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NONFERROUS ALLOYS

Ni	
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

1. GENERAL
Nimonic 90 is an age-hardenable nickel-base superalloy containing substantial amounts of chromium and cobalt and with smaller additions of titanium and aluminum for precipitation hardening. It has excellent mechanical properties and oxidation resistance at temperatures up to about 1600F, and it is weldable, machinable and formable. Because of this combination of properties it is suitable for elevated temperature applications in aircraft engines and other aerospace hardware. It is available in most common wrought forms. A cast version is designated NIMOCAST alloy 90.

1.01 Commercial Designations
Nimonic 90, AECMA Ni-P96-HT, all forms (European Aircraft Std.)

1.02 Alternate Designations
NIMOCAST alloy 90, UNS NO7090.

1.03 Specifications
AMS 5829, welding wire (1)
B.S. 2HR2, bars and forgings (British)
B.S. 2HR202, cold rolled sheet and strip (British)
B.S. HR402, cold drawn tube (British)
B.S. 2HR501, cold drawn wire for springs (British)
B.S. 2HR502, cold drawn solution treated wire (British)
B.S. 2HR503, cold drawn wire for thread inserts (British)

1.04 Composition
Table 1.04

1.05 Heat Treatment

1.051 Generally, the precipitation-hardening heat treatment of Nimonic 90, which produces optimum mechanical properties, consists of two steps: first, solution treatment (anneal) at a high temperature followed by air cooling or more rapid cooling, and second, aging at a lower temperature and air cooling.

Appreciable variations in solution temperature from 1750F to 2100F, in aging temperature from 1250F to 1400F, and in time at temperature - depending on temperature level and product form - have been used with acceptable results. In recent years, a three-step treatment, which includes an intermediate anneal at 1700F and relatively short times at high temperatures, has been developed for thin sections such as sheet and wire. The short-time three-step treatment minimizes intergranular oxidation, which can be a problem when longer solution times are applied to these product forms unless inert protective atmospheres are employed (2)(5)(7)(10)(12)(19).

1.052 In current practice the following solution and aging cycle is recommended for relatively heavy product forms, such as bar, forgings, and castings: 1975F 8 hours, AC + 1290F 16 hours, AC. This treatment can also be effective on thin sections, such as sheet and wire, but an inert protective atmosphere is recommended during the solution treatment of these types of products (7)(12).

1.053 The three-step treatment recommended for sheet is as follows: 2100F 3 min, WQ or fluidized bed quench to room temperature + 1700F 1 hr, AC + 1380F 4 hr, AC. The fluidized bed quench minimizes distortion. Modifications in the second step of this treatment, ranging from 1900F 20 min, AC to complete elimination, have little effect on strength properties but do result in slightly lower tensile and rupture ductility (7)(12).

1.054 Annealing for softening purposes is normally carried out at about 1900F followed by water quench or air cooling. Exposure time at 1900F varies from 20 min to 8 hr depending on section size (12).

1.06 Hardness
Table 1.06.

1.07 Forms and Conditions Available
Nimonic 90 is generally available in the forms of bar, rod, billet, extrusions, sheet, strip, tube and castings (12)(15).

1.08 Melting and Casting Practice
Electric-arc melting is rarely used. Induction melting is usual; electro-slag melting is also used.

1.09 Special Considerations
A marked reduction in ductility occurs in the temperature range 1200 to 1600F, which is characteristic of many nickel-base superalloys. For example, see Figures 3.0314, 3.03711 and 3.0231. Improved three-stage treatments given (10).

2. PHYSICAL AND ENVIRONMENTAL EFFECTS

2.01 Thermal Properties
2.011 Melting range. 2390 - 2498F (7)(12)
2.012 Phase changes. Alloy is age hardenable.
2.0121 Time-temperature-transformation diagrams.
2.013 Thermal conductivity.
2.0131 Effect of temperature on thermal conductivity. Figure 2.0131.
2.014 Thermal expansion. Figure 2.014.
2.015 Specific heat.
2.0151 Effect of temperature on specific heat, Figure 2.0151.
2.016 Thermal diffusivity.

2.02 Other Physical Properties
2.021 Density. 0.296 lb per cu in. 8.18 gr per cu cm (12).
2.022 Electrical properties.
2.0221 Electrical properties of bar and sheet. Table 2.0221.
2.023 Magnetic properties.
2.0231 Magnetic permeability, Figure 2.0231.
2.024 Emittance.
2.025 Damping capacity.

2.03 Chemical Environment
2.031 Weight loss as a result of oxidation after 100 hours at elevated temperatures. Figure 2.031.
2.032 Effects of cyclic heating to various temperatures - 15 min in furnace and 5 min outside - on oxidation in still air, Table 2.032.
2.033 Although Nimonic 90 does not corrode in sea water under turbulent and high-velocity flow conditions, it is subject to severe pitting and crevice corrosion in still or slowly flowing (less than 3 ft per sec) sea water. It is resistant to stress corrosion in sea water (17).
2.034 Weight loss as a result of exposures to atmospheres containing sulfur dioxide at elevated temperatures, Table 2.034.

2.04 Nuclear Environment

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.02 Mechanical Properties at Room Temperature
3.021 Tension - stress-strain diagrams - tension properties.
3.0211 Stress-strain curves at room temperature for sheet cold rolled various amounts between mill annealing and aging, Figure 3.0211.
3.0212 Tensile properties at room temperature for annealed and age-hardened sheet. Table 3.0212.
3.0213 Effect of cold rolling on tensile properties of sheet, Figure 3.0213.
3.0214 Tensile properties of castings, Table 3.0214.
3.022 Compression - stress-strain diagrams - compression properties.
3.0221 Compressive stress-strain curves at room temperature, Figure 3.0221.
3.0222 Compressive yield strength at room temperature, Table 3.0222.
3.023 Impact.
3.0231 Effect of exposures to elevated temperatures in impact

Ni	
20	Cr
18	Co
2.5	Ti
1.5	Al

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strength at room temperature, Figure 3.0231.

3.024 Bending.

3.0241 Annealed 0.070 inch sheet can withstand close 180 degree bends in both longitudinal and transverse orientations without visible cracking (19).

3.025 Torsion and shear (see Figures 3.0351 and 3.0352).

3.026 Bearing.

3.027 Stress concentration.

3.0271 Notch properties.

3.0272 Fracture toughness.

3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures

3.031 Tension - stress-strain diagrams - tension properties.

3.0311 Stress-strain curves for sheet at temperatures from 68F to 1110F, Figure 3.0311.

3.0312 Stress-strain curves determined at various temperatures at a rapid strain rate after rapid heating of sheet cold rolled 0, 10 and 20 percent between mill annealing and aging, Figure 3.0312.

3.0313 Stress-strain curves determined at various temperatures at a rapid strain rate after rapid heating of sheet cold rolled 30 and 50 percent between mill annealing and aging, Figure 3.0313.

3.0314 Effects of temperature on tensile properties of extruded bar, Figure 3.0314.

3.0315 Effects of temperature on tensile properties of hot-rolled bar, Figure 3.0315.

3.0316 Effects of temperature on tensile properties of sheet, Figure 3.0316.

3.0317 Effects of elevated temperatures on tensile properties of transverse and longitudinal sheet specimens, Figure 3.0317.

3.0318 Effects of temperature on tensile properties of annealed + cold + aged sheet tested at a rapid strain rate of 0.1 in per in per sec, Figure 3.0318.

3.0319 Effects of temperature on tensile properties of annealed sheet, Figure 3.0319.

3.032 Compression - stress-strain diagrams - compression properties.

3.033 Impact

3.0331 Elevated-temperature impact strength of bar after various exposure times at test temperature, Figure 3.0331.

3.034 Bending.

3.035 Torsion and shear.

3.0351 Effects of temperature on shear strength of bar, Figure 3.0351.

3.0352 Effects of temperature on maximum shear strength of bar in torsion, Figure 3.0352.

3.036 Bearing.

3.037 Stress concentration.

3.0371 Notch properties.

3.03711 Effects of temperature on crack strength of sheet in comparison with smooth tensile properties, Figure 3.03711.

3.0372 Fracture toughness.

3.038 Combined properties.

3.04 Creep and Creep Rupture Properties

3.041 Creep-rupture curves for bar at temperatures from 1290F to 1600F, Figure 3.041.

3.042 0.1, 0.2 and 0.3 percent creep curves for bar at temperatures from 1110F to 1600F, Figure 3.042.

3.043 Creep-rupture curves for sheet at temperatures from 1290F to 1650F, Figure 3.043.

3.044 0.1 and 0.2 percent creep curves for sheet at temperatures from 1290F to 1650, Figure 3.044.

3.045 Creep and rupture curves for transverse sheet specimens at 1350, 1500 and 1650F, Figure 3.045.

3.046 Creep and rupture curves for longitudinal sheet specimens at 1350, 1500 and 1650F, Figure 3.046.

3.047 Short-time creep and rupture curves for annealed + aged sheet heated to test temperature within 10 sec, Figure 3.047.

3.048 Short-time creep and rupture curves for annealed + 10 percent CR + aged sheet heated to test temperature within 10 sec, Figure 3.048.

3.049 Short-time creep and rupture curves for annealed + 20 percent CR + aged sheet heated to test temperature within 10 sec, Figure 3.049.

3.0410 Short-time creep and rupture curves for annealed + 30 percent CR + aged sheet heated to test temperature within 10 sec, Figure 3.0410.

3.0411 Short-time creep and rupture curves for annealed + 50 percent CR + aged sheet heated to test temperature within 10 sec, Figure 3.0411.

