NIMONIC® alloy 81

NIMONIC® alloy 81 is a wrought nickel alloy hardened by controlled additions of titanium and aluminum, and designed to provide enhanced resistance to high temperature corrosion coupled with good high temperature strength.

It has excellent hot corrosion resistance due to its high chromium content. Elevated temperature strength characteristics are similar to those of NIMONIC alloy 80A. Melting, hot-working, cold-working and machining practices are also broadly similar to those for NIMONIC alloy 80A.

Applications include components for gas turbines, piston engine exhaust valves, and heat-exchange plant subject to attack by deposits resulting from the combustion of impure fuels, particularly by alkali metal sulfates and chlorides.

Nominal Composition

% max. unless stated

Carbon	0.05
Silicon	0.50
Copper	0.20
Iron	1.0
Manganese	0.50
Chromium	30.0
Titanium	1.8
Aluminum	0.9
Cobalt	2.0
Molybdenum	0.30
Boron	0.003
Zirconium	0.06
Sulfur	0.015
Nickel	Balance

Publication Number SMC-095

Heat Treatment

NIMONIC alloy 81 is normally used in the solution- and precipitation-treated condition. This heat treatment is generally carried out in air. Material is usually supplied in the solution-treated condition and is aged by the customer as part of the fabrication process. NIMONIC alloy 81 can, however, be supplied to any requested heat-treatment condition. Details of the recommended heat treatments for various forms are given below, where the stated times represent the times at temperature. In establishing furnacing time due allowance must, of course, be made for furnace characteristics and charge weight.

Form	Solution treatment	Aging treatment
Extruded or forged bar and section for forging, rolling and /or machining	8h/1100°C/ AC or WQ	16h/700°C/ AC
Hot-rolled plate and sheet	approx. ½h/1100°C/ AC or WQ	16h/700°C/ AC
Cold-rolled sheet	5-15min/1100°C/ FBQ or WQ	16h/700°C/ AC

Hot-worked products may be cooled from the solution-treatment temperature either by air cooling (AC) or by water quenching (WQ). Cold-worked products, especially sheet, may be fluidized bed quenched (FBQ): this produces less distortion than water quenching without a significant change in properties.

Interstage annealing to remove residual cold-work is normally applied during manipulation operations. The following treatment is recommended for sheet:

5-15 min/1100°C/AC or WQ

Welding operations should be carried out with the alloy in the solution-treated condition. A full, two stage heat treatment should then be applied to develop maximum properties in the welded component.

Details of welding practice are given subsequently under “Fabrication”.

Physical Properties

Density, Mg/m^3 ....8.06

lb/in^3 ....0.291

Melting Range

Liquidus temperature, °C...1375

Solidus temperature, °C 1305

The exact density value is dependent on compositional variation within the release specification, on form, and on heat treatment.

Table 1 - Mean Coefficient of Linear Thermal Expansion

°C	µm/m • °C	
	Extruded and subsequently stretched bar	Cold rolled sheet
20-100	11.1	11.7
20-200	12.5	12.3
20-300	13.0	12.8
20-400	13.5	13.2
20-500	14.0	13.6
20-600	14.6	14.0
20-700	15.2	14.4
20-800	16.3	15.1
20-900	18.8	16.0
20-1000	19.5	17.4

Mean coefficient of linear expansion between 20°C and temperature shown.

Dynamic Moduli

Table 3 - Dynamic Moduli

°C	Dynamic Young's modulus		Dynamic torsional modulus
	Extruded bar	Sheet	
	GPa	GPa	GPa
20	196	212	80
100	194	210	79
200	188	205	77
300	181	199	75
400	177	194	72
500	170	188	69
600	163	181	66
700	156	172	62
800	147	163	59
900	134	150	54
1000	123	133	48

Table 2 - Physical Properties

Temperature	Specific Heat	Thermal Conductivity	Electrical Resistivity at 20°C = 1.27 μΩ • m
°C	J/kg•°C	W/m•°C	Relative Resistance
20	461	10.9	1.000
100	461	12.6	1.013
200	502	13.8	1.028
300	502	15.5	1.043
400	544	17.2	1.057
500	586	18.4	1.067
600	586	20.1	1.068
700	628	21.8	1.065
800	670	23.4	1.059
900	670	25.5	1.050
1000	712	27.2	1.047

