INCONEL® alloy N06230 (UNS N06230 / W.Nr. 2.4733) is a carbide strengthened nickel-chromium-tungsten-molybdenum alloy with an exceptional combination of strength, stability, and resistance to corrosion at very high temperatures. Alloy N06230 offers particularly good resistance to oxidation at temperatures greater than 1800°F (980°C). It also offers good resistance to carburization and nitridation.

The limiting composition of alloy N06230 is listed in Table 1. The alloy is nickel-base. Chromium imparts resistance to high temperature corrosion. Oxidation is further enhanced by a micro-addition of the rare earth element, lanthanum. Tungsten and molybdenum in conjunction with the alloy's high carbon content are largely responsible for the strength of the alloy. The creep resistance of alloy N06230 is optimized by control of the boron content.

The combination of high temperature strength and resistance to creep, stress rupture, and corrosion make the alloy attractive for service at temperatures above 1800°F (980°C). Potential applications include equipment and components for land-based gas turbines, thermal and petrochemical processing, heat treating, and ore and metal refining.

Table 1 - Limiting Chemical Composition, %

Nickel	Balance[a]
Iron	3.0 max.
Chromium	20.0-24.0
Cobalt	5.0 max.
Molybdenum	1.0-3.0
Tungsten	13.0-15.0
Carbon	0.05-0.15
Silicon	0.25-0.75
Manganese	0.30-1.00
Phosphorus	0.030 max.
Sulfur	0.015 max.
Aluminum	0.20-0.50
Lanthanum	0.005-0.050
Boron	0.015 max.

*Reference to the 'balance' of a composition does not guarantee this is exclusively of the element mentioned but that it predominates and others are present only in minimal quantities.

Physical and Thermal Properties

Physical and thermal properties of INCONEL alloy N06230 are reported in Tables 2-5 and Figures 1-2. The values for Young's Modulus were determined by a dynamic method. Poisson's ratio was calculated from the modulus values.

Table 2 - Physical and Thermal Properties at 70°F

Young's Modulus, psi	30.67×10^6
GPa	211.5
Shear Modulus, psi	11.43×10^6
GPa	78.8
Poisson's Ratio	0.34
Magnetic Permeability (70°F, 200 oersteds)	1.002
Electrical Resistivity, µohm cm	126.3
ohm circ mil-ft	759.4
Coefficient of Thermal Expansion (70 to 600°F)	
in/in °F	6.9×10^{-6}
cm/cm °C	12.42×10^{-6}
Density, lb/in³	0.322
g/cm³	8.91
Melting Range, °F	2480-2570
°C	1360-1410

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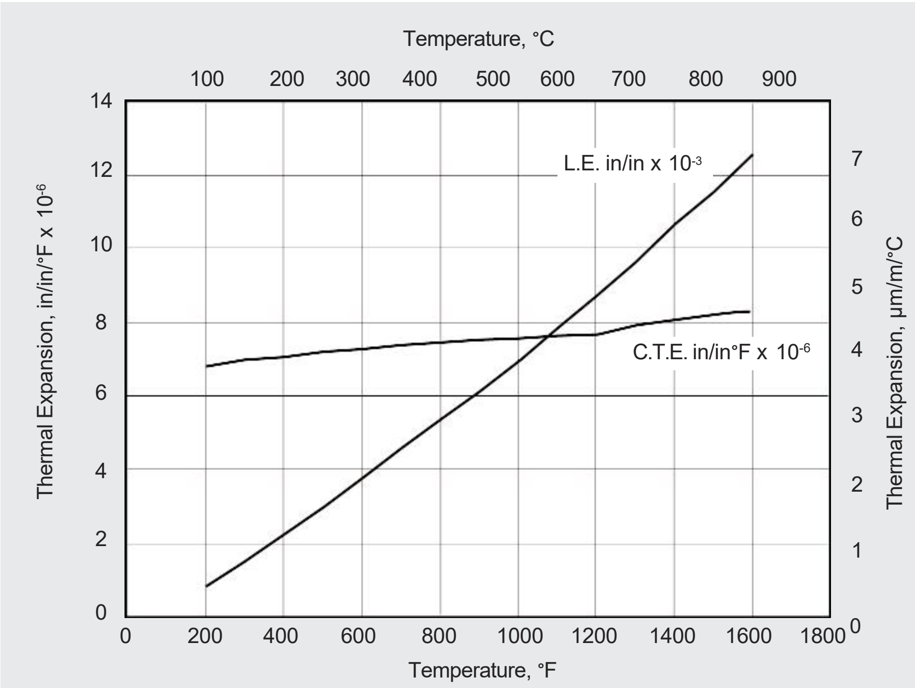

