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INCOLOY® alloy 864 (UNS S35135) was specifically developed for automotive exhaust system flexible couplings, EGR tubes, manifolds and tailpipes. It exhibits excellent fatigue resistance, thermal stability and resistance to hot salt corrosion, pitting and chloride stress-corrosion cracking.

INCOLOY alloy 864 is covered by U.S. Patent 5,827,377.

Table 1 - Limiting Chemical Composition, wt %

Ni	30 - 38	C	0.08 max.
Cr	20 - 25	Mn	1.0 max.
Mo	4.0 - 4.8	S	0.015 max.
Si	0.6 - 1.0	Fe	Balance
Ti	0.4 - 1.0		

Table 3 - Modulus of Elasticity

Temperature	Young's Modulus	Temperature	Young's Modulus
°F	10^3 ksi	°C	GPa
70	28.3	20	195
200	27.6	100	190
400	26.5	200	183
600	25.2	300	175
800	24.1	400	168
1000	23.3	500	158
1200	22.0	600	156
1400	21.1	700	145
1600	19.8	800	142
1800	18.5	900	134

Applicable Specifications

INCOLOY alloy 864 is designated UNS S35135.

Sheet and strip - ASTM A 240 & A 480

Publication number SMC-025

Physical Properties

Table 2 - Physical constants

Density, lb/in³	0.290
g/cm³	8.02
Melting Range, °F	2467-2539
°C	1353-1393
Electrical Resistivity at 70°F (21°C)	
ohm•circ mil/ft	628
μΩ•m	1.04
Permeability at 200 oersted (15.9 kA/m)	1.004

Table 4 - Thermal properties

Temperature	Coefficient of Expansion[a]	Thermal Conductivity
°F	10^{-6} in/in•°F	Btu-in/ft²-h•°F
73	–	78.1
200	8.2	86.2
400	8.4	99.0
600	8.7	113
800	8.9	124
1000	9.0	139
1200	9.2	158
1400	9.5	163
1600	9.7	172
1800	9.8	184
2000	9.9	198
2200	–	211
°C	μm/m•°C	W/cm •°K
23	–	0.11
100	14.7	0.13
200	15.1	0.14
300	15.5	0.16
400	15.9	0.17
500	16.1	0.19
600	16.4	0.22
700	16.8	0.23
800	–	0.24
900	–	0.25
1000	–	0.27
1100	–	0.29

[a]Mean coefficient of linear expansion between 70°F (21°C) and temperature shown)

INCOLOY® alloy 864

Room Temperature Mechanical Properties

Table 5 -Typical Tensile Properties of Annealed Sheet, 0.006-0.062 in (0.15-1.6 mm) thick

0.2% Yield Strength		Ultimate Tensile Strength		Elongation
ksi	MPa	ksi	MPa	%
40	276	94	648	44

