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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 A 753; 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] 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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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 ~~either~~ customary (cgs-emu and inch-pound) units ~~or SI units~~ are to be regarded ~~separately~~ as standard. ~~Within the text, the SI units are shown in brackets.~~ The values ~~stated~~ given in ~~each system~~ parentheses are mathematical conversions to SI units which are provided for information only and are not ~~exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with this specification.~~ considered standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 34/A 34M Practice for Sampling and Procurement Testing of Magnetic Materials[2]

A 340 Terminology of Symbols and Definitions Relating to Magnetic Testing[2]

A 341/A 341M Test Method for Direct Current Magnetic Properties of Materials Using ~~D-C~~ dc Permeameters and the Ballistic Test Methods[2]

A 343 Test Method for Alternating-Current Magnetic Properties of Materials at Power Frequencies Using Wattmeter-Ammeter-Voltmeter Method and 25-cm Epstein Test Frame[2]

A 480/M 480M Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip[3]

A 484/A 484M Specification for General Requirements for Stainless and Heat-Resisting Steel Bars and Shapes, Carbon, Rolled from "T" Rails[3]

A 555/A 555M Specification for General Requirements for Stainless Steel Wire and Wire Rods[3]

A 596/A 596M Test Method for Direct-Current Magnetic Properties of Materials Using the Ballistic Method and Ring Specimens[2]

A 772 Test Method for ~~A-C~~ ac Magnetic Permeability of Materials Using Sine~~usoidal~~ Current[2]

[2] *Annual Book of ASTM Standards,* Vol 03.04.

[3] *Annual Book of ASTM Standards,* Vol 01.03.

A 773/A 773M Test Method for ~~D-C~~ dc Magnetic Properties of Materials Using Ring and Permeameter Procedures with ~~D-C~~ dc Electronic Hysteresigraphs[2]

E 527 Practice for Numbering Metals and Alloys (UNS)[4]

E 1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel and in Iron, Nickel, and Cobalt Alloys[5]

3. Terminology

3.1 The terms and symbols used in this specification are defined in Terminology A 340.

4. Classification

4.1 Four specific alloy types are covered:

Alloy Type	UNS Number[A]	Nominal Range of Nickel, %[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 E 527 for details.
[B] Alloy Types 3 and 4 have additions of molybdenum, copper, and chromium to improve magnetic performance.

4.2 Alloy Type 2 in thin-strip form (thickness less than or equal to 0.0200 in. ~~[~~ (0.508 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. 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.

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 6) and grade where appropriate.

5.1.3 Dimensions and tolerances (Section 11).

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 ~~purchaser~~ 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 ~~purchaser's~~ 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 1. Since magnetic performance is paramount, analysis variations are permitted by mutual agreement between the ~~purchaser~~ user and producer.

[4] *Annual Book of ASTM Standards*, Vol 01.01.
[5] *Annual Book of ASTM Standards*, Vol 03.0~~6~~5.

TABLE 1 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 ~~purchaser.~~ user. Analysis of carbon and sulfur shall be done in accordance with Test Methods E 1019.

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 A 341/A 341M) 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 A 34/A 34M. 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 ~~purchaser.~~ user.

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

		Assumed Density	
~~Alloy Type~~	~~UNS~~	~~g/cm^3~~	~~[kg/m^3]~~
Alloy Type	UNS No.	g/cm^3	(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

8.4 *Heat Treatment*—The heat treatment applied to the test specimen shall be mutually agreed upon between the producer and ~~purchaser.~~ user. If no such agreement exists, the heat treatment applied to the test specimen shall be chosen by the producer to exceed the magnetic property requirements listed in Tables 2 and 3 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 methods 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 0.0200 in. ~~[~~ (0.508 mm~~]~~) or less.

9.2 Testing shall be conducted using either Test Method A 596/A 596M or Test Method A 773/A 773M.

9.3 The dc magnetic property requirements after appropriate heat treatment are shown in Table 2. 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 0.0200 in. ~~[~~ (0.508 mm~~]~~) or less.

