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Standard Specification for Powder Forged (P/F) Ferrous Structural Parts¹

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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 Metallurgy²

B 311 Test Method for Density Determination for Powder Metallurgy (P/M) Materials Containing Less Than Two Percent Porosity²

B 795 Test Method for Determining the Percentage of Alloyed or Unalloyed Iron Contamination Present in Low-Alloy Powder Forged (P/F) Steel Parts²

B 796 Test Method for Nonmetallic Inclusion Level of Low-Alloy Powder Forged (P/F) Steel Parts²

B 797 Test Methods for Surface Finger Oxide Penetration Depth and Presence of Interparticle Oxide Networks in Low-Alloy Powder Forged (P/F) Steel Parts²

E 3 Methods of Preparation of Metallographic Specimens³

E 8 Test Methods for Tension Testing of Metallic Materials³

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials³

E 23 Test Methods for Notched Bar Impact Testing of Metallic Materials³

E 350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron⁴

E 415 Test Method for Optical Emission Vacuum Spectrometric Analysis of Carbon and Low-Alloy Steel⁵

E 562 Practice for Determining Volume Fraction by Systematic Manual Point Count³

E 1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, and in Iron, Nickel, and Cobalt Alloys⁴

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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 than 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 · Al₂O₃ · 3SiO₂.

^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.

E 1077 Test Method for Estimating the Depth of Decarburization of Steel Specimens³

2.2 Other Standards:

J 423 SAE Recommended Practice, Methods of Measuring Case Depth⁶

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),

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.

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.

9.5 *Cross Product Contamination:*

9.5.1 The amount of unalloyed iron contamination of P/F-42XX, P/F-46XX, P/F-44XX, or P/F-49XX, or alloyed iron contamination of P/F-10XX, P/F-10CXX, P/F-11XX, or P/F-11CXX parts shall not exceed that agreed between the manufacturer and purchaser.

9.5.2 Determine alloyed or unalloyed iron contamination in accordance with Test Method B 795.

10. Sampling

10.1 *Lot*—Unless otherwise specified, a lot shall consist of parts of the same form and dimensions, produced from a single mixed powder batch, compacted, and processed under the same conditions and submitted for inspection at one time.

10.2 *Chemical Analysis*—When a full chemical analysis is requested on the purchase order, either the chemical analysis provided by the powder supplier for the specific lot of powder used to make the parts, or, testing of the forged parts, may be used to meet this requirement. However, the forged carbon content, and oxygen content when specified, shall be measured on the forged parts. Take samples from the core area of the part. For spectrometric analysis, the sample shall consist of a single solid piece carefully cut using a cutting fluid to prevent overheating. After cutting, wash the piece with low residue acetone to remove the cutting fluid and dry with 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. Take care to keep dirt and foreign substances out of the sample.

10.3 *Mechanical Tests*— The manufacturer and purchaser

shall mutually agree on a representative number of specimens for qualification testing or mechanical property testing.

11. Inspection

11.1 Inspection of the parts supplied under this specification shall be the responsibility of the manufacturer or a mutually agreed upon third party.

11.2 If the purchaser desires that his representative inspect or witness the inspection and testing of the material prior to shipment, such a requirement shall be part of the purchase order.

12. Rejection and Rehearing

12.1 Parts that fail to conform to the requirements of this specification may be rejected. Rejection should be reported to the manufacturer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the manufacturer or supplier may make claim for a rehearing.

13. Certification

13.1 When specified in the purchase order, furnish a manufacturer's certification to the purchaser that the parts were manufactured, sampled, tested, and inspected in accordance with this specification and have been found to meet the requirements. When specified in the purchase order, furnish a report of the test results.

14. Keywords

14.1 powder forged (P/F) parts; powder forged (P/F) steels; powder forging (P/F)

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the purchase order.

S1. Forged Oxygen Content

S1.1 The maximum permissible oxygen content of forged parts shall be as specified by the applicable part drawing or the purchase order.