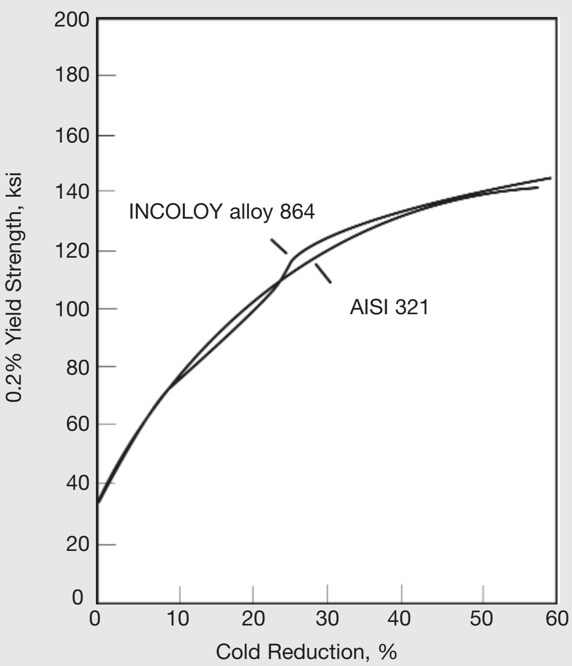

Figure 1 - Effect of cold work on yield strength

High Temperature Mechanical Properties

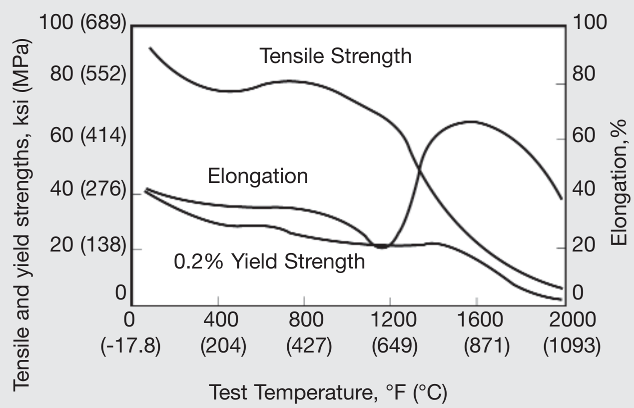

Figure 2 - Effect of Temperature on Tensile Properties

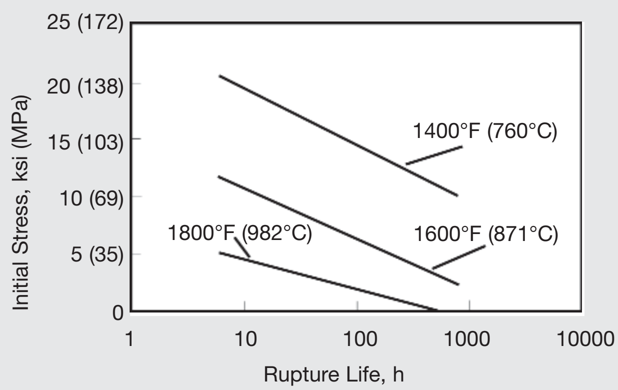

Figure 3 - Stress Rupture Life at Various Temperatures

Table 6 - Effect of High-Temperature Exposure on Ductility-% Elongation Tested at Room-Temperature

Starting Condition	Exposure Time, h	Exposure Temperature, °F (°C)				
		800°F (427°C)	1150°F (621°C)	1250°F (677°C)	1400°F (760°C)	1600°F (871°C)
Annealed-42.7% elongation	300	42.8	29.4	—	21.8	—
Annealed	2000	43.3	28.5	—	11.4	—
Annealed-46.6% elongation	1000	47.6	32.5	34.8	22.2	26.2
CR 30%	1000	—	—	13.2	—	—
CR 30%-18.0% elongation	1000	17.5	41.4	17.6	17.3	32.4
CR 30%-7.4% elongation	2000	12.2	10.2	—	17.6	—

High Temperature Mechanical Properties (continued)

