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NONFERROUS ALLOYS

Ni
18 Cr
2 ThO_2

TD NiCr

1. GENERAL

TD NiCr is a further development of the TD Ni dispersion strengthened system (see Code 4115) to produce an alloy with useful creep strength up to 2200F combined with good oxidation resistance. The materials is produced by a proprietary powder metallurgical process. The powder is processed to dense mill shapes by extrusion, forging or roll consolidation. Thermomechanical processing is the preferred method for breakdown of these consolidated slabs to produce sheet with the best high temperature strength. This process involves heavy reductions ($\approx$ 90 percent) at 1200 to 1500F followed by annealing at 2150F. The resulting structure possesses an oriented texture, primarily cubic with grain aspect ratios of about 3:1 to 6:1. Other processes of breakdown have been employed involving cold reduction alone or combinations of warm and cold work but these do not appear capable of producing as high an elevated temperature strength as the previously described thermomechanical processing. It should be noted that the mechanical properties of the alloy will be a strong function of the processing history.

This alloy has excellent elevated temperature strength properties in the temperature range between 1800 and 2200F and is a candidate for such applications as reentry heat shields and burner hardware in advanced turbines. It is difficult to fusion weld with out seriously impairing its high temperature strength, however brazing has been used in the manufacture of turbine hard ware. Oxidation under cyclic temperature or dynamic airflow conditions leads to a degradation of tensile properties. Considerable scatter is observed in the tensile and creep properties and very low values of elongation characterize those processing conditions producing the highest elevated temperature strength. It is expected that with further development the variability of mechanical properties will be reduced.

1.01 Commercial Designation
TD NiCr

1.02 Alternate Designations
None.

1.03 Specifications
1.031 AMI 11 (14).
1.032 Company Specification. Fansteel Product specifications S-TC-S-01-R-1 December 1, 1969. S-DMM-S-01-R-0 January 1, 1969.

1.04 Composition
Table 1.04.

1.05 Heat Treatment
(see also GENERAL)
1.051 Recrystallization anneal or stress relief 2150 to 2200F, 2 hr in H_2.

1.06 Hardness

1.07 Forms and Conditions Available
Table 1.07.

1.08 Melting and Casting Practice
(see GENERAL)

1.09 Special Considerations (see also 2.03 and 4.03)
Considerable scatter chacterizes the reported strength values for TD NiCr sheet and foil at both room and elevated temperature. The producer's specified properties for thermomechanically processed sheet are at the lower end of the scatter band at room temperature and near the midpoint at elevated temperatures (compare Table 3.011 with Table 3.0212 and Figure 3.0314). It is likely that the specified minimum properties will change with further development of the alloy.

Processing conditions producing high strength at elevated temperatures result in low values of tensile elongation for sheet (see Figure 3.0314) and low reduction in area values for bar (see Figure 3.0316). At 2200F creep rupture specimens of thermomechanically processed materials exhibit essentially zero elongation (see Figure 3.042). Mild notch tests on sheet with an unspecified processing history exhibited notch weakening at 2200F (see Table 3.03711). The significance of these low values of ductility on the fracture toughness should be determined by suitable tests using specimens containing fatigue cracks.

Material which has been cold worked or thermomechanically processed to obtain high strength at elevated temperatures exhibits considerable directionality with the transverse direction being of lower strength in tensile and creep rupture tests (see Table 3.0313, Figures 3.042 and 3.044).

TD NiCr is slightly radioactive due to the ThO_2 content. It is an alpha emitter and requires precautions be taken if dust is generated by dry grinding.

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties
2.011 Melting range. 2550 to 2600F (2).
2.012 Phase changes. None.
2.013 Thermal conductivity.
2.0131 Thermal conductivity of bar, Figure 2.0131.
2.014 Thermal expansion.
2.0141 Effect of temperature on mean coefficient of thermal expansion, Figure 2.0141.
2.015 Specific heat.
2.016 Thermal diffusivity.

2.02 Other Physical Properties
2.021 Density. 0.306 lb per cu in (8.41 gm per cu cm).
2.022 Electrical properties.
2.0221 Electrical resistivity, 42.5 microhm-in.
2.023 Magnetic properties. Alloy is not ferromagnetic.
2.024 Emittance.
2.0241 Effect of temperature and surface preparation on total hemispherical emittance, Figure 2.0241.
2.025 Damping capacity.

2.03 Chemical Properties
2.031 General. The general corrosion resistance has not been reported but should be at least as good as TD Nickel (Code 4115). The alloy has exceptionally good oxidation resistance and in this respect is superior to TD Nickel.
2.032 Oxidation. In cyclic exposure to still air (760 torr) at 2200F the alloy shows very little weight gain in several hundred hours and is much superior to conventional superalloys in this respect (see Figure 2.0321). However, under cyclic dynamic conditions (arc jet) oxidation appears to be more rapid (see Figure 2.0322) and specimens subjected to these conditions exhibit internal porosity (6). Cyclic oxidation at 2200 and 2400F in 760 torr air produces losses in both retained room temperature and elevated temperature tensile strength and elongation values (see Table 2.0323).
2.0321 Effect of cyclic oxidation on weight gain for TD NiCr and Hastelloy X sheet, Figure 2.0321.
2.0322 Low pressure dynamic and static oxidation results for sheet tested at 2200F, Figure 2.0322.
2.0323 Tensile properties of sheet at room and elevated temperatures after elevated temperature cyclic exposure, Table 2.0323.

