The NILO® and NILOMAG® Nickel-Iron Alloys

Special Metals Corporation produces a range of nickel-iron alloys, mainly for controlled expansion and magnetic applications. The compositions of the principal NILO and NILOMAG alloys are given in Table 1. Physical and mechanical properties are described in Tables 2 to 18 and Figures 1 to 4.

NILO alloy 36 (UNS K93600 & K93601/W. Nr. 1.3912), a binary nickel-iron alloy containing 36% nickel. Its very low room-temperature thermal expansion coefficient makes it useful for tooling for aerospace composites, standards of length, measuring tapes and gauges, precision components, and pendulum and thermostat rods. It is also used as the low expansion component in bi-metal strip, in cryogenic engineering, and for laser components.

NILO alloy 42 (UNS K94100/W. Nr. 1.3917), a binary nickel-iron alloy containing 42% nickel. It has a low, and nominally constant, coefficient of expansion over the range 20-300°C (85-570°F). It is used for tooling for aerospace composites, thermostat rods, for semiconductor lead frames, in thermostatic bi-metal strip, and for glass sealing applications in microelectronic components, vacuum devices and electric lamp bulbs.

NILO alloy 48 (UNS K94800/W. Nr. 1.3922, 1.3926 & 1.3927), a binary nickel-iron alloy containing 48% nickel. Its main use is for glass-to-metal seals in soft lead or soda lime type glasses. It is also used for thermostats in industrial applications up to 450°C (840°F).

NILO alloy K (UNS K94610/W. Nr. 1.3981), a nickel-iron-cobalt alloy containing approximately 29% nickel and 17% cobalt. Its thermal expansion characteristics match those of borosilicate glasses and alumina type ceramics. It is manufactured to a close chemistry range, yielding repeatable properties which make it eminently suitable for glass-to-metal seals in mass production applications, or where reliability is of paramount importance.

The magnetic properties of Nilo alloy K are governed basically by its composition and by the heat treatment applied.

The composition of the alloy generally decides the optimum values of the magnetic properties, such as permeability, coercive force and hysteresis loss. The heat treatment given to the alloy will vary these properties between the worst and optimum levels.

The temperature is effective in changing permeability and other properties. For example, coercive force and residual induction will almost invariably decrease with increasing temperature, when no phase change occurs. It also follows that hysteresis decreases with increasing temperature.

In addition fabrication affects the magnetic properties. The magnetic properties are shown in Table 20 and Figures 5, 6, and 7.

NILOMAG alloy 77, a nickel-iron-copper-molybdenum soft magnetic alloy, has an extremely high level of initial permeability and is particularly useful in applications where it is necessary to keep power requirements to a minimum. It is used in transformers, inductors, magnetic amplifiers, switching devices, magnetic shields, tape recorder heads, and memory storage devices.

Other nickel-iron alloys with controlled expansion or magnetic properties are manufactured, usually on the basis of a minimum production quantity. For a cold-rolled strip product, this minimum quantity would typically be 2000 kg (4400 lb).

Table 1 - Nominal Compositions, %. (Not for specification purposes)

Alloy	Ni	Fe	Others
NILO alloy 36	36.0	64.0	–
NILO alloy 42	42.0	58.0	–
NILO alloy 48	48.0	52.0	–
NILO alloy K	29.5	53.0	Co 17.0
NILOMAG alloy 77	77.0	13.5	Cu 5.0, Mo 4.2

Table 2 - Density

Alloy	g/cm³	lb/in³
NILO alloy 36	8.11	0.293
NILO alloy 42	8.11	0.293
NILO alloy 48	8.20	0.296
NILO alloy K	8.16	0.295
NILOMAG alloy 77	8.77	0.317

Publication Number SMC-031

Table 3 - Melting and Inflection Points of NILO alloys

Alloy	Melting Point		Inflection Point	
	°C	°F	°C	°F
NILO alloy 36	1430	2605	220	430
NILO alloy 42	1435	2615	370	700
NILO alloy 48	1450	2640	460	860
NILO alloy K	1450	2640	450	840

Table 4 - Thermal Conductivity at 20°C (68°F)

Alloy	W/m°C	Btu in/ft²h °F
NILO alloy 36	10.0	69.3
NILO alloy 42	10.5	72.8
NILO alloy 48	16.7	116
NILO alloy K	16.7	116

