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Standard Specification for Iron-Silicon Relay Steels[1]

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1. Scope

1.1 This specification covers wrought iron-silicon (Fe-Si) steels that are generally used in the manufacture of electromechanical devices, such as relays and solenoids, requiring higher electrical resistivity, higher permeability, and lower coercivity and residual magnetism than provided by either carbon steels or soft magnetic low-carbon irons. The steels covered in this specification are:

Steel Type	Nominal Composition
1	1.1 % Si-Fe
1F	1.1 % Si-Fe free machining
2	2.3 % Si-Fe
2F	2.3 % Si-Fe free machining
3	4.0 % Si-Fe

1.2 This specification covers steels in the form and condition required for fabrication into parts. The fabricated parts typically require a final heat treatment to obtain the desired magnetic performance. The term mill annealed as used in this specification applies to a heat treatment, typically applied by the producer, intended to improve formability. The mill anneal does not provide the optimum magnetic performance and is not intended to replace the need for the finish annealing of parts.

1.3 This specification covers steels in the form of forging billets, hot-rolled bar and strip, cold-finished bar, wire, and cold-rolled strip in thicknesses up to 0.250 in. (6.35 mm).

1.4 This specification does not cover electrical sheet steels used in transformer and motor laminations.

1.5 This specification does not cover powder metallurgy materials capable of being processed into magnetic core components having similar silicon contents.

1.6 The values stated in customary (cgs-emu and inch-pound) units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units which are provided for information only and are not considered standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 34/A 34M Practice for Sampling and Procurement of Magnetic Materials[2]

A 341 Test Method for Direct-Current Magnetic Properties of Materials Using dc Permeameters and the Ballistic Test Methods[2]

A 596 Test Method for Direct-Current Magnetic Properties of Materials Using the Ballistic Method and Ring Specimens[2]

A 773 Test Method for dc Magnetic Properties of Materials Using Ring and Permeameter Procedures with dc Electronic Hysteresigraphs[2]

2.2 *Other:*

IEC Publication 404-7 Methods of Measurement of the Coercivity of Magnetic Materials in an Open Magnetic Circuit[3]

3. Ordering Information

3.1 Orders to this specification shall include as much of the following information as is required to describe the desired steel:

3.1.1 ASTM Specification number and steel type,

3.1.2 Dimensions and tolerances. The tolerances are to be mutually agreed upon between the consumer and the producer,

3.1.3 Quantity (weight or number of pieces),

3.1.4 Form and condition,

3.1.5 Magnetic property requirements if they are otherwise than stated herein,

3.1.6 Certification of chemical analysis or magnetic property evaluation, or both,

3.1.7 Marking and packaging,

3.1.8 *End Use*—Whenever possible the consumer should specify whether the product will be machined, blanked into flat pieces, blanked and formed, or deep drawn to shape. This information will help the producer provide the most suitable product for the consumer's fabrication practice, and

3.1.9 Exceptions to this specification or special requirements.

4. Chemical Composition

4.1 The chemical composition requirements are shown in Table 1. Since magnetic and, possibly, mechanical properties

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

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[2] Annual Book of ASTM Standards, Vol 03.04.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

TABLE 1 Chemical Composition Requirements

	Type 1	Type 1F	Type 2	Type 2F	Type 3
Carbon	0.04 max	0.04 max	0.04 max	0.04 max	0.04 max
Manganese	0.50 max	0.50 max	0.50 max	0.50 max	0.50 max
Silicon	1.10 nom	1.10 nom	2.30 nom	2.30 nom	4.00 nom
Phosphorus	0.05 max	0.10/0.22	0.05 max	0.10/0.25	0.05 max
Sulfur	0.04 max	0.04 max	0.04 max	0.04 max	0.04 max
Aluminum	0.35 max	0.35 max	0.50 max	0.50 max	0.50 max
Iron [A]	balance	balance	balance	balance	balance

[A] Iron is not analyzed nor is it reported.

are of primary importance, variations in composition from those shown in Table 1 are permitted by mutual agreement between the consumer and the producer.