3.0412 Creep-rupture curves for sand castings, Figure 3.0412

3.05 Fatigue Properties

3.051 Stress-range fatigue diagram for bar at elevated temperatures, Figure 3.051.

3.052 Fatigue life of bar at elevated temperatures, Figure 3.052.

3.053 Effects of temperature on fatigue stress for a life of 1.2×10^7 cycles in sheet, Figure 3.053.

3.054 A comparison of the axial fatigue life (A = 0.83) of forged Nimonic 90 at 1560F in air and in an environment of fuel-rich gases, from the combustion of kerosene containing 0.5 percent sulfur, showed no significant effect of the fuel-rich atmosphere (21).

3.06 Elastic Properties

3.061 Poisson's ratio.

3.062 Modulus of elasticity.

3.0621 Static modulus of elasticity of sheet in tension and compression at room temperature, Table 3.0621.

3.0622 Effects of temperature on static modulus of elasticity of sheet, Figure 3.0622.

3.0623 Effects of temperature on static modulus of elasticity of bar, Figure 3.0623.

3.0624 Effects of temperature on dynamic modulus of elasticity Figure 3.0624.

3.0625 Effects of temperature on modulus of elasticity of annealed + cold rolled + aged sheet tested in tension at a rapid strain rate of 0.1 in per in per sec, Figure 3.0625.

3.063 Modulus of rigidity.

3.0631 Effects of temperature on modulus of rigidity, Figure 3.0631.

3.064 Tangent modulus.

3.065 Secant modulus.

4. FABRICATION

4.01 Forming

4.011 Nimonic 90 should be hot formed in the temperature range 2190 to 1920F. The mechanical properties can be adversely affected by slow cooling from temperatures above 2000F, so rapid cooling is recommended after hot forming (12)(13).

4.012 The alloy can be cold formed in the annealed condition. Interstage annealing, when needed, should be carried out at 1900F (see Section 1.054) (12).

4.013 Nimonic 90 has excellent explosive-forming characteristics at room temperature. The effect of explosive forming between solution treatment and aging is to reduce the precipitation-hardening response, but because of a large increase in hardness resulting from explosive deformation the peak hardnesses are greater than those of undeformed precipitation-hardened material (22).

4.02 Machining and Grinding

Nimonic 90 should be in the fully heat-treated condition for all machining operations. Its high hardness in this condition necessitates the use of rigid machining set-ups and slow machining speeds (12)(13).

4.03 Joining

4.031 Nimonic 90 can be fusion welded by conventional GMA and GTA processes in sections up to about 0.20 inch thick. Above this thickness microfissuring may occur in both the weld and the heat affected zone. Nimonic 90 filler wire is recommended (12).

4.032 Electron beam, friction, resistance, inertia and flash butt welding have all been successfully applied to thicknesses greater than 0.20 in (12).

4.033 Welding should be carried out on annealed material. In general, the full solution and aging heat treatment should be applied after welding (see Section 1.052). For thin sections, such as sheet and wire, welding should be carried out between the first-step 2100F solution treatment and the second-step 1700F treatment (see Section 1.053) (12).

4.034 Sound brazed joints between Nimonic 90 parts can be made in vacuum or hydrogen atmosphere. A liquid flux, such as boric oxide or borax, is required with hydrogen atmosphere. Nickel-base or cobalt-base brazing alloys are recommended (16).

4.0341 Creep-rupture strength in shear at 1470F for Nimonic 90 alloy joints brazed with various filler metals in vacuum or in hydrogen with liquid flux, Figure 4.0341.

4.04 Surface Treatment

Removal of hot-work and heat-treat scales is best done by immersion in one of the commercially available caustic-base salt baths followed by pickling in hot sulfuric and hot nitric-hydrofluoric acid.

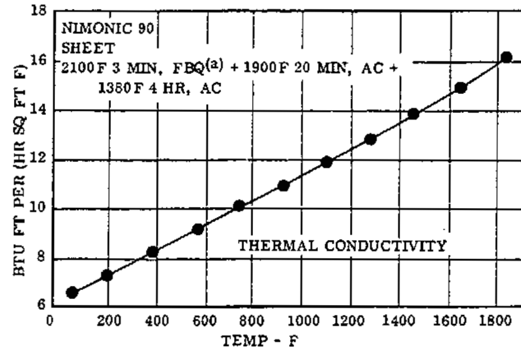

FIG. 2.0131 EFFECT OF TEMPERATURE ON THERMAL CONDUCTIVITY. (12)

(a) FLUIDIZED BED QUENCH TO ROOM TEMPERATURE.

Ni	
20	Cr
18	Co
2.5	Ti
1.5	Al

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Source	(1)	
	Percent	
	Min.	Max.
Carbon	-	0.13
Manganese	-	1.00
Silicon	-	1.00
Sulfur	-	0.015
Chromium	18.00	21.00
Cobalt	15.00	21.00
Titanium	2.00	3.00
Aluminum	1.00	2.00
Iron	-	1.50(a)
Copper	-	0.20
Zirconium	-	0.15
Boron	-	0.02
Lead	-	0.002
Silver	-	0.0005
Bismuth	-	0.0001
Nickel	Balance	

(a) The casting version of the alloy - NIMOCAST alloy 90 - is similar in composition except that a maximum of 5.0 percent iron is allowed (15).

TABLE 1.04 COMPOSITION

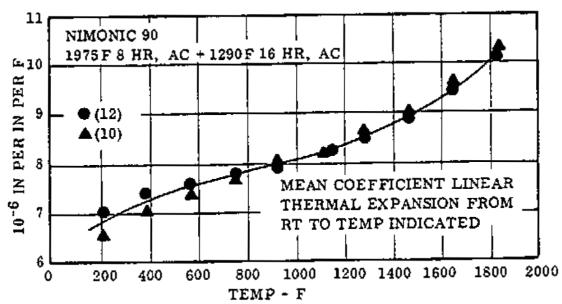

FIG. 2.014 THERMAL EXPANSION. (10)(12)

Alloy		Nimonic 90	
Source	Form	Condition	Hardness
(7)	Bar	1975F 8 hr, AC + 1290F 16 hr, AC Annealed	340-400 VHN 230-300 VHN
(7)	Sheet	2100F 3 min, AC + 1700F 1 hr, WQ + 1380F, 4 hr, AC Annealed	320-380 VHN 220-260 VHN
(20)	Sheet	2000F 15 min, WQ + CR 19 percent + 1350F 16 hr. AC	44 RC
(15)	Sand Cast	1975F 4 hr, AC + 1290F 16 hr, AC As cast	291 VHN 280 VHN
(15)	Investment Cast	1975F 4 hr, AC + 1290F 16 hr, AC As cast	291 VHN 278 VHN

TABLE 1.06 HARDNESS

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

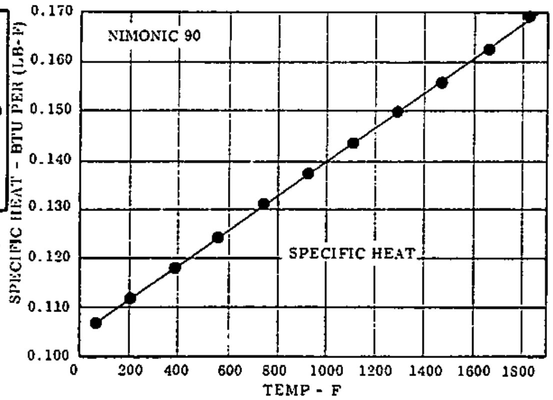

FIG. 2.0151 EFFECT OF TEMPERATURE ON SPECIFIC HEAT. (12)

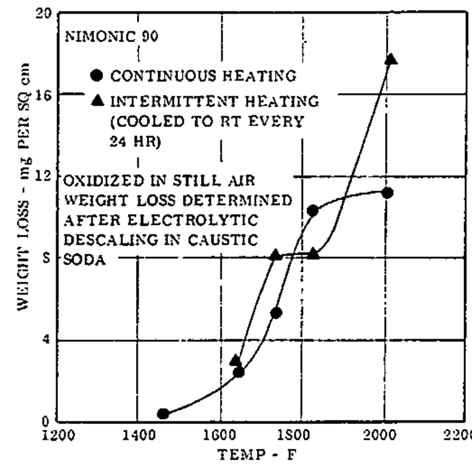

FIG. 2.031 WEIGHT LOSS AS A RESULT OF OXIDATION AFTER 100 HOURS AT ELEVATED TEMPERATURES. (12)

Alloy	Nimonic 90					
Form	1 in dia HR Bar			CR Sheet		
Condition	1975F 8 hr, AC + 1290F 16 hr, AC			2100F 3 min, FBQ(a) + 1900F 20 min, AC + 1380F 4 hr, AC		
Source	(11)			(12)		
	Electrical Conductivity		Electrical	Electrical Conductivity		Electrical
Temp. F	percent IACS	megmhos per in^3	Resistivity microhm-in.	percent IACS	megmhos per in^3	Resistivity microhm-in.
68	1.46	0.0215	46.5	1.46	0.0215	46.5
212	1.43	0.0211	47.3	1.42	0.0210	47.6
392	1.40	0.0206	48.5	1.41	0.0207	48.4
572	1.39	0.0204	48.9	1.37	0.0202	49.5
752	1.37	0.0202	49.6	1.35	0.0198	50.4
932	1.35	0.0198	50.4	1.32	0.0194	51.6
1112	1.35	0.0198	50.4	1.32	0.0194	51.6
1292	1.37	0.0202	49.6	1.32	0.0194	51.6
1472	1.39	0.0204	48.9	1.32	0.0194	51.6
1652	-	-	-	1.33	0.0196	51.0
1832	-	-	-	1.35	0.0198	50.4
(a) Fluidized bed quench.						