Table 5 - Physical and Magnetic Properties of NILOMAG alloy 77*

Initial Permeability	60,000
Maximum Permeability	300,000
Saturation Induction	0.63 T (6300 G)
Remanence	0.39 T (3900 G)
Coercivity	0.80 A/m (0.01 oersted)
Curie Point	400°C (750°F)
Resistivity at 20°C (68°F)	60 microhm cm (361 ohm. circ mil/ft)

*0.35 mm (0.014 inch) thick strip

Table 6 - Electrical Resistivity

Temperature		Microhm cm (ohm.circ mil/ft)			
°C	°F	NILO alloy 36	NILO alloy 42	NILO alloy 48	NILO alloy K
20	68	80 (481)	61 (367)	47 (283)	43 (259)
100	212	86 (517)	70 (421)	54 (325)	55 (331)
200	392	97 (583)	87 (523)	71 (427)	72 (433)
300	572	105 (632)	101(608)	89 (535)	88 (529)
400	752	111 (668)	110 (662)	104 (626)	100 (602)
500	932	117 (704)	116 (698)	116 (698)	109 (656)
600	1112	121 (728)	120 (722)	121 (728)	114 (686)

Table 7 - Typical Thermal Expansion of NILO alloy 36

Temperature Range		Total Expansion	Mean Linear Coefficient	
°C	°F	10^{-3}	10^{-6}/°C	10^{-6}/°F
-200-20	-328-68	-0.33	1.5	0.8
-100-20	-148-68	-0.16	1.3	0.7
20-100	68-212	0.12	1.5	0.8
20-150	68-302	0.26	2.0	1.1
20-200	68-392	0.47	2.6	1.4
20-250	68-482	0.80	3.5	1.9
20-300	68-572	1.54	5.5	3.1
20-350	68-662	2.37	7.2	4.0
20-400	68-752	3.19	8.4	4.7
20-450	68-842	4.01	9.3	5.2
20-500	68-932	4.85	10.1	5.6

Table 8 - Typical Thermal Expansion of NILO alloy 42

Temperature Range		Total Expansion	Mean Linear Coefficient	
°C	°F	10^{-3}	10^{-6}/°C	10^{-6}/°F
20-100	68-212	0.42	5.3	2.9
20-150	68-302	0.69	5.3	2.9
20-200	68-392	0.95	5.3	2.9
20-250	68-482	1.22	5.3	2.9
20-300	68-572	1.48	5.3	2.9
20-350	68-662	1.80	5.4	3.0
20-400	68-752	2.36	6.2	3.4
20-450	68-842	3.05	7.1	3.9
20-500	68-932	3.84	8.0	4.4

Table 9 - Typical Thermal Expansion of NILO alloy 48

Temperature Range		Total Expansion	Mean Linear Coefficient	
°C	°F	10^{-3}	10^{-6}/°C	10^{-6}/°F
20-100	68-212	0.68	8.5	4.7
20-150	68-302	1.11	8.5	4.7
20-200	68-392	1.55	8.6	4.8
20-250	68-482	1.98	8.6	4.8
20-300	68-572	2.44	8.7	4.8
20-350	68-662	2.88	8.7	4.8
20-400	68-752	3.34	8.8	4.9
20-450	68-842	3.84	8.9	4.9
20-500	68-932	4.37	9.1	5.1

