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Standard Specification for Iron-Nickel and Iron-Nickel-Cobalt Alloys for Low Thermal Expansion Applications[1]

This standard is issued under the fixed designation F1684; 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 two iron-nickel alloys and one iron-nickel-cobalt alloy, for low thermal expansion applications. The two iron-nickel alloys, both containing nominally 36 % nickel and 64 % iron, with the conventional alloy designated by UNS No. K93603, and the free-machining alloy designated as UNS No. K93050. The iron-nickel-cobalt alloy, containing nominally 32 % nickel, 5 % cobalt and 63 % iron, is designated by UNS No. K93500. This specification defines the following product forms for UNS No. K93603 and UNS No. K93500: wire, rod, bar, strip, sheet plate, and tubing. The free-machining alloy, UNS No. K93050, is defined for bar products only. Unless otherwise indicated, all articles apply to all three alloys.

1.2 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.

1.3 This pertains only to the test method section, Section 13. *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1971 Practices for Digestion of Water Samples for Determination of Metals by Flame Atomic Absorption, Graphite Furnace Atomic Absorption, Plasma Emission Spectroscopy, or Plasma Mass Spectrometry

E8 Test Methods for Tension Testing of Metallic Materials [Metric] E0008_E0008M

E10 Test Method for Brinell Hardness of Metallic Materials

E18 Test Methods for Rockwell Hardness of Metallic Materials

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E45 Test Methods for Determining the Inclusion Content of Steel

E92 Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials

E112 Test Methods for Determining Average Grain Size

E140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness

E228 Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer

E354 Test Methods for Chemical Analysis of High-Temperature, Electrical, Magnetic, and Other Similar Iron, Nickel, and Cobalt Alloys

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

E1601 Practice for Conducting an Interlaboratory Study to Evaluate the Performance of an Analytical Method

[1] This specification is under the jurisdiction of ASTM Committee F01 on Electronicsand is the direct responsibility of Subcommittee F01.03 on Metallic Materials, Wire Bonding, and Flip Chip.

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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.

3. Ordering Information

3.1 Orders for material under this specification shall include the following information:

3.1.1 Alloy, as indicated with UNS number,

3.1.2 Size,

3.1.3 Temper designation (Section 6),

3.1.4 Surface finish (Section 10),

3.1.5 Marking and packaging (Section 18), and

3.1.6 Certification, if required.

NOTE 1—Certification should include traceability of the heat to the original manufacturer.

4. Chemical Requirements

4.1 Each alloy shall conform to the requirements as to chemical composition prescribed in Table 1.

NOTE 2—Lower levels of phosphorus and sulfur may be required for certain welding applications. These lower levels shall be negotiated, as needed, between the vendor and user. Welding of the free-machining alloy (UNS No. K93050) is generally not recommended.

5. Surface Lubricants

5.1 All lubricants used during cold-working operations, such as drawing, rolling, or spinning, shall be capable of being removed readily by any of the common organic degreasing solvents.

6. Temper

6.1 The desired temper of the material shall be specified in the purchase order.

6.2 *Tube*—(UNS No. K93603 and No. K93500 only) Unless otherwise agreed upon between the supplier or manufacturer and the purchaser, these forms shall be given either a final bright anneal or anneal and descale by the manufacturer, and supplied in the annealed temper.

6.3 *Strip and Sheet*— (UNS No. K93603 and No. K93500 only) These forms shall be supplied in one of the tempers given in Table 2 or in deep-drawing temper, as specified.

6.4 *Wire and Rod*— These forms shall be supplied in one of the tempers given in Table 3 as specified. Unless otherwise specified, the material shall be bright annealed and supplied in Temper A (annealed).

6.5 *Rod*—(UNS K93050 only) For Temper D (unannealed) material, in rod sizes greater than ½ in. diameter, the mid-radius Brinell Hardness shall be 235 maximum. Consult Test Method E10 for Brinell Hardness test procedures.

6.6 *Plate*—Plate will be supplied in annealed temper. The properties for UNS K93603 and UNS K93500 will be as shown in Table 4.