2.04 Nuclear Properties

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties
3.011 AMI and producers specified mechanical properties, Table 3.011

Ni
18 Cr
2 ThO_2

TD NiCr

3.02 Mechanical Properties at Room Temperature (see also 3.03)
3.021 Tension.
3.0211 Stress-strain diagrams.
3.0212 Average and spread of tensile properties for sheet, Table 3.0212.
3.0213 Average and spread of tensile properties for foil, Table 3.0213.
3.0214 Effect of cold work on tensile properties of extruded bar, Figure 3.0214.
3.023 Impact.
3.024 Bending.
3.025 Torsion and shear.
3.026 Bearing.
3.027 Stress concentration.
3.0271 Notch properties (see 3.037).
3.0272 Fracture toughness.
3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures
3.031 Tension.
3.0311 Stress-strain diagrams.
3.0312 Average and spread of tensile properties for foil at 2000F, Table 3.0312.
3.0313 Average and spread of tensile properties of foil at 2200F, Table 3.0313.
3.0314 Spread of elevated temperature tensile properties for annealed sheet and the effect of exposure on these properties, Figure 3.0314.
3.0315 Effect of angle between testing direction and rolling direction on 2000F tensile properties of sheet, Figure 3.0315.
3.0316 Effect of cold work on 2000F tensile properties of extruded bar, Figure 3.0316.
3.033 Impact.
3.034 Bending.
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration.
3.0371 Notch properties.
3.03711 Mild notch strength ratio of sheet at room and elevated temperatures, Table 3.03711.
3.0372 Fracture toughness (see 1.09).
3.038 Combined properties.

3.04 Creep and Creep Rupture Properties (see also Figure 3.053)
3.041 Effect of temperature on 100 hr creep rupture strength of sheet showing spread of data from various sources, Figure 3.041.
3.042 Short time creep rupture curves at 2200F for sheet, Figure 3.042.
3.043 Effect of temperature on stress to produce various amounts of total creep in 100 hours for sheet, Figure 3.043.
3.044 Effect of angle between testing and rolling direction on 2000F, 100 hr rupture strength of sheet, Figure 3.044.
3.045 Effect of stress on 2000F minimum creep rate of extruded and cold worked rod, Figure 3.045.
3.046 Creep rupture curves at 2000F for extruded and cold worked rod, Figure 3.046.

3.05 Fatigue Properties
3.051 Room and elevated temperature fatigue strength of sheet, Table 3.051.
3.052 Flexural fatigue resistance of sheet strain cycled at 2200F, Figure 3.052.
3.053 Static and cyclic creep rupture of sheet, Figure 3.053.

3.06 Elastic Properties
3.061 Poissons ratio.
3.062 Modulus of elasticity.
3.0621 Elastic modulus in tension at elevated temperatures, Figure 3.0621.
3.0622 Effect of testing direction with respect to rolling direction on room temperature and 2000F tension modulus of sheet, Figure 3.0622.

4. FABRICATION

4.01 Formability
4.011 General. Only a limited amount of experience has been obtained with forming this alloy. A summary of available information is given by Holko (6). In simple bending a radius of at least 3T should be used to avoid cracking. Various configurations and shapes have been made from TD NiCr sheet, these include rib stiffened panels, honeycomb core segments, turbine vane air foils and flame holders (6)(7).

4.02 Machining and Grinding
(see TD Nickel, Code 4115)

4.03 Welding and Brazing
4.031 General. Very little experience has been obtained on the mechanical properties of welded or brazed joints. Fusion welding produces segregation and agglomeration of ThO_2 particles and the loss of the strengthening effect of prior thermomechanical processing. These effects result in 30 to 50 percent joint efficiencies in short time elevated temperature testing (6). Resistance spot welding has been used to successfully join sheet but ThO_2 agglomeration was noted in the fusion zone (6). Solid state welding using the hot vacuum press process with special surface preparation apparently can produce welds in sheet in which the deleterious effects associated with fusion welding are substantially reduced. Thus, using this technique to produce lap joints 100 percent shear joint efficiencies have been achieved in 2000F creep rupture tests (6). Conventional resistance heating has been used to produce solid state welds; however, recrystallization was encountered at the weld line (6).

Brazing with a Hastelloy-C (+4 percent Si) alloy has been used to produce airfoil shapes but various difficulties are evident: (1) Si diffusion with the TD NiCr causes ThO_2 agglomeration. (2) The brazing time is critical and too long times produce errosion of the TD NiCr. (3) This braze alloy has a lower strength at high temperatures than TD NiCr and may become porous at these temperatures (6). Other brazing processes will likely be subject to one or more of these difficulties.

