

1 **GENERAL**
 The 19-9 DL is a high carbon modification of the well-known 18-8 stainless steels. It contains small amounts of molybdenum, tungsten, titanium, and columbium for additional solid solution strengthening. The alloy is intended for high-strength applications up to 1200 F. Above 1200 F, it offers a modest strength advantage over regular austenitic stainless steels. The 19-9 DL is not normally heat treated but is usually strengthened by cold working or by hot-cold working. Aircraft engine applications include rotors, buckets, fasteners, manifolds, ducting, and casings. The 19-9 DL alloy is also used in chemical processing and oil refining equipment and in high temperature steam service. Modified compositions are available for welding.

1.01 **Commercial Designation**
 19-9 DL.

1.02 **Alternate Designations**
 AISI 651, UNS K63198, UNS J92843 (castings); 19-9 WX and UNS K63199. (welding wire and covered welding electrodes).

1.03 **Specifications**, Table 1.03.

1.04 **Composition**, Table 1.04.

1.05 **Heat Treatment**

1.051 Castings are solution heat treated at 2000 F for at least 30 minutes and air cooled, followed by a precipitation heat treatment at 1600 F for at least 8 hours and air cooled (1).

1.052 Sheet, strip, and plate are solution heat treated at 1800 F for a time commensurate with thickness and air cooled (2).

1.053 Stress relief anneal is 1 hour at 1200 F.

1.054 Strength can be increased by aging for 16 hours at 1290 F after 10 percent cold reduction.

1.055 Heating should be accomplished in a neutral or slightly oxidizing atmosphere.

1.06 **Hardness**

1.061 The alloy is normally hardened by cold work or by hot-cold working. The alloy can also be hardened by cold work followed by aging at 1290 F.

1.062 Hardness of bar and forgings varies between 185 and 320 BHN, depending on processing and annealing history. Hardness of sheet may vary between 90 HRB and 30 HRC.

1.07 **Forms and Conditions Available**

1.071 The alloy is normally hardened by cold work or by hot-cold working. The alloy can also be hardened forgings, and tubing. The alloy is also available in the form of sand castings.

1.072 All products are available in the annealed, hot worked, hot-cold worked, or cold worked, and stress relieved conditions.

1.08 **Melting and Casting Practice**
 Electric arc furnace melt.

1.09 **Special Considerations**

1.091 Alloy is susceptible to stress cracking after forming unless stress relieved or annealed.

1.092 Heating at temperatures in the vicinity of 1100 to 1200 F sensitizes the alloy, i.e., develops susceptibility to intergranular attack in acid.

1.093 Alloy may crack after cold work or welding unless annealed or stress relieved.

2 **PHYSICAL PROPERTIES AND ENVIRONMENTAL EFFECTS**

2.01 **Thermal Properties**

2.011 Melting range, 2590 to 2615 F.

2.012 Phase changes.

2.0121 Time-temperature-transformation diagrams.

2.013 Thermal conductivity, Figure 2.013.

2.014 Thermal expansion, Figure 2.014.

2.015 Specific heat, 0.10 Btu/lb F.

2.016 Thermal diffusivity.

2.02 **Other Physical Properties**

2.021 Density, 0.287 lb/in.³, 7.94 g/cm³.

2.022 Electrical properties.

2.0221 Electrical resistivity, 30.6 microhm-inches.

2.023 Magnetic properties, alloy is nonmagnetic.

2.0231 Permeability, Table 2.0231.

2.024 Emission.

2.025 Damping capacity.

2.03 **Chemical Environments**

2.031 Corrosion resistance.

2.0311 General corrosion resistance is very similar to that of austenitic stainless steels with a correspondingly high carbon content.

2.0312 Intergranular corrosion may occur in acid environments unless annealed at 1800 F, followed by rapid cooling. Heating to temperatures between 1100 and 1200 F will again sensitize this steel.

2.0313 To avoid stress cracking after cold working or welding, the steel should be immediately stress relieved or annealed.

2.032 Oxidation resistance is good up to 1750 F for continuous service and up to 1450 F for intermittent service.

2.033 Reactions with hydrogen.

2.0331 The hydrogen diffusivity in 19-9 DL at 1200 at 1500 F is expressed by $D = 3.2 \times 10^{-2} e^{-14100/(460 + T(F))} \text{cm}^2/\text{sec}$ (9). The permeability of hydrogen through 19-9 DL at 1400 to 1500 F, which is of interest for hot hydrogen containment applications such as the Stirling engine, is reduced by a factor of 2 to 3 by doping the hydrogen with an oxygen-containing impurity such as CO or CO₂ at levels up to 5 volume percent. This causes formation of an oxide layer on the surface of the alloy which has low permeability for hydrogen. The permeability reduction obtained with 19-9 DL in doped hydrogen is less than that observed for other high temperature alloys (such as N-155, Incoloy 800, Inconel 718) because of the low content of strong oxide forming constituents in 19-9 DL (10). Modified 19-9 DL alloys containing 2.5Ni plus 0.5Al, 2.0Cb, or 0.3 misch metal have significantly lower permeabilities to hydrogen at 1300 to 1600 F (11).

2.0332 The hydrogen solubility in 19-9 DL at 1200 to 1500 F is expressed by $S = 14.9 e^{-3250/(460 + T(F))} \text{wt ppm (atm)}^{1/2}$ (9).

