Fe
17 Cr
7 Ni
+ Ti

Stainless W

1\. GENERAL

This alloy is one of the first precipitation-hardening, semi-austenitic stainless steels. Precipitation hardening after solution annealing is primarily due to the presence of titanium and also influenced by the balance of other elements. The alloy can be aged to strengths up to about 220 ksi and possesses good oxidation and corrosion resistance. It can be machined and formed in its annealed condition and is available in most wrought forms, (6). After fabrication this alloy may be converted into a wide range of high strength conditions by a simple single heat treatment for a short period at moderate temperatures with a minimum of surface oxidation distortion and dimensional changes. The alloy has had usages such as knives in paper pulp refining machinery, pump shafts, valve parts, springs, bearing plate on bridges, rollers and locks for dams, flexible nozzle walls of supersonic wind tunnels and flak panels on bombers, (10).

1.01 Commercial Designation
Stainless "W".

1.02 Alternate Designations
USS "W", AISI 635.

1.03 Specification
None.

1.04 Composition
Table 1.04.

TABLE 1.04

Source	DMIC (1)		US STEEL (6)		AISI (10)
Aluminum	Percent		Percent		Percent
	Min	Max	Min	Max	Typical
Aluminum	-	1.00	-	1.00	0.20
Carbon	-	0.12	-	0.10	0.06
Chromium	16.0	18.0	16.0	18.0	17.0
Manganese	-	1.00	-	1.00	0.55
Nickel	6.00	8.00	6.00	8.00	7.00
Silicon	-	1.00	-	1.50	0.60
Titanium	-	1.00	-	1.20	0.80
Nitrogen	-	0.2	-	-	-
Phosphorus	-	-	-	0.045	-
Sulfur	-	-	-	0.030	-
Iron	Balance		Balance		Balance

1.05 Heat Treatment
1.051 Solution anneal. 1850 to 1950F, 15 to 30 minutes, air cool, (3).
1.0511 Effect of solution annealing temperature on room temperature tensile properties of aged sheet, Fig. 1.0511.
1.052 Age. 950 to 1150F, 30 minutes, air cool. Exact treatment depends on properties desired, see 1.062 and 3.0211. Most widely used age treatment, 1000F, 30 minutes, air cool or quench, (10).

1.06 Hardness
1.061 Transformation to martensite after air cooling from solution anneal temperature requires 2 to 4 hours. Resulting hardness RC 22 to 28, (6).
1.062 Effect of aging temperature and time on hardness, Fig. 1.062.
1.063 Effect of low temperature on hardness of aged alloy, Fig. 1.063.

1.07 Forms and Conditions Available
The alloy is available in the form of strip, sheet, plate, bar, variety of forged shapes, forging billets, extrusions and wire, (6).

1.08 Melting and Casting Practice
Conventional arc or induction electric furnace practices employed for producing standard stainless steels can be used. However, attention must be given to holding the aluminum, titanium and nitrogen within specifications to avoid entrapment of aluminum and titanium oxide inclusions, (7).

1.09 Special Considerations
None.

2\. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties
2.011 Melting range
2.012 Phase changes. Ac_3 approx. 1050F,
Ar_3 approx. 250F.
2.013 Thermal conductivity, Fig. 2.013.
2.014 Thermal expansion, Fig. 2.014.
2.015 Specific heat
2.016 Thermal diffusivity

2.02 Other Physical Properties
2.021 Density. 0.28 lb per cu in. 7.65 gr per cu cm, (7).
2.022 Electrical resistivity. 39.37 microhm-in, annealed, (6), 33.46 microhm-in, aged, (2).
2.023 Magnetic properties
2.0231 Magnetic permeability. At H = 100 oersteds:
Annealed = 81;
Aged = 101,(6).
2.024 Emissivity
2.025 Damping capacity

2.03 Chemical Properties
2.031 Corrosion resistance. This steel is not susceptible to intergranular corrosion and satisfactorily resists corrosion when subjected to salt spray or sea water immersion tests. Resistance to corrosion from boiling nitric acid is inferior to other stainless steels, especially in the precipitation hardened condition. Resistance to atmospheric corrosion and corrosion resistance to hydrogen sulphide gas, sulfur dioxide gas and hot milk are equivalent to 18-8 stainless steel, (8).
2.0311 Effect of stress level on atmospheric stress corrosion of solution annealed and aged sheet, Fig. 2.0311.
2.0312 Tests performed at Monroeville, Pa., of atmospheric stress corrosion on solution annealed and aged sheet of a stress level of 75 percent of F_{ty} = 210 ksi, had 7 specimens which were exposed 520 days without failure, (11).
2.032 Oxidation resistance
2.0321 Effect of rate of oxidation in air on exposure temperature of alloy, Fig. 2.0321.

