Standard Specification for Thin-Gauge 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 thin-gauge nonoriented fully processed electrical steel shall conform. Nominal thicknesses included in this specification are 0.004 in. (0.10 mm) to 0.012 in. (0.30 mm).

1.1.1 Refer to Specification A677 for properties of flat-rolled nonoriented fully processed electrical steel in nominal thicknesses of 0.014 in. (0.36 mm) to 0.025 in. (0.64 mm).

1.1.2 Refer to Specification A876 for properties of flat-rolled grain-oriented fully processed electrical steel.

1.1.3 Thin-gauge nonoriented electrical steels with a high silicon content (typically 6½ %) manufactured using silicon vapor-deposition or similar processes are not included in this specification.

1.2 The steel covered in this specification is produced to specified maximum core loss values and is intended primarily for use in rotating electrical machinery and other electromagnetic devices operating at moderate to elevated frequencies (100 Hz and greater). Desirable core loss and permeability characteristics are developed during mill processing; however, lamination manufacturing processes may adversely affect these mill-produced properties. Additional stress-relief heat treatment by the user may therefore be helpful in remediating these properties in the manufactured laminations. Stress-relief annealing is discussed further in Appendix X2.

1.3 These thin-gauge nonoriented fully processed electrical steels are low-carbon, silicon-iron, or silicon-aluminum-iron alloys typically containing 2.5 to 3.5 % silicon and a small amount of aluminum.

1.4 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.

1.5 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

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

A348/A348M Test Method for Alternating Current Magnetic Properties of Materials Using the Wattmeter-Ammeter-Voltmeter Method, 100 to 10 000 Hz and 25-cm Epstein Frame

A664 Practice for Identification of Standard Electrical Steel Grades in ASTM Specifications

A677 Specification for Nonoriented Electrical Steel Fully Processed Types

A700 Practices 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

A876 Specification for Flat-Rolled, Grain-Oriented, Silicon-Iron, Electrical Steel, Fully Processed Types

A927/A927M Test Method for Alternating-Current Magnetic Properties of Toroidal Core Specimens Using the Voltmeter-Ammeter-Wattmeter Method

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

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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.

A976 Classification of Insulating Coatings for Electrical Steels by Composition, Relative Insulating Ability and Application
E18 Test Methods for Rockwell Hardness of Metallic Materials
E384 Test Method for Knoop and Vickers Hardness of Materials

3. Terminology

3.1 *Definitions*—See Terminology A340.

4. Classification

4.1 The thin-gauge 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 designation.

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 shall be negotiated between the user and the producer.

6. Manufacture

6.1 *Typical Melting and Casting:*

6.1.1 These thin-gauge fully processed nonoriented electrical steels may be made by basic-oxygen, electric-furnace, or other steel making practices.

6.1.2 These thin-gauge fully processed nonoriented electrical steels are characterized by low carbon content, usually less than 0.02 %. 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 Additional alloying elements that may be present depending on mill processing procedures include sulfur, typically less than 0.025 %, manganese in amounts between 0.10 and 0.40 %, and phosphorus, copper, nickel, chromium, molybdenum, antimony, and tin in residual amounts.

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

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

6.2.1 *Commercial Rerolling*—When commercial practice calls for the cold-rolling to finished thickness and the development of the final annealed and coated condition to take place at a production facility other than the original melting and hot-rolling mill, this rerolling facility should prepare final test data and certifications as well as package and ship the finished material to the user in accordance with the requirements for producers stated in this standard.

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 the maximum core loss requirements as shown in Table 1.

7.2 *Permeability*—The permeability at all magnetic flux density levels 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 *Minimum Magnetic Flux Density*—The minimum magnetic flux density of materials at specified magnetic field strengths is frequently useful to the user. Typical values of minimum magnetic flux density 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.