Figure 1. Thermal expansion of annealed INCONEL alloy N06230.

Table 3 - Coefficient of Thermal Expansion

Temperature °F	Coefficient of Expansion 10^{-6} in./in./°F
200	6.90
300	6.98
400	7.10
500	7.18
600	7.29
700	7.40
800	7.48
900	7.52
1000	7.56
1100	7.61
1200	7.70
1300	7.87
1400	8.04
1500	8.12
1600	8.24
Temperature °C	**Coefficient of Expansion µm/m/°C**
100	12.44
150	12.51
200	12.57
250	12.73
300	12.93
350	13.12
400	13.32
450	13.41
500	13.54
550	13.64
600	13.71
650	13.77
700	13.87
750	14.19
800	14.48
850	14.74
900	14.97

Table 4 - Electrical Resistivity of Annealed INCONEL alloy N06230

Temperature °F	Resistivity			Temperature °C	Resistivity
	µΩ cm	µΩ in	Ω circ mil/ft		µΩ cm
72	126.25	49.70	759.43	22	126.25
100	126.25	49.70	759.43	100	126.43
200	126.25	49.70	759.43	150	127.09
300	127.75	50.30	768.47	200	127.75
400	127.75	50.30	768.47	250	128.12
500	128.49	50.59	772.91	300	128.49
600	128.49	50.59	772.91	350	129.95
700	129.94	51.16	781.64	400	131.40
800	132.74	52.26	798.49	450	132.07
900	132.74	52.26	798.49	500	132.74
1000	132.74	52.26	798.49	550	133.09
1100	133.42	52.53	802.58	600	133.43
1200	133.46	52.54	802.82	650	132.80
1300	132.05	51.99	794.35	700	132.17
1400	131.36	51.72	790.16	750	131.51
1500	130.65	51.44	785.92	800	130.85
1600	129.94	51.16	781.64	850	130.4
1700	129.94	51.16	781.64	900	129.94
1800	129.94	51.16	781.64	950	129.94
1900	129.94	51.16	781.64	1000	129.94
2000	130.65	51.44	785.92	1050	130.01

Table 5 - Young's Modulus, Shear Modulus and Poisson's Ratio for Annealed INCONEL alloy N06230

Temperature °F	Young's Modulus 10^3 ksi	Shear Modulus 10^3 ksi	Poisson's Ratio	Temperature °C	Young's Modulus GPa	Shear Modulus GPa
72	30.67	11.43	0.34	22	79	212
100	30.62	11.53	0.33	100	78	208
200	30.22	11.35	0.33	150	77	205
300	29.81	11.16	0.34	200	76	203
400	29.45	10.99	0.34	250	75	201
500	29.27	10.87	0.35	300	74	199
600	28.71	10.75	0.34	350	73	196
700	28.53	10.62	0.34	400	73	194
800	27.90	10.53	0.32	450	72	191
900	27.37	10.34	0.32	500	71	188
1000	27.00	10.13	0.33	550	69	185
1100	26.60	9.90	0.34	600	68	183
1200	26.04	9.81	0.33	650	67	179
1300	25.36	9.68	0.31	700	67	175
1400	24.77	9.47	0.31	750	65	171
1500	24.08	9.03	0.33	800	63	167
1600	23.51	8.82	0.33	850	61	163

