DURANICKEL® alloy 301

DURANICKEL® alloy 301 (UNS N03301), an age-hardenable material, combines the excellent corrosion resistance of Nickel 200 with the added advantages of greater strength and hardness. It is used for springs requiring high electrical conductivity, parts of equipment requiring good thermal conductivity, and magnetostrictive units which are operated under stress conditions for which the fatigue strength of Nickel 200 is inadequate. Composition is shown in Table 1.

Table 1 - Limiting Chemical Composition, %

Nickel (plus cobalt)	93.0 min.
Copper	0.25 max.
Iron	0.60 max.
Manganese	0.50 max.
Carbon	0.30 max.
Silicon	1.00 max.
Sulfur	0.01 max.
Aluminum	4.00-4.75
Titanium	0.25-1.00

Physical Properties

Physical constants and thermal properties of DURANICKEL alloy 301 are shown in Tables 2 and 3. Elevated-temperature modulus data are shown in Table 4.

Resistivity is lower in the aged condition. Age hardening an annealed specimen decreased resistivity from 273 to 259 ohm•circ mil/ft (0.454 to 0.431 μΩ •m).

Table 2 - Physical Constants

Density, lb/in³	0.296
g/cm³	8.19
Melting Range, °F	2550-2620
°C	1400-1440
Specific Heat, Btu/lb•°F	0.104
J/kg•°C	435
Curie Temperature, °F	
Annealed material	60-120
Aged material	200
°C	
Annealed material	15-50
Aged material	95
Modulus of Elasticity, 10^3 ksi	
Tension (E)	30
Torsion (G)	11
GPa	
Tension (E)	207
Torsion (G)	76
Poisson's Ratio (μ)	0.31[a]

[a] Calculated from $\mu = \frac{E-2G}{2G}$

In the soft condition, the alloy is slightly magnetic at room temperature, becoming nonmagnetic above about 120°F (50°C). Age hardening increases the magnetic properties slightly and raises the Curie temperature. Room-temperature permeability data are shown in Table 5.

Table 3 - Thermal Properties of Age-Hardened DURANICKEL alloy 301

Temperature	Coefficient of Expansion[a]	Thermal Conductivity[b]	Electrical Resistivity
°F	10^{-6} in/in•°F	Btu•in/ft²•h•°F	ohm•circ mil/ft
70	–	165	255
200	7.2	176	280
400	7.6	198	301
600	7.8	223	319
800	8.0	243	337
1000	8.2	265	349
1200	8.5	286	358
1400	8.8	306	367
1600	9.1	326	379
1800	–	342	391
2000	–	358	403
°C	µm/m•°C	W/m•°C	µΩ•m
20	–	23.8	0.424
100	13.0	25.5	0.467
200	13.7	28.3	0.499
300	14.0	31.4	0.527
400	14.3	34.3	0.554
500	14.7	37.1	0.575
600	15.0	39.8	0.588
700	15.5	42.4	0.602
800	15.8	45.1	0.617
900	16.6	47.7	0.635
1000	–	49.8	0.653
1100	–	51.8	0.672

[a] Mean coefficient of linear expansion between 70°F (21°C) and temperature shown.
[b] Calculated from electrical resistivity.

Age-hardened alloy 301 shows exceptional dimensional stability. Samples at 70°F (20°C) showed zero change during 3 months of testing, and samples cycled 10 times from 70 to -95°F (20 to -70°C) shrank only 0.0005%.

Table 4 - Modulus of Elasticity (Dynamic) in Tension of Cold-Drawn, As-Drawn DURANICKEL alloy 301 Rod

Temperature		Modulus	
°F	°C	10^3 ksi	GPa
80	27	30.0	207
200	93	29.8	205
300	150	29.4	203
400	205	29.0	200
500	260	28.5	197
600	315	28.1	194
700	370	27.7	191
800	425	27.2	188
900	480	26.8	184
1000	540	26.3	181
1100	595	25.9	179