4.05 Surface Treatment
4.051 Scale removal. Acid pickling can be used to remove light oxide scale (see Table 4.0511).
4.0511 Solutions used for acid pickling, Table 4.0511.

TABLE 1.04

Alloy	TD NiCr			
Source	(6)		(2)	
	Percent		Percent	
Element	minimum	maximum	minimum	maximum
Chromium	18	22	18.00	22.00
Thoria	1.8	2.6	1.50	3.00
Carbon	-	0.05	-	0.05
Sulphur	-	0.015	-	0.015
Nickel	Balance		Balance	

Ni
18 Cr
2 ThO_2

TD NiCr

TABLE 1.07

Source	(3)		
Alloy	TD NiCr		
Form	Sheet*		
Thickness - in	0.010 to 0.030	0.040 to 0.050	0.060 to 0.075
Width - in	18	20	22
Length - in	36	48	48
* Plate and foil (< 0.010 in) available on special order.			

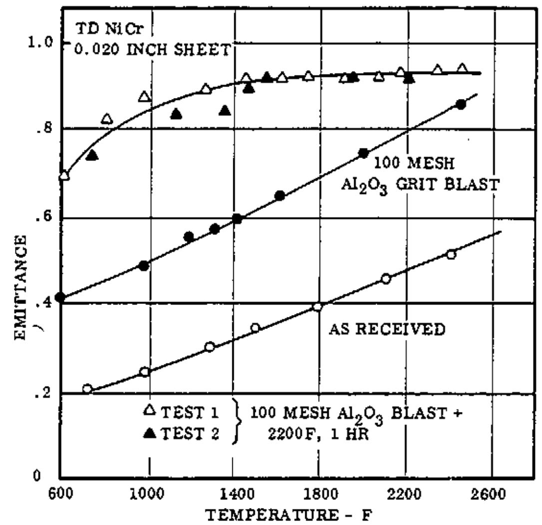


FIG. 2.0241 EFFECT OF TEMPERATURE AND SURFACE PREPARATION ON TOTAL HEMISPHERICAL EMITTANCE. (7, p. 77)

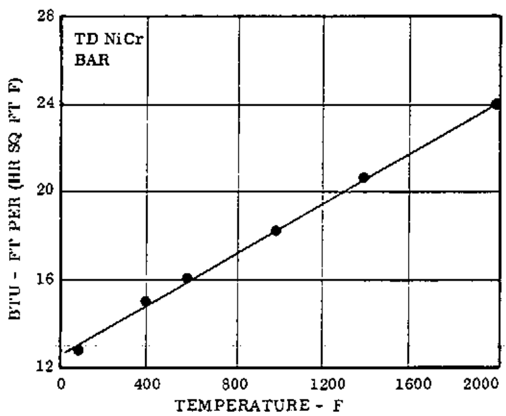


FIG. 2.0131 THERMAL CONDUCTIVITY OF BAR. (3)

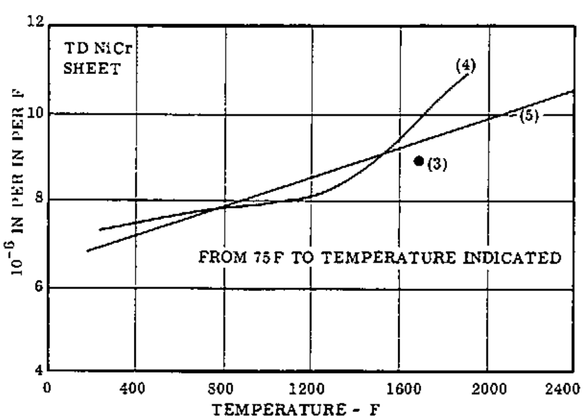


FIG. 2.0141 EFFECT OF TEMPERATURE ON MEAN COEFFICIENT OF THERMAL EXPANSION. (3)(4)(5)

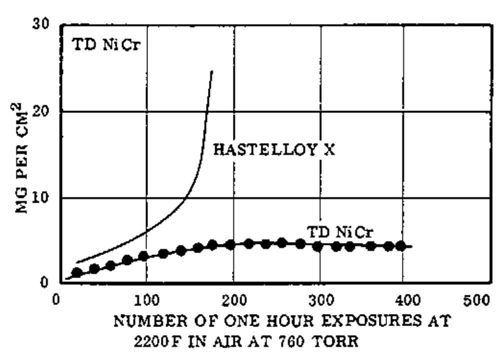


FIG. 2.0321 EFFECT OF CYCLIC OXIDATION ON WEIGHT GAIN FOR TD NiCr AND HASTELLOY X SHEET. (3)

