

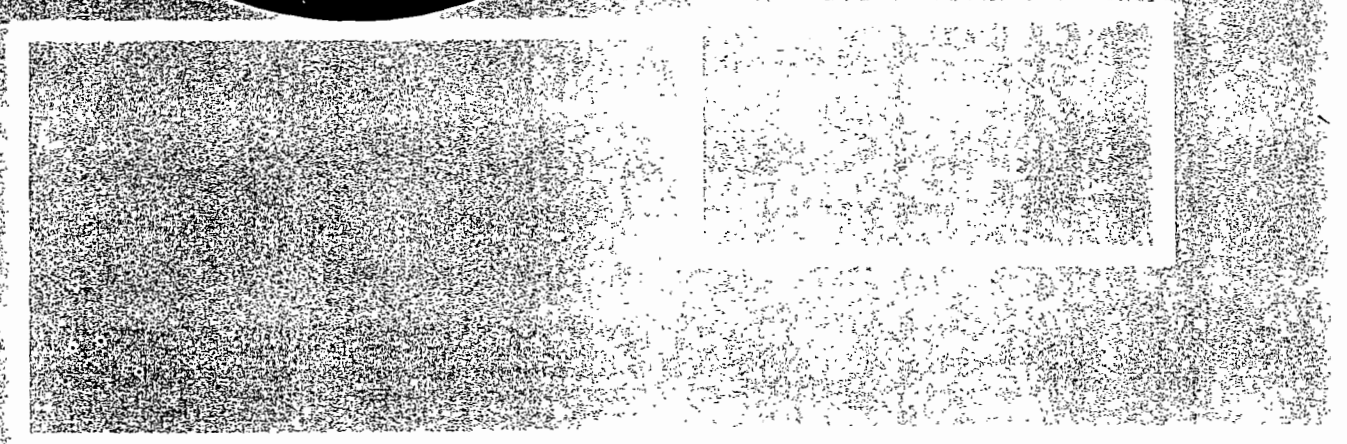
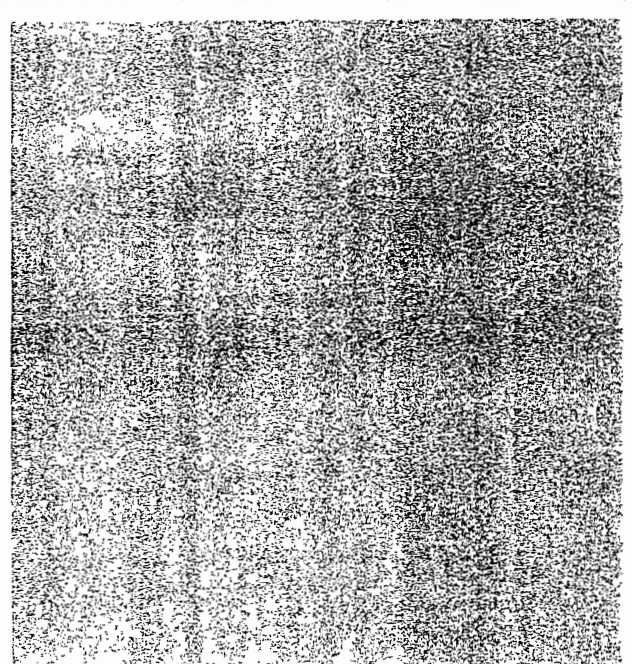
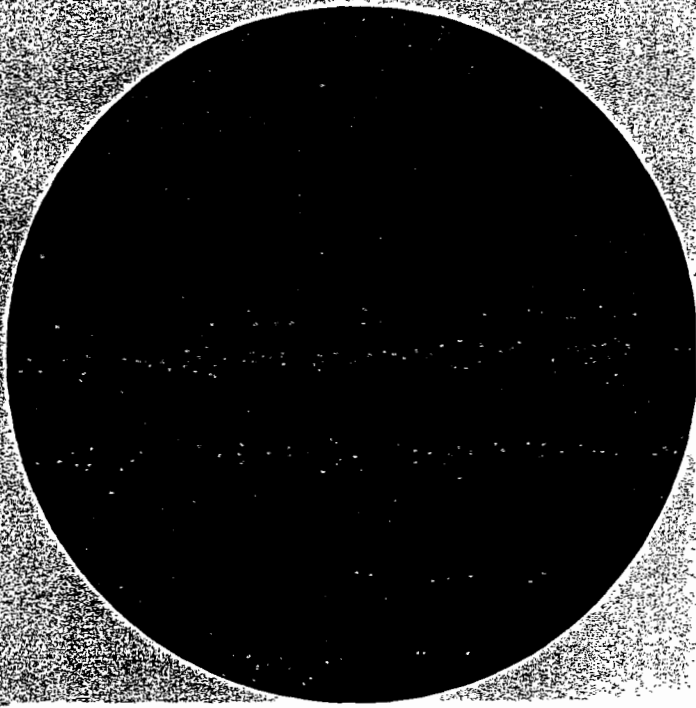
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# Engineering properties at elevated temperatures