Table 5 - Room-Temperature Permeability of DURANICKEL alloy 301

Form	Maximum Permeability	Permeability			
		300 oersted (24kA/m)	200 oersted (16kA/m)	100 oersted (8kA/m)	50 oersted (4kA/m)
Strip, Annealed	250 at 25 gauss (0.0025 tesla)	3.66	4.28	5.93	8.44
Strip, Aged at 1500-1600°F (815-870°C)	527 at 315 gauss (0.0315 tesla)	7.46	10.58	18.63	32.8
Rod, Aged at 1100°F (595°C)/10 hr, F.C.	105 at 475 gauss (0.0475 tesla)	6.90	9.45	16.85	30.0

Mechanical Properties

Nominal ranges of tensile properties of DURANICKEL alloy 301 are shown in Table 6. Figures 1 through 4 show the approximate relationship between tensile properties and hardness for rod and strip.

Compressive Strength

Tensile and compressive strengths are compared in Table 7.

Fatigue Strength

Fatigue strength is shown in Table 8.

Table 6 - Nominal Mechanical Properties of DURANICKEL alloy 301

Form	Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Hardness	
	ksi	MPa	ksi	MPa		Brinell (3000 kg)	Rockwell
Rod and Bar							
Hot-Finished	90-130	620-900	35-90	240-620	55-30	140-240	75B-22C
Hot-Finished, Aged	160-200	1100-1380	115-150	795-1035	30-15	300-375	32-42C
Cold-Drawn	110-150	760-1035	60-130	415-900	35-15	185-300	90B-40C
Cold-Drawn, Aged	170-210	1170-1450	125-175	860-1210	25-15	300-380	32-42C
Annealed	90-120	620-830	30-60	205-415	55-35	135-185	75-90B
Annealed, Aged	150-190	1035-1310	110-140	760-965	30-20	285-360	30-40C
Strip							
Annealed	90-120	620-830	35-60	240-415	50-30	–	90B max.
Annealed, Aged	160-190	1100-1310	–	–	25-10	–	30-40C
Half-Hard	130-155	900-1070	–	–	15-3	–	25-34C
Half-Hard, Aged	170-210	1170-1450	–	–	20-7	–	33-42C
Spring	155-190	1070-1310	–	–	10-2	–	30-40C
Spring, Aged	180-230	1240-1585	–	–	15-5	–	36-46C
Wire							
Annealed	90-120	620-900	–	–	50-25	–	–
Annealed, Aged	160-190	1100-1310	–	–	25-10	–	–
Spring	160-200	1100-1380	–	–	5-2	–	–
Spring, Aged	200-240	1380-1655	–	–	10-5	–	–

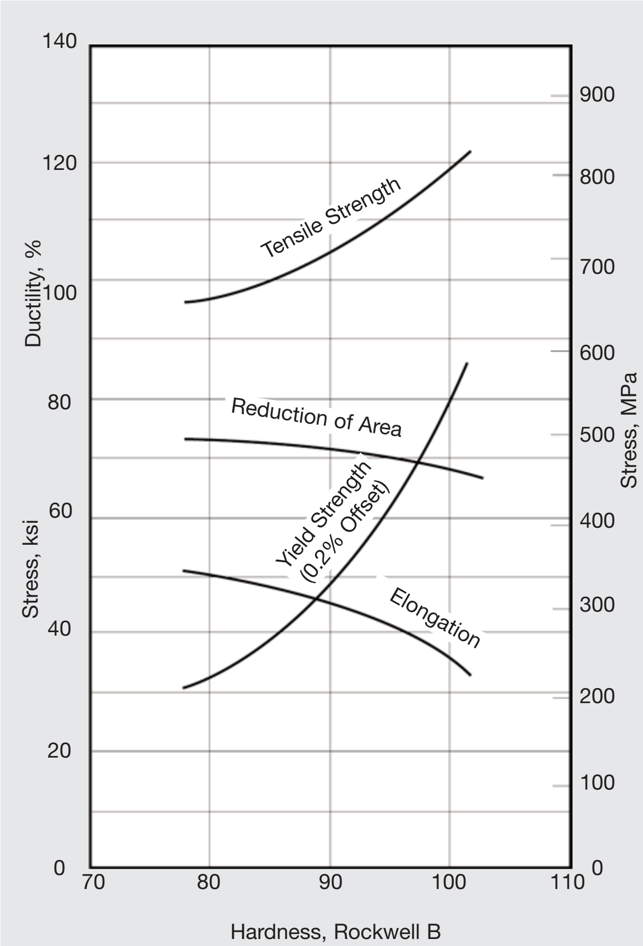

Figure 1. Approximate relationships between tensile properties and hardness of hot-rolled and annealed DURANICKEL alloy 301 rod.

