

## Monel Nickel-Copper Alloy 400 (UNS No4400)



Monel 400 is a solid solution Ni-Cu alloy that can be hardened by cold processing and prevents attack in the variety of conditions. It is the only metal that attains minimum corrosion in the all types of application environments. That is why it is an ideal Nickel based superalloy. 400 alloy offers superior mechanical features at the subzero temperature ranges. The firmness and hardness improve with minor impairment of ductility or impact strength. The alloy 400 doesn't show ductile to brittle transformation when it freezes to the liquid hydrogen point.

### Chemical Composition

Aluminum (Al)	2.30 to 3.15%
Carbon (C)	below 0.25%
Copper (Cu)	26 to 33%
Iron (Fe)	below 2.5%
Manganese (Mn)	below 1.5%
Nickel (Ni)	63%
Silicon (Si)	0.5%

### Physical Properties

Density	8.8 g/cm <sup>3</sup>	0.318 lb/in <sup>3</sup>
Melting Point	1350oC	2460oF
Coefficient of expansion	13.9 μm/m °C at (20 - 100°C)	7.7 x 10 <sup>-6</sup> in/in °F at (70 - 212°F)
Modulus of rigidity	65.3 kN/mm <sup>2</sup>	9471 ksi
Modulus of elasticity	173 kN/mm <sup>2</sup>	25092 ksi
Poisson's Ratio	0.32	
Curie Temperature, oC	21-49	

The curie temperature of alloy 400 is affected by the change in chemical composition and heating at the room temperature. It is widely used to fulfill the non-magnetic requirements in the various applications. This is noticed against the various ferrous materials that are brittle at the lower temperature ranges.

## Thermal Properties

Temp, oF	Mean Linear Expansion	Thermal Conductivity	Specific Heat,	Electrical Resistivity
-320 oF	-	-	-	.360 $\mu\Omega\cdot m$
-300 oF	11.1 $\mu m/m\cdot^{\circ}C$	16.5 W/m $\cdot^{\circ}C$	223 J/kg $\cdot^{\circ}C$	-
-200 oF	11.4 $\mu m/m\cdot^{\circ}C$	18.2 W/m $\cdot^{\circ}C$	320 J/kg $\cdot^{\circ}C$	-
-100 oF	12.4 $\mu m/m\cdot^{\circ}C$	19.8 W/m $\cdot^{\circ}C$	378 J/kg $\cdot^{\circ}C$	-
70 oF	-	22.0 W/m $\cdot^{\circ}C$	427 J/kg $\cdot^{\circ}C$	0.511 $\mu\Omega\cdot m$

## Mechanical Properties

### Room temperature Tensile features

Wire, cold treated	Tensile strength, ksi	Yield strength, ksi	Elongation %	Hardness, Rc
Annealed	70 ksi - 95 ksi	30 ksi - 55 ksi	45 % - 25 %	-
No. 1 Temper	85 ksi - 100 ksi	50 ksi - 75 ksi	30 % - 20 %	-
Quarter-Hard	95 ksi - 120 ksi	65 ksi - 95 ksi	25 % - 15 %	-
Half-Hard	110 ksi - 135 ksi	85 ksi - 120 ksi	15 % - 8 %	-
Three-Quarter-Hard	125 ksi - 150 ksi	100 ksi - 135 ksi	8 % - 5 %	-
Full-Hard--Spring Temper	145 ksi - 180 ksi	125 ksi - 170 ksi	5 % - 2 %	-
Tube and Pipe				
Cold-Drawn, Annealed	70 ksi - 85 ksi	25 ksi - 45 ksi	50 % - 35 %	75
Cold-Drawn, Stress-Relieved	85 ksi - 120 ksi	55 ksi - 100 ksi	35 % - 15 %	85 - 100
Heat-Exchanger, Annealed	70 ksi - 85 ksi	28 ksi - 45 ksi	50 % - 35 %	75
Heat-Exchanger, Stress-Relieved	85 ksi - 105 ksi	55 ksi - 90 ksi	35 % - 15 %	85 - 97
Hot-Extruded	-	-	-	-
No. 1 Temper (Annealed)	85 ksi	30 ksi - 45 ksi	45 % - 30 %	73
Strip, Cold-Rolled				
Annealed	70 ksi - 85 ksi	25 ksi - 45 ksi		
Spring Temper	100 ksi - 140 ksi	90 ksi - 130 ksi		

## Corrosion Resistance

Alloy 400 resists corrosion in the variety of reducing conditions. It also significantly resists the oxidizing environments as compare to high concentration copper alloys. The versatility of this alloy makes it suitable for using in the different environments. Monel 400 is extensively utilized in the marine operations. It exhibits nominal corrosion rate in the flowing sea water and stagnant conditions.

