E1077. For quenched and tempered parts an effective decarburization depth (depth to a specific hardness) may be specified.
4. Nonmetallic inclusions – the level of nonmetallic inclusions, as determined in accordance with ASTM B796. For alloys containing MnS additions,

the inclusion assessment is modified to count only those discrete inclusions greater than or equal to 100 µm maximum caliper (Feret's) diameter.

5. Cross-product contamination – the amount of unalloyed iron contamination in a prealloyed steel composition, or, the amount of prealloyed contamination in carbon or copper steel compositions, determined in accordance with ASTM B795.

PF Material Code Designations

The PF material code designation defines a specific material with respect to chemical composition, alloying method, and minimum density. The code consists of the PF prefix to designate the material as having been manufactured by the powder-forging process. For the carbon and low-alloy steels, this is followed by a four digit code number that is a modification of the AISI–SAE nomenclature for wrought steels. For example, 10XX designates a carbon steel and the XX the amount of carbon; 46XX designates a low-alloy steel and the XX the amount of carbon. The XX designates the forged product carbon content, in hundredths of a percent. Composition limits for alloy and impurity elements may differ from the AISI–SAE limits. Most powder-forged copper steels follow this approach but with the addition of the letter C to designate a copper steel. For example, 11CXX designates a nominally 2 wt.% copper steel with admixed manganese sulfide to aid machinability. Copper steels with higher copper content have two digits prior to the C that indicate the nominal copper content. For example, 1135CXX designates a nominally 3.5 wt.% copper steel with admixed manganese sulfide.

Obsolete Acronym

The old acronym for powder forging P/F has been replaced by PF throughout this document. The change in the prefix for the material designations is to match the currently approved acronym for powder forging. No change has been made to the material specification and performance characteristics for the various powder-forged materials.

Additional Material Code Designations

The following PF steel alloys have been designated but mechanical property data have not yet been developed. They are manufactured from prealloyed steel powder admixed with graphite as the source of carbon.

Material Designation	TABLE 1 Chemical Composition Requirements, % - PF-44XX and PF-49XX										
	Fe (D)	Ni	Mo	Mn	Cu	Cr	S	Si	P	C	O
PF-44XX	Bal.	0.10 (max)	0.80-0.95	0.08-0.20	0.15 (max)	0.10 (max)	0.03 (max)	0.03 (max)	0.03 (max)	(B)	(C)
PF-49XX	Bal.	0.10 (max)	1.4-1.6	0.08-0.20	0.15 (max)	0.10 (max)	0.03 (max)	0.03 (max)	0.03 (max)	(B)	(C)

For (B), (C) and (D) refer to the chemical composition tables in the materials section of the standard.

Grade Selection

Before a particular grade of material can be selected, a careful analysis is required of the design of the part and its end use, including dimensional tolerances and an analysis of part design versus tool design. In addition, the final property requirements of the finished part should be considered, e.g., static and dynamic loading, wear resistance, machinability and any other requirements pertinent to the application. It is recommended that all of the above aspects be subjects of discussion between the producer and the purchaser prior to the final grade selection.

Proof Testing

It is highly recommended that a proof test and/or destructive test method be established between the purchaser and PF parts producer to ensure that the actual PF part meets the intent of the design. If possible, this test should be related to the actual function of the part, e.g., gear tooth break load, crush test, pull test, etc. It may require a written procedure, a special test fixture or sub-assembly for use by both the PF parts producer and the purchaser. Establishment of values should be determined by actual testing of production lots. It is recommended that such tests supplement the material specification designated on the engineering drawing.

Density

The density of the PF part is determined using Archimedes' principle, by immersion in water, in accordance with MPIF Standard 54.

The minimum density requirements are listed in various material sections of the standard.

Impact Energy

Impact energy, measured in ft·lbf (J), is a measurement of the energy absorbed in fracturing a specimen with a single blow. The V-notch Charpy specimen is most commonly used for PF steels (ASTM E23).

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 10 for additional details—machined round specimen.)

Yield Strength

Yield strength, expressed in 10^3 psi (MPa), is the load at which the material exhibits a 0.2% offset from proportionality on a stress-strain curve in tension divided by the original cross-sectional area (ASTM E8).

