NIMONIC® alloy PK33 is a vacuum processed nickel-base alloy that was developed to provide a sheet material offering improved ductility in welded assemblies and high creep strength to replace NIMONIC alloys 80A and 90.

NIMONIC alloy PK33 is extremely resistant to thermal shock and thermal fatigue, has good weldability and is, therefore, attractive for combustion chambers, jet pipes and reheat systems for high performance gas turbine engines.

Although the alloy was developed as a sheet material, associated forgings and ring components were also required and it is now standard practice to produce forging billet, bar and section for maching using the consumable-electrode vacuum-arc melting process.

The welding techniques for this alloy are similar to those in common use on other nickel-base age-hardenable alloys.

Composition[a], %

Carbon	0.07 max.
Silicon	0.5 max.
Copper	0.2 max.
Iron	1.0 max.
Manganese	0.5 max.
Chromium	16.0-20.0
Titanium	1.5-3.0
Aluminum	1.7-2.5
Cobalt	12.0-16.0
Molybdenum	5.0-9.0
Boron	0.005 max.
Zirconium	0.06 max.
Sulfur	0.015 max.
Nickel	Balance*

[a] As stated in D.T.D. 5057.

*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.

Heat Treatment

NIMONIC alloy PK33 is normally put into service after a two-stage heat treatment, that is in the solution-treated and age-hardened 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 PK33 can however be supplied in 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 bars and section for forging, rolling and/or machining	1½-2½h/1100-1120°C/AC or WQ	4h/850°C/AC
Hot-rolled sheet	approx. ½/1100-1120°C/AC or WQ	4h/850°C/AC
Cold-rolled sheet and strip	5-15 min/1100-1120°C/FBQ,WQ or AC	4h/850°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 produced less distortion than water quenching without a significant change in properties.

Interstage annealing to remove residual cold work is normally applied during manipulatory operations. The following treatment is recommended for sheet: 5-15 min/1100-1120°C/AC, WQ or FBQ

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".

Publication Number SMC-103

Physical & Thermal Properties

Table 1- Physical Properties

Density, g/cm^3	8.21
lb/in^3	0.297
Melting Range	
Liquidus Temperature, °C	1345
Solidus Temperature, °C	1300
Specific Heat, J/kg•°C	419

Table 2 - Specific Heat

°C	Specific Heat (Calculated[a] Values) J/Kg K
20	419
100	461
200	461
300	502
400	502
500	544
600	586
700	586
800	628
900	670
1000	670

[a] The specific heat condition for NIMONIC alloy PK33 given in Table 2 have been calculated from the composition according to the equation developed by L.R. Jackson (reference “Material Properties for Design of Airframe Laboratory Report No. 38 March 23rd, 1956, pages 39 et seq.) The validity of such calculations for NIMONIC alloy PK33 has been assessed on similar high temperature materials, when good agreement between actual and calculated values was demonstrated.

Thermal Conductivity

The thermal conductivity data for NIMONIC alloy PK33 given in Table 3 have been calculated from electrical resistance measurements on a single fully heat-treated sheet specimen using the modified Wiedemann-Franz equations obtained by R.W. Powell. (For a summary reference see “The Engineer” April 29, 1960 pages 729-732.)

Table 3 - Thermal Conductivity

°C	Thermal Conductivity (Calculated Values) W/m K
20	11.3
100	12.6
200	13.8
300	15.5
400	17.2
500	18.4
600	20.1
700	21.8
800	23.0
900	25.1
1000	27.2

Linear Thermal Expansion

The thermal expansion characteristics given in Table 4 represent the average data for 15 casts of billet slices which have been forged down to bar and typical data for 3 casts of cold-rolled sheet of 0.028 to 0.075 inch thickness. All material was given the recommended full heat treatment prior to testing.

The sheet was tested in directions both parallel and transverse to the rolling direction, and the difference in expansion was not shown to be significant.

Table 4 - Mean Coefficient of Linear Thermal Expansion

Temperature Range, °C	Mean Coefficient to Linear Thermal Expansion Millionths/°C	
	Average Data for Billet Slices Forged	Typical Data for Sheet
20-100	10.0	10.6
20-200	11.7	11.7
20-300	12.3	12.2
20-400	12.8	12.7
20-500	13.3	13.2
20-600	13.8	13.4
20-700	14.5	14.1
20-800	15.2	15.0
20-900	16.4	16.7
20-1000	17.9	18.5

Electrical Resistivity

The typical data for Table 5 have been obtained on fully heat-treated NIMONIC alloy PK33 sheet.

Table 5 - Electrical Resistivity at 20°C = 126 microhm cm

Temperature, °C	Relative Resistance
20	1.000
100	1.015
200	1.035
300	1.053
400	1.069
500	1.086
600	1.093
700	1.091
800	1.088
900	1.078
1000	1.056

Magnetic Permeability

Table 6 - Magnetic Permeability

Heat-Treatment Condition	Permeability μ at field strengths of 200 to 3000 oersteds
Annealed	1.000517
Fully Heat-Treated	1.000507

The magnetic permeability data for NIMONIC alloy PK33 in Table 6 represent the mean obtained on 3 casts of sheet (0.028 to 0.075 inches thickness), tested in the annealed and in the fully heat-treated condition. No change in permeability with field strength was detected; neither was the permeability significantly influenced by sample orientation with respect to rolling direction.

Dynamic Young's Modulus

The dynamic Young's modulus data given in Table 7 were obtained on cylindrical specimens taken from forged bar, and on sheet specimens. Both forms of sample were tested in the fully heat-treated condition and vibrated in the flexural mode. These measurements were made at very low stress levels and are slightly higher than the corresponding static Young's modulus. The difference between the static and dynamic moduli is approximately 0.2% at room temperature increasing to about 1% at 1000°C.

The sheet data were determined on 3 casts in sheet form and of 0.028 to 0.075 inches thickness. Testing of sheet also embraced annealed material and an examination of modulus for samples taken parallel and transverse to rolling direction. No significant difference between the annealed and the fully heat-treated specimens was established, neither was the effect of rolling direction significant.

Again, comparing data in Table 7 for sheet with that for forged bar shows an insignificant difference in dynamic Young's modulus, both sets of data (±1.0 x 10^3 kgf/mm^2). The dynamic Young's modulus of material not further worked after extrusion is, however, lower and shows considerably greater scatter.

