AUSTENITIC CHROMIUM-NICKEL STAINLESS STEELS — ENGINEERING PROPERTIES AT ELEVATED TEMPERATURES

A PRACTICAL GUIDE TO THE USE OF NICKEL-CONTAINING ALLOYS

Nº 2980

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Contents

AISI and ACI standard composition ranges for wrought and cast chromium-nickel stainless steels. American Iron and Steel Institute classification of chromium-nickel stainless steels.									
	Composition, %								
AISI type	C max	Mn max	P max	S max	Si max	Cr	Ni	Mo	Other
201	0.15	5.50-7.50	0.060	0.030	1.00	16.00-18.00	3.50-5.50	-	N 0.25 max
202	0.15	7.50-10.00	0.060	0.030	1.00	17.00-19.00	4.00-6.00	-	N 0.25 max
301	0.15	2.00	0.045	0.030	1.00	16.00-18.00	6.00-8.00	-	-
302	0.15	2.00	0.045	0.030	1.00	17.00-19.00	8.00-10.00	-	-
302B	0.15	2.00	0.045	0.030	2.00-3.00	17.00-19.00	8.00-10.00	-	-
303	0.15	2.00	0.20	0.15 min	1.00	17.00-19.00	8.00-10.00	0.60 max	-
303Se	0.15	2.00	0.20	0.06	1.00	17.00-19.00	8.00-10.00	-	Se 0.15 min
304	0.08	2.00	0.045	0.030	1.00	18.00-20.00	8.00-12.00	-	-
304L	0.03	2.00	0.045	0.030	1.00	18.00-20.00	8.00-12.00	-	-
305	0.12	2.00	0.045	0.030	1.00	17.00-19.00	10.00-13.00	-	-
308	0.08	2.00	0.045	0.030	1.00	19.00-21.00	10.00-12.00	-	-
309	0.20	2.00	0.045	0.030	0.75	22.00-24.00	12.00-15.00	-	-
309S	0.08	2.00	0.045	0.030	0.75	22.00-24.00	12.00-15.00	-	-
309H	0.04-0.10	2.00	0.045	0.030	0.75	22.00-24.00	12.00-15.00	-	-
310	0.25	2.00	0.045	0.030	1.50	24.00-26.00	19.00-22.00	-	-
310S	0.08	2.00	0.045	0.030	1.50	24.00-26.00	19.00-22.00	-	-
310H	0.04-0.10	2.00	0.045	0.030	0.75	24.00-26.00	19.00-22.00	-	-
314	0.25	2.00	0.045	0.030	1.50-3.00	23.00-26.00	19.00-22.00	-	-
316	0.08	2.00	0.045	0.030	1.00	16.00-18.00	10.00-14.00	2.00-3.00	-
316L	0.03	2.00	0.045	0.030	1.00	16.00-18.00	10.00-14.00	2.00-3.00	-
317	0.08	2.00	0.045	0.030	1.00	18.00-20.00	11.00-15.00	3.00-4.00	-
D319	0.07	2.00	0.045	0.030	1.00	17.50-19.50	11.00-15.00	2.25-3.00	-
321	0.08	2.00	0.045	0.030	1.00	17.00-19.00	9.00-12.00	-	Ti 5xC min
347	0.08	2.00	0.045	0.030	1.00	17.00-19.00	9.00-13.00	-	Nb- Ta 10xC min
348	0.08	2.00	0.045	0.030	1.00	17.00-19.00	9.00-13.00	-	(Nb+Ta) 10xC min; Ta 0.10 max; Co 0.20 max
384	0.08	2.00	0.045	0.030	1.00	15.00-17.00	17.00-19.00	-	-
385	0.08	2.00	0.045	0.030	1.00	11.50-13.50	14.00-16.00	-	-
330	0.04-0.08	2.00	0.03	0.03	1.0-1.5	18.0-20.0	34.0-37.0	-	-

Alloy Casting Institute division (SFSA) classification of chromium-nickel stainless steel castings										
Cast alloy designation	Wrought alloy type [1]	Composition, %								
		C max	Mn max	P max	S max	Si max	Cr	Ni	Mo	Other
CA-6NM	-	0.06	1.00	0.04	0.04	1.00	11.5-14	3.5-4.5	0.40-1.0	-
CD-4MCu	-	0.04	1.00	0.04	0.04	1.00	25-26.5	4.75-6.00	1.75-2.25	Cu 2.75-3.25
CE-30	-	0.30	1.50	0.04	0.04	2.00	26-30	8-11	-	-
CF-3	304L	0.03	1.50	0.04	0.04	2.00	17-21	8-12	-	-
CF-8	304	0.08	1.50	0.04	0.04	2.00	18-21	8-11	-	-
CF-20	302	0.20	1.50	0.04	0.04	2.00	18-21	8-11	-	-
CF-3M	316L	0.03	1.50	0.04	0.04	1.50	17-21	9-13	2.0-3.0	-
CF-8M	316	0.08	1.50	0.04	0.04	1.50	18-21	9-12	2.0-3.0	-
CF-12M	316	0.12	1.50	0.04	0.04	1.50	18-21	9-12	2.0-3.0	-
CF-8C	347	0.08	1.50	0.04	0.04	2.00	18-21	9-12	-	Nb 8xC min, 1.0 max or (Nb+Ta) 10xC min, 1.35 max
CF-16F	303	0.16	1.50	0.17	0.04	2.00	18-21	9-12	1.5 max	Se 0.20-0.35
CG-8M	317	0.08	1.50	0.04	0.04	1.50	18-21	9-13	3.0-4.0	-
CH-20	309	0.04-0.20	1.50	0.04	0.04	2.00	22-26	12-15	-	-
CK-20	310	0.04-0.20	1.50	0.04	0.04	2.00	23-27	19-22	-	-
CN-7M	-	0.07	1.50	0.04	0.04	1.50	18-22	27.5-30.5	2.0-3.0	Cu 3-4

[1] Wrought alloy type numbers are included only for the convenience of those who wish to determine corresponding wrought and cast grades. The chemical composition ranges of the wrought materials differ from those of the cast grades.

Austenitic chromium-nickel stainless steels —Engineering properties at elevated temperatures

INTRODUCTION

As a result of their alloy content, particularly of chromium, the austenitic stainless steels have excellent oxidation resistance at elevated temperatures. This property combined with the strength and ductility resulting from the face-centered cubic structure results in materials which are superior to the ferritic steels in performance at elevated temperatures.

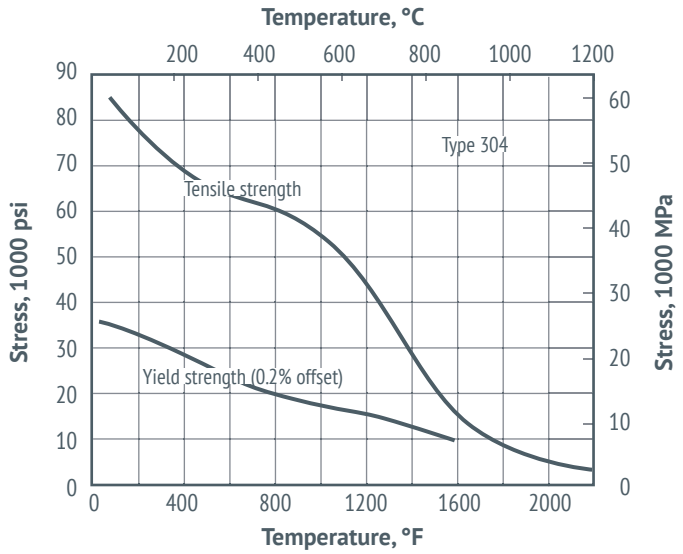
SHORT TIME MECHANICAL PROPERTIES

The tensile properties of several chromium-nickel stainless steels are given, as a function of temperature, in *Figures 1* through *7*. These are average curves, based on data on commercial steels from 22 sources, as collected in ASTM STP 124.[1] The raw data showed considerable scatter as a result of compositional and testing variables.

The effects of temperature on the tensile, compressive, and bearing properties of annealed Type 302 and half-hard Type 301 are listed in *Tables 1* and *2*.

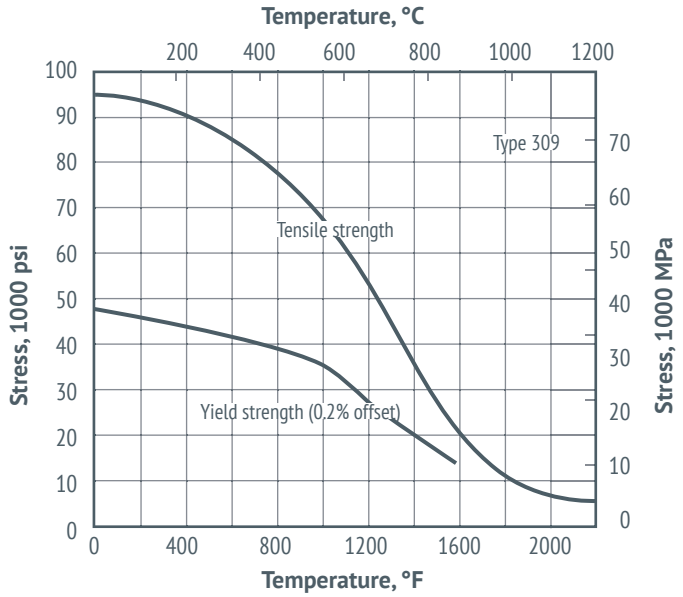
The tensile properties of a number of cast chromium-nickel stainless steels are shown in *Table 3*. These properties were determined on individual heats and are not necessarily typical.