Ni
18 Cr
2 ThO_2

TD NiCr

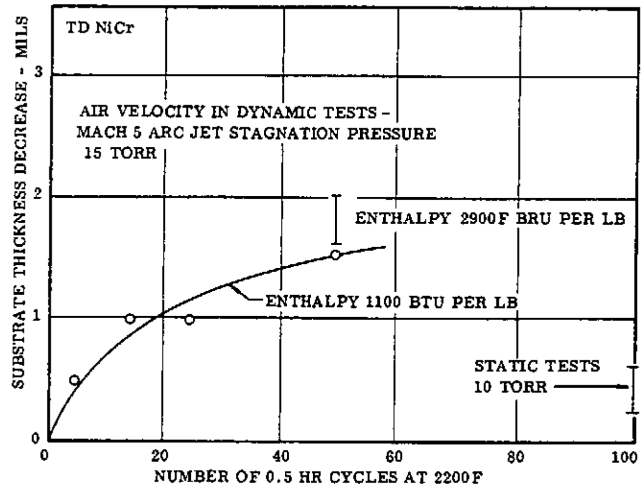


FIG. 2.0322 LOW PRESSURE DYNAMIC AND STATIC OXIDATION RESULTS FOR SHEET TESTED AT 2200 F. (12)

TABLE 2.0323

Source	(8, p. 56)									
Alloy	TD NiCr									
Form	0.010 inch Sheet									
Condition	Stress Relieved, L									
Exposure*	None				100 cycles at 2200F and 760 torr			100 cycles at 2400 F, 760 torr		100 cycles at 2400 F, 0.18 torr
Test Temp- F	RT	1600	2000	2200	RT	1600	2200	RT	1600	RT
F_{tu} - ksi	136	31.3	16.4	14.4	126	24.5	12.2	125	24	115
F_{ty} - ksi	90	31.3	16.1	-	83	24.1	-	77	24	82
e(2 in) percent	15	1.1	0.2	0.2	10.3	0.2	0.15	12	0.3	8

* Time at (max cyclic temperature - 50 F) was 12 and 13 minutes for 2200 and 2400 F max temperatures respectively. Pressure = 760 torr air.

TABLE 3.0212

Source	(1)
Alloy	TD NiCr
Form	0.010 to 0.063 in sheet
Condition	Warm roll + anneal, L and T
F_{tu} - avg, ksi	130
Spread ksi	96-148
F_{ty} - avg, ksi	90
Spread ksi	73-103
e(2 in) -avg, percent	16
Spread percent	11-20

TABLE 3.0213

Source	(1)							
Alloy	TD NiCr							
Form	Foil							
Condition	0.010 or 0.020 in sheet rolled 50 percent at 1300 to 1500 F + 2200 F (H_2) +				0.020 in sheet rolled 75 percent at 1300 to 1500 F + 2200 F (H_2) +			
	55 to 64 percent CR		44 to 58 percent CR		60 percent CR		40 to 44 percent CR	
Thickness, in	0.004		0.005		0.002		0.003	
Data Points *	8	8	12	12	5	5	3	3
Direction	L	T	L	T	L	T	L	T
F_{tu} - avg - ksi	130	130	130	131	126	134	129	128
Spread ksi	103-139	119-145	124-138	119-139	121-131	129-142	128-129	122-137
F_{ty} - avg - ksi	98	100	99	101	96	104	104	98
Spread ksi	82-104	94-111	84-108	84-109	87-100	98-121	89-115	92-109
e( ) - avg-percent	12	14	9	9	9	9	7	7
Spread percent	6-18	3-18	6-14	6-14	6-13	3-13	5-9	4-10

* Number of specimen results included in average and spread.

TABLE 3.011

Alloy	TD NiCr					
Form	Sheet					
Thickness - in	0.020 to 0.075				0.010 to < 0.020	
Source	AMI 11(13)		(2)		(2)	
Temperature - F	RT	2000	RT	2000	RT	2000
F_{tu} - min - ksi(a)	115	15	110	15	100	10
F_{ty} - min - ksi	75	-	75	-	65	-
e(1 in)-min-percent	10	2	10	1	8	1
20 hr - min - rupture life at ksi	-	5.5(b) or 6.0	-	5.5	-	4

(a) AMI specifies tensile tests in L direction for widths <9 inches and T direction for widths >9 inches. Producer specifies all T properties.

(b) AMI gives 5.5 ksi for 0.020 <Thickness < 0.040 inch and 6.0 ksi for 0.075< thickness <0.075 inch