Table 7 - Dynamic Young's Modulus

Temperature, °C	Typical Dynamic Young's Modulus			
	Forged Bar		Sheet	
	ksi x 10^3	GPa*	ksi x 10^3	GPa*
20	31.5	217	32.1	221
100	31.1	214	31.6	218
200	30.3	209	30.6	207
300	29.4	203	29.8	206
400	28.6	197	28.9	199
500	27.6	190	28.0	193
600	26.6	183	27.0	186
700	25.3	174	25.9	179
800	24.1	166	24.6	170
900	22.4	154	23.1	159
1000	20.3	140	20.0	138

*Converted data

Dynamic Torsional Modulus

The dynamic torsional modulus given in Table 8 represents the mean values obtained on 3 casts of fully heat-treated sheet, where the same samples as those used for the dynamic Young's modulus were employed. Very similar results were obtained on annealed sheet, and the effect of rolling direction was again shown to be insignificant.

Table 8 - Dynamic Torsional Modulus

Temperature, °C	Typical Dynamic Torsional Modulus	
	Forged Bar	
	ksi x 10^3	GPa*
20	11.7	81
100	11.4	79
200	11.3	78
300	10.9	75
400	10.6	73
500	10.2	70
600	9.9	68
700	9.5	66
800	8.9	61
900	8.2	57
1000	7.2	50

*Converted data

Mechanical Properties

Tensile Properties

BAR

The data given in Table 9, and presented graphically in Figure 1 represent typical properties for NIMONIC alloy PK33 forged bar, heat-treated 2h/1100°C/AC + 4h/850°C/AC. Limited testing on a forged ring gave comparable results.

Table 9 - Tensile Properties of Bar

Heat treatment 2 h/1100°C/AC + 4 h/850°C/AC

Temperature, °C	0.1% Proof Stress		Tensile Strength		Elongation on 5.56 $\sqrt{So}$, %	Reduction of Area %
	ksi	MPa*	ksi	MPa*		
20	96	664	164	1127	33	41
100	94	648	161	1112	33	39
200	90	618	159	1096	35	39
300	87	602	155	1065	38	40
400	85	587	148	1019	40	42
500	85	587	141	973	37	44
600	83	571	139	957	31	40
700	83	571	141	973	21	29
800	83	571	110	757	18	22
900	65	448	72	494	29	43
1000	16	108	25	170	79	82

*Converted data
Strain rate 0.005/min to proof stress (at room temperature), 0.002/min to proof stress (at elevated temperatures) and 0.1/min thereafter.

SHEET

The data given in Table 10, and presented graphically in Figure 2 represent average tensile properties for NIMONIC alloy PK33 cold-rolled sheet of 0.028 to 0.075 inch thickness, heat-treated 10 min/1100°C/FBQ + 4h/850°C/AC. All test specimens were taken transversely to the rolling direction.

Table 10 - Tensile Properties of Sheet Heat treatment 10 min/1100°C/FBQ + 4h/850°C/AC

Temperature, °C	0.1% Proof Stress		Tensile Strength		Elongation on 2 in, %
	ksi	MPa*	ksi	MPa*	
20	109	754	171	1181	29.8
100	107	735	163	1124	29.5
200	105	721	162	1113	31.5
300	101	699	158	1092	30.1
400	101	698	152	1047	32.0
500	100	690	147	1016	33.3
600	97	667	147	1014	25.5
700	101	698	149	1028	28.3
800	82	564	108	741	15.1
900	45	313	63	432	28.5
1000	13	86	19	134	56.6

*Converted data
Strain rate 0.005/min to proof stress (at room temperature), 0.002/min to proof stress (at elevated temperatures) and 0.1/min thereafter.

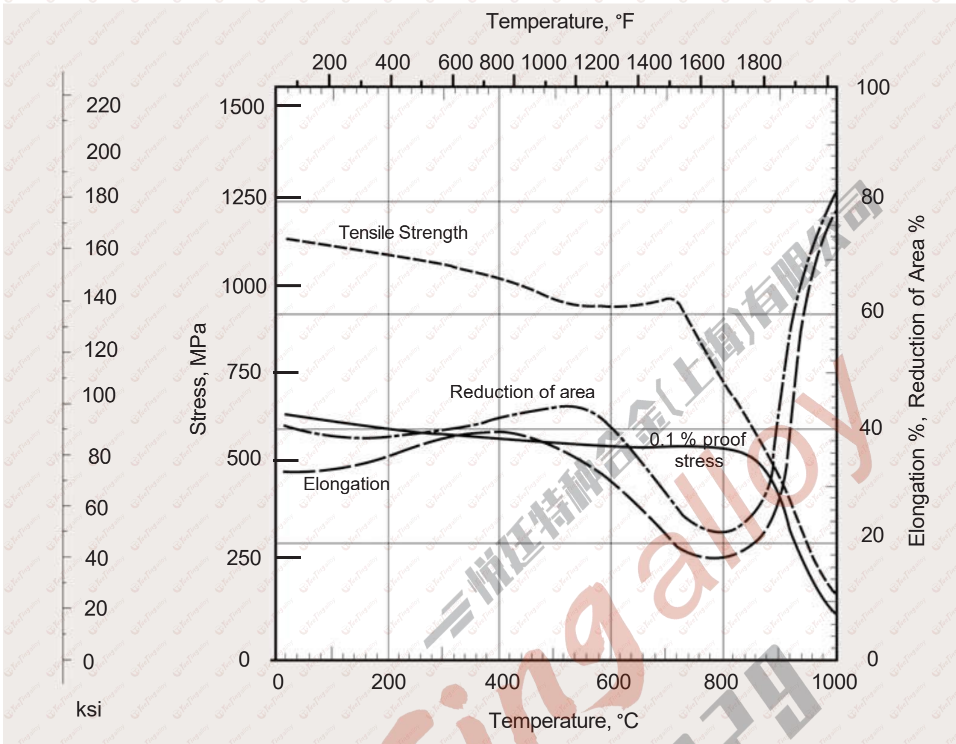

Figure 1. Tensile properties of bar. Fully heat-treated condition.