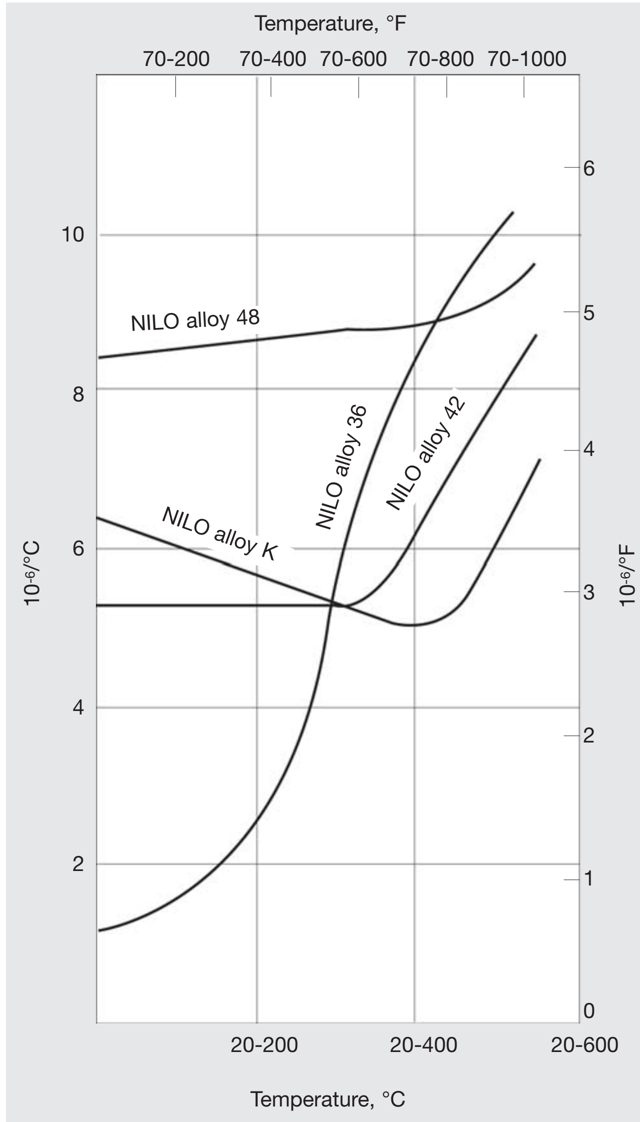

Figure 1 - Thermal expansion coefficients for NILO alloys 36, 42, 48, and K.

Table 10 - Typical Thermal Expansion of NILO alloy K

Temperature Range		Total Expansion	Mean Linear Coefficient	
°C	°F	10^{-3}	10^{-6}/°C	10^{-6}/°F
20-100	68-212	0.48	6.0	3.3
20-150	68-302	0.75	5.8	3.2
20-200	68-392	0.99	5.5	3.1
20-250	68-482	1.22	5.3	2.9
20-300	68-572	1.43	5.1	2.8
20-350	68-662	1.62	4.9	2.7
20-400	68-752	1.86	4.9	2.7
20-450	68-842	2.28	5.3	2.9
20-500	68-932	2.98	6.2	3.4

Table 11 - Typical Mechanical Properties of NILO alloy 36

Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Elongation on 50 mm (2 inch) %	Reduction of Area %
°C	°F	MPa	ksi	MPa	ksi		
20	68	490	71.0	240	35.0	42	70
100	212	430	62.0	180	26.0	43	70
200	392	430	62.0	110	16.0	45	70
300	572	410	59.0	93	13.0	48	70
400	752	350	51.0	93	13.0	53	70
500	932	290	42.0	93	13.0	59	69
600	1112	210	30.0	77	11.0	68	67

Hot-rolled, annealed bar.

Table 12 - Typical Mechanical Properties of NILO alloy 42

Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Elongation on 50 mm (2 inch) %	Reduction of Area %
°C	°F	MPa	ksi	MPa	ksi		
20	68	490	71.0	250	36.0	43	72
100	212	450	65.0	210	30.0	43	72
200	392	450	65.0	130	19.0	43	72
300	572	410	59.0	110	16.0	44	72
400	752	370	54.0	93	13.0	44	71
500	932	310	45.0	93	13.0	47	66
600	1112	210	30.0	93	13.0	56	55

Hot-rolled, annealed bar.

Table 13 - Typical Mechanical Properties of NILO alloy 48

Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Elongation on 50 mm (2 inch) %	Reduction of Area %
°C	°F	MPa	ksi	MPa	ksi		
20	68	520	75.0	260	38.0	43	72
100	212	480	70.0	210	30.0	43	72
200	392	470	68.0	160	23.0	43	72
300	572	460	67.0	150	22.0	43	72
400	752	400	58.0	130	19.0	44	70
500	932	320	46.0	120	17.0	47	64
600	1112	240	35.0	110	16.0	51	55

Hot-rolled, annealed bar.