(See MPIF Standard 10 for additional details—machined round specimen.)

Elongation

Elongation (plastic), expressed as a percentage of the original gauge length (usually 1 inch) (25 mm), is based on measuring the increase in gauge length after the fracture, provided the fracture takes place within the gauge length. Elongation can also be measured with a breakaway extensometer on the tensile specimen. The recorded stress-strain curve displays total elongation (elastic and plastic). Plastic strain at failure is calculated by subtracting elastic strain from the total strain at failure.

(See MPIF Standard 10 for additional details—machined round specimen.)

Reduction of Area

Reduction of area, expressed as a percentage of the original gauge cross-sectional area, is based on measuring the reduced diameter at the fracture, calculating the cross-sectional area at this point and then determining the percent reduction in area as compared with the original cross-sectional area (ASTM E8).

Compressive Yield Strength

Compressive yield strength, expressed in 10^3 psi (MPa), is the stress at which a material exhibits a specified permanent set. The 0.1% permanent offset was measured utilizing a clip-on extensometer on a 0.375 inch (9.53 mm) diameter by 1.05 inch (26.7 mm) long specimen.

For certain heat-treated steels listed in the data tables the hardenability of the alloy is not sufficient to completely through harden the 0.375 inch (9.53 mm) diameter test specimen. Examination of the tensile yield and compressive yield values for the prealloyed steels find their values comparable for the section sizes tested (up to 0.375 inch [9.53 mm]). Typically, smaller cross sections have higher compressive yield strengths and larger sections somewhat lower strengths due to the hardenability response.

(See MPIF Standard 61 for additional details.)

Hardness

The hardness value of a PF part is determined by using a conventional indentation hardness tester, such as a Rockwell or Rockwell Superficial. The producer and purchaser should agree on the hardness value, the hardness scale and the critical location for testing, in accordance with ASTM E18.



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Fatigue Limit and Fatigue Strength

Fatigue strength, expressed in 10^3 psi (MPa), is the maximum alternating stress that can be sustained for a specified number of cycles without failure, the stress being reversed with each cycle unless otherwise stated. The number of cycles survived should be stated with each strength listed. The fatigue limit is the stress sustainable for an indefinite number of cycles, and no cycle number is given. For PF steels, like wrought steels, fatigue strengths of 10^7 cycles duration using smooth, unnotched specimens on R.R. Moore style testing machines are considered to be sustainable indefinitely and are therefore stated as fatigue limits (also termed endurance limits).

The fatigue limits in this standard were generated through statistical analysis of rotating beam fatigue strength data. Due to the limited number of data points available for the analysis, these fatigue limits were determined as the 50% survival stress, i.e., the fatigue stress at which 50% of the test specimens survived 10^7 cycles. (See MPIF Standard 56 for additional details.)

Elastic Constants

The elastic constants for the PF steels were not measured directly from test specimens. Since the minimum density requirement for these materials is greater than 99.5% that of the equivalent wrought steel, the elastic constants are considered equal to the accepted values for wrought steel, typically:

Young's Modulus (E) = 30×10^6 psi (207 GPa)

Poisson's Ratio = 0.3

Engineering Information

Hardenability and Jominy Curves

SI Units

Data were measured 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. 10	Tensile Properties of Powder Metallurgy (PM) Materials
Std. 54	Density of Impermeable Powder Metallurgy (PM) Materials
Std. 56	Rotating Beam Fatigue Endurance Limit of Powder Metallurgy (PM) Materials
Std. 61	Compressive Yield Strength of Powder Metallurgy Materials
Std. 66	Sample Preparation and Determination of Hardenability of PM Steels (Jominy End-Quench Hardenability)
Std. 67	Sample Preparation for the Chemical Analysis of the Metallic Elements in PM Materials

Comparable Standard

ASTM B848 Standard Specification for Powder Forged (PF) Ferrous Structural Parts.

Carbon Steel

This subsection covers PF materials manufactured from elemental iron powders that are essentially free of other alloying elements. Graphite is admixed to achieve the desired carbon content.