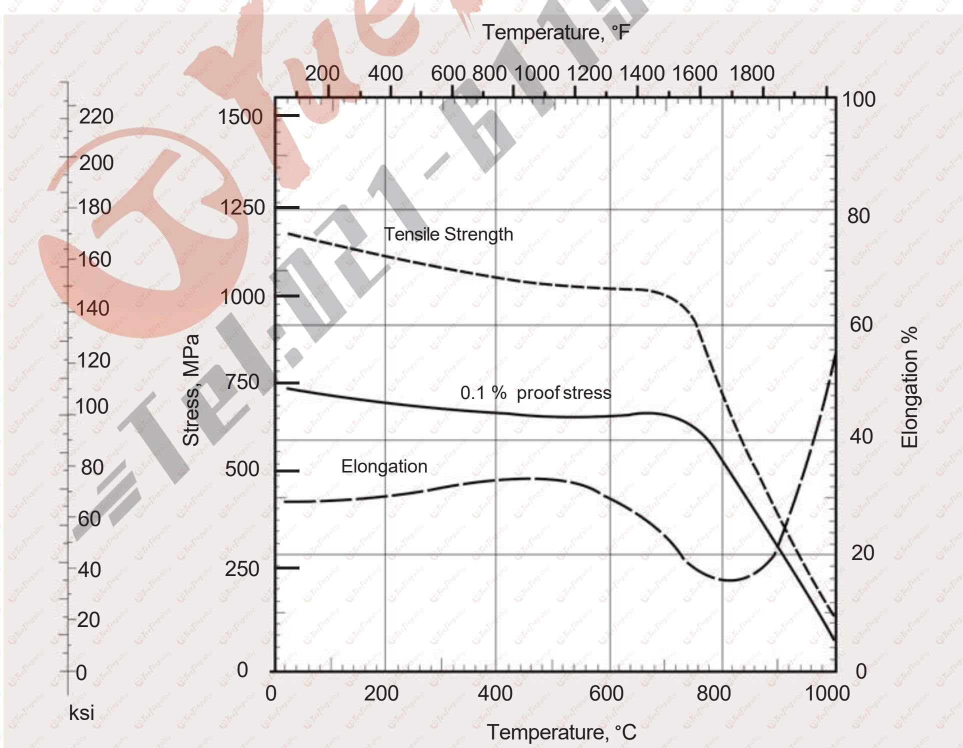

Figure 2. Tensile properties of sheet. Fully heat-treated condition.

Tensile Properties (continued)

The tensile properties for plain and for welded NIMONIC alloy PK33 0.048-inch thick sheet are compared for a single cast in Table 11. The plain sheet specimens were heat-treated 15min/1100°C/FBQ + 4h/850°C/AC, whilst the welded specimens were autogenously welded in the annealed condition and again heat-treated 15min/1100°C/FBQ + 4h/850°C/AC prior to testing.

Table 11 - Tensile Properties for Plain and Welded Sheet

Temperature, °C	Plain			Welded		
	Tensile Strength		Elongation on 2 in, %	Tensile Strength		Elongation on 2 in, %
	ksi	MPa*		ksi	MPa*	
20	163	1121	28	154	1064	20
200	160	1104	34	143	987	18
400	145	1001	30	131	902	18
500	145	997	35	125	863	17
600	141	973	23	123	845	15
700	146	1007	24	124	854	12
800	110	758	14	109	752	11
900	62	425	30	65	451	10
1000	20	137	57	20	137	26

*Converted data
All except one welded specimen fractured through the weld, the exception being one of the two specimens tested at 800°C.

Creep Properties

Bar

Typical creep-rupture properties for NIMONIC alloy PK33 bar given the recommended heat treatment of 2h/1100°C/AC + 4h/850°C/AC are shown by the continuous line in Larson-Miller presentation, Figure 3. These represent test data in excess of 1000 hours.

Derived creep-rupture data together with fracture elongation ranges, obtained on a single cast of fully heat-treated bar are given in Table 12. Good agreement with these data has been shown by a limited number of tests conducted on a different cast tested as a fully heat-treated forged ring.

Sheet

Typical creep-rupture curves for fully heat-treated cold-rolled sheet are shown by the continuous line in Larson-MIller presentation, Figure 4.

Mean rupture curves for fully heat-treated 18 swg (0.048 in) thick sheet, obtained by Graham-Walles analysis, are given as log stress-log time plots in Figure 5. Derived rupture values together with fracture elongation ranges are shown in Table 13.

Preliminary total plastic strain data for 18 swg sheet, heat-treated 15min/1100°C/AC + 4h/850°C/AC are given in Table 14 where the loading strain was completely elastic for all tests.

Creep-rupture tests on autogenously and on dressed filler welded NIMONIC alloy PK33 sheet have also been carried out. All tests were conducted on a single cast in the form of 18 swg sheet. This material was welded after annealing for 15min/1100°C/FBQ, and heat treated 15min/1100°C/AC + 4h/850°C/AC prior to testing. The results obtained are compared with plain sheet from the same cast in Figure 6. Except for filler welded specimens, tested at 700°C, the rupture lives were similar to the plain sheet. All welded specimens fractured in the parent metal.

