

MPIF STANDARD
35

Materials Standards

for

P/M
STRUCTURAL
PARTS

2003 edition



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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."

*For P/M 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 P/M Structural 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 conventional P/M materials for structural parts. It does not apply to P/M self-lubricating bearings, powder forged (P/F) materials or metal injection molded (MIM) products which are covered in separate editions of MPIF Standard 35. The same materials may appear in more than one section of the standard depending upon their common use, e.g., some structural materials may also be used in bearing applications and vice versa. Each section of this standard is divided into subsections based on the various types of P/M materials in common commercial use within that section. Notes at the beginning of each subsection discuss the characteristics of that 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 P/M 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 - 2003

Materials Standards for P/M Structural Parts

Explanatory Notes and Definitions

Minimum Value Concept

The Metal Powder Industries Federation has adopted the concept of *minimum* strength values for P/M materials for use in a structural application. These strength values may be used in designing for a P/M part application. It should be noted that the powder metallurgy process offers equivalent minimum tensile strength values over a wide range of materials. It is seen as an advantage of the process that equivalent strengths can be developed by varying chemical composition, particle configuration, density and/or processing techniques.

As an aid to the user in selecting materials, in addition to minimum strength values, *typical* values for other properties are listed. This makes it possible for the user to select and specify the exact P/M material and properties most suitable for a specific application. The data provided define values for listed materials and display typical mechanical properties achieved under commercial manufacturing procedures. Physical and mechanical property performance characteristics may be changed by the use of processing steps beyond those designated in this standard. *To select a material optimum in both properties and cost-effectiveness, it is essential that the part application be discussed with the P/M parts manufacturer.*

Minimum Value

For structural P/M materials in the *as-sintered* condition the minimum value is expressed in terms of the *yield* strength (0.2% offset method) in thousand pounds per square inch (10^3 psi) or megapascals (MPa).

For structural P/M materials in the *heat treated* condition (quenched and tempered), the minimum value expressed is *ultimate* tensile strength in thousand pounds per square inch (10^3 psi) or megapascals (MPa). When P/M materials are heat treated, tensile properties and hardness increase; however, the failure mode is such that 0.2% offset yield points are not always attainable. The yield and ultimate tensile strengths are therefore approximately the same for heat treated materials. (See **Heat Treatment** and **Sinter Hardening** page 3).

For soft magnetic materials the maximum value is expressed in terms of the coercive field in oersteds $\times 10$.

The tensile properties utilized for establishing this Standard were obtained from tensile specimens prepared specifically for evaluating P/M materials. Tensile properties of specimens machined from commercial parts may vary from those obtained from individual specimens pre-

pared specifically for evaluating P/M materials.

(See *MPIF Standard 10* for additional details on tensile test specimens.)

What "Minimum Value" Means When Specifying a P/M Material

The recommended method of demonstrating minimum strength values is through the use of a static or dynamic proof test (see **Proof Testing** page 6) 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 analyzed statistically 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.

Acceptable strength can also be demonstrated on tensile or transverse rupture test specimens. These should be of the same lot of material, have the same density as the parts themselves and should be sintered and heat treated along with the production parts. This method becomes less reliable when the parts are much larger than the test specimens. If transverse rupture test specimens are selected as the evaluating medium, manufacturer and purchaser must agree on minimum values because these may be lower than the typical values shown in the tables of data.

The least desirable method for demonstrating minimum property is to machine a test specimen from the part itself. This is particularly difficult with small or heat treated parts.

If this method is to be used, manufacturer and purchaser must agree on the location from which the test specimen will be removed. This is necessary because density and strength can vary from point to point in a complex P/M multi-level part. The tensile data reported in this specification are based on a 0.190 in. (4.83 mm) diameter gauge section, 1.0 in. (25.4 mm) long for hardened specimens, and 0.140 in. (3.56 mm) thick as-pressed specimens as per Figure 1 in MPIF Standard 10 for as-sintered values. If other sizes are used, it must be demonstrated separately that equivalent results are obtained.

Utilization of MPIF Standard 35 to specify a P/M material means that unless the purchaser and manufacturer

have agreed otherwise, the material will have the minimum value specified in the Standard. It is understood that if a test specimen is used to determine this value it shall have the dimensions and other characteristics determined by the manufacturer and prepared specifically for evaluating such material under conditions equivalent to those used in the manufacture of the part.

(See **Material Properties** beginning on page 10.)

Typical Value

For each P/M material listed, a set of *typical* values is shown for properties in addition to strength, e.g., density, hardness, elongation, etc., some or all of which may be important for a specific application. Typical values at the densities shown were determined by interpolation and extrapolation of graphs of average mechanical properties versus density. The mechanical property data were derived from interlaboratory studies for the sintering and heat-treating of test bars.

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 discussed thoroughly with the P/M parts manufacturer before establishing the specification. Required property values, other than those expressed as minimum, should be separately specified for each P/M part, based on its intended use.

Chemical Composition

The chemical composition table for each material lists the principal elements by minimum and maximum mass percentage. “Other elements” include the total other elements and is reported as a maximum percentage. These may include other minor elements added for specific purposes. The chemical composition table for each material specifies the basic material before any oil impregnation, resin impregnation, steam treating or other such process has taken place.

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. The impact energy (unnotched Charpy) and transverse rupture strength data were derived from standard test specimens designed for this purpose. (See

MPIF Standards 40 and 41 for additional details.)

Hardness values of heat treated specimens are given first as apparent hardness and second, when available, as microindentation hardness values. Microindentation hardness values shown as Rockwell C were converted from 100 g load (0.981 N) Knoop microindentation hardness measurements. (See *MPIF Standard 51*.)

Heat Treatment

Ferrous P/M parts containing 0.3% or higher combined carbon can be quench hardened and tempered for increased strength, hardness and wear resistance. The percentages of carbon and other alloying elements effectively combined in the material and its density, determine the degree of hardening possible for any given quench condition. Microindentation hardness values of 650 HK₁₀₀ (56 HRC) and higher can be obtained by quench hardening.

The recommended procedure for heat treatment and/ or carburization of ferrous P/M parts is with a gas type atmosphere or vacuum. The use of liquid salts is not recommended because of the possibility of surface absorption and subsequent bleed-out of the salts and internal corrosion. Low density parts may carburize throughout while higher density parts (7.0 g/cm³ or higher) may develop a carburized case. Process control is necessary to ensure that specified carbon levels are maintained.

(See *MPIF Standard 52* for additional details.)