10.2 Testing shall consist of impedance permeability measurement and shall be conducted using Test Method A 772.

10.3 The ac magnetic property requirements after appropriate heat treatment are shown in Table 3.

10.3.1 For thicknesses not listed, the requirements shall be determined by linear interpolation of data shown in Table 3.

10.3.2 For thicknesses outside the ranges shown in Table 3, the ac magnetic property requirements shall be as mutually agreed between the producer and ~~purchaser.~~ 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 ~~purchaser.~~ user. In lieu of such agreement, the tolerances listed in the latest issue of the following specifications shall apply.

TABLE 2 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)~~	~~[Relative] Permeability at 40 G [14 mt], min~~	~~. . .~~	~~. . .~~	~~. . .~~	~~35 000~~	
	[Relative] Permeability at 40 G (14 mT), min	. . .	. . .	. . .	. . .	35 000
~~*Bar, Wire, Plate, Plate Coil* $d >$ 0.500 in. [12.7 mm]~~	~~[Relative] Permeability at 100 G [10 mT], min~~	~~4 500~~	~~6 000~~	~~. . .~~	~~42 000~~	
Billet (all sizes) *Bar, Wire, Plate, Plate Coil* $d >$ 0.500 in. (12.7 mm)	[Relative] Permeability at 100 G (10 mT), min	4 500	6 000	. . .	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]~~	
	Coercive Field Strength, Oe (A/m), max.	0.080 (6.4)	0.075 (6.0)	. . .	0.025 (2.0)	
~~*Bar, Wire, Plate, Plate Coil* $d \leq$ 0.500 in. [12.7 mm]~~	~~[Relative] Permeability at 40 G [4 mt], min~~	~~. . .~~	~~. . .~~	~~. . .~~	~~35 000~~	
	[Relative] Permeability at 40 G (4 mT), min	. . .	. . .	. . .	. . .	35 000
Bar, Wire, Plate, Plate Coil $d \leq$ 0.500 in. (12.7 mm)	~~[Relative] Permeability at 100 G [10 mT], min~~	~~5 000~~	~~7 500~~	~~. . .~~	~~42 000~~	
	[Relative] Permeability at 100 G (10 mT), min	5 000	7 500	. . .	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]~~	
	Coercive Field Strength, Oe (A/m), max.	0.080 (6.4)	0.070 (5.6)	. . .	0.025 (2.0)	
~~*Sheet and Strip* $0.0600 \leq d \leq 0.187$ in. [$1.52 \leq d \leq 4.75$ mm]~~	~~[Relative] Permeability at 40 G [4 mT], min~~	~~. . .~~	~~. . .~~	~~. . .~~	~~35 000~~	
	[Relative] Permeability at 40 G (4 mT), min	. . .	. . .	. . .	. . .	35 000
Sheet and Strip $0.0600 \leq d \leq 0.187$ in. ($1.52 \leq d \leq 4.75$ mm)	~~[Relative] Permeability at 100 G [10 mT], min~~	~~6 000~~	~~8 000~~	~~. . .~~	~~42 000~~	
	[Relative] Permeability at 100 G (10 mT), min	6 000	8 000	. . .	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 [2.01]~~	
	Coercive Field Strength, Oe (A/m), max.	0.080 (6.4)	0.070 (5.6)	. . .	0.025 (2.01)	
	~~[Relative] Permeability at 40 g [4 mT], min~~	~~. . .~~	~~. . .~~	~~50 000~~	~~50 000~~	
	[Relative]					