TABLE 2.0221 ELECTRICAL PROPERTIES OF BAR AND SHEET

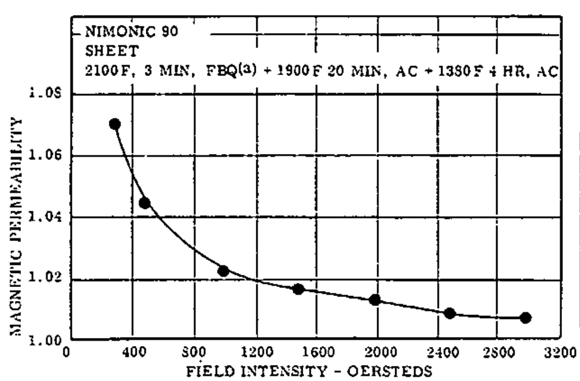

FIG. 2.0231 MAGNETIC PERMEABILITY. (12)
(a) FLUIDIZED BED QUENCH TO ROOM TEMPERATURE.

Alloy	Nimonic 90	
Source	(12)	
Temp. F	Time to start of spalling, hr.	Weight change in 1000 hr. mg/cm^2
1635	> 1000	+ 2.95
1670	> 1000	+ 5.52
1815	250	-214
1550	200	-332
1995	100	-850
2030	75	-1107

TABLE 2.032 EFFECTS OF CYCLIC HEATING TO VARIOUS TEMPERATURES - 15 MIN. IN FURNACE AND 5 MIN. OUTSIDE FURNACE - ON OXIDATION IN STILL AIR.

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

Alloy	Nimonic 90			
Source	(12)			
Atmosphere	Descaled weight loss after 1000 hr at following temperatures, mg/cm^2			
	1110F	1290F	1470F	1650F
3 percent SO_2 - argon	3.7	18.0	40.0	-
3 percent SO_2 - air	4.5	8.1	1.4	2.0
3 percent SO_2 - 5 percent O_2-argon	1.9	4.2	1.3	3.7

TABLE 2.034 WEIGHT LOSS AS A RESULT OF EXPOSURES TO ATMOSPHERES CONTAINING SULFUR DIOXIDE AT ELEVATED TEMPERATURES.

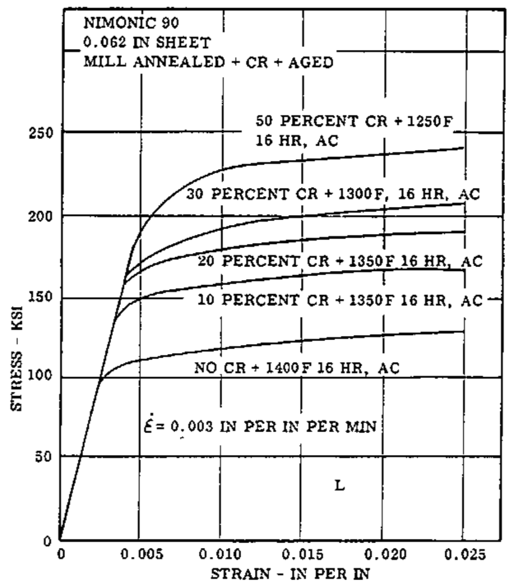

FIG. 3.0211 STRESS-STRAIN CURVES AT ROOM TEMPERATURE FOR SHEET COLD ROLLED VARIOUS AMOUNTS BETWEEN MILL ANNEALING AND AGING. (5)(6)

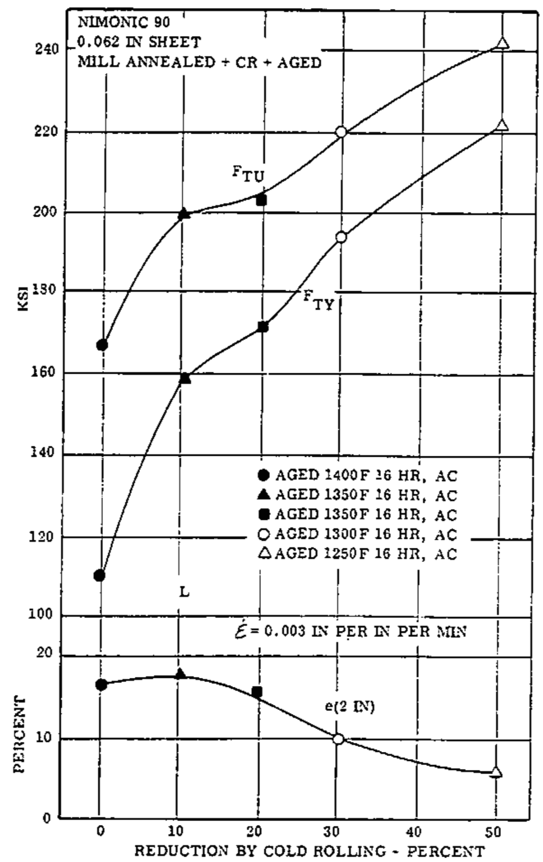

FIG. 3.0213 EFFECT OF COLD ROLLING ON TENSILE PROPERTIES OF SHEET. (5)(6)

Alloy	Nimonic 90			
Form	0.070 in. sheet			
Source	(19)			
Condition	Specimen Orientation	Fty (ksi)	F_{tu} (ksi)	e (2 in) (percent)
Annealed 2100F, 3 min, WQ	L	65.6	127	50.0
	T	64.3	126	48.0
1750F 15 min, AC + 1350F 4.5 hr, AC	L	127	194	25.0

TABLE 3.0212 TENSILE PROPERTIES AT ROOM TEMPERATURE FOR ANNEALED AND AGE-HARDENED SHEET

Ni
20 Cr
18 Co
2.5 Ti
1.5 Al

NIMONIC 90

Alloy	Nimonic 90 (NIMOCAST alloy 90)					
Form	Castings					
Source	(15)					
Condition	As Cast			1975F 8 hr, AC + 1290F 16 hr, AC		
Casting Process	F_{ty} (ksi)	F_{tu} (ksi)	e $(4\sqrt{A})$(a) (percent)	F_{ty} (ksi)	F_{tu} (ksi)	e $(4\sqrt{A})$(a) (percent)
Sand cast	72.8	92.5	8.1	79.6	106.0	12.6
Investment	74.4	91.8	14.6	75.3	101.4	14.1

(a) Gage length equals 4 x the square root of the cross-sectional area of the gage section.

TABLE 3.0214 TENSILE PROPERTIES OF CASTINGS

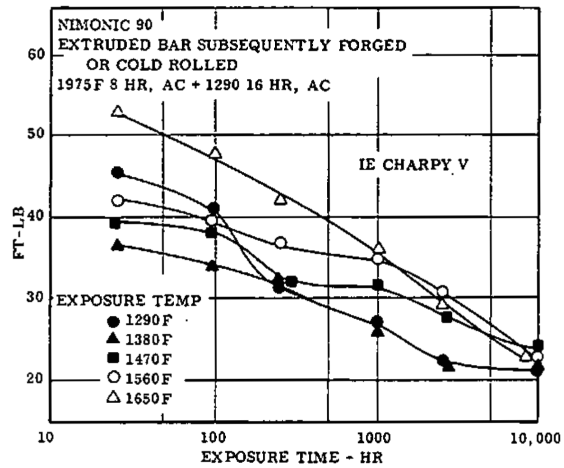

FIG. 3.0231 EFFECTS OF EXPOSURES TO ELEVATED TEMPERATURES ON IMPACT STRENGTH AT ROOM TEMPERATURE. (12)

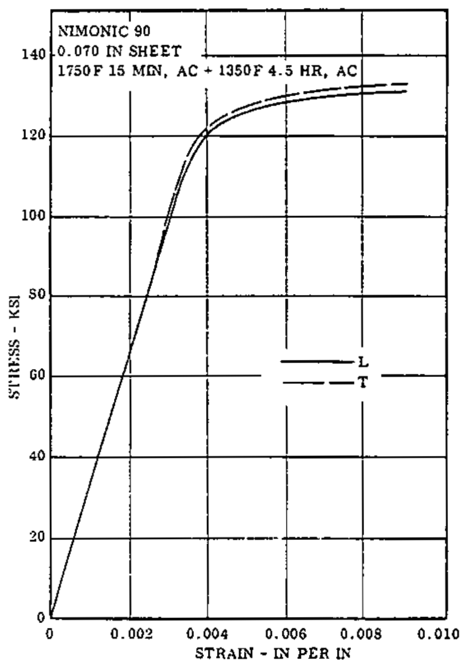

FIG. 3.0221 COMPRESSIVE STRESS-STRAIN CURVES AT ROOM TEMPERATURE. (19)

Alloy	Nimonic 90
Form	0.070 in. sheet
Condition	1750F 15 min, AC + 1350F 4.5 hr, AC
Source	(19)
Specimen Orientation	F_{cy} (ksi)
L	130
T	131

TABLE 3.0222 COMPRESSIVE YIELD STRENGTH AT ROOM TEMPERATURE.

