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Standard Specification for Wrought Nickel-Iron Soft Magnetic Alloys (UNS K94490, K94840, N14076, N14080)[1]

This standard is issued under the fixed designation A753; 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 commonly used wrought nickel-iron soft magnetic alloys produced or supplied expressly for use in magnetic cores and other parts requiring high magnetic permeability, high electrical resistivity, low coercive field strength, and low core loss.

1.2 This specification covers materials supplied by a producer or converter to the form and physical condition desired for fabrication into parts that will later be given a final heat treatment to achieve the desired magnetic characteristics. It covers materials supplied in the form of forging billet; hot-rolled plate, strip, and bar; cold-finished bar; cold-rolled and annealed sheet and strip; shaped bar and wire; and wire.

1.2.1 This specification does not cover either powder metallurgically produced or cast parts.

1.2.2 This specification lists requirements for strip products having isotropic or semi-isotropic magnetic properties but does not include requirements for anisotropic or square hysteresis loop alloys or alloys processed to yield flattened hysteresis loops by use of heat treatments in an applied magnetic field.

1.2.3 This specification does not cover alloys modified by the addition of elements such as sulfur and selenium to enhance machinability.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that 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

A341/A341M Test Method for Direct Current Magnetic Properties of Materials Using D-C Permeameters and the Ballistic Test Methods

A480/A480M Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip

A484/A484M Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings

A555/A555M Specification for General Requirements for Stainless Steel Wire and Wire Rods

A596/A596M Test Method for Direct-Current Magnetic Properties of Materials Using the Ballistic Method and Ring Specimens

A772/A772M Test Method for AC Magnetic Permeability of Materials Using Sinusoidal Current

A773/A773M Test Method for dc Magnetic Properties of Materials Using Ring and Permeameter Procedures with dc Electronic Hysteresigraphs

E527 Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)

E1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Fusion Techniques

3. Terminology

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

4. Classification

4.1 Four specific alloy types are covered in Table 1.

4.2 Alloy Type 2 in thin-strip form (thickness less than or equal to 0.020 in. (0.51 mm)) is available in two different grades. Grade 1 is semi-isotropic and is recommended for use in transformer laminations. Grade 2 is isotropic and is recommended for use in rotating machinery laminations and magnetic shielding parts. These grades are the result of different mill processing (that is, cold-rolling and annealing) practices and cannot be created by changes in the final heat treatment given to the laminations or parts.

[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 Specific Alloy Types

Alloy Type	UNS Number[A]	Nickel Range, %[B]
1	K94490	43.5 to 46.5
2	K94840	47.0 to 49.0
3	N14076	75.0 to 78.0
4	N14080	79.0 to 82.0

[A] UNS refers to the Unified Numbering System, an alloy identification system supported by ASTM. Refer to Practice E527 for details.
[B] Alloy Types 3 and 4 have additions of molybdenum, copper, and chromium to improve magnetic performance.

5. Ordering Information

5.1 Orders for material conforming to this specification shall include the following information:

5.1.1 Reference to this specification and year of issue or revision.

5.1.2 Alloy type (Section 4) and grade where appropriate.

5.1.3 Dimensions and tolerances (Section 12).

5.1.4 Quantity (weight or number of pieces as appropriate).

5.1.5 Form and condition (Section 7).

5.1.6 Magnetic property requirements if they are other than those listed in this specification.

5.1.7 Certification of chemical analysis and magnetic quality evaluation.

5.1.8 Marking and packaging requirements.

5.1.9 *End Use*—Whenever possible, the user should specify whether the material will be machined, blanked into flat pieces, blanked and formed, deep drawn to shape, wound into a core, punched into laminations, or photo-etched. This will help the producer to provide the most suitable material for the user's fabricating practices.

5.1.10 Exceptions to this specification or special requirements such as mechanical property requirements.

6. Chemical Composition

6.1 The alloys shall conform to the requirements prescribed in Table 2. Since magnetic performance is paramount, analysis variations are permitted by mutual agreement between the user and producer.

TABLE 2 Chemical Requirements (Weight Percent)

	Alloy 1 UNS K94490	Alloy 2 UNS K94840	Alloy 3 UNS N14076	Alloy 4 UNS N14080
Carbon, max.	0.05	0.05	0.05	0.05
Manganese, max.	0.80	0.80	1.5	0.80
Silicon, max.	0.50	0.50	0.50	0.50
Phosphorus, max.	0.03	0.03	0.02	0.02
Sulfur, max.	0.01	0.01	0.01	0.01
Chromium	0.30 max.	0.30 max.	2.0-3.0	0.30 max.
Nickel	43.5-46.5	47.0-49.0	75.0-78.0	79.0-82.0
Molybdenum	0.30 max	0.30 max.	0.50 max	3.5-6.0
Cobalt, max.	0.50	0.50	0.50	0.50
Copper	0.30 max	0.30 max.	4.0-6.0	0.30 max.
Iron[A]	balance	balance	balance	balance

[A] Iron is the balance by difference. Quantitative analysis of this element is not required.