	Fe
20	Cr
10	Ni
1.5	Mo
1.5	W

19-9 DL

	Fe
20	Cr
10	Ni
1.5	Mo
1.5	W

19-9 DL

3	MECHANICAL PROPERTIES	3.042	The creep and creep-rupture of 19-9 DL sheet are shown in Figures 3.043 and 3.044, respectively. The rupture strength is significantly affected by grain size, with coarse grained material being stronger than fine grained material, as shown in Figure 3.045 (13, 14). Prior exposure for 3500 hours at 1400 F slightly reduces the rupture strength (not shown), with the effect being more noticeable in large grained than in fine grained material (13). For optimum creep and rupture properties at temperatures above 1200 F, solution heat treat at 1800 F to 2150 F and age for stability at 1200 F to 1400 F (15).
3.01	Specified Mechanical Properties	3.043	Creep properties of 19-9 DL sheet, Figure 3.043.
3.011	AMS specified mechanical properties at room temperature, Table 3.011.	3.044	Creep-rupture properties of 19-9 DL sheet [(a) heat treated at 1800 F, and (b) heat treated at 2200 F] Figure 3.044.
3.02	Mechanical Properties at Room Temperature	3.045	Effects of temperature and grain size on 100-hour and 1000-hour rupture strengths of 19-9 DL, Figure 3.045.
3.021	Tension—stress-strain diagrams—tension properties.	3.046	Stress relaxation data for times up to 8760 hours are shown in Figure 3.047. These data indicate that 19-9 DL does not relax significantly at 1020 F for times up to 8760 hours. At 1110 F, relaxation occurs after about 1000 hours and at 1200 F and higher, after about 100 hours (16):
3.0211	Tensile properties depend upon processing. F_{TU} may vary between about 100 and 150 ksi, F_{TY} between 40 and 120 ksi, and e between 60 and 15 percent.	3.047	Stress relaxation of 19-9 DL at elevated temperatures [(a) 1020 F, (b) 1110 F, (c) 1200 F, (d) 1290 F, and (e) 1380 F] Figure 3.047.
3.022	Compression—stress-strain diagrams—compression properties.	3.05	Fatigue Properties
3.023	Impact.	3.051	Fatigue properties of bar, Figure 3.051.
3.024	Bending.	3.06	Elastic Properties
3.025	Torsion and shear.	3.061	Poisson's ratio, Figure 3.061.
3.026	Bearing.	3.062	Modulus of elasticity, Figure 3.062.
3.027	Stress concentration.	3.063	Modulus of rigidity, Figure 3.063.
3.0271	Notch properties.	3.064	Tangent modulus.
3.0272	Fracture toughness.	3.065	Secant modulus.
3.028	Combined properties.	4	FABRICATION
3.03	Mechanical Properties at Various Temperatures	4.01	Forming
3.031	Tension—stress-strain diagrams—tension properties.	4.011	General forming properties of sheet, strip, and plate, annealed at 1800 F, are similar to those of the austenitic stainless steels. The alloys consume greater power, strain harden more rapidly and require more frequent intermediate anneals when forming parts in several operations. Severe cold forming should be followed immediately by a full anneal or a stress relief at 1200 F, to avoid stress cracking.
3.0311	Effect of test temperature on tensile properties of stress relieved sheet, plate, and bar, Figure 3.0311.	4.012	Forging. Starting temperature for parts ranging from 5 to 1000 lb, 2020 F maximum, finishing temperature 1500 F minimum. When the hot-cold worked condition is desired, forging temperature may be as low as 1200 F effecting 20 to 40 percent reductions between 1500 and 1200 F.
3.0312	Effect of test temperature on tensile properties of annealed sheet and plate, Figure 3.0312.	4.02	Machining and Grinding
3.0313	The effects of various thermal-mechanical processing treatments on the tensile properties of 19-9 DL at 1200 F are shown in Table 3.0314. The ultimate tensile strengths and reductions in area are comparable for the various treatments with exception of those materials aged at 1290 F and those final annealed at 2100 F to grain sizes of 19-21 microns. There are, however, significant differences in the elongations resulting from the different treatments. The more ductile materials, based on elongation, result from double annealing at 1900 F and 1540 F or from 30 percent reduction at -320 F plus annealing at 1800 F. Material aged at 1290 F displays high strength but low elongation. The large grained material annealed at 2100 F also has high strength but low ductility as measured both by elongation and by reduction in area (12).	4.021	Recommendations for obtaining the best machinability of bar include annealing, 15 to 20 percent cold drawing, and stress relieving at 1200 F with a hardness of 200 to 240 BHN. Hot-cold worked and stress relieved material possesses similar machining characteristics. Where such material is not available, annealing at 1650 F to a hardness of 185 to 200 BHN is recommended.
3.0314	Tensile properties of 19-9 DL at 1200 F in argon, Table 3.0314.		
3.032	Compression—stress-strain diagrams—compression properties.		
3.0321	Effect of test temperature on compressive yield strength of sheet, Figure 3.0321.		
3.0333	Impact.		
3.0331	Effect of test temperature on impact strength of bar, Figure 3.0331.		
3.034	Bending.		
3.035	Torsion and shear.		
3.036	Bearing.		
3.0361	Effect of test temperature on bearing properties of sheet, Figure 3.0361.		
3.037	Stress concentration.		
3.0372	Fracture toughness.		
3.038	Combined properties.		
3.04	Creep and Creep-Rupture Properties		
3.041	Creep-rupture curves for bar at 1000 to 1500 F, Figure 3.041.		

- 4.022 Alloy can be machined by all common techniques used for austenitic stainless steels. The tool wear will be higher than the 300 series steels. Heavy sulfur base lubricants are recommended. 8
- 4.03 **Joining**
- 4.031 The alloy is readily weldable by all common techniques. 9
- 4.032 For fusion welding 19-9 DL special grades of bare wire and coated electrodes have been developed. Stress relieving of welded parts at 1200 F minimum and, preferably, full annealing at 1800 F, followed by air cooling, are recommended. 10
- 4.04 **Surface Treating**
Pickling of this alloy should be performed in a molten salt bath, such as sodium hydride. This should be followed by pickling for a few minutes in an 8 to 15 percent sulfuric acid solution at 130 to 140 F, rinsing and dipping in 8 to 12 percent nitric acid, 1 percent hydrofluoric acid at 110 F. If acid pickling is to be performed, the material should be first annealed at 1650 F or higher. 11

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"19-9 DL Iron Base Alloys for High Temperatures", Allegheny Ludlum Steel Corporation, Pittsburgh, Pennsylvania, Trade Literature (1961).

Tanaka, C. and Ohba, T., "Stress Relaxation Data of 1Cr-0.5Mo-0.25V, 12Cr-1Mo-1W-0.25V, and 19Cr-9Ni-1.4Mo-1.4W-Nb Bolting Steels", *Transactions of National Research Institute for Metals*, Vol. 20, No. 2 (March 1978), pp 138-153.

