Designation: ~~A677 – 12~~ A677 – 16

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

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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 ~~customary (cgs-emu and inch-pound)~~ SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to ~~SI~~ 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
~~E92 Test Methods for Vickers Hardness and Knoop 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.

[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] 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 ~~15 kG (1.5 T)~~ and 60 Hz[C] for As-Sheared Epstein Specimens[D]

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

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 ~~15 kG (1.5 T)~~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. 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.

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 ~~inductions~~ 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 ~~Requirements~~ 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 ~~E92~~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, in. (mm)~~ Thickness, mm (in.)
~~0.0140 (0.36)~~
0.36 (0.0140)
~~0.0185 (0.47)~~
0.47 (0.0185)
~~0.0250 (0.64)~~
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 ~~⅜ in. (10 mm)~~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.

TABLE 2 Thickness Tolerances

Specified Thickness, ~~in. (mm)~~	Thickness Tolerances, Over or Under, ~~in. (mm)~~ for Specified Width, ~~in. (mm)~~			
	~~6 (0.15)~~ and Under	Over ~~6 (0.15)~~ to ~~12 (0.30)~~, incl.	Over ~~12 (0.30)~~ to ~~36 (0.91)~~, incl.	Over ~~36 (0.91)~~ to ~~48 (1.22)~~. incl.
~~0.014 (0.36) to 0.020 (0.51), incl~~	~~0.0015 (0.038)~~	~~0.002 (0.051)~~	~~0.002 (0.051)~~	~~0.003 (0.076)~~
~~0.021 (0.53) to 0.031 (0.79), incl~~	~~0.002 (0.051)~~	~~0.002 (0.051)~~	~~0.003 (0.076)~~	~~0.003 (0.076)~~

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)

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 ~~1 to 2 in. (25 to 51 mm)~~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 ~~2 in. (50 mm)~~50 mm (2 in.) or less from either edge of the ordered width will apply:

~~Ordered Thickness, in. (mm)~~ Ordered Thickness, mm (in.)	~~Maximum Taper, in. (mm)~~ Maximum Taper, mm (in.)
~~0.0140 (0.36)~~	~~0.0010 (0.025)~~
0.36 (0.0140)	0.025 (0.0010)
~~0.0185 (0.47)~~	~~0.0012 (0.030)~~
0.47 (0.0185)	0.030 (0.0012)
~~0.0250 (0.64)~~	~~0.0014 (0.036)~~
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 ~~¼ in. (6.4 mm) per 96 in. (2.4 m)~~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 ~~1/16 in. (1.6 mm) per 6 in. (152 mm)~~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.

TABLE 3 Width Tolerances

Ordered Width, ~~in. (m)~~	Width Tolerances, ~~in. (mm)~~	
	Over	Under
~~To 6 (0.15), incl~~	~~0.008 (0.20)~~	~~0.008 (0.20)~~
~~Over 6 (0.15) to 10 (0.25), incl~~	~~0.016 (0.41)~~	~~0.016 (0.41)~~
~~Over 10 (0.25) to 15 (0.38), incl~~	~~0.032 (0.81)~~	~~0.032 (0.81)~~
~~Over 15 (0.38) to 20 (0.51), incl~~	~~0.125 (3.18)~~	~~0 (0)~~
~~Over 20 (0.51) to 32 (0.81), incl~~	~~0.188 (4.76)~~	~~0 (0)~~
~~Over 32 (0.81) to 48 (1.22), incl~~	~~0.25 (6.35)~~	~~0 (0)~~

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)