5. Form and Condition

5.1 As the silicon content increases, cold working becomes more difficult, hence, not all product forms are available in each type of steel. The desired form and condition should be specified and discussed with the producer to assure receiving the appropriate product. Available forms and conditions are:

5.1.1 *Forging Billet* (all steel types)—Billet surface ground, grit blasted, or acid cleaned.

5.1.2 *Hot-Rolled Product* (all steel types)—Hot rolled, hot rolled and acid cleaned, and hot-rolled and mechanically cleaned.

5.1.3 *Cold-Finished Bars*—Mill annealed, centerless ground (all steel types), cold drawn (all grades up to 0.500 in. (12.7 mm) round), cold-processed shapes such as squares, rectangles, hexagons (all types except Type 3), centerless ground, and machine turned.

5.1.4 *Strip* (all types except Type 3)—As-supplied condition must be specified as either cold rolled to hardness or mill annealed. Steel can be supplied in coil form or as straightened and cut to length flat product. Product can be supplied having a rolled edge, either round or flat, or an edge produced by slitting.

5.1.5 *Wire* (all types except Type 3)—Cold drawn, cold drawn and mill annealed in either coils or straightened and cut to length.

6. Magnetic Property Requirements

6.1 Under this specification, only the coercive field strength (H_c) is required to be measured. This measurement can be done either using ring or permeameter methods or by use of a coercimeter. Since coercimeters saturate the test specimen before measurement of the coercive field strength, two different sets of requirements are necessary, one for ring and permeameter testing and one for coercimeter testing.

6.2 *Test Specimen Heat Treatment*—The test specimen shall be heat treated before testing as follows; heat at 845 ± 10°C for 4 h in a wet hydrogen atmosphere (dew point of − 20 to 5°C) then cool at a rate of 50 to 100°C/h to a temperature less than 540°C followed by further cooling at any convenient rate. For heat treatment of Type 3 steels, dry hydrogen (dew point less than − 40°C) shall be used instead of wet hydrogen.

6.3 *Conventional dc Magnetic Testing*:

6.3.1 Either ring or permeameter techniques may be used. For ring specimens either Test Methods A 596 or A 773 is permitted. For straight-length specimens, either Test Methods A 341 or A 773 is permitted.

6.3.2 Whenever possible, test specimen size and shape shall conform to Practice A 34/A 34M. The densities of these steels for testing purposes are listed in Table X1.1.

6.3.3 *Requirements*—The coercive force requirements of specimens heat treated in accordance with 6.2 are shown in Table 2. The coercive field strength shall be measured from a maximum flux density of 10.0 kG (1.00 T).

6.4 *Coercimeter Testing*:

6.4.1 Coercimeters are permitted provided it is demonstrated that flux density in the test specimen reaches at least 15 kG (1.5 T) during the magnetization cycle and that the test method and test equipment satisfy the requirements of IEC Publication 404-7.

6.4.2 *Requirements*—The coercive field strength requirements of specimens heat treated in accordance with 6.2 and tested using a coercimeter are shown in Table 3.

7. Packaging and Marking

7.1 Packaging shall be subject to agreement between the consumer and the producer.

7.2 Material furnished under this specification shall be identified by the name or symbol of the producer, by alloy type, melt number, and material size. Each producer lot applied to a order must be identified and packaged separately.

8. Investigation of Claim

8.1 Where any order fails to meet the requirements of this specification, disposition of the material so designated shall be subject to agreement between the consumer and the producer.