2.04 Nuclear Properties
2.041 Effect of irradiation on tensile yield stress of alloy, Table 2.041.

TABLE 2.041

Source	(12, p.36,37)	
Alloy	Fe-17Cr-7Ni-+Ti	
Temp-F	RT	
Irradiation	5.1×10^{20} n per sq cm at RT	
	Irradiated	Control
F_{tu}, -ksi	134	113

3\. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.02 Mechanical Properties at Room Temperature
3.021 Tension
3.0211 Stress-strain diagrams
3.02111 Stress-strain curves for different aging temperatures of sheet, Fig. 3.02111.

3.0212 Effect of aging temperature on room temperature tensile properties, Table 3.0212.

TABLE 3.0212

Source	(6)(10)							
Alloy	Fe-17Cr-7Ni+Ti							
Form			Sheet, strip			Bar, plate		
Thickness-in			≤0.030	>0.030 <0.060	>0.060	≤1/2	>1/2	
Heat treatment	F_{tu} -ksi	F_{ty} -ksi	e(2 in) percent minimum for thickness indicated					RC
SA(1)	135	95	3	4	5	8	10	26
SA(1)+aged at 950F, 30 minutes, AC	210	200	3	4	5	8	10	44
SA(1)+aged at 1000F, 30 minutes, AC	200	190	3	4	5	8	10	42
SA(1)+aged at 1050F, 30 minutes, AC	190	170	4	5	7	8	10	39
SA(2)	135		5	6	7	10	12	26
SA(2)+aged at 950F, 30 minutes, AC	170	155	5	6	7	10	12	38
SA(2)+aged at 1000F, 30 minutes, AC	160	145	5	6	7	10	12	37
SA(2)+aged at 1050F, 30 minutes, AC	150	130	5	6	8	10	12	34

SA(1) 1850F to 1950F, air cool
SA(2) 1850F to 1950F, air cool
+ 1300F, air cool

3.0213 Effect of exposure time and temperature on room temperature tensile properties of solution annealed sheet, Fig. 3.0213.
3.0214 Effect of exposure time and temperature on room temperature tensile properties of aged sheet, Fig. 3.0214.
3.022 Compression
3.0221 Stress-strain diagrams
3.023 Impact
3.0231 Effect of exposure time and temperature on room temperature impact strength of solution annealed and aged alloy, Fig. 3.0231.
3.024 Bending
3.025 Torsion and shear
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
3.0311 Stress-strain diagrams
3.03111 Stress-strain curves in tension at room and elevated temperatures for sheet, Fig. 3.03111.
3.0312 Effect of test temperature on tensile property of aged, forged bar, Fig. 3.0312.
3.0313 Effect of test temperature on tensile properties of solution annealed and aged sheet, Fig. 3.0313.
3.0314 Effect of low temperature on tensile properties of solution annealed and aged alloy, Fig. 3.0314.
3.032 Compression
3.0321 Stress-strain diagrams
3.03211 Stress-strain curves in compression at room and elevated temperatures for sheet, Fig. 3.03211.
3.0322 Effect of test temperature on the compressive yield strength of solution annealed and aged sheet, Fig. 3.0322.
3.033 Impact
3.0331 Effect of test temperature on impact energy of alloy, Fig. 3.0331.
3.0332 Effect of low test temperature on impact energy of solution annealed and aged alloy, Fig. 3.0332.
3.034 Bending
3.035 Torsion and shear
3.036 Bearing
3.037 Stress concentration
3.0371 Notch properties
3.0372 Fracture toughness
3.038 Combined properties

3.04 Creep and Creep Rupture Properties
3.041 Creep and creep rupture properties of aged bar, Table 3.041.

TABLE 3.041

Source	(8, p. 24-25)			
Alloy	Fe-17Cr-7Ni+Ti			
Condition	SA, 1650F, 40 min + 1000F, 1 hr			
Form	Bar			
Thickness - in	1			
Test temp. - F	600	800	1000	1200
Stress for 0.2% plastic deformation in 500 hr, ksi	125	40	-	-
Rupture stress ksi, in 100 hr	-	-	32	12.5

3.05 Fatigue Properties
3.051 S-N curves for smooth and notched specimen of aged bar stock, Fig. 3.051.
3.052 Torsional endurance limit (20,000,000 cycles) solution treated 1950F, air cool and aged 925F, 2 hours, 58 ksi, (8).
3.053 Fatigue limit for thin sheet as received and ground and polished, Table 3.053.

