



HIGH PURITY NICKEL STRIP

FOR BATTERY APPLICATIONS

The Benefits of Commercially Pure
Wrought Powder Metallurgy Alloy Strip
in Battery Systems



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ABSTRACT

Described herein are high purity wrought powder metallurgy alloys which conform to the general compositional description of commercially pure nickel (99% min. Ni+Co) yet offer property advantages for battery applications which are not available in conventional cast and wrought commercially pure alloy grades. In particular, the powder metallurgy approach enables use of very low level alloy additions with favorable impact on mechanical, welding, and other properties without detracting from the high electrical and thermal conductivity achievable for high purity materials. Application details requiring special properties are noted and property comparisons are given between powder metallurgy and melted materials.

INTRODUCTION

Commercially pure nickels have been available for many years. They are used in a variety of applications because of a unique combination of properties such as good electrical and thermal conductivity, resistance to tarnishing or chemical reactivity in ambient temperature, atmospheric environments, good formability, ease of plating, good weldability, moderate resistance to acids and excellent resistance to caustic solutions. Metallurgically, the alloys may be described as single-phase, face-centered, cubic-solid solution alloys. Phase stability and general low chemical reactivity impart a practically useful degree of metallurgical simplicity. The alloys are thus easy to work with in many processing steps.

Exceptions to the above general comments on metallurgical simplicity do exist. The alloys are sensitive to sulfur pick-up and can be embrittled by sulfur. Carbon embrittlement is also possible during long-term exposures at 600°F and above if carbon exceeds about 0.02 weight percent. The high purity nature of the alloys also results in significant property changes on a percentage basis for small variations in impurity and/or alloying levels and can result in excessive grain growth during component fabrication or assembly thermal treatments.

Described herein are powder metallurgy alloys resulting from over 40 years of experience in powder metallurgy process and alloy developments. Alloys with tailored properties have been developed which circumvent problems that can be encountered with high purity nickel. Alloys featuring these tailored properties have already found applications in a range of energy systems including a 10,000 ampere-hour lithium-thionyl-chloride cell, lithium-iodine cardiac pacemaker cell, and conventional AA and D nickel-cadmium cells. With the properties described herein, designers of future systems can rely on state-of-the-art high purity powder metallurgy strip alloys to perform in high reliability applications in the most demanding environments.

AMETEK Specialty Metal Products has capabilities beyond the parameters listed above. We also provide narrow strip on traverse wound tools. If you have specific requirements not covered in this brochure, email **Matt Lappen** at **matt.lappen@ametek.com**.

POWDER METALLURGY STRIP PROCESS OVERVIEW

Specific details of the AMETEK Specialty Metal Products alloying and processing powder metallurgy technology for nickel strip are proprietary and thus will not be elaborated upon. General steps are **(a)** preparation of elemental blends from carbonyl nickel powder containing less than 20 ppm metallic impurities, **(b)** roll compaction of powder into strip having a thickness of approximately 0.125 inch, **(c)** sintering, and **(d)** further densification, homogenization, and purification of the strip using a series of cold roll and thermal treatment steps. Material is exposed to a temperature of 2200°F or above. Roll compaction and sintering steps are continuous. All rolling is performed cold and thus hot working alloying additions are not required. The majority of applications involve strip thicknesses that have been reduced 50% and more by cold rolling. The term, "wrought powder metallurgy strip" is sometimes used to differentiate the product from other powder metallurgy products which have been compacted and sintered but not worked to full density to optimize mechanical properties.

ALLOY DESIGNATIONS AND CHEMISTRIES

Four common commercially pure alloy grade types are shown in Table 1. Included are selected compositional notes for each grade. Table 2 shows other compositional specifications for AMETEK SMP grades.