6.2 Determination of metallic constituents and phosphorus shall be by a method(s) acceptable to both producer and user. Analysis of carbon and sulfur shall be done in accordance with Test Methods E1019.

7. Form and Condition

7.1 These materials are capable of being produced in a wide variety of forms and conditions suitable for further manufacture into specific magnetic articles. The desired form and condition shall be specified and should be discussed with the producer before ordering to assure receiving the appropriate product. Available forms and conditions are:

7.1.1 *Forging Billet*— Hot worked; hot worked with surfaces prepared by grinding.

7.1.2 *Hot-Rolled Plate, Strip, and Bar*—Hot-rolled; hot-rolled and acid cleaned; hot-rolled and annealed; hot-rolled, annealed, and acid cleaned; hot-rolled and mechanically cleaned; mechanical properties as specified.

7.1.3 *Cold-Finished Bars*—Cold-drawn; cold-drawn and centerless ground; cold-drawn and annealed to specified mechanical properties.

7.1.4 *Cold-Rolled Sheet and Strip* —Cold-rolled; deep draw quality; cold-rolled and annealed to specified mechanical properties.

7.1.5 *Wire*—Cold-drawn; cold-drawn and annealed to specified mechanical properties.

7.1.6 *Shaped Bar and Wire*—Cold-worked; cold-worked and annealed to specified mechanical properties.

8. Magnetic Property Requirements—General Requirements

8.1 *Test Methods*— Because of the extremely high magnetic permeabilities developed in these alloys after heat treatment, the use of permeameters (Test Method A341/A341M) is expressly forbidden. Allowable test methods are those using ring-type specimens.

8.2 *Test Specimen*— Whenever possible, test specimen size and shape shall conform to those listed in Practice A34/A34M. Specimen shapes such as stacked laminations, solid rings, and spirally wound tape and wire cores are necessary for the most accurate results. If, however, the product form or dimensions precludes the use of a preferred test specimen, the specimen shape and size shall be mutually agreed upon between the producer and user.

8.3 *Density*—The assumed densities of these materials for purposes of magnetic testing shall be as in Table 3:

8.4 *Heat Treatment*— The heat treatment applied to the test specimen shall be mutually agreed upon between the producer and user. If no such agreement exists, the heat treatment

TABLE 3 Assumed Density

Alloy Type	UNS No.	Assumed Density g/cm^3	Assumed Density (kg/m^3)
1	K94490	8.17	8170
2	K94840	8.25	8250
3	N14076	8.58	8580
4 (4 % Mo)	N14080	8.74	8740
4 (5 % Mo)	N14080	8.77	8770

applied to the test specimen shall be chosen by the producer to exceed the magnetic property requirements listed in Tables 4 and 5 of this specification. Refer to Appendix X2 for information on heat treatment of these alloys.

9. dc Magnetic Property Requirements

9.1 dc magnetic testing shall be the only magnetic test method used for all product forms and sizes other than thin strip and sheet. Thin sheet and strip is defined as flat-rolled product having a thickness of 0.020 in. (0.51 mm) or less.

9.2 Testing shall be conducted using either Test Method A596/A596M or Test Method A773/A773M.

9.3 The dc magnetic property requirements after appropriate heat treatment are shown in Table 4. The symbol *d* refers to the minimum dimension such as thickness or diameter.

10. ac Magnetic Property Requirements (Thin Sheet and Strip Only)

10.1 ac magnetic testing shall be used for all strip and sheet with a thickness of 0.020 in. (0.51 mm) or less.

10.2 Testing shall consist of impedance permeability measured at 60Hz and shall be conducted using Test Method A772/A772M.

10.3 The ac magnetic property requirements after appropriate heat treatment are shown in Table 5.

10.3.1 For thicknesses not listed, the requirements shall be determined by linear interpolation of data shown in Table 5.

10.3.2 For thicknesses outside the ranges shown in Table 5, the ac magnetic property requirements shall be as mutually agreed between the producer and user.

11. Typical Physical and Mechanical Properties

11.1 Typical physical and mechanical properties are listed in Appendix X1.

12. Dimensions and Tolerances

12.1 Dimensions and tolerances for all product forms and sizes shall be as mutually agreed upon between the producer and user. In lieu of such agreement, the tolerances listed in the latest issue of the following specifications shall apply.

TABLE 4 dc Magnetic Property Requirements

NOTE 1—The coercive field strength for Alloy Types 1 and 2 is determined from a maximum induction of 10 kG (1.0 T), while for Alloy Types 3 and 4 the coercive field strength is determined from a maximum induction of 5 kG (0.5 T).