TABLE 3.053

Source	(10, p. 87)					
Alloy	Fe-17Cr-7Ni +Ti					
Condition	SA 1950F +Age 925F, 30 Min					SA 1600F + 925F, 30 min
Form	Sheet					
Surface	As received				Ground*	As received
Thickness-in	0.018		0.050		0.050	0.018
Direction	L	T	L	T	L	L
F_{tu}, -ksi	183.5	168.6	196.5	201.0	-	168.4
Fatigue limit - ksi	56.0	54.0	54.0	54.0	70.0	50.0

* and polished

3.054 Effect of low temperature on the fatigue strength of alloy, Fig. 3.054.

3.06 Elastic Properties
3.061 Poisson's ratio at variuos temperatures, Fig. 3.061.
3.062 Modulus of elasticity
3.0621 Modulus of elasticity at various temperatures, Fig. 3.0621.
3.0622 Compression modulus at various temperatures, Fig. 3.0622.
3.063 Modulus of rigidity at various temperatures, Fig. 3.063.

4. FABRICATION

4.01 Formability
4.011 May be hot rolled, cold rolled or extruded by conventional process. Maximum formability is obtained in the solution annealed or overaged condition. However, the rather low elongations limit the amount of deformation during forming, (3)(7). The alloy in the softest solution annealed condition has cold formability approximating that of 1/2 hard AISI Type No. 302. When more than moderate forming is required, it is necessary to do the forming in one or more draws with intermediate annealing between draws. Intermediate annealing at 1200 to 1300F provides optimum ductility, (10).
4.012 Forging and hot working characteristics of the alloy are similar to those of AISI Type No. 321 stainless steel. Forging may be performed over a wide range of temperatures. Best practice dictates the use of temperature no higher than is necessary to accomplish the required deformations and to avoid excessive holding times at forging or rolling temperatures, particularly at temperatures above 2100F. Initial forging temperatures of 2100 to 2150F and finishing temperatures above 1700F are suggested, (10).

Fe
17 Cr
7 Ni
+ Ti

Stainless W

4.02 Machining and Grinding

4.021 The alloy may be machined in either annealed or the precipitation hardened conditions with about the same tooling and machining set ups as used for the austenitic stainless steels. The use of high speed steel or carbide tools, sturdy machines, slow feeds and speeds are important.
Ordinarily rough machining is performed on the alloy in the solution annealed condition and light finish machining done subsequently on the part after it has been aged when the part is to be used in the hardened condition. Machining of the hardened alloy leaves a good finish, removes the heat tint resulting from the aging treatment and also removes any minor distortion or dimension changes, (10).

4.03 Welding

4.031 Stainless W can be welded in either the solution annealed or aged condition by using techniques conventional for austenitic stainless steels. When welded in the solution treated condition, 100 percent joint efficiency is obtained. Aged material welded and reheat treated, exhibits about 90 percent joint efficiency. Specially coated electrodes having composition similar to that of the parent metal are recommended, (8).

4.032 Bend test of sheet welded with direct current with argon as the shielding gas, Table 4.032.

TABLE 4.032

Source	(10, p. 83)							
Alloy	Fe-17Cr-7Ni +Ti							
Form	Sheet							
Condition	SA 1900F+							
	weld, 1000F, 1/2hr		weld, SA 1870F+ 1000F, 1/2hr		1000F, 1/2hr, weld		1000F, 1/2hr, weld, 1000F, 1/2hr	
Direction bend to weld	L	T	L	T	L	T	L	T
Angle of bend to failure	180	90	140	90	180*	135	110	90

*No failure

4.04 Heat Treatment

4.041 Close temperature control is necessary during aging due to the rapid response to precipitation hardening.

4.05 Surface Treatment

4.051 Cleaning methods for this alloy are similar to Type 302 stainless steel.

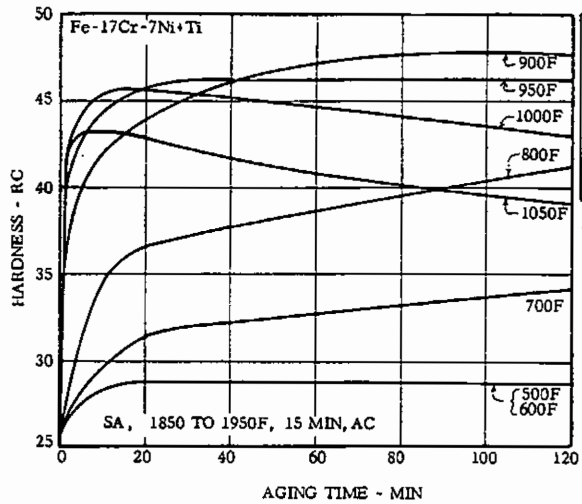

FIG. 1.062 EFFECT OF AGING TEMPERATURE AND TIME ON HARDNESS (6, p. 8-9)