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The information and data in this publication are as complete and accurate as possible at the time of publication.  
The characteristics of a material can vary according to the precise method of production, fabrication and treatment.  
Wherever available full details of the condition of the test pieces are included. As these data are derived from various sources, suppliers of materials should always be consulted concerning the specific characteristics of their products.

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# Austenitic chromium-nickel stainless steels – Engineering properties at elevated temperatures

| Contents                                                                    | <i>Page</i> |
|-----------------------------------------------------------------------------|-------------|
| AISI and ACI classifications of wrought and cast stainless steels . . . . . | 2           |
| Short time mechanical properties . . . . .                                  | 3 –7        |
| Long time creep and rupture properties . . . . .                            | 4, 8 –11    |
| Short time creep properties . . . . .                                       | 8, 11 –12   |
| Physical properties . . . . .                                               | 12 –17      |
| References . . . . .                                                        | 17          |

# 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

| AISI Type | Composition, % |            |       |          |           |             |             |           |                                            |
|-----------|----------------|------------|-------|----------|-----------|-------------|-------------|-----------|--------------------------------------------|
|           | C max          | Mn max     | P max | S max    | Si max    | Cr          | Ni          | Mo        | Other                                      |
| 201       | 0.15           | 5.50-7.50  | .060  | .030     | 1.00      | 16.00-18.00 | 3.50-5.50   | —         | N 0.25 max                                 |
| 202       | 0.15           | 7.50-10.00 | .060  | .030     | 1.00      | 17.00-19.00 | 4.00-6.00   | —         | N 0.25 max                                 |
| 301       | 0.15           | 2.00       | .045  | .030     | 1.00      | 16.00-18.00 | 6.00-8.00   | —         | —                                          |
| 302       | 0.15           | 2.00       | .045  | .030     | 1.00      | 17.00-19.00 | 8.00-10.00  | —         | —                                          |
| 302B      | 0.15           | 2.00       | .045  | .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  | .06      | 1.00      | 17.00-19.00 | 8.00-10.00  | —         | Se 0.15 min                                |
| 304       | .08            | 2.00       | .045  | .030     | 1.00      | 18.00-20.00 | 8.00-12.00  | —         | —                                          |
| 304L      | .03            | 2.00       | .045  | .030     | 1.00      | 18.00-20.00 | 8.00-12.00  | —         | —                                          |
| 305       | 0.12           | 2.00       | .045  | .030     | 1.00      | 17.00-19.00 | 10.00-13.00 | —         | —                                          |
| 308       | .08            | 2.00       | .045  | .030     | 1.00      | 19.00-21.00 | 10.00-12.00 | —         | —                                          |
| 309       | 0.20           | 2.00       | .045  | .030     | 1.00      | 22.00-24.00 | 12.00-15.00 | —         | —                                          |
| 309S      | .08            | 2.00       | .045  | .030     | 1.00      | 22.00-24.00 | 12.00-15.00 | —         | —                                          |
| 310       | 0.25           | 2.00       | .045  | .030     | 1.50      | 24.00-26.00 | 19.00-22.00 | —         | —                                          |
| 310S      | .08            | 2.00       | .045  | .030     | 1.50      | 24.00-26.00 | 19.00-22.00 | —         | —                                          |
| 314       | 0.25           | 2.00       | .045  | .030     | 1.50-3.00 | 23.00-26.00 | 19.00-22.00 | —         | —                                          |
| 316       | .08            | 2.00       | .045  | .030     | 1.00      | 16.00-18.00 | 10.00-14.00 | 2.00-3.00 | —                                          |
| 316L      | .03            | 2.00       | .045  | .030     | 1.00      | 16.00-18.00 | 10.00-14.00 | 2.00-3.00 | —                                          |
| 317       | .08            | 2.00       | .045  | .030     | 1.00      | 18.00-20.00 | 11.00-15.00 | 3.00-4.00 | —                                          |
| D319      | .07            | 2.00       | .045  | .030     | 1.00      | 17.50-19.50 | 11.00-15.00 | 2.25-3.00 | —                                          |
| 321       | .08            | 2.00       | .045  | .030     | 1.00      | 17.00-19.00 | 9.00-12.00  | —         | Ti 5 x C min                               |
| 347       | .08            | 2.00       | .045  | .030     | 1.00      | 17.00-19.00 | 9.00-13.00  | —         | Cb-Ta 10 x C min                           |
| 348       | .08            | 2.00       | .045  | .030     | 1.00      | 17.00-19.00 | 9.00-13.00  | —         | Cb-Ta 10 x C min; Ta 0.10 max; Co 0.20 max |
| 384       | .08            | 2.00       | .045  | .030     | 1.00      | 15.00-17.00 | 17.00-19.00 | —         | —                                          |
| 385       | .08            | 2.00       | .045  | .030     | 1.00      | 11.50-13.50 | 14.00-16.00 | —         | —                                          |

