

REVISED: DECEMBER 1970

NONFERROUS ALLOYS

1. **GENERAL**
 TD Nickel is a high temperature alloy consisting of thoria dispersed in a nickel matrix (2 volume percent or 2.2 weight percent thoria). Compared to other nickel base alloys, it has a higher melting point and higher strength at temperatures above about 1900 F, especially on applications involving long-time service where the inherent metallurgical stability of the thoria dispersoid contributes to the creep rupture strength. At room temperature and moderately high temperatures it is, however, not as strong as nickel and cobalt base alloys. It is also very ductile at room temperature, contributing to good fabricability. It is readily machinable.

Because the properties of the alloy depend critically on the fine thoria dispersoid, any fusion process, such as is involved in welding and joining, must be avoided. Solid-state welding has recently been developed which produces very high joint efficiencies in tensile loading. Efficiencies are low, however, in creep loading. Although the alloy retains its strength well above 2000 F, it must be protected from oxidizing environments. Recent developments have provided promising coatings and claddings.

1.01 **Commercial Designation**
 TD Nickel

1.02 **Alternate Designations**
 None (although other thoria-dispersed nickel base alloys, produced by different processes, and containing other percentages of thoria are available).

1.03 **Specifications**
 No final AMS documents have been issued. Tentative documents, designated AMD, show intended specifications when fully approved, Table 1.03.

TABLE 1.03

Alloy	TD Nickel
Sheet and Strip	Bars, Extrusions, Forgings
AMD55DG	AMD56DH

1.04 **Composition**
 Table 1.04.

TABLE 1.04

Source	(49)(50)	
	Minimum	Maximum
Thoria (ThO ₂)	1.80	2.60
Cobalt	-	0.20
Copper	-	0.15
Iron	-	0.050
Chromium	-	0.050
Titanium	-	0.050
Carbon	-	0.02
Sulfur	-	0.01
Hydrogen	To be Reported	
Nitrogen	To be Reported	
Nickel	Balance	

1.05 **Heat Treatment**
 1.051 Bar and sheet.
 1.0511 Stress relieve (anneal) by heating 2000-2200 F, 1 hour minimum, in vacuum, argon, or hydrogen, and by furnace cooling below 500 F in vacuum, argon, or hydrogen (49, 50).

1.06 **Hardness**
 1.061 Effect on hardness of bar due to cold rolling followed by vacuum annealing at 1500 F, Figure 1.061.

1.063 Effect of cold rolling on room temperature hardness of sheet, Figure 1.062.
 1.064 Effect of anneal temperature on room temperature hardness of as-received sheet, Figure 1.063.
 1.064 Effect of cold roll and anneal on hardness of .050 inch sheet, Figure 1.064.
 1.065 Effect of cold roll and anneal on hardness of 0.028 inch sheet, Figure 1.065.
 1.066 Effect of annealing temperature on hardness of 0.010 inch sheet in 93 percent cold rolled condition, Figure 1.066.
 1.067 Effect of annealing time at 2340 F on hardness of .014 inch sheet in 50 percent cold rolled condition, Figure 1.067.

1.07 **Forms and Conditions Available**
 1.071 Alloy is available in sheet, bar, wire, rod, tubing, and fastener forms. Sheet and bar available in stress-relieved condition (9).

1.08 **Melting and Casting Practice**
 1.081 General. The alloy is produced by powder fabrication. Prepared powder is compacted at 60 ksi. The compacted billet is then sintered in high purity hydrogen, heated and extruded in 3 inch diameter bar and heat treated again at 1800 F (2).
 1.082 The fabrication of the alloy does not depend on an exacting thermal cycle to produce dispersed phase strengthening. Uniform thoria distribution is achieved by a chemical codeposition process(2).

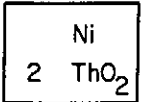
1.09 **Special Considerations**
 1.091 The radiation levels experienced during handling and during fabrication of the alloy are well below the AEC established tolerances (11).
 1.092 Although the special merit of the alloy is reflected by its retention of strength at high temperatures for long service periods, alloy must be protected from oxidation by suitable coating or cladding (see Section 2.0312 for recent progress).

1.093 Because alloy achieves a major component of strength from the cold work induced during processing, its strength is very sensitive to test direction. Caution should be exercised in use to insure that the principal loads are supported by material oriented in the major working direction.
 1.094 Directionality of strength is reflected in shear strengths measured in direction of principal deformation. Care should be exercised to avoid introduction of shear loads in weak directions.
 1.095 Joining by welding or other processes involving high temperature, especially in the presence of foreign elements or alloys, can seriously degrade long-time properties even if short-time tensile strengths are retained (for recent progress in joining, see Section 4.031).

2. **PHYSICAL AND CHEMICAL PROPERTIES**

2.01 **Thermal Properties**
 2.011 Melting point, 2650 F (8).
 2.012 Phase changes. The thoria is virtually inert with respect to the nickel matrix, and no phase changes occur (2).
 2.0121 Time-temperature-transformation diagrams. This concept is inapplicable for the alloy, since thoria solution and precipitation does not occur in the conventional sense as indicated in 2.012.
 2.013 Thermal conductivity, Figure 2.013.
 2.014 Thermal expansion, Figure 2.014.
 2.015 Specific heat.
 0.107 btu per lb F from 70 to 212 F (calculated).
 2.016 Thermal diffusivity.
 2.017 Thermal emf, Figure 2.017.

2.02 **Other Physical Properties**
 2.021 Density 0.322 lb per cu in, 8.9 gr per cu cm (8).
 2.022 Electrical resistivity, Figure 2.022.



TD Nickel

Ni
2 ThO₂

TD Nickel

2.023 Magnetic properties, Table 2.023.

TABLE 2.023

Source	(8)		
Alloy	TD Nickel		
Form	Saturation Magnetization (emu/gr)	Remanent Magnetization (emu/gr)	Coercive Force (Oersteds)
Bar	53	25-35	40-60
Sheet	-	25-30	28-31

2.041 External radiation measurements of bar and sheet of alloy, Table 2.041.

TABLE 2.041

Source	(11)			
Alloy	TD Nickel			
Distance	Beta and gamma emissions MR per HR(a)			
	43 lb - 0.060 Inch Sheet	32 lb - 2 1/4 In Diameter Bar	Unpackaged	Packaged(b)
Surface	0.30	0.15	0.43	0.30
1 inch	0.27	0.14	0.30	0.22
6 inches	0.15	0.09	0.13	0.09
12 inches	0.07	0.06	0.07	0.04
24 inches	nil	nil	0.03	0.02

AEC limits for external radiation in a restricted area permit an average of 2.5 MR/HR.
 (a) Tracer Lab Survey Meter Model SU14.
 (b) Package for sheet: Wood (1/2 inch thick) crating.
 Package for bar: Cardboard tube 1/2 inch wall.

2.024 Emissance, Figure 2.024.
 2.025 Damping capacity.
 2.0251 Effect of test temperature on internal damping of as-received bar and of swaged and recrystallized wire, Figure 2.0251.
 2.0252 Effect of test temperature and specimen direction on internal damping of as-received bar, Figure 2.0252.

2.03 Chemical Properties

2.031 Oxidation.
 2.0311 There appears to be no selective oxidation at the grain boundaries, but the dispersed thorium lowers the rate of reaction at the interface, thus partially controlling oxidation (52). At a given time and temperature, the weight gain per unit surface is approximately half the weight gain of wrought nickel (53). The weight gain in still air is approximately parabolic with time and exponential with temperature (54).

2.0312 Above approximately 2000F, the material requires a coating if it is used in prolonged exposure to an oxidizing environment. Coatings based on chromium and aluminum, in combination with each other, or with further alloying elements, have been successfully applied, but such coatings are limited to temperatures below 2200 F, especially under thermal cycling conditions which cause spalling. For higher temperatures, and where thermal cycling is necessary, claddings have been sought. To date, the most successful has been a .010 inch cladding of Fe-25Cr-4Al-0.08Y-0.5Ta which survived and retained ductility after 800 hours of cyclic furnace exposure at 2300F. Extensive interdiffusion occurred after 100 hours, and nearly complete homogenization occurred after 300 hours (51). More recently glass-based controlled viscosity coatings have been studied, but both the metallic claddings and controlled viscosity coatings require further study (55).

2.032 Corrosion.
 2.0321 Alloy has good corrosion resistance even when welded or brazed, although salt corrosion resistance of welded alloy is better than after brazing.

2.04 Nuclear Properties

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 Tension, Table 3.01.

TABLE 3.01

Source	AMD (49) (50)				
Alloy	Ni-2.2ThO ₂ (TD Nickel)				
Temperature	70F (a)		2000F (b)		
	Bar	Sheet and Strip(c)	Bar	Sheet and Strip (c)	Sheet and Strip (c)
Form and Size			0.5-0.75 diameter	>0.75-1.25 diameter	
F _{tu} - ksi, min	57	60	15	12	12
F _{ty} - ksi, min	42	40	13.5	11.5	9.5
e (1 in) - percent, min	15	10	2	2	2
RA - percent, min	50	-	5	5	-

(a) Strain rate .003-.007 per min to 0.6 percent offset, followed by crosshead speed of 0.03-0.07 in per min to fracture.
 (b) Rate of separation of heads 0.03-0.07 in per min to fracture.
 (c) For widths 5 inches and over, specimen shall be perpendicular to rolling direction; for widths less than 5 inches, test axis shall be parallel to rolling direction.

3.012 Additional specified properties.
 3.0121 Minimum hardness, Rockwell B 75.
 3.0122 Stress rupture at 2000 F, Table 3.0122.

TABLE 3.0122

Source	AMD (49)(50)		
Alloy	Ni-2.2ThO ₂ (TD Nickel)		
Form and Size	Bar, Extrusion, Forging		Sheet and Strip
	0.500 to 0.750 dia	>.750 to 1.250 dia	
Stress for rupture in 20 hours - ksi	8	7	5.5
e (1 in)	Report	Report	Report
RA	Report	Report	-

3.02 Mechanical Properties at Room Temperature
 3.021 Tension (see also 3.03).
 3.0211 Stress-strain curves for sheet at room temperature, Figure 3.0211.
 3.0212 Tensile data for sheet, Table 3.0212.

TABLE 3.0212

Source	(12)								(15)
Alloy	TD Nickel								
Form	Sheet								
	Condition	As received	Oxidized, 24 hr		Calorized (57)			Exposed*	
			2000 F	2400 F	Unexposed	2200 F, 192 hr	2400 F, 88 hr		
Thickness - in	0.025	0.050						0.060	
F _{tu} , ksi	-L	-	84.8	76.2	71.3	-	76.1	50.7	63.6
	-T	80.0	79.2	77.5	-	75.4	-	-	63.8
F _{ty} , ksi	-L	-	62.4	56.8	51.9	-	45.0	33.2	46.2
	-T	52.6	56.5	52.5	-	52.3	-	-	45.6
e - (percent)									
	-L	-	19.5	18.0	12	-	14	8	14.5
	-T	21.0	18.5	17.0	-	-	-	-	14.4

* Partial failure of coating.

- 3.0213 Effect of cold work on tensile strength of wire, Figure 3.0213.
- 3.0214 Effect of 1 hour exposure at high temperature on room temperature tensile properties of sheet, Figure 3.0214.
- 3.0215 Effect of elevated temperature exposure on tensile properties of bar, Table 3.0215.
- 3.03124 Effect of test temperature on tensile properties of sheet of various thicknesses, Figure 3.03124.
- 3.03125 Effect of test temperature on tensile properties of vacuum annealed sheet, Figure 3.03125.

Ni
2 ThO ₂

TD Nickel

TABLE 3.0215

Source	(7, p. 233)							
Alloy	Ni-2.2ThO ₂ (TD Nickel)							
Form	Bar							
	F _{ty} - ksi		F _{tu} - ksi		e - percent		RA - percent	
	70 F	2000 F	70 F	2000 F	70 F	2000 F	70 F	2000 F
1 in, stress-relieved, as received	52.9	8.4	68.2	14.8	21.2	9.7	77.7	11
As received + 2000 F, 1 hr	56.1	-	70	-	20.7	-	90.2	-
As received + 2500 F, 1 hr	48.4	13.3	65.4	13.7	22.3	3.3	85.9	6.2
1/2 in, stress relieved, as received	65.5	16.8	75.9	18	19.8	5.3	85.8	2.5
As received + 2200 F, 1 hr	54.7	-	69.2	-	21.8	-	94	-
As received + 2500 F, 1 hr	49.2	13	65.25	16.2	21.3	5.1	79.5	6.1
1/4 in, as-swaged	82.9	18.2	85.5	18.9	16.7	4.1	93.7	4.0
As received + 2000 F, 1 hr	52.5	-	69	-	22.7	-	90.2	-
As received + 2500 F, 1 hr	46.6	16.2	64.45	16.7	19.2	4	76.2	1

- 3.022 Compression (see also 3.03).
- 3.0221 Stress-strain diagrams (see Figure 3.0321).
- 3.023 Impact.
- 3.0231 Typical impact values of sheet and bar, Table 3.0231.
- 3.0232 Effect of exposure time and temperature on room temperature impact strength of nonstandard Charpy-V specimens, Figure 3.0232.
- 3.024 Bending.
- 3.0241 Stress-strain diagrams.
- 3.02411 Stress versus plastic strain in bending of sheet and bar vacuum annealed at various temperatures, Figure 3.02411.
- 3.02412 Stress versus plastic strain in bending of bar cold rolled followed by vacuum annealing at 1500 F, Figure 3.02412.
- 3.025 Torsion and shear (see also 3.035).
- 3.0251 Shear strength of sheet in longitudinal and transverse directions, Table 3.0251.
- 3.03126 Effect of test temperature on tensile strength of sheet in as-received condition and exposed for 100 hours at 2200 F or 1 hour at 2400 F prior to testing, Figure 3.03126.
- 3.03127 Effect of test temperature on tensile properties of sheet coated by TRW and DuPont with chromium-aluminum alloys, Figure 3.03127.
- 3.0313 Bar.
- 3.03131 Compilation from several sources on effect of elevated temperature on tensile properties of bar, Figure 3.03131.
- 3.03132 Effect of test temperature on tensile properties of as-received bar and recrystallized sheet, Figure 3.03132.
- 3.03133 Effect of elevated test temperature and test direction on tensile properties of bar, Figure 3.03133.
- 3.03134 Effect of elevated test temperature and test direction on tensile strength of bar at two crosshead speeds, Figure 3.03134.
- 3.03135 Effect of orientation on tensile properties of bar at 2000 F, Figure 3.03135.
- 3.03136 Effect of cold work on longitudinal and transverse tensile strength of bar at 2000 F, Figure 3.03136.
- 3.03137 Effect of test temperature on tensile and yield strength of calorized bolts, Figure 3.03137.
- 3.03138 Tensile properties of as-received and recrystallized bar at room temperature and 2000 F, Table 3.03138.