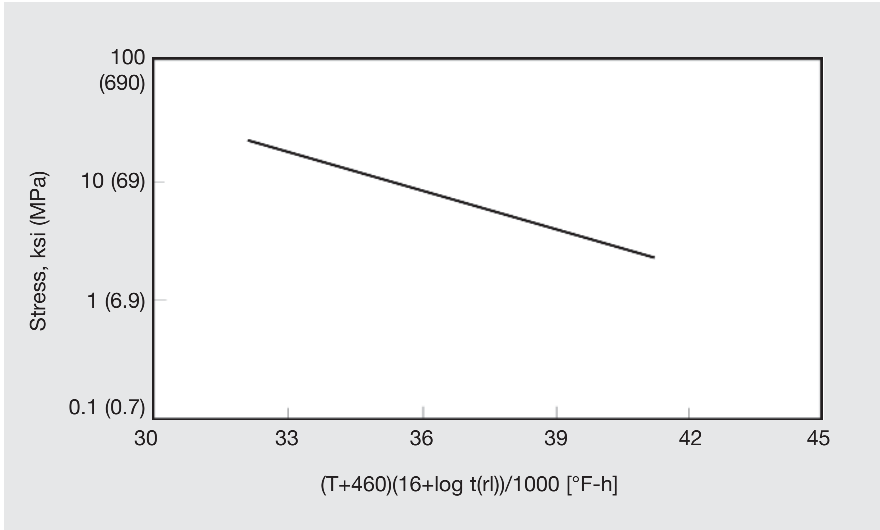

Figure 4 - Larson-Miller Plot

Fatigue Resistance

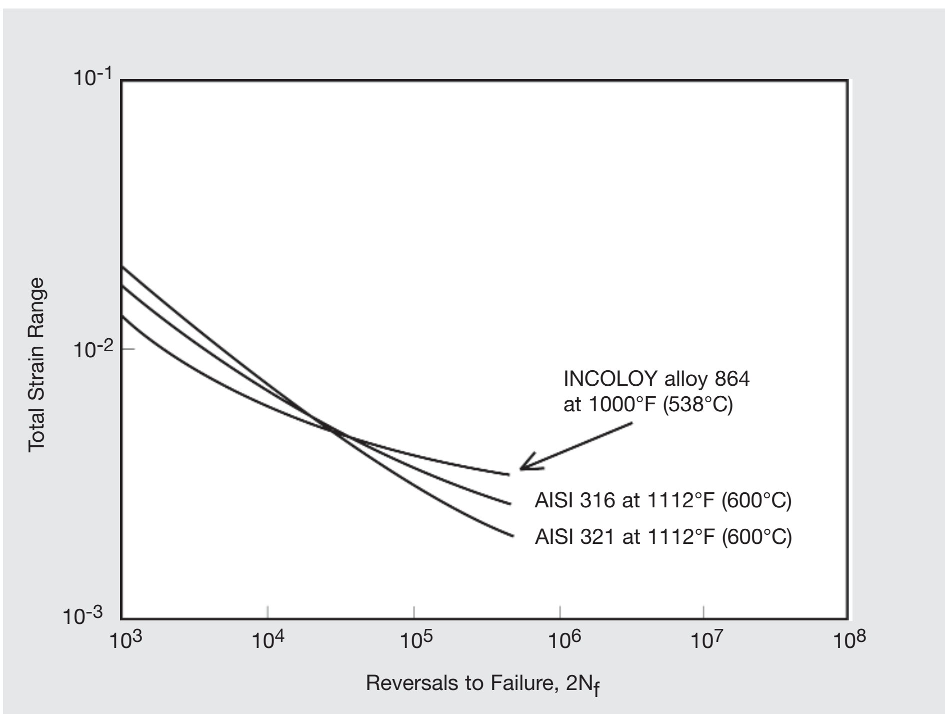

Figure 5 - Total strain range vs. reversals to failure at high temperature

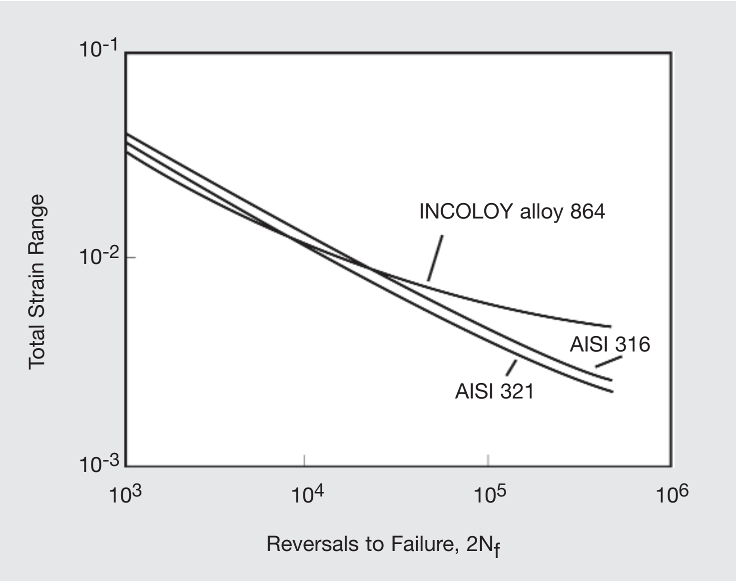

Figure 6 - Total strain range vs. reversals to failure at 75°F (24°C)