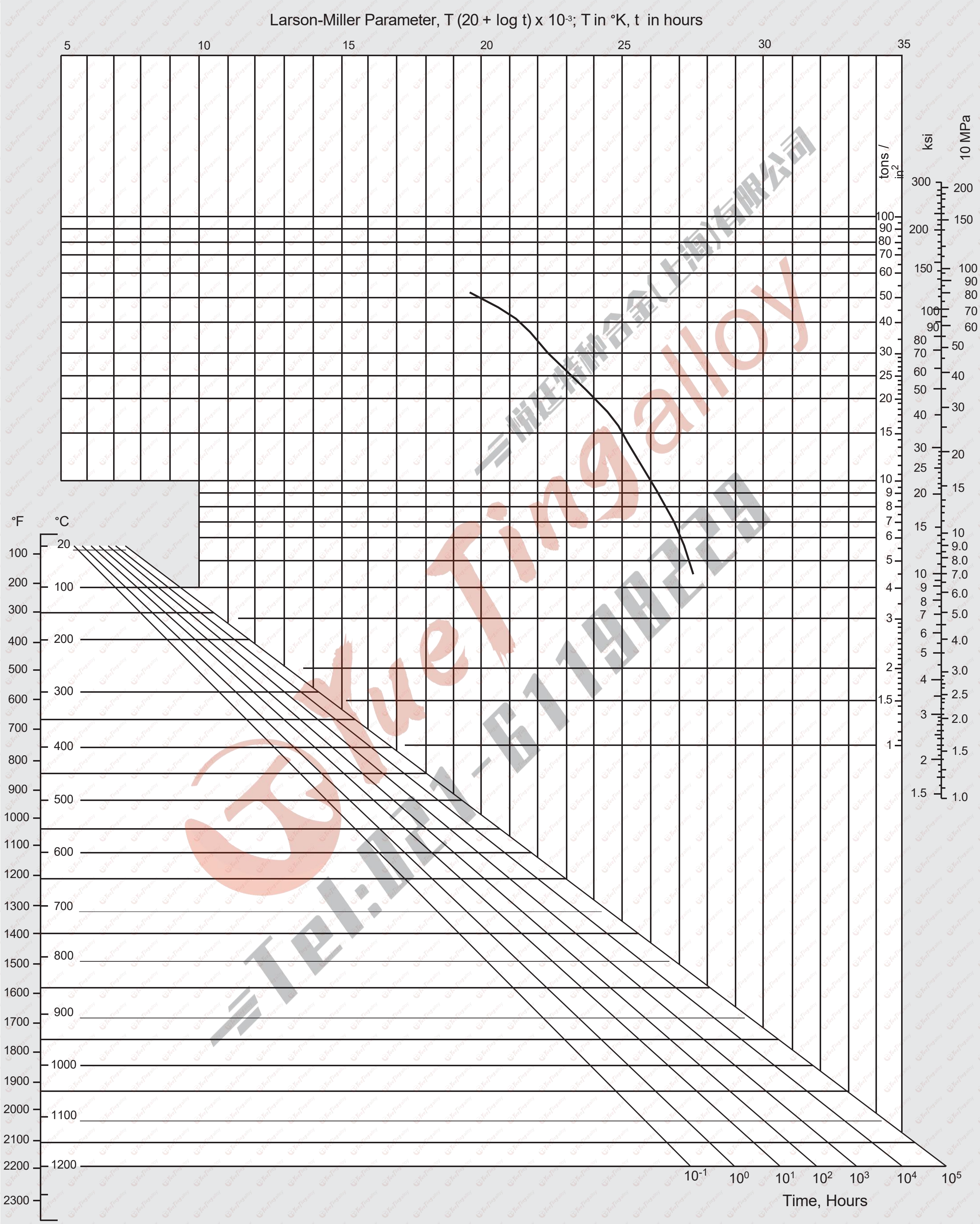

Figure 3. Typical creep-rupture properties for NIMONIC alloy PK33 bar in the fully heat-treated condition.

Table 12 - Creep-Rupture Characteristics for NIMONIC alloy PK33 Forged Bar

Heat-treated 2h/1100°C/AC + 4h/850°C/AC

Test Temp., °C	Stress to Give Rupture in										Elongation at Fracture, %
	30h		100h		300h		1000h		3000h		
	ksi	MPa*	ksi	MPa*	ksi	MPa*	ksi	MPa*	ksi	MPa*	
700	94	648	87	602	76	525	67	463	(58)	(401)	4-11
750	75	517	65	448	57	394	49	340	(43)	(293)	9-31
800	57	394	49	340	43	294	(34)	(232)	(27)	(185)	16-27
850	43	293	34	232	27	185	20	139	(16)	(108)	16-25
900	25	262	21	147	17	116	13	93	(10)	(69)	14-33

*Converted data

Values in parentheses are extrapolated from isothermal curves.

Table 13 - Creep-Rupture Characteristics for NIMONIC alloy PK33 Cold-Rolled Sheet

Heat-treated 2h/1100°C/AC + 4h/850°C/AC

Test Temp., °C	Stress to Give Rupture in												Elongation at Fracture, %
	50h		100h		300h		500h		1000h		3000h		
	ksi	MPa*	ksi	MPa*	ksi	MPa*	ksi	MPa*	ksi	MPa*	ksi	MPa*	
700	101	695	92	633	81	556	76	525	69	479	60	417	4-9
750	73	502	65	448	56	386	53	363	48	332	40	278	6-17
800	53	363	47	324	40	278	36	247	30	208	24	162	11.5-14
850	37	255	31	216	24	162	21	143	17	120	13	93	9-20
900	24	162	19	134	15	102	13	90	11	77	—	—	13-20