Tensile Properties

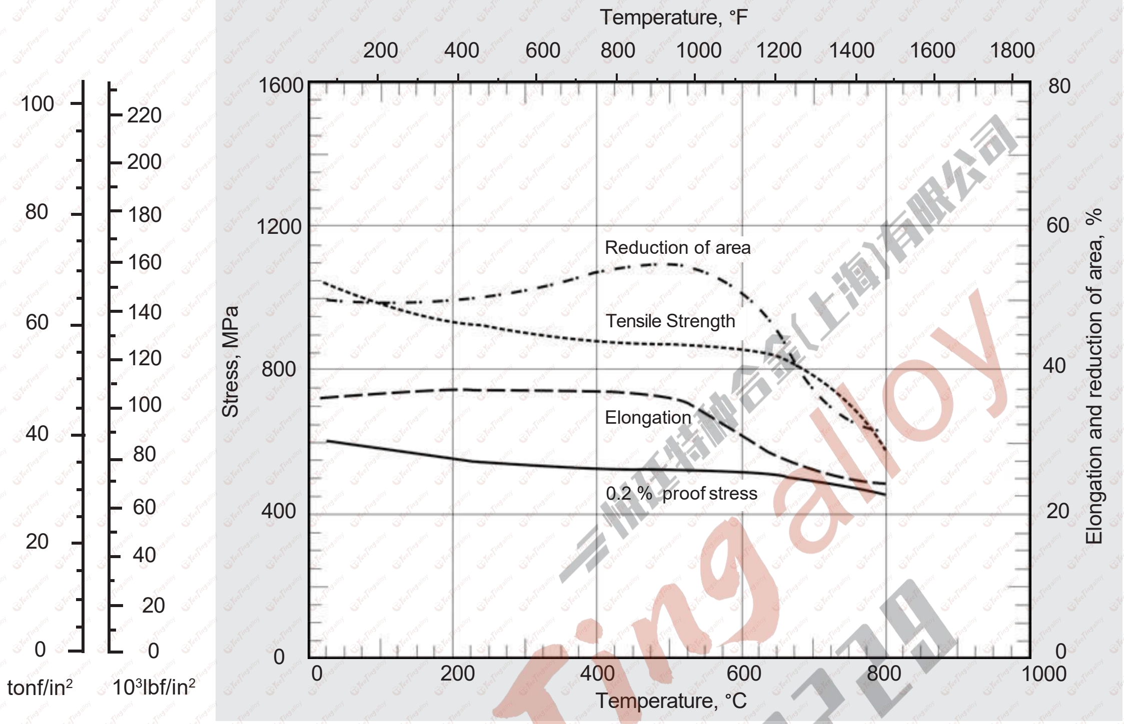

Figure 1. Tensile properties of extruded bar subsequently cold stretched Heat treatment 8h/1100°C/AC + 16h/700°C/AC
Strain rate 0.005/min to proof stress (at room temperature) and 0.002/min to proof stress (at elevated temperatures) and 0.1/min thereafter.

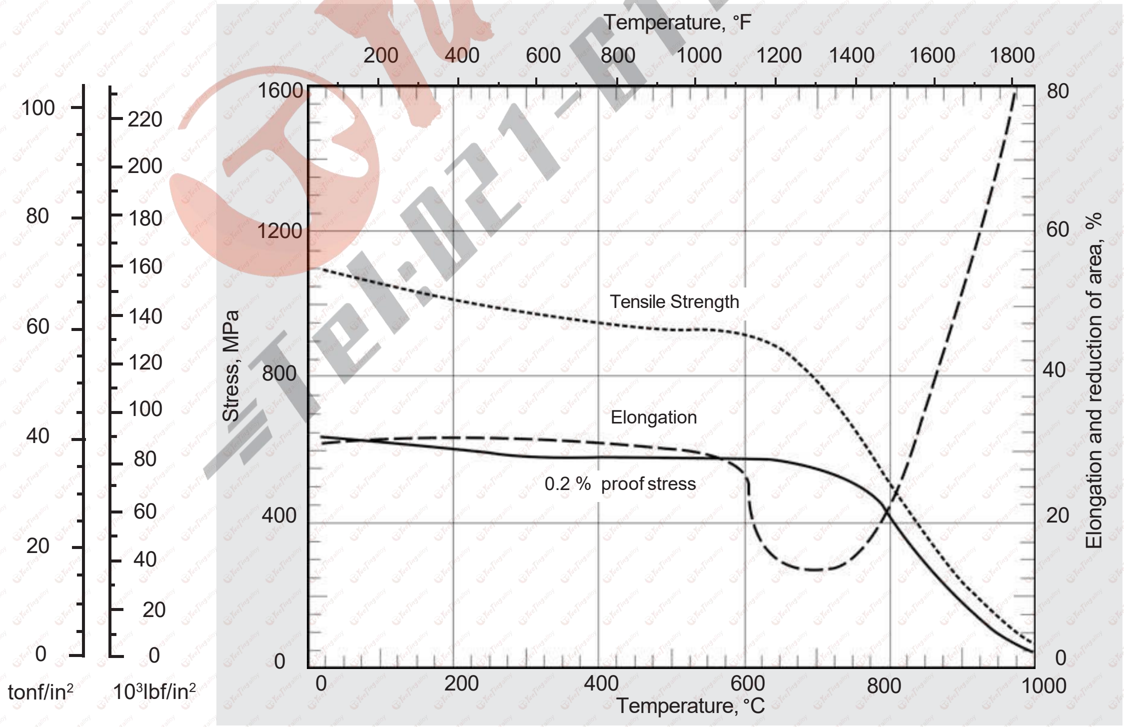

Figure 2. Tensile properties of cold rolled sheet
Heat treatment 15 min/1100°C/FBQ or WQ + 16h/700°C/AC

Tensile Properties (continued)

Table 4 - Tensile Properties of Autogenously Welded Sheet

Heat treatment 15 min/1100°C/AC + weld + 15 min/1100°C/AC + 16 h/700°C/AC

°C	0.1% Proof Stress MPa	0.2% Proof Stress MPa	Tensile Strength MPa	Elongation, %	
				on 25 mm	on 50 mm
20	536	565	874	14.0	11.5
100	551	570	860	14.0	12.0
200	499	513	808	16.0	14.0
400	503	520	819	17.0	15.0
600	403	423	641	16.0	13.0
650	445	466	653	13.0	9.5
700	406	431	596	12.0	9.5
750	425	442	598	12.0	11.0
800	391	412	513	10.0	8.0
850	318	344	394	12.0	9.5
900	158	168	229	30.0	25.5
1000	37	42	76	96.0	62.0

All Samples except that tested at 1000°C fractured in the weld.