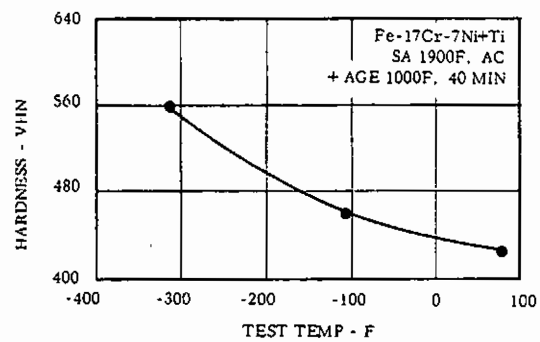

FIG. 1.063 EFFECT OF LOW TEMPERATURE ON HARDNESS OF AGED ALLOY (10, p. 88)

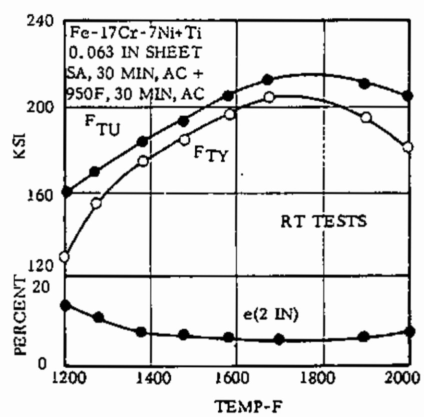

FIG. 1.0511 EFFECT OF SOLUTION ANNEALING TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF AGED SHEET (6, p. 8)

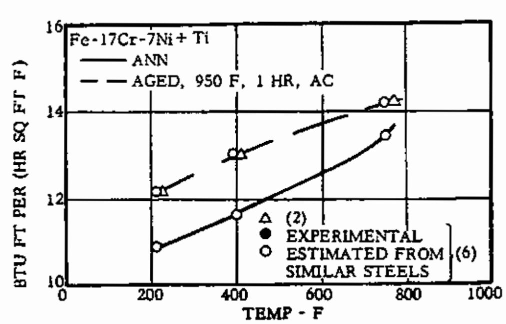

FIG. 2.013 THERMAL CONDUCTIVITY (2, p. 8) (6, p. 15)

	Fe
17	Cr
7	Ni
+	Ti

Stainless W

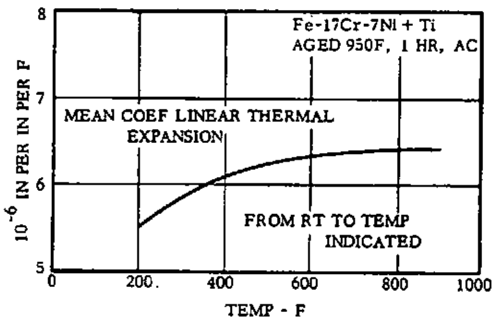

FIG. 2.014 THERMAL EXPANSION

(2, p. 8)

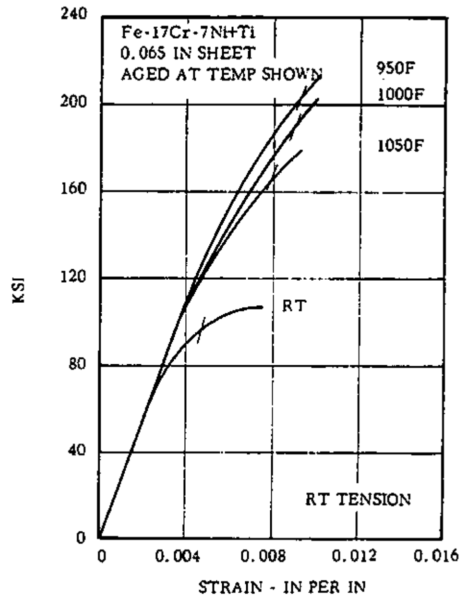

FIG. 3.02111 STRESS-STRAIN CURVES IN TENSION FOR DIFFERENT AGING TEMPERATURES OF SHEET (10, p. 88)

