Standard Specification for Nonoriented Electrical Steel Fully Processed Types[1]

This standard is issued under the fixed designation A677; 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 the detailed requirements to which flat-rolled nonoriented fully processed electrical steel shall conform.

1.2 This steel is produced to specified maximum core-loss values and is intended primarily for commercial power frequency (50 and 60 Hz) applications in magnetic devices. Desirable core-loss and permeability characteristics are developed during mill processing, so additional heat treatment by the user is usually not necessary.

1.3 These nonoriented fully processed electrical steels are low-carbon, silicon-iron, or silicon-aluminum-iron alloys containing up to about 3.5 % silicon and a small amount of aluminum.

1.4 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.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A34/A34M Practice for Sampling and Procurement Testing of Magnetic Materials
A340 Terminology of Symbols and Definitions Relating to Magnetic Testing
A343/A343M Test Method for Alternating-Current Magnetic Properties of Materials at Power Frequencies Using Wattmeter-Ammeter-Voltmeter Method and 25-cm Epstein Test Frame
A664 Practice for Identification of Standard Electrical Steel Grades in ASTM Specifications
A700 Guide for Packaging, Marking, and Loading Methods for Steel Products for Shipment
A717/A717M Test Method for Surface Insulation Resistivity of Single-Strip Specimens
A719/A719M Test Method for Lamination Factor of Magnetic Materials
A720/A720M Test Method for Ductility of Nonoriented Electrical Steel
A937/A937M Test Method for Determining Interlaminar Resistance of Insulating Coatings Using Two Adjacent Test Surfaces
A971/A971M Test Method for Measuring Edge Taper and Crown of Flat-Rolled Electrical Steel Coils
A976 Classification of Insulating Coatings for Electrical Steels by Composition, Relative Insulating Ability and Application
E18 Test Methods for Rockwell Hardness of Metallic Materials
E140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness
E384 Test Method for Microindentation Hardness of Materials

3. Terminology

3.1 *Definitions*—The terms and symbols used in this specification are defined in Terminology A340.

4. Classification

4.1 The nonoriented electrical steel types described by this specification are as shown in Table 1.

5. Ordering Information

5.1 Orders for material under this specification shall include as much of the following information as necessary to describe the desired material adequately:

5.1.1 ASTM specification number.
5.1.2 Core-loss type number.
5.1.3 Surface coating type.
5.1.4 Thickness, width, and length (if in cut lengths instead of coils).
5.1.5 Total weight of ordered item.
5.1.6 Limitations in coil size or lift weights.

[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.

Current edition approved April 1, 2016. Published April 2016. Originally approved in 1973. Last previous edition approved in 2012 as A677 – 12. DOI: 10.1520/A0677-16.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

TABLE 1 Core-Loss Types[A] and Maximum Core Losses[B] at a Magnetic Flux Density of 1.5 T (15 kG) and 60 Hz[C] for As-Sheared Epstein Specimens[D]

0.36 mm (0.0140 in.) Thickness			0.47 mm (0.0185 in.) Thickness			0.64 mm (0.0250 in.) Thickness		
Core-Loss Type	Maximum Core Loss, W/kg	(W/lb)	Core-Loss Type	Maximum Core Loss, W/kg	(W/lb)	Core-Loss Type	Maximum Core Loss, W/kg	(W/lb)
36F145	3.20	(1.45)	. . .	. . .	. . .	. . .	. . .	. . .
36F155	3.42	(1.55)	47F165	3.64	(1.65)	64F200	4.41	(2.00)
36F165	3.64	(1.65)	47F180	3.97	(1.80)	64F210	4.63	(2.10)
36F175	3.86	(1.75)	47F190	4.19	(1.90)	64F225	4.96	(2.25)
36F185	4.08	(1.85)	47F200	4.41	(2.00)	64F235	5.18	(2.35)
36F195	4.30	(1.95)	47F210	4.63	(2.10)	64F250	5.51	(2.50)
36F205	4.52	(2.05)	47F240	5.29	(2.40)	64F275	6.06	(2.75)
. . .	. . .	. . .	47F280	6.17	(2.80)	64F320	7.05	(3.20)
. . .	. . .	. . .	47F400	8.82	(4.00)	64F500	11.02	(5.00)
. . .	. . .	. . .	47F450	9.92	(4.50)	64F550	12.13	(5.50)

[A] See Practice A664.
[B] The test density shall be the correct ASTM assumed density (in accordance with 14.2) for the chemistry used by the producer to meet the property requirements of the specification.
[C] Maximum core losses at a magnetic flux density of 1.5 T (15 kG) and 50 Hz are 0.79 times maximum core losses at 60 Hz.
[D] One half of strips cut parallel to the steel rolling direction, one half of strips cut perpendicular to the steel rolling direction.