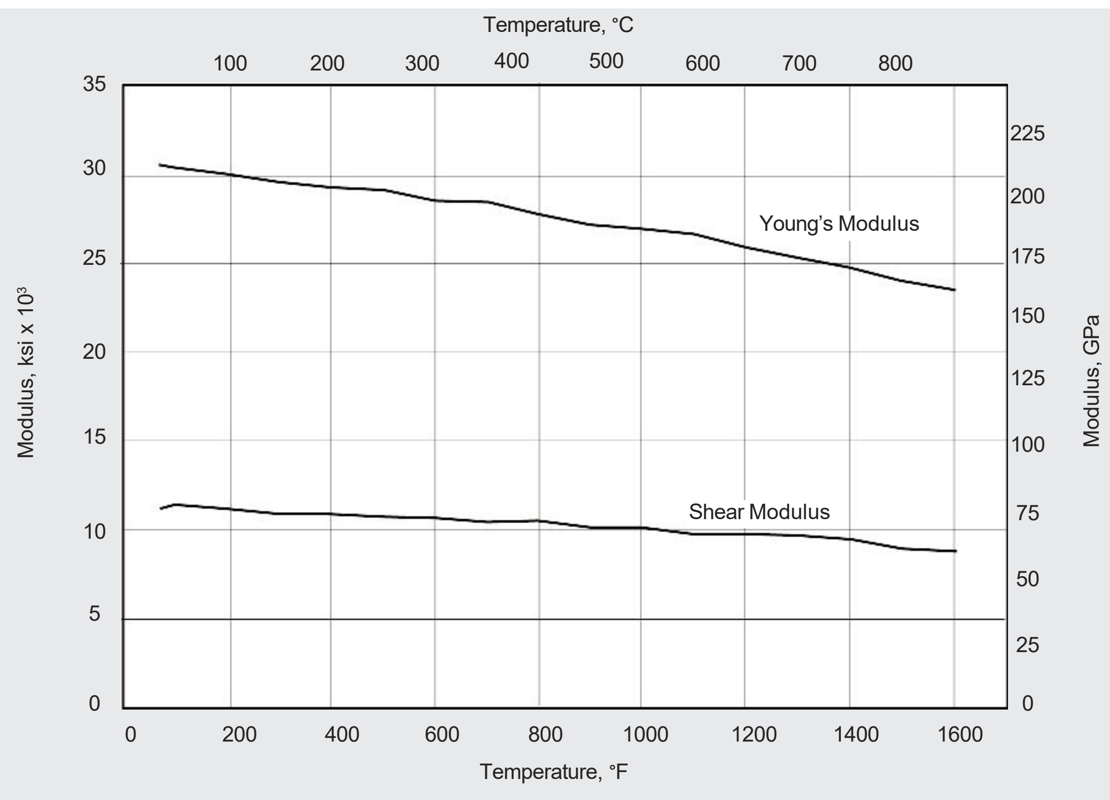

Figure 2. Shear Modulus and Young's Modulus.

Mechanical Properties

INCONEL alloy N06230 products exhibit excellent mechanical properties over a broad range of temperatures. The alloy's strength at temperatures greater than 1800°F (982°C) is of particular importance to designers and engineers. Alloy N06230's resistance to high temperature corrosion in conjunction with high strength enhances its usefulness.

Tensile Properties

Typical values for tensile and yield strength and elongation are compared to specified requirements in Table 6. The effect of temperature on mechanical properties is shown in Figure 3.

Table 6 - Room-Temperature Properties of Hot-Rolled/Annealed Plate

	Ultimate Tensile Strength ksi	0.2% Yield Strength ksi	Elongation, %
Typical Range	117 / 122	55 / 62	44 / 48
AMS 5878A	115 min.	50 min.	40 min.