TABLE 3.0231

Source	(15)
Alloy	Ni-2.2ThO ₂ (TD Nickel)
Charpy, ft - lb	
Sheet	30
Bar	29

TABLE 3.0251

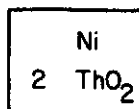
Source	(15)
Alloy	Ni-2.2ThO ₂ (TD Nickel)
Thickness - inch	0.060 Sheet
F _{su} - ksi, L	57.9
T	58.4

- 3.026 Bearing.
- 3.027 Stress concentration.
- 3.0271 Notch properties (see 3.0371).
- 3.0272 Fracture toughness.
- 3.028 Combined properties.
- 3.03 Mechanical Properties at Various Temperatures
- 3.031 Tension.
- 3.0311 Stress-strain diagrams.
- 3.03111 Stress-strain curves in tension for sheet at 70 to 1800 F, Figure 3.03111.
- 3.03112 Stress-extension curves for sheet at elevated temperatures, Figure 3.03112.
- 3.03113 Stress-strain curves for as-received bar and recrystallized sheet at room and elevated temperatures, Figure 3.03113.
- 3.0312 Tensile properties of sheet (see also 3.03132).
- 3.03121 Effect of low test temperature on tensile properties of sheet, Figure 3.03121.
- 3.03122 Typical short time tensile properties of sheet at low and elevated temperatures, Figure 3.03122.
- 3.03123 Compilation from several sources on effect of elevated temperature on tensile properties of sheet, Figure 3.03123.
- 3.032 Compression.
- 3.0321 Stress-strain curves in compression for sheet at 70 to 2000 F, Figure 3.0321.
- 3.0322 Compressive yield strength of sheet at room and elevated temperatures, Figure 3.0322.
- 3.033 Impact.
- 3.0331 Charpy-V impact at room temperature and at 1800 F is approximately 30 ft-lbs.
- 3.034 Bending.
- 3.0341 Bend ductility at low and at room temperature for sheet, Figure 3.0341.
- 3.035 Torsion and shear (see also 4.03).
- 3.0351 Effect of test temperature on shear strength of 0.012 inch sheet, Figure 3.0351.
- 3.0352 Effect of test temperature on shear strength of 0.050 inch sheet, Figure 3.0352.

TABLE 3.03138

Source	(7, p. 233)			
Alloy	Ni-2.2ThO ₂ (TD Nickel)			
Form	1 Inch Bar*			
	70 F		2000 F	
	As Received	Re-crystallized	As Received	Re-crystallized
F _{ty} - ksi	52.9	39.1	14.9	14.6
F _{tu} - ksi	68.2	75.85	15.5	14.6
e(2 in) - percent	21.2	30.6	2.6	3.5
RA - percent	70	44	3.7	3.7

* Rolled 50 percent at 70 F + 2200 F, 1 hour to produce recrystallized structure.



TD Nickel

- 3.036 Bearing.
3.037 Stress concentration.
3.0371 Notch properties.
3.03711 Effect of test temperature in notch strength of alloy, Figure 3.03711.
3.03712 Effect of low test temperature on notch strength ratio of sheet, Figure 3.03712.
3.0372 Fracture toughness.
3.038 Combined properties.
- 3.04 Creep and Creep Rupture Properties
3.041 Creep.
3.0411 Creep curve for recrystallized sheet at 1300F for stress of 16 ksi, Figure 3.0411.
3.0412 Creep curves of stress relieved sheet at 2000, 2200, and 2400F, Figure 3.0412.
3.0413 Creep curves for bar at 36 ksi and temperatures between 617F and 710F, Figure 3.0413.
3.0414 Creep curves for bar at 18 ksi and temperatures between 1652 and 1787F, Figure 3.0414.
3.0415 Effect of test temperature on steady state creep rate of recrystallized sheet for stresses of 12, 14, and 16 ksi, Figure 3.0415.
3.0416 Effect of test temperature on steady state creep rate of as-received bar, Figure 3.0416.
3.0417 Stress to produce 0.2 percent deformation of stress-relieved sheet at 1600 to 2000F, Figure 3.0417.
3.0418 Effect of stress and temperature on steady state creep rate of bar, Figure 3.0418.
3.0419 Relation between stress, temperature, and minimum creep rate at absolute temperatures above half the melting point, Figure 3.0419.
3.042 Creep rupture.
3.0421 Typical creep rupture ranges at 1800 to 2100F for sheet in air, Figure 3.0421.
3.0422 Creep rupture curves of stress-relieved sheet at 1600 to 2000F, Figure 3.0422.
3.0423 Creep rupture curves for 0.5 and 1.25 inch diameter bar at temperatures from 1600 to 2400F, Figure 3.0423.
- 3.05 Fatigue Properties
3.051 Room temperature properties.
3.0511 Axial tension-tension fatigue in longitudinal and transverse directions for annealed .010 inch sheet, Figure 3.0511.
3.0512 Axial fatigue of smooth and notched sheet, Figure 3.0512
3.0513 Axial fatigue of bar under completely reversed loading, Figure 3.0513.
3.0514 Load variation required to maintain 1.34 percent strain range in completely reversed axial strain cycling for worked bar, Figure 3.0514.
3.0515 Cyclic hardening curves for bar in axial push-pull loading, Figure 3.0515. (Compare with Figure 3.0514 which shows cyclic strain softening for material initially in harder condition.)
3.052 Elevated temperature properties.
3.0521 Reversed bending fatigue of sheet at 1200 and 1800F, Figure 3.0521.
3.0522 Axial fatigue of smooth and notched sheet at 1600 and 1800F, Figure 3.0522.
3.0523 Low cycle fatigue at 1800F for coated and uncoated plate, Figure 3.0523.
- 3.06 Elastic Properties
3.061 Poisson's ratio assumed as approximate by 1/3 (10).
3.062 Elastic modulus at room and elevated temperature, Figure 3.062.
3.063 Modulus of rigidity 7000 kg/mm², 9.8 x 1000 ksi (10).

4. FABRICATION

- 4.01 Formability
Most sheet forming operations can be carried out at room temperature using standard shop practices. Bending, spinning, hydro-forming, and drop hammer forming have been used (4)(5).

- 4.02 Machining and Grinding
See reference 17 for recommended machine tool settings. Grinding can be carried out as with Nickel-200, but adequate ventilation should be provided during dry-grinding to remove airborne particles containing thorium (11).

- 4.03 Welding and Joining
4.031 General. Because strength properties depend critically on retaining purity together with a fine dispersoid of ThO₂ in the nickel matrix, welding and joining can seriously degrade properties either by introducing foreign material or by destroying local microstructure. The detrimental effects may not be so evident in short-time properties as in long-time creep effects, where the dispersion method of strengthening develops its greatest benefit.

Conventional welding, diffusion bonding, and brazing have been used on this material, but most evaluations have been conducted by use of short-time tests, hiding some potentially detrimental effects. The most effective joining method used to date is hot isostatic pressing wherein the parts to be joined are canned and subjected to high temperature and external pressure. Butt welds made in this manner can achieve 100 percent efficiency (weld strength equal to parent metal strength) at room temperature and about 50 percent efficiency at 2000F in tensile loading. If interleafs of a cobalt base alloy are used, efficiency at 2000F can also be raised to 100 percent. Weld efficiency in shear loading is nearly 100 percent with or without the use of interleafs (although the shear strength of parent metal at 2000F is so low that even with 100 percent efficiency, the joint is still weak at this temperature, and allowance must be made for low strength by increasing shear areas)(see Table 4.0321).

Long-time tests in both shear and tension reveal, however, relatively low strengths at temperatures of about 2000F. It appears that any foreign material or disturbance of the dispersoid structure is detrimental to long-time strength, and tests are advised to insure if adequate strength is available for required application (see Figure 4.0322).

- 4.032 Bar.
4.0321 Tensile and shear strengths at room temperature and at 2000F of butt welds made by hot isostatic pressing of bar, Table 4.0321.

TABLE 4.0321

Alloy		Ni-2.2ThO ₂ (TD Nickel)			
Form		1/2 inch Bar			
Condition		Hot Isostatic Pressed (HIP) 2000F, 20 ksi in Helium, 2 hours			
Source		(56)			
		Room Temperature		2000F	
		Parent Metal	HIP Weld	Parent Metal	HIP Weld
F _{TU} - ksi		95.3	95	22.9	12.1*
F _{SU} - ksi		56	54	3.3	3.1

* With cobalt alloy and Hastelloy X interlayers F_{TU} values of 22.9 and 20 ksi respectively were achieved.

- 4.0322 Creep rupture curves at 2000F for hot isostatic pressed butt weldments of bar with various metallic interleafs, Figure 4.0322.
4.033 Sheet.

4.0331 Tensile properties of diffusion bonded joints, Table 4.0331.

TABLE 4.0331

Alloy	Ni-2.2ThO ₂ (TD Nickel)			
Thickness	.010 Inch Sheet			
Source	(40, pp. 30, 89, 177)			
Condition	Stress Relieved, Bonded at 2100 F, 10 ksi, 20 seconds			
	Temperature - F			
	70	2000	2200	
F _{ty} - ksi	Base Metal	54.7	11.5	7.5
	As Joined	54.4	9.3	8.2
	Oxidized (a)	44.4	-	9.1(b)
F _{tu} - ksi	Base Metal	70.1	12.8	7.6
	As Joined	61.5	13.0	8.2
	Oxidized(a)	51.8	-	9.1(b)
e(1 in)	Base Metal	5.7	4.8	3.5
	As Joined	1.8	0.5	-
	Oxidized(a)	0.3	-	0.7

(a) 100 cycles of 1 hour at 2200F.
(b) Fracture stress.

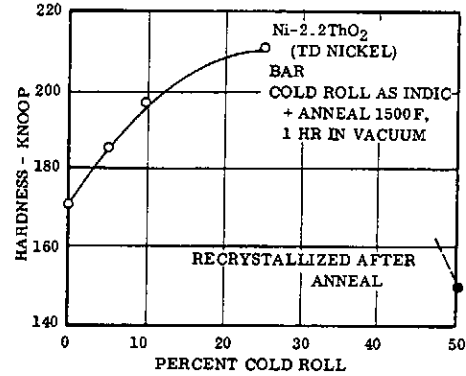
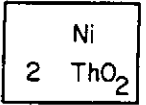


FIG. 1.061 EFFECT ON HARDNESS OF BAR DUE TO COLD ROLLING FOLLOWED BY VACUUM HEATING AT 1500 F. (45, p. 1300)



TD Nickel

- 4.0332 Effect of overlap on shear strength of brazed sheet at 2000 F, Figure 4.0332.
- 4.0333 Effect of test temperature on shear strength in double shear of diffusion bonded sheet, Figure 4.0333.
- 4.0334 Effect of test temperature on shear strength of spot welds obtained by fusion and by diffusion bonding, Figure 4.0334.
- 4.0335 Effect of test temperature on tensile strength of flash welded sheet; Figure 4.0335.
- 4.0336 Effect of test temperature on tensile strength of diffusion bonded and fusion welded sheet, Figure 4.0336.
- 4.0337 Creep rupture properties in shear at 1800 and 2000 F for .050 inch sheet spot welded by fusion or by diffusion bonding followed by heating at 2300 F for 1 hour, Figure 4.0337.
- 4.0338 Creep rupture at 2000 F for diffusion bonded sheet, Figure 4.0338.
- 4.0339 Creep rupture properties in shear at 1800 and 2000 F for 0.125 inch sheet with I-T overlap brazed with TD-6 brazing alloy, Figure 4.0339.
- 4.03310 Creep rupture properties in shear at 1800 F and 2000 F for .050 inch sheet with 4.5-T overlap brazed with TD-20 alloy, Figure 4.03310.

4.04 Heat Treatment
(see 1.051, 1.052)

4.05 Surface Treatment
Sand blasting and/or belt abrading (120-180 grit alumina wet belts) may be used for removal of scale.

4.051 Chemical condition. Either of the following baths* are recommended:

- a) 50 percent H₂O
25 percent of 48 percent (by weight) HF
12.5 percent of 42° Be HNO₃
12.5 percent of 66° Be H₂SO₄
room temperature, rinse-hot water.

- b) 0.05 lb salt per gallon of solution
21 percent H₂O
32 percent of 66° Be H₂SO₄
47 percent of 42° Be HNO₃
room temperature, rinse-hot water.

* All percentages by volume unless otherwise specified.

4.052 Heavy scales can be removed by fused caustic baths such as "Virgo", "Kolene", or sodium hydride.

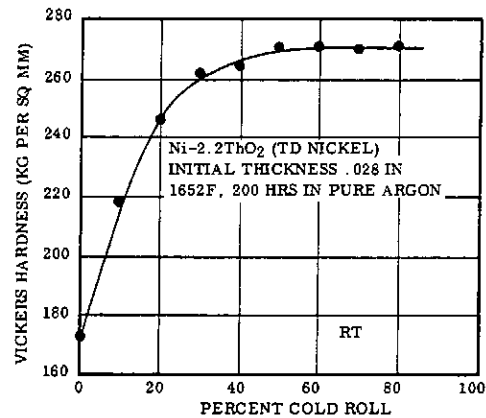
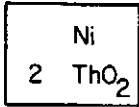


FIG. 1.062 EFFECT OF COLD ROLLING ON ROOM TEMPERATURE HARDNESS OF SHEET. (27, Fig 3)



TD Nickel

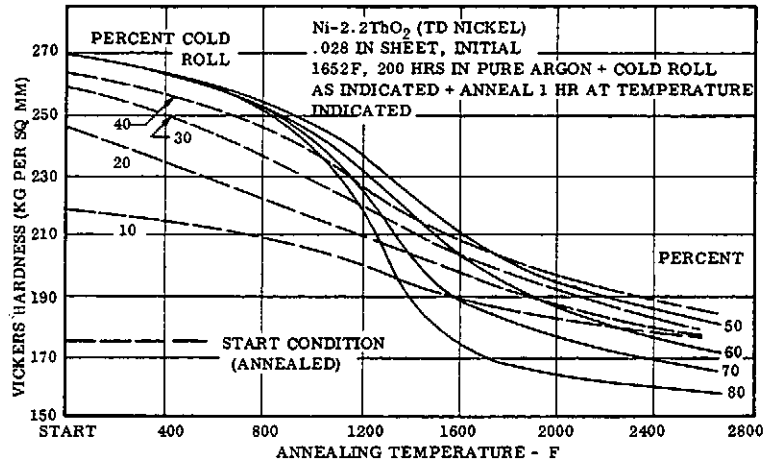


FIG. 1.065 EFFECT OF COLD ROLL AND ANNEAL ON HARDNESS OF .028 INCH SHEET. (27, Fig. 5)

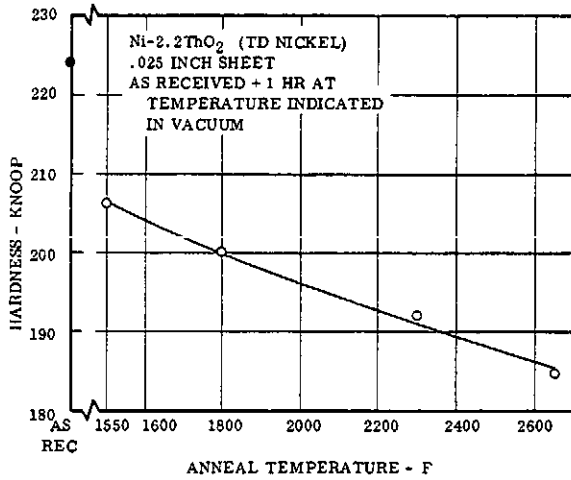


FIG. 1.063 EFFECT OF ANNEAL TEMPERATURE ON ROOM TEMPERATURE HARDNESS OF SHEET. (45, p. 1299)

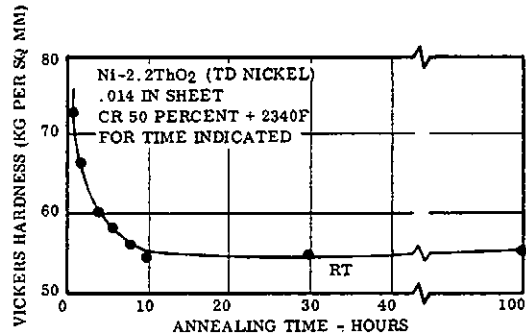


FIG. 1.067 EFFECT OF ANNEALING TIME AT 2340F ON HARDNESS OF .014 INCH SHEET IN 50 PERCENT COLD ROLLED CONDITION. (27, Fig. 7)