5.1.7 *End Use*—The user shall disclose as much pertinent information as possible about the intended application to enable the producer to provide material characteristics most suitable for specific fabricating practices.

5.1.8 Special requirements or exceptions to the provisions of this specification.

6. Manufacture

6.1 *Typical Melting and Casting :*

6.1.1 These fully processed electrical steels may be made by basic-oxygen, electric-furnace, or other steelmaking practice.

6.1.2 These electrical steels are characterized by low carbon, usually less than 0.020 %. The principal alloying element is commonly silicon, but aluminum up to about 0.8 % is sometimes used instead of or in addition to silicon, depending on mill-processing practice for the desired magnetic grade. Individual producers will often have different silicon or aluminum contents for a particular grade because of intrinsic mill-processing procedures.

6.1.3 Sulfur content is typically less than 0.025 % and is usually lowest in the numbered types representing lowest core loss. Manganese is typically present in amounts between 0.10 and 0.40 %. Phosphorus, copper, nickel, chromium, molybdenum, antimony, and tin are usually present only in residual amounts except in the higher numbered core-loss types in which phosphorus up to 0.15 % and tin or antimony up to 0.10 % may be present.

6.1.4 The producer is not required to report chemical composition of each lot except when a clear need for such information has been shown. In such cases, the analyses to be reported shall be negotiated between the producer and the user.

6.2 *Typical Rolling and Annealing*— The processing sequence for fully processed, nonoriented electrical steel comprises hot-rolling, annealing, pickling, cold-rolling, and decarburizing annealing.

6.3 When changes in the manufacture of the material are believed to exert possible significant effects upon the user's fabricating practices and upon the magnetic performance to be obtained in the specified end use, the producer shall notify the user before shipment is made so the user has an opportunity to evaluate the effects.

7. Magnetic Properties

7.1 *Specific Core Loss*—Each core-loss type of electrical steel is identified by a maximum core-loss limit as shown in Table 1.

7.2 *Permeability*—The permeability at all magnetic flux density values shall be as high as possible, consistent with the required core-loss limits that govern the grade. Typical relative peak permeability (μ_p) values are given in Appendix X1.

7.3 *Specific Exciting Power*—The knowledge of the approximate value of rms exciting power required for the excitation of a particular type of electrical steel is frequently useful to the user. Typical values of specific exciting power are given in Appendix X1.

7.4 *Magnetic Aging*—Although steel sold to this specification is considered non-aging, the maximum core-loss values of Table 1 are based on tests of freshly sheared specimens. The guarantee of magnetic properties after an aging treatment is subject to negotiation between the user and the producer. The definition of aging coefficient and the aging treatments usually specified are given in Terminology A340.

8. Surface Insulation Characteristics

8.1 Unless otherwise specified, fully processed nonoriented electrical steels are supplied with a smooth surface finish and a thin, tightly adherent surface oxide (Coating Type C-0 in Classification A976) which has sufficient insulating ability for most small cores.

8.2 *Applied Coatings:*

8.2.1 Several types of thin, tightly adherent applied coatings (Coating Types C-3, C-4, C-5, and C-6 in Classification A976) with higher levels of insulating ability are available on fully processed nonoriented electrical steels. If an applied coating is needed, the user shall specify the coating type.

8.2.2 If the insulating ability of the applied coating is unusually critical to the application, the user shall specify not only the coating type, but also the test method (either Test Method A717/A717M or Test Method A937/A937M) and test conditions to be used to evaluate the insulating ability of the coating, as well as the corresponding minimum value of insulating ability.

8.2.3 A thinner-than-usual applied coating may be preferred when the core-fabricating practice involves welding or die casting. In such cases, the coating type shall be suffixed by the letter "A."

9. Mechanical and Physical Properties

9.1 *Lamination Factor*—The lamination factor shall be as high as practicable. It is greatest for thicker gages and when the surface is smooth, uncoated, and without significant amounts of oxide. Lamination factors can be determined using Test Method A719/A719M. Typical values of lamination factor are given in Appendix X1.

9.2 *Ductility*—The material shall be as ductile as possible. When required, the ductility can be determined by the bend test for ductility as described in Test Method A720/A720M. Ductility is a function of microstructure and may differ between producers. The user's anneal may also affect ductility. Typical values for ductility are given in Appendix X1.

9.3 *Hardness*—The hardness of these materials can be determined using Test Methods E18 or Test Method E384. Hardness is affected by chemistry and by the grain size and microstructure of the final product. Typical values for the hardness of "as-produced" materials are given in Appendix X1.