Tempering or stress relief is required after quenching for maximum strength and durability; typically one (1) hour at temperature per 1 in. (25.4 mm) of section thickness. A compromise between hardness and such properties as impact energy is necessary because the tempering temperature to achieve surface hardness will not necessarily provide optimum strength properties. The tempering temperature is a major factor in determining final hardness.

Sinter Hardening

Some P/M materials may, in effect, be quench hardened during the cooling cycle following sintering; this is known as sinter hardening. This is especially the case with prealloyed nickel, molybdenum and manganese steels containing admixed copper. It is also true for martensitic stainless steels. Tempering or stress relief after hardening is required for maximum strength and durability.

Surface Finish

The overall finish and surface reflectivity of P/M materials depends on density, tool condition and secondary operations. Conventional profilometer readings give an erroneous impression of surface finish because a different surface condition exists from that found on the machined or ground surfaces of wrought materials. Conventional readings take into account the peaks and valleys of machined surfaces,

while P/M parts have a series of very smooth surfaces that are interrupted with varying sized pores.

Effective surface smoothness of P/M components compares favorably with ground or ground and polished surfaces of wrought and cast components. Surface finish can be improved further by secondary operations such as repressing, honing, burnishing or grinding. The surface finish requirements and methods of determination must be established by mutual agreement between purchaser and producer, considering end use of the part. (See *MPIF Standard 58* for additional details.)

Microstructure

The examination of the microstructure of a P/M part can serve as a diagnostic tool and reveal the degree of sintering and other metallurgical information critical to the powder metallurgy process. There are several observations common to most sintered materials, as described briefly below. Comments on specific materials will be found in the subsections devoted to those particular materials.

In selecting a section of a P/M 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 part should show 20% of its area as pores.

Parts with open porosity can be impregnated with liquid epoxy during preparation of the specimen for microstructural examination. This will help prevent distortion of the voids during grinding or polishing.

Sintered parts are always examined first in the unetched condition. In an average sinter there will be very few or no original particle boundaries seen at 200X. The more rounded the pores, the higher the strength, ductility and impact resistance.

For mixes of iron and carbon with low nickel and copper content, the approximate carbon content can be estimated by the area fraction of pearlite. For an iron-copper carbon alloy with less than 5% copper, one hundred percent pearlite corresponds to approximately 0.8% combined carbon. Lesser amounts of pearlite mean proportionally less carbon. In nickel steels, even with only 2 to 4% by mass of nickel, the nickel-rich areas occupy a substantial area fraction. These should be discounted in estimating the area fraction of pearlite. The nickel-rich areas should not be confused with ferrite. Loss of surface carbon is generally to be avoided because of the lower hardness and wear resistance. If a part is to have 0.6-0.9% carbon, decarburization is indicated if a surface layer measures less than 0.6% carbon. Minor amounts of surface decarburization are seldom a problem but if the layer is deeper than 0.010 in. (0.25 mm) it may be necessary to prove that function has not been impaired.

Heat treated ferrous parts generally show a mixture of martensite and fine pearlite. This is particularly true for the P/M nickel and carbon steels which are of low hardenability. The maximum tensile strength has been found to occur in parts with 10% to 35% fine pearlite. The prealloyed steels usually show all martensite because of their greater hardenability. The formation of a carbide network embrittles the martensite in a hardened part and is generally to be avoided. Minor amounts of carbide in the outer 0.005 in. (0.13 mm) of parts usually cause no problem. Minor amounts of retained austenite toughen the martensitic structure and usually cause no problem. Higher percentages are generally avoided because retained austenite can transform to brittle martensite in service.

In preparing P/M specimens for microstructural examination, the following etchants and procedures are recommended. Ferrous parts containing carbon are generally etched in 2% nital or concentrated picral. Austenitic stainless steel may be etched in glyceresia (10 mL HNO₃, 20 mL HCl, 30 mL glycerine) by swabbing for one to two minutes. Discard solution after 30 minutes. Marble's reagent may also be used (10 grams Cu₂SO₄, 50 mL HCl, 50 mL H₂O). Swab 5 to 60 seconds. To develop grain boundaries in small grain clusters in bronze, etch by swabbing for 10 to 20 seconds in a mixture of 2 grams of K₂Cr₂O₇, 4 mL of concentrated NaCl solution, 8 mL of H₂SO₄, 100 mL of H₂O. To develop a red color in copper-rich regions in bronze, etch by swabbing 10 to 20 seconds in 4% FeCl₃ and H₂O. For etching brasses, swab for 20 seconds in a solution of 5 mL of NH₄OH, three drops of H₂O₂, 5 mL of H₂O. This solution is unstable and should be replaced after 20 minutes of usage. The K₂Cr₂O₇ solution may also be used on nickel silver.

P/M Material Code Designation

The P/M material code designation or identifying code in the case of structural P/M parts defines a specific material as to chemistry and minimum strength expressed in 10³ psi. For example, FC-0208-60 is a P/M copper steel material containing nominal 2% copper and 0.8% combined carbon possessing a minimum yield strength of 60 X 10³ psi (60,000 psi) (410 MPa) in the as-sintered condition.

A coding system offers a convenient means for designating both the chemistry and minimum strength value of any standard P/M material. It is based on the system established by the industry with the addition of a two- or three-digit suffix representing minimum strength in place of a suffix letter indicating density range. The density is given for each standard material as one of the typical values.

Code designations in this Standard and revisions thereof apply only to P/M materials for which MPIF Standards have been adopted. In order to avoid confusion, the MPIF coding system is intended for use only with such materials and should not be used to create non-standard materials.

The explanatory notes, property values, and other contents of this Standard have no application to any other materials.

In the coding system, the prefix letters denote the general type of material. For example, the prefix “CT” represents copper (C) and tin (T) which is known as bronze.

Prefix Letter Code

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

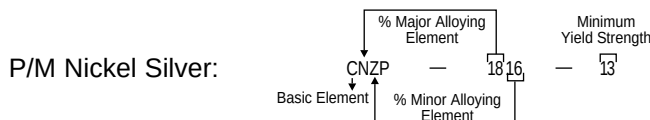
Prefix and Four Digit Code

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.

For improved machinability lead is sometimes the third alloying element in a nonferrous alloy system. Lead will only be indicated by the letter “P” in the prefix. The percentage of lead or any other minor alloying element which happens to be excluded from the four digit nomenclature, is represented in the “Chemical Composition” which 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.