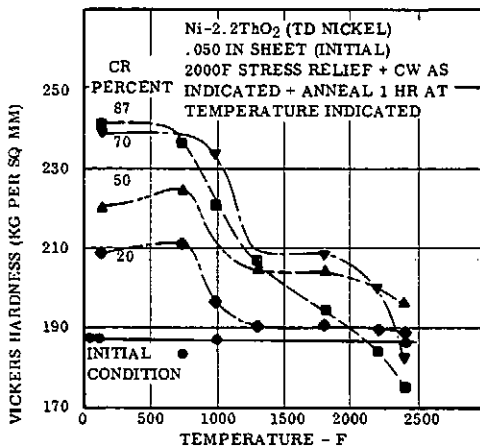


FIG. 1.064 EFFECT OF COLD ROLL AND ANNEAL ON HARDNESS OF .050 INCH SHEET. (36, p. 643)

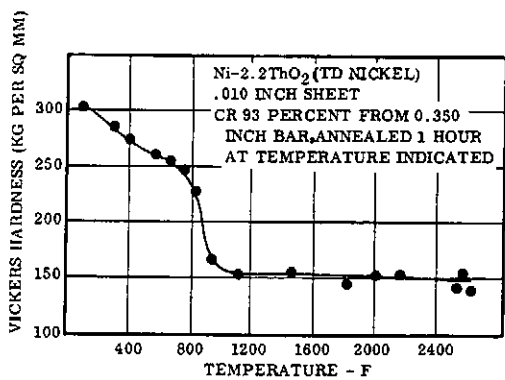


FIG. 1.066 EFFECT OF ANNEALING TEMPERATURE ON HARDNESS OF .010 INCH SHEET IN 93 PERCENT COLD ROLLED CONDITION. (35, p. 702)

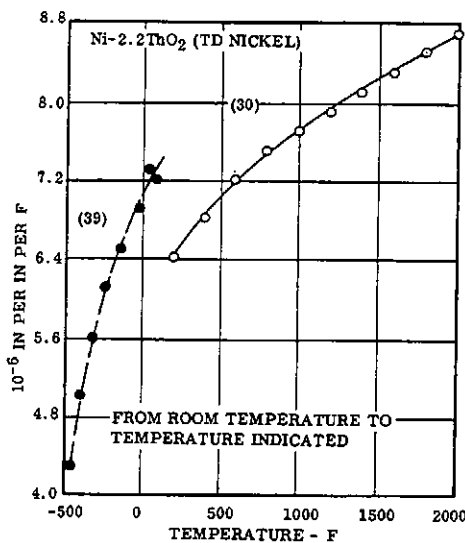
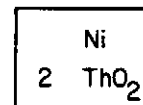


FIG. 2.014 THERMAL EXPANSION. (30, p. 52) (39, p. 286)



TD Nickel

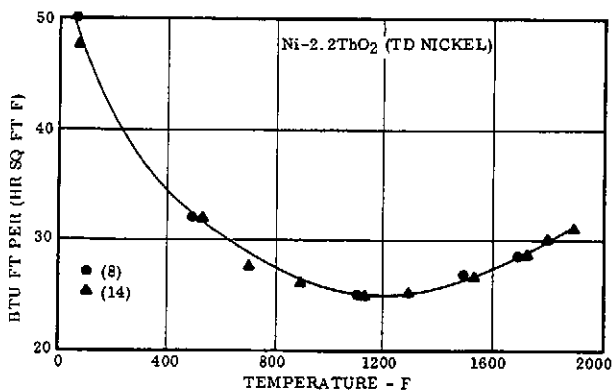


FIG. 2.013 THERMAL CONDUCTIVITY. (8)(14)

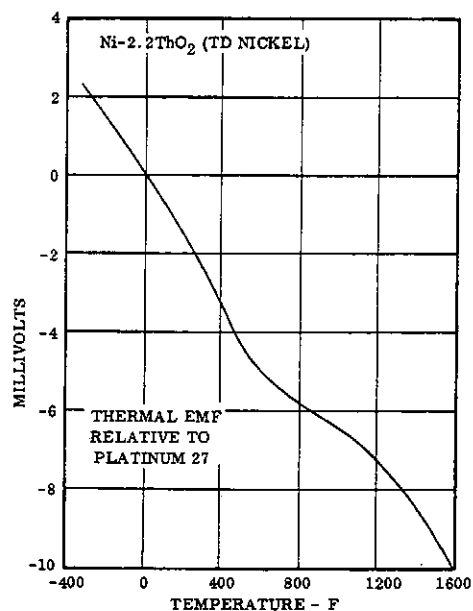


FIG. 2.017 THERMAL EMF. (38)(24, pp. 19, 20)

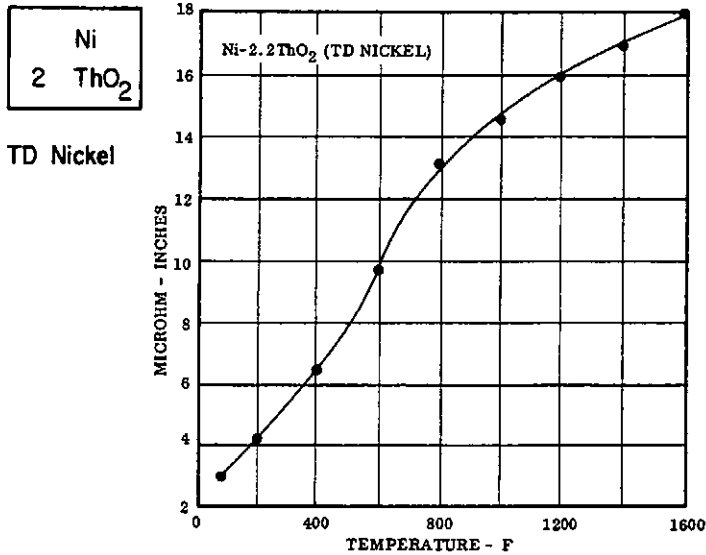


FIG. 2.022 ELECTRICAL RESISTIVITY. (38)(24, p. 19)

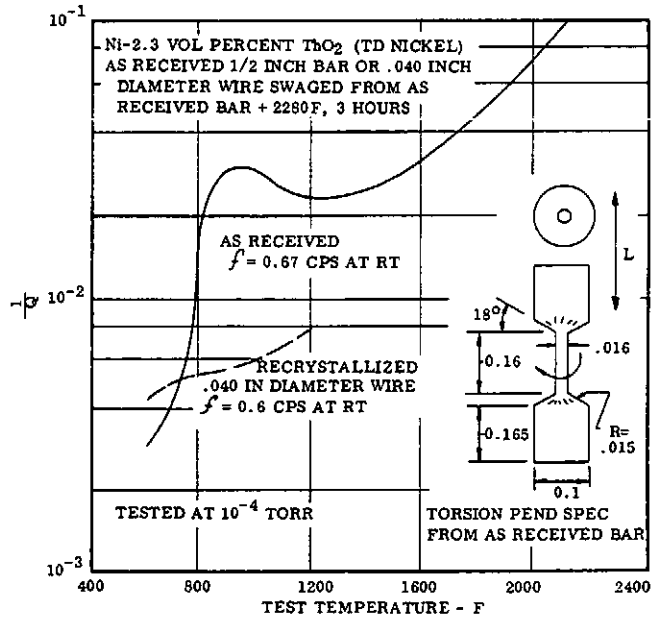


FIG. 2.0251 EFFECT OF TEST TEMPERATURE ON INTERNAL DAMPING OF AS RECEIVED BAR AND OF SWAGED AND RECRYSTALLIZED WIRE. (48, p. 1944)

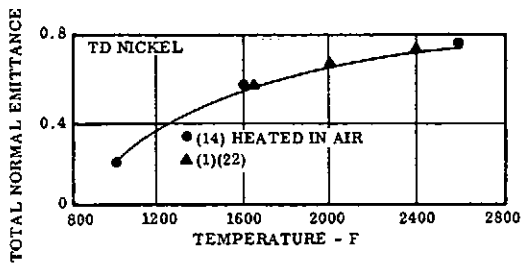
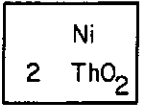


FIG. 2.024 EMITTANCE. (1)(14, p. 82)(22)



TD Nickel

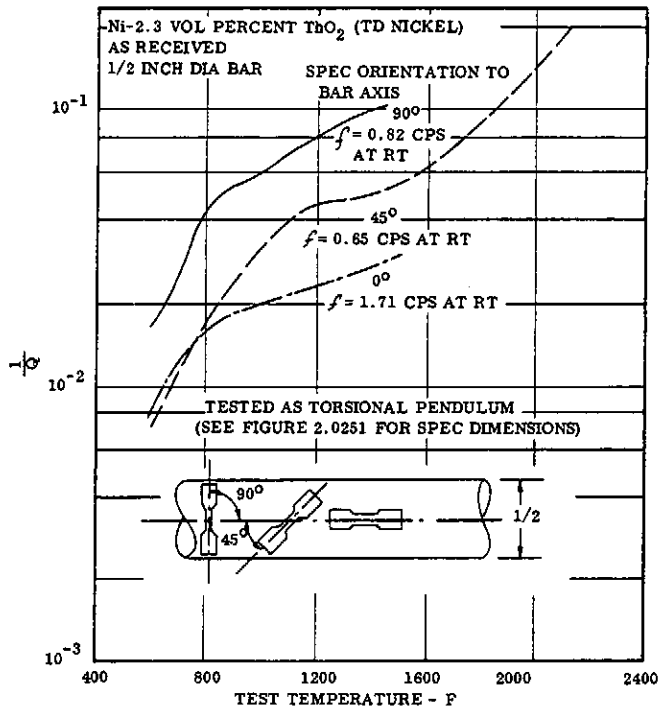


FIG. 2.0252 EFFECT OF TEST TEMPERATURE AND SPECIMEN DIRECTION ON INTERNAL DAMPING OF AS RECEIVED BAR. (45, p. 1945)

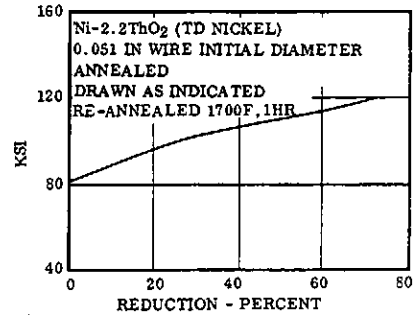


FIG. 3.0213 EFFECT OF COLD WORK ON TENSILE STRENGTH OF WIRE. (14, p. 83)

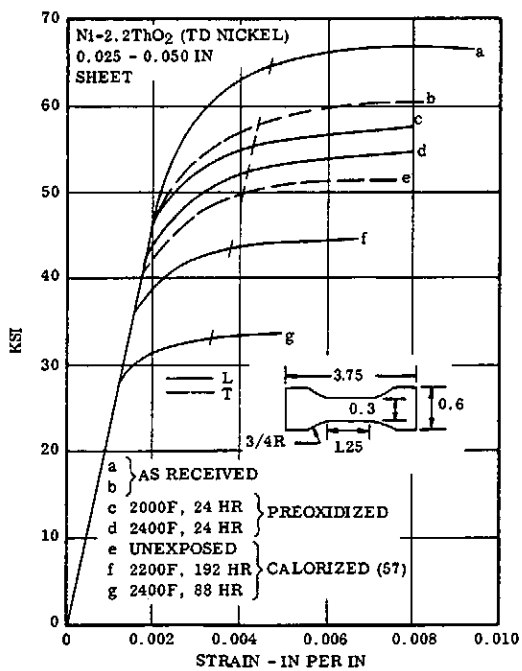


FIG. 3.0211 STRESS-STRAIN CURVES AT ROOM TEMPERATURE FOR SHEET. (12)

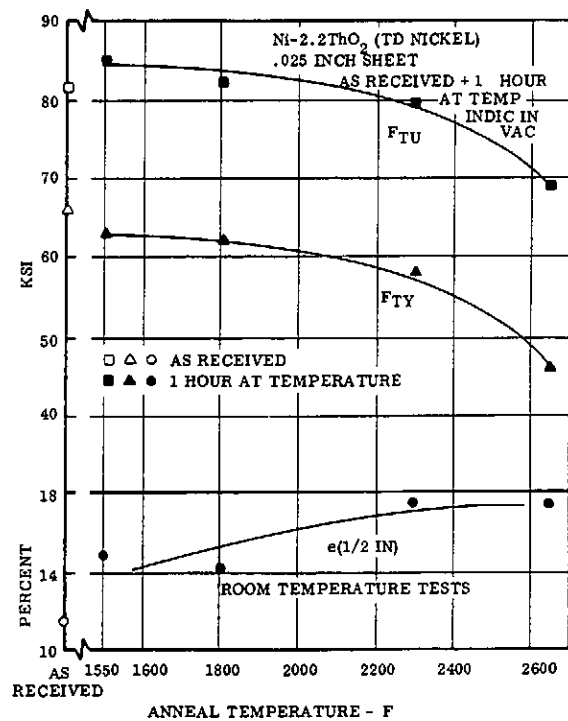
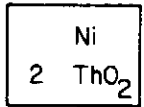


FIG. 3.0214 EFFECT OF 1 HOUR EXPOSURE AT HIGH TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF SHEET. (45, p. 1299)



TD Nickel

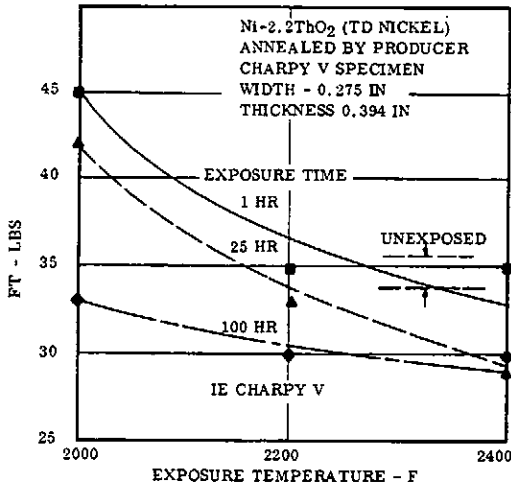


FIG. 3.0232 EFFECT OF EXPOSURE TIME AND TEMPERATURE ON ROOM TEMPERATURE IMPACT STRENGTH OF NONSTANDARD CHARPY-V SPECIMENS. (42)(84, p. 18)

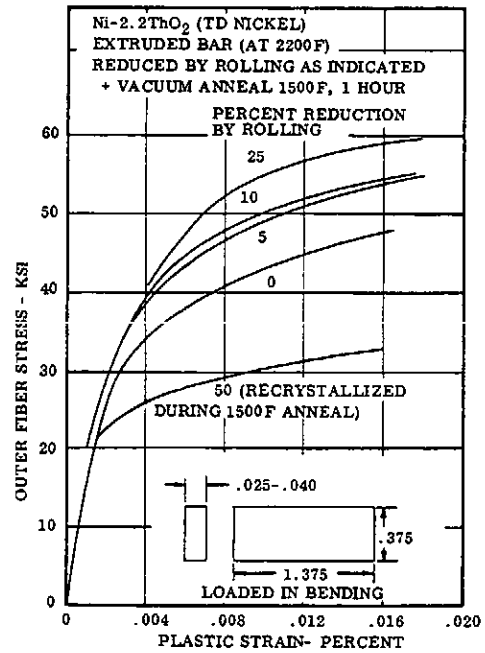


FIG. 3.02412 STRESS VERSUS PLASTIC STRAIN IN BENDING OF BAR COLD ROLLED FOLLOWED BY VACUUM ANNEALING AT 1500 F. (45, p. 1302)