6.7 For rod forms, air anneal, followed by centerless grinding to remove scale, is an acceptable alternate.

TABLE 1 Chemical Requirements

NOTE 1—Round observed or calculated values to the nearest unit in the last right-hand place of figures used in expressing the limiting value, in accordance with the rounding-off method of Practice E29.

Element	UNS No. K93603	UNS No. K93050	UNS No. K93500
Iron, nominal	remainder[A]	remainder[A]	remainder[A]
Nickel, nominal	36[A]	36[A]	32[A]
Cobalt, max	0.50	0.50	5[A]
Manganese, max	0.60	1.00	0.60
Silicon, max	0.40	0.35	0.25
Carbon, max	0.05	0.15	0.05
Aluminum, max	0.10[B]	... [C]	0.10[B]
Magnesium, max	0.10[B]	... [C]	0.10[B]
Zirconium, max	0.10[B]	... [C]	0.10[B]
Titanium, max	0.10[B]	... [C]	0.10[B]
Chromium, max	0.25	0.25	0.25
Selenium	...	0.15 to 0.30	...
Phosphorus, max	0.015[D]	0.020	0.015[D]
Sulfur, max	0.015[D]	0.020	0.015[D]

[A] For UNS No. K93603 and K93050, the iron, and nickel requirements are nominal, while for UNS No. K93500, the iron, nickel, and cobalt requirements are nominal. These levels may be adjusted by the manufacturer to meet the requirements for the coefficient of thermal expansion as specified in 12.1.

[B] The total of aluminum, magnesium, titanium, and zirconium shall not exceed 0.20 %.

[C] These elements are not measured for this alloy.

[D] The total of phosphorus and sulfur shall not exceed 0.025 %.

7. Grain Size

7.1 (UNS No. K93603 and No. K93500 only) Strip and sheet for deep drawing shall have an average grain size not larger than ASTM No. 5 (Note 3), and no more than 10 % of the grains shall be larger than No. 5 when measured in accordance with Test Methods E112.

NOTE 3—This corresponds to a grain size of 0.065 mm, or 16 grains/in.^{2} of image at 100×.

7.2 Finer grain sizes for deep drawing quality shall be negotiated between user and supplier.

8. Hardness

8.1 *Deep-Drawing Temper*—(UNS No. K93603 and No. K93500 only) For deep drawing, the hardness shall not exceed 157 Vickers Hardness for material 0.100 in. (2.54 mm) and less in thickness and 85 HRB for material over 0.100 in. in thickness. The Vickers Hardness test shall be determined in accordance with Test Method E92, while the Rockwell Hardness test shall be determined in accordance with Test Methods E18.

NOTE 4—For hardness conversions, use Table 3 of Standard E140.

8.2 *Rolled and Annealed Tempers*—Hardness tests when properly applied can be indicative of tensile strength. Hardness scales and ranges for these tempers, if desirable, shall be negotiated between supplier and purchaser.

9. Tensile Strength

9.1 *Strip and Sheet:* (UNS No. K93603 and No. K93500 only)

TABLE 2 Tensile Strength Requirements for Strip and Sheet

Temper Designation	Temper Name	Tensile Strength ksi (MPa)	
		UNS No. K93603	UNS No. K93500 (Nominal Values)
A	anealed	85 max (586 max)	85 max (586 max)
B	½ hard	86 min (593)	86 min (593)
C	hard	105 min (724)	105 min (724)

TABLE 3 Tensile Strength Requirements for Wire and Rod

NOTE 1—The tensile strength limits for Temper D apply only to material ½ in. diameter and under. Consult 6.5 for hardness limits which apply to larger rod sizes.

Temper Designation	Temper Name	Tensile Strength ksi (MPa)		
		UNS No. K93603	UNS No. K93050	UNS No. K93500
A	Annealed	85 max (586 max)	85 max (586 max)	85 max (586 max)
B	Cold worked	86 min (593 min)	86 min (593 min)	86 min (593 min)
D	Unannealed	. . .	111 max (765 max)	. . .