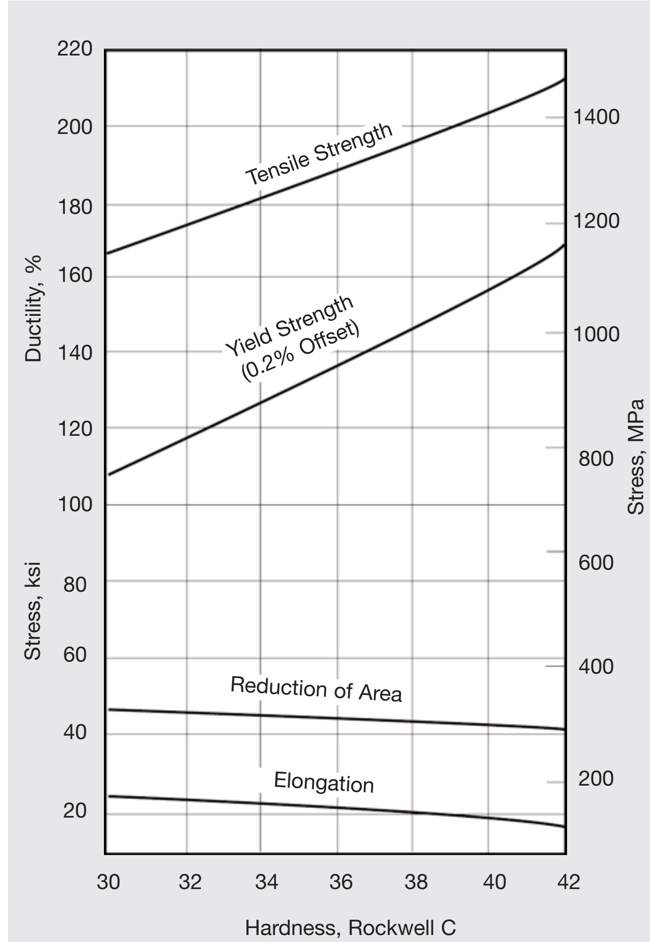

Figure 2. Approximate relationships between tensile properties and hardness of age-hardened DURANICKEL alloy 301 rod.

Table 7 - Tensile and Compressive Strength of DURANICKEL alloy 301

Form	Tension				Compression Yield Strength (0.2% Offset)	
	Tensile Strength		Yield Strength (0.2% Offset)			
	ksi	MPa	ksi	MPa	ksi	MPa
Hot-rolled,						
As-rolled	109.0	751	49.0	340	52.5	362
Aged[a]	184.5	1272	131.5	907	137.5	948
Cold-drawn,						
Aged[a]	196.0	1350	154.5	1065	151.5	1045

[a]1100°F (595°C)/16 hr, F.C. 15°F (8°C)/hr to 900°F (480°C), A.C.

Table 8 - Fatigue Strength of DURANICKEL alloy 301[a]

Form	Tension				Ratio, Fatigue to Tensile Strength
	Fatigue Strength 10^8 cycles		Tensile Strength		
	ksi	MPa	ksi	MPa	
Cold-drawn,					
As-drawn	46.2	319	120.5	831	0.38
Aged[b]	55.4	382	184.0	1270	0.30
Hot-rolled,					
As-rolled	42.8	295	103.5	715	0.41
Annealed[c]	45.0	310	101.0	695	0.45
Aged[b]	51.0	350	176.0	1215	0.29
Annealed[c] & Aged[b]	48.5	335	161.5	1115	0.30

[a] Rotating-beam tests of polished specimens of rod.
[b] 1100°F (595°C)/16 hr, F.C. to 1000°F (540°C)/6 hr, A.C.
[c] 1725°F (940°C)/15 min, W.Q.