Fe
20 Cr
10 Ni
1.5 Mo
1.5 W

19-9 DL

REFERENCES

- 1 AMS 5369C (January 1, 1984).
- 2 AMS 5526F (July 1, 1984).
- 3 AMS 5579A (January 15, 1979).
- 4 AMS 5782B (July 16, 1979).
- 5 AMS 5783C (July 16, 1979).
- 6 Universal Cyclops Steel Corporation, "Uniloy 19-9 DL and Uniloy 19-9 DX", Technical Bulletin (July 1956).
- 7 North American Aviation, Inc., Materials Research, "Materials Property Manual and Summary Report" (October 30, 1957).

19-9 DL			
Form	AMS Specification	Military Specification	ASTM Standards
Bolts			A453
Castings	5369C		
Sheet, Strip, Plate	5526F		A457
Tubing, Welded	5579A		
Welding Wire	5782B	MIL-R-5031, Comp 6	
Welding Electrode	5783C	MIL-E-6844, Cl 6	
Bar & Forgings			A458, A477

TABLE 1.03. SPECIFICATIONS

20	Fe
10	Cr
1.5	Ni
1.5	Mo
1.5	W

19-9 DL

Specification	19-9 DL							
	AMS 5369C		AMS 5526F AMS 5579A		AMS 5782B		AMS 5783C	
	Percent		Percent		Percent		Percent	
Element	Min	Max	Min	Max	Min	Max	Min	Max
Chromium	18.00	21.00	18.00	21.00	19.00	22.00	18.00	21.00
Nickel	8.00	11.00	8.00	11.00	8.00	9.50	8.00	9.50
Molybdenum	1.00	1.75	1.00	1.75	0.35	0.65	0.35	0.65
Tungsten	1.00	1.75	1.00	1.75	1.25	1.75	1.25	1.75
Manganese	0.75	1.50	0.75	1.50	1.00	2.00	1.00	2.50
Columbium plus Tantalum	0.30	0.70	0.25	0.60	1.00	1.40	0.75	1.20
Titanium	0.15	0.50	0.10	0.35	0.10	0.30	—	0.15
Carbon	0.28	0.35	0.28	0.35	0.07	0.13	0.07	0.13
Silicon	—	1.00	0.30	0.80	0.25	1.00	—	1.00
Copper	—	0.50	—	0.50	—	0.50	—	0.50
Phosphorus	—	0.04	—	0.04	—	0.04	—	0.04
Sulfur	—	0.04	—	0.03	—	0.03	—	0.03

TABLE 1.04. COMPOSITION (1, 2, 3, 4, 5)

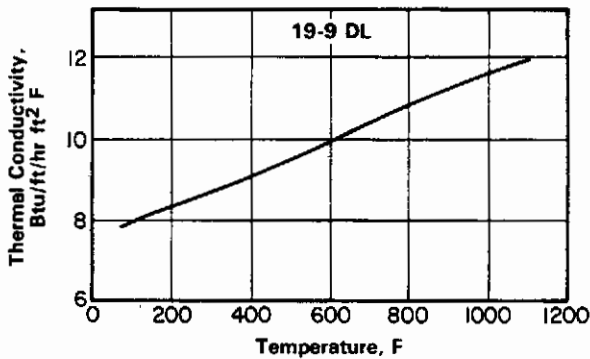


FIGURE 2.013. THERMAL CONDUCTIVITY (6)

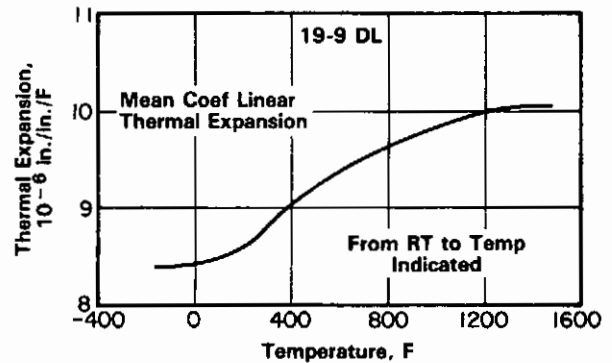


FIGURE 2.014. THERMAL EXPANSION (6)

19-9 DL	
Condition	Magnetic Permeability at 20 Oersted
ST (1800 F), AC	1.005
ST (1800 F), WQ	1.030
ST + 1500 F	1.014 to 1.018
HW + 1200 F	1.090

TABLE 2.0231. PERMEABILITY (6)

	Fe
20	Cr
10	Ni
1.5	Mo
1.5	W

19-9 DL

19-9 DL													
AMS Spec	Product Form	Metallurgical Condition ^(a)	Thickness, in.	F _{tu} , ksi		F _{ty} , ksi, Min	Elongation, percent Min	Hardness, Max	Bending				
				Min	Max				Type of Bend	Angle, deg, Min	Bend Factor		
5369C	Castings	SHT + PHT	—	—	—	—	—	229 BHN	—	—	—		
5526F	Sheet, Strip, and Plate	SHT	All	95	120	45	30	—	—	—	—		
			< 0.050	—	—	—	—	—	—	Free Bend	180	2	
			< 0.050	—	—	—	—	—	—	—	V-Block	135	2
			0.050-0.749	—	—	—	—	—	—	—	Free Bend	90	2
			0.050-0.749	—	—	—	—	—	—	—	V-Block	135	4
5579A	Tubing	SHT + Welded	≈2% OD	95	125	45	30 ^(b) 35 ^(c)	—	—	180	2		
5782B	Welding Wire	Cold Drawn	—	110	150	—	—	—	—	—	—		

Note: The original AMS documents should be consulted for complete specification details.

(a) SHT = solution heat treated; PHT = precipitation heat treated.

(b) Specification for strip.

(c) Specification for full section.