Figure 1 Effect of temperature on the short time tensile properties of annealed Type 304 stainless steel



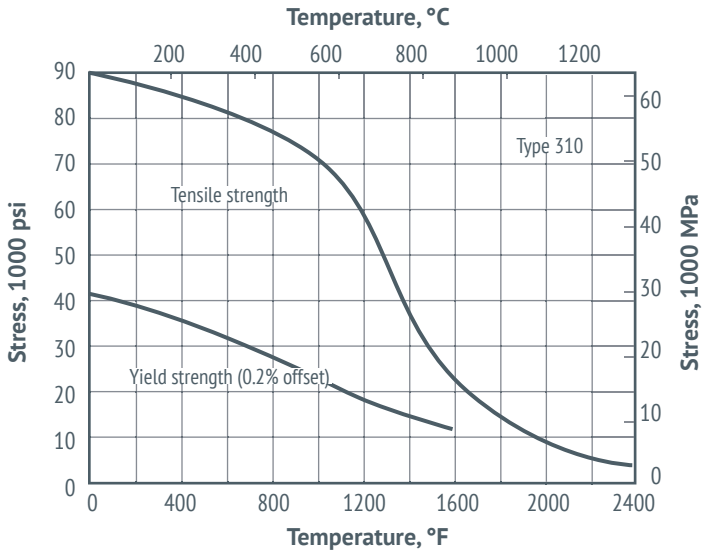
Simmons and Cross [1]

Figure 2 Effect of temperature on the short time tensile properties of annealed Type 309 stainless steel



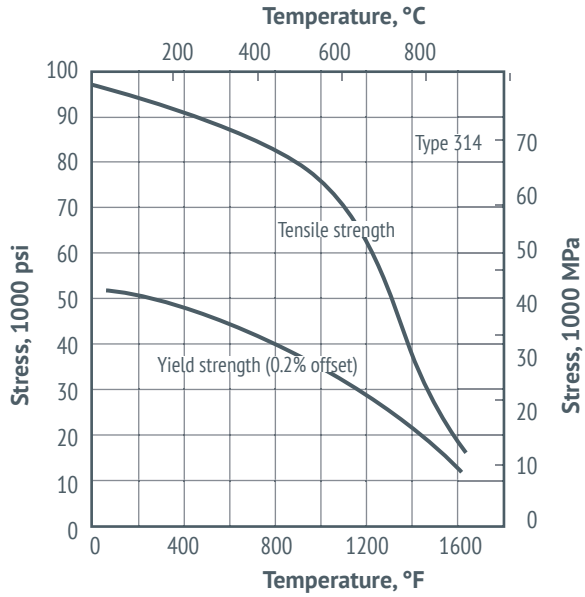
Simmons and Cross [1]

Figure 3 Effect of temperature on the short time tensile properties of annealed Type 310 stainless steel



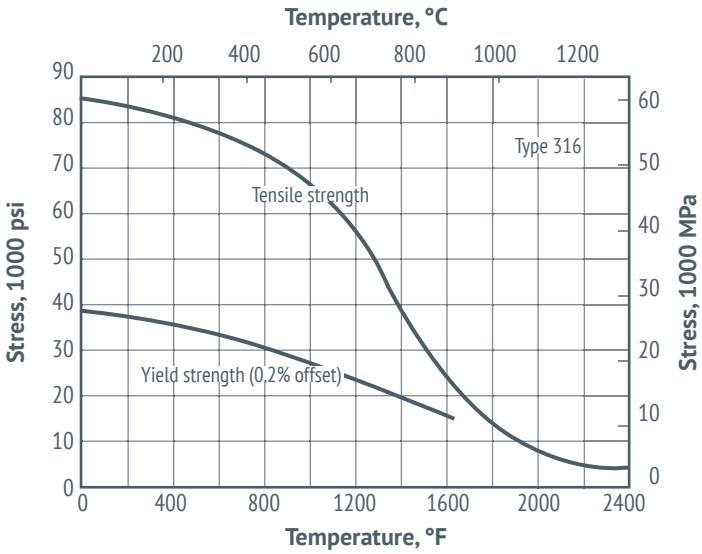
Simmons and Cross [1]

Figure 4 Effect of temperature on the short time tensile properties of annealed Type 314 stainless steel



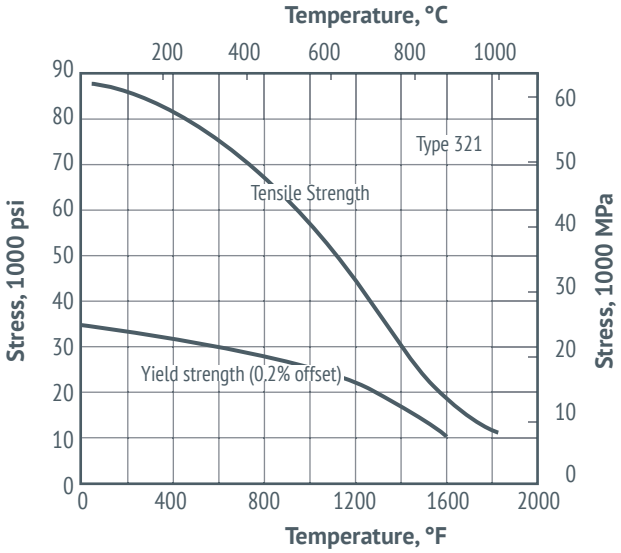
Simmons and Cross [1]

Figure 5 Effect of temperature on the short time tensile properties of annealed Type 316 stainless steel



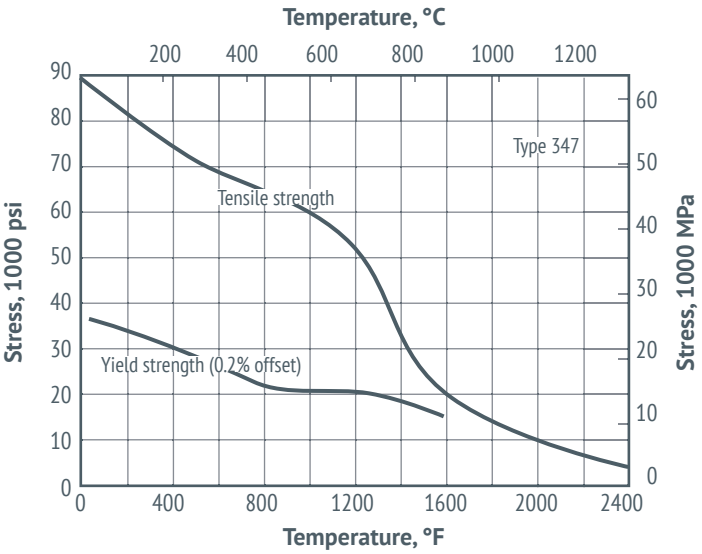
Simmons and Cross [1]

Figure 6 Effect of temperature on the short time tensile properties of annealed Type 321 stainless steel



Simmons and Cross [1]

Figure 7 Effect of temperature on the short time tensile properties of annealed Type 347 stainless steel



Simmons and Cross [1]

LONG TIME CREEP AND RUPTURE PROPERTIES

At elevated temperatures, the strain is dependent upon both the applied stress and the time. Therefore, strengths are generally expressed either in terms of the stress that will cause a specified rate of deformation in a given time (the creep stress) or as the stress that will cause rupture in a certain time (the rupture strength). Both values should be available to the designer.

The stresses that will cause rupture in 10,000 and 100,000 hours of several austenitic stainless steels are shown in *Figures 8* and *9* as a function of temperature.

Stresses that will cause creep at the rates of 0.0001 and 0.00001 per cent per hour are shown for the same steels in *Figure 10*. Interpolation to other rupture times, creep rates, and stresses can be made by using *Figures 11* to *18*, which show the effects of applied stresses on the rupture times and creep rates for the same steels at a number of temperatures.

The creep and rupture properties of a number of cast chromium-nickel stainless steels are given in *Figures 19* to *24*. These data were determined on individual heats and are not necessarily typical.