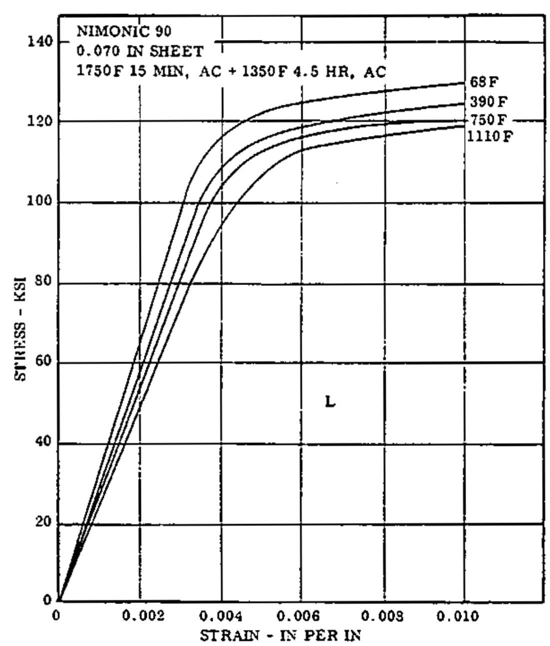

FIG. 3.0311 STRESS-STRAIN CURVES FOR SHEET AT TEMPERATURES FROM 68F TO 1110F. (19)

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

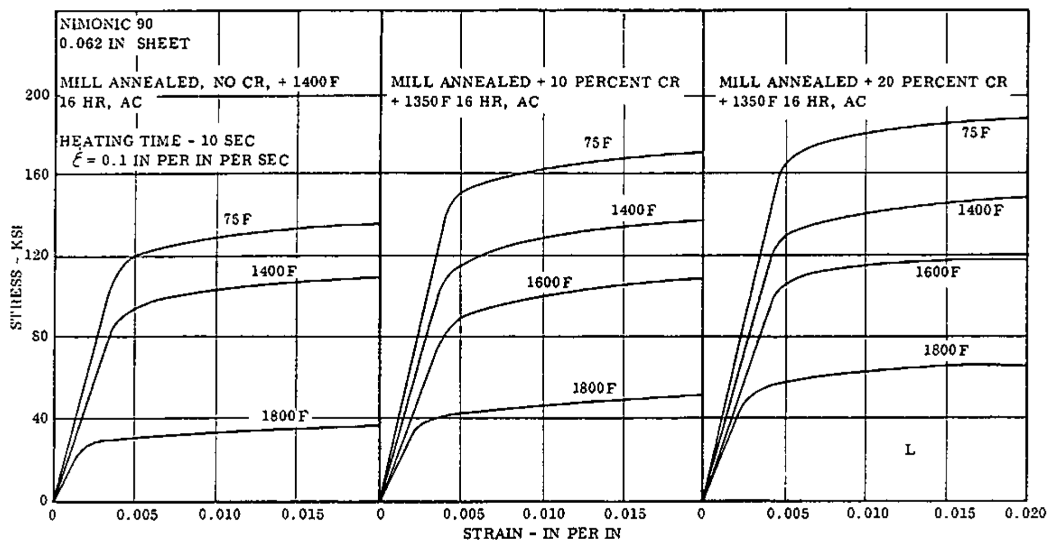

FIG. 3.0312 STRESS-STRAIN CURVES DETERMINED AT VARIOUS TEMPERATURES AT A RAPID STRAIN RATE AFTER RAPID HEATING OF SHEET COLD ROLLED 0, 10, AND 20 PERCENT BETWEEN MILL ANNEALING AND AGING. (5)(6)

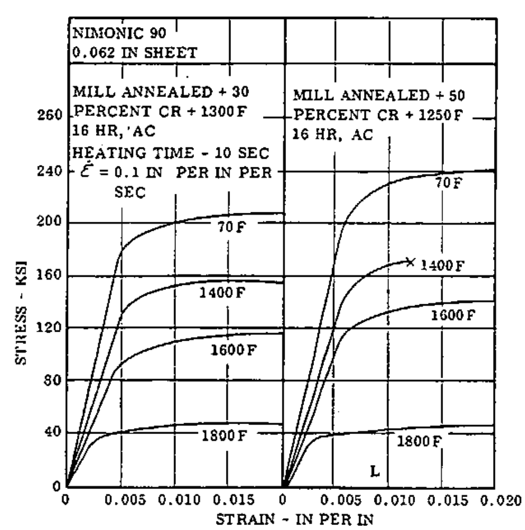

FIG. 3.0313 STRESS-STRAIN CURVES DETERMINED AT VARIOUS TEMPERATURES AT A RAPID STRAIN RATE AFTER RAPID HEATING OF SHEET COLD ROLLED 30 AND 50 PERCENT BETWEEN MILL ANNEALING AND AGING. (6)

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

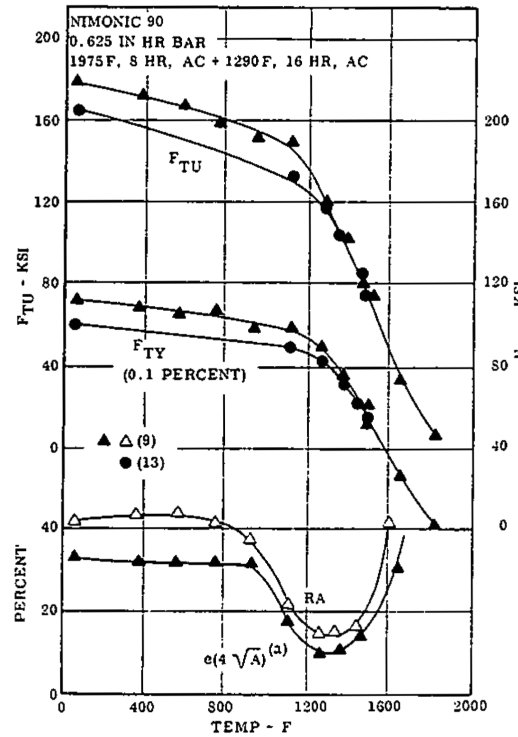

FIG. 3.0315 EFFECTS OF TEMPERATURE ON TENSILE PROPERTIES OF HOT-ROLLED BAR. (9)(13)

(a) GAGE LENGTH IS 4 x THE SQUARE ROOT OF THE CROSS-SECTIONAL AREA OF THE GAGE SECTION.

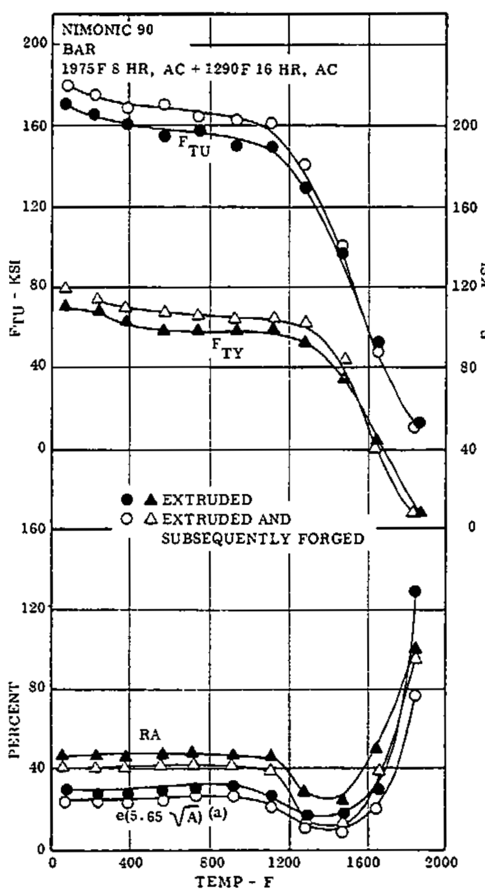

FIG. 3.0314 EFFECTS OF TEMPERATURE ON TENSILE PROPERTIES OF EXTRUDED BAR. (12)

(a) GAGE LENGTH IS 5.65 x THE SQUARE ROOT OF THE CROSS-SECTIONAL AREA OF THE GAGE SECTION.

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

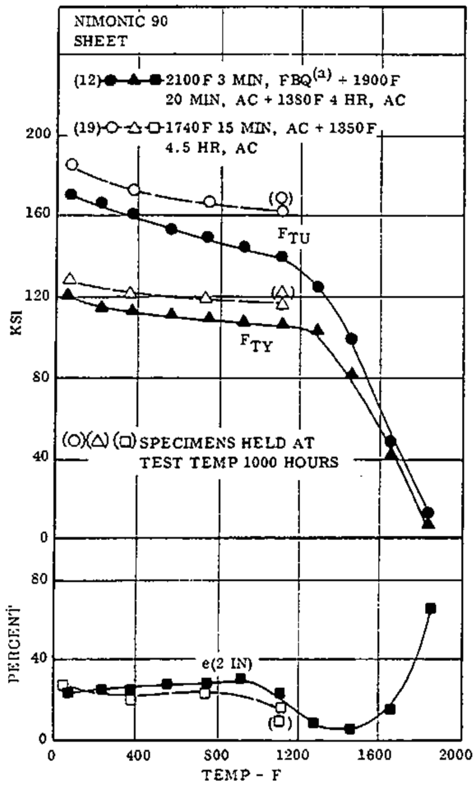

FIG. 3.0316 EFFECTS OF TEMPERATURE ON TENSILE PROPERTIES OF SHEET. (12)(19)
(a) FLUIDIZED BED QUENCH TO ROOM TEMPERATURE.