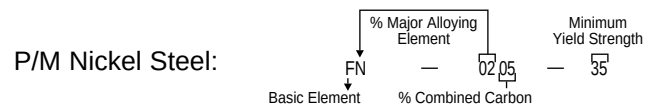
Combined carbon content in ferrous materials is designated by the last two digits in the four-digit series. The individual chemical composition tables show limits of carbon content for each alloy.

The range of carbon that is metallurgically combined is

indicated by the coding system. The combined carbon level can be estimated metallographically for sintered P/M steels that have a well defined ferrite/pearlite microstructure. For compositions with very low allowable carbon levels (< 0.08 %) total carbon determined analytically (ASTM E 1019) is the recommended method.

NOTE: When a clear pearlite to ferrite ratio cannot be determined metallographically, such as with heat treated steels and materials made from prealloyed base powders or diffusion alloyed powders, then determination of combined carbon by normal metallographic methods is not practical. It is recommended that the carbon content of these materials should be reported as total carbon using the combustion method (ASTM E 1019). The test method used should be identified in the report and identified as metallurgically combined carbon or total carbon. While total carbon will approximate the combined carbon in many materials, free graphite and other carbonaceous material will raise the total carbon content above the level of combined carbon, possibly causing the total carbon content to exceed the combined carbon level specified for the material.

Illustration of P/M ferrous material designation coding:



In the case of P/M stainless steels and P/M prealloyed low alloy steels, the four-digit series is replaced with a designation derived from modifications of the American Iron and Steel Institute alloy coding system, e.g., SS-316L-15, FL-4605-100HT.

When a P/M prealloyed low alloy steel powder is modified with elemental additions, a three or four alpha-numeric designator will be used, e.g., FLN-4205-40, FLN-4205-105HT.

As with other P/M materials, the suffix number denotes the specified minimum strength value expressed in 10^3 psi.

In the case of soft magnetic alloys, the phosphorus containing irons are treated differently, since the amount of phosphorus is usually less than 1%. To indicate more accurately the nominal amount of phosphorus the code takes the nominal percent phosphorus, multiplies by 100 and uses this number for the first two digits in the code. The last two digits remain “00” since no carbon is required. For example, the iron-0.45% phosphorus alloy would be designated as: FY-4500.

Suffix Digit Code

The two- or three-digit suffix represents the minimum strength value, expressed in 10^3 psi, that the user can expect from the P/M material possessing that chemistry.

Examples of P/M Material Designation Coding

Material	Compositions by Percent	Complete Code for Material, Composition & Minimum Strength (10 ³ psi)	
P/M Bronze	Cu-90, Sn-10	CT-1000-13	
P/M Nickel Silver	Cu-64, Ni-18, Zn-18	CNZ-1818-17	
P/M Nickel Silver	Cu-64, Ni-18, Zn-16, Pb-2	CNZP-1816-13	
P/M Brass	Cu-90, Zn-10	CZ-1000-11	
P/M Brass	Cu-78, Zn-20, Pb-2	CZP-2002-12	
		As-sintered	Heat Treated
P/M Iron	Fe, 99, C-0.2	F-0000-20	—
P/M Steel	Fe, 98, C-0.8	F-0008-35	F-0008-85HT
P/M Copper Steel	Fe, 96, Cu-2, C-0.8	FC-0208-60	FC-0208-95HT
P/M Nickel Steel	Fe, 96, Ni-2, C-0.5	FN-0205-35	FN-0205-180HT
P/M Infiltrated Iron	Fe, 78, Cu-20	FX-2000-25	—
P/M Infiltrated Steel	Fe, 77, Cu-20, C-0.8	FX-2008-60	FX-2008-90HT
P/M Phosphorus Iron	Fe, P-0.45	FY-4500-20W	
P/M Stainless Steel (austenitic)	AISI 316 (modified)	SS-316N1-25	—
P/M Stainless Steel (martensitic)	AISI 410 (modified)		SS-410-90HT
P/M 4600 Steel (prealloyed)	AISI 4600 (modified), C-0.5	FL-4605-45	FL-4605-140HT
P/M 4200 Steel (prealloyed+addition)	AISI 4200 (modified), Ni-1.5, C-0.5	FLN-4205-40	FLN4205-105HT

In the as-sintered condition the strength is tensile yield; in the heat treated condition, it is ultimate tensile.

(See **Minimum Value** page 2.)

Suffix Letter Code

When the code designation “HT” appears after the suffix digits it is understood that the P/M material specified has been quench hardened and tempered and that the strength represented is ultimate tensile in 10³ psi.

In the case of the soft magnetic alloys the suffix does NOT designate yield or tensile strength, but rather the maximum coercive field (10 times the value in oersteds) and an alphabetic designator for the minimum density as follows:

Designator	Minimum Density (g/cm ³)
U	6.5
V	6.7
W	6.9
X	7.1
Y	7.3
Z	7.4

For example, a pure iron material at a minimum density of 6.9 g/cm³ and coercive field of 2.3 Oe would be designated as F-0000-23W. The iron-0.45% phosphorus alloy at a 7.1 g/cm³ minimum density and coercive field of 2.0 Oe would be designated as FY-4500-20X.

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 requirement of the finished part should be con-

sidered, e.g., static and dynamic loading, corrosion resistance, wear resistance, machinability, brazability, pressure tightness 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 the final grade selection.

(See **Powder Metallurgy Design Manual** published by the Metal Powder Industries Federation.)

Proof Testing

It is highly recommended that a proof test and/or destructive test method be established between the purchaser and the P/M parts manufacturer to ensure that the actual P/M 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 special fixture or sub-assembly for use by both the P/M parts manufacturer 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.

Chemical Analysis

The chemical composition of P/M materials is determined by standard analytical test methods, such as optical emission spectroscopy, atomic absorption spectroscopy, inductively coupled plasma spectroscopy, X-ray fluorescence, or titration/gavimetric (see ASTM standards for appropriate test methods). For the elements carbon, nitrogen, oxygen or sulfur the ASTM E 1019 test method describes appropriate combustion-infra-red absorption and inert gas fusion methods. The carbon method of ASTM E 1019 determines total carbon content, which may

include both metallurgically combined carbon (in steel) as well as free carbon (such as soot, oil or graphite). Metallurgically combined carbon can be estimated metallographically for sintered structural steels with a microstructure of ferrite and pearlite. For compositions with very low allowable carbon levels (< 0.08 %) total carbon is the recommended method. If chemical composition is critical to the product application then identification of the appropriate analytical test method should be agreed upon by the manufacturer and purchaser during contract review.