Product Form and Size	Magnetic Property	Alloy Type 1 UNS K94490	Alloy Type 2 UNS K94840	Alloy Type 3 UNS N14076	Alloy Type 4 UNS N14080
Billet (all sizes) *Bar, Wire, Plate, Plate Coil* *d* > 0.500 in. (12.7 mm)	(Relative) Permeability at 40 G (14 mT), min	. . .	. . .	. . .	35 000
	(Relative) Permeability at 100 G (10 mT), min	4500	6000	. . .	42 000
	(Relative) Maximum Permeability, min	35 000	50 000	. . .	175 000
	Coercive Field Strength, Oe (A/m), max.	0.080 (6.4)	0.075 (6.0)	. . .	0.025 (2.0)
Bar, Wire, Plate, Plate Coil *d* ≤ 0.500 in. (12.7 mm)	(Relative) Permeability at 40 G (4 mT), min	. . .	. . .	. . .	35 000
	(Relative) Permeability at 100 G (10 mT), min	5000	7500	. . .	42 000
	(Relative) Maximum Permeability, min	40 000	60 000	. . .	175 000
	Coercive Field Strength, Oe (A/m), max.	0.080 (6.4)	0.070 (5.6)	. . .	0.025 (2.0)
Sheet and Strip 0.060 ≤ *d* ≤ 0.187 in. (1.52 ≤ *d* ≤ 4.75 mm)	(Relative) Permeability at 40 G (4 mT), min	. . .	. . .	. . .	35 000
	(Relative) Permeability at 100 G (10 mT), min	6000	8000	. . .	42 000
	(Relative) Maximum Permeability, min	50 000	90 000	. . .	200 000
	Coercive Field Strength, Oe (A/m), max.	0.080 (6.4)	0.070 (5.6)	. . .	0.025 (2.0)
Sheet and Strip 0.020 < *d* < 0.060 in. (0.51 < *d* < 1.52 mm)	(Relative) Permeability at 40 g (4 mT), min	. . .	. . .	55 000	55 000
	(Relative) Permeability at 100 G (10 mT), min	7500	9000	70 000	70 000
	(Relative) Maximum Permeability, min	55 000	100 000	250 000	250 000
	Coercive Field Strength, Oe (A/m), max.	0.070 (5.6)	0.060 (4.8)	0.015 (1.2)	0.015 (1.2)

TABLE 5 60–Hz ac Magnetic Property Requirements

NOTE 1—Alloy Type 2 Grade 1 is not normally produced in thickness greater than 0.014 in. (0.35 mm).

Alloy Type and Grade	Thickness in. (mm)	Minimum (Relative) Impedance Permeability (μz) at the Peak Flux Density of:				
		40 G (4 mT)	200 G (20 mT)	2000 G (200 mT)	4000 G (400 mT)	8000 G (800 mT)
Type 2 UNS K94840 Grade 1	0.014 (0.36)	10 500	15 000	32 000	. . .	. . .
	0.010 (0.25)	11 000	17 000	40 000	. . .	. . .
	0.006 (0.15)	12 000	18 000	44 000	. . .	. . .
Type 2 UNS K94840 Grade 2	0.020 (0.51)	7000	11 500	23 000	27 000	23 500
	0.014 (0.36)	10 000	17 000	32 000	40 000	45 000
	0.010 (0.25)	10 000	17 000	37 000	47 000	59 000
	0.008 (0.20)	9500	16 500	39 000	51 000	66 500
	0.006 (0.15)	8500	14 500	39 000	55 000	73 000
	0.004 (0.010)	7000	12 000	35 000	52 000	72 000
	0.002 (0.05)	5000	8000	26 000	41 000	58 000
Type 4 UNS N14080	0.020 (0.51)	35 000	40 000	50 000	. . .	. . .
	0.014 (0.36)	50 000	60 000	80 000	. . .	. . .
	0.010 (0.25)	60 000	75 000	105 000	. . .	. . .
	0.008 (0.20)	65 000	80 000	120 000	. . .	. . .
	0.006 (0.15)	70 000	90 000	140 000	. . .	. . .
	0.004 (0.010)	95 000	110 000	190 000	. . .	. . .
	0.003 (0.076)	100 000	120 000	230 000	. . .	. . .
	0.002 (0.051)	90 000	100 000	190 000	. . .	. . .
	0.001 (0.025)	75 000	80 000	150 000	. . .	. . .

12.1.1 *Bars and Billets*— Specification A484/A484M.

12.1.2 *Plate, Sheet, and Strip*—Specification A480/A480M.

12.1.3 *Wire and Wire Rod*—Specification A555/A555M.

13. Rejection and Rehearing

13.1 Material that fails to conform to the requirements of this specification may be rejected by the user. The rejection shall be reported to the producer promptly and in writing. The rejected material shall be set aside, adequately protected and correctly identified.