Material Characteristics

These materials are manufactured by pressing, sintering and then forging. Chemical composition and minimum density requirements are given in Tables 1 and 2 respectively.

Application

PF carbon steels are used primarily in the normalized condition where moderate strength and hardness are desired. Carbon steels are not through hardenable on heat treatment except in very thin sections.

Microstructure

The normalized structure consists of ferrite and pearlite where the amount of pearlite increases with increasing carbon content. Powder forged material typically is fine grained.

TABLE 1											
Material Designation	Chemical Composition Requirements, % - Carbon Steel										
	Fe (D)	Ni	Mo	Mn	Cu	Cr	S	Si	P	C	O
PF-10XX	Bal.	0.10 (max)	0.05 (max)	0.10-0.25	0.30 (max)	0.10 (max)	0.025 (max)	0.03 (max)	0.03 (max)	(B)	(C)
PF-11XX	Bal.	0.10 (max)	0.05 (max)	0.30-0.60 (A)	0.30 (max)	0.10 (max)	0.23 (A)	0.03 (max)	0.03 (max)	(B)	(C)

- (A) Covers manganese sulfide (MnS) additions from 0.3 to 0.5%. The manganese content in solution is similar to PF-10XX or PF-10CXX, that is 0.10 to 0.25%.
- (B) Nominal carbon content shall be as specified by the purchaser. Unless otherwise agreed upon between the purchaser and producer, the forged product carbon content shall be within $\pm 0.05\%$ of the specified carbon content.
- (C) When required, maximum oxygen content shall conform to the amount specified by the purchaser.
- (D) For information only. Quantitative determination of this element is not required.

TABLE 2	
Minimum Density for Carbon Steel Compositions (Fully Annealed Heat Treatment Condition – Ferrite/Pearlite Microstructure ^{(1) (2)})	
Material Designation	Density (g/cm ³)
PF-1020	7.81
PF-1040	7.81
PF-1060	7.81
PF-1140	7.79
PF-1160	7.78

- (1) Quench-hardening and tempering will reduce the density values. Normalized samples may have lower density values than fully annealed materials.
- (2) Based on the method described in Smith, D. W. "Calculation of the Pore-Free Density of P/M Steels: Role of Microstructure and Composition", *The International Journal of Powder Metallurgy*, Vol. 28, No. 3, 1992, p. 259. Calculations based on 350 ppm max oxygen content and all oxygen combined as 3MnO·Al₂O₃·3SiO₂.

To select a material optimum in both properties and cost-effectiveness, it is essential that the part application be discussed with the PF parts producer. Both the purchaser and producer should, in order to avoid possible misconceptions or misunderstandings, agree on the following conditions prior to the manufacture of a PF component: material selection, chemical composition and alloying method, proof testing, typical property values and processes which may affect the part application.

PF Steel Material Properties – Inch-Pound Units

Material Code Designation	Heat Treat Condition (B)	TYPICAL VALUES(A)							
		Tensile Properties				Hardness Rockwell	Impact Energy ft.-lbf	Compressive Yield Strength 0.1% offset 10 ³ psi	Mean Fatigue Limit 10 ³ psi
		Ultimate Strength 10 ³ psi	Yield Strength 0.2% offset 10 ³ psi	Elongation (in 1 inch) %	Reduction of Area %				
PF-1020	N	64	50	30	55	70 HRB	20	55	N/D
PF-1040	N	75	45	27	50	75 HRB	3	60	N/D
	Q	140	120	12	42	30 HRC	15	110 (C)	N/D
PF-1060	N	90	55	17	37	90 HRB	2	65	45
	Q	125	100	12	30	26 HRC	4	95 (C)	N/D
	Q	195	175	8	25	40 HRC	10	130 (C)	N/D

(A) Mechanical property data derived from laboratory prepared test specimens sintered and forged under commercial manufacturing conditions.
(B) N: normalized condition (austenitize and cool in still air).
Q: quenched and tempered condition (austenitized, oil quenched and tempered 1 hour at temperature to Rockwell C hardness level indicated).
(C) Since the cross section of the tensile yield test specimen is smaller than the compressive yield specimen a direct correspondence between tensile and compressive yield strength data is not possible.

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