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Standard Specification for Powder Forged (P/F) Ferrous Structural Parts[1]

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1. Scope

1.1 This specification covers powder forged ferrous materials fabricated by hot densification of atomized prealloyed or iron powders and intended for use as structural parts.

1.2 This specification covers powder forged parts made from the following materials:

1.2.1 *Compositions*:

1.2.1.1 P/F-10XX Carbon Steel (produced from atomized iron powder and graphite powder),

1.2.1.2 P/F-10CXX Copper-Carbon Steel (produced from atomized iron powder, copper and graphite powders),

1.2.1.3 P/F-11XX Carbon Steel with manganese sulfide for enhanced machinability (produced from atomized iron powder, manganese sulfide, and graphite powders),

1.2.1.4 P/F-11CXX Copper-Carbon Steel with manganese sulfide for enhanced machinability (produced from atomized iron powder, copper, manganese sulfide, and graphite powders),

1.2.1.5 P/F-42XX Nickel-Molybdenum Steel (produced from prealloyed atomized iron-nickel-molybdenum powder and graphite powder),

1.2.1.6 P/F-46XX Nickel-Molybdenum Steel (produced from prealloyed atomized iron-nickel-molybdenum powder and graphite powder),

1.2.1.7 P/F-44XX Molybdenum Steel (produced from prealloyed atomized iron-molybdenum powder and graphite powder), and

1.2.1.8 P/F-49XX Molybdenum Steel (produced from prealloyed atomized iron-molybdenum powder and graphite powder).

NOTE 1—Alloy composition designations are modifications of the AISI-SAE nomenclature. For example: 10CXX designates a plain carbon steel containing copper and XX amount of carbon. Compositional limits of alloy and impurity elements may be different from the AISI-SAE limits. Chemical composition limits are specified in Section 6.

NOTE 2—XX designates the forged carbon content, in hundredths of a percent, that is specified by the purchaser for the application. For a given specified carbon content, the permissible limits shall be as specified in 6.2.

1.2.2 *Grades*:

1.2.2.1 *Grade A*—Density equivalent to a maximum of 0.5 % porosity. The minimum density of those sections of the powder forged part so designated by the applicable part drawing shall not be less than the value specified in Table 1.

1.2.2.2 *Grade B*—Density equivalent to a maximum of 1.5 % porosity. The minimum density of those sections of the powder forged part so designated by the applicable part drawing shall not be less than the value specified in Table 1.

1.3 Property values stated in inch-pound units are the standard. Conversion factors to SI units may be approximate.

2. Referenced Documents

2.1 *ASTM Standards:*

B 243 Terminology of Powder Metallurgy[2]

B 311 Test Method for Density Determination for Powder Metallurgy (P/M) Materials Containing Less Than Two Percent Porosity[2]

B 795 Test Method for Determining the Percentage of Alloyed or Unalloyed Iron Contamination Present in Low-Alloy Powder Forged (P/F) Steel Parts[2]

B 796 Test Method for Nonmetallic Inclusion Level of Low-Alloy Powder Forged (P/F) Steel Parts[2]

B 797 Test Methods for Surface Finger Oxide Penetration Depth and Presence of Interparticle Oxide Networks in Low-Alloy Powder Forged (P/F) Steel Parts[2]

E 3 Methods of Preparation of Metallographic Specimens[3]

E 8 Test Methods for Tension Testing of Metallic Materials[3]

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials[3]

E 23 Test Methods for Notched Bar Impact Testing of Metallic Materials[3]

E 350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron[4]

E 415 Test Method for Optical Emission Vacuum Spectrometric Analysis of Carbon and Low-Alloy Steel[5]

E 562 Practice for Determining Volume Fraction by Systematic Manual Point Count[3]

E 1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, and in Iron, Nickel, and Cobalt Alloys[4]

[1] This specification is under the jurisdiction of ASTM Committee B-9 on Metal Powders and Metal Powder Productsand is the direct responsibility of Subcommittee B09.11 on Near Full Density Powder Metallurgy Materials.

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[2] *Annual Book of ASTM Standards*, Vol 02.05.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 03.05.

[5] *Annual Book of ASTM Standards*, Vol 03.06.

TABLE 1 Minimum Density for Selected Powder Forged Steel Compositions (Fully Annealed Heat Treatment Condition—Ferrite/Pearlite Microstructure)[A]

Chemical Composition	Density (g/cm^3)	
	Grade A (0.5 % porosity)[B]	Grade B (1.5 % porosity)[B]
P/F-1040	7.81	7.74
P/F-1060	7.81	7.73
P/F-10C40	7.81[C]	7.74[C]
P/F-10C60	7.81[C]	7.73[C]
P/F-1140	7.79	7.71
P/F-1160	7.78	7.70
P/F-11C40	7.79[C]	7.71[C]
P/F-11C60	7.79[C]	7.71[C]
P/F-4220	7.82	7.74
P/F-4240	7.81	7.73
P/F-4260	7.80	7.72
P/F-4420	7.82	7.74
P/F-4440	7.81	7.73
P/F-4460	7.81	7.73
P/F-4620	7.82	7.74
P/F-4640	7.81	7.73
P/F-4660	7.81	7.73
P/F-4680	7.80	7.72
P/F-4920	7.83	7.75
P/F-4940	7.82	7.74
P/F-4960	7.81	7.74

[A] Quench-hardening and tempering will reduce the density values. Normalized samples may have lower density values then fully annealed materials.