TABLE 1 Core-Loss Types[A] and Maximum Specific Core Losses[B] at a Magnetic Flux Density of 10 kG (1.0 T) for As-Sheared Epstein Specimens[C]

Thickness in. (mm)	Core-Loss Type	Maximum Core Loss at 400 Hz W/lb (W/kg)	Maximum Core Loss at 1000 Hz W/lb (W/kg)
0.004 (0.10)	10T590	5.90 (13.0)	12.0 (26.4)
0.005 (0.12)	12T610	6.10 (13.5)	15.3 (33.7)
0.006 (0.15)	15T640	6.40 (14.0)	17.4 (38.3)
0.007 (0.18)	18T650	6.50 (14.4)	19.5 (43.0)
0.008 (0.20)	20T680	6.80 (15.0)	22.4 (49.4)
0.009 (0.22)	22T700	7.00 (15.4)	25.0 (55.1)
0.010 (0.25)	25T730	7.30 (16.0)	28.0 (61.7)
0.011 (0.27)	27T770	7.70 (17.0)	30.2 (66.6)
0.012 (0.30)	30T820	8.20 (18.0)	32.8 (72.3)

[A] See Practice A664
[B] The test density shall be the correct ASTM assumed density (in accordance with 13.2) for the chemistry used by the producer to meet the property requirements of the specification.
[C] One half of strips cut parallel to the steel rolling direction, one half of strips cut perpendicular to the steel rolling direction. Refer to Section 13 for applicable test methods.

8. Surface Insulation Characteristics

8.1 Unless otherwise specified, thin-gauge 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 many small cores.

8.2 *Applied Coatings:*

8.2.1 Several types of thin, tightly adherent applied coatings with higher levels of insulating ability, including coating type C-5 in Classification A976 as well as other standard and proprietary coating types are available on thin-gauge 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 and characteristics shall be determined by agreement of the user and producer.

9. Mechanical Requirements

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 *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 and may differ between producers. If tests for hardness are to be included with a production order, the test method or methods to be used and acceptable hardness values shall be negotiated between the user and the producer.

10. Dimensions and Permissible Variations

10.1 *Thickness*—Nominal thicknesses of each core-loss type are shown in Table 2.

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 0.375 in. (0.95 mm) 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 1 to 2 in. (25 to 51 mm) 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; allowable taper as measured along a straight line perpendicular to the mill edge within the first 2 in. (51 mm) or less from either edge of the ordered width is presented in Table 3. It may be expected that the following limits on the differences in thickness measured will apply.

TABLE 2 Thickness Tolerances

Core-Loss Type	Nominal Thickness in. (mm)	Thickness Tolerance in. (mm)
10T590	0.004 (0.10)	± 0.0003 (0.008)
12T610	0.005 (0.12)	± 0.0004 (0.010)
15T640	0.006 (0.15)	± 0.0005 (0.013)
18T650	0.007 (0.18)	± 0.0005 (0.013)
20T680	0.008 (0.20)	± 0.0006 (0.015)
22T700	0.009 (0.22)	± 0.0007 (0.018)
25T730	0.010 (0.25)	± 0.0008 (0.020)
27T770	0.011 (0.27)	± 0.0009 (0.023)
30T820	0.012 (0.30)	± 0.0012 (0.030)

TABLE 3 Maximum Taper

Core-Loss Type	Nominal Thickness in. (mm)	Maximum Taper in. (mm)
10T590	0.004 (0.10)	0.0003 (0.008)
12T610	0.005 (0.12)	0.0003 (0.008)
15T640	0.006 (0.15)	0.0004 (0.010)
18T650	0.007 (0.18)	0.0005 (0.013)
20T680	0.008 (0.20)	0.0005 (0.013)
22T700	0.009 (0.22)	0.0006 (0.015)
25T730	0.010 (0.25)	0.0007 (0.018)
27T770	0.011 (0.27)	0.0007 (0.018)
30T820	0.012 (0.30)	0.0008 (0.02)

10.4 *Width Tolerances*—Maximum deviations from the ordered width shall be as shown in Table 4. Allowable deviations for widths >40 in. (1.0 m) shall be negotiated between the producer and the user.

10.5 *Length Tolerances*—The maximum deviations from the ordered length shall be as shown in Table 5. Allowable deviations for lengths >120 in. (3.1 m) shall be negotiated between the producer and the user.

