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Standard Specification for Iron-Phosphorus Powder Metallurgy (P/M) Parts for Soft Magnetic Applications¹

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¹ This specification is under the jurisdiction of ASTM Committee A06 on Magnetic Properties and is the direct responsibility of Subcommittee A06.02 on Materials Specifications.

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1. Scope

1.1 This specification covers parts produced from iron-phosphorus powder metallurgy materials. These parts are used in magnetic applications requiring higher permeability and electrical resistivity and lower coercive ~~force~~ field strength than attainable routinely from parts produced from iron powder.

1.2 Two powder types are covered; Type I containing nominally 0.45 % phosphorus, and Type II containing nominally 0.8 % phosphorus.

1.3 This specification deals with P/M parts in the sintered or annealed condition. Should the sintered parts be subjected to any secondary operation that causes mechanical strain, such as machining or sizing, they should be resintered or annealed.

1.4 The values stated in ~~either~~ customary (cgs-emu and inch-pound) units ~~or SI units~~ are to be regarded ~~separately~~ as standard. ~~Within the text, the SI units are shown in brackets. The values stated given in each system parentheses are mathematical conversions to SI units which are provided for information only and are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with this specification. considered standard.~~

2. Referenced Documents

2.1 ASTM Standards:

A 34/A 34M Practice for Procurement, Testing and Sampling of Magnetic Materials²

A 596/A 596M Test Method for Direct- Current Magnetic Properties of Materials Using the Ballistic Method and Ring Specimens²

A 773/A 773M Test Method for ~~D-C~~ dc Magnetic Properties of Materials Using Ring and Permeameter Procedures with ~~D-C~~ dc Electronic Hysteresigraphs²

B 328 Test Method for Density, Oil Content, and Interconnected Porosity of Sintered Powder Metal Structural Parts and Oil-Impregnated Bearings³

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

3. Ordering Information

3.1 Purchase orders for parts conforming to this specification shall include the following information:

3.1.1 Reference to this specification and year of issue/revision.

3.1.2 The type of powder to be used (see 4.1 and Table 1).

3.1.3 Reference to an applicable part drawing.

3.1.4 Quantity required.

3.1.5 A critical cross section of the part shall be defined and so indicated on the applicable part drawing. The location of the critical section is by mutual agreement between the purchaser user and the producer (see 5.2).

3.1.6 Magnetic property requirements if they are other than stated in Table 2.

² Annual Book of ASTM Standards, Vol 03.04.

³ Annual Book of ASTM Standards, Vol 02.05.

⁴ Annual Book of ASTM Standards, Vol 03.065.



TABLE 1 Chemical Composition Requirements (in Weight Percent)

Element	Type I	Type II
Phosphorus	0.40/0.50	0.75/0.85
Carbon, max	0.03	0.03
Oxygen, max	0.10	0.10
Nitrogen, max	0.01	0.01
Iron ^A	balance	balance

^A Iron is the balance by difference. Quantitative analysis of this element is not required.

TABLE 2 Maximum Coercive Field Strength Requirements

Grade	Powder Type I (0.45 % P)	Powder Type II (0.8 % P)
4	1.40 Oe {111 A/m}	1.20 Oe {95.5 A/m}
1	1.4 Oe (110 A/m)	1.2 Oe (96 A/m)
2	1.60 Oe {127 A/m}	1.40 Oe {111 A/m}
2	1.8 Oe (140 A/m)	1.4 Oe (110 A/m)
3	2.00 Oe {159 A/m}	1.70 Oe {135 A/m}
3	2.0 Oe (160 A/m)	1.7 Oe (140 A/m)

3.1.7 Whether certification of chemical analysis or magnetic property evaluation is required (see Sections 4 and 6).

3.1.8 Marking and packaging requirements (see Section 11).

3.1.9 Whether testing for magnetic aging is required.

3.1.10 Exceptions to this specification or special requirements such as functional testing, as mutually agreed upon between the producer and the purchaser-user.

4. Chemical Composition

4.1 The chemical composition of the parts shall conform to the requirements prescribed in Table 1.

4.2 Chemical analysis for phosphorus shall be determined by wet chemistry in accordance with a method to be agreed upon between the purchaser-user and the producer. Analysis of carbon, oxygen, and nitrogen shall be done in accordance with Test Methods E 1019.

5. Sintered Density Requirements

5.1 Magnetic and residual induction of P/M parts strongly depend on density. The density of P/M parts is determined by the compressibility of the powder, the compacting pressure, and sintering practice (temperature, time, and atmosphere).