TABLE 3.011. AMS SPECIFIED MECHANICAL PROPERTIES AT ROOM TEMPERATURE (1, 2, 3, 4)

	Fe
20	Cr
10	Ni
1.5	Mo
1.5	W
19-9 DL	

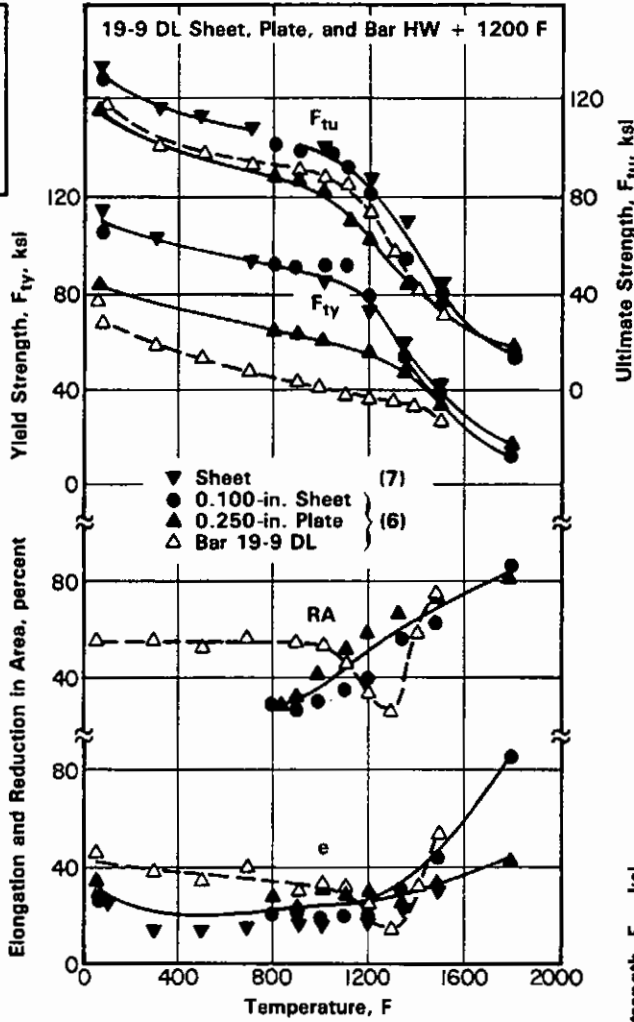


FIGURE 3.0311. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF STRESS RELIEVED SHEET, PLATE, AND BAR (6, 7)

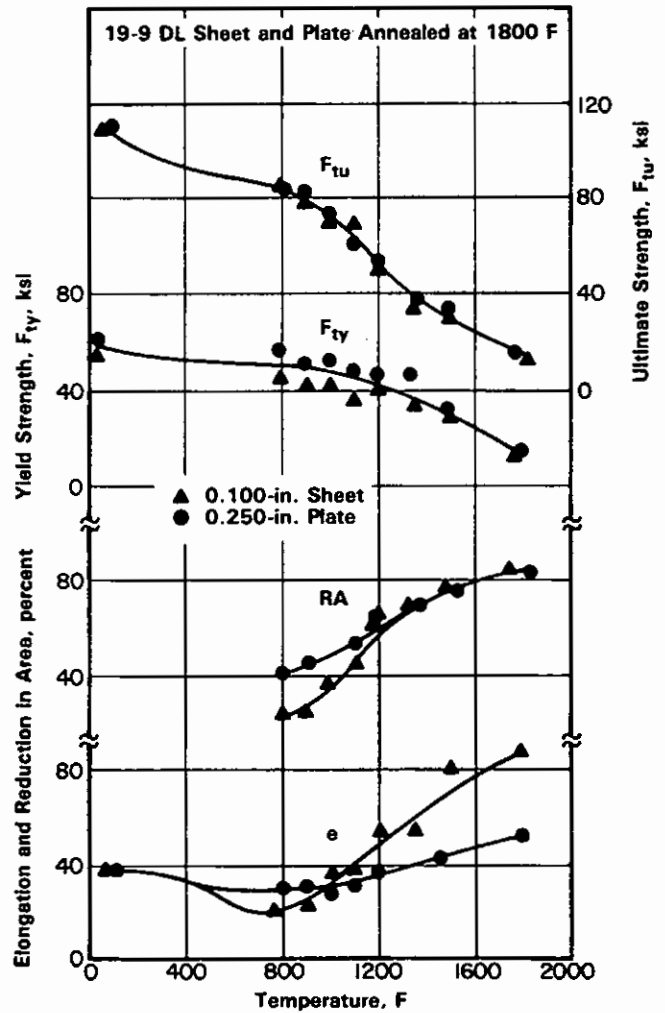


FIGURE 3.0312. EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF ANNEALED SHEET AND PLATE (6)

Fe
20 Cr
10 Ni
1.5 Mo
1.5 W

19-9 DL

19-9 DL						
Thermal-Mechanical Treatment ^(b)	Grain Size, microns	Strain Rate, min ⁻¹	F _{ty} , ksi	F _{tu} , ksi	Elongation (1 in.), percent	Reduction in Area, percent
Annealed 1800 F, reduced 80 percent, annealed 1800 F	5	1×10 ⁻²	28.0	44.2	36	53
		1×10 ⁻³	29.3	36.0	50	71
		2×10 ⁻⁴	20.0	27.3	45	72
Annealed 2300 F, reduced 80 percent, annealed 1800 F	6	1×10 ⁻²	38.0	45.7	41	54
		1×10 ⁻³	30.0	37.4	31	62
		2×10 ⁻⁴	22.0	29.1	43	71
Annealed 1800 F, reduced 80 percent, annealed 1900 F and 1540 F	6	1×10 ⁻²	25.3	41.7	53	59
		1×10 ⁻³	25.3	34.8	62	69
		2×10 ⁻⁴	20.1	27.9	59	72
Annealed 2300 F, reduced 80 percent, annealed 1800 F reduced 10 percent, aged 16 hr 1290 F	6	1×10 ⁻²	54.0	58.2	27	53
		1×10 ⁻³	42.0	45.9	32	62
		2×10 ⁻⁴	42.0	44.7	16	53
Annealed 1800 F, reduced 80 percent, annealed 1800 F plus 2 hr 1900 F	8	1×10 ⁻²	21.3	47.6	45	50
		2×10 ⁻⁴	18.7	27.3	53	61
Annealed 1800 F, reduced 50 percent, at -320 F, annealed 1800 F plus 2 hr 1900 F in H ₂	8	1×10 ⁻²	25.3	49.5	41	45
		2×10 ⁻⁴	21.3	32.3	49	59
Annealed 1800 F, reduced 50 percent, at -320 F, annealed 1800 F	8	1×10 ⁻²	29.3	44.4	46	57
		1×10 ⁻³	23.3	33.2	65	71
		2×10 ⁻⁴	20.0	27.1	49	68
Annealed 1800 F, reduced 30 percent, at -320 F, annealed 1800 F	10	1×10 ⁻²	31.3	47.7	50	63
		1×10 ⁻³	18.7	31.9	60	72
		2×10 ⁻⁴	19.3	28.5	57	72
Annealed 1800 F, reduced 80 percent, annealed 1800 F plus 2100 F	19	1×10 ⁻²	18.0	55.6	11	15
		2×10 ⁻⁴	18.7	41.1	6	10
Annealed 1800 F, reduced 50 percent, at -320 F, annealed 1800 F plus 2100 F in H ₂	21	1×10 ⁻²	19.3	60.9	14	13
		2×10 ⁻⁴	18.0	48.1	8	7