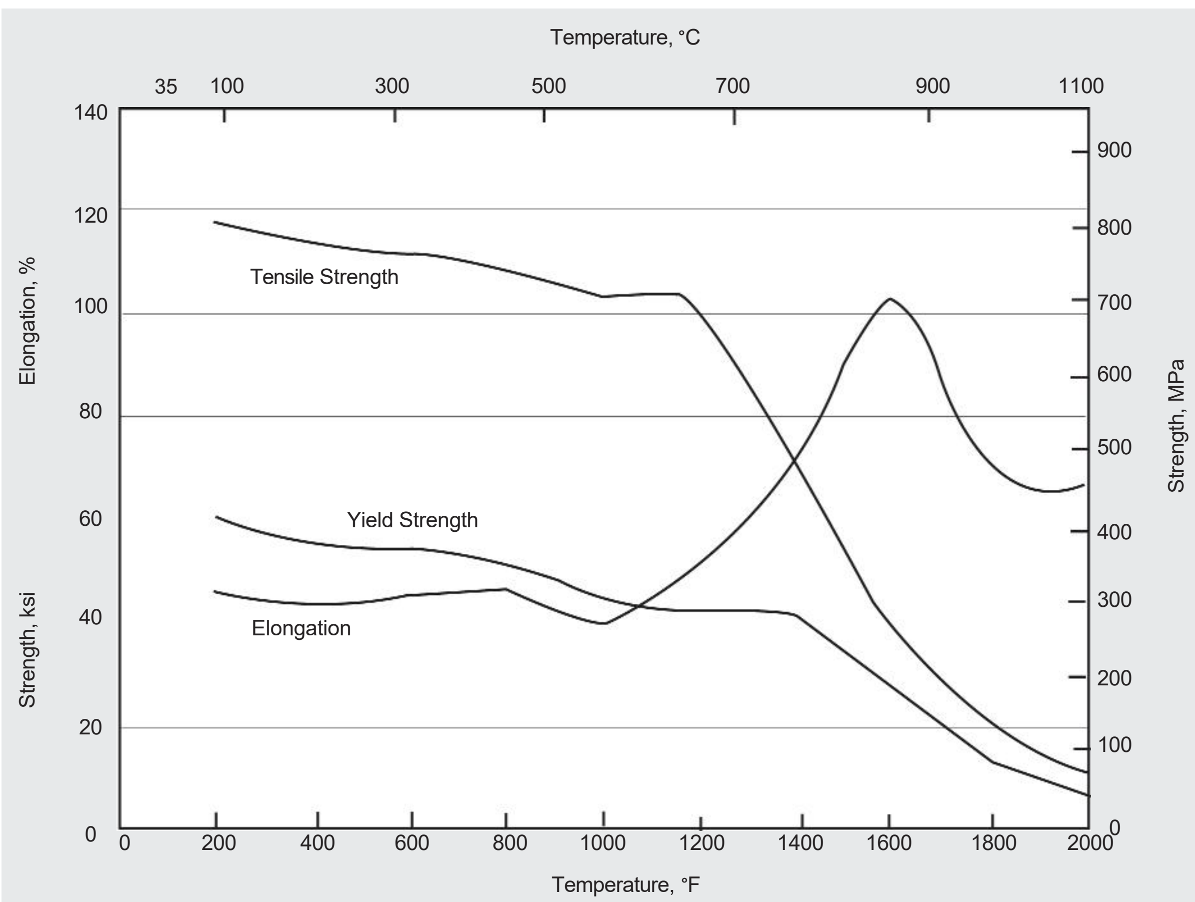

Figure 3. Effect of Temperature on Mechanical Properties of INCONEL alloy N06230

Impact

Impact properties (determined at room temperature) of hot-rolled/annealed plate are reported in Table 7. Tests were conducted with material from both rolling orientations. The test specimens were Charpy V notch sub-size specimens (10 mm x 5 mm).

Table 7 - Room-Temperature Impact Properties of Hot-Rolled/Annealed Plate

Test Orientation	Impact Strength, Joules/sq cm
Longitudinal	81.3
Transverse	74.6
Transverse	74.6
Transverse	81.3

Creep and Rupture Properties

Typical values for stress to rupture and rupture ductility are compared to specified requirements in Table 8.