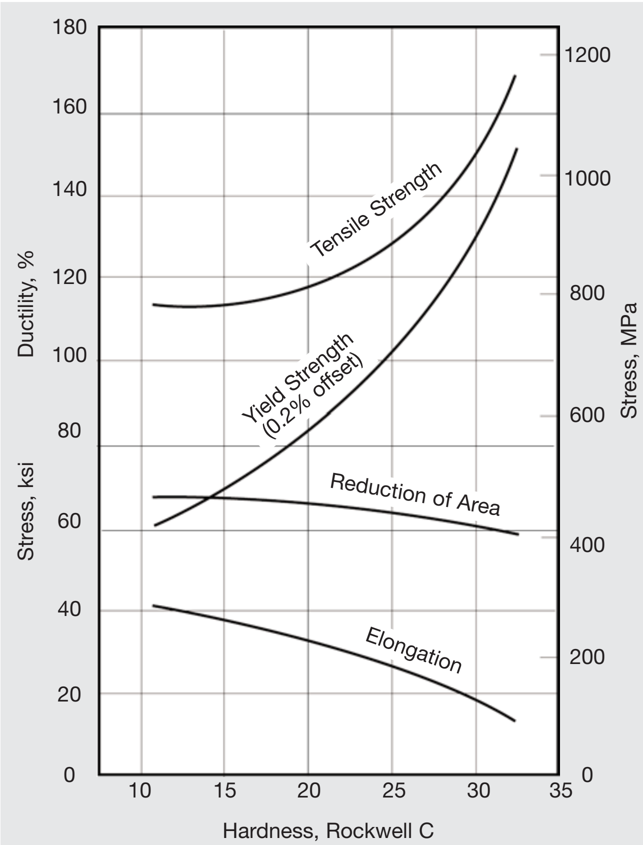

Figure 3. Approximate relationships between tensile properties and hardness of cold-drawn DURANICKEL alloy 301 rod.

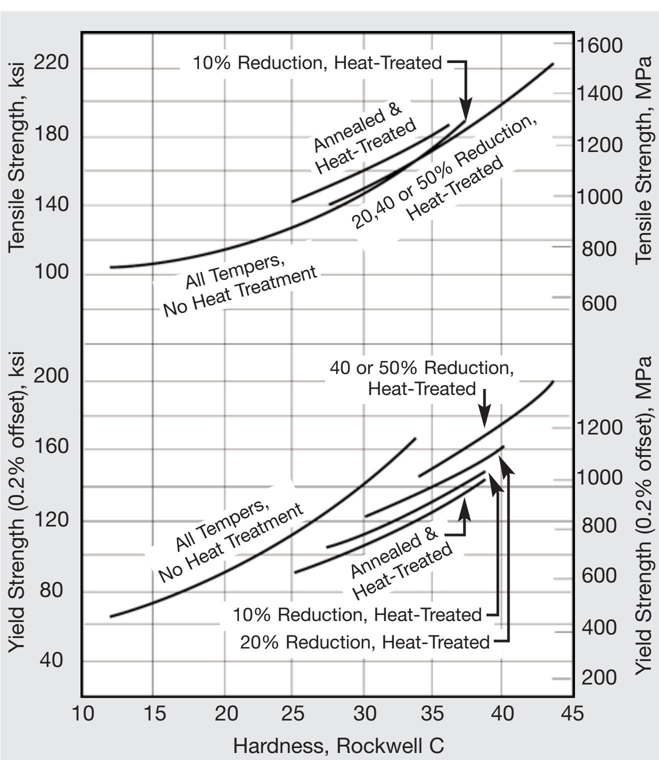

Figure 4. Approximate relationships between tensile properties and hardness of cold-rolled DURANICKEL alloy 301 strip.

Spring Properties

Minimum tensile strength of spring wire is shown in Table 9.

High-Temperature Properties

High-temperature properties of alloy 301 are shown in Figure 5.