Density

Density is expressed in grams per cubic centimeter (g/cm³). "Dry density" is the mass per unit volume of an unimpregnated P/M part. "Wet density" is the mass per unit volume of a P/M part impregnated with oil or other non-metallic materials. Normally, density of structural components is reported on a dry basis and density of bearings on a fully impregnated basis.

A method commonly used is as follows:

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

Where:

- D = density, in grams per cubic centimeter,
- A = mass of the unimpregnated sample in air, in grams,
- B = mass of the oil impregnated sample in air, in grams,
- C = mass of the oil impregnated sample immersed in water, in grams, and
- E = mass (tare) of suspending wire or basket, in water, in grams.
- ρ_w = density of water at test temperature, in grams per cubic centimeter.

Note 1. Mass A, B and C shall be determined to within 0.1 percent.

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 water in the amount of 0.05 to 0.1 volume percent.

Note 3. Water density may usually be approximated as 1 gram per cubic centimeter; at usual 66 °F-72 °F (19 °C-22 °C) test temperatures, a density of 0.998 grams per cubic centimeter is more precise.

(See *MPIF Standard 42* for additional details.)

Density, and therefore mechanical properties, may vary within a P/M part. The location of critical areas should be identified on the engineering drawing.

Transverse Rupture Strength

Transverse rupture strength, expressed in 10³ psi (MPa), is the stress, calculated from the bending strength formula, required to break a specimen of a given dimension. The specimen is supported near the ends with a load applied

midway between the fixed centerline of the supports. From the value of the break load, the transverse rupture strength can be calculated as follows:

$$S = \frac{3 \times P \times L}{2 \times T^2 \times W} \times \frac{1}{1000}$$

Where:

- S = transverse rupture strength, in 10³ psi (MPa),
- P = break load in pounds (N),
- L = distance between the supporting members of the test fixture, in inches (mm) (usually 1.000 inch) (25.4 mm),
- T = thickness of the piece in inches (mm), and
- W = width of the piece, in inches (mm).

This strength formula is strictly valid only for non-ductile materials; however, it is widely used for materials that bend before fracture, and is useful for establishing comparative strengths. Data for such materials are included as *typical* properties in this Standard.

(See *MPIF Standard 41* for additional details.)

Impact Energy

Impact energy, measured in foot-pounds (J), is a measurement of the energy absorbed in fracturing a specimen with a single blow. The unnotched Charpy specimen is most commonly used in powder metallurgy.

(See *MPIF Standard 40* for additional details.)

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 10* for additional details.)

Yield Strength

Yield strength, expressed in 10³ psi (MPa), is the load at which a material exhibits a 0.2% offset from proportionality on a stress-strain curve in tension divided by the original cross-sectional area.

(See *MPIF Standard 10* for additional details.)

Elongation

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

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 in. (9.53 mm) diameter by 1.05 in. (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 in. (9.53 mm) diameter test specimen. Due to variation in hardenability among the heat treated steels listed in the data tables, the compressive yield strength data are appropriate only for 0.375 in. (9.53 mm) sections. Typically, smaller cross sections have higher compressive yield strengths and larger sections somewhat lower strengths due to the hardenability response. 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.

Shear Strength

The yield strength in shear for a limited number of P/M steel alloys (both sintered and heat treated) was determined using a hollow torsional specimen. The results found the shear yield equal to 55% of the tensile yield for these materials, confirming the established ratio for wrought steels.

Macrohardness (Apparent)

The hardness value of a P/M part when using a conventional indentation hardness tester is referred to as "apparent hardness" because it represents a combination of matrix hardness plus the effect of porosity. Apparent hardness measures the resistance to indentation or brinelling. Following is a recommended procedure for measuring the apparent hardness of a P/M material:

- A. Specify a region for evaluation.
- B. Remove any burrs that might affect the indentation hardness reading both on indenter and support surfaces.
- C. Obtain a minimum of five hardness readings per part, eliminating gross anomalies.
- D. Average the readings.
- E. Report the average results to the nearest whole number.

Because of possible density variations in a finished P/M part, the location of critical apparent hardness measurements should be specified on the engineering drawing of the purchased part. The manufacturer and purchaser should agree on the hardness, the measuring procedure, and the hardness scale, e.g., HRB or HRC, for each part tested. Also, because of the effect of possible void closure as a result of polishing or machining, on hardness readings, the surface condition should be specified and agreed upon by the manufacturer and purchaser.

(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.

Care should be taken in converting Knoop to HRC because the usual conversion chart is based on a 500 gf load, while the recommended load for a P/M material is 100 gf. A description of the microstructure must be reported. It is important to be sure that the specimen is polished so as to reveal all porosity. If the indenter strikes an undischarged 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 3 indentations be made, anomalous readings discarded, and an average taken of the remainder.

(See *MPIF Standard 51* for additional details.)

Fatigue Limit and Fatigue Strength

Fatigue strength, expressed in units of 10^3 psi (MPa), is the maximum alternating stress that can be sustained for a specific 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 P/M ferrous materials, like wrought ferrous materials, fatigue strengths of 10^7 cycles duration using smooth, unnotched specimens on R. R. Moore testing machines are considered to be sustainable indefinitely and are therefore stated as fatigue limits (also termed endurance limits). By contrast, nonferrous P/M materials do not have 10^7 cycle maximum fatigue strengths sustainable for indefinite times and therefore these stress limits remain as simply the 10^7 cycle fatigue strengths. The fatigue limits in this standard were generated through statistical analysis of rotating bending fatigue strength data. Due to the limited number of data points available for the analysis, these fatigue limits were determined as the 90% survival stress, i.e. the fatigue stress at which 90% of the test specimens survived 10^7 cycles.

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.

Machinability

See page 32.

Hardenability

See page 33.

Coefficient of Thermal Expansion (CTE)

See page 34.

Fracture Toughness

See page 34.

Corrosion Resistance

See page 35.

Axial Fatigue

See page 36.

Rolling Contact Fatigue (RCF)

See page 37.

Soft Magnetic Alloys

This standard includes four characteristic properties of soft magnetic materials, measured under DC magnetization conditions. These properties are illustrated in the graph and described below:

B_m is the maximum magnetic induction measured in the material at a specific magnetizing field. For this standard the B_m value was measured at a field of 15 Oe.