TABLE 4 Room Temperature Tensile Strength Requirements for Plate (UNS K93603 and K93500) Products

0.2 % Yield Strength	33.33 ksi (230 MPa) min – 50.7 ksi (350 MPa) max
Tensile Strength	58 ksi (400 MPa) min – 72.5 ksi (500 MPa) max
Hardness	Rockwell B60 min – 85 max

9.1.1 Tensile strength shall be the basis for acceptance or rejection for the tempers given in Table 2 and shall conform with the requirements prescribed, unless alternative mechanical properties (for example, ductility) and limits are negotiated between user and supplier.

9.1.2 Tension test specimens shall be taken so the longitudinal axis is parallel to the direction of rolling, and the test shall be performed in accordance with Test Methods E8.

9.2 *Wire and Rod:*

9.2.1 Tensile strength shall be the basis for acceptance or rejection for the tempers given in Table 3 and shall conform to the requirements prescribed, unless alternative mechanical properties (for example, ductility) and limits are negotiated between user and supplier.

9.2.2 The test shall be performed in accordance with Test Methods E8.

10. Surface Finish

10.1 The standard surface finishes available shall be those resulting from the following operations:

10.1.1 Hot rolling,
10.1.2 Forging,
10.1.3 Centerless grinding (rod),
10.1.4 Belt polishing,
10.1.5 Cold rolling,
10.1.6 Wire and rod drawing,
10.1.7 Annealed and descaled, and
10.1.8 Bright annealed.

11. Inclusion Content

11.1 *Wire, Rod, Bar, Strip and Sheet Plate*—(UNS No. K93603 and No. K93500 only) These product forms shall be free of inclusions, cracks, blow holes, and other defects that are detrimental to the quality of subsequent product.

11.2 Inclusion ratings for certain applications (for example, deep drawing) shall be negotiated between user and supplier. Rating criteria shall be based on Test Methods E45.

12. Thermal Expansion Characteristics

12.1 The average linear coefficients of thermal expansion shall be within the limits specified in Table 5. For UNS No. K93050, the supplier is requested to supply data over the temperature range 30 to 150°C. Nonmandatory thermal expansion data are found in the Appendix X1 – Appendix X3.

12.2 Typical thermal expansion data, thermal expansion data for annealed material to higher temperatures, and for the three-step anneal used for UNS K93600, are contained in Appendix X1 – Appendix X3.

13. Test for Thermal Expansion

13.1 *UNS No. K93603*— Heat the specimen in a non-oxidizing atmosphere for a minimum of 1 h at 875± 25°C. Cool at a rate not to exceed 300°C/h.

13.2 *UNS No. K93050*— Heat the specimen in a non-oxidizing atmosphere for a minimum of 15 min at 815 ± 25°C. Air cool.

13.3 *UNS No. K93500*— (*1*) Heat the specimen in a non-oxidizing atmosphere for a minimum of 1 h at 845 ± 25°C. Water quench. (*2*) Heat the specimen for a minimum of 1 h at 315 ± 15°C. Air cool. (*3*) Heat the specimen for a minimum of 24 h at 95 ± 10°C. Air cool.

NOTE 5—(Applies to 13.1 – 13.3): Alternative thermal treatments and resulting values of thermal coefficient of expansion may be negotiated between the supplier and purchaser.

13.4 Determine the thermal expansion characteristics in accordance with Test Method E228.

14. Transformation in UNS No. K93500 Alloy

14.1 Because its nominal 5 wt % addition of cobalt, UNS No. K93500 Alloy is metastable at temperatures less than room temperature. If needed, specific minimum transformation temperatures may be negotiated between purchaser and supplier.

15. Chemical Analysis

15.1 This section describes the chemical analysis techniques to be used in case of dispute. Wherever applicable, the analysis procedures described in Practices D1971, Test Methods E354, E1019 and Practice E1601 should be utilized.

15.2 *Carbon, Sulfur*— Combustion method.

15.3 *Aluminum, Chromium, Magnesium*—Atomic absorption method.

15.4 *All Other Elements Shown in* Table 1 *(Excluding Iron, Nickel, and Cobalt)*—Atomic absorption, optical emission or inductively coupled plasma (ICP or ICAP) methods.

NOTE 6—The iron, nickel, and cobalt requirements are nominal (see Table 1).