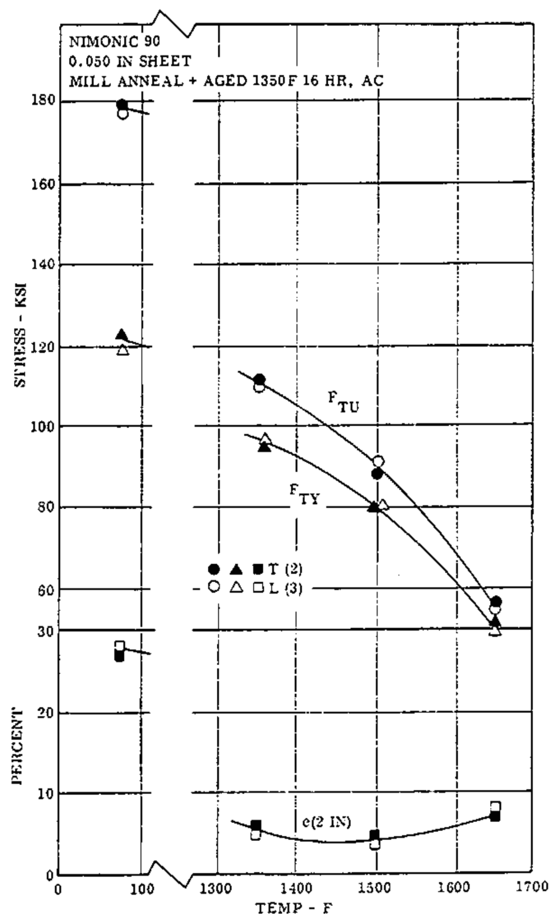

FIG. 3.0317 EFFECTS OF ELEVATED TEMPERATURES ON TENSILE PROPERTIES OF TRANSVERSE AND LONGITUDINAL SHEET SPECIMENS. (2)(3)

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

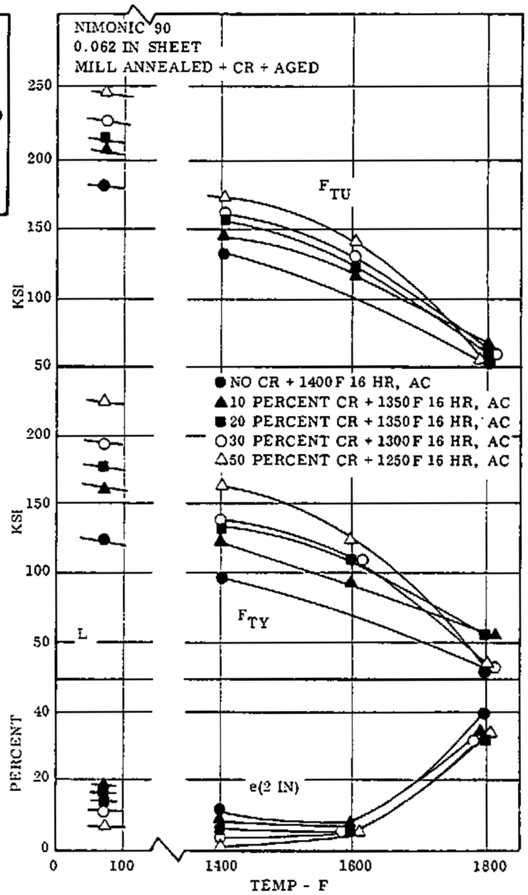

FIG. 3.0318 EFFECTS OF TEMPERATURE ON TENSILE PROPERTIES OF ANNEALED + COLD ROLLED + AGED SHEET TESTED AT A RAPID STRAIN RATE OF 0.1 IN PER IN PER SEC. (5)(6)

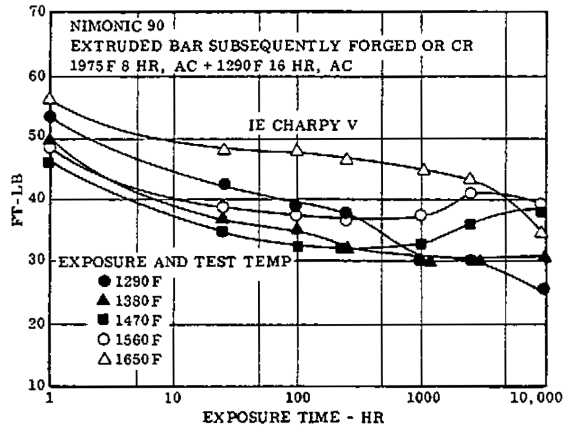

FIG. 3.0331 ELEVATED-TEMPERATURE IMPACT STRENGTH OF BAR AFTER VARIOUS EXPOSURE TIMES AT TEST TEMPERATURE. (12)

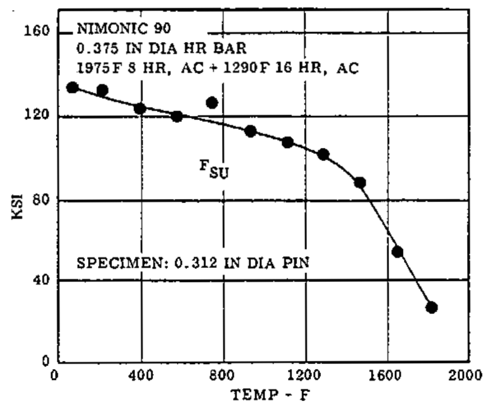

FIG. 3.0351 EFFECTS OF TEMPERATURE ON SHEAR STRENGTH OF BAR. (9)

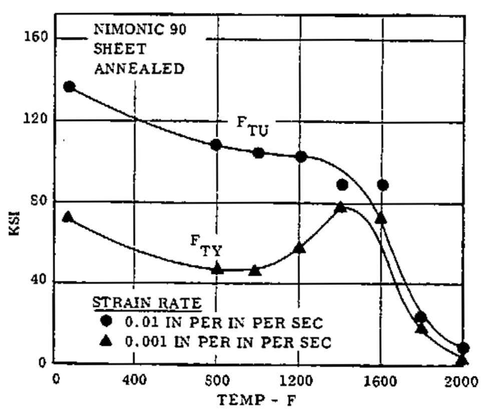

FIG. 3.0319 EFFECTS OF TEMPERATURE ON TENSILE PROPERTIES OF ANNEALED SHEET. (12)

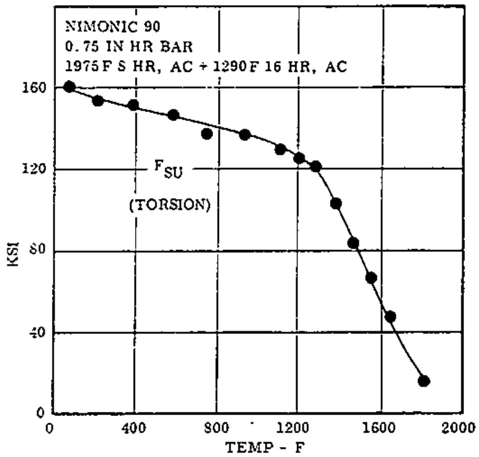

FIG. 3.0352 EFFECTS OF TEMPERATURE ON MAXIMUM SHEAR STRENGTH OF BAR IN TORSION. (9)

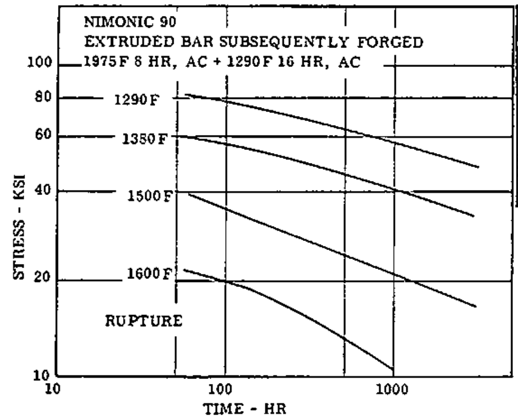

FIG. 3.041 CREEP-RUPTURE CURVES FOR BAR AT TEMPERATURES FROM 1290 TO 1600F. (12)

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

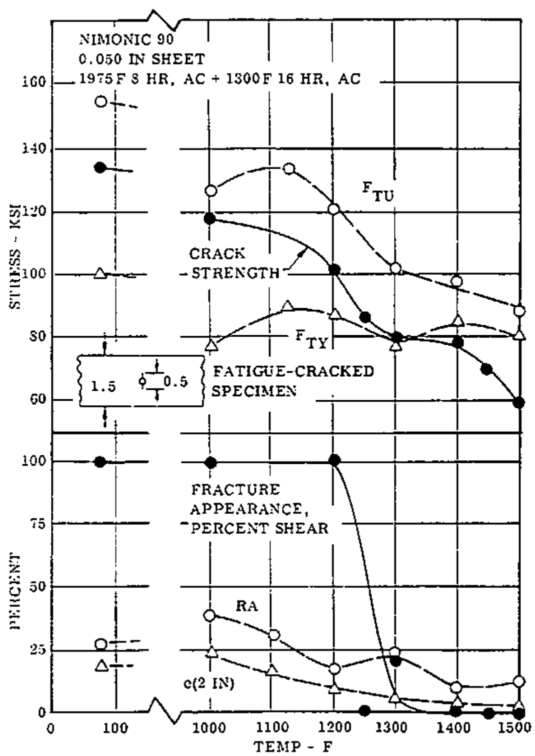

FIG. 3.03711 EFFECTS OF TEMPERATURE ON CRACK STRENGTH OF SHEET IN COMPARISON WITH SMOOTH TENSILE PROPERTIES. (4)