Table 8 - Stress Rupture of Hot-Rolled/Annealed Plate at 1700°F and 9 ksi

	Rupture Life	Elongation at Rupture
Test Result	75 hrs	65%
AMS 5878A	36 hrs min.	10% min.

Microstructure

INCONEL alloy N06230 has a fully austenitic structure. By virtue of the alloy's carbon content, the microstructure contains quantities of secondary carbide particles (predominantly M_6C and $M_{23}C_6$), which contribute significantly to the alloy's strength. The carbide particles exhibit an intragranular distribution; they are not preferentially located on the grain boundaries. In the solution annealed condition, the grain size is typically ASTM No. 6. Figure 4 is a photomicrograph of the microstructure of alloy N06230 plate.

Figure 4. Photomicrograph of INCONEL alloy N06230.

Corrosion Resistance

INCONEL alloy N06230 is designed to offer resistance to a variety of corrosion mechanisms at high temperatures. While the alloy's resistance to carburization and nitridation is exemplary, its resistance to oxidation at temperatures over 2000°F (1093°C) is unsurpassed by any other conventional, high strength alloy. The response to exposure of various alloys to oxidizing environments at 1000, 1100 and 1200°C (1832, 2012 and 2192°F) is shown in Figures 5, 6 and 7. (Environments as indicated. All samples cycled to room temperature once per week.)

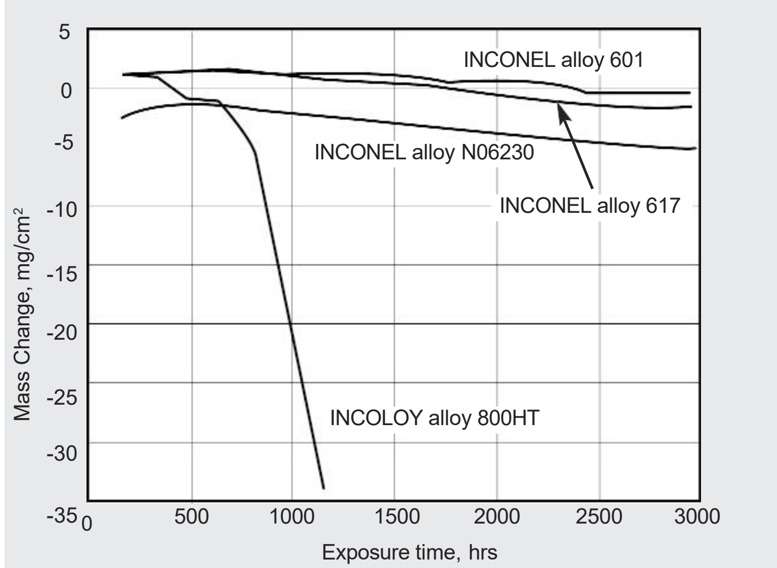

Figure 5. Oxidation resistance at 1000°C (Air + 5% water vapor).

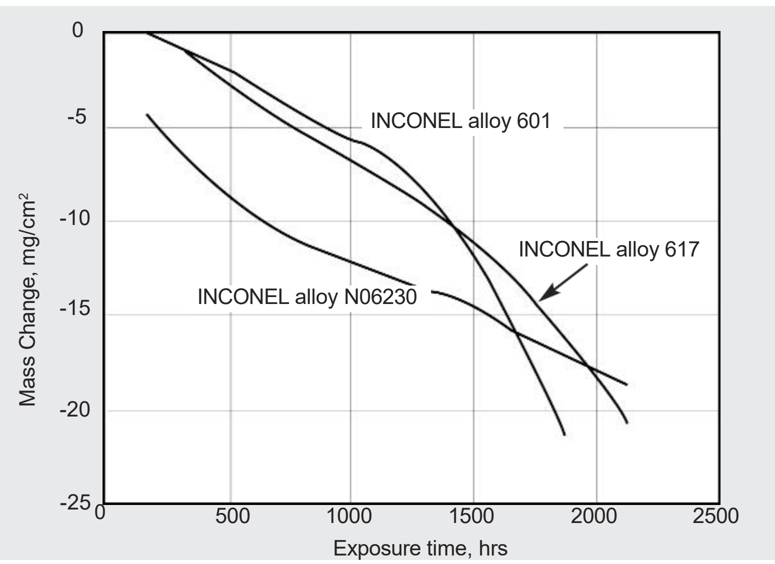

Figure 6. Oxidation resistance at 1100°C (Air + 5% water vapor).