Figure 7 - Photomicrograph of the as-polished cross section of an INCOLOY alloy 864 burner rig sample after 500 h exposure at 950°C (1742°F). Magnification: 500X

Corrosion Resistance

INCOLOY alloy 864 was first developed as a corrosion-resistant material specifically for automotive exhaust systems. Most of the data presented in the following pages relate to that area of application. However, the alloy's potential for other, non-automotive, applications is of sufficient interest to pursue laboratory test programs in other media. Iso-corrosion charts for INCOLOY alloy 864 in hydrochloric and sulfuric acids are presented at the end of this section.

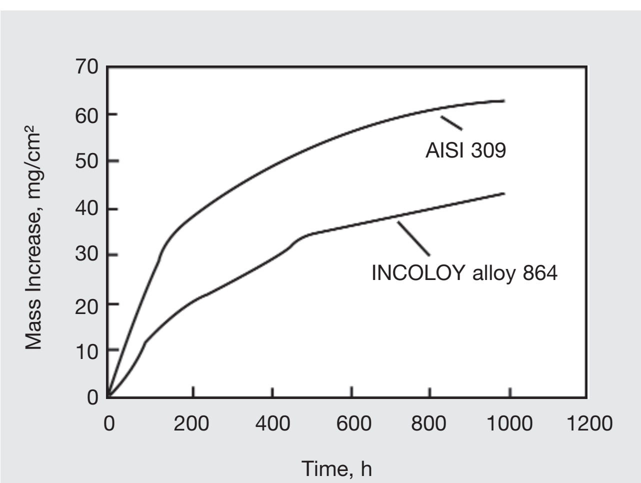

Figure 8 - Carburization Resistance in H_2-1% CH_4 at 1000°C (1832°F)

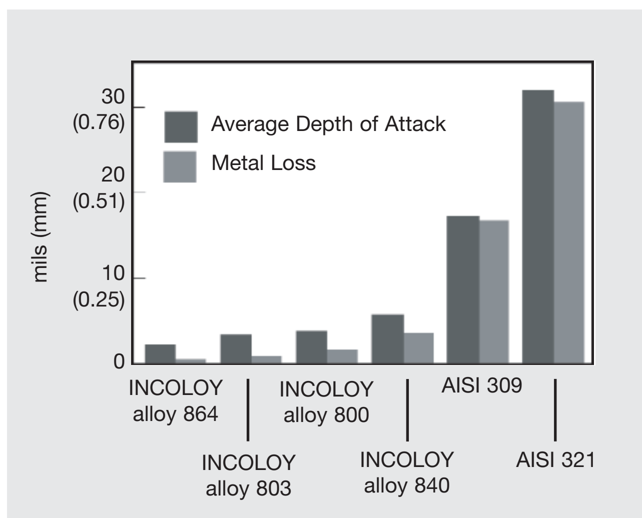

Figure 9 - Metal loss in burner rig samples at 950°C (1742°F) in JP-4 fuel (no salt). Exposed for 500 h.

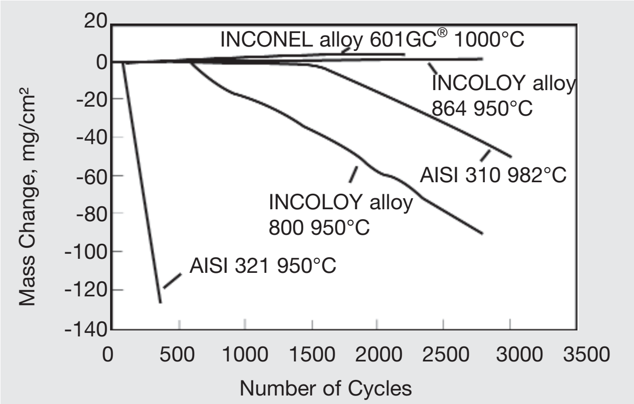

Figure 10 - Mass changes in a cyclic oxidation rig. (15 minutes at temperature / 5 minutes cooling in air)