(a) Specimens were 0.030 in. thick with 0.25-in.-wide reduced section and 1.00-in. gage length. Tested in longitudinal direction.

(b) All annealing treatments were 1 hr unless noted otherwise.

TABLE 3.0314. TENSILE PROPERTIES OF 19-9 DL AT 1200 F IN ARGON^(a) (12)

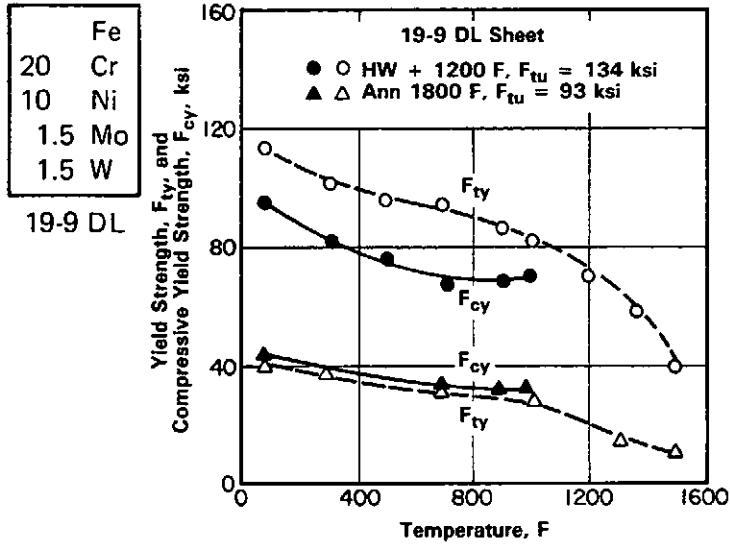


FIGURE 3.0321. EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF SHEET (7)

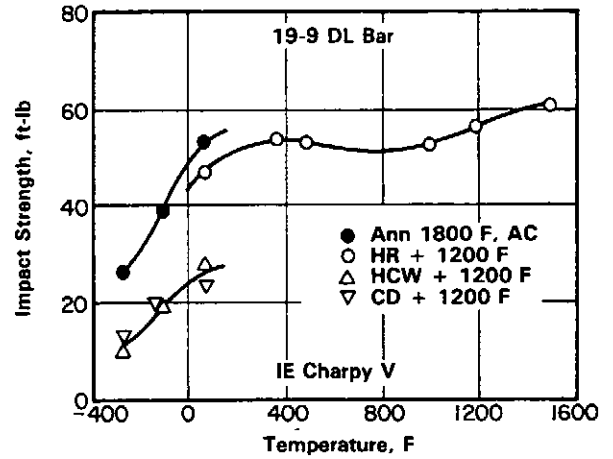


FIGURE 3.0331. EFFECT OF TEST TEMPERATURE ON IMPACT STRENGTH OF BAR (6)

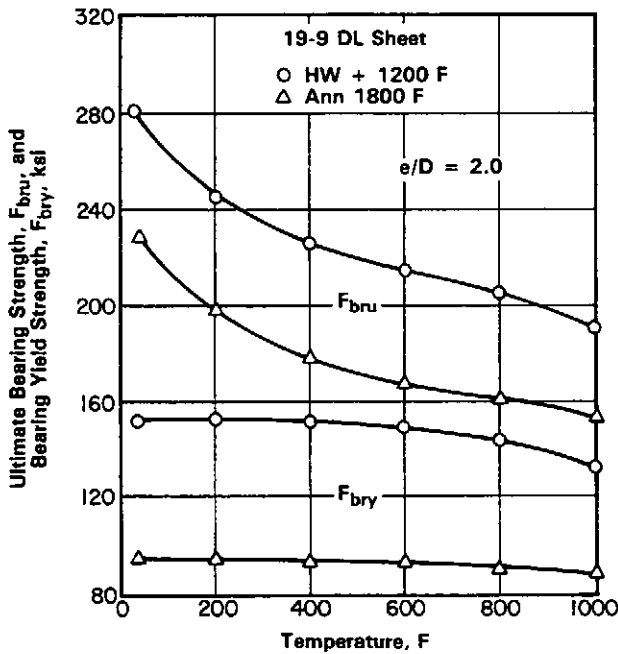


FIGURE 3.0361. EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF SHEET (8)