Table 9 - Minimum Tensile Strength of DURANICKEL alloy 301 Spring Wire[a] in Coils

Diameter		Condition			
		As-Drawn		Age-Hardened	
in.	mm	ksi	MPa	ksi	MPa
0.057 & less	1.44 & less	170	1175	205	1415
Over 0.057 to 0.229 inclusive	Over 1.44 to 5.82 inclusive	160	1105	200	1380
Over 0.229 to 0.312 inclusive	Over 5.82 to 7.92 inclusive	155	1070	190	1310

[a]60 to 70% cold-drawn.

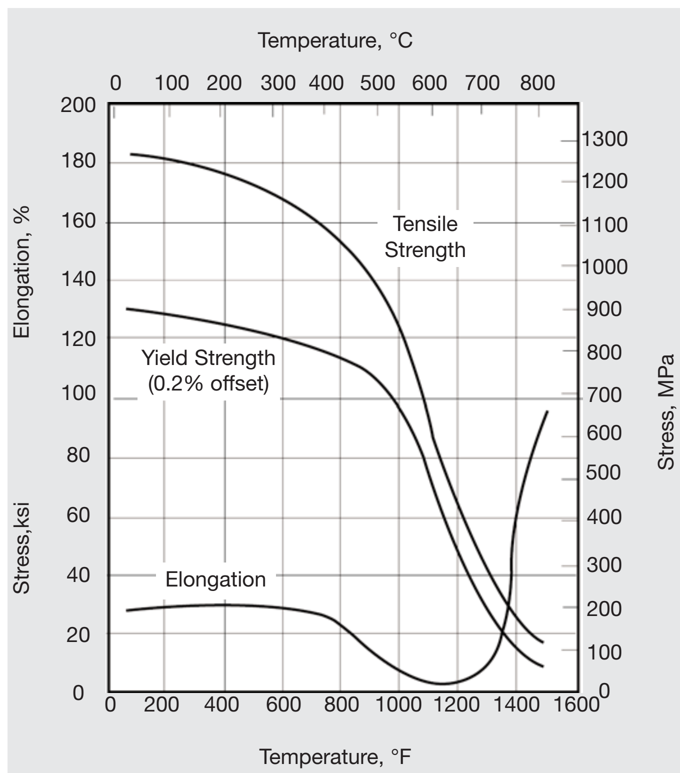

Figure 5. High-temperature tensile properties of age-hardened DURANICKEL alloy 301.

Corrosion Resistance

Corrosion resistance of DURANICKEL alloy 301 is essentially the same as that of Nickel 200.

In the age-hardened condition, it has excellent resistance to stress-corrosion cracking, superior to most other alloys of comparable strength.

Age-hardened alloy 301 bolts proved to be very effective for use on valve bonnets and flange connections on hydrofluoric acid alkylation units. The alloy has exceptional corrosion resistance to fluoride glasses and is used for glass molds. Another proven application is for extrusion dies for plastics, particularly polyvinyl chloride.

Fabrication

Heating and Pickling

Heating and pickling procedures for alloy 301 are described in the Special Metals' publication "Fabricating" on the website www.specialmetals.com. That publication should be consulted prior to carrying out any of these operations.

The alloy can be bright-annealed only in vacuum or superpure hydrogen. Conventional bright atmospheres such as dry hydrogen with a -50°F (-46°C) dew point, cracked ammonia, or cracked natural gas will produce a light film of oxide. It can be removed by mechanical polishing or by pickling.

Age hardening in air will produce an adherent oxide coating on the surface. This coating can be removed by machining, polishing, or pickling.

Annealing

Work-hardened material is softened by open annealing followed by rapid cooling or, preferably, by quenching in water. The effects of annealing times and temperatures are shown in Figure 6.

Most intermediate process annealing can be accomplished by heating the material at temperatures of 1600°-1800°F (870°-980°C) for 1-5 minutes at temperature. Alloy 301 should not be heated longer than necessary; excessive time will produce a coarse grain, which is undesirable for forming operations.

Age Hardening for Maximum Properties

When maximum properties are desired, the initial hardness of the material must be considered in choosing times and temperatures for aging. If not measured, hardness may be estimated from the data in Table 6. The following procedures are recommended for developing maximum hardness:

1. Annealed material (135-185 Brinell, 75-90 Rockwell B) can be hardened by heating for 16 hr at 1080°-1100°F (580°-595°C), followed by furnace cooling to 900°F (480°C) at a rate of not more than 15°F (8°C) per hour. Cooling from 900°F (480°C) may be by furnace or air cooling or by quenching.