*Converted data

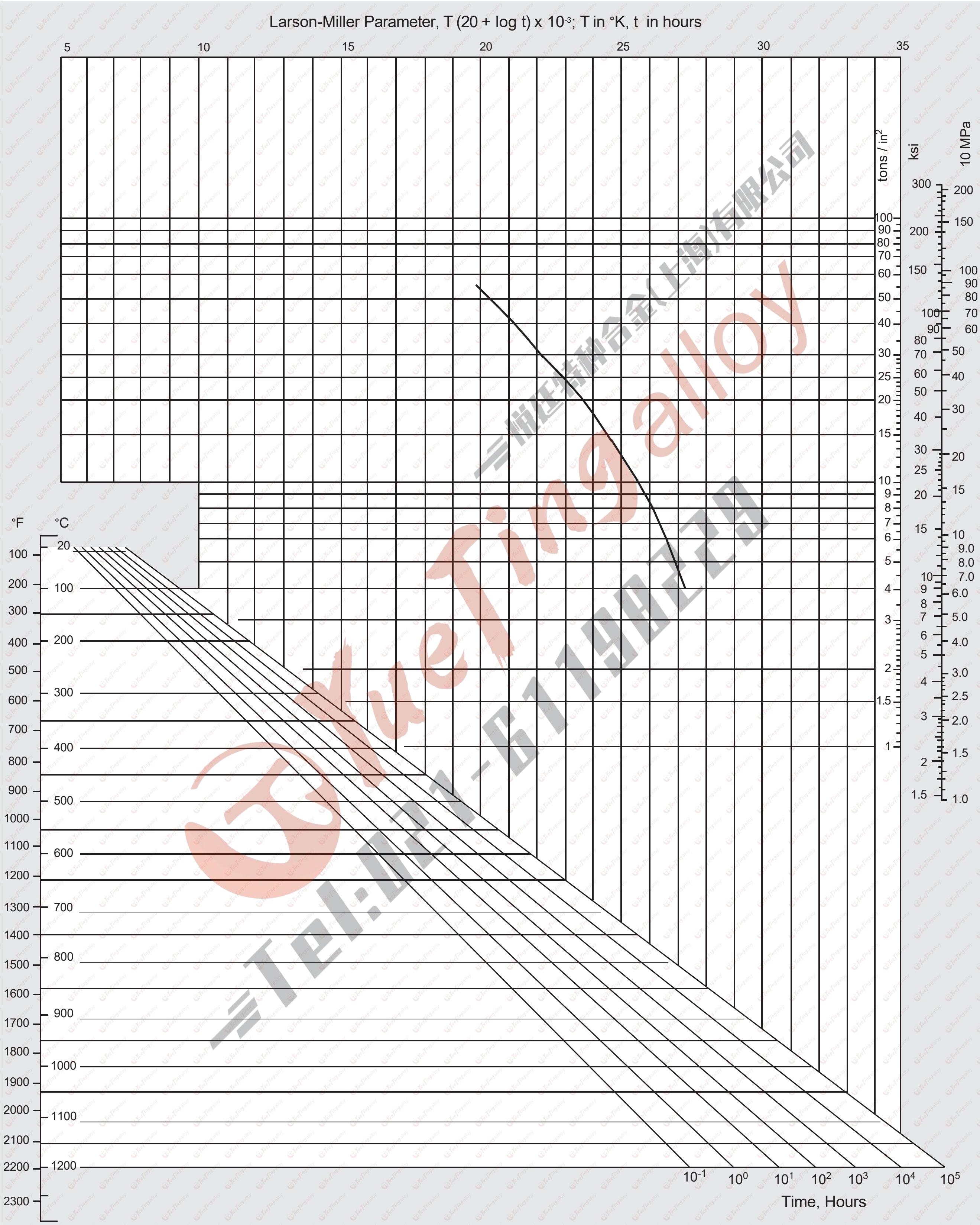

Figure 4. Typical creep-rupture properties for NIMONIC alloy PK33 sheet in the fully heat-treated condition.

Table 14 - Typical Total Plastic Strain Data for NIMONIC alloy PK33 Cold-Rolled Sheet

Heat-treated 15min/1100°C/AC + 4h/850°C/AC

Test Temp., °C	Strain	Stress to Give Total Plastic Strain in											
		50h		100h		300h		500h		1000h		3000h	
		ksi	MPa*	ksi	MPa*	ksi	MPa*	ksi	MPa*	ksi	MPa*	ksi	MPa*
700	0.1	66	455	60	417	52	355	48	332	44	301	—	—
	0.2	75	517	69	479	59	409	55	378	49	340	46	317
	0.5	82	564	75	517	65	448	60	417	56	386	52	359
	1.0	84	579	77	533	68	471	64	440	59	409	56	386
750	0.1	47	324	41	286	34	232	31	216	27	185	23	159
	0.2	54	370	48	332	40	278	37	255	32	224	28	193
	0.5	60	417	55	378	46	317	43	293	38	262	34	234
	1.0	64	440	58	401	50	347	47	324	41	286	38	262
800	0.1	30	208	27	185	21	142	18	127	15	105	12	83
	0.2	36	247	31	216	25	170	22	154	19	131	15	103
	0.5	41	286	37	255	29	201	26	178	24	154	18	124
	1.0	46	317	40	278	32	224	29	201	27	170	20	138
850	0.1	18	124	15	103	11	76	9	65	8	52	—	—
	0.2	22	153	19	128	14	96	12	82	11	68	—	—
	0.5	26	178	22	151	17	114	14	97	13	80	—	—
	1.0	28	193	25	170	18	127	16	110	14	90	10	69
900	0.1	11	74	9	60	6	42	5	34	<5	<34	<5	<34
	0.2	13	90	11	74	7	51	6	43	5	34	<5	<34
	0.5	15	107	13	88	9	63	8	52	7	42	<5	<34
	1.0	17	119	14	97	10	69	9	59	7	46	<5	<34

*Converted data

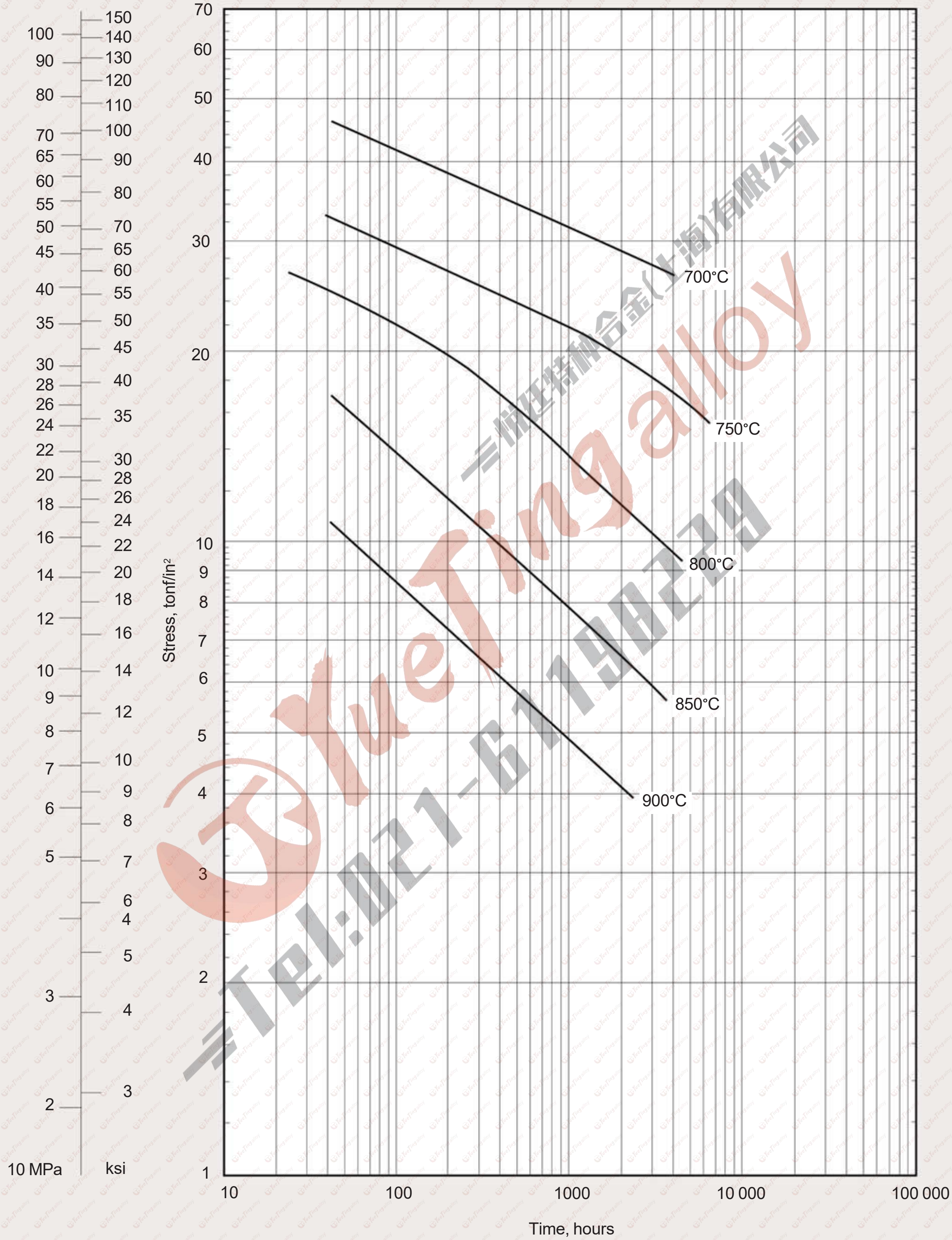

Figure 5. Typical creep-rupture properties for NIMONIC alloy PK33 sheet in the fully heat-treated condition.