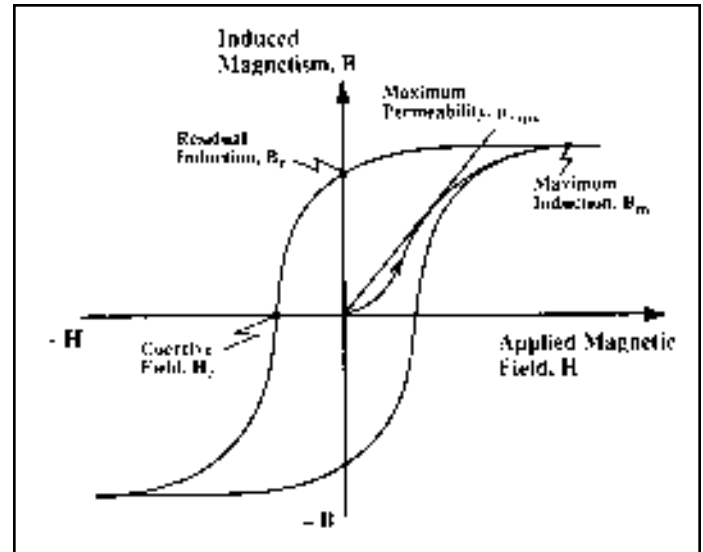
B_r is the remnant magnetic induction that remains in the material after the magnetizing field has been reduced to zero from the maximum applied field.

H_c is the coercive field strength or magnetic field remaining in the material when the magnetic induction has been decreased to zero.

μ_{max} is the maximum slope of the initial magnetization curve.

SI Units

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



Idealized Magnetic Hysteresis Curve

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

Comparable Standards

Standards for powder metallurgy structural and soft magnetic parts have been issued by both ASTM and ISO. The ASTM standards for structural parts were adapted from MPIF Standard 35 and use the MPIF nomenclature system. The ISO standards provide information on various powder metallurgy materials.

ASTM B 783	Standard Specification for Materials for Ferrous Powder Metallurgy (P/M) Structural Parts
ASTM B 823	Standard Specification for Materials for Nonferrous Powder Metallurgy (P/M) Structural Parts
ASTM A 811	Specification for Soft Magnetic Iron Parts Fabricated by Powder Metallurgy Techniques
ASTM A 839	Specification for Phosphorus Iron Fabricated by Powder Metallurgy Techniques
ASTM A 904	Specification for 50 Nickel - 50 Iron Powder Metallurgy Soft Magnetic Alloys
ISO 5755	Sintered Metal Materials-Specifications
IEC 404-8-9	Standard Specification for Soft Magnetic Materials

Additional P/M materials and properties 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 www.mpif.org to access data that will appear in the next printed edition of this standard.

Iron and Carbon Steel

This subsection covers P/M materials manufactured from elemental iron powders that are essentially free of other alloying elements except carbon.

Material Characteristics

These materials are manufactured by pressing and sintering iron powder with or without graphite additions to introduce carbon. When the final density is to be 7.0 g/cm³ or more, it may be reached by pressing, presintering, repressing and sintering.

Application

Unalloyed P/M iron (F-0000) materials are typically used for lightly loaded structural applications and also for structural parts requiring self-lubrication when strength is not critical. At high densities, unalloyed iron is used for soft magnetic applications. (See pages 30 and 58.)

P/M carbon steel (F-0005) materials are used primarily where moderate strength and hardness combined with

machinability (drilling, tapping, lathe turning, milling, etc.) are desired.

P/M steels with higher carbon content (F-0008) are used when loading is moderate. F-0008 is more difficult to machine than F-0005. F-0008 and F-0005 materials may be heat treated to enhance strength and wear resistance. They may also be steam treated for improved shelf life, pore closure and to increase hardness.

All of the iron and carbon steel materials with densities of 7.0 g/cm³ or less may be oil impregnated when self-lubricating properties are required.

Microstructure

The carbon content of a sintered structure can be estimated metallographically from the area fraction of pearlite where 100% pearlite is equivalent to approximately 0.8% carbon. Carbon dissolves rapidly in iron; therefore, after about five minutes at 1900 °F (1038 °C) it is unusual to see uncombined carbon.

Chemical Composition, % – Iron and Carbon Steel

Material Designation	Fe	C	Element
F-0000	Bal.	0.0	Minimum
	Bal.	0.3	Maximum
F-0005	Bal.	0.3	Minimum
	Bal.	0.6	Maximum
F-0008	Bal.	0.6	Minimum
	Bal.	0.9	Maximum

Other Elements: 2.0% maximum may include other minor elements added for specific purposes.

NOTES:

- Suffix numbers represent *minimum* strength values in 10³ psi (see page 2); yield in the as-sintered condition and ultimate in the heat treated condition.
- Mechanical property data derived from laboratory prepared test specimens sintered under commercial manufacturing conditions.
- Additional data in preparation will appear in subsequent editions of this standard.
- Yield and ultimate tensile strength are approximately the same for heat treated materials (see page 3).
- Tempering temperature for heat treated (HT) materials: 350 °F (177 °C).

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

To select a material optimum in both properties and cost-effectiveness, it is essential that the part application be discussed with the P/M parts manufacturer. (See **Explanatory Notes: Minimum Value Concept** page 2.) Both the purchaser and the manufacturer should, in order to avoid possible misconceptions or misunderstandings, agree on the following conditions prior to the manufacturer of a P/M part: minimum strength value, grade selection, chemical composition, proof testing, typical property values and processes that may affect the part application.

P/M Material Properties



Iron-Copper and Copper Steel

This subsection covers P/M materials produced from admixtures of elemental iron powder and elemental copper powder with or without graphite powder (carbon). The proportions of each depend on the strength levels required and whether the material is to be used in the as-sintered or heat treated condition.

Material Characteristics

Because graphite diffuses readily into an iron powder matrix during sintering, combined carbon of 0.8% or more is attainable. Copper powder is added to increase strength, hardness and wear resistance. Wear resistance can be enhanced by heat treatment. When the final density is to be 7.0 g/cm³ or more, these materials may be manufactured by pressing, presintering, repressing and sintering.

Application

P/M iron-copper and copper steel materials find wide usage in medium strength structural applications. Copper contents of 2% are typical. When secondary machining is

required, combined carbon contents of less than 0.5% should be specified. Material in this category also can be heat treated to increase strength and wear resistance. Higher copper content materials (in the range of 5%) are recommended when maximum wear resistance is required and when heat treating is not practical. Low density parts can be oil-impregnated for self-lubrication in use.

