



Designation: A867 – 19

# Standard Specification for Iron-Silicon Relay Steels<sup>1</sup>

This standard is issued under the fixed designation A867; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 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 6.35 mm (0.250 in.).

1.4 This specification does not cover electrical sheet steels used in transformer and motor laminations. Please refer to Specifications [A677](#), [A683](#), [A726](#), [A876](#), and [A1086](#) for standards pertaining to these material types.

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

<sup>1</sup> 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.

Current edition approved Aug. 1, 2019. Published August 2019. Originally approved in 1986. Last previous edition approved in 2013 as A867 – 03 (2013). DOI: 10.1520/A0867-19.

1.6.1 There are selected values presented in two units, both of which are in acceptable SI units. These are differentiated by the word “or,” as in “μΩ-cm, or, Ω-m.”

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

- [A34/A34M Practice for Sampling and Procurement Testing of Magnetic Materials](#)
- [A341/A341M Test Method for Direct Current Magnetic Properties of Soft Magnetic Materials Using D-C Permeameters and the Point by Point \(Ballistic\) Test Methods](#)
- [A596/A596M Test Method for Direct-Current Magnetic Properties of Materials Using the Ballistic Method and Ring Specimens](#)
- [A677 Specification for Nonoriented Electrical Steel Fully Processed Types](#)
- [A683 Specification for Nonoriented Electrical Steel, Semi-processed Types](#)
- [A726 Specification for Cold-Rolled Magnetic Lamination Quality Steel, Semiprocessed Types](#)
- [A773/A773M Test Method for Direct Current Magnetic Properties of Low Coercivity Magnetic Materials Using Hysteresigraphs](#)
- [A876 Specification for Flat-Rolled, Grain-Oriented, Silicon-Iron, Electrical Steel, Fully Processed Types](#)
- [A1086 Specification for Thin-Gauge Nonoriented Electrical Steel Fully Processed Types](#)

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard’s Document Summary page on the ASTM website.

2.2 *International Electrotechnical Commission Standard:*<sup>3</sup>  
IEC 60404-7 Magnetic materials. Part 7: Method of measurement of the coercivity of magnetic materials in an open magnetic circuit

### 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 user 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 user 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 user's fabrication practice.
- 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 are of primary importance, variations in composition from those shown in Table 1 are permitted by mutual agreement between the user 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 12.7 mm (0.500 in.) 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 a specified 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 ( $H_{CB}$ ) 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  $845^{\circ}\text{C} \pm 10^{\circ}\text{C}$  ( $1553^{\circ}\text{F} \pm 18^{\circ}\text{F}$ ) for 4 hours in a wet hydrogen atmosphere (dew point of  $-20^{\circ}\text{C}$  to  $5^{\circ}\text{C}$  ( $-4^{\circ}\text{F}$  to  $41^{\circ}\text{F}$ )) then cool at a rate of  $50^{\circ}\text{C}$  to  $100^{\circ}\text{C}$  per hour ( $122^{\circ}\text{F}$  to  $212^{\circ}\text{F}$  per hour) to a temperature less than  $540^{\circ}\text{C}$  ( $1000^{\circ}\text{F}$ ) followed by further cooling at any convenient rate. For heat treatment of Type 3 steels, dry hydrogen (dew point less than  $-40^{\circ}\text{C}$  ( $-40^{\circ}\text{F}$ )) 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 Method A596/A596M or Test Method A773/A773M is permitted. For straight-length specimens, either Test Method A341/A341M or Test Method A773/A773M is permitted.

6.3.2 Whenever possible, test specimen size and shape shall conform to Practice A34/A34M. The densities of these steels for testing purposes are listed in Table X1.1.

<sup>3</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

TABLE 1 Chemical Composition Requirements

NOTE 1—Values in mass percent

	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 to 0.22	0.05 max	0.10 to 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 <sup>A</sup>	Balance	Balance	Balance	Balance	Balance

<sup>A</sup> Iron is not analyzed nor is it reported.

6.3.3 *Requirements*—The coercive field strength 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 magnetic flux density of 1.0 T (10 kG).