5.2 Parts produced in conformance with this specification shall have a minimum sintered density of 6.8 g/cm³ {6800 kg/m³} in the critical section of the part. The critical section shall be defined by agreement between the purchaser-user and the producer.

5.3 Sintered density shall be determined in accordance with Test Method B 328.

6. Magnetic Property Requirements

6.1 Due to the nature of P/M parts production, magnetic testing of each lot is not required by this specification. However, it is strongly recommended that the purchaser-user require the producer to conduct periodic magnetic evaluations and to certify the results obtained. Such magnetic property evaluations shall be conducted in the following manner.

6.2 When requested, each lot of parts should be sintered with at least one and preferably three ring test specimens which comply with the geometric requirements listed in Practice A 34/A 34M. The ring specimen(s) shall be produced from the same mixed lot of powder used to produce the parts.

6.3 The dc magnetic properties shall be determined in accordance with Test Methods A 596/A 596M or A 773/A 773M.

6.4 For the purpose of this specification, only the coercive force field strength determined from a maximum applied magnetic field strength of 15 Oe {1200 A/m} needs to be determined. Other magnetic properties may be specified by mutual agreement between the purchaser-user and the producer.

6.5 *Coercive Force Field Strength Requirements*—Three grades, defined by coercive force, field strength, are stipulated by this specification and are listed in Table 2. The coercive force field strength requirements for Grade 3 were developed from Type I are based on interlaboratory studies and apply separately to each type of powder, study conducted by ASTM Committee B09. The values requirements for Grades 1 and 2 Type II are based on a literature review both interlaboratory study and are believed to reflect the current industry capabilities—technical literature.

6.6 *Magnetic Aging*—Nitrogen introduced during sintering can cause time-dependent degradation of magnetic properties. Therefore, when requested by the purchaser-user, the producer shall test for aging. To determine the susceptibility of the parts to aging, the test ring(s) should be heated for either 100 h at 150°C or 600 h at 100°C and the coercive force field strength remeasured. A change in coercive force field strength of 10 % or more of the original value is evidence that aging has occurred.

6.7 Since magnetic properties are strongly affected by process conditions, refer to the Appendix X1-Appendix X3 for typical values and explanatory notes.

7. Workmanship, Finish and Appearance

7.1 The parts shall be uniform in composition and uniform in density within critical sections.

7.2 If parts are sectioned or fractured, there shall be no readily recognizable defects.

8. Sampling

8.1 A lot shall consist of parts of the same form and dimensions, produced from a single mixed powder batch and from an unchanged process, without discontinuity in production, and submitted for inspection at one time.

8.2 The ~~purchaser~~ user and the producer shall agree upon a representative number of specimens for testing.

9. Rejection and Rehearing

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

9.2 The disposition of rejected parts shall be subject to agreement between the ~~purchaser~~ user and the producer.

10. Certification

10.1 When specified in the purchase order or contract, the ~~purchaser~~ user shall be furnished certification that samples representing each lot have either been tested or inspected as directed in this specification and the requirements have been met.

10.2 When specified in the purchase order or contract, a report of the test results shall include:

10.2.1 Chemical composition,

10.2.2 Part density in the critical section,

10.2.3 Magnetic test results, if required by the ~~purchaser~~ user, and

10.2.4 The results of any other tests stipulated in the purchaser order or contract.

11. Packaging and Package Marking

11.1 Packaging shall be subject to agreement between the ~~purchaser~~ user and the producer.

11.2 Parts furnished under this specification shall be in a container identified by the name or symbol of the parts producer.

12. Keywords

12.1 ~~coercive force~~; field strength; iron-phosphorus; powder metallurgy (P/M); P/M parts

APPENDIXES

(Nonmandatory Information)

X1. TYPICAL MAGNETIC AND MECHANICAL PROPERTIES SINTERED AT 1120°C IN DISSOCIATED AMMONIA

X1.1 The data provided in this appendix are for information only and are not requirements in this specification. Typical magnetic and mechanical properties are listed in Table X1.1 and Table X1.2, respectively. The influence of sintered density is shown in both tables. For Table X1.1, the maximum flux density, residual induction, and ~~coercive force~~ field strength are measured from a maximum applied magnetic field strength of 15 Oe ~~(1200 A/m)~~.