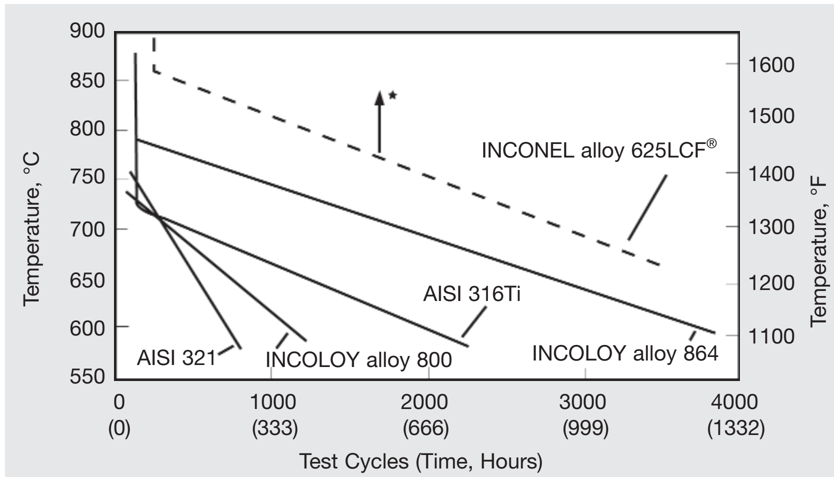

Figure 11 - Minimum temperature and test cycles (time) required to produce attack to a depth of 0.10 mm (4 mils) in hot salt corrosion test. 15-5 minute cycle - 7.5% NaCl + 2.5% $CaCl_2$ solution

*attack of less than 0.10 mm (4 mils)

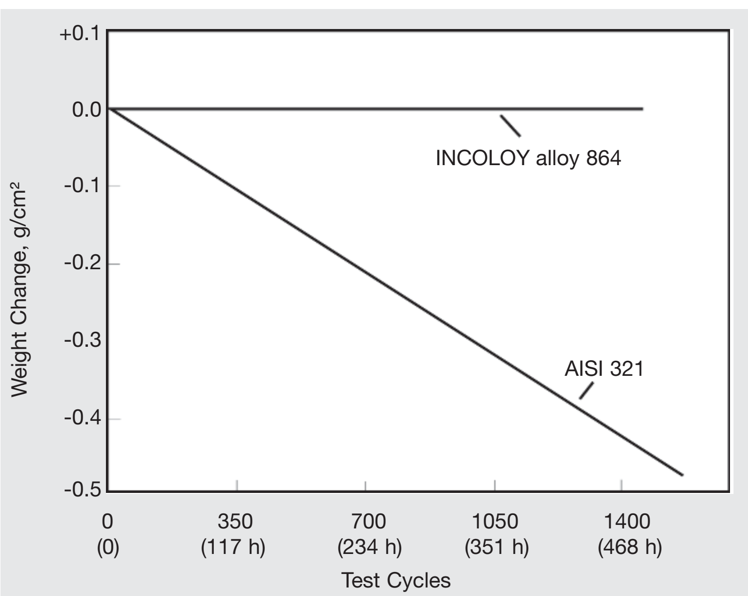

Figure 12 - Mass change in hot salt corrosion at 1400°F (760°C). 15-5 minute cycle with a daily dip in 7.5% NaCl + 2.5% $CaCl_2$

Table 7 - Depth of Penetration Measurements after Exposure in Air + 5% H_2O (Cycled Weekly) at 1650°F (899°C)

Material	Exposure Time	Mass Change	Metal Loss		Maximum Attack	
	hours	mg/cm^2	in	mm	in	mm
AISI 309	2016	0.58	0.0007	0.018	0.0027	0.069
AISI 316Ti	360	8.62	n/a*	n/a*	n/a*	n/a*
AISI 321	2016	-39.06	0.0052	0.132	0.0059	0.150
INCOLOY alloy 864	2016	2.52	0.0006	0.015	0.0031	0.079

*Wastage extremely severe. Sample broke up.