## Alloy Casting Institute Division (SFSA) Classification of Chromium-Nickel Stainless Steel Castings

| Cast Alloy Designation | Wrought Alloy Type <sup>1</sup> | Composition, % |        |       |       |        |         |           |           |                                                     |
|------------------------|---------------------------------|----------------|--------|-------|-------|--------|---------|-----------|-----------|-----------------------------------------------------|
|                        |                                 | C max          | Mn max | P max | S max | Si max | Cr      | Ni        | Mo        | Other                                               |
| CA-6NM                 | —                               | .06            | 1.00   | .04   | .04   | 1.00   | 11.5-14 | 3.5-4.5   | 0.40-1.0  | —                                                   |
| CD-4MCu                | —                               | .04            | 1.00   | .04   | .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   | .04   | .04   | 2.00   | 26-30   | 8-11      | —         | —                                                   |
| CF-3                   | 304L                            | .03            | 1.50   | .04   | .04   | 2.00   | 17-21   | 8-12      | —         | —                                                   |
| CF-8                   | 304                             | .08            | 1.50   | .04   | .04   | 2.00   | 18-21   | 8-11      | —         | —                                                   |
| CF-20                  | 302                             | 0.20           | 1.50   | .04   | .04   | 2.00   | 18-21   | 8-11      | —         | —                                                   |
| CF-3M                  | 316L                            | .03            | 1.50   | .04   | .04   | 1.50   | 17-21   | 9-13      | 2.0-3.0   | —                                                   |
| CF-8M                  | 316                             | .08            | 1.50   | .04   | .04   | 1.50   | 18-21   | 9-12      | 2.0-3.0   | —                                                   |
| CF-12M                 | 316                             | 0.12           | 1.50   | .04   | .04   | 1.50   | 18-21   | 9-12      | 2.0-3.0   | —                                                   |
| CF-8C                  | 347                             | .08            | 1.50   | .04   | .04   | 2.00   | 18-21   | 9-12      | —         | Cb 8 x C min, 1.0 max or Cb-Ta 10 x C min, 1.35 max |
| CF-16F                 | 303                             | 0.16           | 1.50   | 0.17  | .04   | 2.00   | 18-21   | 9-12      | 1.5 max   | Se 0.20-0.35                                        |
| CG-8M                  | 317                             | .08            | 1.50   | .04   | .04   | 1.50   | 18-21   | 9-13      | 3.0-4.0   | —                                                   |
| CH-20                  | 309                             | 0.20           | 1.50   | .04   | .04   | 2.00   | 22-26   | 12-15     | —         | —                                                   |
| CK-20                  | 310                             | 0.20           | 1.50   | .04   | .04   | 2.00   | 23-27   | 19-22     | —         | —                                                   |
| CN-7M                  | —                               | .07            | 1.50   | .04   | .04   | 1.50   | 18-22   | 27.5-30.5 | 2.0-3.0   | Cu 3-4                                              |

<sup>1</sup>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.

# Mechanical and Physical Properties of the Austenitic Chromium-Nickel Stainless Steels at Elevated Temperatures

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.<sup>1</sup> 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 I and II.