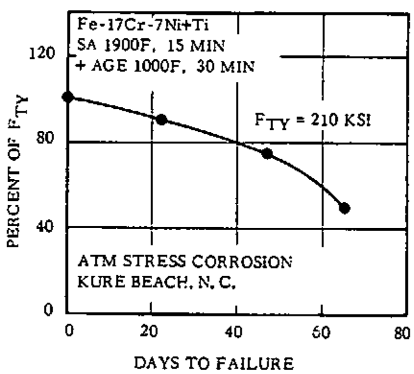

FIG. 2.0311 EFFECT OF STRESS LEVEL ON ATMOSPHERIC STRESS CORROSION OF SOLUTION ANNEALED AND AGED SHEET (11, p. 48, 51)

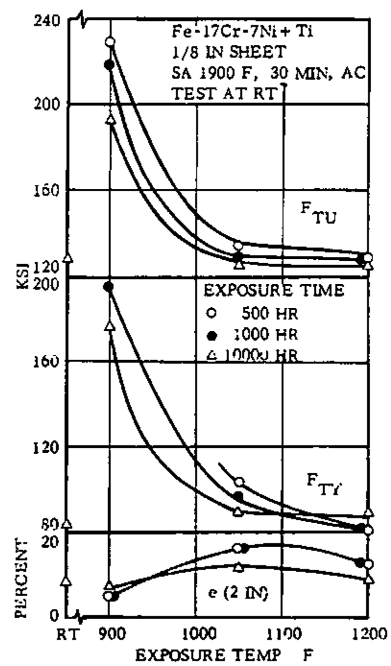

FIG. 3.0213 EFFECT OF EXPOSURE TIME AND TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF SOLUTION ANNEALED SHEET

(6, p. 13)

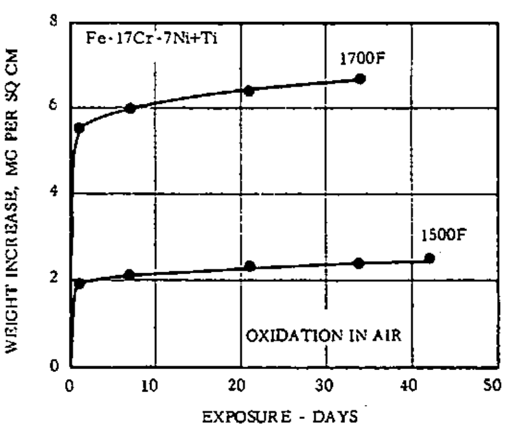

FIG. 2.0321 EFFECT OF RATE OF OXIDATION IN AIR ON EXPOSURE TEMPERATURE OF ALLOY

(10, p. 89)

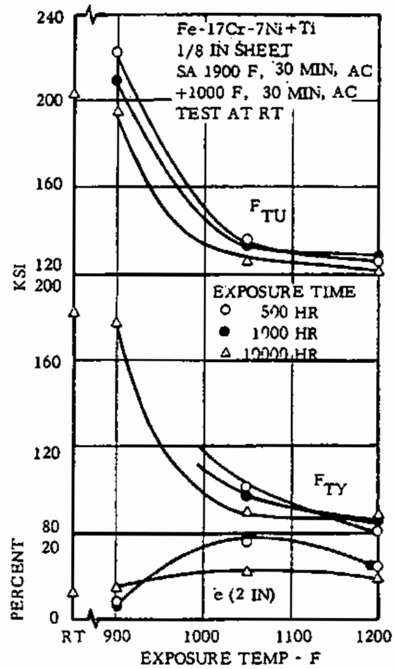

FIG. 3.0214 EFFECT OF EXPOSURE TIME AND TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF AGED SHEET

(6, p. 13)

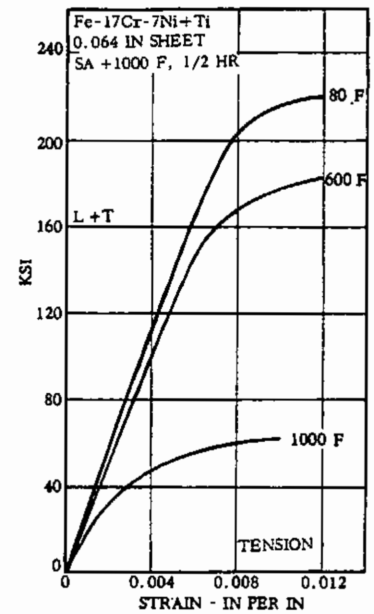

FIG. 3.03111 STRESS STRAIN CURVES IN TENSION AT ROOM AND ELEVATED TEMPERATURES FOR SHEET

(9, p. 19)