Table 14 - Typical Mechanical Properties of NILO alloy K

Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Elongation on 50 mm (2 inch) %	Reduction of Area %
°C	°F	MPa	ksi	MPa	ksi		
20	68	520	75.0	340	49.0	42	72
100	212	430	62.0	260	38.0	42	72
200	392	400	58.0	210	30.0	42	72
300	572	400	58.0	140	20.0	45	73
400	752	400	58.0	110	16.0	49	76

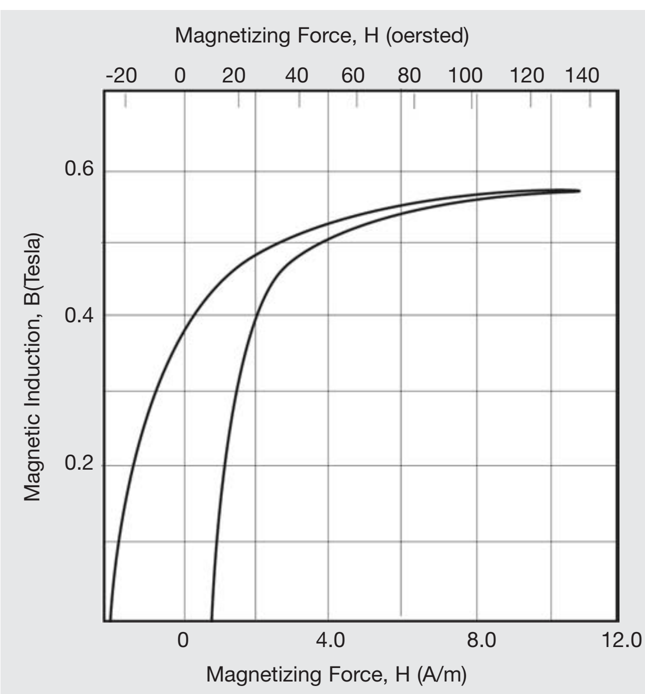

Figure 2 - Hysteresis loop for NILOMAG alloy 77

Table 15 - Hardness

Alloy	HV	HRB
NILO alloy 36, annealed	150 max.	80 max.
full hard	220 min.	96 min.
NILO alloy 42, annealed	140 max.	76 max.
full hard	240 min.	99 min.
NILO alloy 48, annealed	150 max.	80 max.
full hard	240 min.	99 min.
NILO alloy K, annealed	160 max.	83 max.
full hard	230 min.	97 min.
NILOMAG alloy 77, annealed	170 max.	86 max.
full hard	300 min.	HRC 30.5 min.