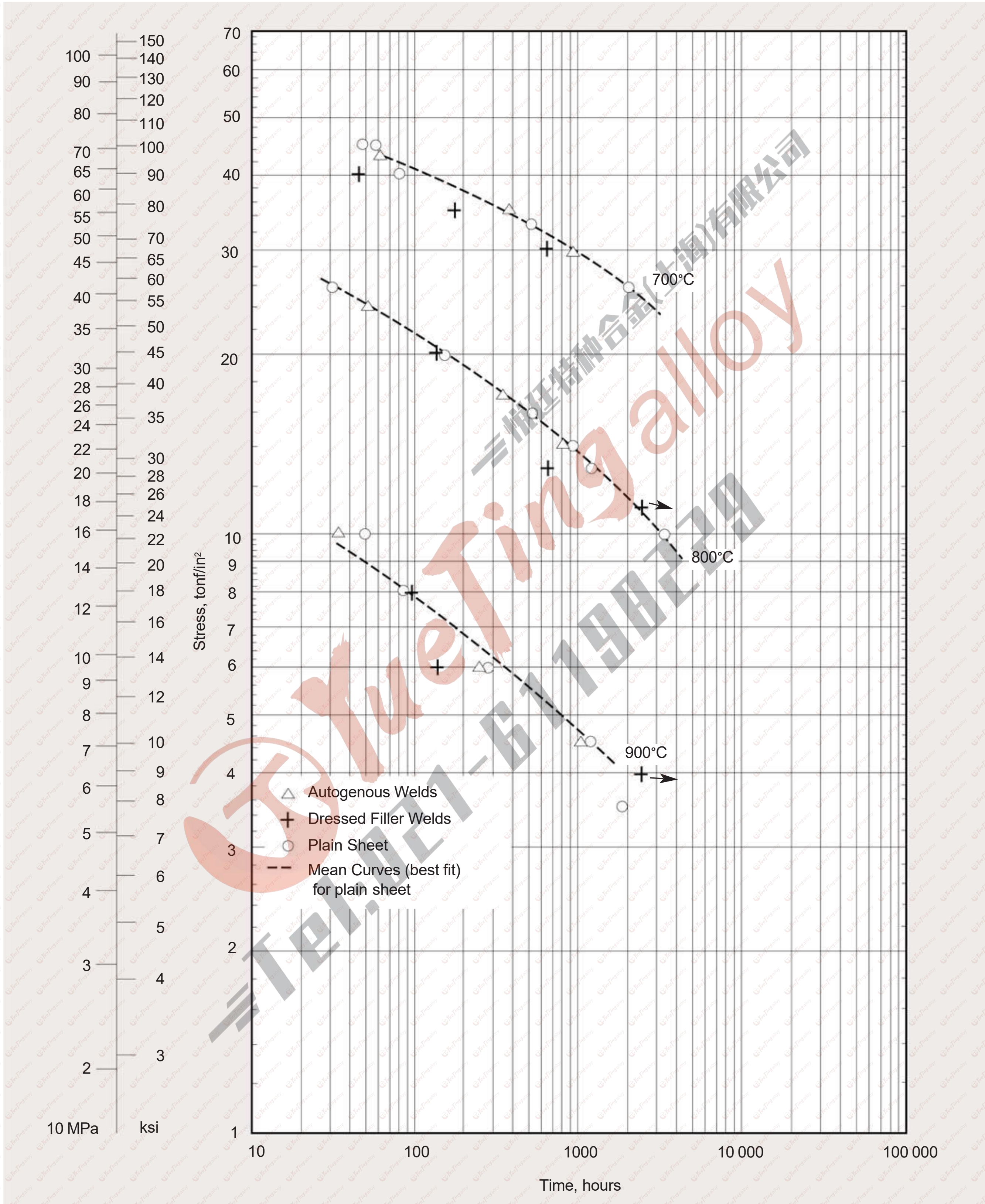

Figure 6. Comparison of creep-rupture properties for NIMONIC alloy PK33 plain and welded sheet in the fully heat-treated condition. All welded specimens fractured in the parent metal.

Fatigue Properties

Mechanical Fatigue

Preliminary mechanical fatigue properties for one cast of NIMONIC alloy PK33 have been obtained from push-pull testing of 16 and 20 swg sheet using Amsler Vibrophore machines. The material was heat treated for 6min/1100°C/AC + 4h/850°C/AC prior to testing.

Table 15 - Mechanical Fatigue Properties

Heat-treated 6min/1100°C/AC + 4h/850°C/AC

Sheet Thickness	Stress System	Test Temperature °C	Frequency Cycles/ Second	Stress Range to give failure in					
				10h		30h		100h	
				ksi	MPa*	ksi	MPa*	ksi	MPa*
16 swg (0.064 in, 1.63 mm)	0±P	20	165	0 ±37.2 to 0 ±47.7	0 ± 256 to 0 ± 329	0 ±36.1 to 0 ±42.1	0 ± 249 to 0 ± 290	0 ±36.1 to 0 ±42.1	0 ± 249 to 0 ± 290
		600	167	0 ±42.1 to 0 ±47.9	0 ± 290 to 0 ± 330	0 ±41.7 to 0 ±47.5	0 ± 287 to 0 ± 327	0 ±41.0 to 0 ±47.0	0 ± 283 to 0 ± 324
		700	167	0 ±31.4 to 0 ±41.2	0 ± 216 to 0 ± 284	0 ±30.0 to 0 ±40.1	0 ± 207 to 0 ± 276	0 ±29.6 to 0 ±38.8	0 ± 204 to 0 ± 267
		800	167	0 ±38.5 to 0 ±45.9	0 ± 266 to 0 ± 320	0 ±37.4 to 0 ±46.4	0 ± 258 to 0 ± 320	0 ±36.5 to 0 ±43.7	0 ± 252 to 0 ± 301
20 swg (0.036 in, 0.91 mm)	P±P	20	156	28.0 ±28.0 to 32.7 ±32.7	193±193 to 225 ±225	28.0 ±28.0 to 32.7 ±32.7	193±193 to 225 ±225	28.0 ±28.0 to 32.7±32.7	193±193 to 225 ±225
		600	156	37.6 ±37.6 to 43.0 ±43.0	259 ± 259 to 296 ± 296	36.5 ±36.5 to 41.7 ±41.7	252 ± 252 to 287 ± 287	35.8 ±35.8 to 39.9 ±39.9	247 ± 247 to 275 ± 275

*Converted data

Impact Data

The room temperature Charpy impact strength for NIMONIC alloy PK33 has been examined for three casts of extruded and subsequently forged bar given the recommended heat treatment of 2h/1100°C/AC + 4h/850°C/AC. The average of duplicate tests gave 36, 32 and 34 ft lbf (5.0, 4.4, and 4.7 kgf m).

