Monel 400 Alloy

The **Monel 400 Alloy** is basically a solid nickel copper alloy that comprises of large strength and hardness at the elevated temperature ranges and offers superior resistance to corrosion in the wide range of corrosive media. **Monel 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 of Monel 400 alloy

Ni	C	Mn	Fe	S	Si	Cu
63 %	0.3 %	2.0 %	2.5 %	0.024 %	0.5 %	28 - 34 %

Physical properties of Monel 400 alloy

Density	8.80 g/cm3
Melting Range oC	1300-1350oC
Modulus of Elasticity	103 ksi
Tension	26.0
Compression	9.5
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 features of Monel 400 alloy

Temp, oF	Mean Linear Expansion, µm/m•°C	Thermal Conductivity, W/m•°C	Specific Heat, J/kg•°C	Electrical Resistivity, µΩ•m
-320	-	-	-	.360
-300	11.1	16.5	223	-
-100	12.4	19.8	378	-
70	-	22.0	427	0.511

Mechanical Properties of Monel 400 Alloy

The hardness of different tempers of Monel 400 sheet and strip is shown in the following table:

Temper	Rockwell B Hardness	
	Sheet	Strip
Deep-Drawing and Spinning Quality	76	76
Annealed	73	68
Skin-Hard	-	68 - 73
Quarter-Hard	73 – 83	73 - 83
Hard	93	93-98

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The below table shows the mechanical features of alloy 400 at the lower temperatures:

Temper	Temperature, oF	Tensile Strength, ksi	Yield Strength ksi	Elongation, %	Reduced Area, %
Cold-Drawn	Room	103.80	93.70	19.0	71.0
	-110	117.45	100.85	21.8	70.2
Forged	70	92.00	67.00	31.0	72.7
	-297	128.25	91.50	44.5	71.8
Annealed	70	78.65	31.30	51.5	75.0
	-297	115.25	49.50	49.5	73.9

Torsional Characteristics of Monel 400 Alloy

Material	Dia, inch	Tensile Properties		Torsional Properties		Ratio		
		Tensile Strength	Yield Strength	Breaking Strength	Proportional Limit	Breaking Strength Torsional / Tensile Strength	Tortional Proportional Limit/ Tensile Strength	Torsional Proportional Limit/ Torsional Breaking Strength
Wire		ksi	ksi	ksi	ksi			
Cold-Drawn,75%	0.148	157	-	110	68	0.700	0.433	0.618
Cold-Drawn,75% Stress-Relieved	0.148	160	-	105	65	0.656	0.404	0.619

Room temperature tensile features of the Monel 400 alloy:

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

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Compressive Features

The compressive features of Monel 400 alloy are calculated in triplicate on single melts. These are shown in the following table:

Temper	Compression		Tension	
	Yield Strength, ksi	Tensile Strength, ksi	Yield Strength, ksi	Elongation, %
Hot-Rolled	33	84	37	39.5
Cold-Drawn	58	97	75	27.0
Annealed	19	78	28	44.0

Shear Strength

The room temperature shear strength of Monel 400 alloy is shown below:

Temper	Thickness, In	Shear Strength, Ksi	Tensile Strength, Ksi	Hardness,Rb
Hot-Rolled, Annealed	0.042	48.75	73.0	65
Cold-Rolled, Annealed	0.029	49.50	76.8	60

The shear strength of rivet wire at the different temperature are shown below:

Shear Strength, ksi	Condition	
	Annealed	B & S No. 1
Room	48.5	54.5
600b	45.0	52.0
800	37.0	47.0
1000	29.0	38.0

In the American navy tear test at the temperature lower up to -320oF, the alloy 400 shows superior ductility and hard fracture features over the wide temperature ranges with the high load improving considerably with the decreasing temperature.

Bearing Strength

In the riveted joints, the failure may occur by tearing the portion of metal to the deformation that is called as bearing firmness. It can be determined by the hard pin or rivet to increase or tear a hole in the specimen. The below table shows the bearing strength of **Monel 400 alloy**:

Temper	Yield strength, ksi	Ultimate Strength, ksi
Annealed	58.0	145.0
Half-Hard	98.1	166.0
Full-Hard	162.0	211.5

The snugly pin was placed in the gap. The highest load for tearing the hole and load necessary for the persistent enlargement of the hole diameter by 2% were determined and calculated as the ultimate and yield strength.

Impact Strength of Monel 400 Alloy

Monel 400 alloy is noted for its hardness that is maintained over the considerable range of temperatures. The below table shows the room temperature charpy and Izod impact strength values of the material obtained during manufacturing.

The tension impact strength of Monel 400 alloy is shown in the below table:

Temper	Tensile Properties				
	Tensile Strengh, ksi	Yield strength, ksi	Elongation %	Reduced Area	Hardness, Rc
Cold Drawn 24% Stress Relieved	97.25	86.65	27.0	66.4	199
Annealed 1450°F/3 hr	78.35	33.35	44.0	65.9	123

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Charpy Torsion Impact Strength of MONEL Alloy 400 Rod is described as following:

Temper	Impact Strength		Angle of Twist, Degree	Hardness, Brine (3000-kg)
	ft•lb	ft•lb/in2		
Hot-Rolled	34	694	101.5	145
Cold-Drawn 24%, Stress-Relieved	39	788	98.0	199
Annealed 1450°F/3 hr	30	599	102.0	123

The complete fracture occurred in the tension impact test materials and the torsion materials remain isolated. The efforts made to make fractures in the torsion materials by decreasing the minimum area by 75% are not fruitful because of the hardness of metal. The effect of reducing temperature on the impact strength of alloy is shown in the following table:

Temper	Impact Strength, ft•lb			
	75°F	-20°F	-112°F	-310°F
Hot-Rolled	219	-	213	196
Cold-Drawn, Annealed	216	212	219	212
Weld, As-Welded	78	-	-	73

The amalgam impact analysis conducted on hot finished plate at liquid hydrogen and liquid helium temperatures is described in the following table:

Temperature, oF	Notch	Orientation	Impact Strength, ft•lb
-423	V	Longitudinal	141-219
-423	V	Transverse	121-216
-423	keyhole	Longitudinal	81-87
-423	Keyhole	Transverse	72-75
-440	V	Longitudinal	Unbroken
-440	V	Transverse	171-193
-440	Keyhole	Longitudinal	123-146
-440	Keyhole	Transverse	91-116

The analysis is done on the samples showing both longitudinal and transverse orientation on the plate.

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.

Microstructure of Monel 400 Alloy

The alloy 400 is a solid solution binary alloy. The nickel and copper metals are mutually soluble in the entire proportions and shown as a single phase. The face centered cubic lattice structure possesses lattice parameter of 3.534 A. In an unetched conditions, the polished Monel 400 alloy takes the random dispersed nonmetallic elements. In few conditions, graphite may also be used.

Corrosion Resistance Properties

The 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 alloy is extensively utilized in the marine operations. It exhibits nominal corrosion rate in the flowing sea water and stagnant conditions.

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Fatigue Strength of Monel 400

The fatigue strength of **Monel 400 alloy Rod** is described in the below table:

Temper	Fatigue Strength, ksi	Tensile Strength, ksi	Ratio, Fatigue Strength/ Tensile Strength
Annealed	33.5	82.0	0.41
Hot-Rolled	42.0	88.0	0.48
Cold-Drawn, As-Drawn	40.5	105.0	0.39
Cold-Drawn, Stress-Equalized	44.0	104.0	0.42
Cold-Drawn, Stress-Relieved	37.0	96.5	0.38

Fatigue strength of Monel 400 sheet, strip is shown in the following table:

Temper	Fatigue Strength (10-8 cycles), ksi	Tensile Strength, ksi	Ratio, Fatigue Strength/Tensile Strength
Annealed	21	74.7	0.28
Quarter-Hard	24.5	76.5	0.32
Half-Hard	28.5	84.2	0.34
Full-Hard	39	126.0	0.31
Full-Hard, Stress-Equalized (525°F/21 hr)	41	133.0	0.31

It also resists stress corrosion cracking and pitting corrosion in the fresh and commercially used waters.

Processing Guidelines for Monel 400 Alloy

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 shows bright and free from discoloration when warmed and quenched in the reducing conditions in the 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 the air subsequent to heating. The cold and hot processing of Monel 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. The stress releasing reduces the stress without recrystallizing the grain structure. 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 Alloy** 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 Monel 400 alloy produces vivid and clean alloy surface.

Fabrication of Monel 400 Alloy

The alloy 400 is easily fabric-able 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:

1. Reheating
2. Forging of alloy that has 5% more space than the end shape that takes minimum 25 % reduction.
3. Quenching of Monel 400 up to 1300oF
4. 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:

1. Reheating of specimen
2. Forging of section that has approximate 25% more space than the end shape that is 5% reduced.
3. Cooling of alloy up to 1300oF.
4. 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.

Cold Forging of Monel 400 Alloy

The alloy 400 is adjustable with entire cold forging methods. The strengths and work toughening rate lie between the mild steel and stainless steel 304.

Machining of Monel 400 Alloy

The Monel 400 alloy is machinable at the moderate rates with the machining equipments that are commonly used on the industrial level. The best equipment and design, paces, coolants and other factors are essential to consider while machining. Commonly the cold drawn and stress relieved material is preferred for the excellent machinability and soft finish.

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The **Monel 400 alloy** is easily joined by following the traditional methods. Many traditional joining methods are valuable for joining Monel 400 to the same or different alloys. The selection of welding material is based on the material joined and the conditions in which this is done.

For the shielded metal arc welding, Monel welding electrode 190 is used to accumulate the almost similar composition of weldments. For the special purposes, the nickel welding electrode 141, inco weld A welding electrode or Inconel welding electrode 112 can also be used. The features of weldments accumulated with the Monel welding electrode 190 between two parts of Monel 400 alloy and carbon steel are described in the below table:

Temperature,oF	Tensile Strength, Ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Reduction of Area, %
Room	74.35	46.65	41.0	66.4
200	42.25	46.05	39.0	56.5
400	68.60	43.10	33.5	64.2
600	69.25	43.15	34.0	59.9
800	66.10	43.00	32.5	47.4

The gas tungsten arc welding and gas metal arc welding, MONEL Filler Metal 60 is employed to collect the similar composition weldments. For few purposes, nickel filler metal 61 or inconel filler metal 625 can also be used. The similar filler metals can be utilized for submerged arc welding. INCOFLUX 5 is employed with the Monel filler metal 60. The Incoflux 6 is utilized with the nickel Filler Metal 61. The INCONEL Filler Metal 625 is utilized for INCOFLUX 7.

Applications of Monel 400 Alloy

The Monel 400 alloy is extensively utilized in the various areas like marine and chemical processing, valves and pumps manufacturing, propeller shaft, marine joints, spring, gasoline and fresh water containers, feed water heating systems and heat exchanging device and de-aerating heaters.

Monel 400 Product Forms Available:

Wire, Wiremesh Screen, Strip, Sheet, Rod, Pipe, Bar, Tubing, Plate, Ribbon, Tape

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