Table 1. Alloy Designations:

Selected Commercially Pure Nickels (99% Min. Ni+CO)

UNS Number	Compositional Notes	AMETEK Alloy Grades
N02270	99.97% min. Ni	AME270-899A
N02233	0.01-0.10/0 mg	AME205-899D
N02201	0.02% C max.	AME200-899L AME201-899M
		AME205-899D AME205-899E
N02200	0.15% C max.	AME200-899L AME201-899M
		AME205-899D AME205-899E

The alloy grades listed above are available in these size ranges:

Thickness - 0.001" (0.05mm) to 0.100" (2.54mm)

Width - 0.060" (1.52mm) to 13.50" (345mm)

Vickers Hardness Range - (Dead Soft to Full Hard) 64-210

Coil Sizes offered (Inside diameter): 3" (76mm), 6" (152mm), 8" (203mm), 12" (203mm), 16" (405mm)

Coil Sizes offered (Outside diameter): 36" (915mm max)

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Table 2. Chemical Composition in Percent

CHEMISTRY	ALL VALUES ARE MAXIMUM WEIGHT PERCENT UNLESS INDICATED AS TYPICAL					
ALLOY	AME270-899A	AME200-899L	AME201-899M	AME205-899D	AME225-899G	AME205-899E
C	0.02	0.02	0.02	0.02	0.02	0.02
Co	0.001	0.01	0.01	0.01	0.01	0.01
Cr	0.001	0.005	0.005	0.005	0.005	0.005
Si	0.001	0.005	0.005	0.005	0.005	0.005
Mn	0.001	0.05 typical	0.02 typical	0.03 typical	0.030 typical	0.20 typical
S	0.0005	0.001	0.001	0.001	0.001	0.001
Cu	0.001	0.005	0.005	0.005	0.005	0.005
Fe	0.005	0.05	0.05	0.05	0.05	0.05
Mg	0.001	0.002	0.002	0.015 typical	0.012 typical	0.001
Sn	0.001	0.005	0.005	0.005	0.005	0.06 typical
Al	0.001	0.005	0.005	0.005	0.005	0.005
Ti	0.001	0.005	0.005	0.005	0.005	0.005
UNS Equivalent Alloy CHEMISTRY	N02270	N02201 N02200	N02201 N02200	N02201	N02233	N02233
C	0.02	0.15	0.15	0.15	0.15	0.15
Si	0.001	0.35	0.35	0.35	0.10	0.10
Mn	0.001	0.35	0.35	0.35	0.30	0.30
S	0.001	0.01	0.01	0.01	0.008	0.008
Cu	0.001	0.25	0.25	0.25	0.10	0.10
Fe	0.0005	0.40	0.40	0.40	0.10	0.10
Mg	0.001				0.01-0.10	0.01-0.10
Ti	0.005				0.005	0.005
Co	0.001					
Cr	0.001					
Ni	99.97 MIN	99.0 MIN	99.0 MIN	99.0 MIN	99.0 MIN	99.0 MIN

UNS N02201 has the same chemistry requirements as N02200 except C is 0.02% maximum.

WELDABILITY

Welding methods frequently used in component assembly are resistance spot welding, gas tungsten arc welding (GTAW), and laser welding. Important alloy parameters for making high reliability GTAW and laser welds are low gas content, low inclusion levels and addition of a strong to moderate oxide former for scavenging of oxygen. Use of a cover gas having oxygen gettering potential significantly improves weld integrity.

A cover gas of high purity argon with 3% hydrogen (30 ppm H₂O maximum) is recommended. In laser welding, use of a straight argon cover gas without hydrogen will result in significantly higher levels of voids and oxide stringers. The same tendencies are observable in GTAW. These weld defects are unacceptable potential leak sites in casing header welds in high reliability lithium-thionyl-chloride batteries.

Grade **AME270-899A** is recommended only for resistance spot welding as the alloy is prone to gas void formation in high speed, 40 inch/minute and above GTAW and laser welding. Approved

AMETEK SMP welding grades are **AME200-899L** and **AME205-899D** and typical welding grade chemistries are noted in Table 3. Welds in these alloys are typically very clean with respect to oxide stringers and impurity element segregation at current grain. Generic Unified Number System (UNS) numbers, and AMETEK SMP alloy grades supplied to the generic UNS alloy type. Alloy N02270 has always been produced via a powder metallurgy approach as the specified high purity level does not permit additions required in melting for proper melt deoxidation and adequate ingot hot-workability. Alloy N02201 has historically been the most widely used of the alloys shown. Alloy N02233 is seldom specified for battery applications.

Table 2 provides additional compositional details for AMETEK SMP grades and those elements which are included as maximums for N02200 and N02201. Silicon, manganese, copper, sulfur, and iron maximums are much lower in AMETEK SMP grades than the N02201 specification, and as will be evident from property comparisons shown later, are also lower than typical currently produced melted alloy chemistries.