10. Dimensions and Permissible Variations

10.1 *Thickness*—Specified thickness should be one of the common thicknesses as follows:

Thickness, mm (in.)
0.36 (0.0140)
0.47 (0.0185)
0.64 (0.0250)

10.2 *Thickness Variations*—The average thickness of the material supplied shall be as close as possible to the ordered thickness. Measurements made with a contacting micrometer at points no closer than 10 mm (0.375 in.) from the edge of a sheet or coil of specified width shall not differ from the specified thickness by more than the values (which include taper) shown in Table 2.

10.3 *Taper*—The rolling of flat-rolled sheets inherently produces an edge which is thinner than the rest of the sheet. This characteristic is termed "tapered edge," "feather," or gamma and occurs primarily within 25 to 51 mm (1 to 2 in.) from the as-rolled edge of the material. The thickness variation involved in edge taper sometimes is the major portion of the total overall thickness variation permitted by 10.2. Edge taper is defined and may be measured in accordance with Test Method A971/A971M. It may be expected that the following limits on the differences in thickness measured along a straight line perpendicular to the mill edge within the first 50 mm (2 in.) or less from either edge of the ordered width will apply:

Ordered Thickness, mm (in.)	Maximum Taper, mm (in.)
0.36 (0.0140)	0.025 (0.0010)
0.47 (0.0185)	0.030 (0.0012)
0.64 (0.0250)	0.036 (0.0014)

10.4 *Width Tolerances*—Maximum deviations from the ordered width shall be as shown in Table 3.

10.5 *Length Tolerances*—The maximum deviations from the ordered length shall be as shown in Table 4.

10.6 *Camber*—Camber is the greatest deviation of a side edge from a straight line, the measurement being taken on the concave side with a straightedge. It is limited to 6.4 mm (0.25 in.) per 2.4 m (96 in.) of length.

10.7 *Out of Square*—This tolerance applies to cut lengths only and represents the deviation of an edge from a straight line placed at a right angle to the side, touching one corner and extending to the other side. It shall not exceed 1.6 mm (0.062 in.) per 152 mm (6 in.) of width or fraction thereof.

11. Workmanship, Finish, and Appearance

11.1 *Flatness*—Adequately defining the degree of flatness necessary for the general application of fully processed electrical steel sheets is extremely difficult; therefore, no specific limits for flatness have been established.

11.1.1 It is intended that flatness shall be suitable for the intended application, and consequently, the user should inform the producer of any requirements for a degree of flatness more critical than that obtained from usual commercial practices. Processes used to improve flatness may affect magnetic and mechanical properties.

11.1.2 Commercial practices recognize that sharp, short waves and buckles are objectionable.

11.1.3 Procedures for judging the degree of critical flatness necessary shall be subject to negotiation between user and producer.

11.2 *Surface Imperfections*—The surface shall be reasonably clean and essentially free of manufacturing defects such as holes, blisters, slivers, indentations, and so forth, which would interfere with its effective use in the intended application.

12. Sampling

12.1 The producer shall assign a number to each test lot for identification. The test lot shall not exceed 9100 kg (20 000 lb) in weight.

TABLE 2 Thickness Tolerances

Specified Thickness, mm (in.)	Thickness Tolerances, Over or Under, mm (in.) for Specified Width, mm (in.)			
	150 (6) and Under	Over 150 (6) to 300 (12), incl.	Over 300 (12) to 910 (36), incl.	Over 910 (36) to 1220 (48), incl.
0.36 (0.014) to 0.51 (0.020), incl	0.038 (0.0015)	0.051 (0.002)	0.051 (0.002)	0.076 (0.003)
0.53 (0.021) to 0.79 (0.031), incl	0.051 (0.002)	0.051 (0.002)	0.076 (0.003)	0.076 (0.003)

TABLE 3 Width Tolerances

Ordered Width, mm (in.)	Width Tolerances, mm (in.)	
	Over	Under
To 150 (6), incl	0.20 (0.008)	0.20 (0.008)
Over 150 (6) to 250 (10), incl	0.41 (0.016)	0.41 (0.016)
Over 250 (10) to 380 (15), incl	0.81 (0.032)	0.81 (0.032)
Over 380 (15) to 510 (20), incl	3.18 (0.125)	0 (0)
Over 510 (20) to 810 (32), incl	4.76 (0.188)	0 (0)
Over 810 (32) to 1220 (48), incl	6.35 (0.25)	0 (0)

TABLE 4 Length Tolerances

Specified Length, mm (in.)	Length Tolerances, mm (in.)	
	Over	Under
To 760 (30), incl	3.2 (0.125)	0 (0)
760 (30) to 1520 (60), incl	6.4 (0.25)	0 (0)
1520 (60) to 2440 (96), incl	12.7 (0.50)	0 (0)
Over 2440 (96) to 3050 (120), incl	19.1 (0.75)	0 (0)
Over 3050 (120) to 3660 (144), incl	25.4 (1.0)	0 (0)

12.2 Test samples shall be obtained after final mill heat treatment or other operation which is the final operation to have significant influence on the magnetic properties of fully processed electrical steel.