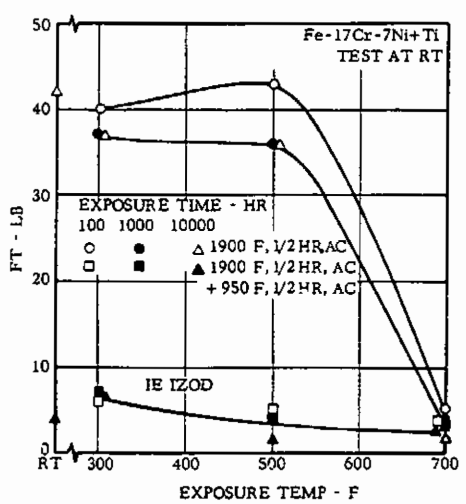

FIG. 3.0231 EFFECT OF EXPOSURE TIME AND TEMPERATURE ON ROOM TEMPERATURE IMPACT STRENGTH OF SOLUTION ANNEALED AND AGED ALLOY

(6, p. 12)

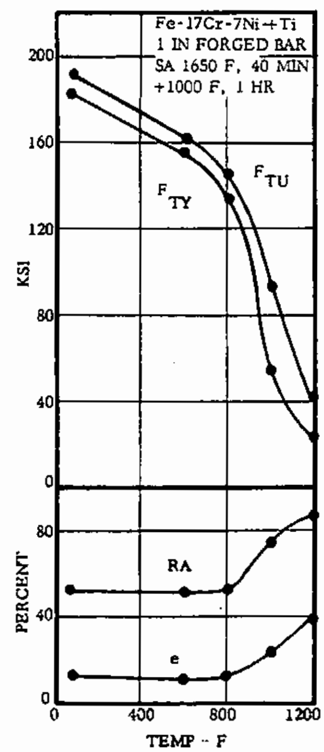

FIG. 3.0312 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF AGED, FORGED BAR

(8, p. 29)

Fe
17 Cr
7 Ni
+ Ti

Stainless W

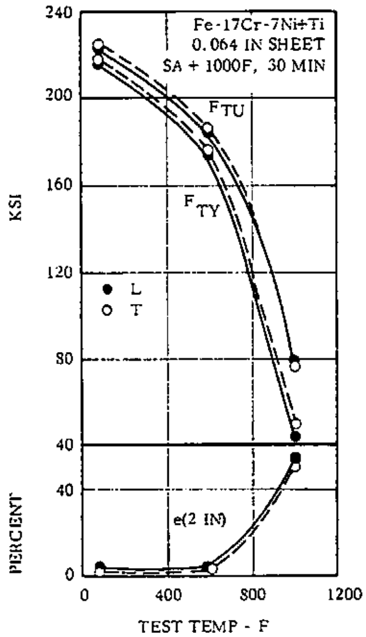

FIG. 3.0313 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SOLUTION ANNEALED AND AGED SHEET (10, p. 88)

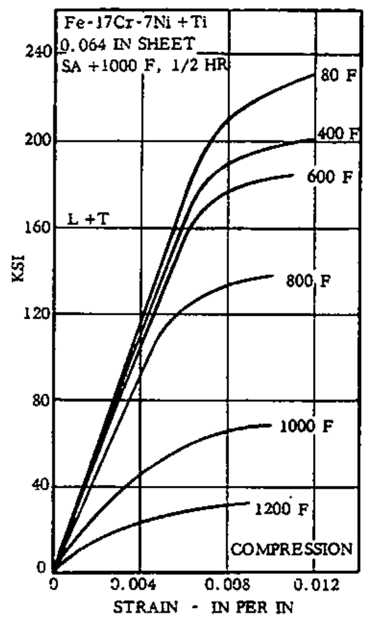

FIG. 3.03211 STRESS-STRAIN CURVES IN COMPRESSION AT ROOM AND ELEVATED TEMPERATURES FOR SHEET (9, p. 20)