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WELDABILITY *continued*

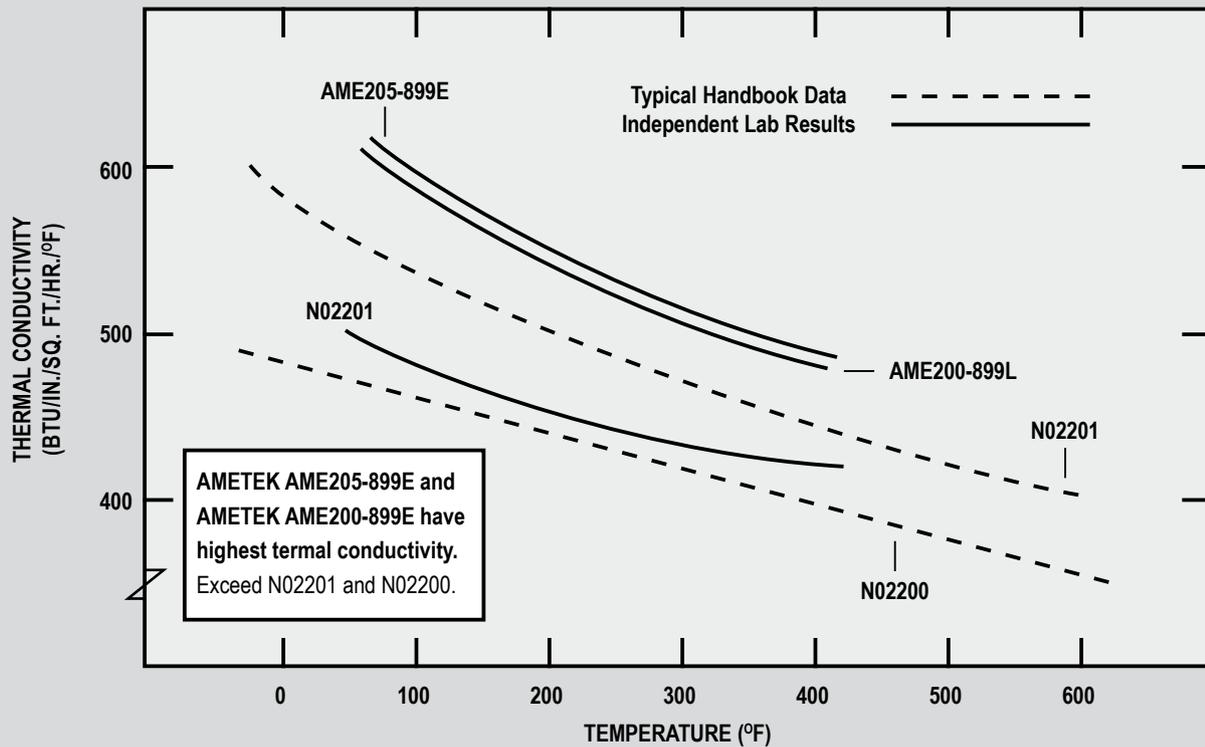
Standard alloying elements used in AMETEK SMP alloys are manganese, magnesium and tin. Magnesium is combined as a fine MgO dispersed phase and as noted in Table 2 the magnesium containing **AME205-899D**, **AME205-899E** and **AME205-899G** grades are noted as “dispersed phase” alloys. Alloying addition levels are closely controlled at plus or minus 100 ppm (by weight) on magnesium and tin and at levels of plus or minus 100-500 ppm on manganese with the actual manganese range depending upon alloy type. These very tight controls on alloying ingredients coupled with the very high purity of the carbonyl-nickel powder are the basis for the unusual chemical reproducibility and attendant property control for the alloys.

Table 3. Typical AME200-899L and AME205-899D Welding Grade Chemistries

Element	Grade - Typical Level, PPM	
	AME200-899L	AME205-899D
Mn	500	2000
O	30	100 ¹
C	200	200
N	1-2	1-2
H	1-2	1-2

¹ 80 PPM combined as MgO

FIGURE 1. THERMAL CONDUCTIVITY



THERMAL CONDUCTIVITY

Thermal conductivity versus temperature is shown in Figure 1. Comparison of independent laboratory results indicates approximately 10% higher thermal conductivity of **AME200-899L** over N02201. The combination of higher thermal conductivity and lower electrical resistivity combine to reduce temperature excursions during overload conditions.