#### 6.4 Coercimeter Testing:

6.4.1 Coercimeters are permitted provided it is demonstrated that magnetic flux density in the test specimen reaches at least 1.5 T (15 kG) during the magnetization cycle and that the test method and test equipment satisfy the requirements of IEC 60404-7.

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 user 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 an order must be identified and packaged separately.

### 8. Rejection and Rehearing

8.1 Material that fails to conform to the requirements of this specification shall be rejected. Rejection should be reported to the producer promptly and in writing. In case of dissatisfaction with the results of the test, the producer may make a claim for a rehearing.

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

### 9. Keywords

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

TABLE 2 DC Coercive Field Strength ( $H_{CB}$ ) Requirements  
(Conventional Testing)

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

**TABLE 3 DC Coercive Field Strength ( $H_{cB}$ ) Requirements  
(Coercimeter Testing)**

	Type 1	Type 1F	Type 2	Type 2F	Type 3
A/m (Oe)	96 (1.2) max	96 (1.2) max	88 (1.1) max	88 (1.1) max	80 (1.0) 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**

	Type 1	Type 1F	Type 2	Type 2F	Type 3
Density, g/cm <sup>3</sup> , or, (kg/m <sup>3</sup> )	7.75, or, 7750	7.75, or, 7750	7.65, or, 7650	7.65, or, 7650	7.6, or, 7600
Electrical resistivity, $\mu\Omega\text{-cm}$ , or, $\Omega\text{-m}$	25, or, $0.25 \times 10^{-6}$	25, or, $0.25 \times 10^{-6}$	40, or, $0.40 \times 10^{-6}$	40, or, $0.40 \times 10^{-6}$	58, or, $0.58 \times 10^{-6}$
Curie Temperature, °C (°F)	761 (1402)	761 (1402)	748 (1378)	748 (1378)	728 (1342)
Mean coefficient of expansion from 25°C to 400°C, $10^{-6}/^{\circ}\text{C}$ ( $10^{-6}/^{\circ}\text{F}$ )	12.8 (7.11)	12.8 (7.11)	13.2 (7.33)	13.2 (7.33)	13.5 (7.50)

**TABLE X1.2 Typical dc Magnetic Properties <sup>A</sup>**

	Type 1	Type 1F	Type 2	Type 2F	Type 3
Maximum relative permeability ( $\mu_m$ )	14 800	14 800	11 200	11 200	9000
Coercive Field Strength ( $H_{cB}$ ), A/m (Oe)	35 (0.44)	35 (0.44)	37 (0.47)	37 (0.47)	0.49
Residual Flux Density ( $B_r$ , T (kG))	0.85 (8.5)	0.85 (8.5)	0.86 (8.6)	0.86 (8.6)	0.70 (7.0)
Saturation flux density, T (kG)	2.1 (21)	2.1 (21)	2.06 (20.6)	2.06 (20.6)	2.0 (20)

<sup>A</sup> Results from ring specimens heat treated in accordance with [6.2](#) and tested in accordance with Test Method [A596/A596M](#). Permeameter test results for maximum permeability and residual flux density are significantly lower as a result of unavoidable loop shearing effects. Coercive field strength and residual flux density are determined at a maximum magnetic flux density of 1.0 T (10 kG).

**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	Type 2	Type 2F	Type 3
Mill annealed	60 HRB	75 HRB	90 HRB	90 HRB	100 HRB
As heat treated for magnetic properties	50 HRB	70 HRB	88 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 (1292°F). 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 (1598°F) as a result of austenitization and subsequent grain refinement upon cooling. Most commonly, heat treatment is conducted at temperatures of approximately 840°C (1544°F) for a minimum of 2 hours followed by slow cooling.

X2.2 A protective non-oxidizing, non-carburizing, and non-nitriding atmosphere should be used. Low dew-point atmo-

spheres 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°C to 5°C) (–4°F to 41°F) hydrogen or forming gas atmosphere to promote decarburization. However, high dew-point atmospheres should not be used (1) at temperatures in excess of 950°C (1742°F), (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.

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