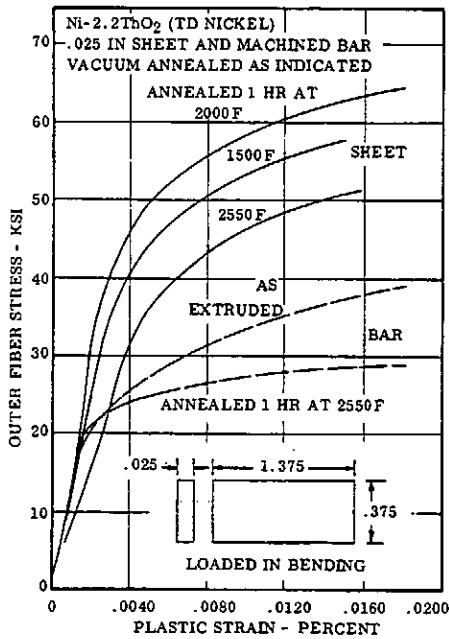
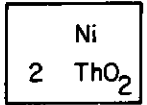


FIG. 3.02411 STRESS VERSUS PLASTIC STRAIN IN BENDING OF SHEET AND BAR VACUUM ANNEALED AT VARIOUS TEMPERATURES. (45, p. 1300)



TD Nickel

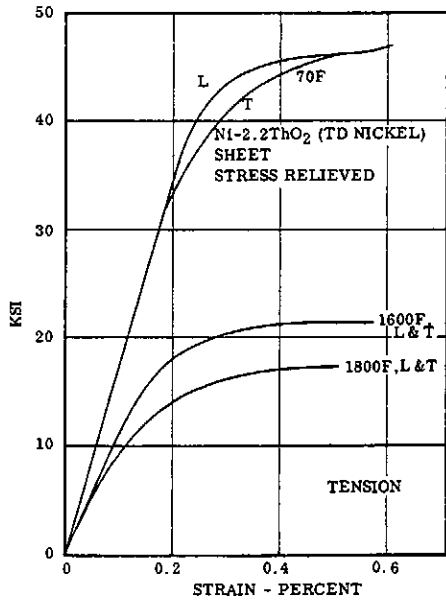


FIG. 3.03111 STRESS-STRAIN CURVES IN TENSION FOR SHEET AT 70 TO 1800F. (30, p. 54)

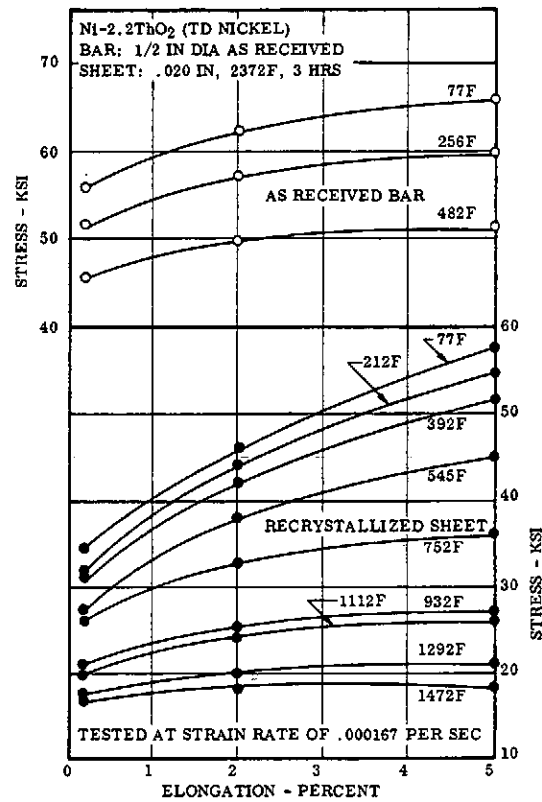


FIG. 3.03113 STRESS-STRAIN CURVES FOR AS-RECEIVED BAR AND RECRYSTALLIZED SHEET AT ROOM AND ELEVATED TEMPERATURES. (25, p. 11)

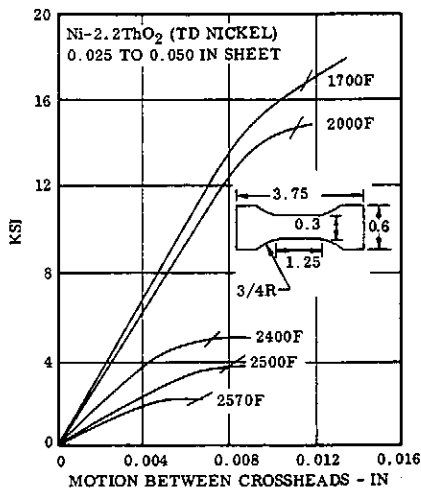
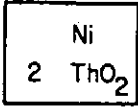


FIG. 3.03112 STRESS-EXTENSION CURVES FOR SHEET AT ELEVATED TEMPERATURES. (12, Fig. 5)



TD Nickel

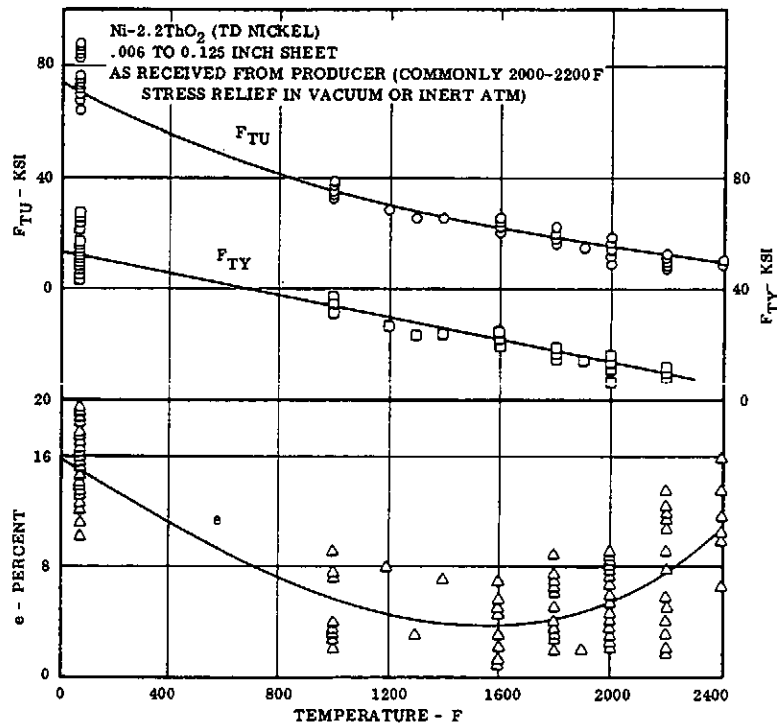
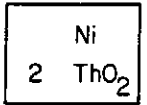
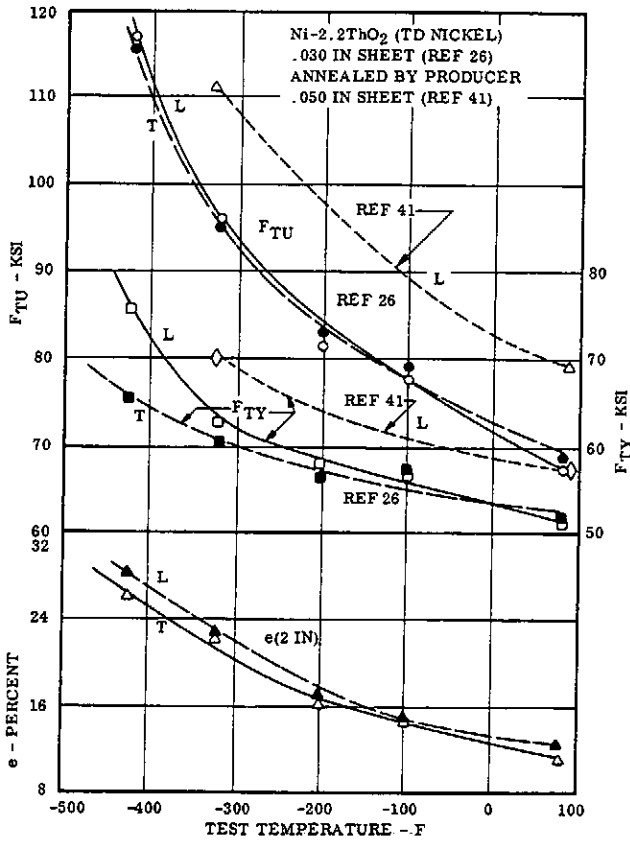


FIG. 3.03123 COMPILATION FROM SEVERAL SOURCES ON EFFECT OF ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF SHEET. (29, pp. 305-308)



TD Nickel

FIG. 3.03121 EFFECT OF LOW TEST TEMPERATURE ON TENSILE PROPERTIES OF SHEET. (26, pp. 14, 15, 58)(41, p. 55)

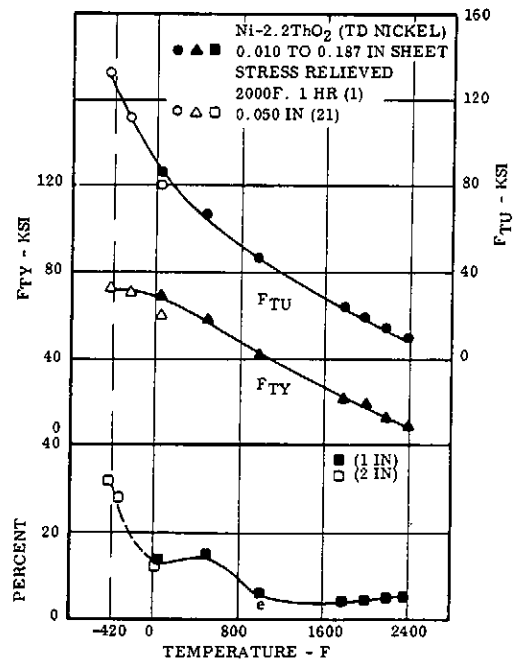
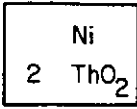


FIG. 3.03122 TYPICAL SHORT TIME TENSILE PROPERTIES OF SHEET AT LOW AND ELEVATED TEMPERATURES. (1, Table 2, Fig. 2)(21)

* Tests below 2000F in air.
 Tests above 2000F in vacuum.



TD Nickel

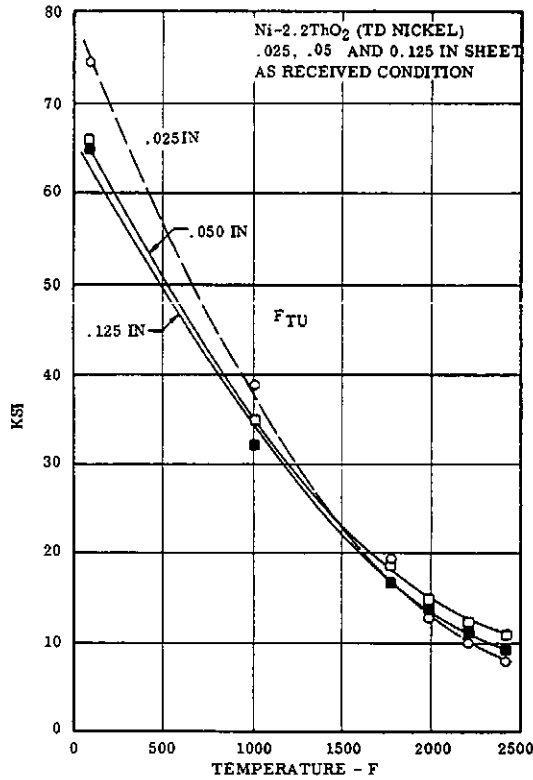


FIG. 3.03124 EFFECT OF TEST TEMPERATURE ON TENSILE STRENGTH OF SHEET OF VARIOUS THICKNESSES. (31, p. 15)

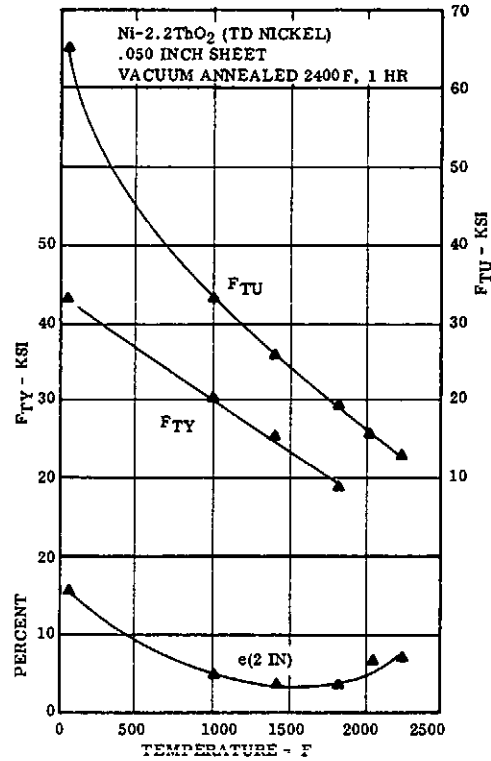


FIG. 3.03125 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF VACUUM ANNEALED SHEET. (31, p. 131)

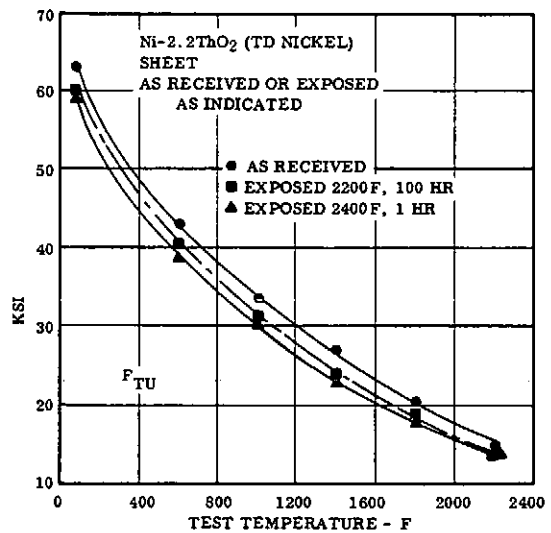
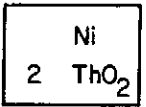
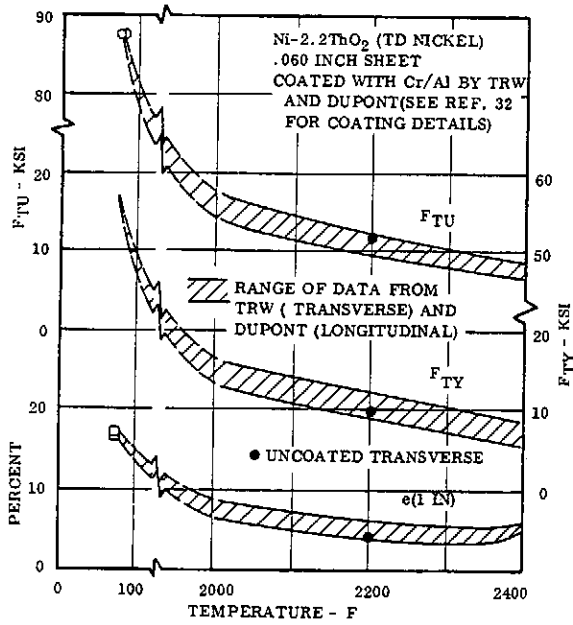


FIG. 3.03126 EFFECT OF TEST TEMPERATURE ON TENSILE STRENGTH OF SHEET IN AS RECEIVED CONDITION AND EXPOSED FOR 100 HOURS AT 2200 F OR 1 HOUR AT 2400 F PRIOR TO TESTING. (38, p. 83)



TD Nickel

FIG. 3.03127 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SHEET COATED BY TRW AND DUPONT WITH CHROMIUM-ALUMINUM ALLOYS. (32, p. 76, Part II)