[B] 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 $3MnO \cdot Al_2O_3 \cdot 3SiO_2$.

[C] The method described by Smith is not considered applicable to steels with admixed copper additions. Pore-free densities for these materials were determined by experiment.

TABLE 2 Chemical Composition Requirements for Powder Forged Parts Chemical Composition (Weight %)

Element	P/F-10XX	P/F-10CXX	P/F-11XX	P/F-11CXX
Nickel, max	0.10	0.10	0.10	0.10
Molybdenum, max	0.05	0.05	0.05	0.05
Manganese	0.10–0.25	0.10–0.25	0.30–0.60[A]	0.30–0.60[A]
Copper	0.30 max	1.8–2.2	0.30 max	1.8–2.2
Chromium, max	0.10	0.10	0.10	0.10
Sulfur, max	0.025	0.025	0.23[A]	0.23[A]
Silicon, max	0.03	0.03	0.03	0.03
Phosphorus, max	0.03	0.03	0.03	0.03
Carbon	[B]	[B]	[B]	[B]
Oxygen	[C]	[C]	[C]	[C]
Total Iron	Balance[D]	Balance[D]	Balance[D]	Balance[D]
Element	P/F-42XX	P/F-46XX	P/F-44XX	P/F-49XX
Nickel	0.40–0.50	1.75–2.00	0.10 max	0.10 max
Molybdenum	0.55–0.65	0.50–0.60	0.80–0.95	1.4–1.6
Manganese	0.20–0.35	0.10–0.25	0.08–0.18	0.08–0.18
Copper, max	0.15	0.15	0.15	0.15
Chromium, max	0.10	0.10	0.10	0.10
Sulfur, max	0.03	0.03	0.03	0.03
Silicon, max	0.03	0.03	0.03	0.03
Phosphorus, max	0.03	0.03	0.03	0.03
Carbon	[B]	[B]	[B]	[B]
Oxygen	[C]	[C]	[C]	[C]
Total Iron	Balance[D]	Balance[D]	Balance[D]	Balance[D]

[A] Covers manganese sulfide (MnS) additions of from 0.3 to 0.5 %. The manganese content in solution is similar to P/F-10XX or P/F-10CXX, that is, 0.10 to 0.25 %.

[B] Carbon content shall be as specified by the purchaser.

[C] When required, maximum oxygen content shall conform to the amount specified by purchaser. See S1.

[D] For information only. Quantitative determination of this element is not required.

E 1077 Test Method for Estimating the Depth of Decarburization of Steel Specimens[3]

2.2 *Other Standards:*

J 423 SAE Recommended Practice, Methods of Measuring Case Depth[6]

3. Terminology

3.1 Definitions—Definitions of powder metallurgy terms can be found in Terminology B 243. Additional descriptive information is available in the Related Material Section of Vol. 02.05 of the *Annual Book of ASTM Standards.*

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *core region*—a core region is one where there is either no decarburization as determined by the procedure in 9.3.4 or there is no hardened surface as determined by the procedure in S2.2.

3.2.2 *critical region*—a critical region of a part is one that requires a density level or a microstructural characteristic to be separately specified.

4. Ordering Information

4.1 Orders for parts conforming to this specification shall include the following:

4.1.1 Alloy composition, including carbon content (see 1.2.1, Section 6, and Table 2),

4.1.2 Grade (minimum density requirement—see 1.2.2 and Section 7),

4.1.3 Heat treatment condition and hardness (see 8.1.3, 8.1.4, and 8.2.3),

4.1.4 Location of critical regions (see 3.2.1),

4.1.5 Whether functional or mechanical property testing is required, what type of testing is required, and what performance level is required (see 8.1.1, 8.1.2, 8.2.1, and 8.2.2),

4.1.6 Whether the purchaser desires that his representative inspect or witness the inspection and testing of the material prior to shipment (see 11.1 and 11.2),

4.1.7 Whether there are special microstructural requirements (see Section 9 and SR4),

4.1.8 Whether certification of the material is required (see Section 13),

4.1.9 Whether there is a maximum forged-oxygen content (see SR1),

4.1.10 Whether case hardening is required (see SR2),

4.1.11 Whether there is a maximum area percent porosity requirement for critical regions (see 3.2.1 and SR3), and

4.1.12 ASTM designation and year of issue.

5. Materials and Manufacture

5.1 Make the structural parts by hot forging of powder metallurgy (P/M) preforms in confined dies with or without subsequent heat treatment. Prepare P/M preforms by pressing, or pressing and sintering material conforming to the designations in 1.2.1 and meeting the chemical compositions specified

[6] Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

in Section 6 and Table 2.