### Corrosion Rate in Hydrochloric Acid

Metal	UNS	Weight %	Temp, oC, oF		Time	Corrosion rate	
			oC	oF		Mm/y	Mpy
Monel 400	N04400	48 %	550 oC	1020 of	35 days	1.2 Mm/y	48 Mpy

Monel 400	N04400	48 %	600 oC	1110 of	35 days	1.8 Mm/y	72 Mpy
Monel 400	N04400	48 %	15 oC to 25 oC	60 of to 80 of	35 days	.08 Mm/y	3.2 Mpy
Monel 400	N04400	48 %	25 oC to 40 oC	80 of to 100 of	35 days	.02 Mm/y	0.9 Mpy
Monel 400	N04400	48 %	40 oC to 95 oC	100 oF to 200 oF	35 days	.12 Mm/y	4.7 Mpy
Monel 400	N04400	48 %	40 oC to 95 oC	100 oF to 200 oF	35 days	.33 Mm/y	13 Mpy
Monel 400	N04400	50 %	40 oC to 95 oC	100 oF to 200 oF	35 days	.46 Mm/y	18 Mpy
Monel 400	N04400	65 %	40 oC to 95 oC	100 oF to 200 oF	35 days	.13 Mm/y	4.8 Mpy
Monel 400	N04400	70 %	40 oC to 95 oC	100 oF to 200 oF	35 days	.14 Mm/y	5.4 Mpy
Monel 400	N04400	50 %	40 oC to 95 oC	100 oF to 200 oF	35 days	.12 Mm/y	4.7 Mpy
Monel 400	N04400	65 %	40 oC to 95 oC	100 oF to 200 oF	35 days	.06 Mm/y	2.3 Mpy
Monel 400	N04400	70 %	40 oC to 95 oC	100 oF to 200 oF	35 days	.05 Mm/y	2 Mpy

Alloy 400 resists corrosion in the variety of reducing conditions. It also significantly resists the oxidizing environments as compare to high concentration copper alloys. The versatility of this alloy makes it suitable for using in the different environments. Monel 400 is extensively utilized in the marine operations. It exhibits nominal corrosion rate in the flowing sea water and stagnant conditions. It also resists stress corrosion cracking and pitting corrosion in the fresh and commercially used waters.

#### Creeping Resistance

Monel 400 nickel-copper alloy is utilized at the higher temperatures of 1000oF in the oxidizing conditions. The elevated temperature conditions are used in the reducing environments.

## Alloy 400 Processing

Monel 400 alloy is easily joined and fabricated. The complete control on amount of hot or cold processing and choosing suitable heat processing, finishing fabrication can be done to produce the extensive range of mechanical characteristics.

#### Heating and Pickling

The normal processes and precautions for heating are followed to obtain the required mechanical characteristics. The alloy is bright and free from discoloration when warmed and quenched in the reducing conditions in an alcohol water solution. The quenching rate doesn't provide any vital impact. It creates an adherent oxide layer if Monel 400 alloy is quenched in air subsequent to heating. The cold and hot processing of 400 alloy needs thermal processing to make an adequate combination of firmness and ductility in reducing the distortion after machining.

The stress equalizing of cold processed material increases the yield strength at 0.00% offset without considerable effects on other features. The stress equalizing is performed by

holding for three hours at a temperature about 575oF. This process is preferred to receive nominal distortion after removing the metal. The heating for one to two hours at a temperature of 1000oF to 1050oF reduces strain in the both hot and cold processed products. The stress relief of 1000oF to 1200oF for one hour subsequent to slower quenching is highly significant as a safety measure to avoid stress corrosion cracking in the particular conditions. The annealing of Monel 400 is capable to soften the work hardening. The time and temperature are based on the quantity of earlier cold processing of alloy. Generally, the alloy is annealed by open heating at temperature of 1600oF to 1800oF for 2 – 10 minutes.

On the other hand box annealing is conducted from 1400oF to 1500oF for three hours. In this process, the cold drawn rod is produced by annealing up to 1300oF for three hours and hot rolled plate is developed by annealing at 1470oF for three hours. The grain development is noticed when Monel 400 is heated in the above region of annealing temperature.

#### Pickling of Monel 400 Alloy

The pickling of alloy 400 produces vivid and clean alloy surface.

#### Fabrication

Alloy 400 is easily fabricable by following the standard methods.

Hot fabrication: Corresponding to the resistance offered by alloy 400 to hot bending, it can be hot fabricated into any form. It is softer than various steels. It is essential to get adequate temperature for hot forging that varies from 1200oF to 2150oF. The preferred temperature for massive reductions is from 1700oF to 2150oF however 1200oF for minor reductions. The low temperature processing brings excellent mechanical characteristics and slight grain development. The extended soaking of alloy 400 at the hot processing temperature is determinate. In case the processing is delayed the furnace temperature is lowered to 1900oF however if it is heated at temperatures more than 2150oF, the alloy is permanently deformed.

The massive forging must not be performed quickly because it leads to overheating of alloy. In hot deformation processes the alloy 400 should be processed quickly once it is taken out of the furnace. The preheating equipments and dies at 500oF are useful to avoid cooling of alloy while processing. The controlled forging process is essential to fulfill the particular requirements of customers. The extent of reduction and finishing temperature should be controlled to produce the required features in the alloy. The forging process incorporates 35% reduction then final heating of alloy 400. This is done in the following manner:

- Reheating
- Forging of alloy that has 5% more space than the end shape takes minimum 25 % reduction.
- Quenching of Monel 400 up to 1300oF

- Processing to get the end size by 5 % reduction.

For the military purposes, high tensile forging also needs at least 35% reduction following the end reheating. It is done in the following way:

- Reheating of specimen
- Forging of section that has approximate 25% more space than the end shape that is 5% reduced.
- Cooling of alloy up to 1300oF.
- Provided finished size by 25 % reduction

The grain filtration is obtained by heating at temperature up to 2000oF for the end heating and increasing the reduction extent of alloy subsequent to end heating.

### **Nickel-Copper Alloy 400 Available Forms**

Wire, mesh, strip, foil, plate, sheet, tube, pipe, bar, rod, flanges