Table 8 - U-bent Stress Corrosion Cracking Results in Hot Salt Test 15-5 Minute Cycle-7.5% NaCl + 2.5% $CaCl_2$

Material	Stress Corrosion Crack Depth, mm	
	800°F (427°C) 1387 Cycles	1050°F (566°C) 750 Cycles
AISI 321	0.02	0.10
AISI 316Ti	0.05	0.09
INCOLOY alloy 864	No cracking	No cracking

Table 9 - Stress-Corrosion Cracking Test Results in Boiling 45% $MgCl_2$, U-bent Specimens

Material	Time to fail, hours (duplicate specimens)
AISI 321	<24/<24
AISI 316Ti	<24/<24
INCOLOY alloy 864	216/336

Table 10 - Critical Pitting Temperature (CPT) and Critical Crevice Corrosion Temperature (CCT) in ASTM G 48-C and D

Material	CPT	CCT
AISI 316Ti (2.3% Mo)	20°C	<0°C
INCOLOY alloy 864 (4.2% Mo)	45°C	10°C

Table 11 - Intergranular Corrosion Test Results

Material	ASTM A262 - E		ASTM A262 - C	
	As Annealed	Anneal + 1250°F (677°C)/1 h	As Annealed	Anneal + 1250°F (677°C)/1 h
INCOLOY alloy 864	No Cracking	No Cracking	10	55
AISI 321	No Cracking	No Cracking	26	64
AISI 316Ti	—	—	48	>521