Long term embrittlement of this alloy has been investigated by room and elevated temperature Charpy impact testing of one cast of extruded and subsequently forged bar given the above recommended heat treatment. The data given in Tables 16 and 17 represent the findings of these investigations and in general show the results of duplicate tests.

Table 16 - Room Temperature Charpy V-Notch Impact Tests

Soaking time h	Soaking Temperature, °C									
	600		700		800		850		900	
	ft lbf	J*	ft lbf	J*	ft lbf	J*	ft lbf	J*	ft lbf	J*
30	38	52	15	20	14	19	22	30	31	42
100	26:23	35:31	14:19	19:26	18:20	24:27	30:31	41:42	28:30	38:41
300	31	42	20	27	27	37	28	38	36	49
1000	16:20	22:27	10:17	14:23	16:20	22:27	22:21	30:29	27:22	37:30
3000	30	41	11	15	17	23	23	31	32	44
10 000	—	—	13	18	15:13	20:18	—	—	38:40	52:54

*Converted data

Table 17 - Elevated Temperature Charpy V-Notch Impact Tests

Soaking time h	Soaking Temperature, °C									
	600		700		800		850		900	
	ft lbf	J*	ft lbf	J*	ft lbf	J*	ft lbf	J*	ft lbf	J*
0	60:58	82:79	50:51	68:69	42:43	57:58	50:52	68:71	51:54	69:73
30	58:55	79:75	42:38	57:52	43:40	58:54	40:43	54:58	47:44	64:60
100	58:55	79:75	28:30	38:41	43:38	58:52	36:40	49:54	46:44	63:60
300	53	72	27	37	36	49	38	52	47	64
1000	45:47	61:64	25	34	33:38	45:52	38:40	52:54	56:45	76:61
3000	59	80	28	38	31	42	—	—	49	67
10 000	40:32	54:44	—	—	28:28	38:38	—	—	58:58	79:79

*Converted data

Fabrication

Hot-Working

NIMONIC alloy PK33 may be hot-worked in the temperature range 980-1140°C.

Cold-Working

Average mechanical properties pertinent to cold forming operations for NIMONIC alloy PK33 annealed sheet of 0.028 to 0.075 inches thickness are given in Table 18.

Table 18 - Average Mechanical Properties for Annealed Sheet

0.1% Proof Stress	66 ksi, 454 MPa
0.2% Proof Stress	71 ksi, 448 MPa
0.5% Proof Stress	75 ksi, 519 MPa
Tensile Strength	137 ksi, 942 MPa
Percentage Elongation on 2 in.	51.0
Hardness - HV	250
Mean Grain Size	ASTM 5.5
Grain Size Range	ASTM 4-7
Erichsen Value*	11.7 mm
Typical Plastic Anisotrophy - $\bar{R}$ Value⁺	0.94
Shear Strength	96 ksi, 659 MPa
Ratio of Shear to Tensile Strength	7.0

*Tests carried out on a Roell and Korthaus B.P. 512 machine using 0.001 inch thick polyethylene sheet lubricant in accordance with B.S. 3855-1965

⁺Mean value of plastic anisotropy ratio R for tests at 0°, 45° and 90° to the final rolling direction using the formula:

$$\bar{R} = \frac{1}{4}(R_{0^\circ} + 2R_{45^\circ} + R_{90^\circ})$$

It is to be noted that the above data were determined on production annealed material; namely, sheet heat-treated for 10 minutes at 1100°C, fluidized bed quenched and stretcher flattened. This material is therefore somewhat harder and slightly finer grained than the laboratory annealed and water quenched samples used to determine the softening and grain size curves Figures 7 and 8 respectively.

Annealing

NIMONIC alloy PK33 in the form of bar or heavy section is usually softened by applying a heat treatment of 2h/1100-1120°C/AC, namely the first stage of the recommended two stage heat treatment for bar. Water quenching from the heat-treatment temperature can also be used.

As previously mentioned under "Heat-Treatment", annealing of NIMONIC alloy PK33 sheet, required during manipulatory operations, should be by heating for 5 to 15 minutes at 1100-1120°C followed by rapid cooling: water quenching for heavier sheet and air cooling for thin section sheet. Fluidized bed quenching may also be used.

Additional information on the effects of annealing conditions for 0.048 inch thick NIMONIC alloy PK33 sheet is demonstrated by Figures 7 and 8. It should again be emphasized that this graphical information was obtained on laboratory scale treatments and that production material will generally yield a slightly harder and finer grained material for a given heat-treatment temperature time.