Table 1 Tensile, compressive, and bearing properties of annealed Type 302 stainless steel* for various temperatures and exposure times							
Temperature		Exposure time, hr**	Yield strength (0.2% offset), psi (MPa)			Ultimate stress, psi (MPa)	
°F	°C		Tensile	Compressive	Bearing	Tensile	Bearing
78	26	-	45,000 (31.6)	45,730 (32.2)	73,100 (51.4)	89,440 (62.9)	167,750 (117.9)
400	204	0.5	33,000 (23.2)	35,800 (25.2)	64,400 (43.9)	68,600 (48.2)	111,100 (78.1)
		2	31,300 (22.0)	36,500 (25.7)	55,600 (39.1)	67,400 (47.4)	110,000 (77.5)
		10	32,200 (22.6)	37,000 (26.0)	57,100 (40.1)	68,400 (48.1)	110,800 (77.9)
		100	31,500 (22.1)	37,200 (26.2)	54,800 (38.5)	67,200 (42.2)	109,600 (77.1)
600	315	0.5	30,700 (21.6)	34,700 (24.4)	57,000 (40.1)	67,800 (47.7)	109,400 (76.9)
		2	30,900 (21.7)	34,000 (23.9)	53,800 (37.8)	67,800 (47.7)	106,500 (74.9)
		10	30,600 (21.5)	31,700 (22.3)	54,400 (38.2)	65,900 (46.3)	108,800 (76.5)
		100	29,600 (20.8)	32,600 (22.9)	57,500 (40.4)	66,600 (46.8)	109,000 (76.6)
800	427	0.5	29,400 (20.7)	31,000 (21.8)	55,400 (39.0)	64,800 (45.6)	104,100 (73.2)
		2	27,600 (19.4)	30,700 (21.6)	53,000 (37.3)	63,000 (44.3)	105,400 (74.1)
		10	28,500 (20.0)	30,500 (21.4)	53,100 (37.3)	65,600 (46.1)	112,700 (79.2)
		100	28,700 (20.2)	30,800 (21.7)	50,300 (35.4)	65,100 (45.8)	100,400 (70.6)
1000	538	0.5	25,300 (17.8)	29,500 (20.7)	46,200 (32.5)	59,700 (42.0)	93,400 (65.7)
		2	24,200 (17.0)	28,700 (20.2)	49,800 (35.0)	61,200 (43.0)	94,300 (66.3)
		10	24,800 (17.4)	27,700 (19.5)	47,900 (33.7)	63,100 (44.4)	93,400 (65.7)
		100	24,400 (17.2)	28,700 (20.2)	44,900 (31.6)	62,000 (43.6)	94,500 (66.4)
1200	649	0.5	23,300 (16.4)	-	44,000 (30.9)	54,400 (38.2)	81,200 (57.1)
		2	22,800 (16.0)	-	44,000 (30.9)	53,900 (37.9)	80,900 (56.9)
		10	23,500 (16.5)	-	42,600 (30.0)	54,400 (38.2)	80,200 (56.4)
		100	22,200 (15.6)	-	42,500 (29.9)	52,000 (36.6)	77,500 (54.5)

* Composition, %								
C	Mn	P	S	Si	Cr	Ni	Mo	Cu
0.08	1.18	0.029	0.012	0.36	17.48	8.44	0.11	0.16

** Time held at temperature prior to testing at indicated temperature.

Doerr [2]

Table 2 Tensile, compressive, and bearing properties of half-hard Type 301 stainless steel* for various temperatures and exposure times							
Temperature		Exposure time, hr**	Yield strength (0.2% offset), psi (MPa)			Ultimate stress, psi (MPa)	
°F	°C		Tensile	Compressive	Bearing	Tensile	Bearing
78	26	-	105,840 (74.4)	75,200 (52.9)	164,400 (115.6)	155,160 (109.1)	231,000 (162.4)
400	204	0.5	85,700 (60.3)	59,800 (42.0)	148,900 (104.7)	108,500 (76.3)	178,300 (125.3)
		2	83,000 (58.4)	62,800 (44.2)	138,600 (97.4)	109,600 (77.1)	158,600 (111.5)
		10	79,500 (55.9)	62,100 (43.7)	136,600 (96.0)	108,700 (76.4)	174,100 (122.4)
		100	78,700 (55.3)	63,700 (44.8)	135,500 (95.3)	112,400 (79.0)	165,500 (116.4)
600	315	0.5	80,800 (56.8)	70,300 (49.4)	142,000 (99.3)	108,300 (76.1)	160,600 (112.9)
		2	79,800 (56.1)	72,300 (50.8)	147,500 (103.7)	104,400 (73.4)	168,100 (118.2)
		10	81,500 (57.3)	69,200 (48.7)	142,300 (100.0)	106,000 (74.5)	160,600 (112.9)
		100	83,100 (58.4)	76,100 (53.5)	145,900 (102.6)	108,000 (75.9)	170,500 (119.9)
800	427	0.5	80,800 (56.8)	69,100 (48.6)	131,200 (92.2)	100,500 (70.7)	161,600 (113.6)
		2	78,800 (55.4)	71,700 (50.4)	131,200 (92.2)	104,000 (73.1)	152,900 (107.5)
		10	74,900 (52.7)	76,900 (54.1)	128,600 (90.4)	99,900 (70.2)	157,500 (110.7)
		100	74,900 (52.7)	78,900 (55.5)	122,500 (86.1)	93,000 (65.4)	148,500 (104.4)

Table 2 cont'd Tensile, compressive, and bearing properties of half-hard Type 301 stainless steel* for various temperatures and exposure times							
Temperature		Exposure time, hr**	Yield strength (0.2% offset), psi (MPa)			Ultimate stress, psi (MPa)	
°F	°C		Tensile	Compressive	Bearing	Tensile	Bearing
1000	538	0.5	70,000 (49.2)	64,100 (45.1)	112,600 (79.2)	85,900 (60.4)	133,300 (93.7)
		2	64,800 (45.6)	65,400 (46.0)	105,500 (74.2)	81,900 (57.6)	128,400 (90.3)
		10	63,400 (44.6)	63,600 (44.7)	108,600 (76.4)	80,700 (56.7)	125,600 (88.3)
		100	63,800 (44.9)	63,600 (44.7)	100,000 (70.3)	78,500 (55.2)	119,500 (84.0)
1200	649	0.5	50,800 (35.7)	-	78,000 (54.8)	65,700 (46.2)	98,800 (69.5)
		2	50,400 (35.4)	-	86,600 (60.8)	63,800 (44.9)	100,700 (70.8)
		10	53,200 (37.4)	-	82,000 (57.7)	66,700 (46.9)	95,400 (67.1)
		100	51,000 (35.9)	-	82,400 (57.9)	61,800 (43.5)	97,700 (68.7)

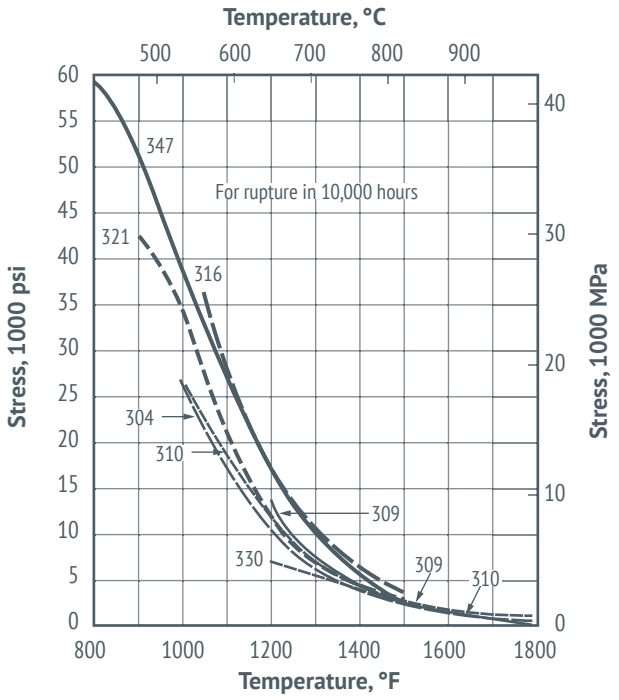
* Composition, %							
C	Mn	P	S	Si	Cr	Ni	Mo
0.10	1.14	0.027	0.017	0.39	17.38	7.46	0.10

** Time held at temperature prior to testing at indicated temperature.

Doerr [2]

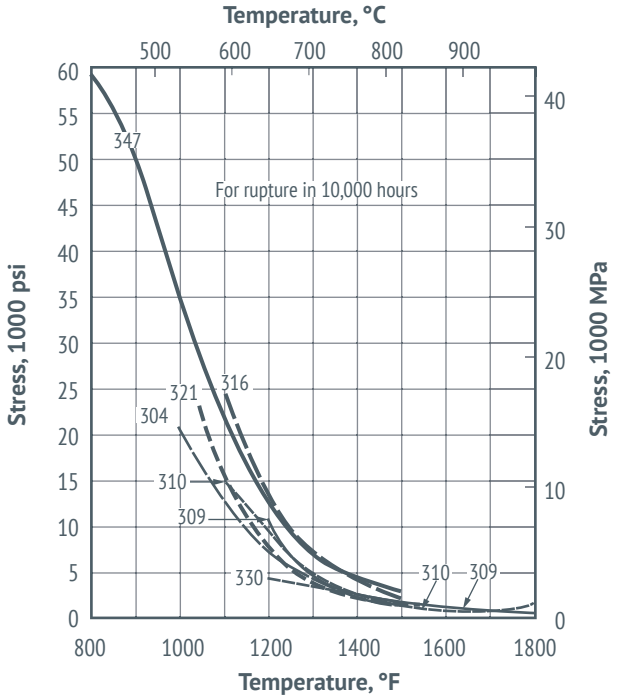
TABLE 3 Short time high temperature properties of cast chromium-nickel stainless steels*							
Temperature		ACI Type					
°F	°C	CF-8	CF-20	CF-8C	CF-8M	CH-20	CK-20
Tensile strength, psi (MPa)							
Room		78,000 (55)	80,000 (56)	78,000 (55)	79,000 (56)	76,000 (53)	80,000 (56)
1000	540	55,000 (39)	58,000 (41)	58,000 (41)	56,000 (39)	-	-
1200	650	44,000 (31)	46,000 (32)	47,000 (33)	40,000 (28)	41,000 (29)	54,000 (38)
1400	760	26,000 (18)	29,000 (20)	26,000 (18)	26,000 (18)	25,000 (18)	32,000 (22)
1600	870	-	-	-	-	12,000 (8)	16,000 (11)
Yield strength (0.2% offset), psi (MPa)							
Room		34,000 (24)	35,000 (25)	34,000 (24)	37,000 (26)	36,000 (25)	33,000 (23)
1000	540	17,000 (12)	17,000 (12)	22,000 (15)	21,000 (15)	-	-
1200	650	16,000 (11)	16,000 (11)	20,000 (14)	18,000 (13)	16,000 (11)	20,000 (14)
1400	760	15,000 (11)	18,000 (13)	18,000 (13)	15,000 (11)	16,000 (11)	19,000 (13)
1600	870	-	-	-	-	10,000 (7)	13,000 (9)
Elongation, %							
Room		65	65	52	50	52	39
1000	540	46	40	28	37	-	-
1200	650	33	29	34	44	36	27
1400	760	26	21	31	29	34	12
1600	870	-	-	-	-	49	11
Reduction of area, %							
Room		74	68	48	70	63	49
1000	540	53	62	57	68	-	-
1200	650	46	46	50	53	50	34
1400	760	40	34	41	50	47	21
1600	870	-	-	-	-	69	18