S1.2 Take at least one sample for analysis from each lot. Take samples from the core region of the part. The sample shall consist of a single solid piece carefully cut with a low speed precision cut-off wheel using cutting fluid to prevent overheating. After cutting, wash the sample with low residue acetone to remove the cutting fluid and dry with compressed air.

S1.3 Determine analysis for oxygen using the inert gas fusion method described in Test Method E 1019. (Calibration standards should be selected with an oxygen level appropriate to the level of oxygen in the powder forged sample.)

S2. Case Hardening

S2.1 The effective case depth of surface hardened (for example, carburized or carbonitrided) powder forged steel parts shall meet the range specified by the applicable part drawing or as agreed upon by the manufacturer and purchaser.

S2.2 Determine the effective case depth of surface hardened

parts in accordance with SAE Recommended Practice, J 423, using the hardness traverse procedure.

S3. Critical Region Porosity

S3.1 The maximum area percent porosity plus oxide inclusions of 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.

S3.2 Determine the critical region percentage porosity plus oxide inclusions in accordance with Practice E 562 or by an agreed upon automated image analysis method.

S4. Microstructural Uniformity

S4.1 Microstructural uniformity requirements for powder forged parts shall be agreed upon between the manufacturer and purchaser.

S4.2 Remove a metallographic specimen representing the specified region or regions of the part for examination. Prepare the specimen following the procedures described in Methods E 3.

APPENDIX

(Nonmandatory Information)

X1. MECHANICAL PROPERTIES OF POWDER FORGED (P/F) FERROUS STRUCTURAL PARTS

X1.1 Data for typical mechanical properties of powder forged ferrous structural parts are given in Table X1.1. The data do not constitute a part of the specification. They are merely intended to indicate to the purchaser the typical mechanical properties that may be expected from specimens machined

from sample blanks of the chemical composition, density, and heat treatment condition specified.

TABLE X1.1 Typical Mechanical Properties of Powder Forged Steels

Chemical Composition	Grade	Heat ^A Treat	Hardness (Rockwell)	UTS ^B (10 ³ psi)	0.2 % Offset Yield (10 ³ psi)	Elongation (in 1 in.), %	R of A, %	Charpy V-notch Impact Energy, ft · lbf
P/F-1040	A	N	80 HRB	75	45	27	50	4
P/F-1040	A	Q	30 HRC	140	120	12	42	15
P/F-1040	B	N	...	...	...	...	...	...
P/F-1040	B	Q	...	...	...	...	...	...
P/F-1060	A	N	80 HRB	85	50	22	39	2
P/F-1060	A	Q	40 HRC	195	175	8	25	10
P/F-1060	B	N	...	...	...	...	...	...
P/F-1060	B	Q	...	...	...	...	...	...
P/F-10C40	A	N	97 HRB	100	70	15	38	3
P/F-10C40	B	N	...	...	...	...	...	...
P/F-10C60	A	N	23 HRC	115	100	11	27	2
P/F-10C60	B	N	...	...	...	...	...	...
P/F-1140	A	N	...	...	...	...	...	...
P/F-1140	A	Q	...	...	...	...	...	...
P/F-1140	B	N	...	...	...	...	...	...
P/F-1140	B	Q	...	...	...	...	...	...
P/F-1160	A	N	...	...	...	...	...	...
P/F-1160	A	Q	...	...	...	...	...	...
P/F-1160	B	N	...	...	...	...	...	...
P/F-1160	B	Q	...	...	...	...	...	...
P/F-11C40	A	N	...	...	...	...	...	...
P/F-11C40	B	N	...	...	...	...	...	...
P/F-11C60	A	N	28 HRC	130	90	11	23	3
P/F-11C60	B	N	...	...	...	...	...	...
P/F-4220	A	N	84 HRB	75	55	25	55	25
P/F-4220	A	Q	26 HRC	120	100	23	55	...
P/F-4220	A	Q	45 HRC	150	130	11	43	...
P/F-4220	B	N	...	...	...	...	...	...
P/F-4220	B	Q	...	...	...	...	...	...
P/F-4240	A	N	93 HRB	90	60	18	45	12
P/F-4240	A	Q	28 HRC	125	115	21	50	...
P/F-4240	A	Q	45 HRC	210	200	10	33	...
P/F-4240	B	N	...	...	...	...	...	...
P/F-4240	B	Q	...	...	...	...	...	...
P/F-4260	A	N	22 HRC	110	75	15	30	5
P/F-4260	A	Q	30 HRC	130	120	18	45	...
P/F-4260	A	Q	45 HRC	245	225	10	29	...
P/F-4260	B	N	...	...	...	...	...	...
P/F-4260	B	Q	...	...	...	...	...	...
P/F-4420	A	N	...	...	...	...	...	...
P/F-4420	A	Q	...	...	...	...	...	...
P/F-4420	B	N	...	...	...	...	...	...
P/F-4420	B	Q	...	...	...	...	...	...
P/F-4440	A	N	...	...	...	...	...	...
P/F-4440	A	Q	...	...	...	...	...	...
P/F-4440	B	N	...	...	...	...	...	...
P/F-4440	B	Q	...	...	...	...	...	...
P/F-4460	A	N	...	...	...	...	...	...
P/F-4460	A	Q	...	...	...	...	...	...
P/F-4460	B	N	...	...	...	...	...	...
P/F-4460	B	Q	...	...	...	...	...	...
P/F-4620	A	N	96 HRB	80	60	20	50	25
P/F-4620	A	Q	28 HRC	140	130	24	65	60
P/F-4620	A	Q	38 HRC	190	155	20	55	35