Table 5 - Tensile Properties of Filler Metal Welded Sheet

Heat treatment 15 min/1100°C/AC + weld + 15 min/1100°C/AC + 16 h/700°C/AC

°C	0.1% Proof Stress MPa	0.2% Proof Stress MPa	Tensile Strength MPa	Elongation, %	
				on 25 mm	on 50 mm
20	568	596	961	20.0	16.0
100	537	558	978	24.0	22.0
200	534	539	914	21.0	17.5
400	499	513	854	22.0	20.0
600	494	508	791	18.0	15.5
650	477	500	737	14.0	11.5
700	420	459	641	12.0	12.0
750	419	448	571	8.0	5.0
800	375	426	524	6.0	4.5
850	284	310	388	7.0	5.0
900	170	190	238	11.0	9.0
1000	32	37	77	66.0	56.0

All Samples except those tested at 700°C and 1000°C fractured in the weld.

Creep Properties

BAR

Typical creep-rupture data for extruded bar subsequently cold-stretched and heat-treated 4h/1100°C/AC + 16h/700°C/AC are shown by Larson-Miller presentation in Figure 3, and as log stress-log time plots in Figure 4.

Total plastic stain data for bar are shown in Table 6.

SHEET

Typical creep-rupture data for cold-rolled sheet given the recommended heat treatment of 15 min/1100°C/AC + 16h/700°C/AC, are shown by Larson-Miller presentation in Figure 5, and as log stress-log time plots in Figure 6.

Total plastic strain data for sheet are shown in Table 7.

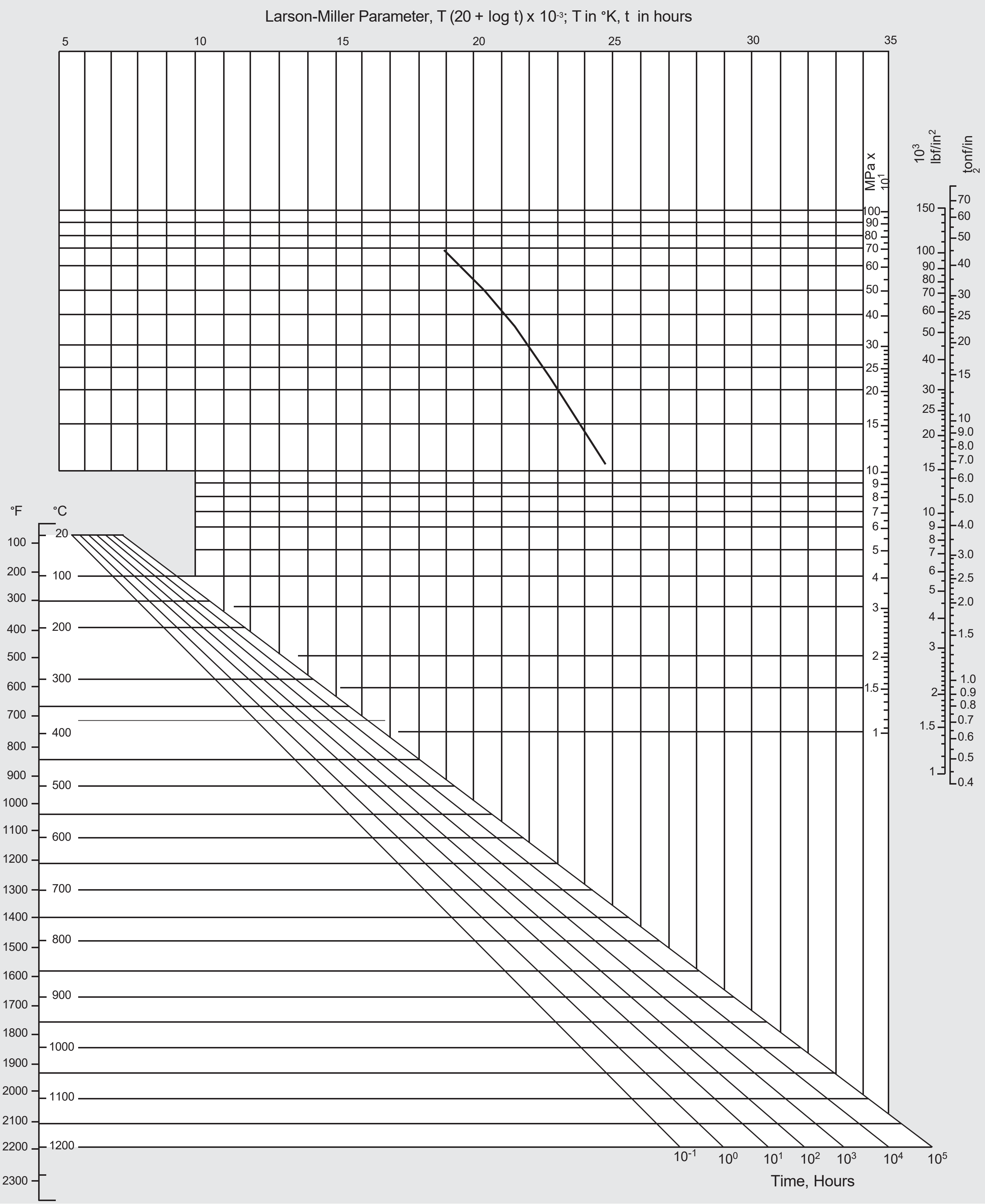

Figure 3. Creep-rupture properties for bar. Fully heat-treated condition.