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 0.25 in. (6.4 mm) per 96 in. (2.4 m) 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 0.063 in. (1.6 mm) per 6 in. (152 mm) 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.

TABLE 4 Width Tolerances

Ordered Width, in. (m)	Width Tolerance, in. (mm)	
Under 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 16 (0.41), incl	+ 0.032 (0.81)	- 0.032 (0.81)
Over 16 (0.41) to 40 (1.0), incl	+ 0.064 (1.6)	- 0.064 (1.6)

TABLE 5 Length Tolerances

Specified Length, in. (m)	Length Tolerance, in. (mm)	
Under 30 (0.8), incl	+ 0.125 (3.2)	- 0 (0)
Over 30 (0.8) to 60 (1.5), incl	+ 0.25 (6.4)	- 0 (0)
Over 60 (1.5) to 96 (2.4), incl	+ 0.5 (12.7)	- 0 (0)
Over 96 (2.4) to 120 (3.1), incl	+ 0.75 (19.1)	- 0 (0)
Over 120 (3.1) to 144 (3.7), incl	+ 1.0 (25.4)	- 0 (0)

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, or other imperfections that 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 20 000 lb (9100 kg) in weight.

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

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

13. Test Methods

13.1 The required tests for core loss to determine the core-loss type, and other tests for magnetic properties, shall be in accordance with the procedure of Test Method A348/A348M.

13.1.1 Test Method A343/A343M may be considered appropriate in special circumstances provided the test frequency is 400 Hz or less. The use of Test Method A343/A343M and acceptable core loss and other measured values shall be determined by agreement of the user and producer.

13.1.2 Magnetic tests using toroidal specimens may be considered appropriate in special circumstances; the use of toroidal specimen tests may be used if agreed to by the user and the producer. Test Method A927/A927M should be used for toroidal specimen tests; acceptable core loss and other measured values shall be determined by agreement of the user and the producer.

13.2 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 the percent aluminum multiplied by 1.70, as determined for the median or aim silicon and aluminum of the melt, shall determine the assumed density to be used. Typical thin-gauge fully processed nonoriented electrical steel will have from 2.5 to 3.5 %silicon and from 0.5 to 0.8 %aluminum; the assumed densities for these materials will be determined as follows:

% Si + (1.70 × % Al)	Assumed Test Density g/cm^3 (kg/m^3)
2.93 - 3.69	7.65 (7650)
3.70 - 4.46	7.60 (7600)

For materials with different silicon or aluminum percentages, please refer to Practice A34/A34M, Table 1, for the determination of assumed test densities.

13.3 *Test Specimen Preparation*—Test specimens for the required test specified in 13.1 shall be prepared in the following manner.

13.3.1 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.

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

14. Certification

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

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

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

14.4 Inclusion of other items in the certification, including contractual or regulatory statements, shall be agreed to by the user and producer.

15. Marking

15.1 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.

15.2 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.

15.3 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.

16. Packaging

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

17. Rejection

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

17.2 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.

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

18. Keywords

18.1 core loss; electrical steel; flat-rolled; fully processed; nonoriented; silicon steel; thin-gauge electrical steel

APPENDIXES

(Nonmandatory Information)

X1. TYPICAL PROPERTIES

INTRODUCTION

The data and procedures provided in these appendixes are for general information only; they are not requirements in this specification and need not be measured.

X1.1 *Peak Permeability*—Typical values for relative peak permeability (μ_p) at a magnetic flux density of 10 kG (1.0 T) determined in accordance with Test Method A348/A348M are given in Table X1.1.

TABLE X1.1 Typical Relative Peak Permeability at a Magnetic Flux Density of 10 kG (1.0 T) and 400 Hz for As-Sheared Epstein Specimens[A]

Core-Loss Type	Thickness, in. (mm)	Typical Relative Peak Permeability
10T590	0.004 (0.10)	8450
12T610	0.005 (0.12)	8400
15T640	0.006 (0.15)	8350
18T650	0.007 (0.18)	8300
20T680	0.008 (0.20)	8200
22T700	0.009 (0.22)	8075
25T730	0.010 (0.25)	7875
27T770	0.011 (0.27)	7600
30T820	0.012 (0.30)	7200

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

X1.2 *Minimum Magnetic Flux Density*—Typical values for minimum magnetic flux density at magnetic field strengths of 31 Oe (2500 A/m) and 63 Oe (5000 A/m) and at 400 Hz determined in accordance with Test Method A348/A348M are provided in Table X1.2.