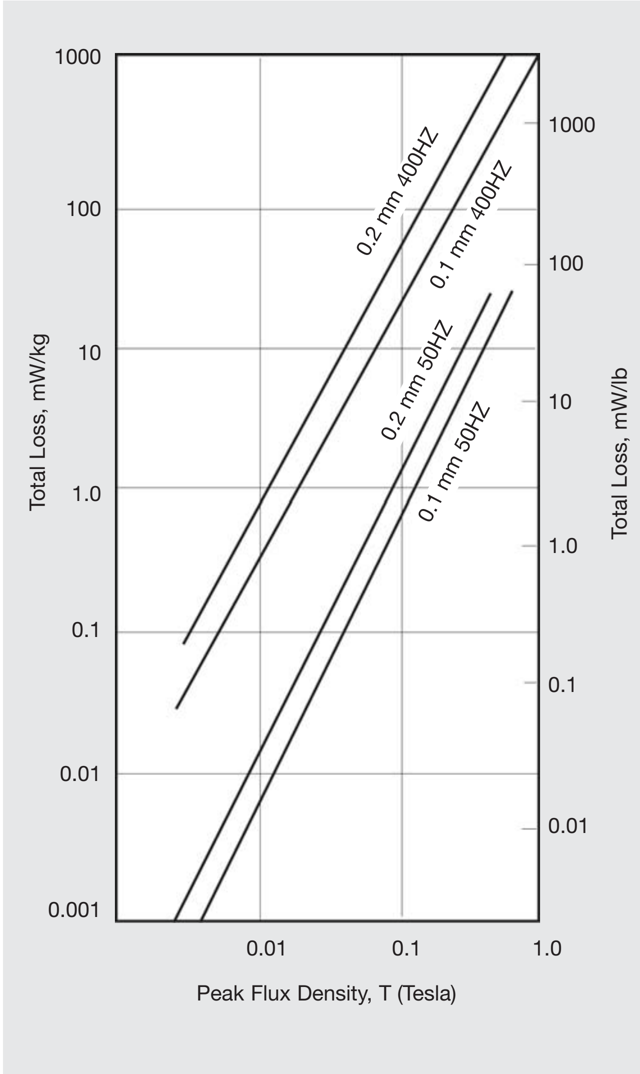

Figure 3 - Total loss curves for NILOMAG alloy 77

Table 16 - Elastic Modulus Data

Alloy	Elastic Modulus	
	GPa	10^3 ksi
NILO alloy 36	140	20.3
NILO alloy 42	150	21.8
NILO alloy 48	160	23.2
NILO alloy K	130	18.9

Table 17 - Tensile Strength of NILOMAG alloy 77 at 20°C (68°F)