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

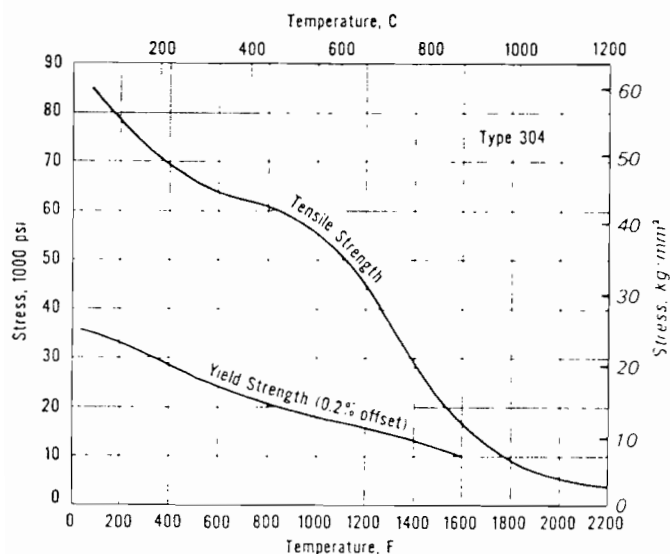


FIG. 1—Effect of temperature on the short time tensile properties of annealed Type 304 stainless steel. Plotted from the data of Simmons and Cross<sup>1</sup>

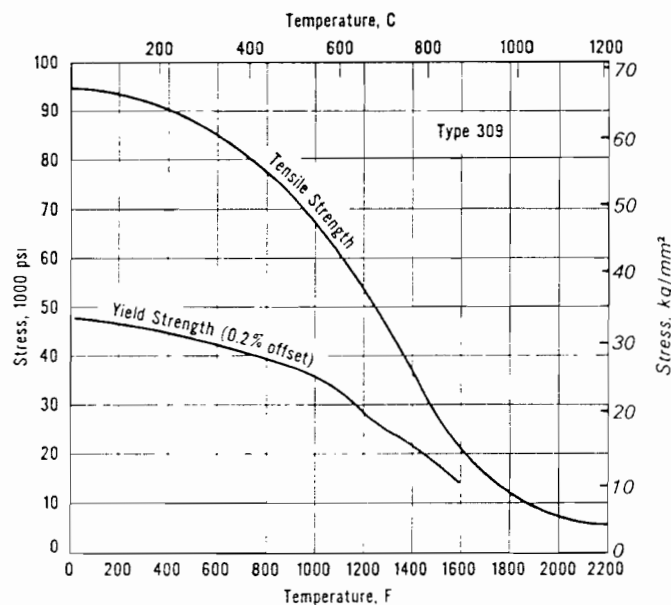


FIG. 2—Effect of temperature on the short time tensile properties of annealed Type 309 stainless steel. Plotted from the data of Simmons and Cross<sup>1</sup>

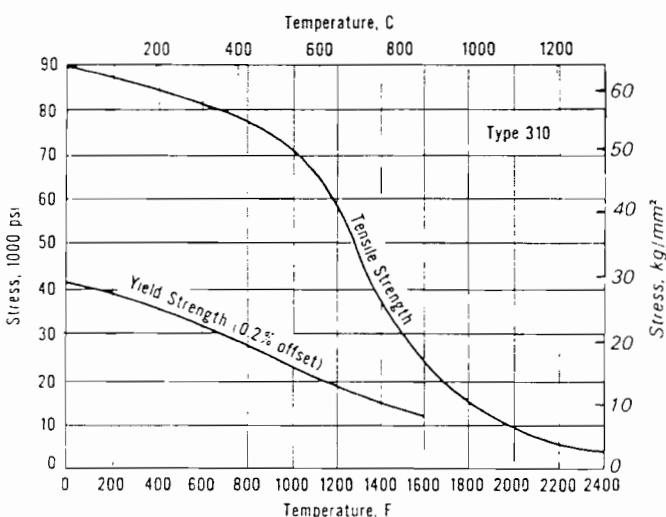


FIG. 3—Effect of temperature on the short time tensile properties of annealed Type 310 stainless steel. Plotted from the data of Simmons and Cross<sup>1</sup>