PROPERTIES

Selected nickel properties of importance to system designers and component fabricators are presented. In tables or graphs showing comparative properties for AMETEK SMP and competitively produced melted product, UNS numbers are used for melted alloys and **AME200-899** grade letter descriptions for AMETEK SMP alloys. Unless noted otherwise, competitive values were determined on commercially obtained samples tested in AMETEK SMP laboratories. Emphasis is given **AME200-899L** and **AME205-899D** grades in the property discussions as these grades offer specialized properties for battery applications.

Table 4. Electrical Resistivity at 70° F for AME200-899 Nickel *ohm/cmF*

NICKEL GRADE	ANNEALED	50% COLD WORK
AME270-899A	44.5	45.0
AME200-899L	45.1 ^(c)	45.6
AME201-899M	46.7	47.6
AME205-899D	47.3	47.8
AME205-899E	48.1	48.6
AME205-899G	45.0	45.5
COMPARATIVE DATA FOR WROUGHT AND CAST NICKEL		
UNS N02270	45.0 ^(a)	
UNS N02201	59.6	62.2
UNS N02201	52.0 ^(b)	
UNS N02200	57.0	59.2

(a) Wrought powder metallurgy (b) Handbook value (c) Special grade with 44 maximum value available

ELECTRICAL RESISTIVITY

Values are shown in Table 4 for annealed and 50% cold-worked tempers. The low values for AME270-899A explain usage as a tab material in special military applications requiring lowest available electrical resistivity in a commercial nickel. However, grade **AME200-899L** is recommended herein for general usage in components requiring low electrical resistivity as electrical resistivity is only slightly higher (1.3%) and the alloy offers resistance to sulfur embrittlement, improved formability, and much better weldability.

In the annealed condition, **AME200-899L** offers an 18.9% resistivity advantage compared with a mean value of 55.6 ohm/cmF for the four melted heats. Reproducibility is an additional expected typical advantage as the PM approach routinely achieves resistivity variations within plus or minus 2%. A plus or minus 7.2% variation applies to the 55.6 ohm/cmF mean value for the melted heats. These cited annealed advantages are actually somewhat greater for cold-worked tempers.

Shown in Figure 2 is a microstructure of a CO₂ laser edge weld with **AME205-899D** alloy. Boundaries in material are adjacent to the heat affected zone (HAZ). Weld parameters were continuous wave mode, 900 watts, and 60 inches/minute with an Ar-3% H₂ cover gas. Penetration approximates 0.030 in. Similar laser welding parameters are used in **AME200-899L** cathode - bus bar and anode - bus bar weldments in a 10,000 ampere - hour lithium thionyl chloride battery.

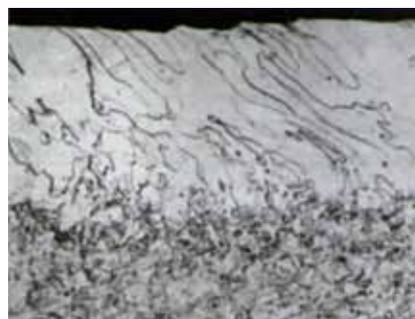


Figure 2. Longitudinal Section of CO₂ Laser Edge Weld in AME205-899 Alloy, 50X.

GRAIN GROWTH

Excessive grain growth can be encountered in high purity nickel during component processing and/or assembly steps. Examples are annealing of drawn parts and the preparation of nickel-to-ceramic joins using copper as a brazing alloy material. Development of large grains reduce mechanical strength and may reduce resistance to chemical attack in aggressive environments. As noted in the following, dispersed phase AMETEK SMP grades conveniently prevent grain growth problems.

Comparative grain growth behaviours for a 50% cold-worked condition are noted in Table 5 for several AMETEK SMP and melted grades. Grain sizes are represented by ASTM numbers which decrease as grain size increases. The largest and smallest sizes are 180 microns and 11 microns for ASTM numbers 2 and 10, respectively. With the exception of **AME270-899A** other **AME200-899** grades clearly exhibit greater resistance to grain growth than the melted alloy. The dispersed phase **AME205-899D** and **AME205-899E** grades show unusual resistance to grain growth.