As-Rolled		Annealed	
MPa	ksi	MPa	ksi
890-920	129.0-133.0	530-550	77.0-80.0

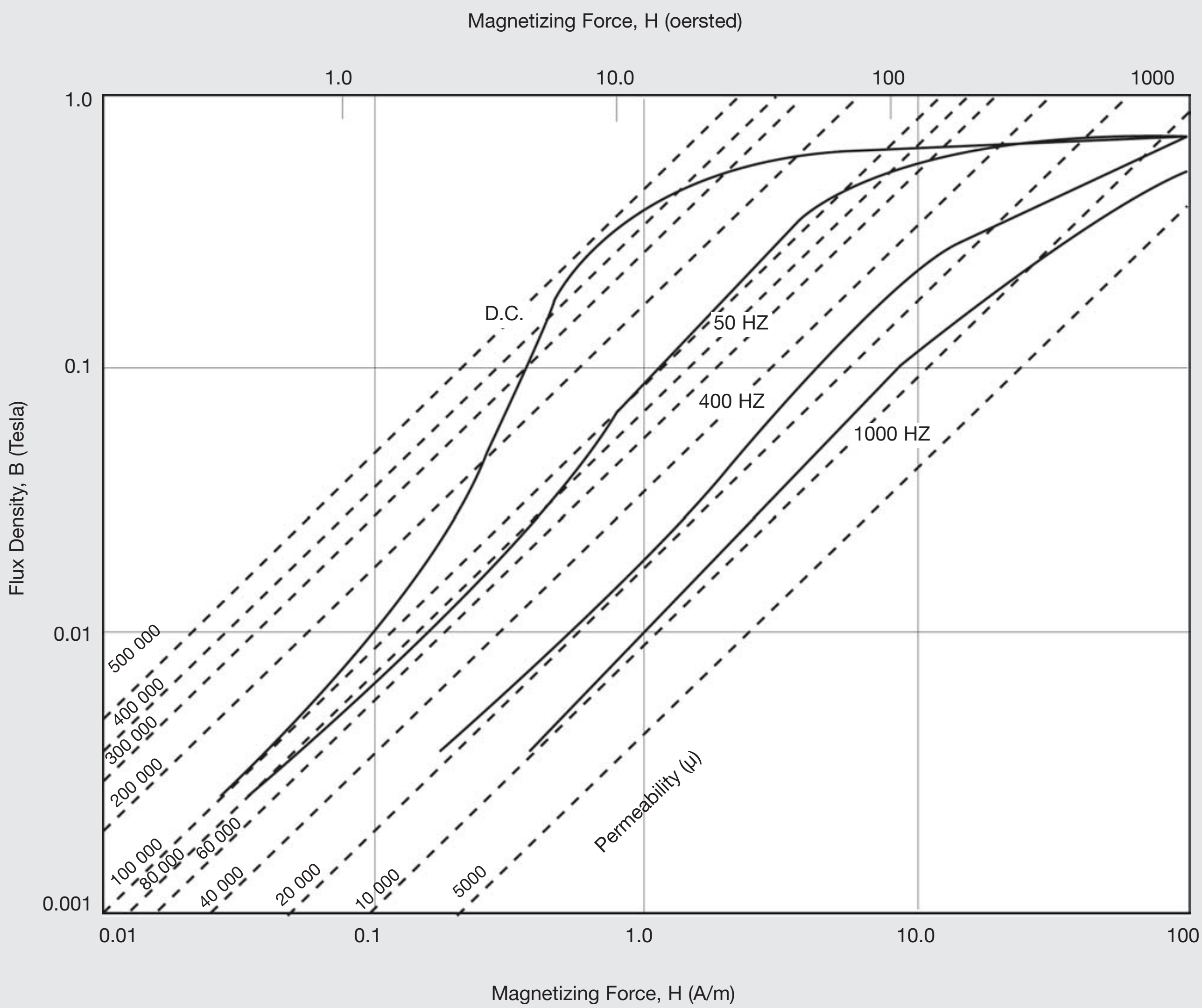

Figure 4 - Normal magnetization curves for NILOMAG alloy 77 ring laminations 0.35mm (0.014 inch) thick.

Table 18 - NILO Alloy K-A Comparison of the Initial Permeabilities, Measured at 50 Hz and a Field Strength of 5 Millioersteds, Produced by Different Heat Treatments

Heat Treatment	Initial Permeability
1 hr. 800°C. 60°C/hr. Furnace cool to Room Temp.	800
1 hr. 900°C. 60°C/hr. Furnace cool to Room Temp.	900
1 hr. 1000°C. 60°C/hr. Furnace cool to Room Temp.	800
1 hr. 1100°C. 60°C/hr. Furnace cool to Room Temp.	800
4 hr. 1100°C. 60°C/hr. Furnace cool to Room Temp.	500
1 hr. 1200°C. 60°C/hr. Furnace cool to Room Temp.	500
4 hr. 1200°C. 60°C/hr. Furnace cool to Room Temp.	500