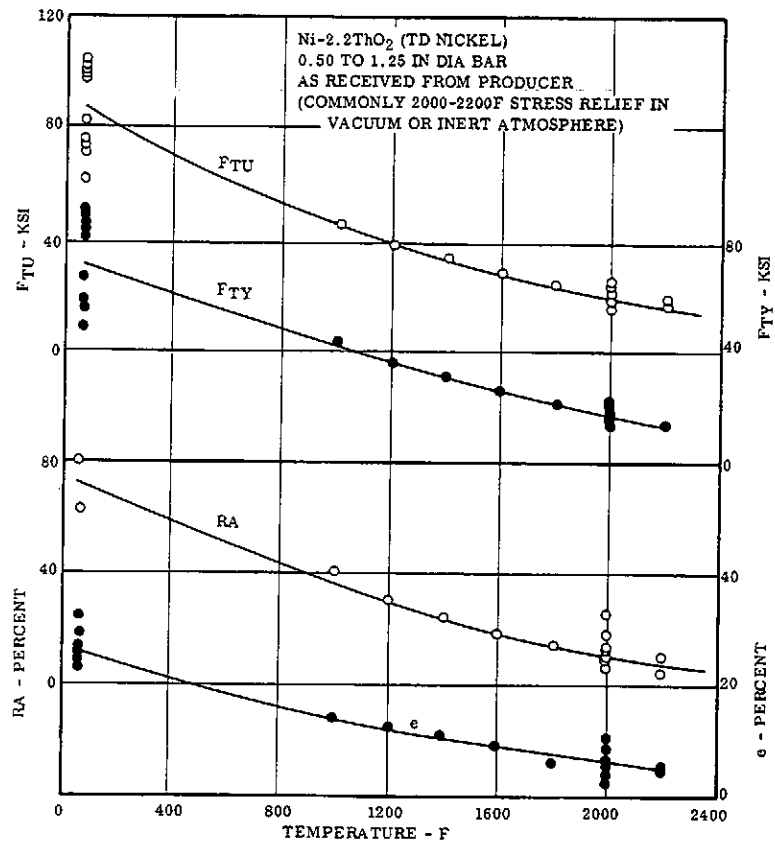
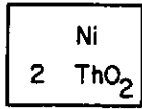


FIG. 3.03131 COMPILATION FROM SEVERAL SOURCES ON EFFECT OF ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF BAR. (29, pp. 316-318)



TD Nickel

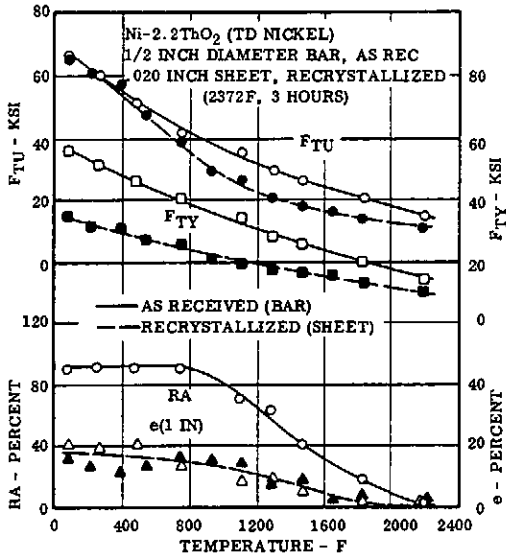


FIG. 3.03132 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF AS RECEIVED BAR AND RECRYSTALLIZED SHEET. (25, p. 11)

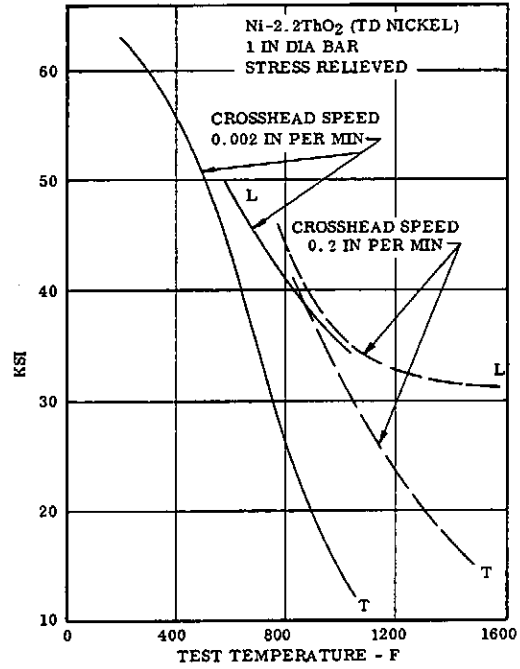


FIG. 3.03134 EFFECT OF ELEVATED TEST TEMPERATURE AND TEST DIRECTION ON TENSILE STRENGTH OF BAR AT TWO CROSSHEAD SPEEDS. (7, p. 414)

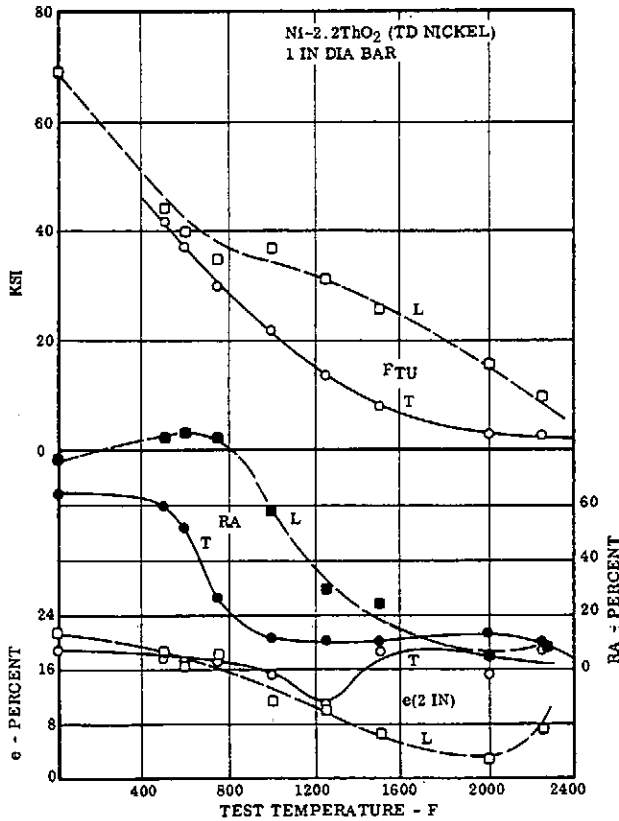


FIG. 3.03133 EFFECT OF ELEVATED TEST TEMPERATURE AND TEST DIRECTION ON TENSILE PROPERTIES OF BAR. (7, p. 414)

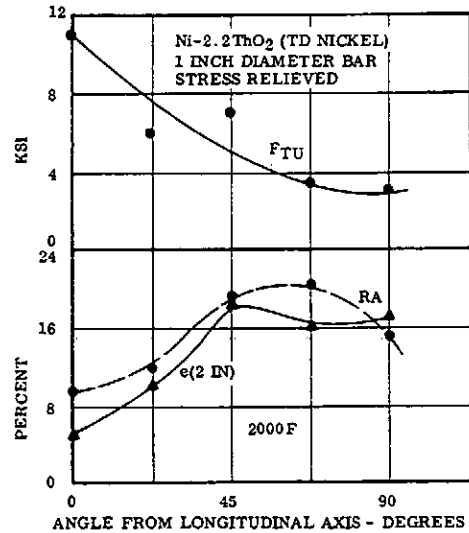


FIG. 3.03135 EFFECT OF ORIENTATION ON TENSILE PROPERTIES OF BAR AT 2000 F. (7, p. 413)

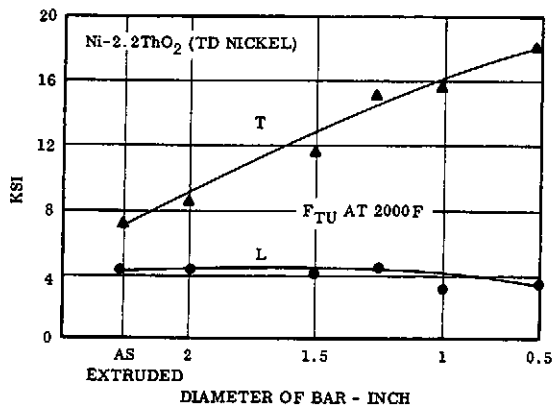


FIG. 3.03136 EFFECT OF COLD WORK ON LONGITUDINAL AND TRANSVERSE TENSILE STRENGTH OF BAR AT 2000 F. (7)

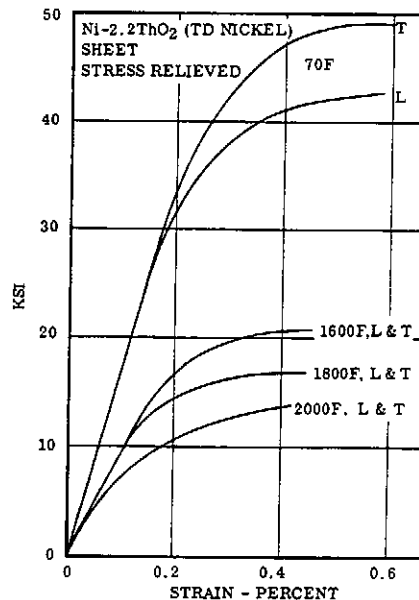


FIG. 3.0321 STRESS-STRAIN CURVES IN COMPRESSION FOR SHEET AT 70 TO 2000 F. (30, p. 56)

Ni
2 ThO₂

TD Nickel

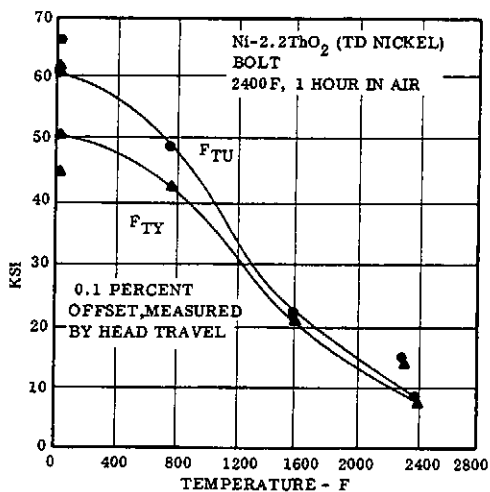


FIG. 3.03137 EFFECT OF TEST TEMPERATURE ON TENSILE AND YIELD STRENGTH OF CALORIZED BOLTS. (18, p. 57)

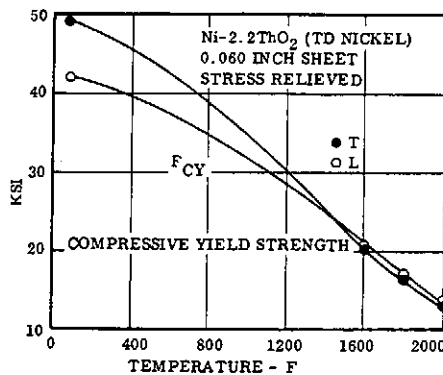


FIG. 3.0322 COMPRESSIVE YIELD STRENGTH OF SHEET AT ROOM AND ELEVATED TEMPERATURES. (19, p. 35)

Ni
2 ThO₂

TD Nickel

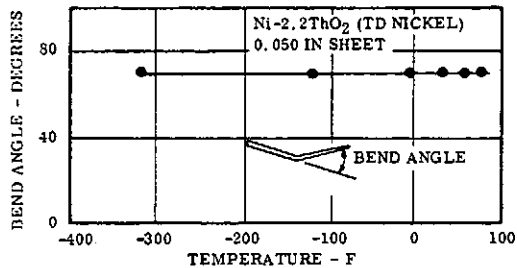


FIG. 3.0341 BEND DUCTILITY CURVE AT LOW AND ROOM TEMPERATURE FOR SHEET. (12, Fig. 9)

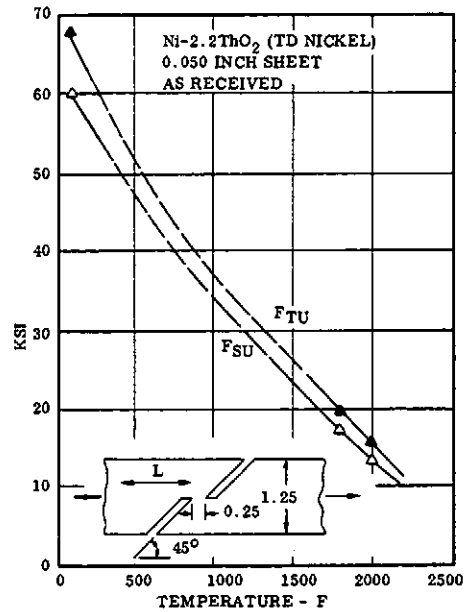


FIG. 3.0352 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF .050 INCH SHEET. (31, pp. 85, 87)

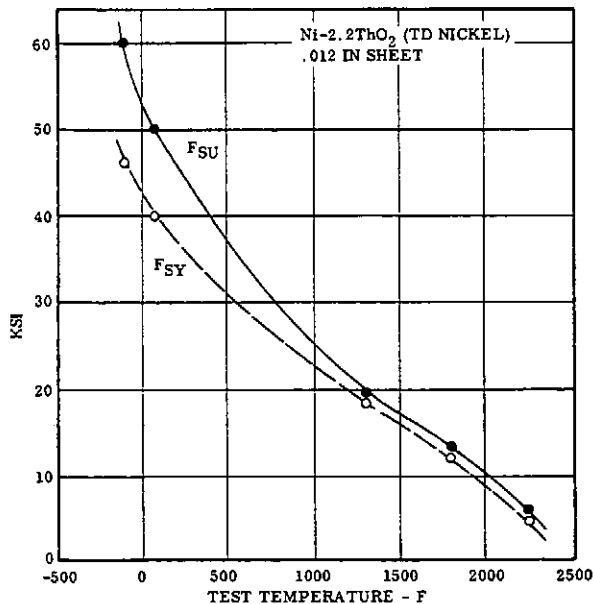


FIG. 3.0351 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF .012 INCH SHEET. (23, Vol II, p. 31)

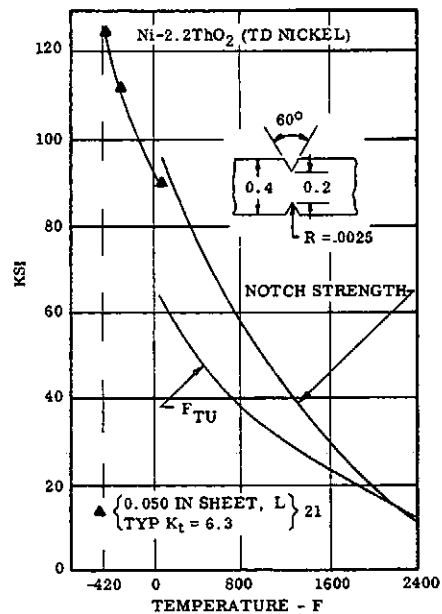


FIG. 3.03711 EFFECT OF TEMPERATURE ON NOTCH STRENGTH OF ALLOY. (14, p. 83)(21)