12.3 The full width coil identified as a test lot shall be sampled in accordance with Practice A34/A34M.

13. Specimen Preparation

13.1 The Epstein test specimen shall be in the as-sheared condition with one-half of the test strips sheared parallel to and one-half transverse to the rolling direction in accordance with Practice A34/A34M.

13.2 Care should be practiced to exclude any bent, twisted, dented, highly burred, or improperly sheared strips from the test specimen.

14. Test Methods

14.1 The required tests for core loss to determine the core-loss grade, and other magnetic tests when made, shall be in accordance with the procedure of Test Method A343/A343M.

14.2 The assumed density of these materials for test purposes varies in accordance with the amounts of silicon and aluminum present in the steel as shown in Practice A34/A34M. The factor, percent silicon plus 1.7 × percent aluminum, as determined for the median or aim silicon and aluminum of the melt, shall determine the assumed density to be used as follows:

(% Si + 1.7 × % Al)	Assumed Test Density, kg/m^3 (g/cm^3)
0.00–0.62	7850 (7.85)
0.63–1.38	7800 (7.80)
1.39–2.15	7750 (7.75)
2.16–2.92	7700 (7.70)
2.93–3.69	7650 (7.65)
3.70–4.46	7600 (7.60)
4.47–5.23	7550 (7.55)

15. Certification

15.1 The producer shall submit to the user, as promptly as possible after shipment, a certified report of the average core-loss values or any other required test values, for each test lot, to show that the material conforms to this specification.

15.2 The test methods and applicable test conditions, including the test density, shall be clearly stated.

15.3 The test report shall carry the lot identification, purchase order number, and other information that is deemed necessary to identify the test results with the proper shipment and shipping lot.

16. Marking

16.1 Each package of coils or lift of cut lengths shall have firmly attached to it, outside its wrappings, a tag showing the user's order number, specification number, grade designation, coating or surface-type designation, thickness, width (and length if in sheet form), weight, and test lot number.

16.2 Each wide coil shall have the specification number, grade designation, coating or surface-type designation, thickness, width, weight, and test lot number marked on the outer surface of the coil itself.

16.3 In a lift of narrow coils, each narrow coil in the package shall be tagged with the specification number, grade designation, coating or surface-type designation, thickness, width, and test lot number.

17. Packaging

17.1 Methods of packaging, loading, and shipping, unless otherwise specified, shall correspond to the latest revision of the procedures recommended by Practices A700.

18. Rejection

18.1 Unless otherwise specified, any rejection shall be reported to the producer within a reasonable time after receipt of material by the user.

18.2 Material that is reported to be defective subsequent to the acceptance at the user's works shall be set aside, adequately protected, and correctly identified. The producer shall be notified as soon as possible so that an investigation may be initiated.

18.3 Samples that are representative of the rejected material shall be made available to the producer so a mutually agreeable settlement can be reached.

19. Keywords

19.1 core loss; electrical steel; flat-rolled; fully processed; nonoriented

APPENDIX

(Nonmandatory Information)

X1. TYPICAL PROPERTIES

X1.1 *Peak Permeability*—Typical values for relative peak permeability (μ_p) at a magnetic flux density of 1.5 T (15 kG) determined in accordance with Test Method A343/A343M are given in Table X1.1.

X1.2 *Specific Exciting Power*—Typical values for specific exciting power for these materials at a magnetic flux density of 1.5 T (15 kG) and 60 Hz determined in accordance with Test Method A343/A343M are provided in Table X1.2.

X1.3 *Lamination Factor*—The lamination factors for these materials as determined using Test Method A719/A719M at a test pressure of 340 kPa (50 psi) typically range from 95 to 98 %, depending on gage, coating, and surface roughness.

X1.4 *Ductility*—Typical values for the ductility of these materials as determined using Test Method A720/A720M are presented in Table X1.3.

X1.5 *Hardness*—Typical values for hardness of these materials determined using Test Methods E18 are presented in Table X1.3. The values given in Table X1.3 are based on Rockwell superficial hardness test results and converted into other hardness test scales per Hardness Conversion Tables E140—Table 2.