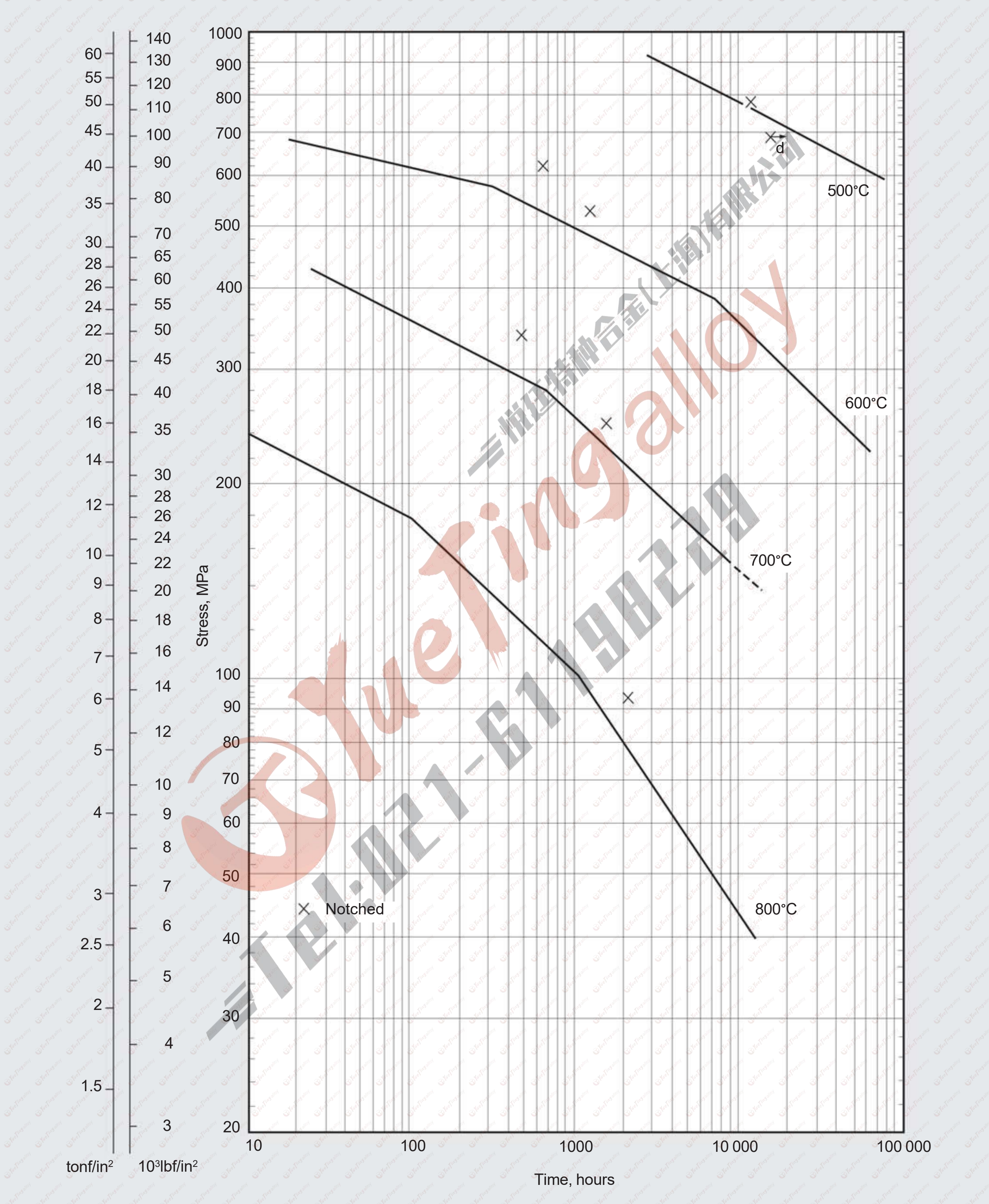

Figure 4. Creep-rupture properties for bar. Fully heat-treated condition.

Table 6 - Total Plastic Strain Data for Extruded and Subsequently Cold Stretched Bar

Heat treatment 4h/1100°C/AC + 16h/700°C/AC

Test **T**emperature °C	**S**train, %	Stress, MPa, to give total plastic strain in			
		100h	300h	1000h	3000h
600	0.1	494	440	386	—
	0.2	—	479	432	378
	0.5	564	510	448	402
	1.0	—	533	463	(402)
700	0.1	247	193	142	—
	0.2	286	239	185	139
	0.5	317	270	224	—
	1.0	—	286	239	—
800	0.1	94	59	31	—
	0.2	117	82	49	—
	0.5	144	110	71	—
	1.0	—	119	82	49

The value in parentheses is extrapolated from isothermal curves.