Step cooling may be used instead of continuously decreasing furnace cooling. Drop the temperature 100°F (55°C) in each step and hold the material for 4-6 hr at each temperature, for example, 1080°-1100°F (580°-595°C)/16 hr, plus 1000°F (540°C)/4-6 hr, plus 900°F (480°C)/4-6 hr.

This procedure is suitable for forgings, annealed or hot-rolled rod, cold-drawn rod over 1½-in. (38-mm) diameter, and annealed wire or strip.

2. Moderately cold-worked material (185-250 Brinell, 8-25 Rockwell C) can be hardened by heating for 8 hr at 1080°-1100°F (580°-595°C), followed by furnace cooling to 900°F (480°C) at a rate of not more than 15°F (8°C) per hr. Step cooling may also be used. Cooling from 900°F (480°C) may be by furnace or air cooling or by quenching.

Higher hardnesses may be obtained by holding as long as 16 hr at temperature, particularly if the material has been cold-worked only slightly. As a general rule only material having an initial hardness of 185-200 Brinell or 8-13 Rockwell C should be held the full 16 hr. Material having an initial hardness of about 250 Brinell or 25 Rockwell C should attain full hardness in 8 hr.

This procedure is applicable to cold-drawn rods, half-hard strip, cold-upset pieces, and intermediate-temper wire.

3. Fully cold-worked material (260-350 Brinell, 26-38 Rockwell C) can be hardened by heating for 6 hr at 980°-1000°F (530°-540°C), followed by furnace cooling to 900°F (480°C) at a rate of not more than 15°F (8°C) per hr. Step cooling may also be used.

Higher hardnesses may be obtained by holding 8-10 hr at temperature, particularly with material near the lower end of the hardness scale.

This procedure is suitable for spring-temper strip, spring wire, or heavily cold-worked parts.

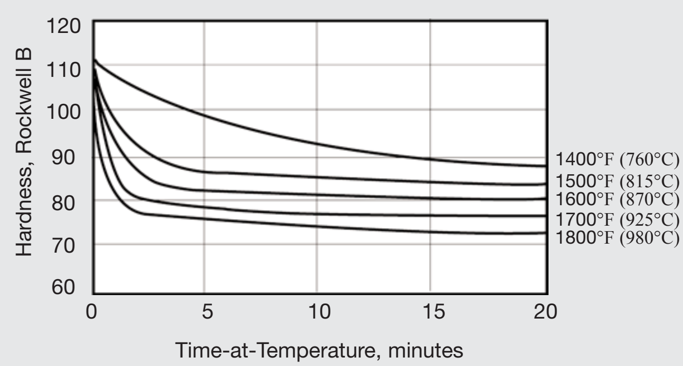

Figure 6. Approximate time-at-temperature for softening DURANICKEL alloy 301 by open annealing.

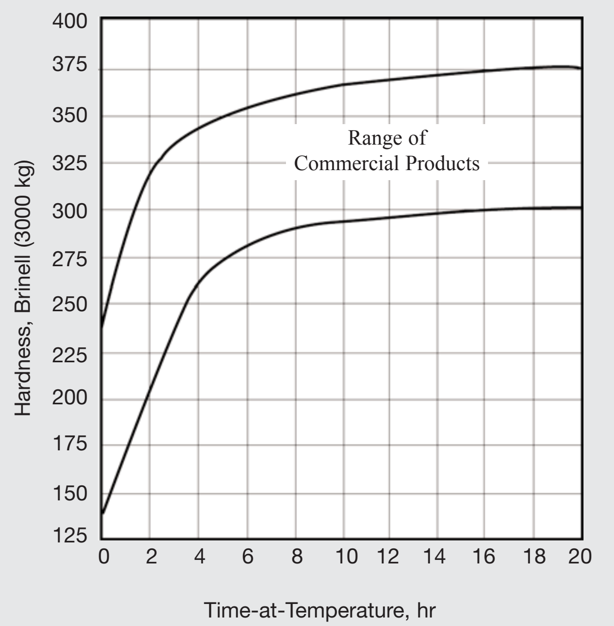

Figure 7. Effect of aging time-at-temperature (1080°-1100°F) (580°-595°C) on DURANICKEL alloy 301. Furnace cooling followed time-at-temperature.