Figure 8 Stress-rupture curves for several annealed stainless steels



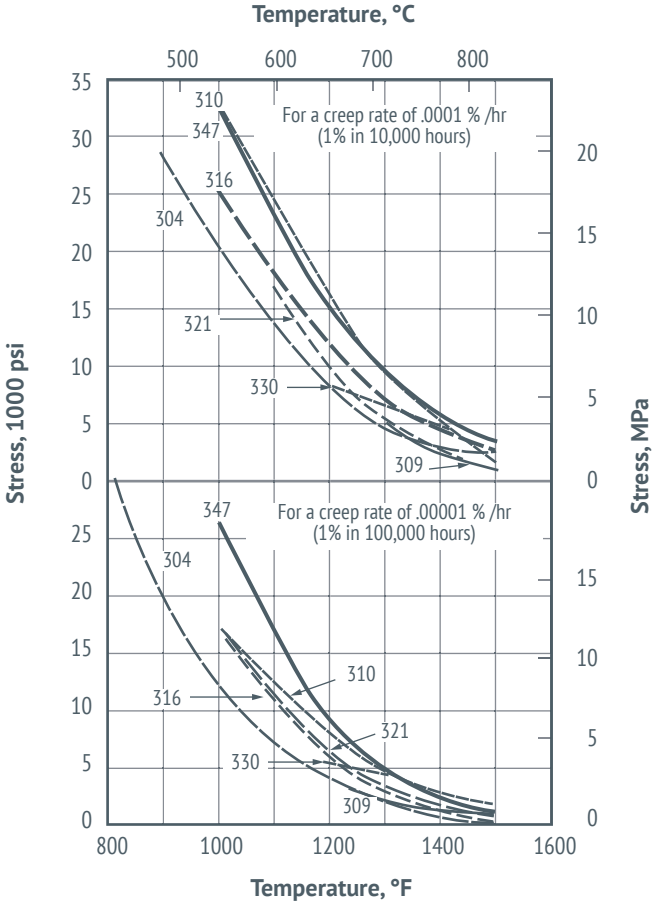
Simmons and Cross [1]

Figure 9 Stress-rupture curves for several annealed stainless steels (Extrapolated data)



Simmons and Cross [1]

Figure 10 Creep-rate curves for several annealed stainless steels



Simmons and Cross [1]

SHORT TIME CREEP PROPERTIES

Although most high temperature applications require data on creep rates for long time periods, the development of the space program requires information on creep over periods of the order of minutes. Data of this type are included in *Figures 25* through *27* for several stainless steels. These data show the effect of stressing on the total deformation in periods ranging from a few seconds to several hours. Stress-total deformation curves at several temperatures are given In *Figure 28*.

Figure 11 Stress versus rupture-time and creep-rate curves for annealed Type 304 stainless steel based on average data

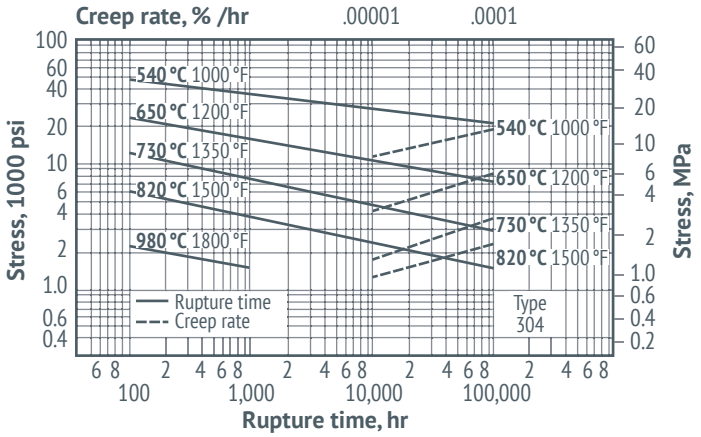


Figure 12 Stress versus rupture-time and creep-rate curves for annealed Type 309 stainless steel based on average data

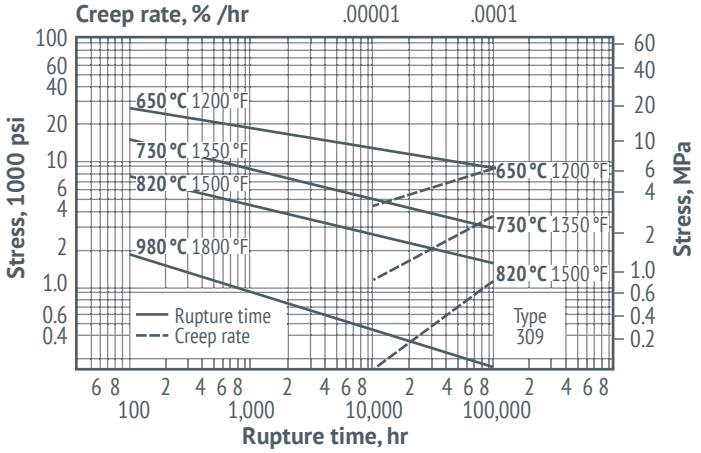


Figure 13 Stress versus rupture-time and creep-rate curves for annealed Type 310 stainless steel based on average data

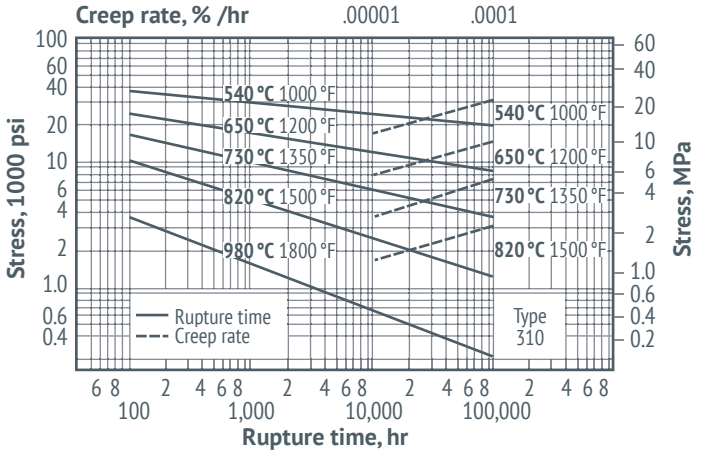


Figure 14 Stress versus rupture-time and creep-rate curves for annealed Type 314 stainless steel based on average data

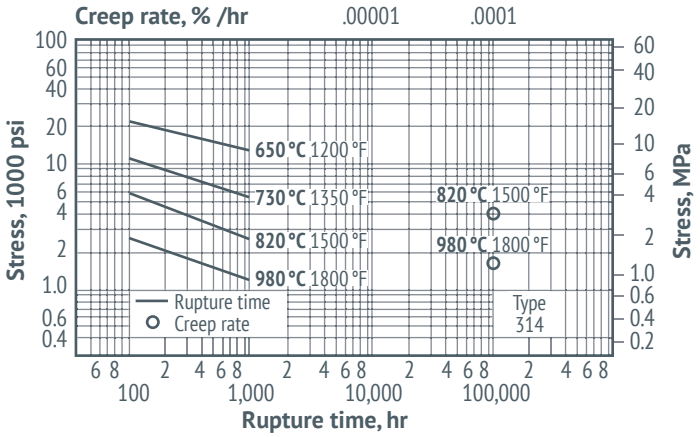


Figure 15 Stress versus rupture-time and creep-rate curves for annealed Type 316 stainless steel based on average data