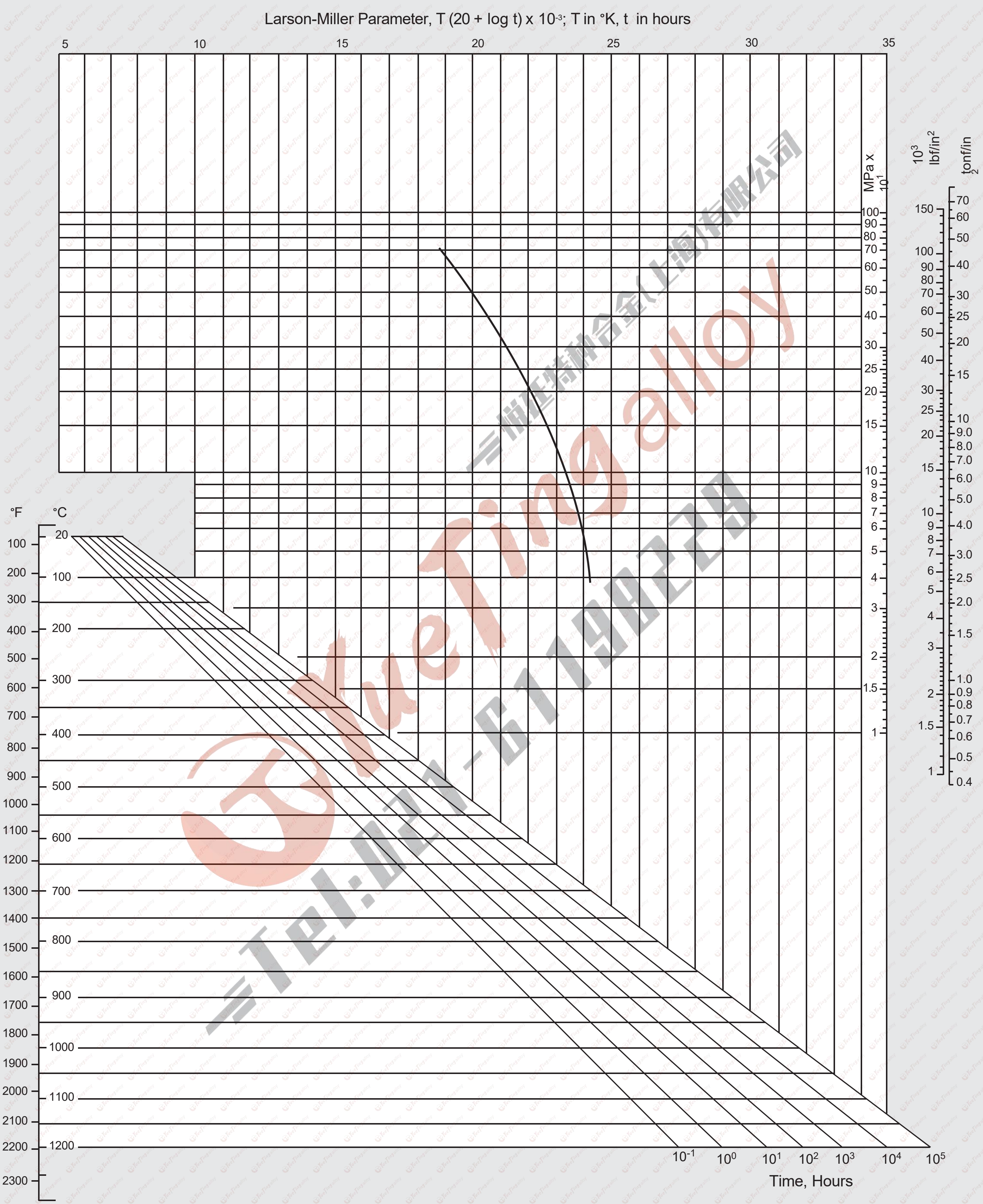

Figure 5. Creep-rupture properties for sheet. Fully heat-treated condition.