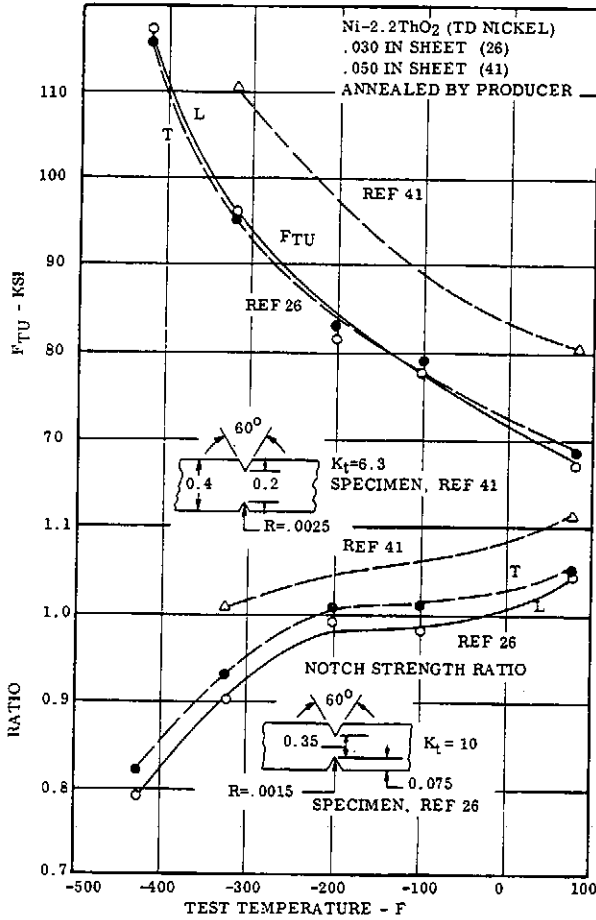


FIG. 3.03712 EFFECT OF LOW TEST TEMPERATURE ON NOTCH STRENGTH RATIO OF SHEET. (26, pp. 14,15,19,58) (41, p. 55)

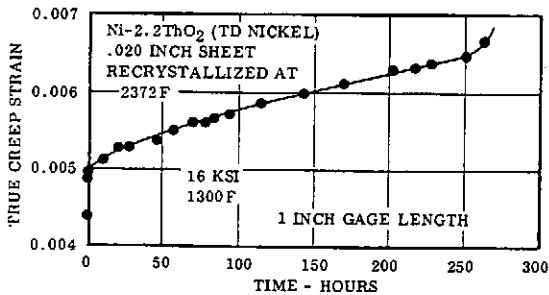


FIG. 3.0411 CREEP CURVE FOR RECRYSTALLIZED SHEET AT 1300 F FOR STRESS OF 16 KSI. (25, p. 25)

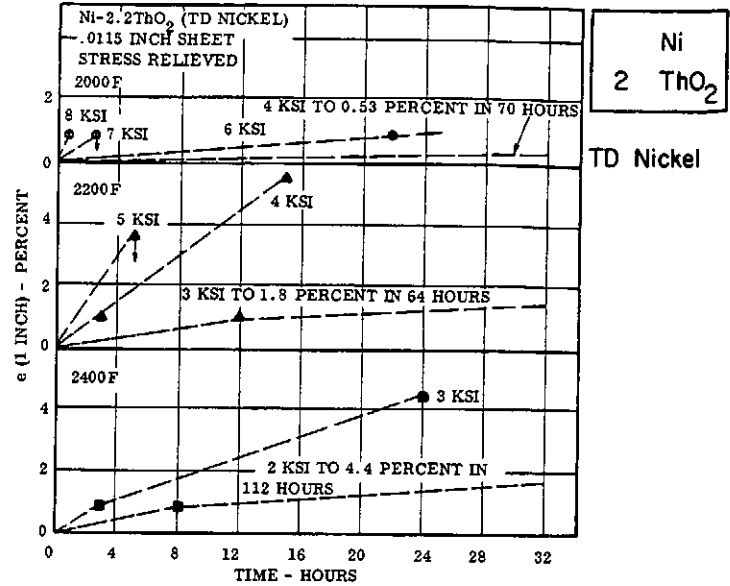


FIG. 3.0412 CREEP CURVES OF STRESS RELIEVED SHEET AT 2000, 2200, AND 2400 F. (40, p. 24)

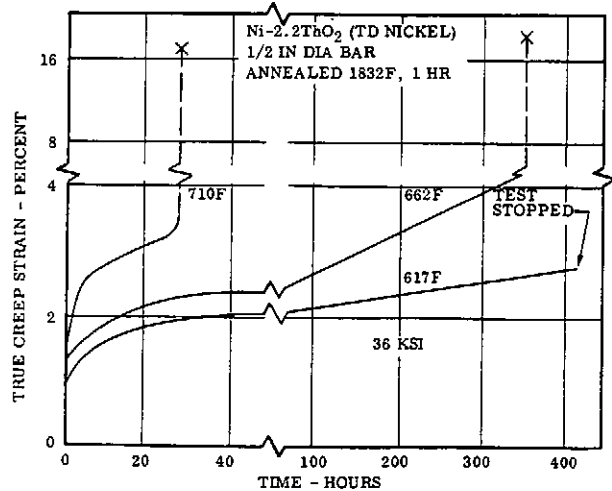


FIG. 3.0413 CREEP CURVES FOR BAR AT 36 KSI AND TEMPERATURES BETWEEN 617 AND 710 F. (16, p. 572)

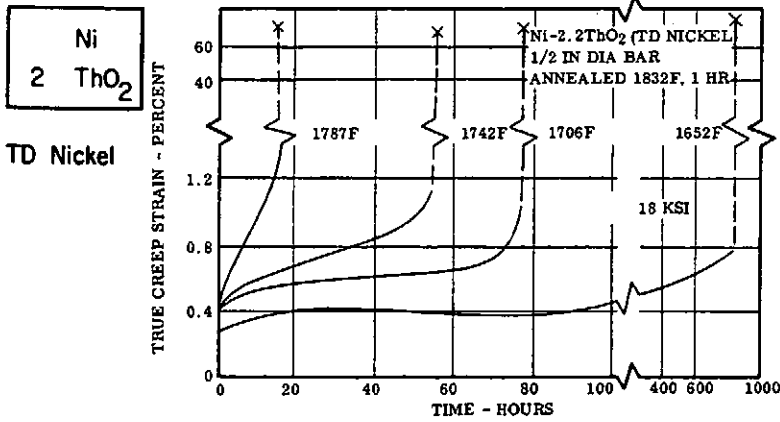


FIG. 3.0414 CREEP CURVES FOR BAR AT 18 KSI AND TEMPERATURES BETWEEN 1652 AND 1787 F. (16, p. 572)

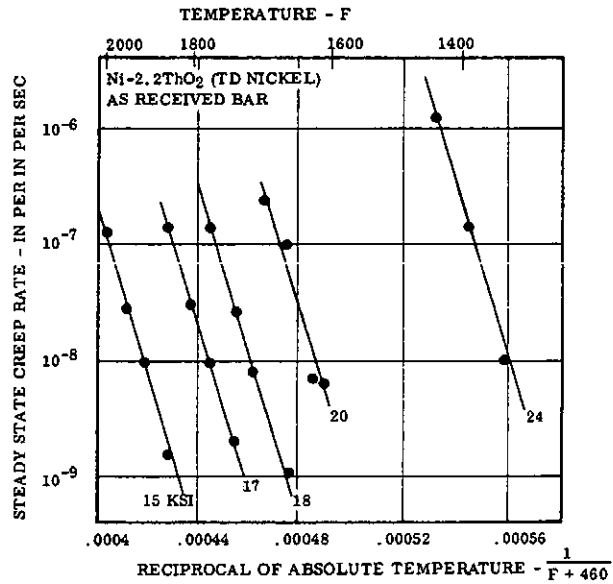


FIG. 3.0416 EFFECT OF TEST TEMPERATURE ON STEADY STATE CREEP RATE OF AS-RECEIVED BAR. (25, p. 29)

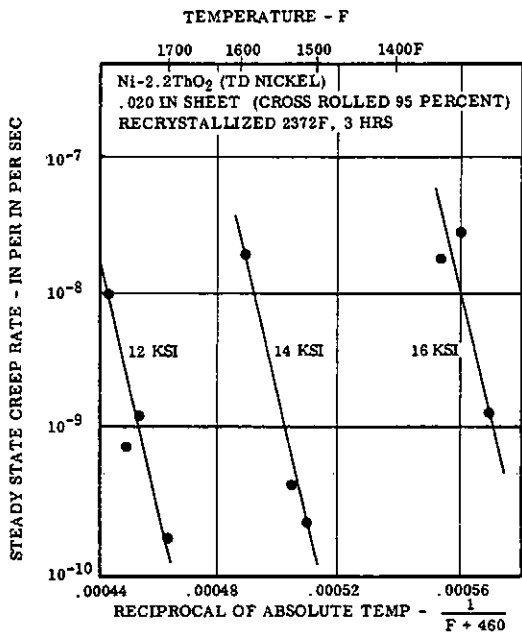


FIG. 3.0415 EFFECT OF TEST TEMPERATURE ON STEADY STATE CREEP RATE OF RECRYSTALLIZED SHEET FOR STRESSES OF 12, 14, AND 16 KSI. (25, p. 20)

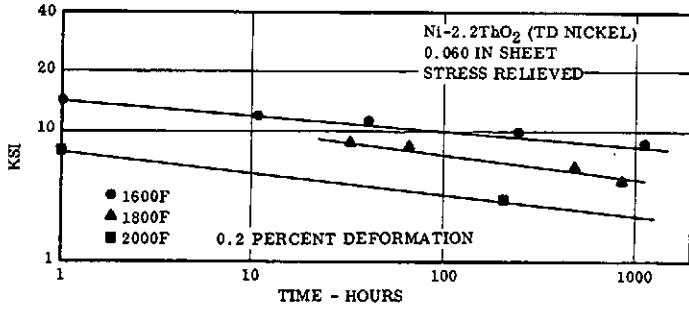
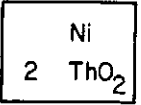


FIG. 3.0417 STRESS TO PRODUCE 0.2 PERCENT DEFORMATION OF STRESS-RELIEVED SHEET AT 1600 TO 2000F. (19, p. 47)



TD Nickel

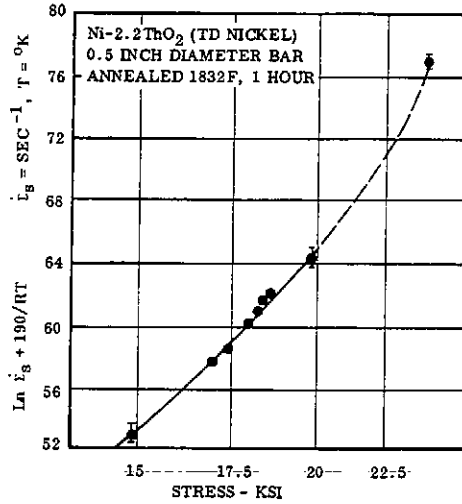


FIG. 3.0419 RELATION BETWEEN STRESS, TEMPERATURE AND MINIMUM CREEP RATE AT ABSOLUTE TEMPERATURES ABOVE HALF THE MELTING POINT. (16, p. 573)

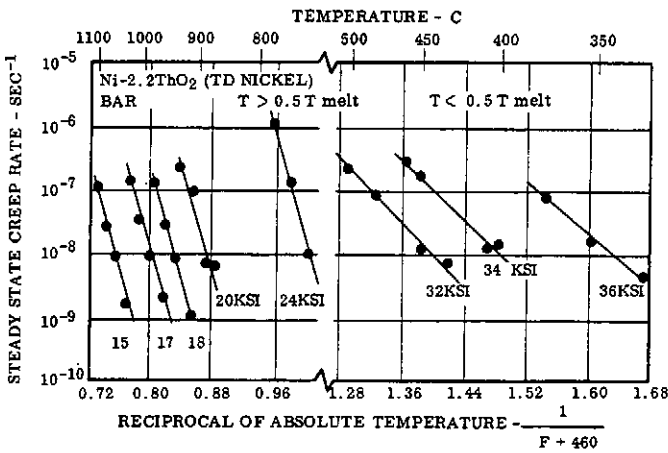


FIG. 3.0418 EFFECT OF STRESS AND TEMPERATURE ON STEADY STATE CREEP RATE OF BAR. (16, p. 572)

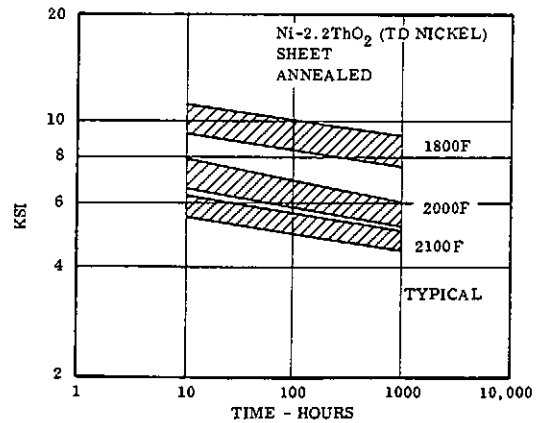


FIG. 3.0421 TYPICAL CREEP RUPTURE RANGES AT 1800 TO 2100F FOR SHEET IN AIR. (1, p. 3)

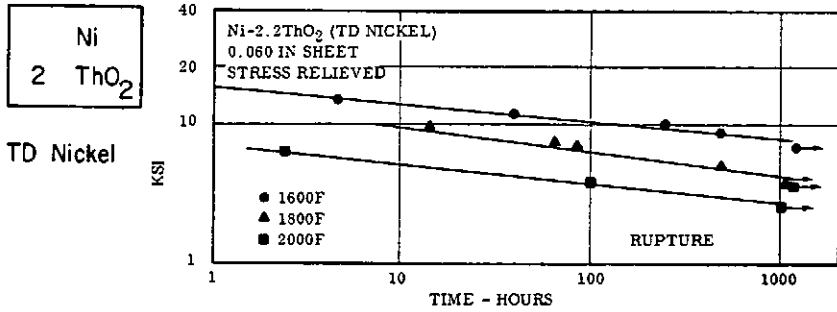


FIG. 3.0422 CREEP RUPTURE CURVES OF STRESS-RELIEVED SHEET AT 1600 TO 2000F. (19, p. 49)

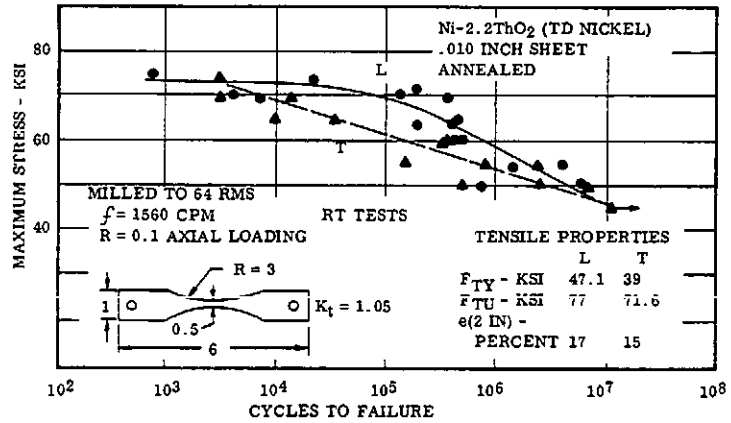


FIG. 3.0511 AXIAL TENSION - TENSION FATIGUE IN LONGITUDINAL AND TRANSVERSE DIRECTIONS FOR ANNEALED .010 INCH SHEET. (47)(24, pp. 16, 17)

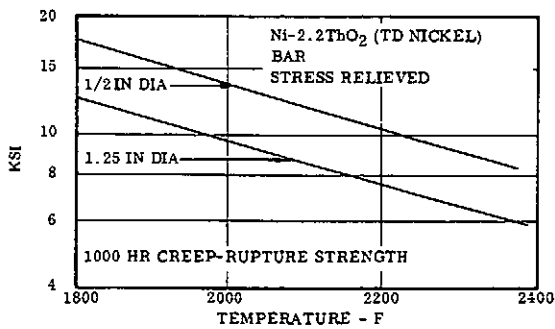


FIG. 3.0423 CREEP RUPTURE CURVES FOR 0.5 INCH AND 1.25 INCH DIAMETER BAR AT TEMPERATURES FROM 1800 TO 2400 F. (2)