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GRAIN GROWTH *continued*

The alloy comparisons in Table 5 are only qualitatively accurate for metal deformation steps other than cold-rolling and can actually be quite misleading. Intermediate annealing of pans during a draw-anneal-draw sequence is an example and is illustrated in Figure 3 and Table 6. First and fourth draw untrimmed parts are shown in Figure 3, anneals being performed after the first, second, and third draws.

The part cross-sections are asymmetrical and the amount and nature of metal deformation varies widely at different locations on the part. Table 6 results for first draw pan-annealing indicate the difficulty in obtaining uniform annealed hardness without excessive grain coarsening with the non-dispersed phase **AME200-899L** alloy (best grain size results for etch grade is highlighted). ASTM grain sizes of #6 or coarser can result in tearing at the part corners (Point 2) upon redraw. Surface cosmetics are also important on final parts as an ASTM grain size of #7 maximum is needed to keep orange peel (surface irregularities) within acceptable limits. Table 6 results clearly demonstrate the merits of the dispersed phase alloy and also show, when compared with Table 5, grain coarsening at lower temperatures for drawn parts than for cold rolled strip.

OXIDATION

Oxidation/reduction behaviour is important in perforated nickel used as an electrode substrate for slurry overcoating in high reliability Ni-Cd batteries. Predictable oxidation of the perforated substrate is required as is ease of oxide reduction during subsequent firing of the slurry-coated substrate. Field experience has shown **AME200-899L** to be a preferred grade as oxidation is predictable and the low level of stable oxide forming elements results in an oxide which is easy to remove in non-perforated tab portions of the substrate that are to be spot-welded.

SOFTENING TEMPERATURES

Softening temperature can be a very important parameter in component fabrication and/or assembly steps and will vary significantly for small chemical differences in high purity nickels. The temperature at which rapid softening of 50% cold-rolled AMETEK SMP alloys occurs ranges from a low and a high of 610 and 960°F respectively, for **AME270-899A** and **AME205-899E** grades. Lower levels of cold-rolling will increase these cited Specialty Metal Products softening temperatures.

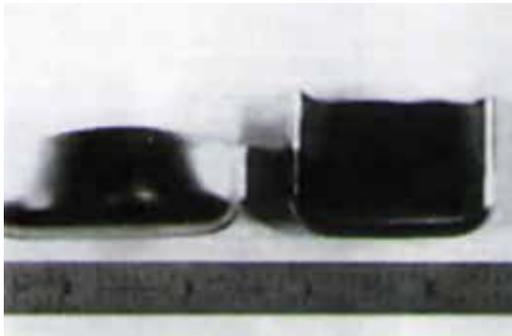


Figure 3. First Draw (left) and Fourth Draw (right) Battery Casing Part from **AME205-899D** Alloy.

Table 5. Grain Growth Comparisons

ASTM GRAIN SIZE AFTER INDICATED HEAT TREATMENT (°F)						
NI Grade	ASTM Grain Size Before 50% Cold Rolled	30 MIN./ 1200°F	30 MIN./ 1450°F	1 HR./ 1800°F	1 HR./ 2000°F	1 HR./ 2200°F
AME270-899A	7.5	7.0	7.0	7.0	2.0	2.0
AME200-899L	8.5	8.5	8.0	7.5	7.0	5.0
AME201-899M	8.0	8.0	7.5	7.5	7.0	5.5
AME205-899D	10.0	10.0	9.0	9.0	9.0	8.5
AME205-899E	10.0	10.0	9.0	9.0	9.0	7.0
AME205-899G	9.0	9.0	8.5	8.0	7.5	7.0
N02233	8.0	8.0	6.5	4.5	3.5	2.5
N02201	8.0	8.0	7.5	3.0	2.0	2.0

Table 6. First Draw Part Annealing Results

Part Condition	HARDNESS (DPH)			ASTM GRAIN SIZE		
	Pt.1	Pt.2	Pt.3	Pt.1	Pt.2	Pt.3
AME200-899L						
1st Draw	111	138	184	8.0	8.0	8.0
30 min @ 1100°F	106	85	0.02	8.0	6.0-7.0	7.0
30 min @ 1100°F	99	86	0.001	8.0	4.5-5.0	6.5
30 min @ 1100°F	93	89	0.25	4.0	4.0	6.0
30 min @ 1100°F	76	86	0.001	5.5	5.5	7.5
AME205-899D						
1st Draw	124	155	194	9.5	9.5	9.5
30 min @ 1100°F	115	136	124	9.5	9.5	9.5
30 min @ 1200°F	113	133	95	9.5	9.5	9.0
30 min @ 1300°F	111	104	106	9.5	9.5	9.0
30 min @ 1400°F	116	103	104	9.5	6.5-9.0	9.0