TABLE X1.1 Typical Relative Peak Permeability at a Magnetic Flux Density of 1.5 T (15 kG) and 60 Hz for As-Sheared Epstein Specimens[A]

0.36 mm (0.014 in.) Thickness		0.47 mm (0.0185 in.) Thickness		0.64 mm (0.025 in.) Thickness	
Core-Loss Type	Typical Relative Peak Permeability	Core-Loss Type	Typical Relative Peak Permeability	Core-Loss Type	Typical Relative Peak Permeability
36F145	700–1100	...	...	...	...
36F155	750–1150	47F165	800–1200	64F200	800–1250
36F165	800–1200	47F180	800–1250	64F210	800–1300
36F175	1000–1600	47F190	800–1650	64F225	800–1700
36F185	1000–1650	47F200	800–1700	64F235	800–1750
36F195	1000–1700	47F210	800–1750	64F250	800–1800
36F205	1000–2000	47F240	900–2050	64F275	900–2100
...	...	47F280	900–2150	64F320	950–2200
...	...	47F400	1500–2250	64F500	1500–2300
...	...	47F450	1500–2400	64F550	1500–2500

[A] One half of strips cut parallel to the steel rolling direction, one half of strips cut perpendicular to the steel rolling direction.

TABLE X1.2 Typical Specific Exciting Power at a Magnetic Flux Density of 1.5 T (15 kG) and 60 Hz for As-Sheared Epstein Specimens[A]

0.36 mm (0.014 in.) Thickness			0.47 mm (0.0185 in.) Thickness		0.64 mm (0.025 in.) Thickness		
Core-Loss Type	Typical Specific Exciting Power, VA/lb (VA/kg)		Core-Loss Type	Typical Specific Exciting Power, VA/lb (VA/kg)	Core-Loss Type	Typical Specific Exciting Power, VA/lb (VA/kg)	
36F145	24.3-28.7	(11.0-13.0)	. . .	. . .	. . .	. . .	
36F155	23.1-27.6	(10.5-12.5)	47F165	22.0-26.5 (10.0-12.0)	64F200	20.9-26.5	(9.5-12.0)
36F165	22.0-26.5	(10.0-12.0)	47F180	20.9-26.5 (9.5-12.0)	64F210	19.8-26.5	(9.0-12.0)
36F175	17.6-22.0	(8.0-10.0)	47F190	16.5-26.5 (7.5-12.0)	64F225	16.5-26.5	(7.5-12.0)
36F185	16.5-22.0	(7.5-10.0)	47F200	15.4-26.5 (7.0-12.0)	64F235	15.4-26.5	(7.0-12.0)
36F195	16.5-22.0	(7.5-10.0)	47F210	15.4-26.5 (7.0-12.0)	64F250	15.4-26.5	(7.0-12.0)
36F205	14.3-22.0	(6.5-10.0)	47F240	13.2-24.3 (6.0-11.0)	64F275	13.2-24.3	(6.0-11.0)
. . .	. . .		47F280	12.1-24.3 (5.5-11.0)	64F320	12.1-23.1	(5.5-10.5)
. . .	. . .		47F400	12.1-15.4 (5.5-7.0)	64F500	12.1-15.4	(5.5-7.0)
. . .	. . .		47F450	11.0-15.4 (5.0-7.0)	64F550	11.0-15.4	(5.5-7.0)

[A] One half of strips cut parallel to the steel rolling direction, one half of strips cut perpendicular to the steel rolling direction.

TABLE X1.3 Typical Ductility and Hardness[A]

Nominal Alloy Content (Si + Al), %	Typical Number of Bends (Test Method A720/A720M)			Typical Rockwell Superficial Hardness			Typical Vickers Hardness HV
	0.36 mm (0.014 in.)	0.47 mm (0.0185 in.)	0.64 mm (0.025 in.)	HR 15T 0.36 mm (0.014 in.)	HR 30T 0.47 mm (0.0185 in.)	HR 45T 0.64 mm (0.025 in.)	
3.50	19	10	8	85–89	67–75	49–61	139–176
3.20	...	18	16	...	66–74	47–59	135–169
2.80	...	22	20	...	64–72	44–56	127–159
2.35	...	25	23	...	...	40–52	119–147
1.85	...	25	24	...	...	37–49	114–139
1.05	...	25	25	...	...	32–43	106–125

[A] Ductility and hardness are also affected by the grain size and microstructure of the final product. The hardnesses presented are for "as-produced" material, not for material that has been stress relief annealed.