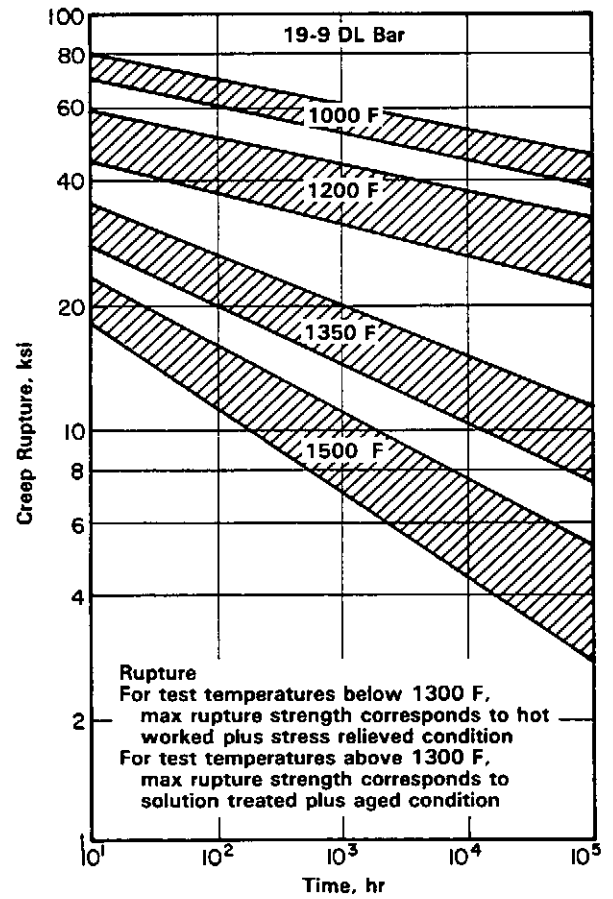


FIGURE 3.041. CREEP-RUPTURE CURVES FOR BAR AT 1000 TO 1500 F (6)

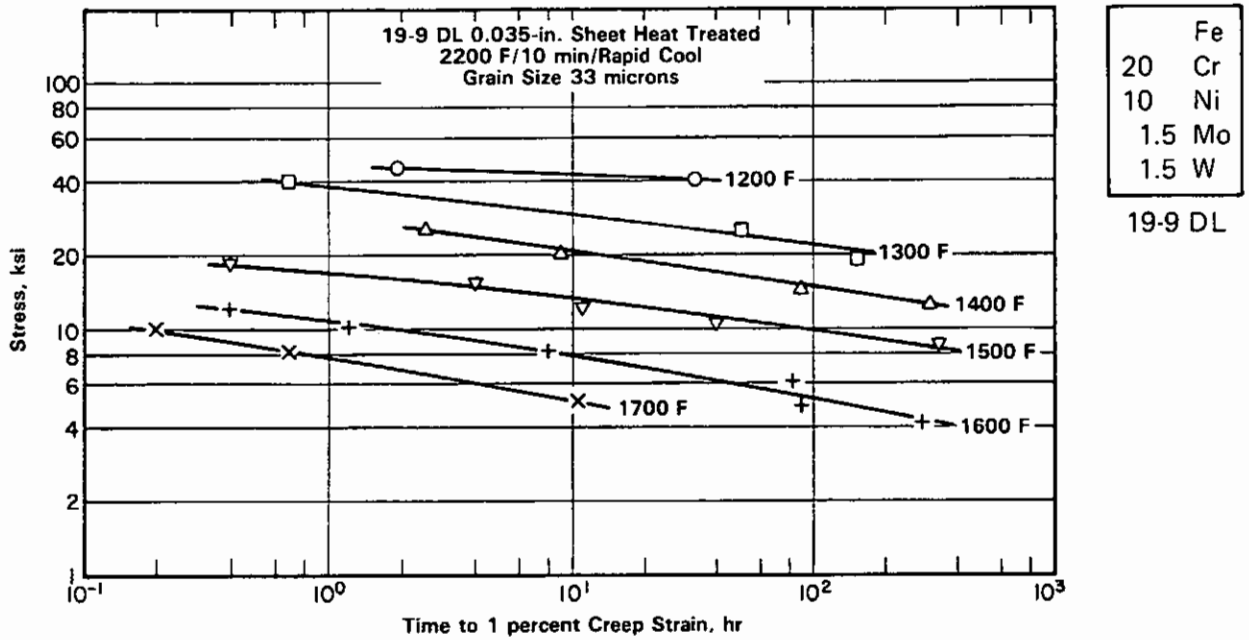


FIGURE 3.043. CREEP PROPERTIES OF 19-9 DL SHEET (14)

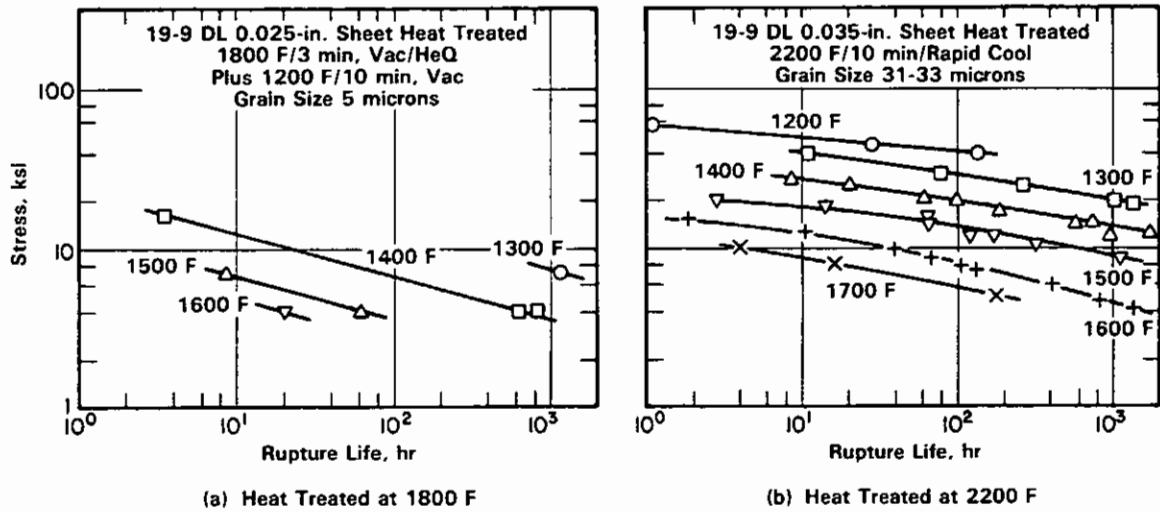


FIGURE 3.044. CREEP-RUPTURE PROPERTIES OF 19-9 DL SHEET (13, 14)