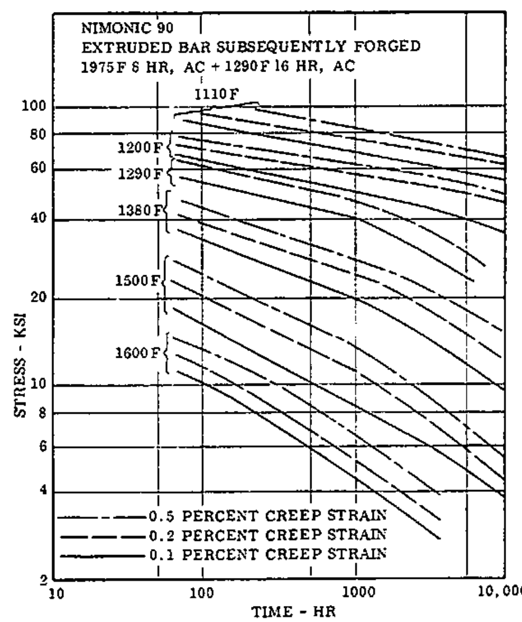

FIG. 3.042 0.1, 0.2 AND 0.5 PERCENT CREEP CURVES FOR BAR AT TEMPERATURES FROM 1110 TO 1600F. (12)

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

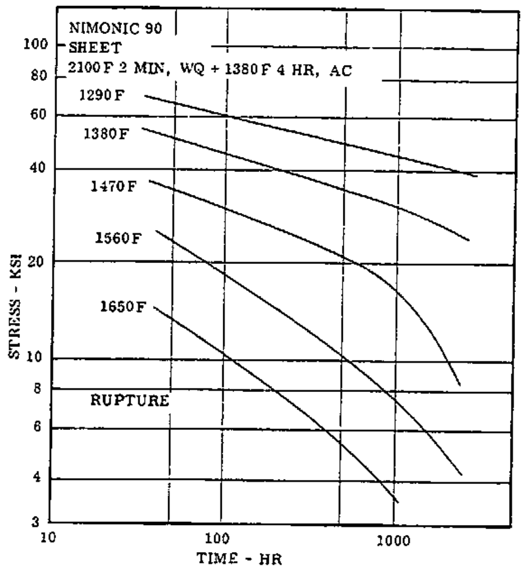

FIG. 3.043 CREEP-RUPTURE CURVES FOR SHEET AT TEMPERATURES FROM 1290F TO 1650F. (12)

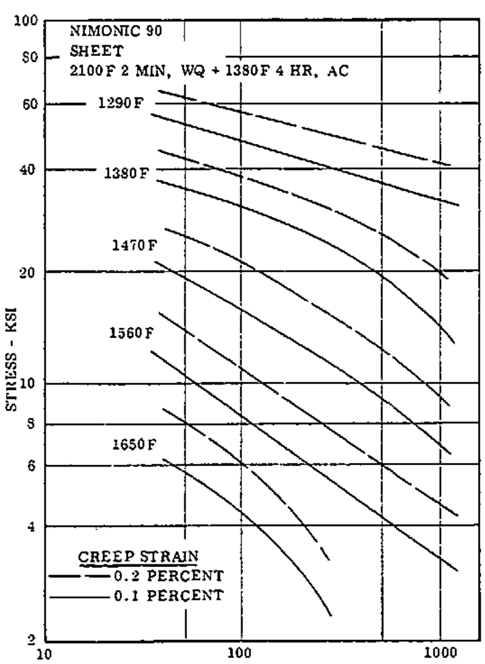

FIG. 3.044 0.1 AND 0.2 PERCENT CREEP CURVES FOR SHEET AT TEMPERATURES FROM 1290F TO 1650F. (12)

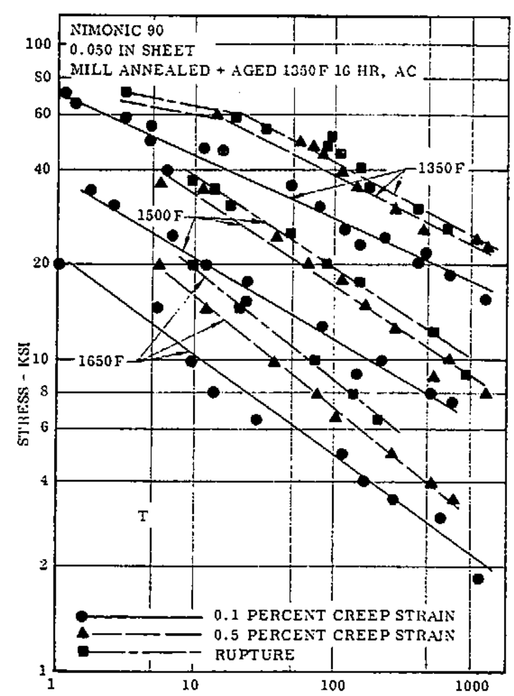

FIG. 3.045 CREEP AND RUPTURE CURVES FOR TRANSVERSE SHEET SPECIMENS AT 1350, 1500 AND 1650F. (2)

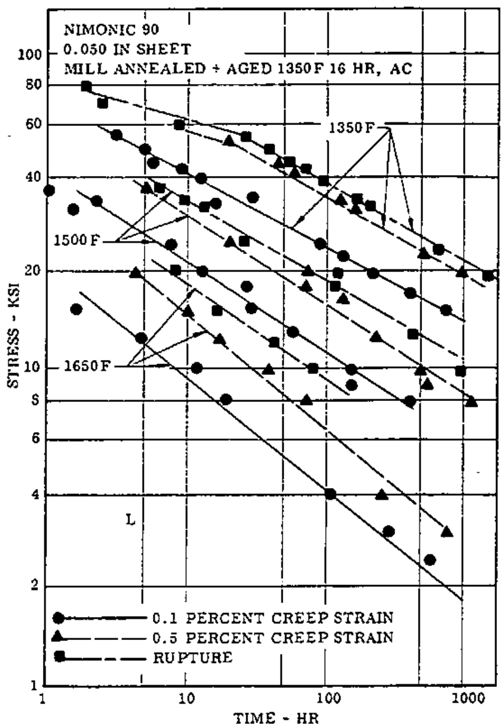

FIG. 3.046 CREEP AND RUPTURE CURVES FOR LONGITUDINAL SHEET SPECIMENS AT 1350, 1500 AND 1650F. (3)

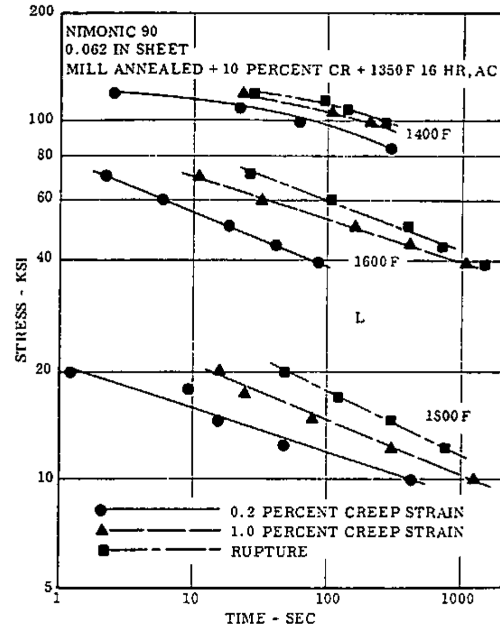

FIG. 3.048 SHORT-TIME CREEP AND RUPTURE CURVES FOR ANNEALED + 10 PERCENT COLD ROLLED + AGED SHEET HEATED TO TEST TEMPERATURE WITHIN 10 SECONDS. (6)

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

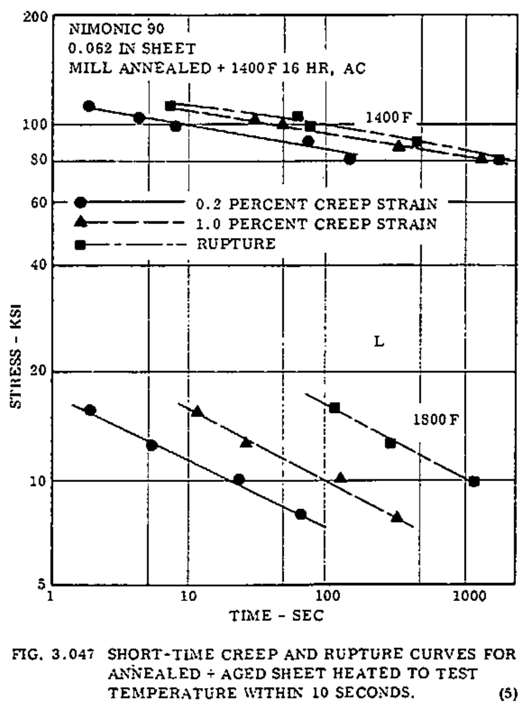

FIG. 3.047 SHORT-TIME CREEP AND RUPTURE CURVES FOR ANNEALED + AGED SHEET HEATED TO TEST TEMPERATURE WITHIN 10 SECONDS. (5)

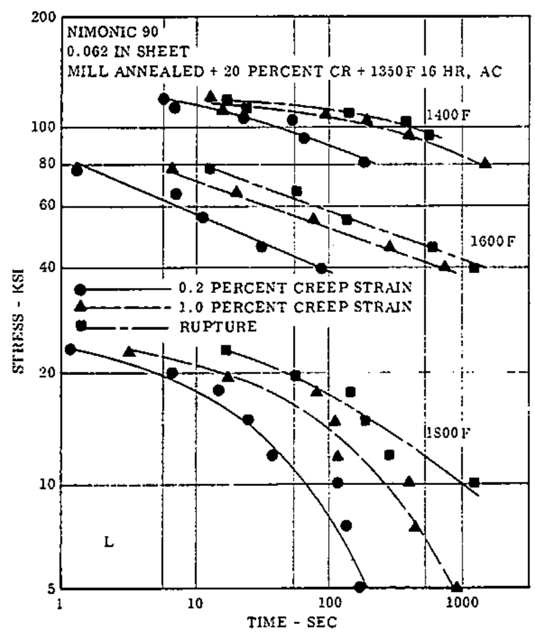

FIG. 3.049 SHORT-TIME CREEP AND RUPTURE CURVES FOR ANNEALED + 20 PERCENT COLD ROLLED + AGED SHEET HEATED TO TEST TEMPERATURE WITHIN 10 SECONDS. (5)