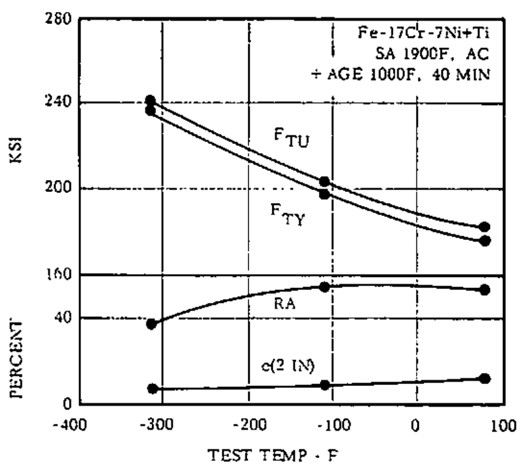

FIG. 3.0314 EFFECT OF LOW TEMPERATURES ON TENSILE PROPERTIES OF SOLUTION ANNEALED AND AGED ALLOY (10, p. 88)

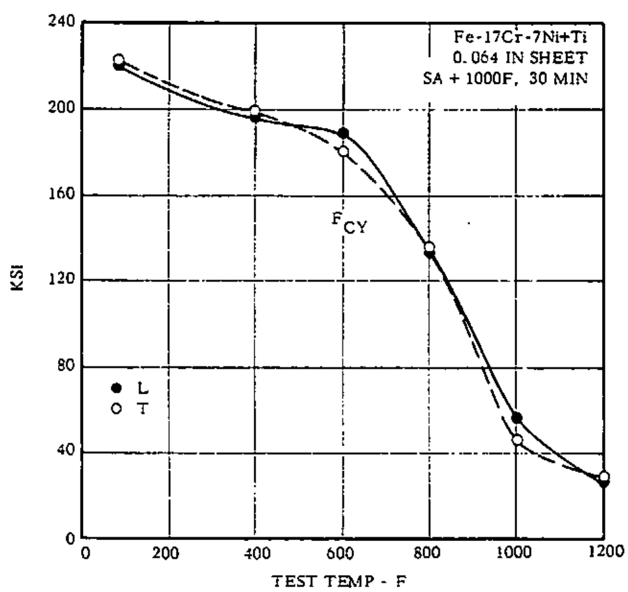

FIG. 3.0322 EFFECT OF TEST TEMPERATURE ON THE COMPRESSIVE YIELD STRENGTH OF SOLUTION ANNEALED AND AGED SHEET (10, p. 88)

	Fe
17	Cr
7	Ni
+	Ti

Stainless W

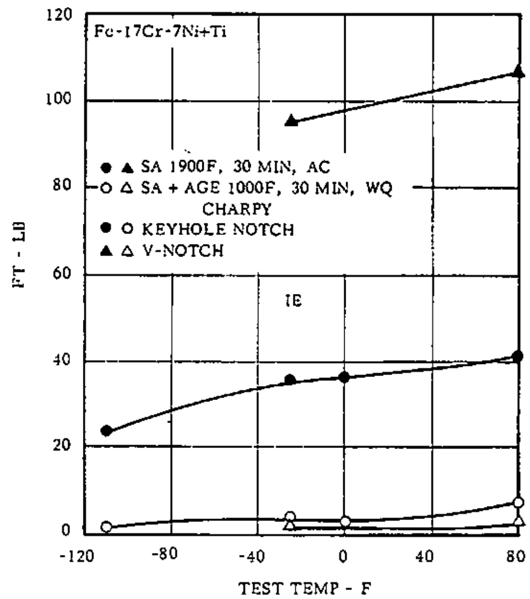

FIG. 3.0331 EFFECT OF TEST TEMPERATURE ON IMPACT ENERGY OF ALLOY (10, p. 88)

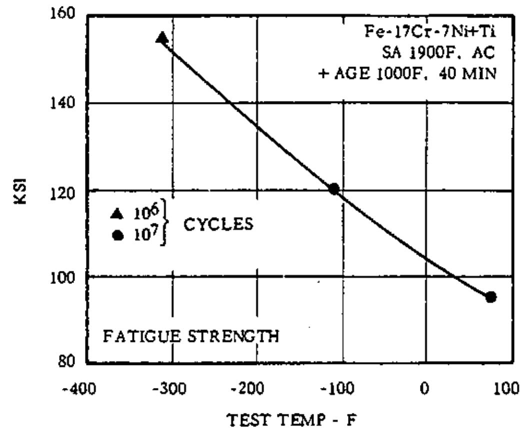

FIG. 3.054 EFFECT OF LOW TEMPERATURES ON THE FATIGUE STRENGTH OF ALLOY (10, p. 88)