Ni
18 Cr
2 ThO_2

TD NiCr

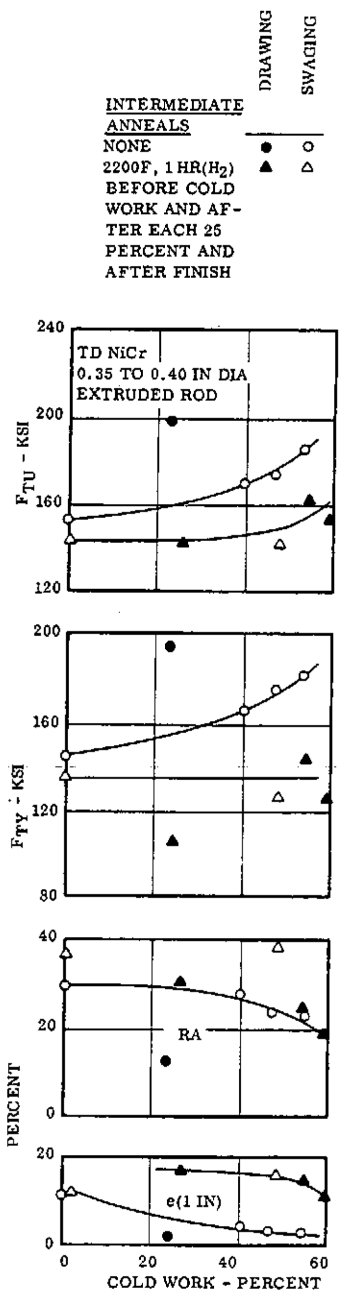


FIG. 3.0214 EFFECT OF COLD WORK ON TENSILE PROPERTIES OF EXTRUDED BAR. (14, Tbl 14)

TABLE 3.0312

Source	(1, pp. 81-83)					
Alloy	TD NiCr					
Form	Foil					
Test Temperature	2000F					
Condition	Same as Table 3.0213					
Thickness - inch	0.005		0.002		0.004	
Data Points*	12	14	6	6	8	10
Direction	L	T	L	T	L	T
F_{tu} - Avg - ksi	11.6	9.3	15.4	13.1	9.7	8.0
Spread - ksi	8.9-16.1	6.4-12.1	13.3-17.8	11.7-16.4	8.4-10.7	6.9-10.0
F_{ty} - avg - ksi	11.1	8.8	15.2	13.0	9.1	7.6
Spread - ksi	8.1-15.4	7.5-11.4	13.1-17.7	11.4-16.4	7.6-10.5	6.4-9.6
e( ) avg-percent	24.2	22.6	2.5	5.3	27	33.2
Spread - percent	2.2-80	1.8-88	1-5	0-17.5	4.1-47	7.6-51
* Number of specimen results included in average and spread.						

TABLE 3.0313

Source	(1, pp. 86-88)					
Alloy	TD NiCr					
Form	Foil					
Test Temp	2200F					
Condition	Same as Table 3.0213					
Thickness - in	0.005		0.004		0.002	
Data Points	11	11	8	8	6	6
Direction	L	T	L	T	L	T
F_{tu}-avg-ksi	8.7	6.8	7.3	6.3	11.6	9.7
Spread - ksi	6.4-11.0	5.8-8.1	6.4-8.7	5.6-7.0	-	-
F_{ty}-avg-ksi	8.5	6.7	7.2	6.2	11.5	9.7
Spread - ksi	6.4-10.5	5.5-7.3	6.1-8.7	5.4-6.9	-	-
e( )-avg-percent	34	41	57	77	9.8	25.6
Spread - percent	2.0-111	2.2-127	5.8-86	53-95	-	-

Ni
18 Cr
2 ThO_2

TD NiCr

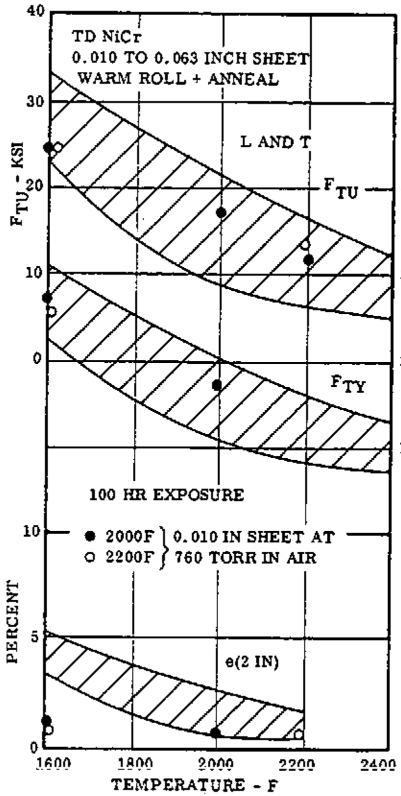


FIG. 3.0314 SPREAD OF ELEVATED TEMPERATURE TENSILE PROPERTIES FOR ANNEALED SHEET AND THE EFFECT OF EXPOSURE ON THESE PROPERTIES. (6)