Hot and Cold Forming

Hot Forming

The optimum hot-forming temperature range for DURANICKEL alloy 301 is 1900°-2250°F (1040°-1230°C). Light finishing can be done down to 1600°F (870°C). For finer grain size in forgings, 2150°F (1180°C) should be the final reheat temperature, and 30% reduction should be taken in the last forging operation.

Material should be water-quenched from hot-working temperatures to avoid excessive hardening and cracking that could occur from slow cooling through the age-hardening range and to maintain good response to subsequent aging. The use of water containing about 2% alcohol will lessen the formation of oxide and facilitate pickling.

Cold Forming

Annealed material can be cold-worked by all the standard methods. Formability and cold-fabricating practices for annealed material are essentially the same as for Nickel 200, except that DURANICKEL alloy 301 has a slightly higher base hardness and will require slightly higher forming pressures. A moderate work-hardening rate coupled with a relatively high ductility permits heavy plastic deformation without damage. High mechanical properties can be obtained by direct aging of cold-worked material. Figure 8 shows the effect of cold work and age hardening on strength and hardness.

Age-Hardening for Intermediate Properties

In some instances, it may be desired to age-harden DURANICKEL alloy 301 to less than its maximum hardness. Intermediate properties may be developed by decreasing both time-at-temperature and the cooling period. The effect of time-at-temperature on hardness of alloy 301 is shown in Figure 7.

Properties of material aged for short periods (up to 8 hr) are shown in Table 10. About 90% of the nominal values was obtained in 4 hr for hot-rolled or annealed material and in 2 hr for heavily cold-worked material. In the case of annealed and lightly cold-worked material, normal furnace cooling after the 4-hr aging treatment will result in slightly higher values than air cooling because of the extra time that temperature is above 900°F (480°C). Normal furnace cooling offers little advantage over air cooling for the heavily cold-worked material.

Aging of pilot specimens is recommended as a guide to developing special aging procedures.

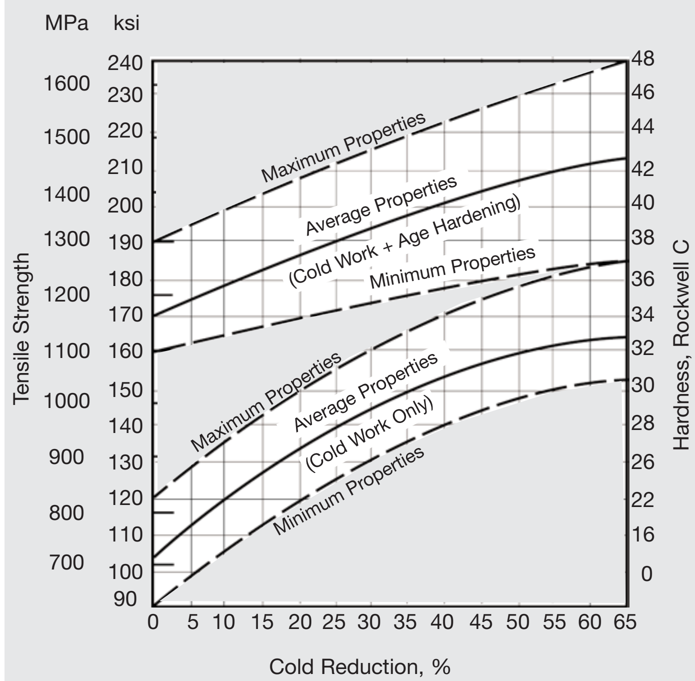

Figure 8. Effect of cold work and age hardening on properties of DURANICKEL alloy 301. Light areas cover range of commercial products.

Machining

Hot-finished or as-drawn material can be machined most easily. Annealed material is not as gummy as Nickel 200 but tends to be slightly abrasive to tool cutting edges. As with Nickel 200, high-speed-steel tooling is preferred to carbide and very high positive rake angles are required. For superior surface finishes, material should be finish-machined in the age-hardened condition. Visit www.specialmetals.com for more details on machining practices.