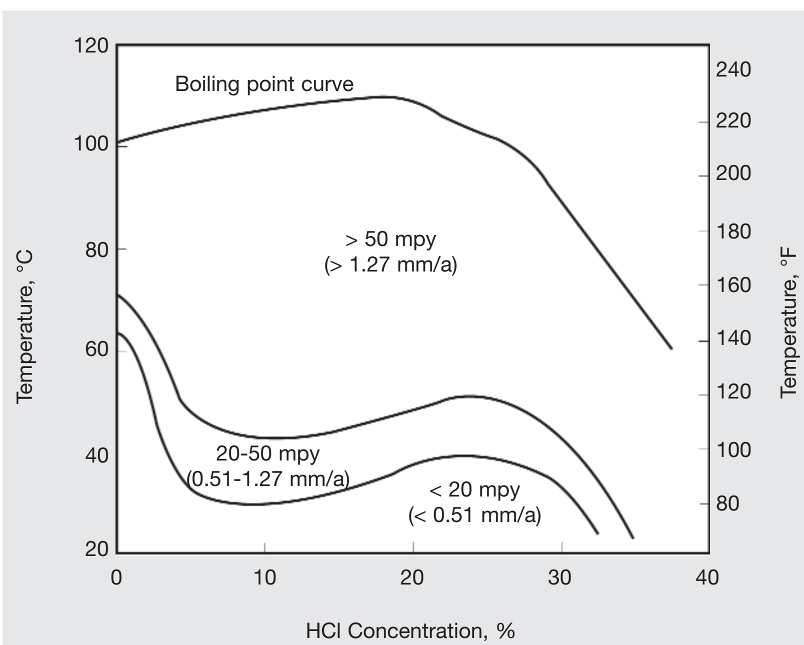

Figure 13 - Iso-corrosion chart for INCOLOY alloy 864 in hydrochloric acid

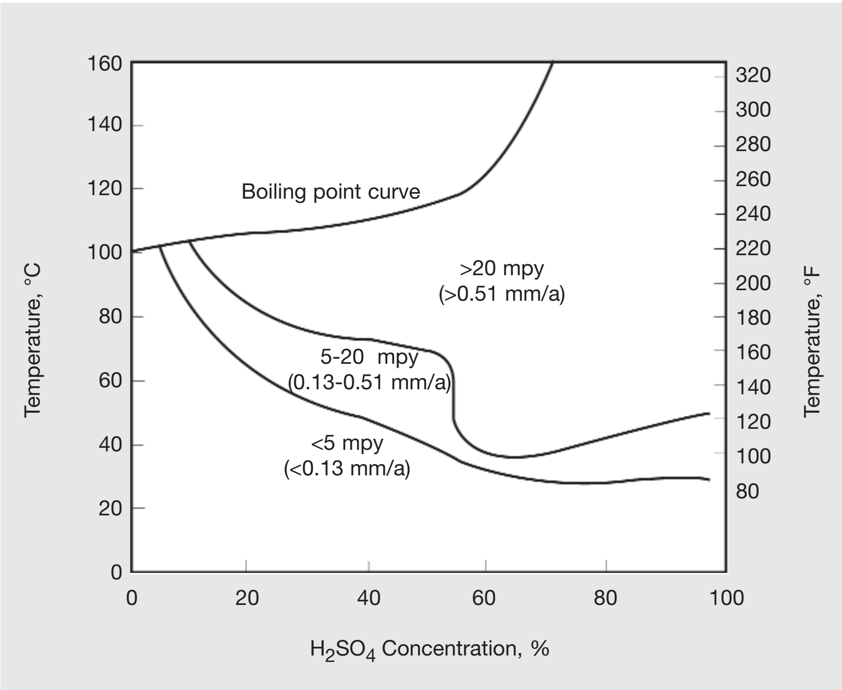

Figure 14 - Iso-corrosion chart for INCOLOY alloy 864 in sulfuric acid

Figure 15 - Photomicrograph illustrating fusion and adjacent heat affected zone integrity of gas tungsten arc welded INCOLOY alloy 864. Etchant - Nital. Magnification: 20X

Welding

Table 12 - Mechanical Test Data for Autogenously Welded INCOLOY alloy 864 Plate, 0.062 in (1.6 mm) thick

Test Temperature	Hardness	Tensile Strength		Yield Strength		Elongation	Fracture Location
	Rb	ksi	MPa	ksi	MPa	%	
70°F (20°C)	82	79.9	550.9	46.1	317.9	17.4	Weld
70°F (20°C)	83	80.4	554.4	45.3	312.3	18.7	Weld
800°F (427°C)	N/A	64.5	444.7	31.7	218.6	20.5	Weld
1000°F (538°C)	N/A	58.4	402.7	30.9	213.1	16.6	Weld
1200°F (648°C)	N/A	58.9	406.1	28.9	199.3	18.4	Weld
1400°F (759°C)	N/A	40.9	282.0	26.4	182.0	23.5	Weld
1600°F (871°C)	N/A	23.4	161.3	15.9	109.6	55.0	Weld

Table 13 - Autogenously Welded Mechanical Test Data for Dissimilar Base Material Combinations

Alloy to Alloy	Plate Thickness (in.)	Test Type	Hardness (HRb)	Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)	Fracture Location
864-321	.062-.062	RTT	82	72.2	42.3	15.1	Weld
		RTT	83	67.6	40.5	14.1	Weld
864-316Ti	.008-.012	RTT	N/A	85.9	38.6	26.0	864
		RTT	N/A	88.2	40.8	19.1	864
864-304	.125-.118	RTT	80	79.6	42.1	23.2	Weld
		RTT	80	74.3	Restart	Restart	Weld
864-439	.008-.016	RTT	N/A	87.1	39.6	15.1	Weld
		RTT	N/A	69.3	41.5	7.4	Weld
864-625LCF	.062-.062	RTT	81	93.9	52.3	26.8	864
		RTT	95	92.0	49.2	25.0	864
864-1008	.062-.062	RTT	82	62.5	49.1	17.6	1008
		RTT	82	63.8	46.7	18.7	1008
864-409	.062-.062	RTT	71	56.2	37.7	17.8	409
		RTT	72	59.5	38.4	20.4	409

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