TABLE 5 Coefficients of Thermal Expansion

Temperature Range,° C	Average Linear Coefficient of Thermal Expansion, µm/m·°C		
	UNS No. K93603	UNS No. K93050	UNS No. K93500
30 to 150	1.2 to 2.7	...	...
−18 to 93	...	...	0.9 max

16. Dimensions and Permissible Variations

16.1 *Cold-Rolled Strip*—(UNS No. K93603 and No. K93500 only) Cold-rolled strip shall conform to the permissible variations in dimensions prescribed in Table 6, Table 7, and Table 8.

16.2 *Round Wire and Rod*—Wire and rod shall conform to the permissible variations in dimensions prescribed in Table 9.

16.3 *Cold-Drawn Tubing*—(UNS No. K93603 and No. K93500 only) Cold-drawn tubing, available either as seamless or welded, shall conform to the permissible variations prescribed in Table 10.

16.4 *Plate*—Plate shall conform to the permissible variations in dimensions as shown in Table 11, Table 12 and Table 13.

17. General Requirements

17.1 The material supplied under this specification shall be commercially smooth, uniform in cross section, in composition, and in temper, it shall be free of scale, corrosion, cracks, seams, scratches, slivers, and other defects as best commercial practice will permit.

18. Packaging and Package Marking

18.1 Packaging shall be subject to agreement between the purchaser and the seller.

18.2 The material as furnished under this specification shall be identified by the name or symbol of the manufacturer and by heat number. The lot size for determining compliance with the requirements of this specification shall be one heat.

19. Investigation of Claims

19.1 Where any material fails to meet the requirements of this specification, the material so designated shall be handled in accordance with a mutual agreement between the purchaser and the seller.

20. Keywords

20.1 iron-nickel alloys; iron-nickel-cobalt alloys; low expansion alloys; precision instruments; UNS No. K93050; UNS No. K93500; UNS No. K93603

TABLE 6 Permissible Variations in Thickness of Cold-Rolled Strip

Specified Thickness, in. (mm)	Permissible Variations in Thickness for Width Given, ± in. (mm)			
	Under 3 (76)	Over 3 to 6 (76 to 152)	Over 6 to 12 (152 to 305)	Over 12 to 16 (305 to 406)
0.160 to 0.100 (4.06 to 2.54), incl	0.002 (0.051)	0.003 (0.076)	0.004 (0.102)	0.004 (0.102)
0.099 to 0.069 (2.51 to 1.75), incl	0.002 (0.051)	0.003 (0.076)	0.003 (0.076)	0.004 (0.102)
0.068 to 0.050 (1.73 to 1.27), incl	0.002 (0.051)	0.003 (0.076)	0.003 (0.076)	0.003 (0.076)
0.049 to 0.035 (1.24 to 0.89), incl	0.002 (0.051)	0.0025 (0.064)	0.003 (0.076)	0.003 (0.076)
0.034 to 0.029 (0.86 to 0.74), incl	0.0015 (0.038)	0.002 (0.051)	0.0025 (0.064)	0.0025 (0.064)
0.028 to 0.026 (0.71 to 0.66), incl	0.0015 (0.038)	0.0015 (0.038)	0.002 (0.051)	0.002 (0.051)
0.025 to 0.020 (0.64 to 0.51), incl	0.001 (0.025)	0.0015 (0.038)	0.002 (0.051)	0.002 (0.051)
0.019 to 0.017 (0.48 to 0.43), incl	0.001 (0.025)	0.001 (0.025)	0.0015 (0.038)	0.002 (0.051)
0.016 to 0.012 (0.41 to 0.31), incl	0.001 (0.025)	0.001 (0.025)	0.0015 (0.038)	0.0015 (0.038)
0.011 to 0.0101 (0.28 to 0.26), incl	0.001 (0.025)	0.001 (0.025)	0.001 (0.025)	0.0015 (0.038)
0.010 to 0.0091 (0.25 to 0.23), incl	0.001 (0.025)	0.001 (0.025)	0.001 (0.025)	0.001 (0.025)
0.009 to 0.006 (0.23 to 0.15), incl	0.00075 (0.019)	0.00075 (0.019)	...	...
Under 0.006 (0.15)	0.0005 (0.013)	0.0005 (0.013)	...	...