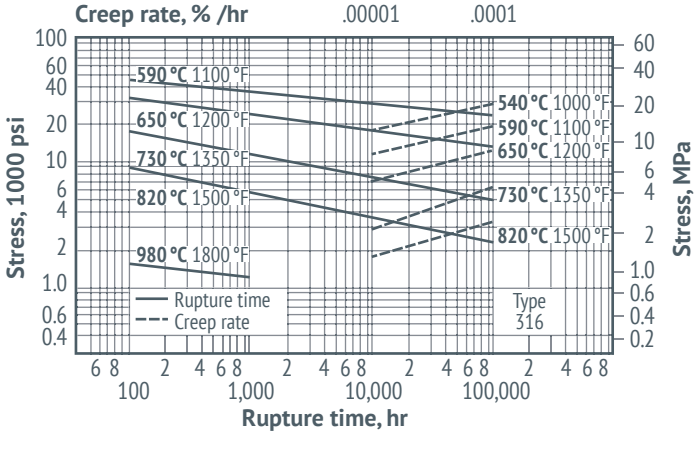
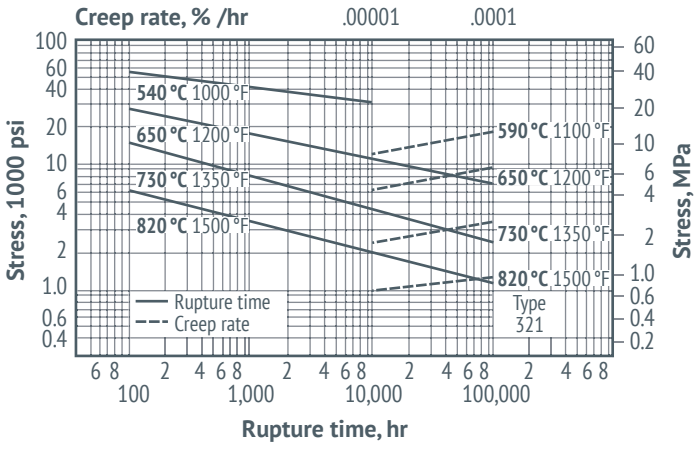
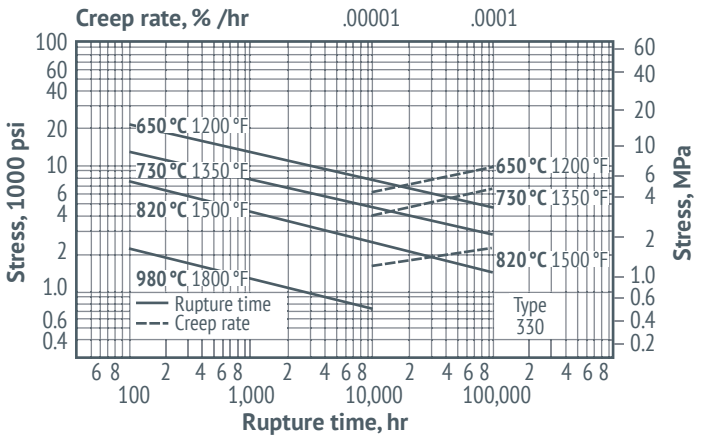


Figure 16 Stress versus rupture-time and creep-rate curves for annealed Type 321 stainless steel based on average data



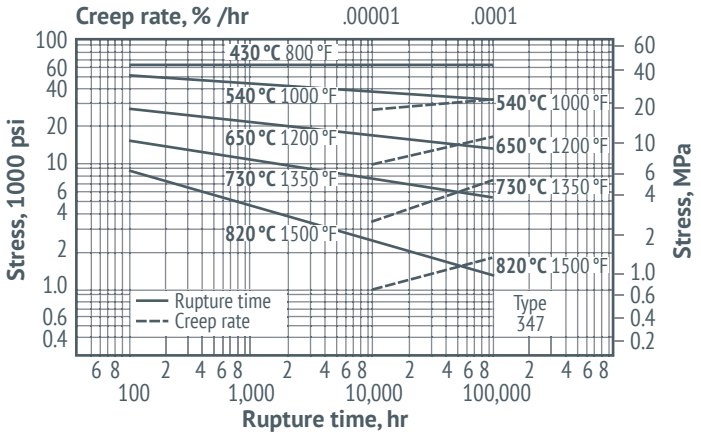
Simmons and Cross [1]

Figure 17 Stress versus rupture-time and creep-rate curves for annealed Type 330 stainless steel based on average data



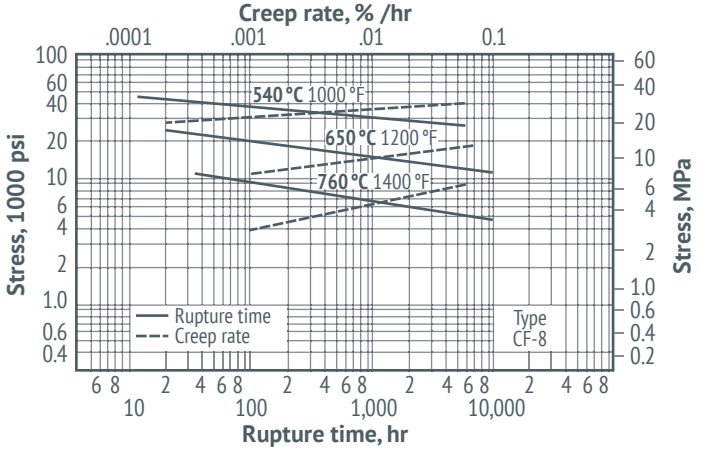
Simmons and Cross [1]

Figure 18 Stress versus rupture-time and creep-rate curves for annealed Type 347 stainless steel based on average data



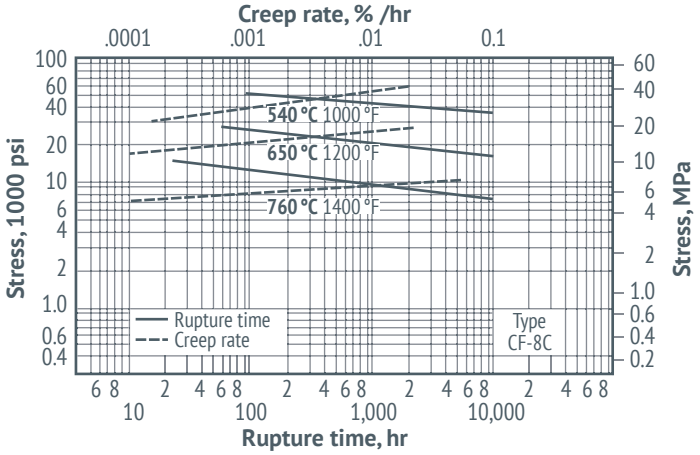
Simmons and Cross [1]

Figure 19 Stress versus rupture-time and creep-rate curves for annealed Type CF-8 stainless steel



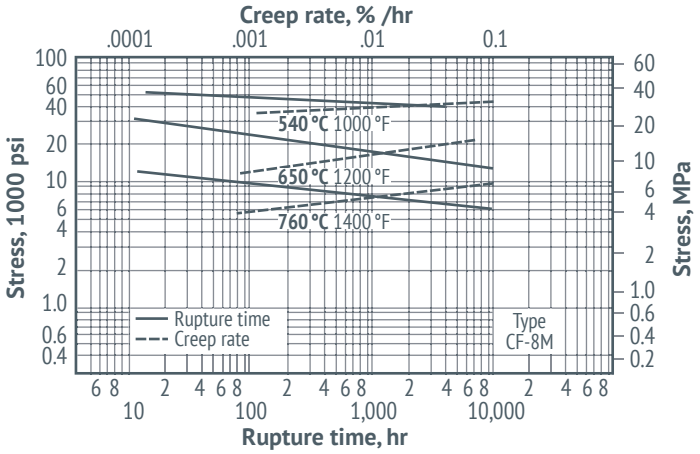
Alloy Casting Institute [3]

Figure 20 Stress versus rupture-time and creep-rate curves for annealed Type CF-8C stainless steel



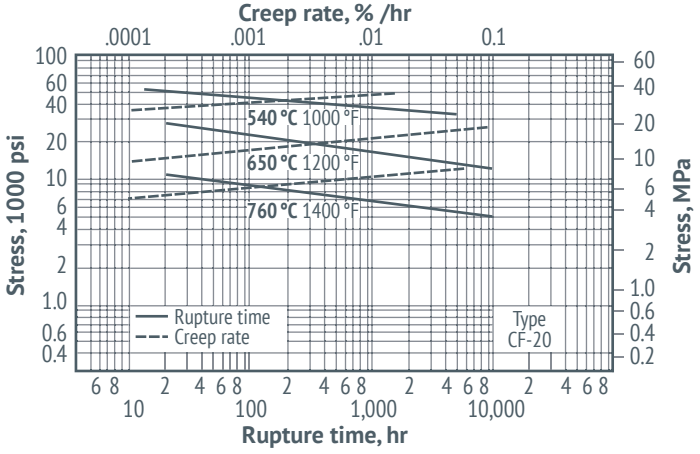
Alloy Casting Institute [3]

Figure 21 Stress versus rupture-time and creep-rate curves for annealed Type CF-8M stainless steel



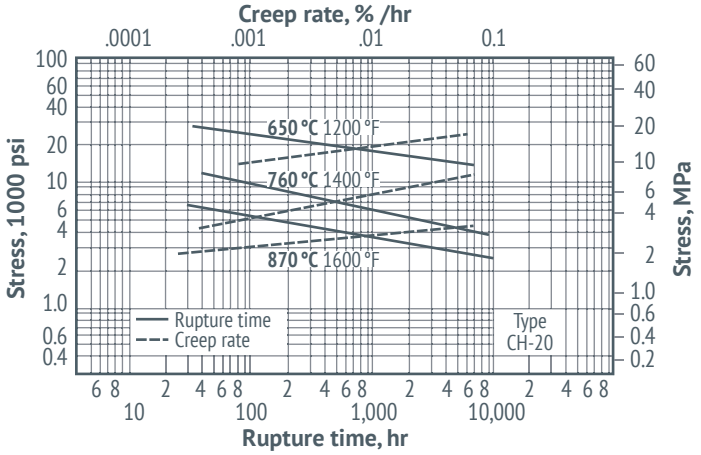
Alloy Casting Institute [3]