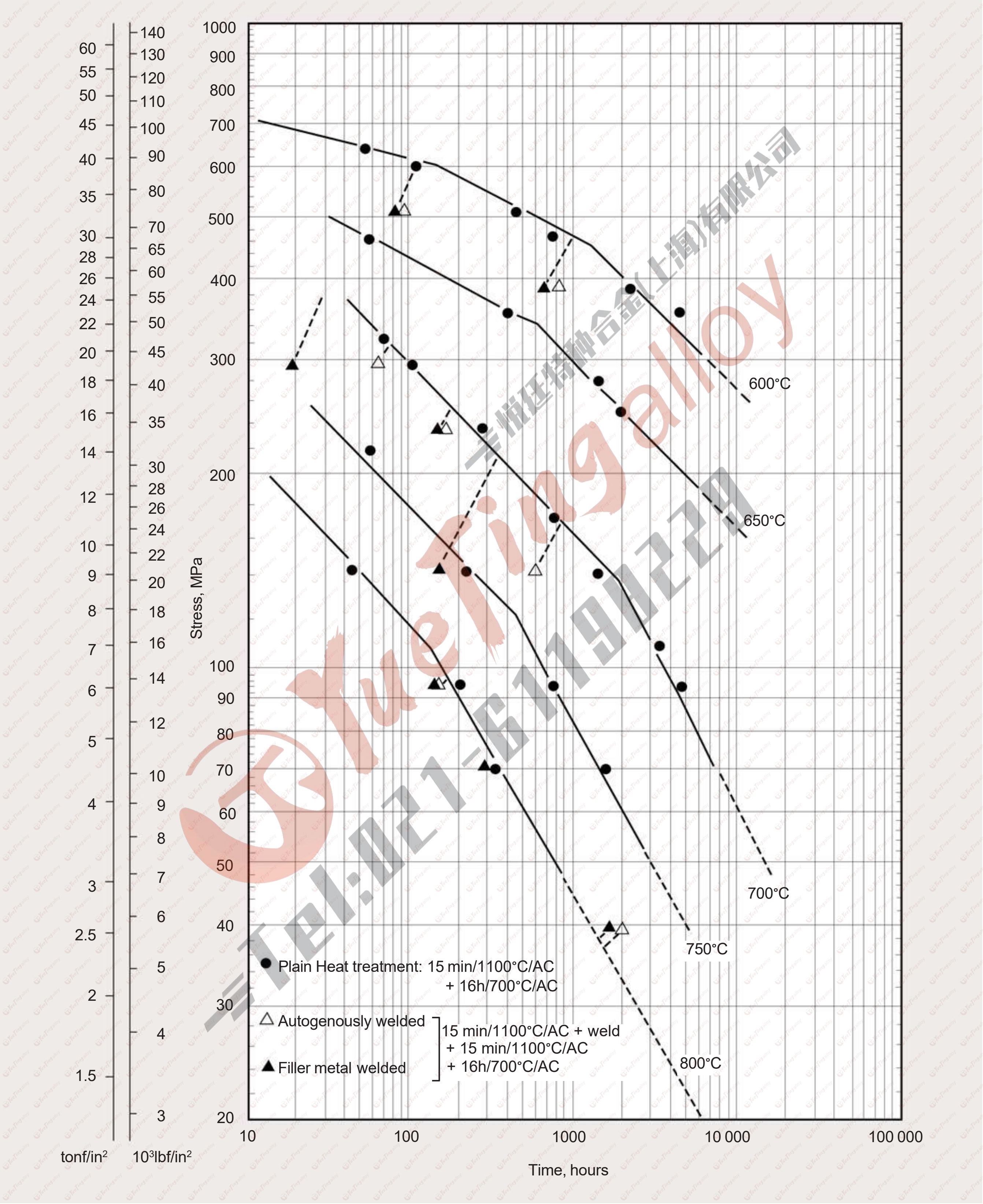

Figure 6. Creep-rupture properties for sheet. Fully heat-treated condition.

Table 7 - Total Plastic Strain Data For Cold-Rolled Sheet

Heat treatment 15 min/1100°C/AC + 16h/700°/AC							
Test Temperature °C	Strain, %	Stress, MPa, to give total plastic strain in					
		50h	100h	300h	1000h	3000h	10 000h
600	0.1	380	343	(292)	(245)	—	—
	0.2	480	430	362	(300)	(250)	—
	0.5	(600)	520	437	364	(307)	—
	1.0	—	552	470	390	(330)	—
	Rupture	640	610	540	465	365	(267)
650	0.1	205	170	(125)	—	—	—
	0.2	335	280	210	(155)	—	—
	0.5	(455)	380	285	207	(155)	—
	1.0	—	(425)	320	233	(175)	—
	Rupture	470	430	370	295	223	(163)
700	0.1	130	105	(74)	(51)	—	—
	0.2	185	146	100	(67)	—	—
	0.5	250	196	133	(88)	—	—
	1.0	305	238	161	107	72	—
	Rupture	355	295	220	160	108	(61)
750	0.1	54	(41)	—	—	—	—
	0.2	77	(56)	(34)	—	—	—
	0.5	119	84	(48)	—	—	—
	1.0	(155)	111	(65)	(36)	—	—
	Rupture	210	175	132	83	(50)	(29)
800	0.1	(16)	—	—	—	—	—
	0.2	25	(15)	—	—	—	—
	0.5	50	32	(15)	—	—	—
	1.0	77	50	(25)	—	—	—
	Rupture	140	115	76	45	(28)	(17)

The values in parentheses are extrapolated from isothermal curves.

Fatigue Properties

Mechanical fatigue

Mechanical fatigue for fully heat-treated NIMONIC alloy 81 has been examined by the rotating bend technique. Specimens of a minimum diameter of 4.06 mm were tested at 700°C and a nominal 3000 revolutions per minute.

Table 8 - Rotating Bend Fatigue Tests at 700°C

Stress MPa	Fatigue life	
	Hours	Cycles x 10^6
550	0.078	0.014
463	12.6	2.263
386	71.6	12.879
309	357.0	64.250

Thermal fatigue

Thermal fatigue testing of NIMONIC alloy 81 has been carried out on fully heat-treated tapered-disc specimens of 41.3 mm diameter and 0.25 mm edge radius, which were alternately immersed in hot and cold fluidized beds. Mean values for the number of cycles to give the first microscopically distinguishable crack are presented in Table 9. These data are compared with NIMONIC alloy 80A, given the 8h/1080°C/AC + 16h/700°C/AC heat treatment and tested under the same conditions. The superiority of NIMONIC alloy 81 under these test conditions is clearly demonstrated.