TABLE X1.1 Typical Magnetic Properties

	Type I Powder (0.45 % P)			Type II Powder (0.8 % P)		
Sintered density, g/cm ³	6.8	7.0	7.2	6.8	7.0	7.2
[kg/m ³]	6 800	7 000	7 200	6 800	7 000	7 200
(kg/m ³)	<u>6 800</u>	<u>7 000</u>	<u>7 200</u>	<u>6 800</u>	<u>7 000</u>	<u>7 200</u>
[Relative] maximum permeability	2 400	2 800	3 000	3 500	4 000	4 500
(Relative) maximum permeability	<u>2 300</u>	<u>2 600</u>	<u>2 700</u>	<u>3 500</u>	<u>4 000</u>	<u>4 500</u>
Maximum flux density, G	10 500	12 000	12 500	14 000	12 000	13 000
Maximum flux density, G	<u>10 500</u>	<u>11 500</u>	<u>12 500</u>	<u>11 000</u>	<u>12 000</u>	<u>13 000</u>
[T]	1.05	1.20	1.25	1.40	1.20	1.30
(T)	<u>1.05</u>	<u>1.15</u>	<u>1.25</u>	<u>1.10</u>	<u>1.20</u>	<u>1.30</u>
Residual induction, G	8 500	9 000	10 000	10 000	11 000	12 000
[T]	0.85	0.90	1.00	1.00	1.10	1.20
(T)	<u>0.85</u>	<u>0.90</u>	<u>1.00</u>	<u>1.00</u>	<u>1.10</u>	<u>1.20</u>
Coercive force, Oe	1.7	1.7	1.7	1.5	1.5	1.5
Coercive field strength, Oe	<u>1.7</u>	<u>1.7</u>	<u>1.7</u>	<u>1.5</u>	<u>1.5</u>	<u>1.5</u>
[A/m]	140	140	140	120	120	120
	<u>140</u>	<u>140</u>	<u>140</u>	<u>120</u>	<u>120</u>	<u>120</u>



Type I Powder (0.45 % P)

Type II Powder (0.8 % P)

(A/m)	140	140	140	120	120	120
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TABLE X1.2 Typical Mechanical Properties

	Type I Powder (0.45 % P)			Type II Powder (0.8 % P)		
Sintered density, g/cm ³	6.8	7.0	7.2	6.8	7.0	7.2
[kg/m ³]	6 800	7 000	7 200	6 800	7 000	7 200
(kg/m ³)	6 800	7 000	7 200	6 800	7 000	7 200
0.2 % Offset yield strength, psi	30 000	32 000	35 000	40 000	45 000	50 000
[MPa]	210	220	240	280	310	340
(MPa)	210	220	240	280	310	340
Ultimate tensile strength, psi	40 000	45 000	50 000	48 000	50 000	55 000
[MPa]	280	310	340	330	340	380
(MPa)	280	310	340	330	340	380
Elongation in 1 in. [25.4 mm], %	5	7	9	2	3	3
Elongation in 1 in. (25.4 mm), %	5	7	7	2	3	3
Apparent hardness, HRB	40	45	55	55	65	70

X2. TYPICAL MAGNETIC AND MECHANICAL PROPERTIES SINTERED AT 1120°C IN DRY HYDROGEN

X2.1 The data provided in this appendix are for information only and are not requirements in this specification. Typical magnetic and mechanical properties are listed in Table X2.1 and Table X2.2, respectively. The influence of sintered density is shown in both tables. For Table X2.1, the maximum flux density, residual induction, and coercive force field strength are measured from a maximum applied magnetic field strength of 15 Oe (1200 A/m).

TABLE X2.1 Typical Magnetic Properties

	Type I Powder (0.45 % P)			Type II Powder (0.8 % P)			
Sintered density, g/cm ³	7.0	7.2	7.4	7.0	7.2	7.4	
[kg/m ³]	7 000	7 200	7 400	7 000	7 200	7 400	
(kg/m ³)	7 000	7 200	7 400	7 000	7 200	7 400	
[Relative] maximum permeability	3 500	4 000	4 500	4 000	4 500	5 000	
(Relative) maximum permeability	3 000	3 200	3 600	4 000	4 500	5 000	
Maximum flux density, G	42 000	42 500	43 000	42 000	43 000	43 500	
Maximum flux density, G	11 500	12 500	13 000	12 000	13 000	13 500	
[T]	4.20	4.25	4.30	4.20	4.30	4.35	
(T)	1.15	1.25	1.30	1.20	1.30	1.35	
Residual induction, G	9 000	10 000	11 000	12 500	10 500	11 500	13 000
[T]	4.00	4.00	4.40	4.25	1.05	1.15	1.30
(T)	1.00	1.00	1.10	4.25	1.05	1.15	1.30
Coercive force, Oe	4.4	4.4	4.4	4.3	4.3	4.3	
Coercive field strength, Oe	1.7	1.7	1.7	1.3	1.3	1.3	
[A/m]	440	440	440	400	400	400	
(A/m)	140	140	140	100	100	100	