TABLE 3 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] Impedence Permeability (μz) at the Peak Flux Density of:					
		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]	
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 [0.35]	10 500	15 000	32 000	. . .	. . .	
	Type 2 UNS K94840 Grade 1	0.014 (0.35)	10 500	15 000	32 000	. . .	. . .
		0.010 [0.25]	11 000	17 000	40 000	. . .	. . .
		0.010 (0.25)	11 000	17 000	40 000	. . .	. . .
	0.006 [0.15]	12 000	18 000	44 000	. . .	. . .	
	0.006 (0.15)	12 000	18 000	44 000	. . .	. . .	
Type 2 UNS K94840 Grade 2	0.020 [0.50]	5 000	6 000	15 000	17 000	. . .	
	Type 2 UNS K94840 Grade 2	0.020 (0.50)	5 000	6 000	15 000	17 000	. . .
		0.014 [0.35]	6 500	12 000	27 000	40 000	41 000
		0.014 (0.35)	6 500	12 000	27 000	40 000	41 000
		0.010 [0.25]	7 000	13 000	32 000	42 000	50 000
		0.010 (0.25)	7 000	13 000	32 000	42 000	50 000
	0.006 [0.15]	7 000	14 000	31 000	41 000	57 000	
	0.006 (0.15)	7 000	14 000	31 000	41 000	57 000	
	0.004 [0.010]	4 000	7 000	30 000	41 000	55 000	
	0.004 (0.010)	4 000	7 000	30 000	41 000	55 000	
	0.002 [0.05]	4 000	7 000	30 000	41 000	55 000	
	0.002 (0.05)	4 000	7 000	30 000	41 000	55 000	
Type 4 UNS N14080	0.020 [0.50]	30 000	33 000	45 000	. . .	. . .	
	Type 4 UNS N14080	0.020 (0.50)	30 000	33 000	45 000	. . .	. . .
		0.014 [0.35]	45 000	55 000	80 000	. . .	. . .
		0.014 (0.35)	45 000	55 000	80 000	. . .	. . .
		0.010 [0.25]	50 000	65 000	85 000	. . .	. . .
		0.010 (0.25)	50 000	65 000	85 000	. . .	. . .
	0.006 [0.15]	55 000	75 000	115 000	. . .	. . .	
	0.006 (0.15)	55 000	75 000	115 000	. . .	. . .	
	0.004 [0.010]	80 000	95 000	160 000	. . .	. . .	
	0.004 (0.010)	80 000	95 000	160 000	. . .	. . .	
	0.002 [0.05]	60 000	80 000	200 000	. . .	. . .	
	0.002 (0.05)	60 000	80 000	200 000	. . .	. . .	
	0.001 [0.025]	60 000	75 000	130 000	. . .	. . .	
	0.001 (0.025)	60 000	75 000	130 000	. . .	. . .	

12.1.1 *Bars and Billets*—Specification A 484/A 484M.
12.1.2 *Plate, Sheet, and Strip*—Specification A 480/A 480M.
12.1.3 *Wire and Wire Rod*—Specification A 555/A 555M.

13. Rejection and Rehearing

13.1 Material that fails to conform to the requirements of this specification may 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 claim for a rehearing.

14. Certification

14.1 When specified in the purchase order or contract, the ~~purchaser~~ 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 ~~purchaser~~ user from the producer.

15. Packaging and Package Marking

15.1 Packaging shall be subject to agreement between the producer and ~~purchaser.~~ 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 bar; billet; nickel-iron; permeability; plate; sheet; strip; wire

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 (μΩ-cm)	55	49	60	60
~~Resistivity [μΩ-mm]~~	~~550~~	~~490~~	~~600~~	~~600~~
Resistivity (μΩ-mm)	550	490	600	600
Saturation Induction, kG	16.0	15.5	6.9	7.8
[T]	1.60	1.55	0.69	0.78
Density, (g/cm3)	8.17	8.25	8.58	8.74-8.77
[kg/m3]	8170	8250	8580	8740-8770
Curie Temperature, °C	440	482	399	460
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 (%)	4	2	. . .	2
Hardness (HR 15T)	93	93	. . .	94

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 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. (%)	38	38	43	40
or 50.8 mm (%)				
Hardness (HR 15T)	80	80	78	81

X2. HEAT TREATMENT OF TEST SPECIMENS

X2.1 Producers usually evaluate the magnetic capability of a test lot using a standard heat treatment practice which 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 ~~purchaser.~~ user.

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