Microstructure

Admixed copper powder melts at approximately 1980°F (1082°C), flows between the iron particles and into small pores, and thus helps the sintering of the steel. Normally sintered alloys with 2% copper show little or no undissolved copper. At higher percentages, the copper will be seen as a separate phase. The copper dissolves in the iron but does not penetrate to the center of the larger iron particles. When copper melts, it diffuses or migrates leaving behind fairly large pores. These pores remain and can easily be seen in the microstructure.

Chemical Composition, % – Iron-Copper and Copper Steel

Material Designation	Fe	Cu	C	Element
FC-0200	Bal.	1.5	0.0	Minimum
	Bal.	3.9	0.3	Maximum
FC-0205	Bal.	1.5	0.3	Minimum
	Bal.	3.9	0.6	Maximum
FC-0208	Bal.	1.5	0.6	Minimum
	Bal.	3.9	0.9	Maximum
FC-0505	Bal.	4.0	0.3	Minimum
	Bal.	6.0	0.6	Maximum
FC-0508	Bal.	4.0	0.6	Minimum
	Bal.	6.0	0.9	Maximum
FC-0808	Bal.	7.0	0.6	Minimum
	Bal.	9.0	0.9	Maximum
FC-1000	Bal.	9.0	0.0	Minimum
	Bal.	11.0	0.3	Maximum

Other Elements: 2.0% maximum may include other minor elements added for specific purposes.

NOTES:

- (A) Suffix numbers represent *minimum* strength values in 10³ psi (see page 2); yield in the as-sintered condition and ultimate in the heat treated condition.
- (B) Mechanical property data derived from laboratory prepared test specimens sintered under commercial manufacturing conditions.
- (C) Additional data in preparation will appear in subsequent editions of this standard.
- (D) Yield and ultimate tensile strength are approximately the same for heat treated materials (see page 3).
- (E) Tempering temperature for heat treated (HT) materials: 350°F (177°C).

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

To select a material optimum in both properties and cost-effectiveness, it is essential that the part application be discussed with the P/M parts manufacturer. (See **Explanatory Notes: Minimum Value Concept** page 2.) Both the purchaser and the manufacturer should, in order to avoid possible misconceptions or misunderstandings, agree on the following conditions prior to the manufacturer of a P/M part: minimum strength value, grade selection, chemical composition, proof testing, typical property values and processes that may affect the part application.

Iron-Copper and Copper Steel

P/M Material Properties

TYPICAL VALUES (B)												
TENSILE PROPERTIES				ELASTIC CONSTANTS		Unnotched Charpy Impact Energy ft-lbf	Transverse Rupture Strength 10³psi	Compressive Yield Strength (0.1%) 10³psi	HARDNESS		Fatigue Limit 90% Survival 10³psi	Density g/cm³
Ultimate Strength 10³psi	Yield Strength (0.2%) 10³psi	Elongation (in 1 in.) %	Young's Modulus 10³psi	Poisson's Ratio	Macro (apparent) Rockwell				Micro-indentation (converted)			
FC-0200 -15 -18 -21 -24	25 28 31 34	20 23 26 29	1.0 1.5 1.5 2.0	14.0 16.5 16.5 19.5	0.25 0.25 0.25 0.27	4.5 5.0 5.5 6.0	45 51 56 63	18 21 23 26	11 HRB 18 26 36	N/D	10 11 12 13	6.0 6.3 6.6 6.9
FC-0205 -30 -35 -40 -45	35 40 50 60	35 40 45 50	<1.0 <1.0 <1.0 <1.0	14.0 16.5 17.5 21.5	0.25 0.25 0.25 0.27	<2.0 3.0 5.0 8.0	60 75 95 115	35 40 45 50	37 HRB 48 60 72	N/D	13 15 21 31	6.0 6.3 6.7 7.1
FC-0205 -60HT -70HT -80HT -90HT	70 80 90 100	(D)	<0.5 <0.5 <0.5 <0.5	16.0 15.5 18.5 20.5	0.25 0.25 0.27 0.27	2.5 3.5 4.5 5.5	95 110 120 135	57 71 86 95	19 HRC 25 31 36	58 HRC 58 58 58	27 30 34 38	6.2 6.5 6.8 7.0
FC-0208 -30 -40 -50 -60	35 50 60 75	35 45 55 65	<1.0 <1.0 <1.0 <1.0	12.5 16.5 17.5 22.5	0.25 0.25 0.25 0.28	<2.0 2.0 5.0 7.0	60 90 125 155	40 45 50 55	50 HRB 61 73 84	N/D	13 17 23 33	5.8 6.3 6.7 7.2
FC-0208 -50HT -65HT -80HT -95HT	65 75 90 105	(D)	<0.5 <0.5 <0.5 <0.5	15.0 17.5 18.5 21.5	0.25 0.27 0.27 0.27	2.5 3.5 4.5 5.5	95 110 130 150	58 72 91 105	20 HRC 27 35 43	60 HRC 60 60 60	25 30 35 40	6.1 6.4 6.8 7.1
FC-0505 -30 -40 -50	44 58 71	36 47 56	<0.5 <0.5 <1.0	12.5 16.5 17.5	0.25 0.25 0.25	3.0 4.5 5.0	77 102 124	50 54 58	51 HRB 62 72	N/D	17 22 27	5.8 6.3 6.7
FC-0508 -40 -50 -60	58 68 82	50 60 70	<0.5 <0.5 <1.0	13.0 16.5 18.5	0.25 0.25 0.27	3.0 3.5 4.5	100 120 145	58 63 68	60 HRB 68 80	N/D	22 26 31	5.9 6.3 6.8
FC-0808 -45	55	50	<0.5	14.0	0.27	3.0	85	62	65 HRB	N/D	21	6.0
FC-1000 -20	30	26	<1.0	14.0	0.27	3.5	53	33	15 HRB	N/D	11	6.0

MINIMUM VALUES (A)			
Material Designation Code	Minimum Strength (A) (E)		
	Yield	Ultimate	
	10 ³ psi		
FC-0200 -15	15		
-18	18		
-21	21		
-24	24		
FC-0205 -30	30		
-35	35		
-40	40		
-45	45		
FC-0205 -60HT		60	
-70HT		70	
-80HT		80	
-90HT		90	
FC-0208 -30	30		
-40	40		
-50	50		
-60	60		
FC-0208 -50HT		50	
-65HT		65	
-80HT		80	
-95HT		95	
FC-0505 -30	30		
-40	40		
-50	50		
FC-0508 -40	40		
-50	50		
-60	60		
FC-0808 -45	45		
FC-1000 -20	20		

2003 Edition
Approved: 1984
Revised: 1987, 1990, 1994, 1997, 2000



Iron-Nickel and Nickel Steel

This subsection covers P/M materials manufactured from admixtures of elemental iron powder, elemental nickel powder and graphite powder (carbon), if required. Nickel additions are typically in the range of 1 to 4%. If no carbon is present the product is designated P/M iron-nickel.