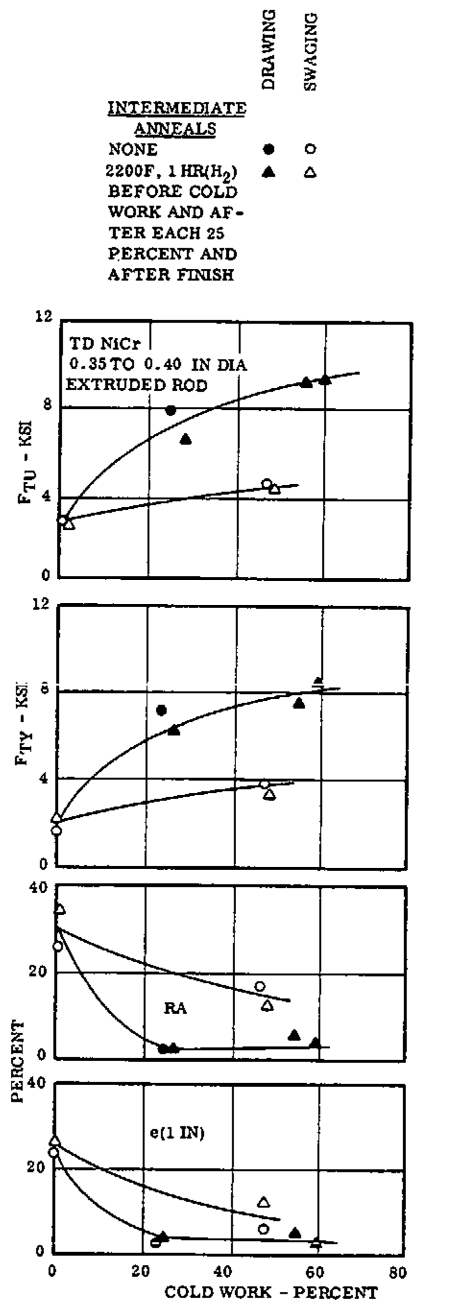


FIG. 3.0316 EFFECT OF COLD WORK ON 2000F TENSILE PROPERTIES OF EXTRUDED BAR. (14, Table 14)

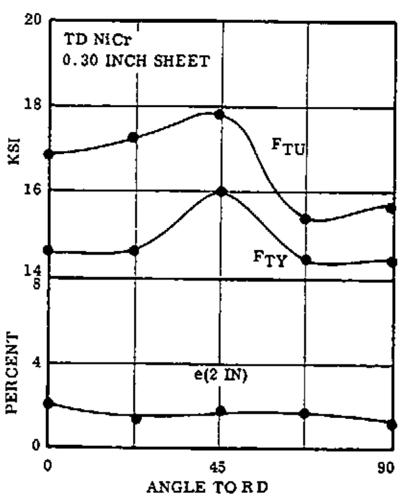


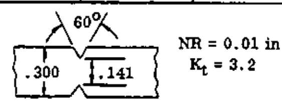
FIG. 3.0315 EFFECT OF ANGLE BETWEEN TESTING DIRECTION AND ROLLING DIRECTION ON 2000F TENSILE PROPERTIES OF SHEET. (9)

Ni
18 Cr
2 ThO_2

TD NiCr

TABLE 3.03711

Source	(8, pp. 56 and 65)		
Alloy	TD NiCr		
Form	0.010 inch sheet		
Condition	Stress Relieved		
Test Temp F	RT	1600	2200
F_{tu} - ksi	136	31	14
NSR*	0.90	0.95	0.77



* Notch Tensile Specimen

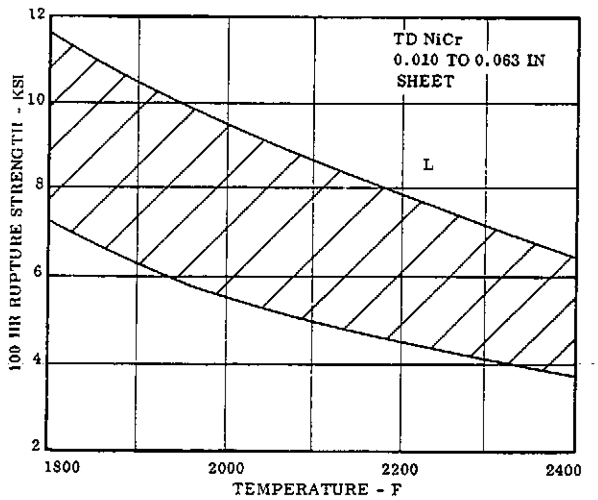


FIG. 3.041 EFFECT OF TEMPERATURE ON THE 100 HOUR CREEP RUPTURE STRENGTH OF SHEET SHOWING SPREAD OF DATA FROM VARIOUS SOURCES (6)

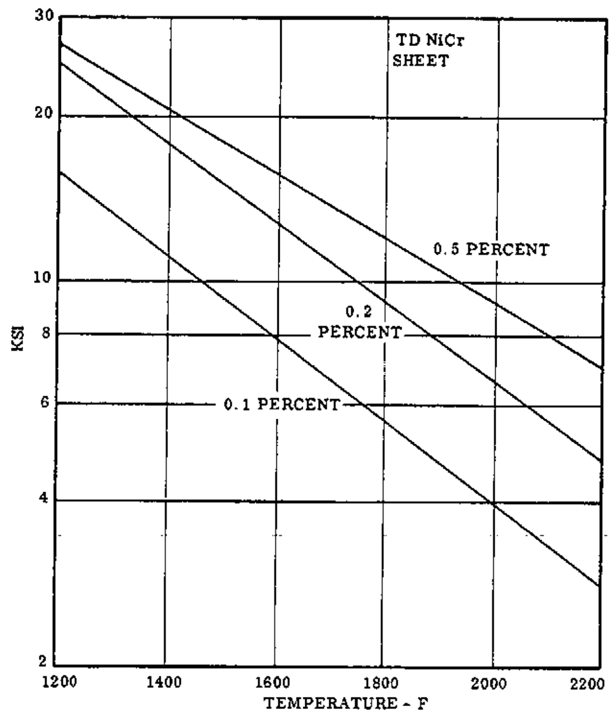


FIG. 3.043 EFFECT OF TEMPERATURE ON STRESS TO PRODUCE VARIOUS AMOUNTS OF TOTAL CREEP IN 100 HOURS FOR SHEET. (6)