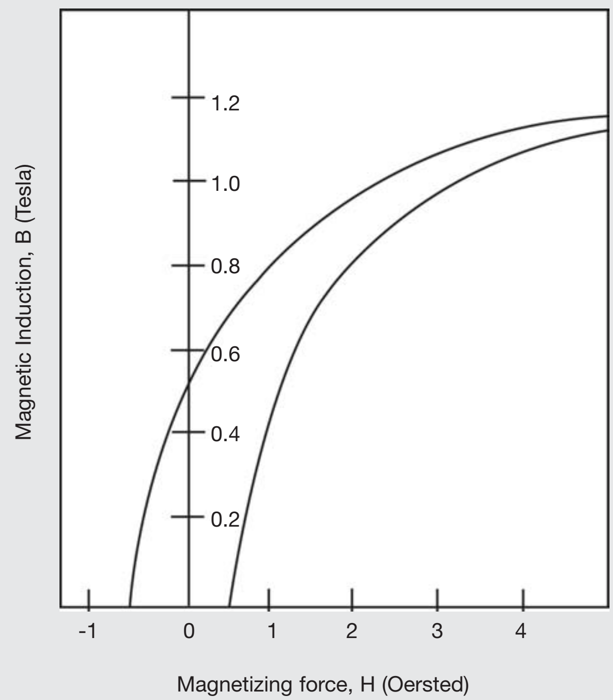

Figure 6 - Hysteresis loop of NILO K at 100°C

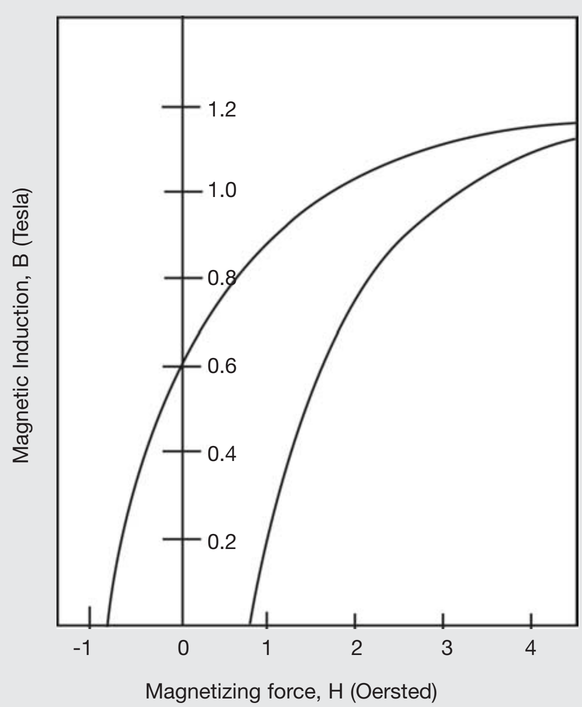

Figure 5 - Hysteresis loop of NILO K at room temperature

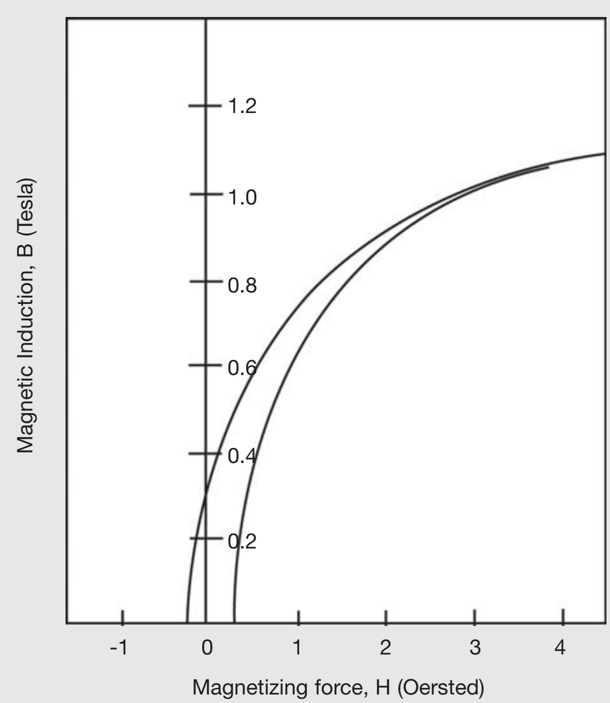

Figure 7 - Hysteresis loop of NILO K at 200°C

Fabrication

NILO alloys 36, 42, 48, and K can be hot or cold worked, machined and formed by processes similar to those used for austenitic stainless steels. For specific advice for particular applications, please consult Special Metals Corporation.

The alloys in the NILO series can be welded, using Nickel Welding Electrode 141, INCO-WELD A, or INCO-WELD B electrodes for the manual metal arc process, and Nickel Filler Metal 61 or INCONEL Filler Metal 82 for TIG, plasma, MIG, or pulsed arc welding. Again, specific advice is available from Special Metals. MIG spray and submerged arc welding processes are not recommended for the NILO series of alloys.

For welding NILO alloys 36 and 42 for tooling for aerospace composites, Special Metals has introduced NILO Filler Metals CF36 and CF42.

Machining

The NILO alloys should be machined in the annealed condition, using high speed steel or tungsten carbide tipped tools. Cutting compounds should be straight cutting oil E.P. medium duty, or soluble oil 20:1 dilution for turning, drilling and milling. Lower dilution ratios should be used for other machining methods.

The following feeds and speeds can be used as a general guide:

	Cutting Speed	Feed
Rough turning, depth of cut 1.25-2.5 mm (0.05-0.10 inch)	30-45 m/min (98-148 ft/min)	0.25-0.4 mm/rev (0.01-0.015 in/rev)
Finish turning, depth of cut 0.125-0.25 mm (0.005-0.010 inch)	45-60 m/min (148-197ft/min)	0.1-0.25 mm/rev (0.0004-0.01 mm/rev)

Drill peripheral speed 15-18 m/min (49-59 ft/min)

Drill feed for hole diameter	1.6 mm (0.06 inch)	0.03 mm/rev (0.001 in/rev)
Drill feed for hole diameter	3.2 mm (0.13 inch)	0.05 mm/rev (0.002 in/rev)
Drill feed for hole diameter	12.7 mm (0.5 inch)	0.13 mm/rev (0.005 in/rev)
Drill feed for hole diameter	25.4 mm (1.0 inch)	0.30 mm/rev (0.01 in/rev)

(Intermediate sizes pro rata)

Heat Treatment

A range of heat treatments has been developed to meet application requirements.

NILO alloy 36

For most uses of NILO alloy 36, where the alloy is to be subjected to a wide range of temperatures, fully annealed material is recommended. A suitable annealing temperature is 850-900°C (1560-1650°F), the time depending on the form and dimensions. Slow cooling is preferred.