The proportions of each element used will depend on the strength levels required and whether the material is to be used in the as-sintered or heat treated condition. Other elements, such as molybdenum, also may be admixed when appropriate, within the ranges shown for other elements.

Material Characteristics

Unlike carbon, complete diffusion of nickel into the iron matrix is not attained with normal commercial sintering cycles. The heterogeneous metallurgical structures developed contain nickel-rich phases which can impart significant improvements in toughness, tensile properties and hardenability. When the final density is to be 7.0 g/cm³ or more, these materials may be manufactured by pressing, presintering, repressing and sintering.

Application

P/M nickel steels are used typically for heat treatable structural parts requiring the combination of strength, wear resistance and impact properties.

Microstructure

The fine nickel powder mixed with the iron and carbon normally do not completely diffuse during ordinary sintering. As-sintered nickel steels show light colored, austenitic nickel-rich islands with needles of martensite or bainite around their edges. Sintering at elevated temperatures, above 2100°F (1149°C), will reduce the volume fraction of austenitic nickel-rich islands. In the heat treated condition, the nickel-rich islands are light colored, austenitic at their center and with martensitic needles at the peripheries (viewed at 1000X). This heterogeneous structure is normal. The matrix is martensite and, depending on quenching rate, 0-35% fine pearlite.

Chemical Composition, % – Iron-Nickel and Nickel Steel

Material Designation	Fe	Ni	C	Cu	Element
FN-0200	Bal.	1.0	0.0	0.0	Minimum
	Bal.	3.0	0.3	2.5	Maximum
FN-0205	Bal.	1.0	0.3	0.0	Minimum
	Bal.	3.0	0.6	2.5	Maximum
FN-0208	Bal.	1.0	0.6	0.0	Minimum
	Bal.	3.0	0.9	2.5	Maximum
FN-0405	Bal.	3.0	0.3	0.0	Minimum
	Bal.	5.5	0.6	2.0	Maximum
FN-0408	Bal.	3.0	0.6	0.0	Minimum
	Bal.	5.5	0.9	2.0	Maximum

Other Elements: 2.0% maximum may include other minor elements added for specific purposes.

NOTES:

- (A) Suffix numbers represent *minimum* strength values in 10³ psi (see page 2); yield in the as-sintered condition and ultimate in the heat treated condition.
- (B) Mechanical property data derived from laboratory prepared test specimens sintered under commercial manufacturing conditions.
- (C) Additional data in preparation will appear in subsequent editions of this standard.
- (D) Yield and ultimate tensile strength are approximately the same for heat treated materials (see page 3).
- (E) Tempering temperature for heat treated (HT) materials: 500°F (260°C).

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

To select a material optimum in both properties and cost-effectiveness, it is essential that the part application be discussed with the P/M parts manufacturer. (See **Explanatory Notes: Minimum Value Concept** page 2.) Both the purchaser and the manufacturer should, in order to avoid possible misconceptions or misunderstandings, agree on the following conditions prior to the manufacturer of a P/M part: minimum strength value, grade selection, chemical composition, proof testing, typical property values and processes that may affect the part application.

Iron-Nickel and Nickel Steel

P/M Material Properties

TYPICAL VALUES (B)												
TENSILE PROPERTIES				ELASTIC CONSTANTS		Unnotched Charpy Impact Energy ft-lbf	Transverse Rupture Strength 10³ psi	Compressive Yield Strength (0.1%) 10³ psi	HARDNESS		Fatigue Limit 90% Survival 10³ psi	Density g/cm³
Ultimate Strength 10³ psi	Yield Strength (0.2%) 10³ psi	Elongation (in 1 in.) %	Young's Modulus 10³ psi	Poisson's Ratio	Macro (apparent) Rockwell				Micro-indentation (converted)			
25	17	3.0	16.5	0.25	10.0	50	16	55 HRF	N/D	10	6.6	
35	25	5.0	20.5	0.27	20.0	80	18	75		13	7.0	
40	30	10.0	23.5	0.28	50.0	105	20	80		15	7.3	
40	25	1.5	16.5	0.25	6.0	65	25	44 HRB	N/D	14	6.6	
50	30	2.5	19.5	0.27	12.0	100	30	59		18	6.9	
60	35	4.0	22.5	0.28	21.0	125	35	69		22	7.2	
70	40	5.5	24.5	0.28	34.0	150	40	78	26	7.4		
90	(D)	<0.5	16.5	0.25	3.5	120	60	23 HRC	55 HRC	26	6.6	
120		<0.5	19.5	0.27	4.5	160	80	29		35	6.9	
145		<0.5	21.5	0.27	6.0	190	100	33		42	7.1	
160		<0.5	22.5	0.28	7.0	215	120	36		47	7.2	
185	55	<0.5	24.5	0.28	9.5	250	140	40	55	54	7.4	
45		35	1.5	17.5	0.25	5.5	85	35	63 HRB	N/D	16	6.7
55		40	1.5	19.5	0.27	8.0	105	40	71		20	6.9
70		45	2.0	21.5	0.27	11.0	130	45	77		25	7.1
80	50	2.5	23.5	0.28	16.0	155	50	83	28		7.3	
90	55	3.0	24.5	0.28	21.0	170	55	88	32	7.4		
90	(D)	<0.5	17.5	0.25	4.0	120	99	26 HRC	57 HRC	29	6.7	
120		<0.5	19.5	0.27	4.5	150	124	31		38	6.9	
145		<0.5	20.5	0.27	5.5	185	136	35		46	7.0	
170		<0.5	22.5	0.28	7.0	220	162	39		54	7.2	
195	60	<0.5	24.5	0.28	8.0	250	188	42	57	62	7.4	
40		30	<1.0	15.5	0.25	4.5	65	33	49 HRB	N/D	14	6.5
60		40	3.0	20.5	0.27	14.5	120	40	71		22	7.0
90		50	4.5	24.5	0.28	33.5	175	45	84		32	7.4
85	(D)	<0.5	15.5	0.25	4.0	115	67	19 HRC	55 HRC		26	6.5
110		<0.5	18.5	0.27	5.0	145	89	25		34	6.8	
135		<0.5	20.5	0.27	6.5	200	103	31		42	7.0	
160		<0.5	23.5	0.28	9.5	245	124	37		49	7.3	
185	60	<0.5	24.5	0.28	13.0	280	132	40	55	57	7.4	
45		40	1.0	15.5	0.25	4.0	75	37	67 HRB	N/D	16	6.5
65		50	1.0	19.5	0.27	7.5	115	50	78		23	6.9
80		60	1.0	22.5	0.28	11.0	150	59	87		28	7.2