GRADE USAGE COMMENTS

Three AMETEK SMP grades, **AME270-899A**, **AME200-899L**, and **AME205-899D**, are currently used in different battery applications of which the author is aware. Grade **AME270-899A** finds limited use as a tab material in special applications. Grade **AME-899L** has more widespread use as a tab and perforated substrate in Ni-Cd batteries, and as cathodes, frames for expanded metal anodes and bus bars in lithium-thionyl-chloride batteries. Grade **AME205-899D** is used as deep-drawn casings, headers, and expanded metal for various lithium-based batteries.

Grades **AME200-899L** and **AME205-899D** are recommended herein. Grade **AME205-899D** is recommended over **AME200-899L**, where grain growth resistance is important or the higher strength of **AME205-899D** can be used to advantage in very difficult forming steps.

SUMMARY

The AMETEK SMP powder metallurgy strip process produces high purity nickel alloys which are uniquely suited for battery applications. Very low impurity levels are achievable and dispersed phase alloying approaches can be utilized to advantage. Tight control over low level alloying additions is also an inherent advantage of the process. As a result, additions in excess of that needed to routinely achieve a particular property are not required and addition impact on other properties is thus minimal. Two alloy grades, **AME200-899L** and **AME205-899D**, are described and recommended which offer the high electrical and thermal conductivities expected of high purity material coupled with the excellent formability and welding properties normally associated with more highly alloyed products.

ADVANTAGES

Our High Purity Nickel strip offers major advantages to the rechargeable battery industry:

- Lowest electrical resistivity available in pure nickel strip
- Homogeneity microcleanliness, and close composition control enhances weldability
- Significantly low levels of surface oxides reduces die wear and provides excellent solderability
- Excellent formability

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SPECIFICATIONS

PHYSICAL PROPERTIES

(Typical handbook values for pure nickel)

DENSITY AT 70° F

8.90 g/cc; 0.322 lb./cu. in.

COEFFICIENT OF LINEAR EXPANSION (IN./IN./°C)

20-100° C 0.000014

20-200° C 0.000014

20-500° C 0.000015

20-700° C 0.000016

YOUNG'S MODULUS, E, PSI X 10⁶

30.1

ELECTRICAL CONDUCTIVITY

22.6% IACS

ELECTRICAL RESISTIVITY AT 20° C

microhm, cm: 7.63

ohms/cir. mil./ft.: 45.9

THERMAL CONDUCTIVITY

cal./cm.2/sec. °C/cm. at 70° C: 0.206

BTU/ft.2/hr./° F/ft. at 158° C: 49.9

TEMPERATURE COEFFICIENT OF

ELECTRICAL RESISTIVITY

20-100° C/°C 0.0058

20-500° C/°C 0.0074

20-800° C/°C 0.0060

ATOMIC NUMBER

28

ATOMIC WEIGHT

58.1

ATOMIC RADIUS (A)

1.25

CRYSTAL STRUCTURE

f.c.c.

LATTICE CONSTANT "a" (A)

3.52

MELTING POINT

1,453° C; 2,647° F

BOILING POINT

2,730° C; 4,950° F

LATENT OF HEAT FUSION

73.8 cal/g

SPECIFIC HEAT AT 20° C-BTU/lb./° F

0.105

ELECTRODE POTENTIAL

0.25 volts

VELOCITY OF SOUND

16,300 ft./sec.; 4,973 m/sec.

POISSON'S RATIO

0.31

THERMAL NEUTRON CROSS SECTION (BARNs)

Absorption: 4.6

Scattering: 17.5

CURIE TEMPERATURE

353° C; 665° F

MAGNETIC PROPERTIES

(Typical handbook values for pure nickel)

CURIE TEMPERATURE

353° C; 665° F

INITIAL PERMEABILITY

130

MAXIMUM PERMEABILITY

124

SATURATION INDUCTION, GAUSS (B)

6050

REMANENCE, GAUSS (B)

3250

COERCIVITY, OERSTEDS (H)

3.0

ISO 9001: 2000
CERTIFIED

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