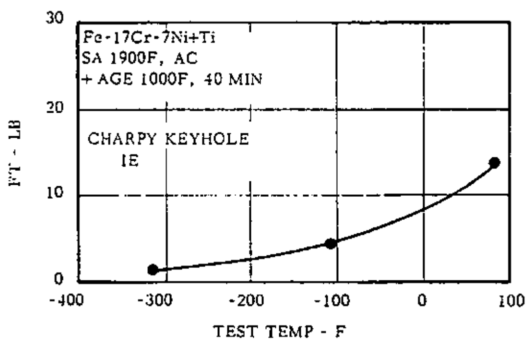

FIG. 3.0332 EFFECT OF LOW TEST TEMPERATURES ON IMPACT ENERGY OF SOLUTION ANNEALED AND AGED ALLOY (10, p. 88)

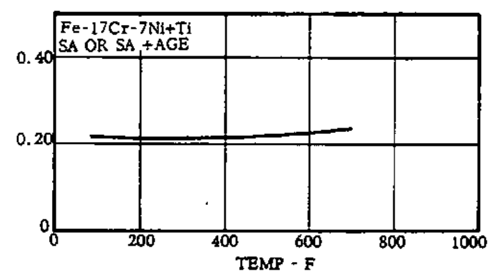

FIG. 3.061 POISSON'S RATIO AT VARIOUS TEMPERATURES (6, p. 16)

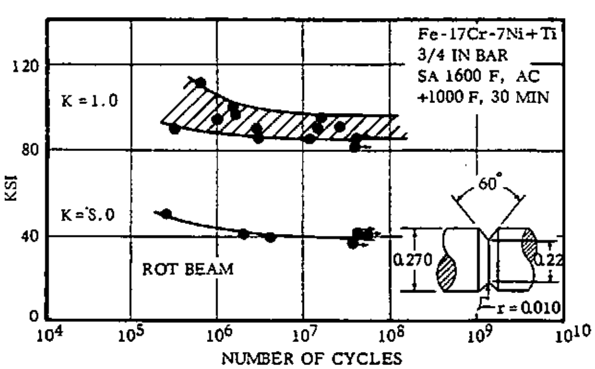

FIG. 3.051 S-N CURVES FOR SMOOTH AND NOTCHED SPECIMEN OF AGED BAR STOCK (8, p. 22)

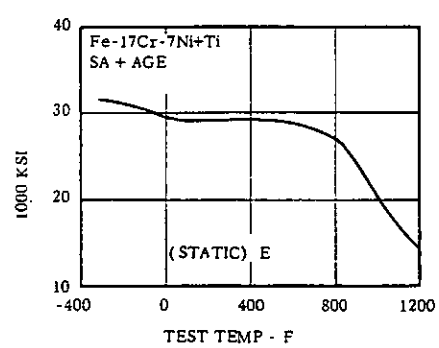

FIG. 3.0621 MODULUS OF ELASTICITY AT VARIOUS TEMPERATURES (6, p. 10), (7, A-6), (10, p. 88)

	Fe
17	Cr
7	Ni
+	Ti

Stainless W

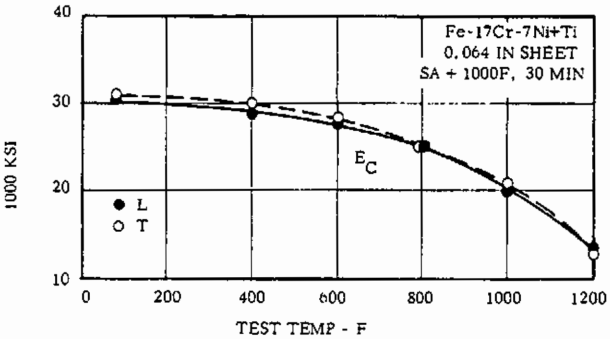

FIG. 3.0622 COMPRESSION MODULUS AT VARIOUS TEMPERATURES (10, p. 88)

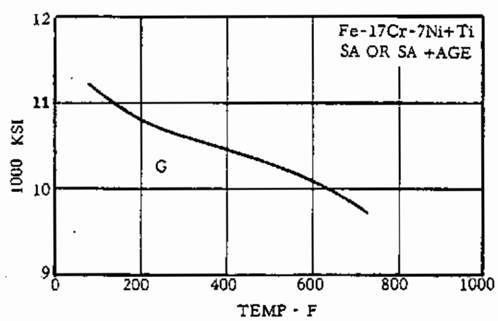

FIG. 3.063 MODULUS OF RIGIDITY AT VARIOUS TEMPERATURES (6, p. 16)

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