MINIMUM VALUES (A)				
Material Designation Code	Minimum Strength (A) (E)		Yield	Ultimate
	Yield	Ultimate		
	10³ psi			
FN-0200 -15 -20 -25	15			
	20			
	25			
FN-0205 -20 -25 -30 -35	20			
	25			
	30			
	35			
FN-0205 -80HT -105HT -130HT -155HT -180HT		80		
		105		
		130		
		155		
FN-0208 -30 -35 -40 -45 -50	30			
	35			
	40			
	45			
FN-0208 -80HT -105HT -130HT -155HT -180HT		80		
		105		
		130		
		155		
FN-0405 -25 -35 -45	25			
	35			
	45			
FN-0405 -80HT -105HT -130HT -155HT -180HT		80		
		105		
		130		
		155		
FN-0408 -35 -45 -55	35			
	45			
	55			

MINIMUM VALUES (A)			
Material Designation Code	Minimum Strength (A) (E)		
	Yield	Ultimate	
	10 ³ psi		
FN-0200 -15 -20 -25	15		
	20		
	25		
FN-0205 -20 -25 -30 -35	20		
	25		
	30		
FN-0205 -80HT -105HT -130HT -155HT -180HT	35		
		80	
		105	
FN-0208 -30 -35 -40 -45 -50		130	
		155	
		180	
FN-0208 -80HT -105HT -130HT -155HT -180HT	30		
	35		
	40		
FN-0405 -25 -35 -45	45		
	50		
		80	
FN-0405 -80HT -105HT -130HT -155HT -180HT		105	
		130	
		155	
FN-0408 -35 -45 -55		180	
	25		
	35		
FN-0408 -35 -45 -55	45		
		80	
		105	
FN-0408 -35 -45 -55		130	
		155	
		180	
FN-0408 -35 -45 -55	35		
	45		
	55		

Low Alloy Steel

This subsection covers P/M materials manufactured from prealloyed low alloy steel powders using nickel, molybdenum and manganese as the major alloying elements. Graphite powder (carbon) is admixed with the prealloyed steel powder to provide the necessary level of carbon in the final material. Varying amounts of elemental powders may also be admixed.

Material Characteristics

Prealloyed steel powders are normally used in medium to high density P/M applications. These materials provide greater hardenability than is possible with admixed copper or nickel steels. When the final density is to be 7.0 g/cm³ or more, these materials may be manufactured by pressing, presintering, repressing and sintering.

Application

Low alloy P/M steels are used typically where high

performance materials capable of being heat treated are required. These alloys will provide high strength and wear resistance after heat treatment.

Microstructure

The eutectoid product in the as-sintered condition is not the same as the fine pearlite of the plain iron-carbon systems. The carbide plates are coarser and spaced in such a way that the proeutectoid ferrite is not clearly defined; therefore, it is difficult to estimate the combined carbon content metallographically. Low alloy steels may contain up to 5% unalloyed iron. Alloys containing copper additions may show martensite in the as-sintered structure.

After heat treatment, the prealloyed steels exhibit a uniform tempered martensitic structure. Elemental powder additions to the prealloyed steel produce a heterogeneous microstructure similar to the admixed steels and improve strength. (See pages 10 and 12.)

Chemical Composition, % – Low Alloy Steel

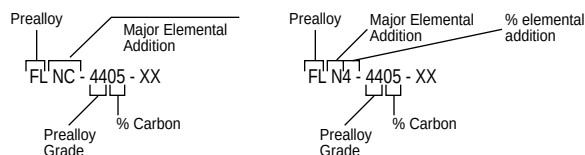
Material Designation	Fe	C	Ni	Mo	Cu	Element
FL-4205	Bal.	0.4	0.35	0.50	—	Minimum
	Bal.	0.7	0.55	0.85	—	Maximum
FL-4405	Bal.	0.4	—	0.75	—	Minimum
	Bal.	0.7	—	0.95	—	Maximum
FL-4605	Bal.	0.4	1.70	0.40	—	Minimum
	Bal.	0.7	2.00	1.10	—	Maximum
FLN-4205	Bal.	0.4	1.35*	0.49	—	Minimum
	Bal.	0.7	2.50*	0.85	—	Maximum
FLN2-4405	Bal.	0.4	1.00	0.65	—	Minimum
	Bal.	0.7	3.00	0.95	—	Maximum
FLN4-4405	Bal.	0.4	3.00	0.65	—	Minimum
	Bal.	0.7	5.00	0.95	—	Maximum
FLN6-4405	Bal.	0.4	5.00	0.65	—	Minimum
	Bal.	0.7	7.00	0.95	—	Maximum
FLNC-4405	Bal.	0.4	1.00	0.65	1.0	Minimum
	Bal.	0.7	3.00	0.95	3.0	Maximum

*At least 1% of the nickel is admixed as elemental powder.

Other Elements: 2.0% maximum may include other minor elements added for specific purposes.

To select a material optimum in both properties and cost-effectiveness, it is essential that the part application be discussed with the P/M parts manufacturer. (See **Explanatory Notes: Minimum Value Concept** page 2.) Both the purchaser and the manufacturer should, in order to avoid possible misconceptions or misunderstandings, agree on the following conditions prior to the manufacturer of a P/M part: minimum strength value, grade selection, chemical composition, proof testing, typical property values and processes that may affect the part application.

The following material designation codes have been established. Material property data are under consideration for these new alloys.



NOTES:

- Suffix numbers represent *minimum* strength values in 10³ psi (see page 2); yield in the as-sintered condition and ultimate in the heat treated condition.
- Mechanical property data derived from laboratory prepared test specimens sintered under commercial manufacturing conditions.
- Additional data in preparation will appear in subsequent editions of this standard.
- Yield and ultimate tensile strength are approximately the same for heat treated materials (see page 3).
- Tempering temperature for heat treated (HT) materials: 350 °F (177 °C).
- Alloys containing copper additions may have lower impact and fatigue limit as compared to the values in the data tables.

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