9. Keywords

9.1 coercive field strength; iron-silicon steel; relay steel

TABLE 2 DC Coercive Field Strength (H_c) Requirements (Conventional Testing)

	Types 1 and 1F	Types 2 and 2F	Type 3
Oe	0.80 max	0.75 max	0.70 max
A/m	64 max	60 max	56 max

TABLE 3 DC Coercive Field Strength (H_c) Requirements (Coercimeter Testing)

	Types 1 and 1F	Types 2 and 2F	Type 3
Oe	1.2 max	1.1 max	1.0 max
A/m	96 max	88 max	80 max

APPENDIXES

(Nonmandatory Information)

X1. TYPICAL PHYSICAL, MECHANICAL, AND MAGNETIC PROPERTIES

X1.1 Typical physical, magnetic, and hardness properties of the five types of steel are listed in Table X1.1, Table X1.2, and Table X1.3, respectively. The data provided are for information only and are not requirements in this specification.

TABLE X1.1 Typical Physical Properties

	Types 1 and 1F	Types 2 and 2F	Type 3
Density (g/cm^3)	7.75	7.65	7.60
(kg/m^3)	7750	7650	7600
Electrical resistivity (μΩ-cm)	25	40	58
(Ω-m)	0.25×10^{-6}	0.40×10^{-6}	0.58×10^{-6}
Saturation flux density (kG)	21.0	20.6	20.0
(T)	2.10	2.06	2.00
Curie temperature (°C)	761	748	728
Mean coefficient of expansion from 25 to 400°C (10^{-6}/°C)	12.8	13.2	13.5

TABLE X1.2 Typical dc Magnetic Properties [A]

	Types 1 and 1F	Types 2 and 2F	Type 3
Maximum permeability	14 800	11 200	9000
Coercive field strength (Oe)	0.44	0.47	0.49
(A/m)	35	37	39
Residual induction (kG)	8.50	8.60	7.00
(T)	0.850	0.860	0.700

[A] Results from ring specimens heat treated in accordance with 6.2 and tested in accordance with Test Method A 596. Permeameter test results for maximum permeability and residual induction are significantly lower as a result of unavoidable loop shearing effects. Coercive field strength and residual induction are determined from a maximum magnetic flux density of 10 000 G (1.00 T).

TABLE X1.3 Typical Annealed Rockwell Hardness

NOTE 1— Bar hardness determined at mid radius.
NOTE 2—Bar and strip that are straightened and cut to length exhibit slightly higher hardness than shown in this table.

	Type 1	Type 1F	Types 2 and 2F	Type 3
Mill annealed	60 HRB	75 HRB	90 HRB	100 HRB
As heat treated for magnetic properties	50 HRB	70 HRB	88 HRB	95 HRB

X2. HEAT TREATMENT OF IRON-SILICON RELAY STEELS

X2.1 Heat treatment of parts made from iron-silicon relay steels is necessary to obtain the best magnetic performance. Magnetic behavior improves (that is, permeability increases and coercive field strength decreases) when heat treating is performed at temperatures as low as 700°C. For steel Types 2, 2F, and 3, further improvement in magnetic performance occurs as the heat-treating temperature is increased. Steel Types 1 and 1F will show a decline in magnetic performance when heat treated above 870°C as a result of austenitization and subsequent grain refinement upon cooling. Most commonly, heat treatment is conducted at temperatures of approximately 840°C for a minimum of 2 h followed by slow cooling.

X2.2 A protective nonoxidizing, noncarburizing, and nonnitriding atmosphere should be used. Low dew-point atmospheres such as hydrogen, forming gas (5 to 15 % hydrogen-nitrogen), and dissociated ammonia can be used. Vacuum heat treatment can also be used.

X2.3 Further improvement in magnetic characteristics is achievable by using a higher dew-point (−20 to 5°C) hydrogen or forming gas atmosphere to promote decarburization. However, the high dew-point atmospheres should not be used (1) at temperatures in excess of 950°C, (2) when heat treating steel Type 3, or (3) when the part, produced from any type, is to be plated after heat treatment.

X2.4 Iron-silicon relay steels are very prone to rusting under ordinary atmospheric conditions. A protective coating should be applied to heat-treated parts as soon as possible. Chromium, nickel, or cadmium plating is most commonly used.