13.2 The producer may make claim for a rehearing. In this event, the user shall make samples that are representative of the rejected material available to the producer for evaluation.

14. Certification

14.1 When specified in the purchase order or contract, the user shall be furnished certification that samples representing each lot have been either tested or inspected as directed in this specification and the requirements have been met. When specified in the purchase order or contract, a report of the test results shall be furnished to the user from the producer.

15. Packaging and Package Marking

15.1 Packaging shall be subject to agreement between the producer and user.

15.2 Material furnished under this specification shall be identified by the name or symbol of the producer, alloy type, grade where appropriate, heat number, and product size. Each heat supplied on an order must be identified and packaged separately.

16. Keywords

16.1 bars; billet; nickel-iron; permeability; plates; sheets; strips; wires

APPENDIXES

(Nonmandatory Information)

X1. TYPICAL PHYSICAL AND MECHANICAL PROPERTIES

X1.1 Typical physical and mechanical properties are listed in Tables X1.1-X1.3, respectively. These properties are provided for information only and are not subject to measurement and certification on an order.

TABLE X1.1 Typical Physical Properties of Annealed Alloy

	Alloy 1 UNS K94490	Alloy 2 UNS K94840	Alloy 3 UNS N14076	Alloy 4 UNS N14080
Electrical Resistivity (μΩ-cm)	55	49	56	60
Electrical Resistivity (μΩ-mm)	550	490	560	600
Saturation Induction:				
kG	16.0	16.0	7.6	7.8
(T)	1.60	1.6	0.76	0.78
Density:				
(g/cm^3)	8.17	8.25	8.58	8.74-8.77
(kg/m^3)	8170	8250	8580	8740-8770
Curie Temperature, °C	440	450	390	390
Mean Linear Coefficient of Expansion, μm/m/°C				
20 to 100°C	7.1	8.4	12.5	11.5
20 to 500°C	8.2	9.8	14.4	14.0
20 to 1000°C	13.4	13.5	16.2	15.9

TABLE X1.2 Typical Mechanical Properties of Cold-Rolled Hard Temper Strip

Strip Items 0.100-in. (2.54-mm) Maximum Thickness				
	Alloy 1 UNS K94490	Alloy 2 UNS K94840	Alloy 3 UNS N14076	Alloy 4 UNS N14080
0.2 % Offset Yield strength:				
(ksi)	115	135	. . .	150
(MPa)	793	931	. . .	1030
Ultimate tensile strength:				
(ksi)	120	140	. . .	160
(MPa)	827	965	. . .	1100
Elongation in 2 in. or 50.8 mm (%)	2	2	2	2
Hardness (HR15N)	74	74	78	78
Hardness (HV1000)	270	270	320	320

TABLE X1.3 Typical Mechanical Properties of Mill Annealed Strip

Strip Items 0.100-in. (2.54-mm) Maximum Thickness				
	Alloy 1 UNS K94490	Alloy 2 UNS K94840	Alloy 3 UNS N14076	Alloy 4 UNS N14080
0.2 % offset Yield strength:				
(ksi)	32	30	30	32
(MPa)	220	210	210	220
Ultimate tensile strength:				
(ksi)	72	73	80	84
(MPa)	500	500	550	580
Elongation in 2 in. or 50.8 mm (%)	38	38	38	40
Hardness (HR15T)	82	82	86	86
Hardness (HV1000)	130	130	160	160

X2. HEAT TREATMENT OF TEST SPECIMENS

X2.1 Producers usually evaluate the magnetic capability of a test lot using a standard heat treatment practice that should be listed on the material certification. Dry hydrogen atmospheres, high annealing temperatures, and prolonged heating periods are used for obtaining the best magnetic performance.

X2.2 The general heat treatment practice for these alloys is:

X2.2.1 Place the prepared test specimens in a sealed (leak-free) retort or equivalent;

X2.2.2 Use a circulated dry hydrogen atmosphere having an entrance dewpoint of –60°F (–51°C) or lower and a free oxygen content of less than 2 ppm;

X2.2.3 Heat to a temperature of 2050 to 2150°F (1120 to 1180°C) and hold for a period of 2 to 6 h. If retort construction permits, even higher temperatures can be used; and

X2.2.4 Cool to room temperature at a rate as prescribed by the producer. Close adherence to prescribed cooling rates is particularly important when heat treating Alloy Types 3 or 4.

X2.3 This general procedure is recommended for determination of magnetic capability and can be used on a production basis. Where applications do not require the ultimate in magnetic performance, a less costly heat treatment practice can be used by the user.

X2.4 To maintain proper qualification, it is recommended that the producer and user use a common heat treatment practice to establish the acceptance quality rating of a lot.