Figure 22 Stress versus rupture-time and creep-rate curves for annealed Type CF-20 stainless steel



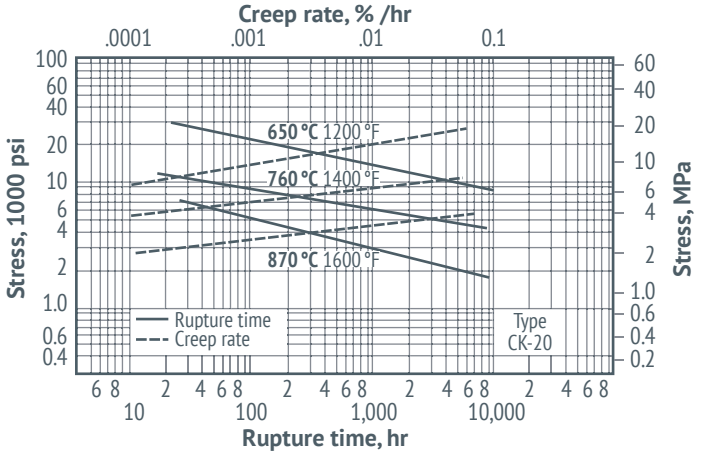
Alloy Casting Institute [3]

Figure 23 Stress versus rupture-time and creep-rate curves for annealed Type CH-20 stainless steel



Alloy Casting Institute [3]

Figure 24 Stress versus rupture-time and creep-rate curves for annealed Type CK-20 stainless steel

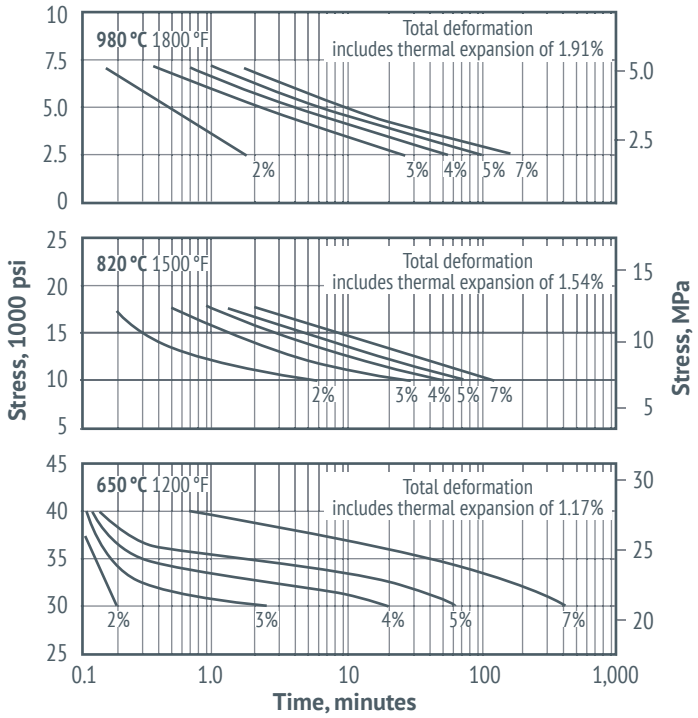


Alloy Casting Institute [3]

DESIGN VALUES

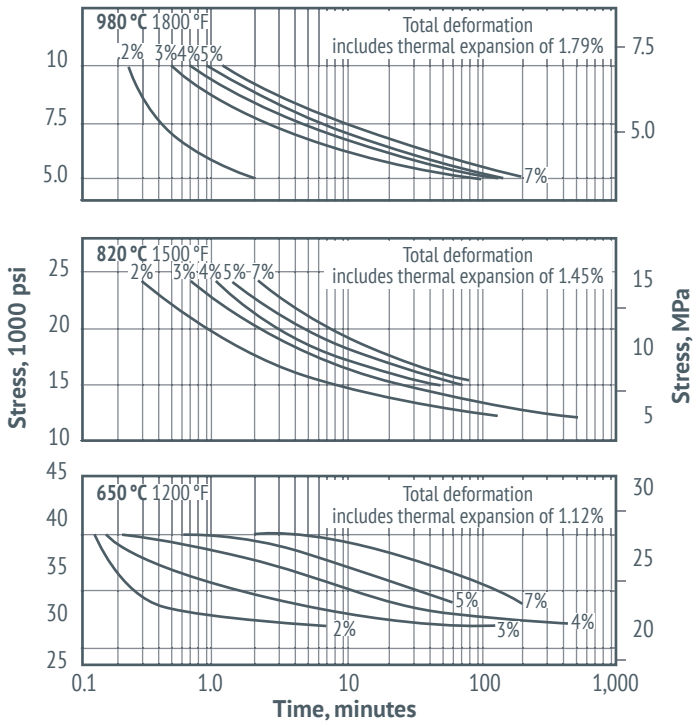
Maximum allowable stress values for design of austenitic stainless steel unfired pressure vessels are given in Section VIII, Division 1 and Division 2, of ASME Boiler and Pressure Vessel Code.

Figure 25 Design curves for Type 304 stainless steel sheet (heating rate 125°F/sec).



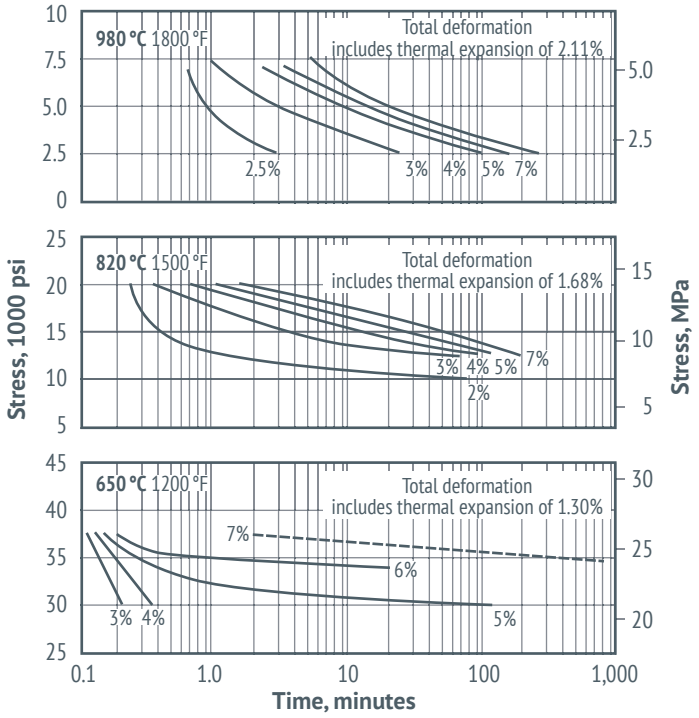
Cross, McMaster, Simmons, and Van Echo [4]

Figure 26 Design curves for Type 314 stainless steel sheet (heating rate 125°F/sec).



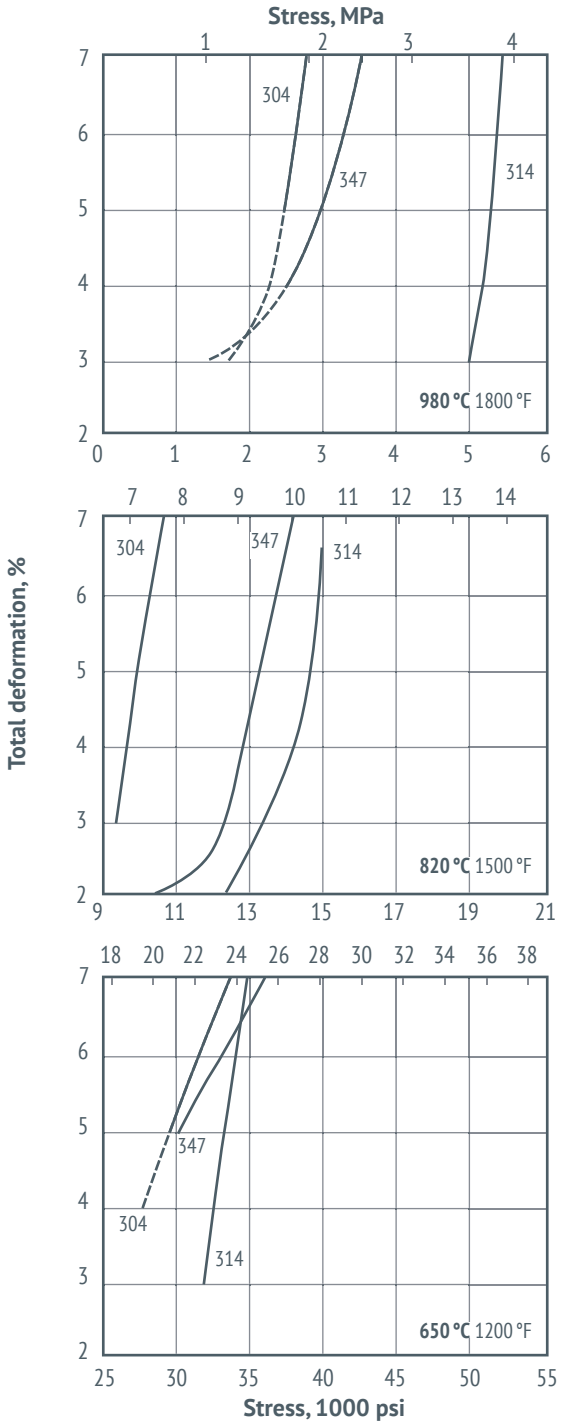
Cross, McMaster, Simmons, and Van Echo [4]

Figure 27 Design curves for Type 347 stainless steel sheet (heating rate 125°F/sec)



Cross, McMaster, Simmons, and Van Echo [4]

Figure 28 Stress-deformation curves for stainless steel sheets under load for 100 minutes.