Fe
20 Cr
10 Ni
1.5 Mo
1.5 W

19-9 DL

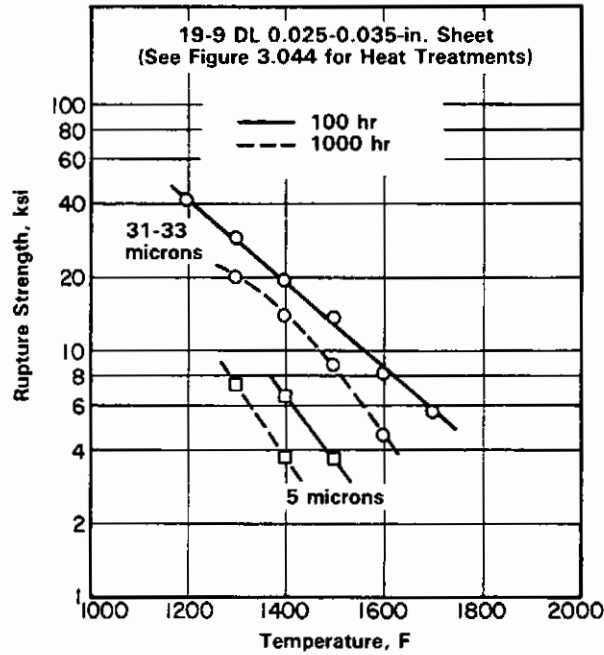


FIGURE 3.045. EFFECTS OF TEMPERATURE AND GRAIN SIZE ON 100-HOUR AND 1000-HOUR RUPTURE STRENGTHS OF 19-9 DL (13, 14)

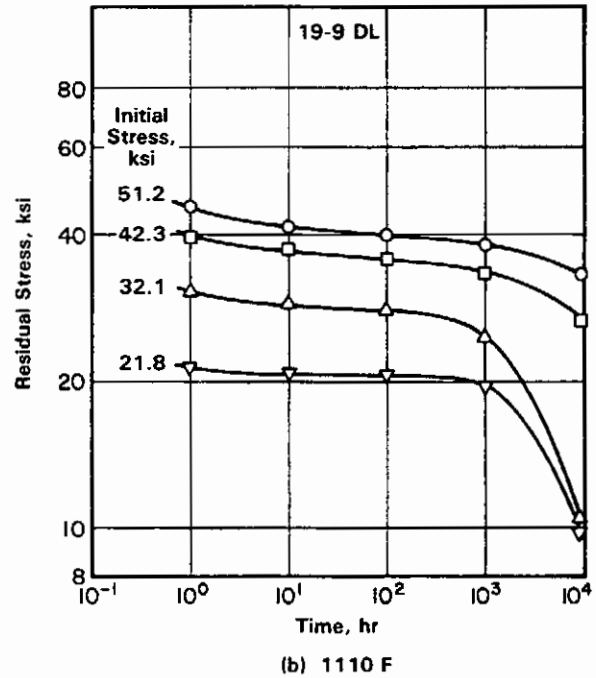
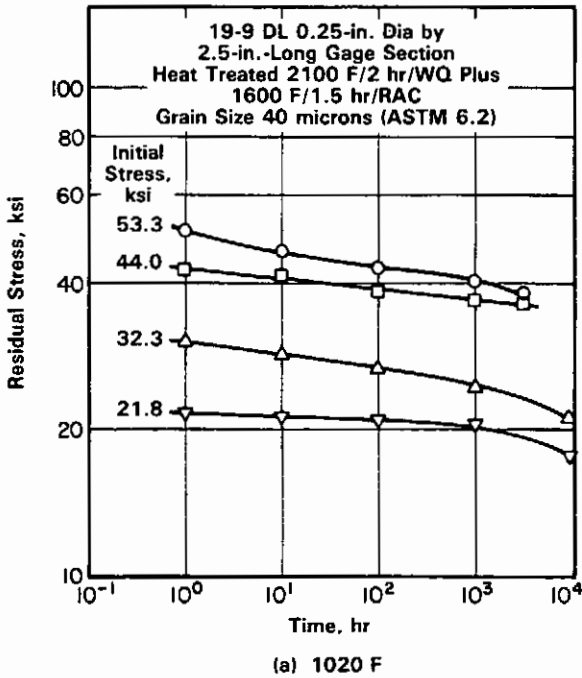
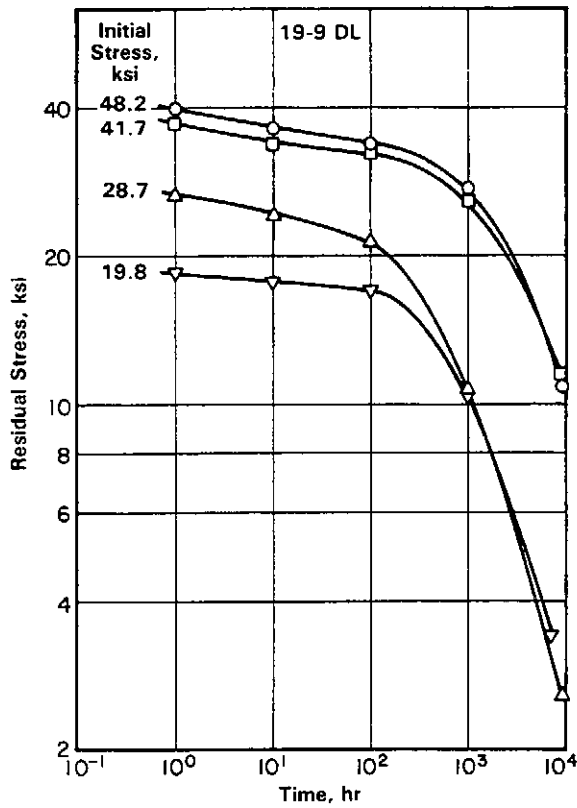
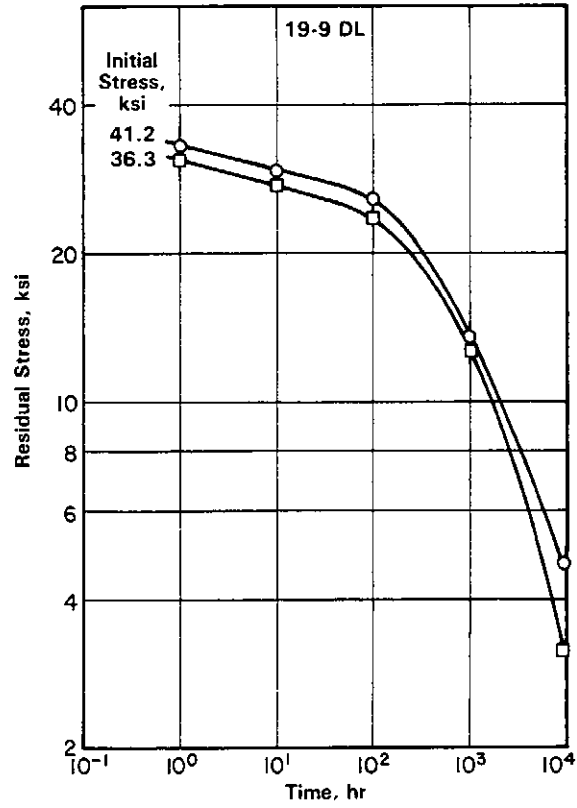