Impact Data

The room temperature Charpy impact strength for NIMONIC alloy 81 has been examined on one cast of extruded bar subsequently cold stretched, and heat-treated 4h/1100°C/AC + 16 h/700°C/AC. A value of 62J was obtained.

The same material was also used to investigate long term embrittlement by room temperature testing.

Table 10 - Room Temperature Charpy V-Notch Impact Tests

Soaking time h	Soaking termperature, °C				
	500	600	700	800	900
	J	J	J	J	J
30	73	62	62	72	111
100	75	61	58	77	103
1000	64	56	54	77	117
3000	47	56	52	81	104
10 000	30	—	43	85	—

Table 9 - Thermal Fatigue Tests Using Taper-Disc Specimens

Peak Temperature °C	NIMONIC alloy 81		NIMONIC alloy 80A	
	Mean of number of cycles to initiate cracking	Number of tests	Mean of number of cycles to initiate cracking	Number of tests
800	876	2	398	3
900	99	2	40	4

Corrosion Resistance

The oxidation resistance of NIMONIC alloy 81 has been examined using the thermobalance technique. The results are given in Figure 8.

The effect of exposing NIMONIC alloy 81 for 1000 hours in air containing 3% sulfur dioxide is indicated in Table 11, where the weight loss was determined after electrolytic descaling in molten caustic soda. Comparable data for NIMONIC alloy 80A are also given.

The corrosion of NIMONIC alloy 81 in salt mixtures is shown in Table 12. Specimens 19.1 mm long by 12.7 mm diameter, and having a wet ground surface finish, were used for these tests. The weight loss was determined after electrolytic descaling in molten caustic soda. Comparable data for NIMONIC alloy 80A where available are also shown.

Additional hot corrosion tests under intermittent salt shower conditions at 800°C are shown in Figure 7. Comparable data for NIMONIC alloy 80A are also given.

Table 11 - Gaseous Corrosion in Air/Sulfur Dioxide Mixture

Temperature °C	1000 hour exposure in air containing 3% by volume SO_2. Weight loss after electrolytic descaling in molten caustic soda, mg/cm²	
	NIMONIC alloy 81	NIMONIC alloy 80A
600	1.4	20.0
700	0.7	4.2
800	2.0	–
900	3.5	–

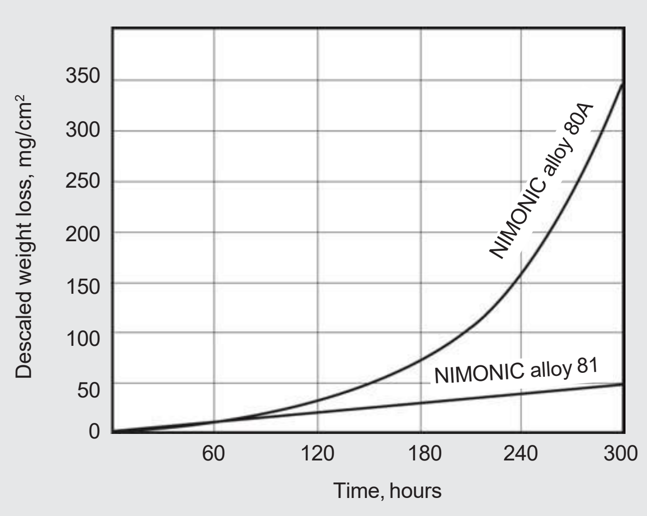

Figure 7. Intermittent salt shower corrosion tests ($75\%\ Na_2SO_4 + 25\%\ NaCl$ at 800°C)

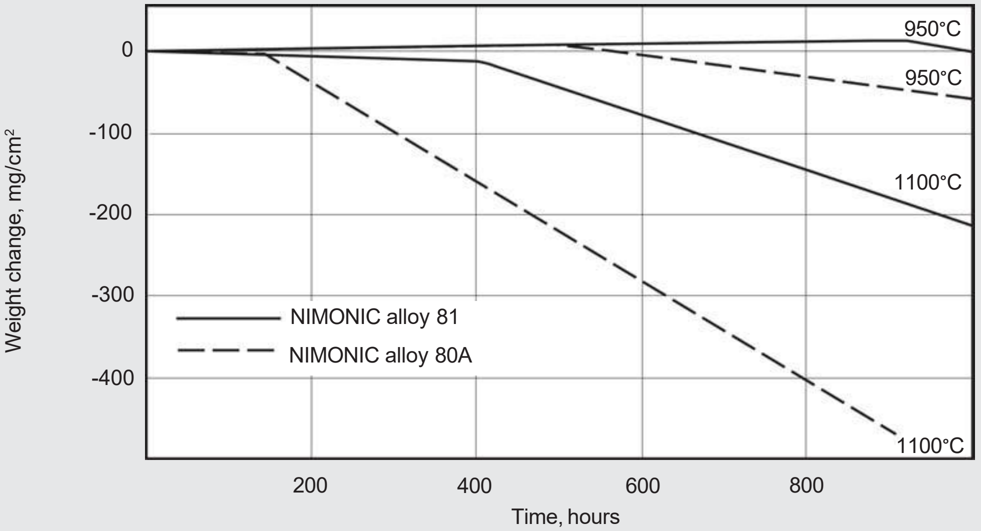

Figure 8. Cyclic oxidation properties of NIMONIC alloys 80A and 81 (Heating cycle: 20 minutes at temperature, 10 minutes at room temperature)