Cross, McMaster, Simmons, and Van Echo [4]

PHYSICAL PROPERTIES

ELASTIC PROPERTIES

The effects of temperature on the moduli of elasticity in tension and shear and on Poisson's ratio are shown in *Tables 4, 5* and *6*.

DENSITY

The variation of density with temperature calculated from thermal expansion data and the mean density at 32 °F for Types 301, 316, and 347 austenitic stainless steels are shown in *Table 7*.

THERMAL PROPERTIES

Specific Heat

Table 8 shows the effect of temperature on the specific heats of Types 301, 316, and 347.

Thermal Conductivity

Average curves showing the effect of temperature on the thermal conductivity of the austenitic stainless steels are shown in *Figure 29*.

TABLE 4 Modulus of elasticity at various temperatures								
Temperature		Modulus of elasticity (tension), 10^6 psi (10^3 MPa)						
°F	°C	Type 302	Type 304	Type 309	Type 310	Type 316	Type 321	Type 347
75	24	29.0 (20.3)	28.3 (19.9)	28.1 (19.8)	29.0 (20.3)	28.3 (19.9)	28.9 (20.3)	28.9 (20.3)
200	90	27.9 (19.6)	27.9 (19.6)	-	28.2 (19.8)	28.1 (19.8)	28.0 (19.7)	28.2 (19.8)
300	150	27.3 (19.2)	27.1 (19.1)	-	27.5 (19.3)	27.5 (19.3)	27.3 (19.2)	27.5 (19.3)
400	200	26.7 (18.8)	26.6 (18.7)	-	26.8 (18.8)	26.9 (18.9)	26.5 (18.6)	26.8 (18.8)
500	260	26.6 (18.3)	26.0 (18.3)	-	26.2 (18.4)	26.3 (18.5)	25.8 (18.1)	26.1 (18.4)
600	320	25.4 (17.9)	25.6 (18.0)	-	25.5 (17.9)	25.6 (18.0)	25.3 (17.8)	25.4 (17.9)
700	370	24.8 (17.4)	24.7 (17.4)	-	24.9 (17.5)	24.9 (17.5)	24.5 (17.2)	24.8 (17.4)
800	430	24.2 (17.0)	24.1 (16.9)	23.1 (16.2)	24.2 (17.0)	24.2 (17.0)	23.8 (16.7)	24.1 (16.9)
900	480	23.6 (16.6)	23.2 (16.3)	-	23.6 (16.6)	23.5 (16.5)	23.2 (16.3)	23.4 (16.5)
1000	540	23.0 (16.2)	22.5 (15.8)	22.6 (15.8)	23.0 (16.2)	22.8 (16.0)	22.5 (15.8)	22.8 (16.0)
1100	590	22.3 (15.7)	21.8 (15.3)	-	22.4 (15.8)	22.2 (15.6)	21.9 (15.4)	22.0 (15.5)
1200	650	21.8 (15.3)	21.1 (14.8)	21.8 (15.3)	21.8 (15.3)	21.5 (15.1)	21.2 (14.9)	21.4 (15.0)
1300	700	21.2 (14.9)	20.4 (14.3)	21.2 (14.9)	21.2 (14.9)	20.8 (14.6)	20.4 (14.3)	20.7 (14.6)
1400	760	20.6 (14.5)	19.4 (13.6)	-	20.5 (14.4)	20.0 (14.0)	19.7 (13.9)	20.0 (14.1)
1500	820	20.0 (14.1)	18.1 (12.7)	19.8 (13.9)	19.0 (13.4)	19.1 (13.4)	19.1 (13.4)	19.4 (13.6)
1600	870	-	-	19.2 (13.5)	19.2 (13.5)	-	-	18.7 (13.2)
Fredericks[3], Garofalo[6]								

TABLE 5 Modulus of rigidity at various temperatures							
Temperature		Modulus of rigidity (shear), 10^6 psi (10^3 MPa)					
°F	°C	Type 302	Type 304	Type 310	Type 316	Type 321	Type 347
75	24	11.2 (7.9)	11.4 (8.0)	11.2 (7.9)	11.3 (7.9)	11.2 (7.9)	11.4 (8.0)
200	90	10.8 (7.6)	11.1 (7.8)	10.9 (7.7)	11.0 (7.7)	10.8 (7.6)	11.0 (7.7)
300	150	10.4 (7.3)	10.8 (7.6)	10.6 (7.5)	10.6 (7.5)	10.6 (7.5)	10.7 (7.5)
400	200	10.1 (7.1)	10.5 (7.4)	10.3 (7.2)	10.3 (7.2)	10.3 (7.2)	10.4 (7.3)
500	260	9.8 (6.9)	10.2 (7.2)	10.0 (7.0)	10.0 (7.0)	9.9 (7.0)	10.1 (7.1)
600	320	9.5 (6.7)	9.9 (7.0)	9.7 (6.8)	9.7 (6.8)	9.7 (6.8)	9.8 (6.9)
700	370	9.3 (6.5)	9.7 (6.8)	9.4 (6.6)	9.4 (6.6)	9.4 (6.6)	9.5 (6.7)
800	430	9.0 (6.3)	9.5 (6.7)	9.1 (6.4)	9.1 (6.4)	9.1 (6.4)	9.2 (6.5)
900	480	8.8 (6.2)	9.2 (6.5)	8.8 (6.2)	8.8 (6.2)	8.8 (6.2)	8.9 (6.3)
1000	540	8.6 (6.0)	8.9 (6.3)	8.5 (6.0)	8.5 (6.0)	8.5 (6.0)	8.6 (6.0)
1100	590	8.4 (5.9)	8.6 (6.0)	8.2 (5.8)	8.3 (5.8)	8.2 (5.8)	8.3 (5.8)
1200	650	8.2 (5.8)	8.3 (5.8)	7.9 (5.6)	8.1 (5.7)	7.9 (5.6)	8.1 (5.7)
1300	700	7.9 (5.6)	8.0 (5.6)	7.6 (5.3)	7.9 (5.6)	7.7 (5.4)	7.8 (5.5)
1400	760	7.7 (5.4)	7.7 (5.4)	7.2 (5.0)	7.7 (5.4)	7.4 (5.2)	7.5 (5.3)
1500	820	7.5 (5.3)	7.4 (5.2)	6.9 (4.9)	7.5 (5.3)	7.1 (5.0)	7.2 (5.0)
1600	870	-	-	6.6 (4.4)	-	-	6.9 (4.9)
Fredericks[3], Garofalo[6]							

TABLE 6 Poisson's ratio at various temperatures							
Temperature		Poisson's ratio					
°F	°C	Type 304	Type 309	Type 310	Type 316	Type 321	Type 347
300	150	0.28	0.28	0.32	0.26	0.23	0.30
500	260	0.30	0.30	0.31	0.29	0.25	0.31
700	370	0.32	0.30	0.31	0.34	0.27	029
900	480	0.28	0.29	0.32	0.30	0.30	0.33
1100	590	0.29	0.27	0.34	0.32	0.29	0.31
1300	700	0.28	0.32	0.34	0.31	0.27	0.35
1500	820	0.25	0.25	0.29	0.24	-	0.28
Garofalo, Malenock and Smith [7]							

TABLE 7 Density of annealed austenitic stainless steels at various temperatures				
Temperature		Density, lb/ cu in. (g/cm³)		
°F	°C	Type 301	Type 316	Type 347
-250	-160	0.2885 (7.99)	0.2897 (8.02)	0.2879 (7.97)
-200	-130	0.2882 (7.98)	0.2894 (8.01)	0.2875 (7.96)
-100	-73	0.2874 (7.96)	0.2886 (7.99)	0.2869 (7.94)
68	20	0.2859 (7.91)	0.2873 (7.95)	0.2856 (7.91)
200	90	0.2848 (7.88)	0.2861 (7.92)	0.2846 (7.88)
400	200	0.2832 (7.84)	0.2846 (7.88)	0.2830 (7.83)
600	320	0.2814 (7.79)	0.2829 (7.83)	0.2813 (7.79)
800	430	0.2797 (7.74)	0.2813 (7.79)	0.2795 (7.74)
1000	540	0.2779 (7.69)	0.2796 (7.74)	0.2777 (7.69)
1200	650	0.2760 (7.64)	0.2779 (7.69)	0.2759 (7.64)
1400	760	0.2741 (7.59)	0.2760 (7.64)	0.2740 (7.58)
1600	870	0.2723 (7.54)	0.2741 (7.59)	0.2721 (7.53)
1800	980	0.2705* (7.49)	0.2723 (7.54)	0.2702 (7.48)
* Extrapolated	Garofalo. Malenock and Smith			

Figure 29 Effect of temperature on the thermal conductivity of chromium-nickel stainless steels.