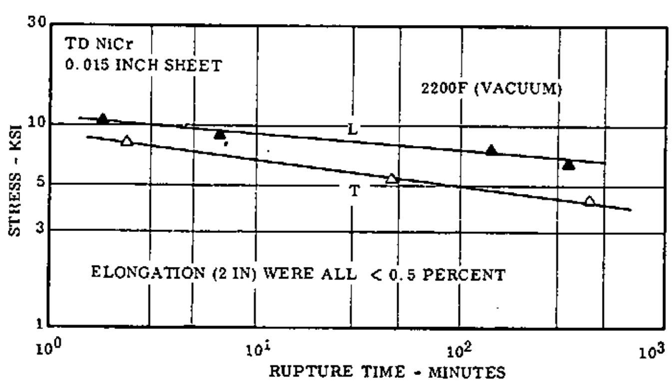


FIG. 3.042 SHORT TIME CREEP RUPTURE CURVES AT 2200F FOR SHEET. (11)

Ni
18 Cr
2 ThO_2

TD NiCr

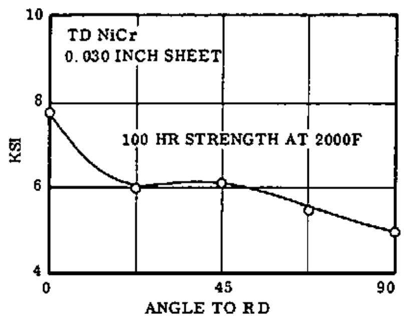


FIG. 3.044 EFFECT OF ANGLE BETWEEN TESTING AND ROLLING DIRECTION ON 2000F, 100 HOUR RUPTURE STRENGTH OF SHEET. (9)

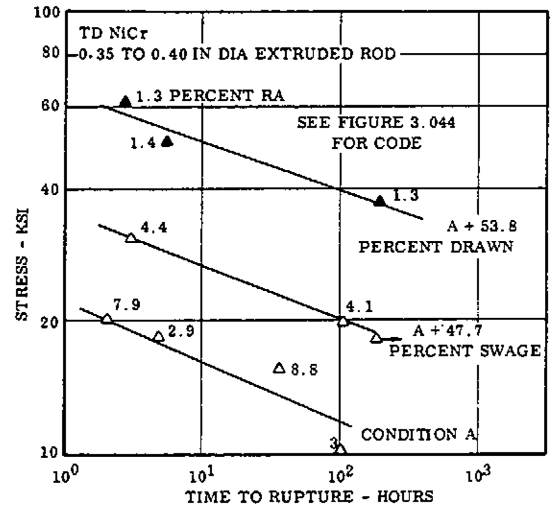


FIG. 3.046 CREEP RUPTURE CURVES AT 2000F FOR EXTRUDED AND COLD WORKED ROD. (14, p. 110)

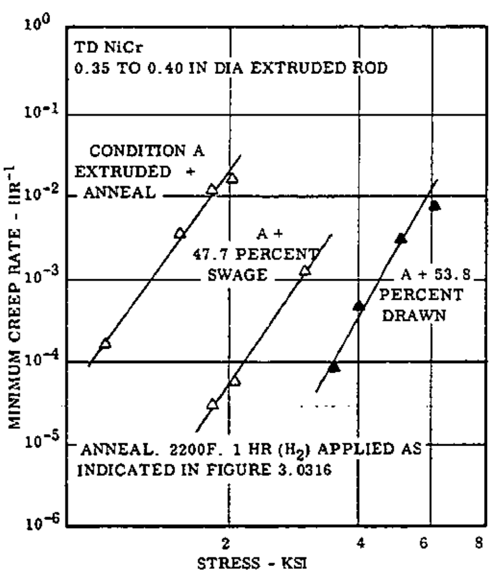


FIG. 3.045 EFFECT OF STRESS ON 2000F MINIMUM CREEP RATE OF EXTRUDED AND COLD WORKED ROD. (14, p 112)

TABLE 3.051

Source	(8)							
Alloy	TD NiCr, T							
Form	0.010 inch Sheet							
Method	Stress Ratio R	Stress Conc	Frequency cpm	Temp F	Fatigue strength - ksi at cycles			
					5×10^4	10^5	10^6	5×10^7
Axial Load	0.15	K_t=1	1020	RT	110	90	80	70
			3000	1600	31	30	29	-