TABLE X1.1 *Continued*

Chemical Composition	Grade	Heat ^A Treat	Hardness (Rockwell)	UTS ^B (10 ³ psi)	0.2% Offset Yield (10 ³ psi)	Elongation (in 1 in.), %	R of A, %	Charpy V-notch Impact Energy, ft · lbf
P/F-4620	B	N	...	...	...	...	...	...
P/F-4620	B	Q	28 HRC	140	130	7	22	6
B	Q	38 HRC	190	150	5	14	4	...
P/F-4640	A	N	98 HRB	95	80	18	40	10
P/F-4640	A	Q	38 HRC	190	155	17	50	25
P/F-4640	A	Q	48 HRC	230	190	11	40	12
P/F-4640	B	N	...	...	...	...	...	...
P/F-4640	B	Q	38 HRC	190	155	3	13	4
P/F-4640	B	Q	48 HRC	230	190	3	7	4
P/F-4660	A	N	23 HRC	115	85	15	30	5
P/F-4660	A	Q	38 HRC	190	155	15	40	20
P/F-4660	A	Q	48 HRC	230	190	10	30	10
P/F-4660	B	N	...	...	...	...	...	...
P/F-4660	B	Q	38 HRC	185	155	5	14	4
P/F-4660	B	Q	48 HRC	230	190	3	8	4
P/F-4680	A	N	...	...	...	...	...	...
P/F-4680	A	Q	48 HRC	230	200	8	15	6
P/F-4680	B	N	...	...	...	...	...	...
P/F-4680	B	Q	...	...	...	...	...	...
P/F-4920	A	N	...	...	...	...	...	...
P/F-4920	A	Q	...	...	...	...	...	...
P/F-4920	B	N	...	...	...	...	...	...
P/F-4920	B	Q	...	...	...	...	...	...
P/F-4940	A	N	...	...	...	...	...	...
P/F-4940	A	Q	...	...	...	...	...	...
P/F-4940	B	N	...	...	...	...	...	...
P/F-4940	B	Q	...	...	...	...	...	...
P/F-4960	A	N	...	...	...	...	...	...
P/F-4960	A	Q	...	...	...	...	...	...
P/F-4960	B	N	...	...	...	...	...	...
P/F-4960	B	Q	...	...	...	...	...	...

^A N = Normalized.

^A Q = Quench-hardened and tempered to the hardness listed.

^B To convert $\left\{ \text{strength} (10^3 \text{ psi}) / \text{impact energy} (ft \cdot lbf) \right\}$ to $\left\{ \text{MPa} / J \right\}$ multiply by $\left\{ 6.895 / 1.356 \right\}$.

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