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

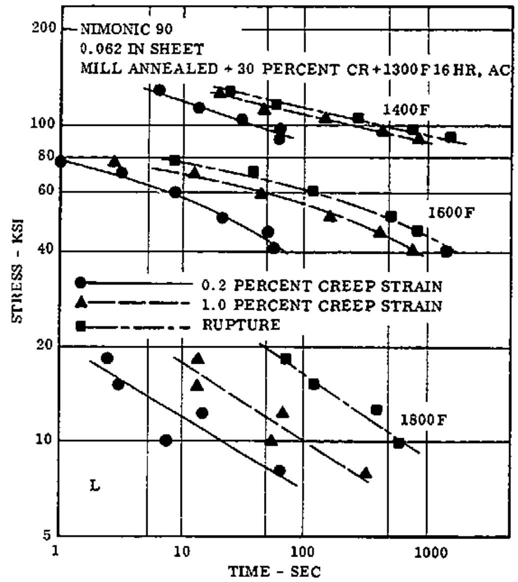

FIG. 3.0410 SHORT-TIME CREEP AND RUPTURE CURVES FOR ANNEALED + 30 PERCENT COLD ROLLED + AGED SHEET HEATED TO TEST TEMPERATURE WITHIN 10 SECONDS. (6)

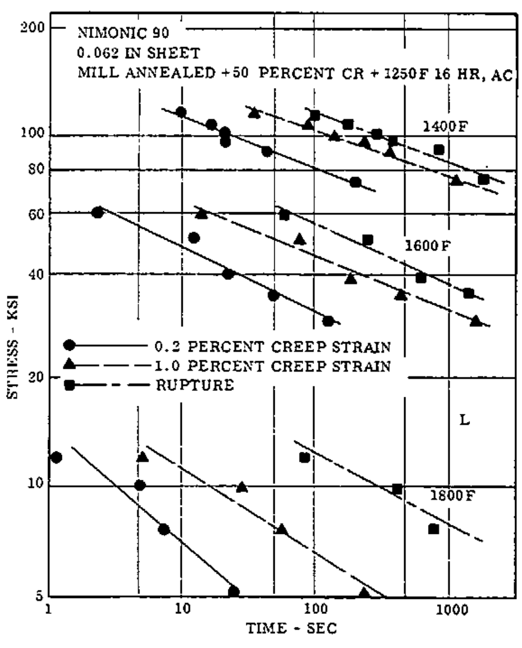

FIG. 3.0411 SHORT-TIME CREEP AND RUPTURE CURVES FOR ANNEALED + 50 PERCENT COLD ROLLED + AGED SHEET HEATED TO TEST TEMPERATURES WITHIN 10 SECONDS. (6)

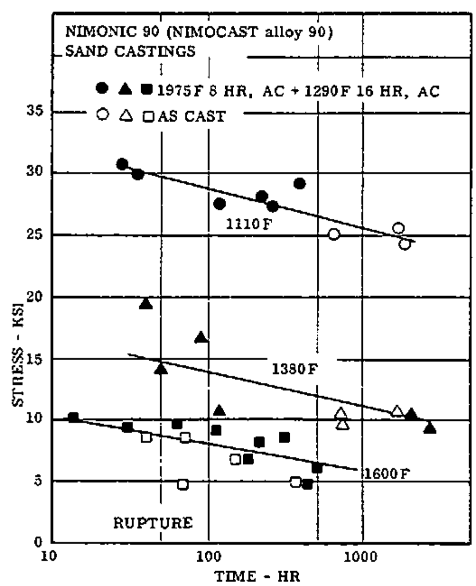

FIG. 3.0412 CREEP-RUPTURE CURVES FOR SAND CASTINGS. (15)

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

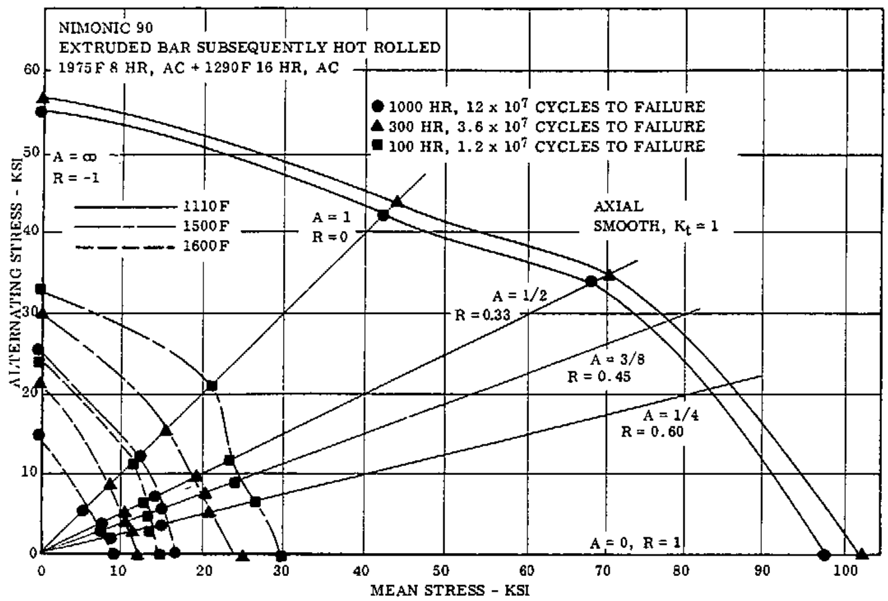

FIG. 3.051 STRESS-RANGE FATIGUE DIAGRAM FOR BAR AT ELEVATED TEMPERATURES. (12)

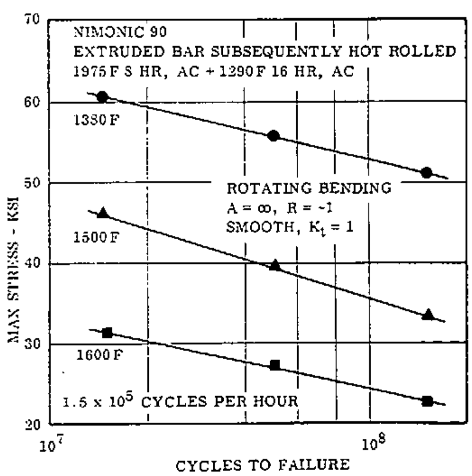

FIG. 3.052 FATIGUE LIFE OF BAR AT ELEVATED TEMPERATURES. (12)

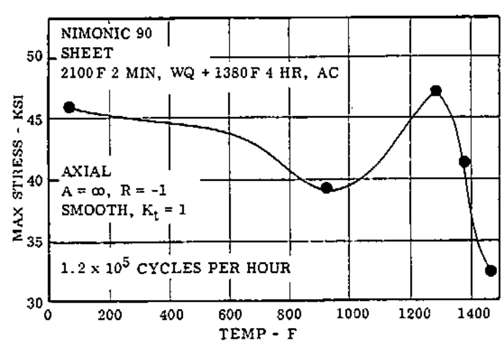

FIG. 3.053 EFFECTS OF TEMPERATURE ON FATIGUE STRESS FOR A LIFE OF 1.2×10^7 CYCLES IN SHEET. (12)

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

Alloy	Nimonic 90		
Form	0.070 in. sheet		
Source	(19)		
Condition	Specimen Orientation	E (10^3 ksi)	E_c (10^3 ksi)
Annealed 2100F 3 min, WQ	L	30.6	-
	T	30.5	-
1750F 15 min, AC + 1350F 4.5 hr, AC	L	31.6	32.7
	T	-	33.0

TABLE 3.0621 STATIC MODULUS OF ELASTICITY OF SHEET IN TENSION AND COMPRESSION AT ROOM TEMPERATURE.