Table 10 - Properties of DURANICKEL alloy 301 Age-Hardened for Intermediate Properties

Condition	Thermal Treatment[a]			Mechanical Properties					
	Temperature		Time, hr	Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Hardness, Rockwell C
	°F	°C		ksi	MPa	ksi	MPa		
Rod, Hot-Rolled	–	–	0	102	703	40	276	47	0
	1100	595	2	156	1076	102	703	34	25
			4	164	1131	108	745	32	28
			8	168	1158	113	779	31	30
Strip, Annealed	–	–	0	104	717	47	324	42	4
	1100	595	2	159	1096	105	724	33	30
			4	164	1131	112	772	30	32
			8	167	1158	114	786	28	32
Strip, Cold-Rolled 10%	–	–	0	118	814	93	641	27	21
	1100	595	2	171	1179	124	855	24	34
			4	173	1193	128	883	23	34
			8	172	1186	130	896	23	35
	1000	540	2	166	1145	119	821	26	33
			4	169	1165	122	841	27	34
			8	178	1227	129	889	23	35
Strip, Cold-Rolled 20%	–	–	0	132	910	119	821	16	26
	1100	595	2	182	1255	146	1007	19	37
			4	184	1269	148	1020	19	37
			8	184	1269	150	1034	18	37
	1000	540	2	182	1255	142	979	21	36
			4	185	1276	144	993	20	37
			8	190	1310	149	1027	20	38
Strip, Cold-Rolled 40%	–	–	0	154	1062	149	1027	5	31
	1100	595	2	202	1393	178	1227	15	40
			4	199	1372	177	1220	15	40
			8	195	1345	173	1193	14	39
	1000	540	2	198	1365	171	1179	15	40
			4	205	1413	178	1227	15	41
			8	209	1441	182	1255	14	42
Strip, Cold-Rolled 50%	–	–	0	158	1089	153	1055	4	33
	1100	595	2	208	1434	186	1282	14	41
			4	204	1407	183	1262	14	41
			8	198	1365	180	1241	12	40
	1000	540	2	208	1434	187	1289	14	42
			4	210	1448	189	1303	13	42
			8	214	1476	191	1317	13	42

[a] Followed by air cooling.

Joining

Applications of alloy 301 seldom require welding. When welding is required, it is usually necessary for attachment of the DURANICKEL alloy 301 to supporting members. Material should be welded in the annealed condition, and the weldment should be stress-relieved at 1500°-1600°F (815°-870°C) for 15-30 minutes. It is important to heat the weldment rapidly to the stress-relieving range to minimize strain age cracking. Welds may be age-hardened to develop additional strength, but they will not show as much response as the base metal. Some typical properties are shown in Table 11.

More information on procedures for gas tungsten-arc welding of DURANICKEL alloy 301 as well as resistance welding, brazing and soldering is given in the publication "Joining" on the website www.specialmetals.com.

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Table 11 - Properties of Welded Joints in 0.062-in. (1.57-mm) Annealed DURANICKEL alloy 301 Sheet

Type Of Joint[a]	As-Welded Condition			Age-Hardened Condition		
	Tensile Strength		Hardness, Rockwell B	Tensile Strength		Hardness, Rockwell C
	ksi	MPa		ksi	MPa	
Parent Metal	107.0	738	85	170.0	1172	36
Manual						
Butt, No Filler	93.0	641	81	164.0	1131	34
Butt, Filler[b]	96.5	665	76	167.0	1151	–
Edge	97.0	669	77	169.0	1165	34
Machine						
Butt, No Filler	95.0	655	82	171.0	1179	33
Butt, Filler[b]	99.9	689	81	165.0	1138	27
Edge	89.0	614	82	156.0	1076	34

[a] No backup or chill on root side.
[b] Nickel Filler Metal 61, 1/16-in. (1.6 mm) diameter.

Available Products

DURANICKEL alloy 301 is available in the standard product forms of round bar and wire. The alloy is designated UNS N03301.

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