Table 12 - Salt Mixture Corrosion - Crucible Tests

		Weight loss (mg/cm²) determined after electrolytic descaling in molten caustic soda									
Alloy	Test Temperature	Half-immersed in Na_2SO_4+ 0.5% NaCl		Half-immersed in Na_2SO_4+ 25% NaCl		Half-immersed in Na_2SO_4+ 20% V_20_5		Half-immersed in Na_2SO_4+ 80% V_20_5		Half-immersed in Na_2SO_4 + 20% NaCl + 20% V_20_5	
		16h	300h	16h	300h	16h	300h	16h	300h	16h	300h
NIMONIC alloy 81	700	0.9	1	0.9	4	3	20	27	84	31	15
	800	0.8	4	2	14	4	20	49	317	1	16
	900	2	13	4	15	3	22	46	591	13	14
	1000	6	22	8	32	6	76	280	861	18	21
NIMONIC alloy 80A	700	—	—	—	—	—	—	—	—	—	—
	800	—	1.4	1453	899	—	594	—	1438	—	154
	900	—	1640	1290	1170	—	1560	—	477	—	86
	1000	—	—	1302	—	—	—	—	—	—	—

Fabrication

Hot Working

NIMONIC alloy 81 may be hot worked in the temperature range 950-1160°C.

Cold Working

Average mechanical properties pertinent to cold forming operations on annealed sheet, 1.2 mm thick, are given in Table 13.

Table 13

0.1 % proof stress	414 MPa
0.2 % proof stress	420 MPa
0.5 % proof stress	429 MPa
Tensile strength	897 MPa
Percentage of elongation on 50 mm	38.3
Hardness	230 HV*
Mean grain size	ASTM 7
Grain size range	ASTM 5.5-8.0
Erichsen value	11.3 mm
Typical plastic anisotropy, $\bar{R}$ value†	0.93
Shear strength	669 MPa
Ratio of shear to tensile strength	0.75

* A typical hardness range of 200-230 HV is obtained on production annealed and flattened material.

† Mean value of plastic anisotropy ratio R for tests at 0°, 45° and 90° to the final rolling direction using the formula $\bar{R} = \frac{1}{4}(R_{o}° + 2R_{45}° + R_{90}°)$

Annealing

NIMONIC alloy 81 bar or heavy section may be softened by a heat treatment of 2 to 4 hours at 1100°C followed by air cooling. A solution treatment of 8 hours at 1100°C followed by air cooling is recommended prior to precipitation hardening.

Annealing of NIMONIC alloy 81 sheet required during manipulation operations should be by heating for 5 to 15 minutes at 1100°C followed by rapid cooling: water quenching for heavier sheet and air cooling for thin section. Fluidized bed quenching may also be used.

Welding

NIMONIC alloy 81 can be compared with NIMONIC alloy 80A in terms of welding response. It is readily welded by the tungsten inert-gas shielded process (T.I.G. welding) in section thicknesses up to 5 mm but above this thickness there is the likelihood of heat-affected-zone cracking. Sheet should be in the solution-treated condition prior to welding and the full heat treatment of 5-15 min/1100°C/AC + 16h/700°C/AC should be applied after welding. Filler wire of matching composition is normally used and joint efficiencies of at least 90% are obtained.

In laboratory circular fusion weldability tests NIMONIC alloy 81 has been shown to be slightly better than NIMONIC alloy 80A, particularly under repair welding conditions. When repair welding fully heat-treated weld material the repair weld can be directly aged without cracking whereas under similar conditions NIMONIC alloy 80A suffers from heat-affected-zone cracking. Under conditions of severe restraint it may, however, be advisable to apply the solution treatment prior to precipitation hardening after repair welding.

Other welding processes which can be applied to NIMONIC alloy 81 include dip-transfer welding (in thicknesses up to 5 mm), resistance-spot, -stitch, and -seam welding and flash-butt welding. For these processes the conditions normally used for NIMONIC alloy 80A should be used as a guide for determining the exact welding parameters. When welding to other NIMONIC alloys the filler wire used for the stronger member of the combination should be used. For example, when welding to NIMONIC alloy 90 use NIMONIC filler metal 90. If welding of NIMONIC alloy 81 to stainless steels or mild steel is required, then INCONEL filler metal 82 should be used.

Available Products

NIMONIC alloy 81 is available in the following forms, subject to minimum order quantities:

Bars and billets for forging Rods and bars for machining
Extruded sections, rectangular or profile, for machining, rolling and welding into rings, etc.
Hot-rolled plate and sheet Cold-rolled sheet and strip
Cold-worked tubes
Cold-drawn wire and filler wire

The Special Metals Corporation trademarks include:

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