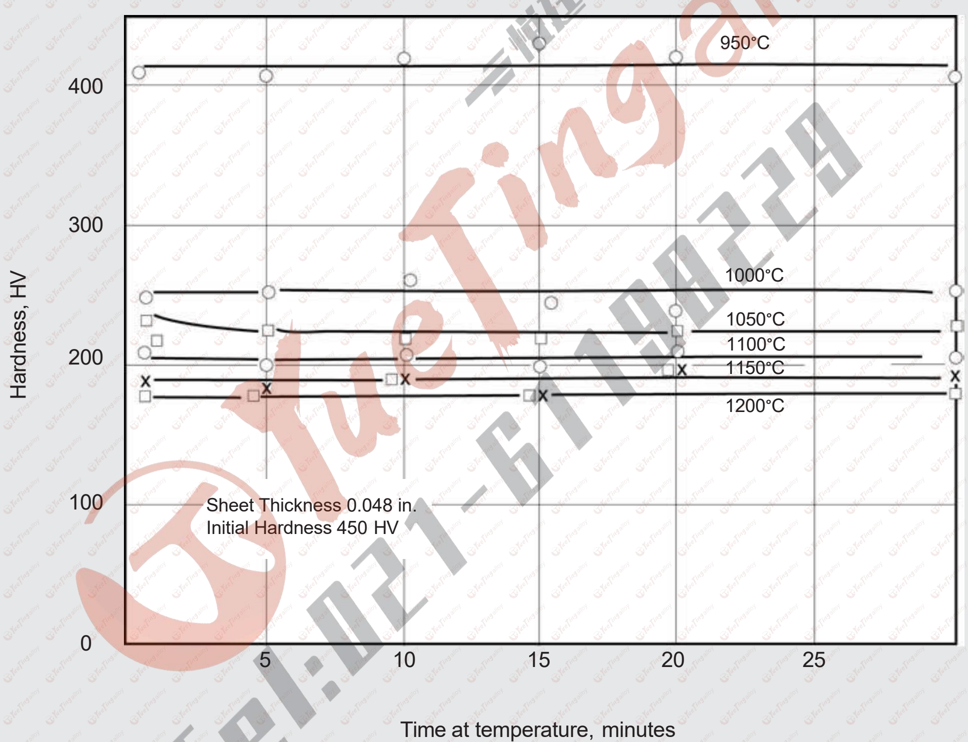

Figure 7. Softening curve for NIMONIC alloy PK33 sheet, water quenched from temperature.

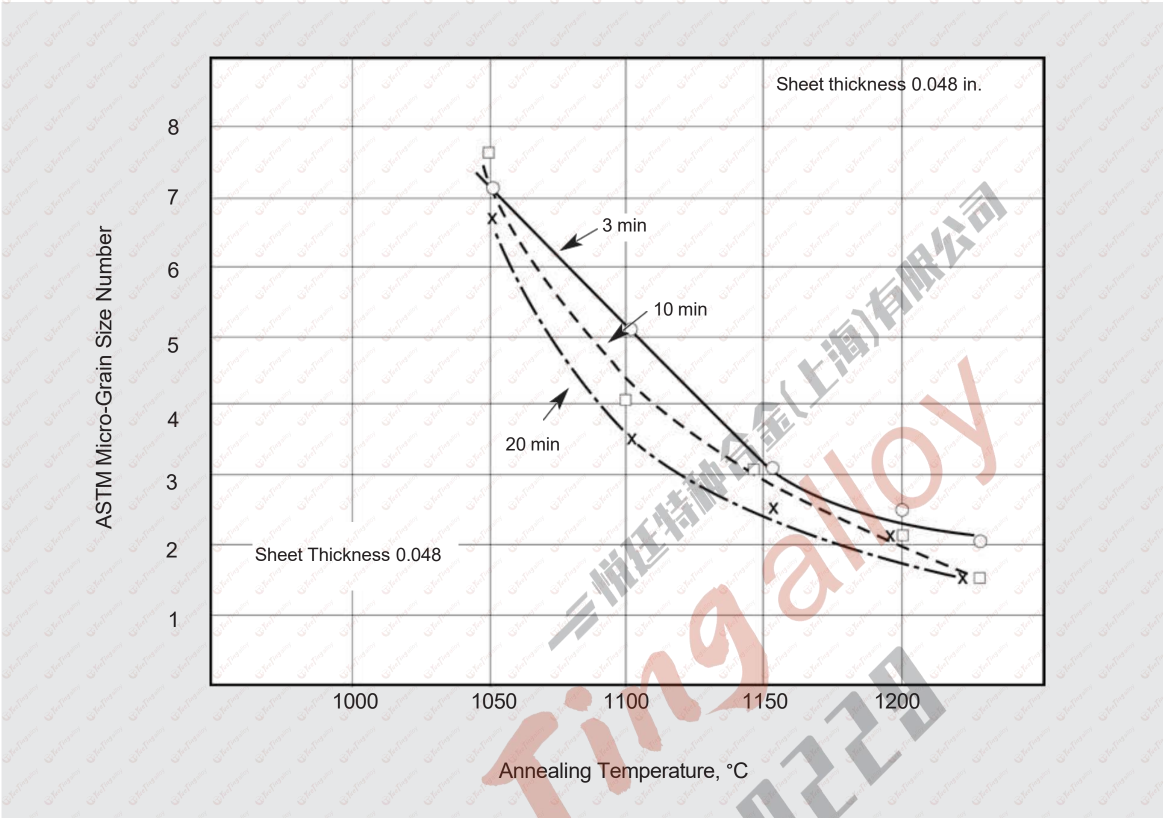

Figure 8. Grain size - Annealing condition curves for NIMONIC alloy PK33 sheet.

Welding

The welding process of NIMONIC alloy PK33 compares favorably with other nickel base precipitation hardening alloys. It is readily welded in section thicknesses up to 3/16 inch using the tungsten inert-gas shielded process (T.I.G. welding) and filler wire of matching composition, namely, NIMONIC filler metal PK33.

Before welding, the material should be in the solution-treated condition. After welding, the full two stage heat treatment detailed previously should be applied, particularly under conditions of severe restraint. Repair welding operations can be carried out with the material in the fully heat-treated condition. The full heat treatment will again be needed after welding, if freedom from cracking and optimum mechanical properties are to be achieved.

NIMONIC alloy PK33 is readily welded to other NIMONIC alloys and NIMOCAST alloys. When welding to NIMOCAST alloys, NIMONIC filler metal PK33 should be used, but when welding to other NIMONIC alloys the filler metal normally used for stronger member of the combination should be used.

Other welding processes which can be used for NIMONIC alloy PK33 are M.I.G. welding (up to 3/16 in), resistance-spot, -stitch, and -seam welding, flash butt welding and electron beam welding. Satisfactory welds have been made in test plates up to ¾ inch thick using the electron beam welding process and these welds developed properties comparable to T.I.G. welds after the appropriate heat treatment.

General recommendations on the condition of the material prior to welding and the techniques to be adopted during welding are given in the publication "Joining" on the website, www.yttzhj.com.

Oxidation

The oxidation characteristics of NIMONIC alloy PK33 sheet have been assessed in terms of tensile, creep-rupture and fatigue properties after exposures of up to 1000 hours at 800°C and at 900°C. The results of these tests are not given in this bulletin since the level of properties obtained is masked by subsequent heat-treatment changes, but the effect of oxidation at service temperatures is minimal.

Available Products and Specifications

NIMONIC alloy PK33 is generally available in the following forms:

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

NIMONIC alloy PK33 in the form of sheet and strip, in the hot-rolled or cold-rolled and solution-treated condition, is covered by the Ministry of Technology Specification D.T.D. 5057.