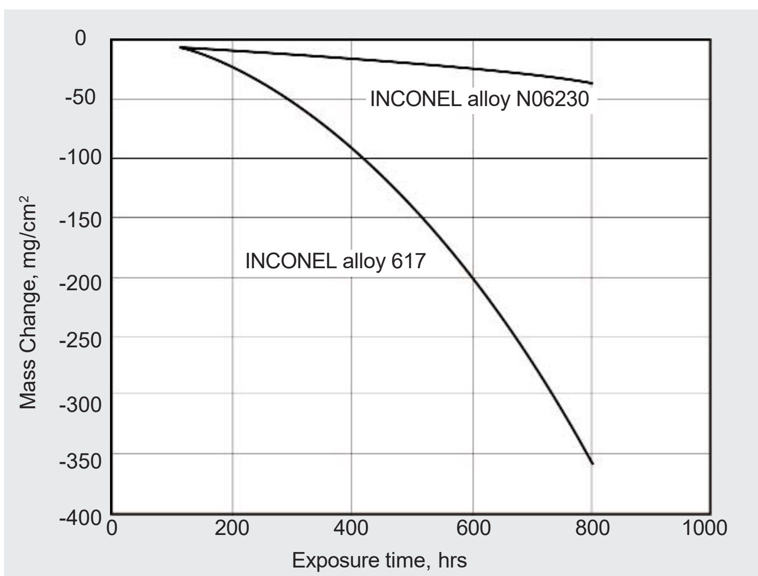

Figure 7. Oxidation resistance at 1200°C ((Laboratory air).

Fabrication

INCONEL alloy N06230 has good fabricability. Forming, machining and welding are accomplished by standard procedures for high strength nickel alloys. Techniques and equipment for some operations may be influenced by the alloy's strength and work hardening rate. General information on fabricating is available in the Special Metals publication "Fabricating" on the website www.yttzhj.com.

Hot and Cold Forming

INCONEL alloy N06230 has good hot formability but requires relatively high forces for deformation because of its inherent strength at high temperatures. In general, the hot-forming characteristics of alloy N06230 are similar to those of INCONEL alloys 617 and 625. The temperature range for heavy forming and forging is 1850 to 2250°F (1010 to 1230°C). Light working may be done at temperatures as low as 1750°F (954°C).

Alloy N06230 is readily cold formed by conventional procedures. However, its work hardening rate is high, as indicated by Figure 8. For best results, the alloy should be cold formed in the fine grain condition. Frequent intermediate anneals should be used. Annealing prior to forming should be done at 1950 to 2100°F (1066 to 1149°C) to avoid a coarse grain structure for forming.