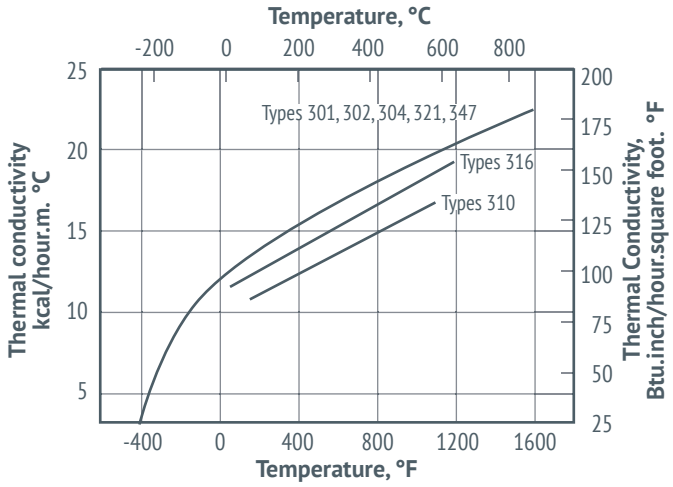


Figure 30 Average instantaneous coefficients of expansion of chromium-nickel stainless steels.

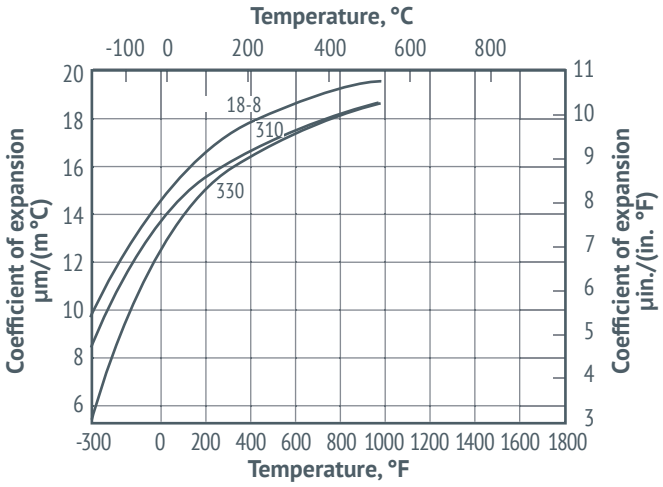


Figure 31 Approximate average coefficients of expansion of chromium-nickel stainless steels between 70°F and the indicated 20°C temperatures.

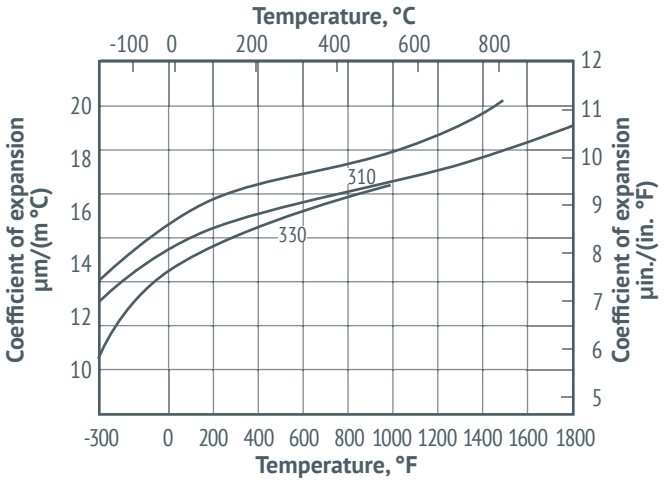
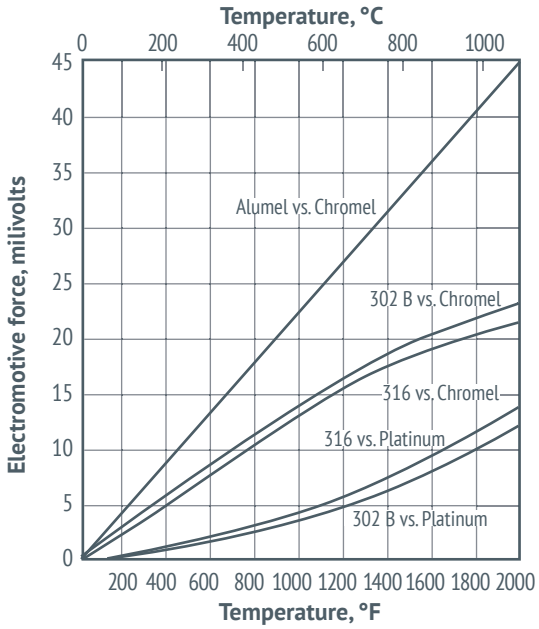


Figure 32 Thermo-electric properties of Types 302B and 316 stainless steels



Dahl and Lonberger[8]

Coefficient of thermal expansion

Figures 30 and *31* show the average and instantaneous coefficients of thermal expansion of the austenitic stainless steels as a function of temperature.

TABLE 8 Specific heats of annealed austenitic stainless steels at various temperatures

Temperature		Specific heat, BTU/lb/°F (J/kg/K)		
°F	°C	Type 301	Type 316	Type 347
-250	-160	0.080 (335)	0.079 (331)	0.080 (335)
-200	-130	0.086 (360)	0.085 (356)	0.085 (356)
-100	-73	0.096 (402)	0.094 (394)	0.094 (394)
68	20	0.109 (456)	0.108 (452)	0.108 (452)
200	90	0.117 (490)	0.116 (486)	0.116 (486)
400	200	0.127 (532)	0.126 (528)	0.124 (519)
600	320	0.133 (557)	0.131 (548)	0.131 (548)
800	430	0.137 (574)	0.135 (565)	0.135 (565)
1000	540	0.140 (586)	0.137 (573)	0.139 (582)
1200	650	0.143 (599)	0.140 (586)	0.144 (603)
1400	760	0.148 (620)	0.147 (615)	0.149 (624)
1600	870	0.154 (645)	0.155 (649)	0.159 (666)
1800	980	0.162* (691)	0.165* (691)	0.175* (733)

* Extrapolated Garofalo. Malenock and Smith

TABLE 9 Diffusivity of annealed austenitic stainless steels at various temperatures				
Temperature		Diffusivity, ft^2/hr (cm^2/hr)		
°F	°C	Type 301	Type 316	Type 347
-250	-160	0.159 (148)	0.156 (145)	0.179 (166)
-200	-130	0.158 (147)	0.151 (140)	0.173 (161)
-100	-73	0.158 (147)	0.147 (137)	0.165 (153)
68	20	0.160 (149)	0.143 (133)	0.158 (147)
200	90	0.162 (151)	0.144 (134)	0.157 (146)
400	200	0.167 (155)	0.148 (137)	0.161 (150)
600	320	0.176 (164)	0.158 (147)	0.168 (156)
800	430	0.185 (172)	0.167 (155)	0.176 (164)
1000	540	0.194 (180)	0.173 (161)	0.185 (172)
1200	650	0.203 (189)	0.188 (175)	0.192 (178)
1400	760	0.209 (194)	0.191 (177)	0.199 (185)
1600	870	0.212 (197)	0.194 (180)	0.200 (186)
1800	980	0.212* (197)	0.195* (181)	0.194* (180)
* Extrapolated	Garofalo. Malenock and Smith			

TABLE 10 Electrical resistivity of annealed stainless steels at various temperatures										
Temperature		Electrical resistivity, microhm-cm								
°F	°C	Type 301	Type 302	Type 303	Type 304	Type 309	Type 310	Type 316	Type 321	Type 347
68	20	68	70	74	72	78	94	74	72	73
200	90	74	77	80	78	83	100	79	79	80
400	200	83	85	89	86	91	105	87	90	88
600	320	90	93	96	95	98	111	93	98	91
800	430	96	99	103	102	105	116	99	105	99
1000	540	102	105	108	108	111	120	104	112	107
1200	650	107	109	113	114	116	124	110	117	111
1400	760	111	113	117	118	120	127	-	121	116
1600	870	-	116	121	125	124	129	-	-	120
1800	980	-	119	-	-	127	-	-	-	-
2000	1090	-	122	-	-	-	-	-	-	-
2200	1200	-	124	-	-	-	-	-	-	-
2400	1320	-	126	-	-	-	-	-	-	-
Note: microhm-cm x 6.0153 = ohms circular mil foot		Various sources								

Diffusivity

The diffusivities of Types 301, 316, and 347 austenitic stainless steels are given in *Table 9*. The data were calculated by the equation

$D=K/C_p d$
K=thermal conductivity
C_p=specific heat
d=density

ELECTRICAL PROPERTIES

Resistivity

The electrical resistivities of the austenitic stainless steels and their variations with temperature are shown in *Table 10*.

Thermo-electric properties

The temperature-electromotive force relationships for Types 302B and 310 austenitic stainless steel coupled with Chromel* and platinum are compared with a Chromel-Alumel* couple in *Figure 32*.

*Trademark

References

1. SImmons, W. F. and Cross, H. C., "Report on the Elevated-Temperature Properties of Stainless Steels." ASTM Spec. Tech. Pub. No. 124. 1952.

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