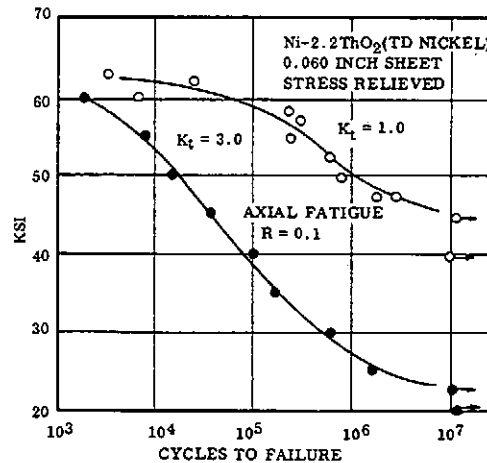
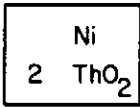


FIG. 3.0512 AXIAL FATIGUE OF SMOOTH AND NOTCHED SHEET. (19, pp. 40, 41)



TD Nickel

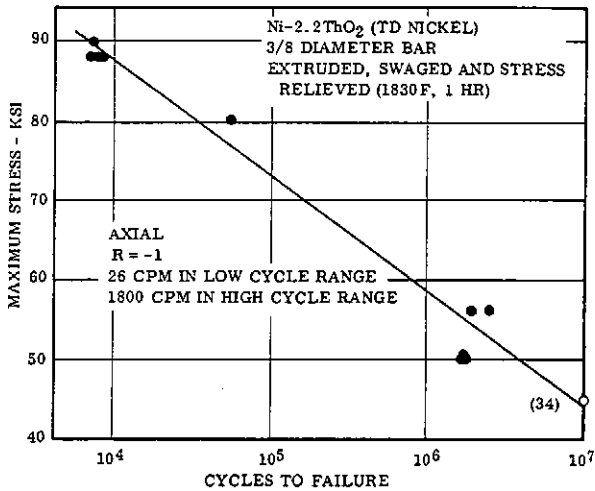


FIG. 3.0513 AXIAL FATIGUE OF BAR UNDER COMPLETELY REVERSED LOADING. (33, p. 722)(34)

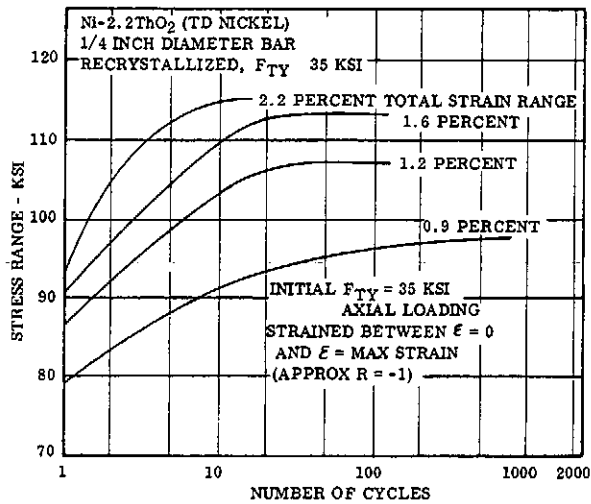


FIG. 3.0515 CYCLIC HARDENING CURVES OF BAR IN AXIAL PUSH-PULL LOADING. (37, p. 1993)

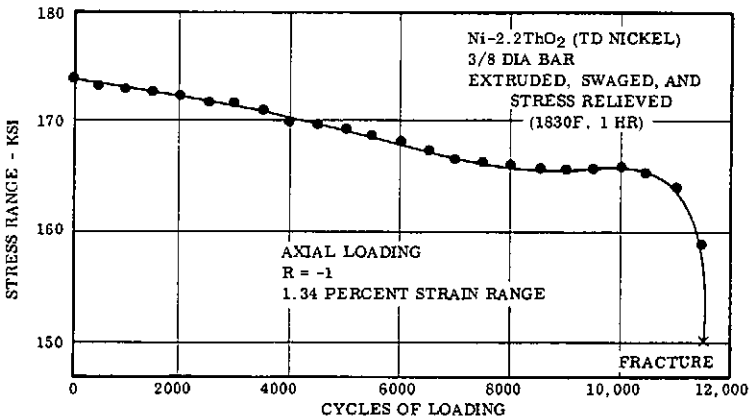


FIG. 3.0514 LOAD VARIATION REQUIRED TO MAINTAIN 1.34 PERCENT STRAIN RANGE IN COMPLETELY REVERSED AXIAL STRAIN CYCLING FOR WORKED BAR. (33, p. 722)

Ni
2 ThO₂

TD Nickel

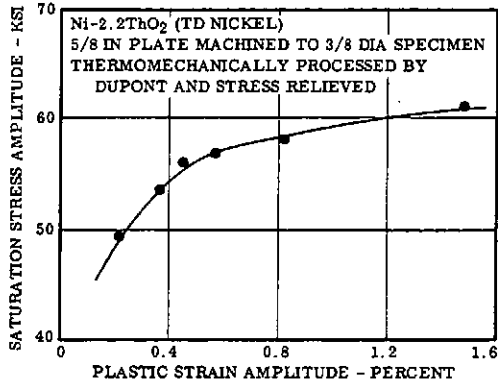


FIG. 3.0516 CYCLIC STRESS-STRAIN CURVE FOR PLATE.
(28, p. 2348)

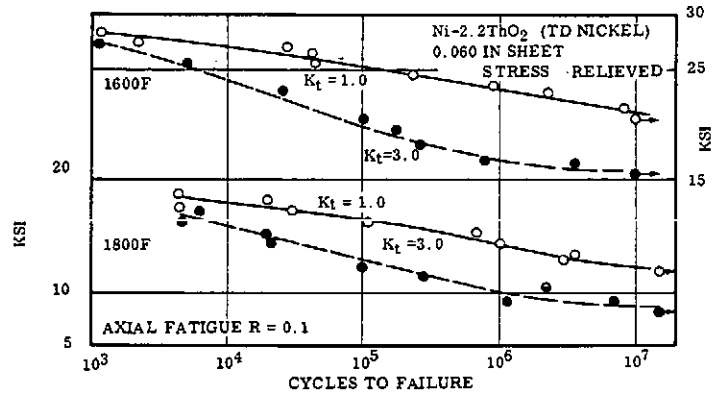


FIG. 3.0522 AXIAL FATIGUE OF SMOOTH AND NOTCHED SHEET AT 1600 AND 1800F.
(19, pp. 40, 41)

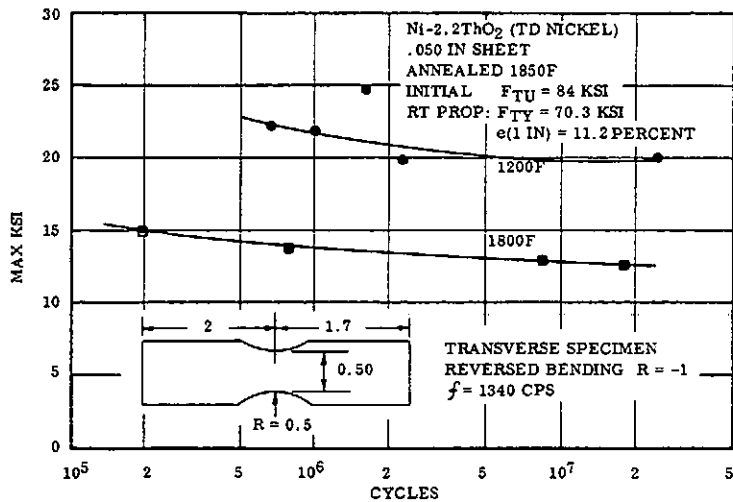
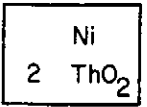
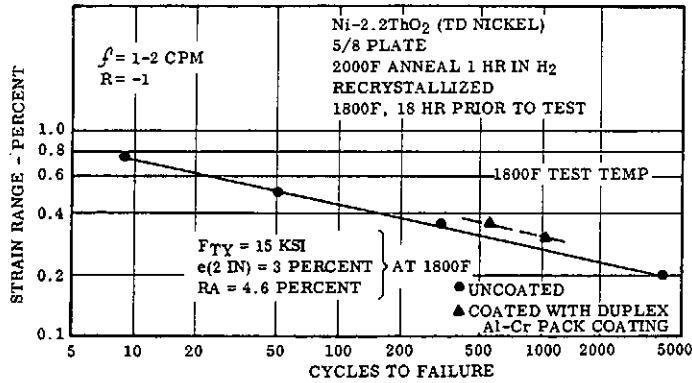


FIG. 3.0521 REVERSED BENDING FATIGUE OF SHEET AT 1200 AND 1800F.
(43, p. 31)



TD Nickel

FIG. 3.0523 LOW CYCLE FATIGUE AT 1800F FOR UNCOATED AND COATED PLATE. (46, p. 2036)

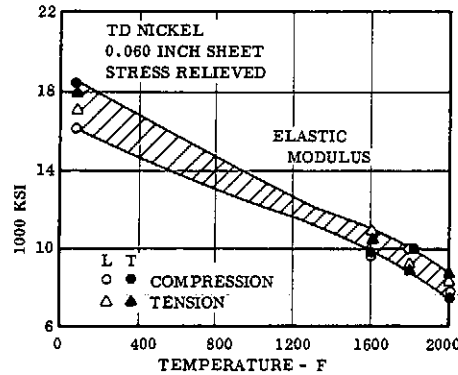


FIG. 3.062 ELASTIC MODULUS AT ROOM AND ELEVATED TEMPERATURES. (19, p. 35)

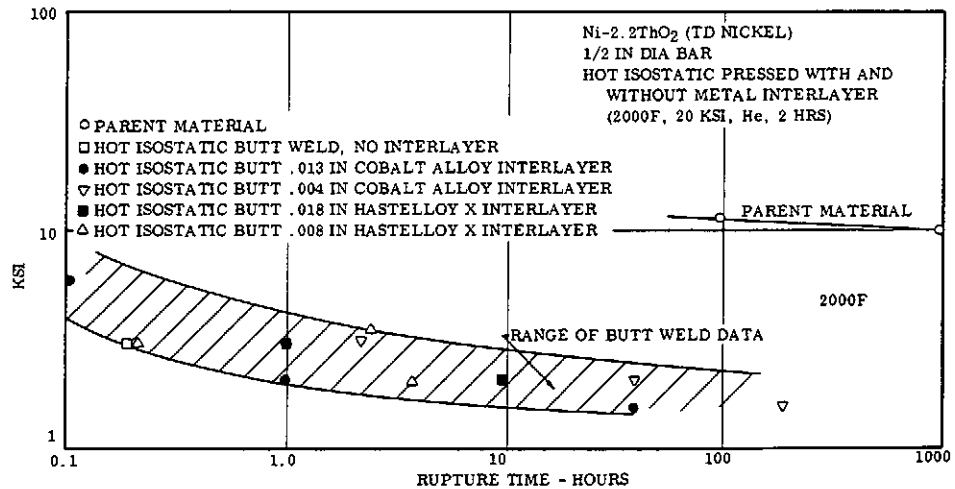


FIG. 4.0322 CREEP-RUPTURE CURVES AT 2000F FOR HOT ISOSTATIC PRESSED BUTT WELDMENTS OF BAR WITH VARIOUS METALLIC INTERLAYERS. (56)

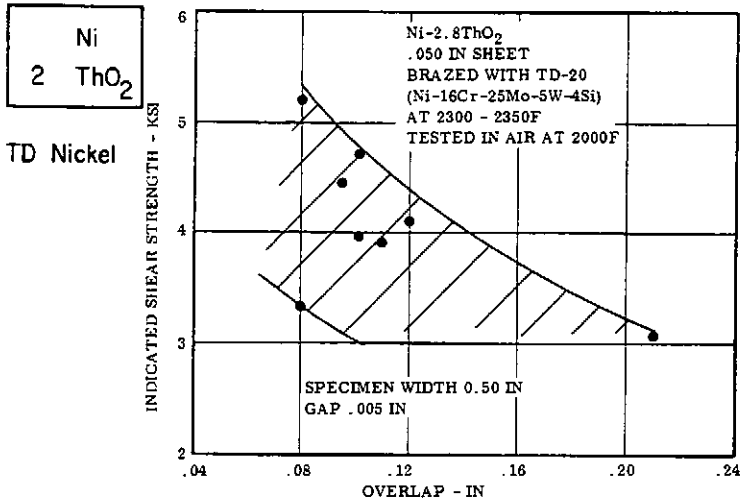


FIG. 4.0332 EFFECT OF OVERLAP ON SHEAR STRENGTH OF BRAZED SHEET AT 2000F. (44, p. 25)

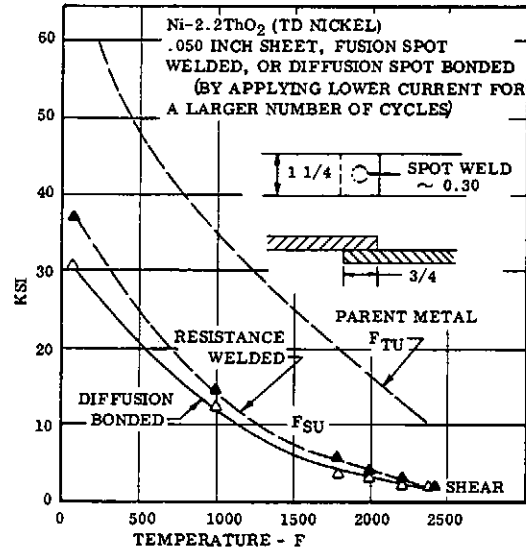


FIG. 4.0334 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF SPOT WELDS OBTAINED BY FUSION AND BY DIFFUSION BONDING. (31, pp. 60, 61)

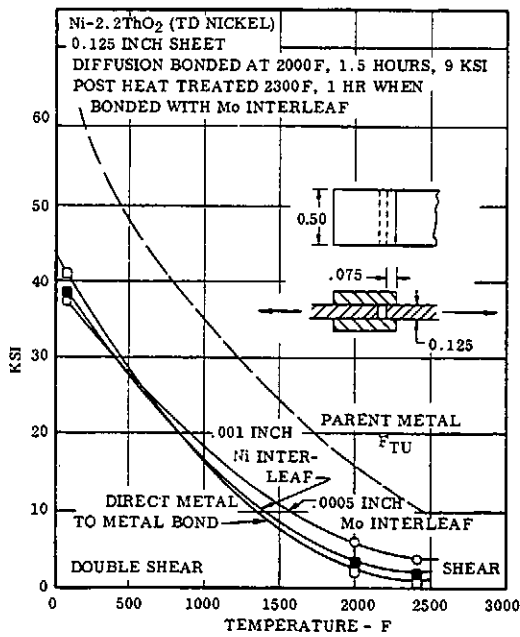


FIG. 4.0333 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH IN DOUBLE SHEAR OF DIFFUSION BONDED SHEET. (31, p. 70)