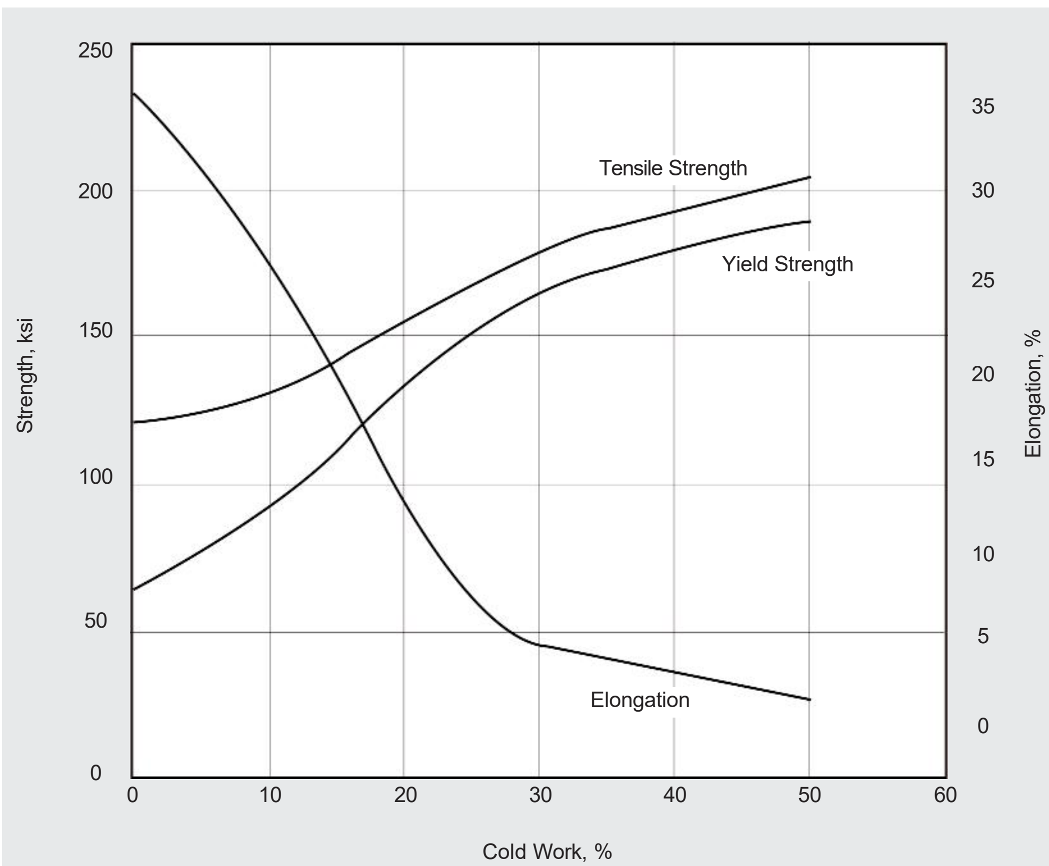

Figure 8. Room temperature work hardening of INCONEL alloy N06230

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Heat Treatment

Alloy N06230 is normally used in the solution-annealed condition. This provides a coarse grain structure that results in optimum creep-rupture strength. It also provides the best bend ductility at room temperature. Solution annealing is normally performed at 2150 to 2250°F (1175 to 1230°C) for a time commensurate with section size, followed by water quenching or rapid air cooling.

Machining

Information on machining nickel alloys is available in the Special Metals publication "Machining" on the website www.yttzhj.com. INCONEL alloy N06230 is classified as Group D-2. Cutting tools should be sharp and have positive rake angles to minimize work hardening of the alloy piece being machined. Cutting feed and depth of cut must be sufficient to prevent burnishing of the work piece surface.

Joining

INCONEL alloy N06230 exhibits good weldability. INCONEL Filler Metals 617 and 230 are used for GTA and GMA welding. INCONEL Welding Electrode 117 is used for SMA welding. Dissimilar welding applications are best accomplished with INCONEL Filler Metal 617 and INCONEL Welding Electrode 117. Additional general welding information is available in the Special Metals publication "Joining" on www.yttzhj.com and www.specialmetalswelding.com.

Fabricators should contact Special Metals Welding Products Company for specific welding product recommendations and for welding product availability.

Specifications

INCONEL alloy N06230 is designated as UNS N06230 and Werkstoff Nr. 2.4733. Allowable design stresses for ASME Boiler and Pressure Vessel Section I and Section VIII, Division 1 construction for operating temperatures up to 1650°F are defined in Table 1B of ASME Section II, Part D.

Rod - ASTM B572, SAE/AMS 5891

Plate - ASTM B435, SAE/AMS 5878

Pipe and Tube - ASTM B622 (Seamless pipe and tube), ASTM B619 (Welded pipe), ASTM B626 (Welded tube)

Fittings - ASTM B366

Forgings - ASTM B564, SAE/AMS 5891

Welding Wire - SAE/AMS 5839

Contact Special Metals for the availability of specific product forms and sizes.