TABLE X2.2 Typical Mechanical Properties

	Type I Powder (0.45 % P)			Type II Powder (0.8 % P)		
Sintered density, g/cm ³	7.0	7.2	7.4	7.0	7.2	7.4
[kg/m ³]	7 000	7 200	7 400	7 000	7 200	7 400
(kg/m ³)	7 000	7 200	7 400	7 000	7 200	7 400
0.2 % Offset yield strength, psi	30 000	35 000	38 000	45 000	48 000	53 000
0.2 % Offset yield strength, psi	32 000	35 000	38 000	45 000	48 000	53 000
[MPa]	240	240	260	340	330	360
(MPa)	220	240	260	310	330	360
Ultimate tensile strength, psi	45 000	50 000	55 000	53 000	57 000	62 000
[MPa]	340	340	380	360	390	430
(MPa)	310	340	380	360	390	430
Elongation in 1 in. [25.4 mm], %	8	40	42	4	4	4
Elongation in 1 in. (25.4 mm), %	7	7	7	4	4	4
Apparent hardness, HRB	45	55	60	65	70	75

X3. TYPICAL MAGNETIC AND MECHANICAL PROPERTIES SINTERED AT 1260°C IN DRY HYDROGEN

X3.1 The data provided in this appendix are for information only and are not requirements in this specification. Typical magnetic and mechanical properties are listed in Table X3.1 and Table X3.2, respectively. The influence of sintered density is shown in both tables. For Table X3.1, the maximum flux density, residual induction, and coercive force field strength are measured from a maximum applied magnetic field strength of 15 Oe $\{1200 \text{ A/m}\}$.

TABLE X3.1 Typical Magnetic Properties

	Type I Powder (0.45 % P)			Type II Powder (0.8 % P)		
	7.0	7.2	7.4	7.0	7.2	7.4
Sintered density, g/cm ³	7.0	7.2	7.4	7.0	7.2	7.4
$\{ \text{kg/m}^3 \}$	7 000	7 200	7 400	7 000	7 200	7 400
(kg/m ³)	7 000	7 200	7 400	7 000	7 200	7 400
[Relative] maximum permeability	4 000	4 500	5 000	5 000	5 500	6 000
(Relative) maximum permeability	3 000	3 200	3 600	5 000	5 500	6 000
Maximum flux density, G	11 500	12 500	13 000	13 500	13 000	13 500
$\{ \text{T} \}$	1.15	1.25	1.30	1.35	1.30	1.35
(T)	1.15	1.25	1.30	1.35	1.30	1.35
Residual induction, G	11 500	12 000	12 500	12 000	12 500	13 000
Residual induction, G	9 000	10 000	11 000	12 000	12 500	13 000
$\{ \text{T} \}$	1.15	1.20	1.25	1.20	1.25	1.30
(T)	0.9	1.00	1.10	1.20	1.25	1.30
Coercive force, Oe	1.2	1.2	1.2	1.0	1.0	1.0
Coercive field strength, Oe	1.5	1.5	1.5	1.0	1.0	1.0
$\{ \text{A/m} \}$	95	95	95	80	80	80
(A/m)	120	120	120	80	80	80

TABLE X3.2 Typical Mechanical Properties

	Type I Powder (0.45 % P)			Type II Powder (0.8 % P)		
	7.0	7.2	7.4	7.0	7.2	7.4
Sintered density, g/cm ³	7.0	7.2	7.4	7.0	7.2	7.4
$\{ \text{kg/m}^3 \}$	7 000	7 200	7 400	7 000	7 200	7 400
(kg/m ³)	7 000	7 200	7 400	7 000	7 200	7 400
0.2 % Offset yield strength, psi	32 000	34 000	37 000	45 000	48 000	53 000
0.2 % Offset yield strength, psi	32 000	39 000	41 000	45 000	48 000	53 000
$\{ \text{MPa} \}$	220	230	260	310	330	360
(MPa)	220	269	283	310	330	360
Ultimate tensile strength, psi	45 000	50 000	55 000	60 000	50 000	55 000
$\{ \text{MPa} \}$	310	340	380	340	380	400
(MPa)	310	379	414	340	380	400
Elongation in 1 in. $\{25.4 \text{ mm}\}$, %	10	12	15	2	2	2
Elongation in 1 in. (25.4 mm), %	10	12	15	2	2	2
Apparent hardness, HRB	45	55	60	65	70	75

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