Ni
18 Cr
2 ThO_2

TD NiCr

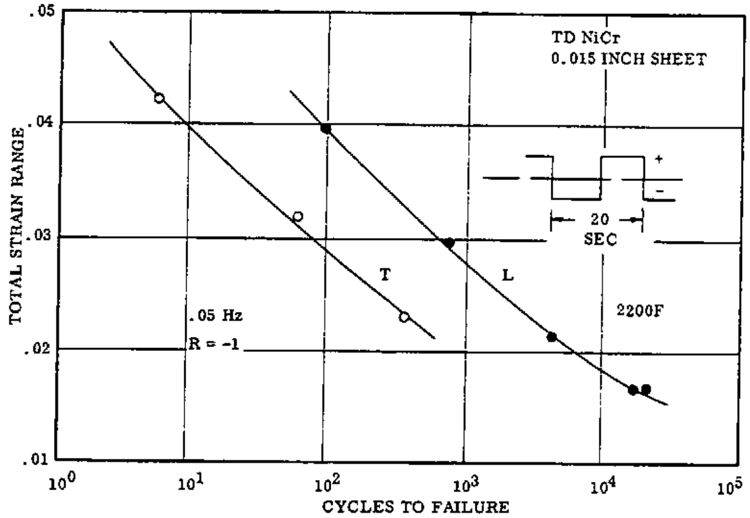


FIG. 3.052 FLEXURAL FATIGUE RESISTANCE OF SHEET STRAIN CYCLED AT 2200F. (11)

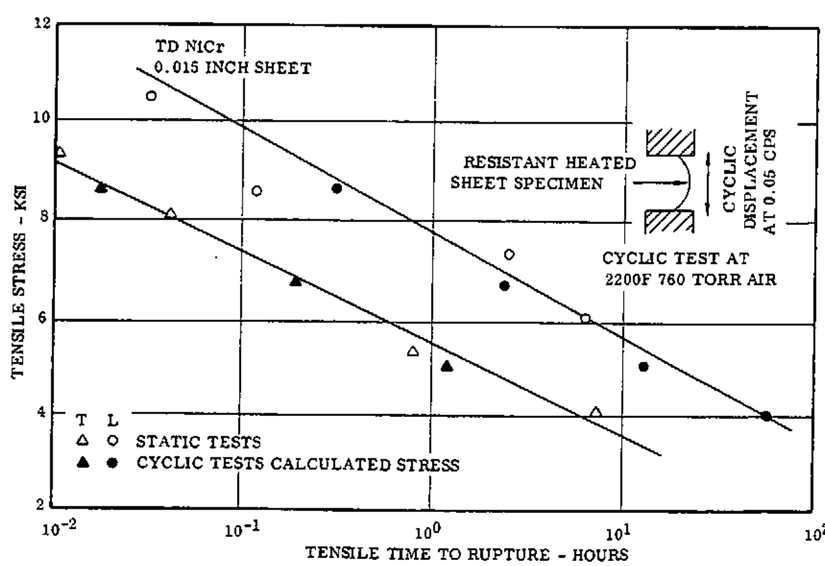


FIG. 3.053 STATIC AND CYCLIC CREEP RUPTURE OF SHEET. (11)

Ni
18 Cr
2 ThO_2

TD NiCr

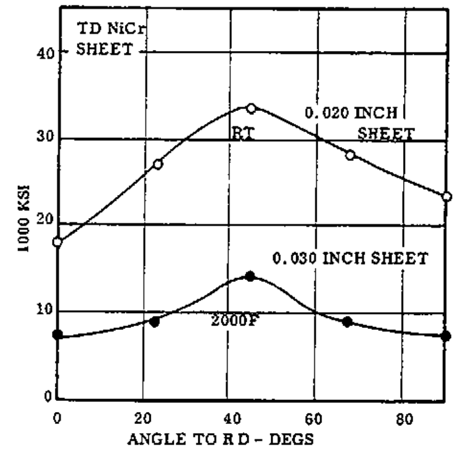


FIG. 3.0622 EFFECT OF TESTING DIRECTION WITH RESPECT TO ROLLING DIRECTION ON ROOM TEMPERATURE AND 2000F TENSION MODULUS OF SHEET. (9)(10)

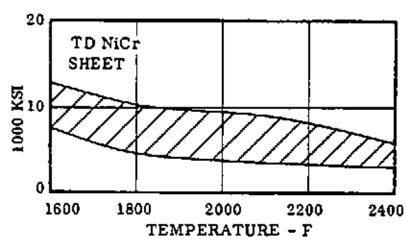


FIG. 3.0621 ELASTIC MODULUS IN TENSION AT ELEVATED TEMPERATURES. (6)

TABLE 4.0511

Source	(6)	
Alloy	TD NiCr	
Constituent	Composition, parts by volume	
	Solution 1	Solution 2
H_2O	15	8
HNO_3 (38^0 baume)	5	8
HF (40 percent)	1	1
Temp of bath - F	120 to 140	70-100

REFERENCES

1. Baily, P. G., "A Manufacturing Process for Thin Sheet and Foil of TD NiCr Alloy," DuPont, AF Contract F33615-67-C-1015, AFML TR 68-87 (April 1968).
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