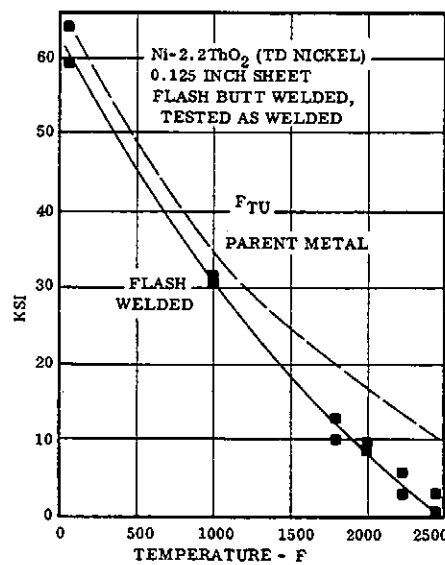


FIG. 4.0335 EFFECT OF TEST TEMPERATURE ON TENSILE STRENGTH OF FLASH WELDED SHEET. (31, p. 96)

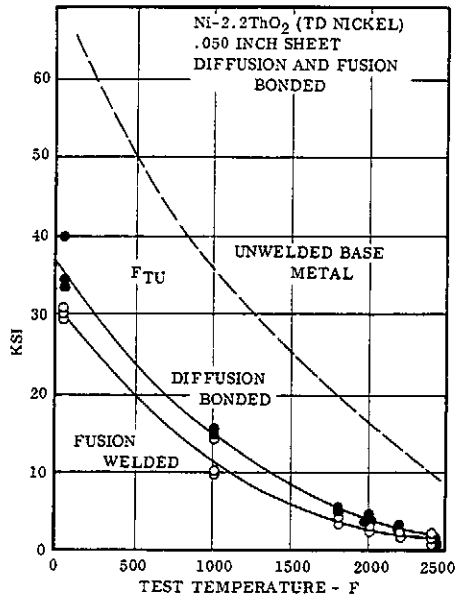


FIG. 4.0336 EFFECT OF TEST TEMPERATURE ON TENSILE STRENGTH OF DIFFUSION BONDED AND FUSION WELDED SHEET. (24, p. 25)

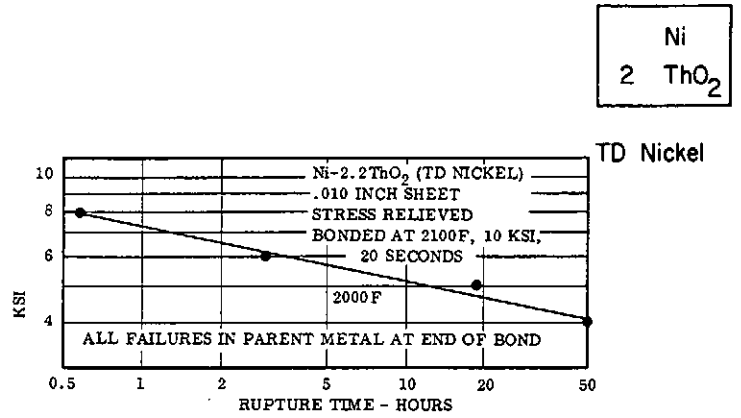


FIG. 4.0338 CREEP RUPTURE CURVE AT 2000F FOR DIFFUSION BONDED SHEET. (40, pp. 30, 102, 177)

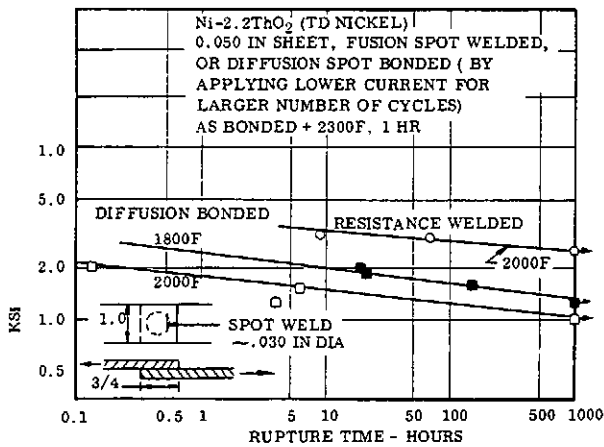


FIG. 4.0337 CREEP-RUPTURE PROPERTIES IN SHEAR AT 1800 AND 2000F FOR .050 INCH SHEET SPOTWELDED BY FUSION OR BY DIFFUSION BONDING FOLLOWED BY HEATING AT 2300F FOR 1 HOUR. (31, p. 165)

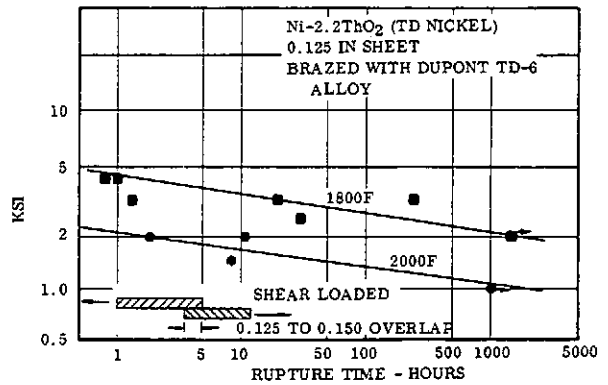
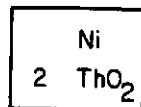


FIG. 4.0339 CREEP-RUPTURE PROPERTIES IN SHEAR AT 1800 AND 2000F FOR 0.125 INCH SHEET WITH 1-T OVERLAP BRAZED WITH TD-6 BRAZING ALLOY. (31, p. 137)



TD Nickel

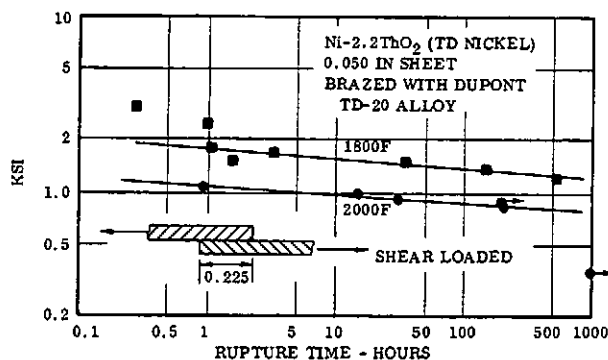
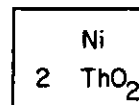


FIG. 4.03310 CREEP-RUPTURE PROPERTIES IN SHEAR AT 1800F AND 2000F FOR .050 INCH SHEET WITH 4.5-T OVERLAP BRAZED WITH TD-20 ALLOY. (31, p. 144)

REFERENCES

1. DuPont Metal Products, "TD-Nickel Sheet-Dispersion Strengthened Metal," A 30682 (April 1963).
2. Anders, F. S., et al., "A Dispersion Strengthened Nickel Alloy," *Metal Progress* (December 1962).
3. Redden, T. K. and Barker, J. F., "Making TD-Nickel Parts," *Metal Progress* (January 1965).
4. General Electric Co., "Development of Joining Technique for TD - Nickel," Contract No. AF33(615)-1403.
5. AiResearch, "Development of Manufacturing Process for a Lightweight Heat Transfer System," Contract No. AF 33 (615) - 1926.
6. Solar, "Diffusion Bonding of TD-Nickel and Refractory Metals," Contract No. AF 33(615)-2304.
7. Doble, G. S. and Quigg, R. J., "Effect of Deformation on the Strength and Stability of TD-Nickel," *Trans. Met. Soc. AIME* 233 (February 1965).
8. DuPont Metal Products, "TD-Nickel Dispersion Strengthened Nickel," A-41076 (February 1965).
9. Inman, M. C., Zwilsky, K. M., and Boone, D. H., "Recrystallization Behavior of Cold-Rolled TD-Nickel," *ASM Trans. Volume 57* (September 1964).
10. VonHelmendahl and Thomas, G., "Substructure and Mechanical Properties of TD-Nickel," *Trans. Met. Soc. AIME* 230 (December 1964).
11. DuPont Metal Products, "The Low Radioactivity Factor of DuPont Metals Containing Thoria," A 41607 (February 1965).
12. Manning, C. R., Jr., Royster, Dick, M., and Braski, D. N., "An Investigation of a New Nickel Alloy Strengthened by Dispersed Thoria," *NASA Technical Note D-1944* (July 1963).
13. DuPont, "Development of Coatings for Protection of Dispersion Strengthened Nickel from Oxidation," Contract No. AF 33(615)-1704.
14. Stuart, R. E. and Starr, "New Design Data on TD-Nickel," *Materials in Design Engineering* (August 1963).
15. Battelle Memorial Institute, "Mechanical Property Data for TD-Nickel," Contract No. AF 33(615)-2494.
16. Wilcox, B. A. and Clauer, A. H., "Creep of Thoriated Nickel Above and Below 0.5 Tm," *Transaction AIME, Volume 236* (April 1966).
17. DuPont New Products Information, "TD-Nickel Machining Recommendations," (July 1965).
18. Stratton, W. K., et al., "Advances in the Materials Technology Resulting from the X-20 Program," *Tech. Report AFML-TR-64-396* (March 1965).
19. Beall, L. G. and Hyler, W. S., "Mechanical Property Evaluations of Newly Developed Structural Materials," *Report No. AFML-TR-66-155* (April 1966).
20. Anon, "Higher Strength, Oxidation Resistance for TD-Nickel," *Materials in Design Engineering, Volume 61, No. 4* (April 1965).
21. DuPont Metal Products, "Typical TD-Nickel Sheet Tensile Data at Cryogenic Temperatures," (January 3, 1963).
22. Roberts, D. A., "Review of Recent Developments in Nickel Base and Cobalt Base Alloys," *DMIC* (October 4, 1963).
23. Metcalfe, A. C., Rose, F. K., Dunning, J. S., and Zumbrennen, A., "Final Report on Diffusion Bonding of Refractory Metals and TD Nickel," Volumes I and II, AFML-TR-64-394, Solar, Division of Int. Harv. Co., San Diego, California (December 1964).
24. Rice, L. P., "Metallurgy and Properties of Thorium-Strengthened Nickel," *DMIC Memo 210* (October 1, 1965).
25. Wilcox, B. A., and Clauer, A. H., "High Temperature Deformation of Dispersion Strengthened Nickel Alloys," *NASA CR-72367* (February 29, 1968).
26. Martin, H. C., Miller, P. C., Ingram, A. G., and Campbell, J. E. "Effects of Low Temperatures on the Mechanical Properties of Structural Metals," *NASA SP-5012(01)* (1968).
27. Inman, M. C., "Recrystallization in Thorium Dispersed Nickel Sheet," AF-AFOSR-669-67 (October 1968) Also submitted to *ASM Transactions*.
28. Leverant, G. R., and Sullivan, C. P., "The Effect of Dispersed Hard Particles on the High Strain Fatigue Behavior of Nickel at Room Temperature," *Transaction AIME, Volume 242* pp. 2347-2352 (November 1968).
29. Moon, D. P. Simon, R. C., and Favor, R. J., "The Elevated Temperature Properties of Selected Superalloys," *ASTM Data series DS 7-S1*.
30. Deel, O. L. and Hyler, W. S., "Engineering Data on Newly Developed Structural Materials," AFML-TR-67-418 (April 1968).
31. Yount, R. E., Kutchera, R. E., and Keller, D. L., "Development of Joining Techniques for TD Nickel," AFML-TR-66-137 (May 1966).
32. E. I. DuPont de Nemours and Company, "Further Development of Coatings for Protection of Dispersion Strengthened Nickel from Oxidation," *Technical Report AFML-TR-67-230* (August 1967).
33. Ham, R. K., and Wayman, M. L. "The Fatigue and Tensile Fracture of TD Nickel," *Transaction AIME, Volume 239*, pp. 721-725 (May 1967).
34. Anders, F. J., Jr., Alexander, G. B., and Wartel, W. S., "A Dispersion-Strengthened Nickel Alloy," *Metal Progress, Volume 82*, pp. 88-91, 118, 120, 122 (December 1962).
35. Inman, M. C., Zwilsky, K. M., and Boone, D. H., "Recrystallization Behavior of Cold Rolled TD Nickel," *Transaction ASM, Volume 57*, pp. 701-712 (1964).

36. Webster, D., "Grain Growth and Recrystallization in Thoria-Dispersed Nickel and Nichrome," Transaction AIME, Volume 242, pp. 640-648 (April 1968).
37. Leverant, G. R., "The Fatigue Behavior of a Dispersion Strengthened Metal," Transaction AIME, Volume 239, pp. 1992-1993 (December 1967).
38. Stuart, R. E., and Starr, C. D., "New Design Data on TD Nickel," Materials Design Engineering, Volume 58, No. 2, pp. 81-85 (August 1963).
39. Clark, A. F., "Low Temperature Thermal Expansion of Some Metallic Alloys," Cryogenics, (October 1968) pp. 282-289.
40. Brentnall, William D, Stetson, Alvin R., and Metcalfe, Arthur G., "Joining of Superalloy Foils for Hypersonic Vehicles," Technical Report AFML-TR-68-299 (October 1968).
41. Christian, J. L., "Mechanical Properties of High Strength Sheet Materials at Cryogenic Temperatures," General Dynamics Astronautics ERR-AN-255 Material Research (November 28, 1962)
42. Mahorter, R. G., "Evaluation of TD Nickel," Report No. NAE-AML-1654, Naval Air Engineering Center, Aeronautical Materials Laboratory, Philadelphia, Pennsylvania (April 3, 1963).
43. Barker, J. F., and Erdeman, V. J., "Mechanical Property Evaluation of TD (2 percent ThO₂) Nickel Alloy Sheet and Bar," G. E. Evendale Report No. R64FPD33 (March 15, 1964).
44. General Electric Company, "Development of Joining Techniques for TD Nickel," Interim Progress Report No. 5-8-211 for Period May 1 to August 1, 1965, Contract No. AF 33(615)-1403, Project No. 8-211.
45. White, J. E., and Carnahan, R. D., "A Microplasticity Study of Dispersion Strengthening in TD Nickel," AIME Transaction, Volume 230 (October 1964), pp. 1298-1303.
46. Leverant, G. R., and Sullivan, C. P., "The Low-Cycle Fatigue of TD Nickel at 1800F," AIME Transaction, Volume 245, (October 1969), pp. 2035-2039.
47. Douglas Aircraft Co., Preliminary Data to DMIC.
48. Sovik, J. H., Clauer, A. H., Maringer, R. E., and Wilcox, B. A., "High Temperature Internal Friction of TD Nickel," Transaction AIME, Volume 245, pp. 1943-1946 (September 1969).
49. AMD 55 DG (November 1, 1967).
50. AMD 56 DH (November 1, 1968).
51. Hill, V. L., Misra, S. K., and Wheaton, H. L., "Development of Ductile Claddings for Dispersion-Strengthened Nickel Base Alloys," NASA-CR-72522 (Contract with ITRI)(October 30, 1968).
52. Jones, D. A. and Westerman, R. E., "Oxidation of a Nickel 2Percent ThO₂ Alloy and the Logarithmic Rate Law of Oxidation," Report No. HW 79350, G. E., Richland, Washington, Under AEC Contract AT (45-1)-1350 (October 1963).
53. DuPont Company, "TD Nickel Dispersion Strengthened Nickel," Report A-41076.
54. Pettit, E. S. and Felton, E. J., "The Oxidation of Nickel 2ThO₂ Between 900 and 1400C," Electrochem. Soc. Journal, Volume III, No. 2, pp. 135-139 (February 1964).
55. Grekila, R. B., Chapman, J. W., and Mattox, D. M., "Development and Evaluation of Controlled Viscosity Coatings for Superalloys," NASA-CR-72520 (Westinghouse Research Labs)(August 31, 1969).
56. Moore, Thomas J. and Holko, K. H., "Solid State Welding of TD Nickel Bar," NASA TN D-5918 (July 1970).
57. Burns, R. M. and Bradley, W. W., "Protective Coatings for Metals," Sec Ed, Rhinehold Publishing Corp. (New York)(1955).



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