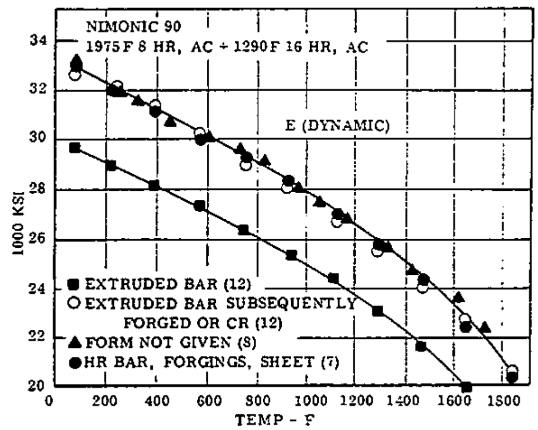

FIG. 3.0624 EFFECTS OF TEMPERATURE ON DYNAMIC MODULUS OF ELASTICITY. (7)(8)(12)

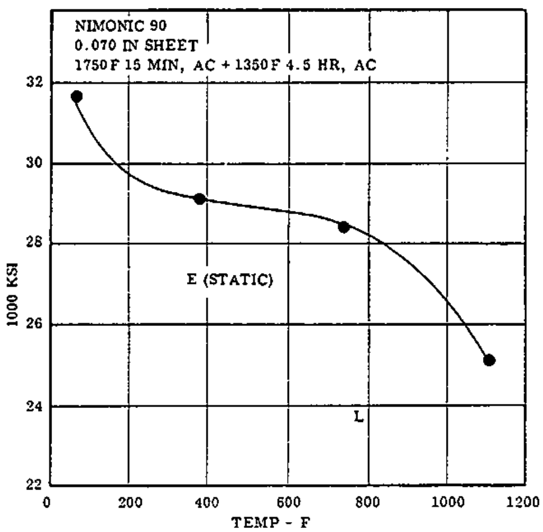

FIG. 3.0622 EFFECTS OF TEMPERATURE ON STATIC MODULUS OF ELASTICITY OF SHEET. (19)

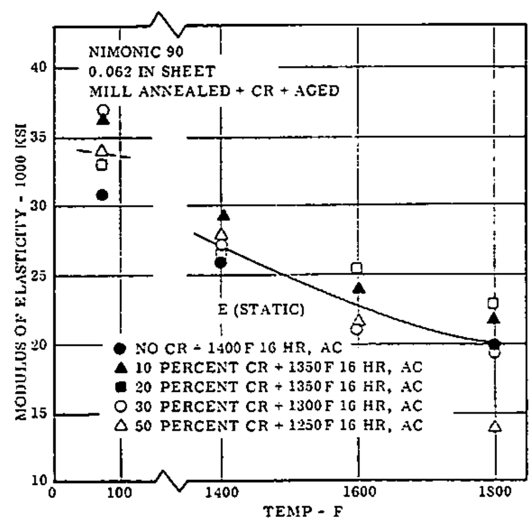

FIG. 3.0625 EFFECTS OF TEMPERATURE ON MODULUS OF ELASTICITY OF ANNEALED + COLD ROLLED + AGED SHEET TESTED IN TENSION AT A RAPID STRAIN RATE OF 0.1 IN PER IN PER SECOND. (5)(6)

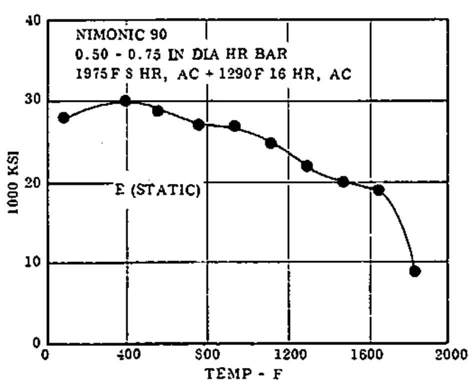

FIG. 3.0623 EFFECTS OF TEMPERATURE ON STATIC MODULUS OF BAR. (9)

	Ni
20	Cr
18	Co
2.5	Ti
1.5	Al

NIMONIC 90

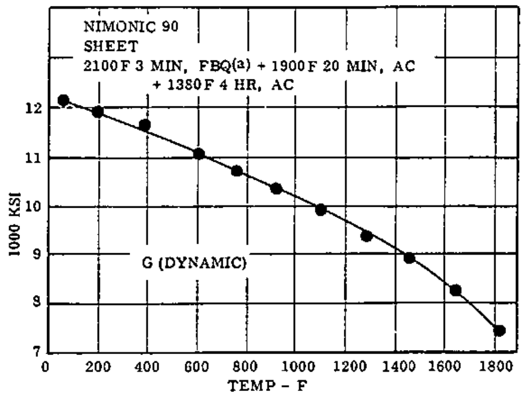

FIG. 3.0631 EFFECTS OF TEMPERATURE ON MODULUS OF RIGIDITY. (12)
(a) FLUIDIZED BED QUENCH TO ROOM TEMPERATURE.

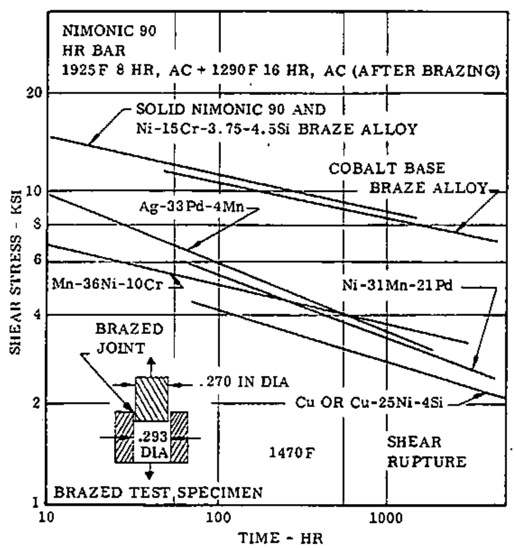

FIG. 4.0341 CREEP-RUPTURE STRENGTH IN SHEAR AT 1470F FOR NIMONIC 90 ALLOY JOINTS BRAZED WITH VARIOUS FILLER METALS IN VACUUM OR IN HYDROGEN WITH LIQUID FLUX. (16)

REFERENCES

1. AMS 5829 (December 1, 1973).
2. "Low Stress Creep Testing of Nimonic 90", Metcut Research Associates, for Air Material Command, Contract No. AF33(600)-36430 (July 24, 1959).
3. "Low Stress Creep Testing of Nimonic 90 (Longitudinal)", Metcut Research Associates, for Air Material Command, Contract No. AF33(600)-36430 (August 19, 1959).
4. Morrison, J.D., Jenkins, P.C. and Kattus, J.R., "An Investigation of the Crack-Propagation Resistance of High-Strength Alloys and Heat-Resistant Alloys", Southern Research Institute, for Bureau of Naval Weapons, Contract NOw 61-0392-d (November 21, 1962)
5. Kattus, J.R., "Tensile and Creep Properties of Structural Alloys Under Conditions of Rapid Heating, Rapid Loading, and Short Times at Temperature", Southern Research Institute, for The International Nickel Co., Inc. (April 10, 1959).
6. Kattus, J.R., "Tensile and Creep Properties of Structural Alloys Under Conditions of Rapid Heating, Rapid Loading and Short Times at Temperature", Supplementary Report by Southern Research Institute, for The International Nickel Co., Inc. (June 5, 1959).
7. "Nimonic Alloys Physical and Mechanical Properties", Publication 3270, Henry Wiggin and Co., Ltd. (August 1966). (See Additional Bibliography)
8. Hill, W.H. and Shimmin, K.D., "Dynamic Young's Modulus of Three Nickel Alloys", Wright Air Development Center, WADD Data Sheet No. 102 (March 1963).
9. "The Nimonic Series of High-Temperature Alloys", Publication 1303A, Henry Wiggin and Co., Ltd. (August 1961).
10. Betteridge, W., "The Nimonic Alloys", Edward Arnold Ltd., London (1959). (See Additional Bibliography)
11. Powell, R.W., "Thermal and Electrical Conductivities of Nickel-Chromium (Nimonic) Alloys", The Engineer (April 29, 1960).
12. "Nimonic Alloy 90", Publication 3575, Henry Wiggin and Co., Ltd. (1971). (See Additional Bibliography)
13. "Nimonic 90 - Heat and Corrosion Resistant Nickel-Base Alloy", Alloy Digest, Filing Code: Ni-6 (December 1961).
14. Yerkovich, L.A. and Guarnieri, G.J., "Compressive Creep Properties of High-Temperature Materials", WADC TR-54-582, Cornell Aero Lab (November 1954).
15. Wood, D.R. and Gregg, J.F., "Some Properties of Nickel-Base Casting Alloys for High-Temperature Service", Metal Treatment and Drop Forging (August 1957).
16. Cibula, M.A. and Malpas, R.C.J., "The Soundness and Strength of High-Temperature Vacuum-Brazed Joints", The British Non-Ferrous Metals Research Association, Research Report A1249 (September 1959).
17. Plummer, F.A., "Sea-Water Corrosion Characteristics of Nickel-Base Alloys", Naval Ship Research and Development Laboratory, Report 2859 (May 1969). (Each transmittal of this document outside the Dept. of Defense must have prior approval of NAVSHIPRANDLAB Annapolis, MD 21402).
18. Cibula, M.A., "High-Temperature Stress-to-Rupture Properties of Brazed Joints in Heat-Resistant Alloys", The British Non-Ferrous Metals Research Association, Research Report A1250 (September 1959).
19. Hayward, D.C., "The Mechanical Properties of Nimonic 80, 90 and 100 Sheet at Room and Elevated Temperatures", Royal Aircraft Establishment, Technical Note No. Met. 266 (June 1957).
20. Mooradian, V.G., Gosch, D.R. and McIsaac, D.F., "Development of Improved Metallic Materials for Electronic Components Operating at High Temperatures", Engelhard Industries Inc., for Bureau of Ships, Contract No. NObs 77085 (September 30, 1960).
21. Vidal, G.P. and Galmard, P.L., "Test Results of Fatigue at Elevated Temperatures on Aeronautical Materials", Fatigue at Elevated Temperatures, ASTM STP 520, American Society for Testing and Materials, p 512-521 (1973).
22. Williams, T. and Finnie, T.M., "The Explosive Forming Behavior of Some Nimonic and Similar Alloys" Royal Armament Research and Development Establishment, Memorandum 5/68 (February 1968).

ADDITIONAL BIBLIOGRAPHY

1. "Nimonic Alloys", Publication 3609, Henry Wiggin & Company Limited,(1973) (Supersedes Publications 3270 and 1303A).
2. W. Betteridge, J. Heslop, "The Nimonic Alloys", Edward Arnold Ltd., London,(1974).
3. "Nimonic Alloy 90", Publication 3525, Henry Wiggin & Company Limited (1972).