X1.3 *Lamination Factor*—The lamination factor for these materials as determined using Test Method A719/A719M at a test pressure of 50 psi (340 kPa) typically range from 92 to 97 % depending on thickness, coating, and surface roughness.

X1.4 *Hardness*—Typical hardness values are not provided in this specification as they may vary from producer to producer and from production lot to production lot depending on mill production and finishing practices. Test Methods E18 or Test Method E384 may be used to test the hardness of these materials. The necessity for hardness tests, the test method or methods to be used and acceptable hardness values should be agreed to by the user and producer.

TABLE X1.2 Typical Magnetic Flux Density at Noted Magnetic Field Strength at 400 Hz for As-Sheared Epstein Specimens[A]

Core-Loss Type	Thickness in. (mm)	Typical Magnetic Flux Density, kG (T)	
		31 Oe (2500 A/m)	63 Oe (5000 A/m)
10T590	0.004 (0.10)	1.45 (1.45)	1.55 (1.55)
12T610	0.005 (0.12)	1.45 (1.45)	1.55 (1.55)
15T640	0.006 (0.15)	1.50 (1.50)	1.60 (1.60)
18T650	0.007 (0.18)	1.50 (1.50)	1.60 (1.60)
20T680	0.008 (0.20)	1.55 (1.55)	1.65 (1.65)
22T700	0.009 (0.22)	1.55 (1.55)	1.65 (1.65)
25T730	0.010 (0.25)	1.55 (1.55)	1.65 (1.65)
27T770	0.011 (0.27)	1.55 (1.55)	1.65 (1.65)
30T820	0.012 (0.30)	1.55 (1.55)	1.65 (1.65)

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

X2. STRESS-RELIEF ANNEALING OF LAMINATIONS

X2.1 Lamination fabrication processes may affect the ultimate magnetic properties of laminations and other components manufactured from thin-gauge electrical steels. A stress-relief annealing procedure performed after the manufacture of the laminations may assist in remediating the magnetic properties of these laminations. Typical stress-relief annealing procedures include a controlled furnace atmosphere, attention to the dew point of the furnace gasses, prescribed furnace heating, soak and cooling profiles and can be performed in both batch and continuous ovens. The necessity for stress-relief annealing of a particular batch of laminations and the specific annealing procedure to be used, including an assessment of the effect of the annealing process on the applied coating, should be determined by the end-user in consultation with the material producer, the lamination manufacturer and the heat treater.

X2.2 General guidelines for stress-relief annealing of thin-gauge electrical steel laminations:

X2.2.1 Laminations and heat treating equipment should be free from oil, grease and other contamination. Items holding or containing laminations to be annealed, such as wires, trays, boxes and covers, should be manufactured from low carbon cold-rolled steel to limit carbon contamination during annealing.

X2.2.2 A typical furnace atmosphere for stress-relief annealing is nitrogen with 2 to 10 % hydrogen. The annealing temperature should be 1400 to 1450°F (760 to 788°C). The time that the furnace load is kept at this temperature (the soak time) depends on the size and weight of the load but is typically a minimum of 1 h. To help prevent lamination deformation caused by overly rapid cooling, the furnace load should be held in the furnace atmosphere and cooled at a controlled rate suitable for the size and weight of the load (typically 100°F (38°C) / h) until 800°F (427°C) or lower is reached. Cooling may continue at an uncontrolled rate below this temperature.

X2.2.3 After stress-relief annealing, laminations should be handled with care and packaged to prevent oxidation of the laminations and to provide protection from moisture and physical damage during storage or shipment.

X2.2.4 Documents assuring compliance with the stress-relief annealing procedure, including certificates of compliance, furnace charts or other reports, should be supplied by the heat treater if required.