6. Chemical Composition

6.1 The hot forged material shall conform to the requirements prescribed in Table 2.

6.2 Unless otherwise specified, the hot forged carbon content shall not deviate from that specified by the purchaser by more than ±0.05 weight percent.

6.3 Determine chemical analysis for the elements copper, chromium, manganese, molybdenum, nickel, phosphorus, and silicon in accordance with Method E 415 (preferred method) or Test Method E 350. Determine analysis for the elements carbon and sulfur in accordance with Test Method E 1019.

7. Density Requirement

7.1 The minimum density of those sections of powder forged parts so designated by the applicable part drawing shall not be less than the values specified in Table 1.

7.2 Determine the density of complete parts or sections of parts in accordance with Test Method B 311.

8. Mechanical Property Requirements

8.1 *Mechanical Properties*:

8.1.1 The preferred method for verifying the acceptable performance of a finished part is for the manufacturer and the purchaser to agree upon a qualification test to be performed on an 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.

8.1.2 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.

8.1.3 The core hardness range of parts shall be in accordance with the applicable part drawing or purchase order.

8.1.4 The surface hardness range of parts shall be in accordance with the applicable part drawing or purchase order.

8.1.5 Typical mechanical properties of materials covered by this specification are shown in Appendix X1.

8.2 *Mechanical Property Test Methods*:

8.2.1 *Tensile Test Method*—When requested, take tensile test specimens from parts in accordance with the applicable part drawing or purchase order. Test tensile specimens in accordance with Test Method E 8. Determine yield strength by the 0.2 % offset method.

8.2.2 *Impact Energy Test Method*—When requested, take Charpy V-notch impact test bars from parts in accordance with the applicable part drawing or purchase order. Test impact bars in accordance with Test Methods E 23; at room temperature, or, at a temperature agreed between the manufacturer and purchaser.

8.2.3 *Hardness Test Method*—Determine hardness measurements in accordance with Test Methods E 18. Make core hardness measurements on sectioned parts within the core region of the part. Determine surface hardness measurements in accordance with the applicable part drawing on the original forged surface, or, if machined, on the machined part surface.

9. Microstructure Requirements

9.1 *Surface Finger Oxide Penetration*:

9.1.1 The maximum depth of penetration of surface finger oxides from the finished part surface, for each designated critical region of a powder forged part, shall not exceed that agreed upon between the manufacturer and purchaser. Designate critical regions by the applicable part drawing or purchase order.

9.1.2 Determine the surface finger oxide penetration in accordance with Test Method B 797.

9.2 *Interparticle Oxide Networks*:

9.2.1 The extent of any interparticle oxide networks in each designated critical region of a powder forged part shall not exceed that agreed upon between the manufacturer and purchaser. Designate critical regions on the applicable part drawing or purchase order.

9.2.2 Determine the interparticle oxide networks in accordance with Test Method B 797.

9.3 *Decarburization Depth*:

9.3.1 The maximum depth of complete decarburization (only ferrite present) of surfaces of powder forged parts shall not exceed that agreed between the manufacturer and purchaser.

9.3.2 The depth of total decarburization (total decarburization = complete decarburization + partial decarburization), the depth at which core carbon content is reached, shall not exceed that agreed between the manufacturer and purchaser. Alternatively, for quenched and tempered parts, an effective decarburization depth (depth to a specified hardness) may be specified.

9.3.3 Determine the depth of complete decarburization by the microscopical method in accordance with Test Method E 1077.

9.3.4 Depth of total or effective decarburization.

9.3.4.1 *Slow-Cooled or Normalized Parts*—Estimate the depth of total decarburization of slow-cooled or normalized parts microscopically from the sum of the depths of complete and partial decarburization in accordance with Test Method E 1077.

9.3.4.2 *Quenched and Tempered Parts*—Determine the depth of effective decarburization by the microhardness method in accordance with Test Method E 1077.

9.4 *Nonmetallic Inclusion Level*:

9.4.1 The nonmetallic inclusion level of Grade A powder forged parts shall not exceed that specified by the applicable part drawing or purchase order.

9.4.2 Determine the nonmetallic inclusion level in accordance with Test Method B 796. For materials that contain manganese sulfide additions, modify the inclusion assessment to count only those discrete inclusions greater than or equal to 100 μm maximum caliper (Feret's) diameter.

NOTE 3—Porosity dominates the mechanical properties of Grade B parts. Inclusion assessment of Grade B parts is therefore not necessary.