Where the highest dimensional stability with minimum expansion is required for devices used within the normal range of ambient temperatures, the following heat treatment is recommended:

Heat to 830°C (1525°F) for 30 minutes/water quench plus re-heat to 300°C (570°F) for 1 hour/air cool plus re-heat to 100°C (212°F) for 48 hours/air cool.

After this treatment the alloy should be fully stable at temperatures up to 100°C (212°F). Protective atmospheres should be used when preheating or annealing.

NILO alloys 42 & 48

Where maximum dimensional stability is required the alloys should be used in the annealed condition. Annealing can be carried out in the range 850°-1000°C (1560-1830°F) in a protective atmosphere.

NILO alloy K

The alloy is normally used in the annealed condition, attained by heating, preferably in hydrogen or cracked ammonia, to 850-1000°C (1560-1830°F).

Decarburization to prepare for glass-to-metal sealing is usually carried out in an atmosphere of wet hydrogen at 900-1050°C (1650-1920°F) for 1 hour. For seals requiring a metal oxide interface, the alloy can be oxidized by heating in air to temperatures in the 600-1000°C (1110-1830°F) range, depending on the thickness of oxide film required.

NILOMAG alloy 77

Optimum magnetic properties are only achieved after suitable heat treatment when all fabrication operations have been completed. Finished components must be treated as follows:

> 2-4 hours at 1100°C (2010°F) in dry hydrogen (dew point below -40°C (°F) followed by a furnace cool to 200°C (390°F) at approximately 69-100°C (140-212°F) per hour, then air cool to room temperature.
>
> Oil , grease, lacquer, and other contaminants should be removed before annealing, and individual parts separated by an inert insulating powder, such as magnesium or aluminum oxide, during annealing.
>
> For shielding applications, it is possible to obtain adequate properties using a protective atmosphere anneal at lower temperatures (1040°C (1900°F) minimum). In general, however, higher annealing temperatures yield higher permeability and shielding properties.

Where necessary, intermediate annealing can be used to relieve stresses and soften the material for further processing operations such as drawing, spinning, forming, bending, etc. This should be carried out by heating for up to 1 hour at temperatures in the range 800-1050°C (1470-1920°F) in a protective atmosphere.

Suitable protective atmospheres for treatments other than the high temperature hydrogen anneal are dissociated ammonia, hydrogen or inert gases such as argon.

Specifications and Designations

The NILO alloys are available to the following specifications and designations:

NILO alloy 36
- UNS K93600 & K93601, W.Nr. 1.3912
- ASTM B 388 & B 753, DIN 1715 (Sheet and strip)
- SEW 385 (Sheet, strip and bar)
- AFNOR NF A54-301(Composition)

NILO alloy 42
- UNS K94100, W.Nr. 1.3917
- ASTM F 29 (Wire)
- ASTM F 30 (Sheet, strip, rod, bar, tubing and wire)
- ASTM B 753 (Sheet and strip)
- SEW 385 (Sheet, strip and bar)
- DIN 17745, AFNOR NF A54-301 (Composition)

NILO alloy 48
- UNS K94800; W.Nr. 1.3922, 1.3926, 1.3927
- ASTM F 30 (Sheet, strip, rod, bar, tubing and wire)
- DIN 17745, AFNOR NF A54-301 (Composition)

NILO alloy K
- UNS K94610, W.Nr. 1.3981
- ASTM F 15 (Rod, bar, sheet, strip, tubing, wire)
- ASTM F 29, SAE AMS 7726 (Wire)
- SAE AMS 7727 (Bars and forgings)
- SAE AMS 7728 (Sheet, strip and plate)
- DIN 17745, AFNOR NF A54-301 (composition)

Availability

The NILO and NILOMAG alloys are available in the following standard product forms:

	Round	Sheet	Strip	Tube	Wire	Section	Plate
NILO alloy 36	•	•	•	•	•	•	•
NILO alloy 42	-	•	•	•	•	-	•
NILO alloy 48	•	-	•	•	•	-	-
NILO alloy K	•	•	•	•	•	-	-
NILOMAG alloy 77	-	•	•	-	-	-	-

Other forms may be available to special order.

Special Metals also provides a technical bulletin directed to the use of the NILO alloys for composite tooling called “The NILO Nickel-Iron Alloys for Composite Tooling”. Visit www.specialmetals.com to access this document.

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