TABLE 7 Permissible Variations in Thickness Across Width of Strip

Specified Thickness, in. (mm)	Maximum Variation in Thickness Across Width of Strip, Within Those Provided for in Table 5 for Edge Measurements for Widths and Thickness Given, in. (mm)		
	5 (127) and Under	Over 5 to 12 (127 to 300)	Over 12 to 24 (300 to 600), incl
0.005 to 0.010, incl (0.17 to 0.03, incl)	0.00075 (0.0191)	0.001 (0.025)	0.0015 (0.038)
Over 0.010 to 0.025, incl (0.03 to 0.06, incl)	0.001 (0.025)	0.0015 (0.038)	0.002 (0.051)
Over 0.025 to 0.065, incl (0.06 to 0.16, incl)	0.0015 (0.038)	0.002 (0.051)	0.0025 (0.064)
Over 0.065 to 3⁄16, excl (0.16 to 0.48, excl) (0.16 to 0.48, excl)	0.002 (0.051)	0.0025 (0.064)	0.003 (0.076)

TABLE 8 Permissible Variations in Width of Cold-Rolled Strip Supplied in Coils

Specified Thickness, in. (mm)	Permissible Variations in Width for Widths Given, ± in. (mm)					
	Under ½ to 3⁄16 (12.7 to 4.8)	½ to 6 (12.7 to 152)	Over 6 to 9 (152 to 229)	Over 9 to 12 (229 to 305)	Over 12 to 20 (305 to 508)	Over 20 to 23 15⁄16 (508 to 608)
0.187 to 0.161 (4.75 to 4.09)	...	0.016 (0.42)	0.020 (0.51)	0.020 (0.51)	0.031 (0.79)	0.031 (0.79)
0.160 to 0.100 (4.06 to 2.54)	0.010 (0.25)	0.010 (0.25)	0.016 (0.41)	0.016 (0.41)	0.020 (0.51)	0.020 (0.51)
0.099 to 0.069 (2.51 to 1.75)	0.008 (0.20)	0.008 (0.20)	0.010 (0.25)	0.010 (0.25)	0.016 (0.41)	0.020 (0.51)
0.068 (1.73) and under	0.005 (0.13)	0.005 (0.13)	0.005 (0.13)	0.010 (0.25)	0.016 (0.41)	0.020 (0.51)

TABLE 9 Permissible Variations in Diameter of Wire and Rod

Specified Diameter, in. (mm)	Permissible Variations in Diameter, ± in. (mm)		
Wire (Coiled, Spooled or Straight Lengths)			
0.002 to 0.0043	(0.05 to 0.110)	0.00020	(0.005)
0.0044 to 0.0079	(0.111 to 0.202)	0.00025	(0.006)
0.008 to 0.0149	(0.20 to 0.379)	0.00030	(0.008)
0.015 to 0.0199	(0.38 to 0.507)	0.00040	(0.010)
0.020 to 0.0309	(0.51 to 0.786)	0.00050	(0.013)
0.031 to 0.0409	(0.79 to 1.04)	0.00060	(0.015)
0.041 to 0.0609	(1.04 to 1.548)	0.00070	(0.018)
0.061 to 0.0809	(1.55 to 2.056)	0.00080	(0.020)
0.081 to 0.1259	(2.06 to 3.199)	0.00100	(0.025)
0.126 to 0.1569	(3.20 to 3.99)	0.00150	(0.038)
0.157 to 0.2500	(4.00 to 6.35)	0.00200	(0.051)
Rod, Centerless Ground Finish (Straight Lengths)			
0.030 to 0.0549	(0.76 to 1.396)	0.0005	(0.013)
0.055 to 0.1249	(1.40 to 3.174)	0.0010	(0.035)
0.125 to 0.499	(3.18 to 12.70)	0.0015	(0.038)
0.500 to 0.999	(12.7 to 25.37)	0.0020	(0.051)
1.000 to 1.625	(25.4 to 41.28)	0.0025	(0.064)
1.626 to 1.749	(41.30 to 44.40)	0.0030	(0.08)
1.750 to 1.999	(44.25 to 50.77)	0.0040	(0.10)
2.000 to 4.000	(50.80 to 101.60)	0.0050	(0.13)