FIGURE 3.047 (a,b). STRESS RELAXATION OF 19-9 DL AT ELEVATED TEMPERATURES (16)

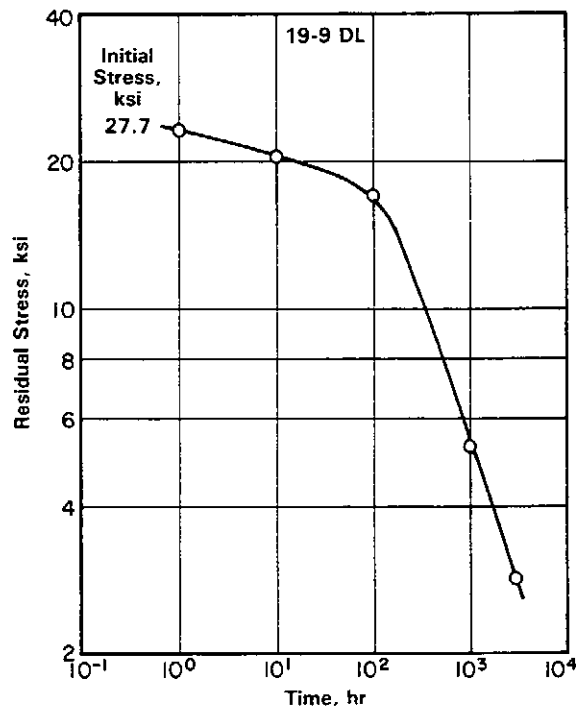


(c) 1200 F



(d) 1290 F

Fe
20 Cr
10 Ni
1.5 Mo
1.5 W
19-9 DL



(e) 1380 F

FIGURE 3.047 (c,d,e). STRESS RELAXATION OF 19-9 DL AT ELEVATED TEMPERATURES (16)

	Fe
20	Cr
10	Ni
1.5	Mo
1.5	W
19-9 DL	

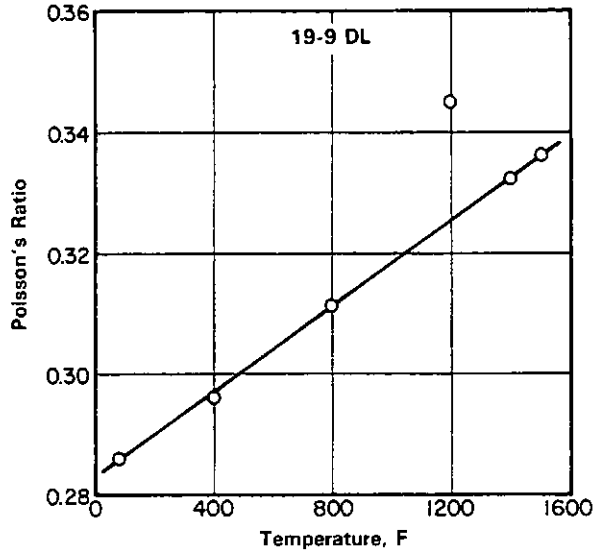


FIGURE 3.061. POISSON'S RATIO (15)

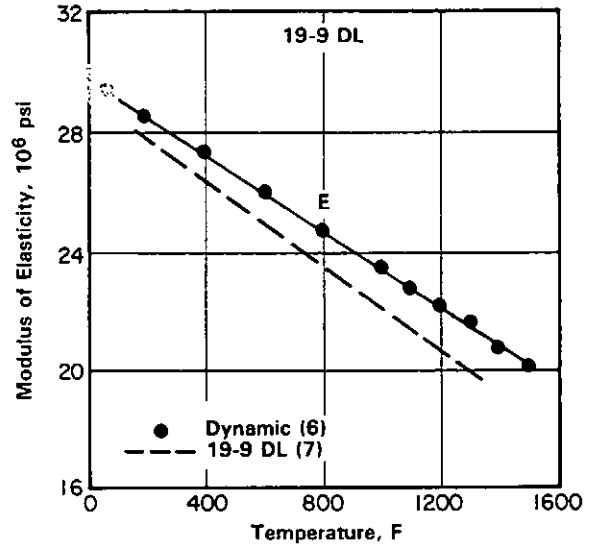


FIGURE 3.062. MODULUS OF ELASTICITY (6, 7)

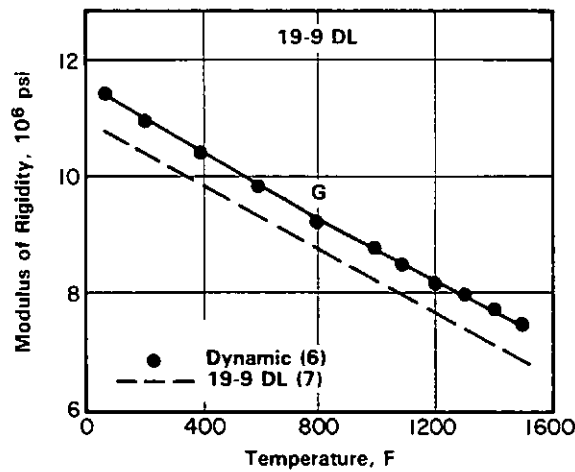


FIGURE 3.063. MODULUS OF RIGIDITY (6, 7)