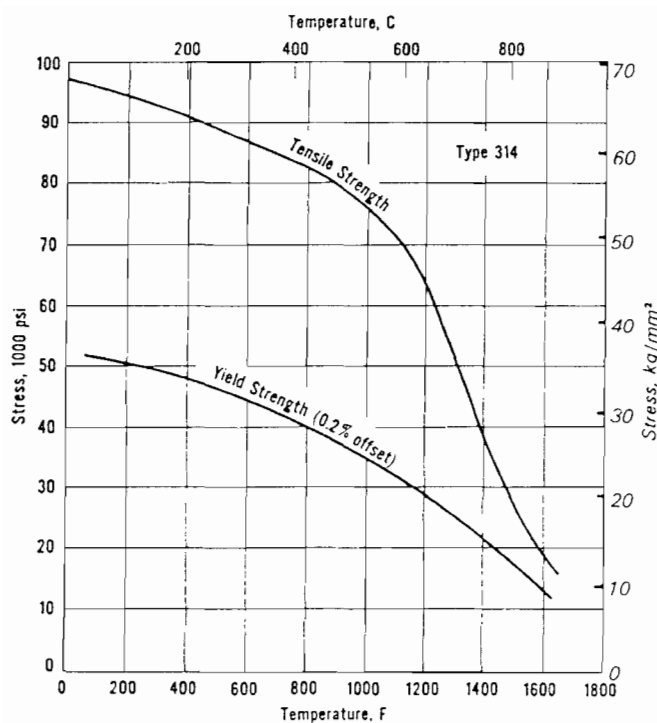


FIG. 4—Effect of temperature on the short time tensile properties of annealed Type 314 stainless steel. Plotted from the data of Simmons and Cross<sup>1</sup>

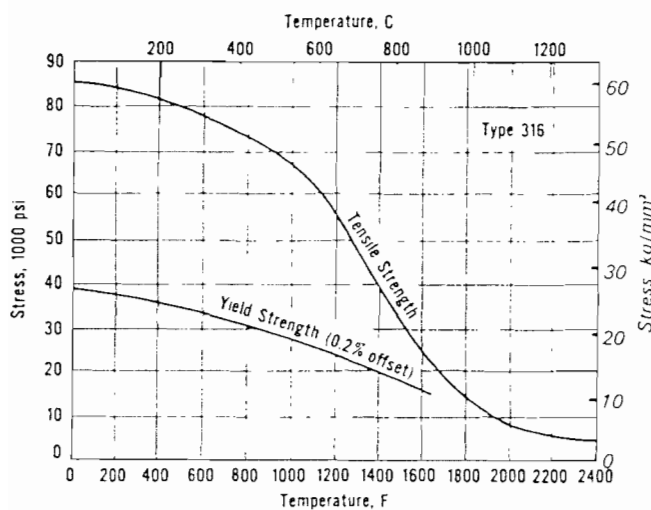


FIG. 5—Effect of temperature on the short time tensile properties of annealed Type 316 stainless steel. Plotted from the data of Simmons and Cross<sup>1</sup>

#### 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

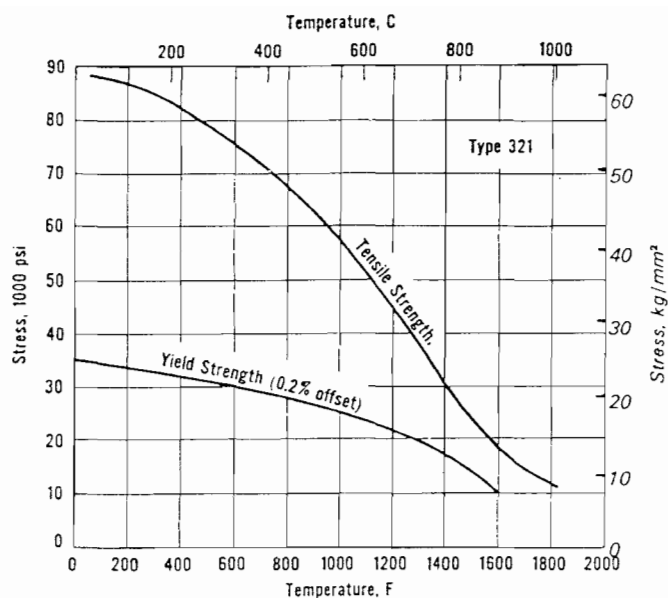


FIG. 6—Effect of temperature on the short time tensile properties of annealed Type 321 stainless steel. Plotted from the data of Simmons and Cross<sup>1</sup>

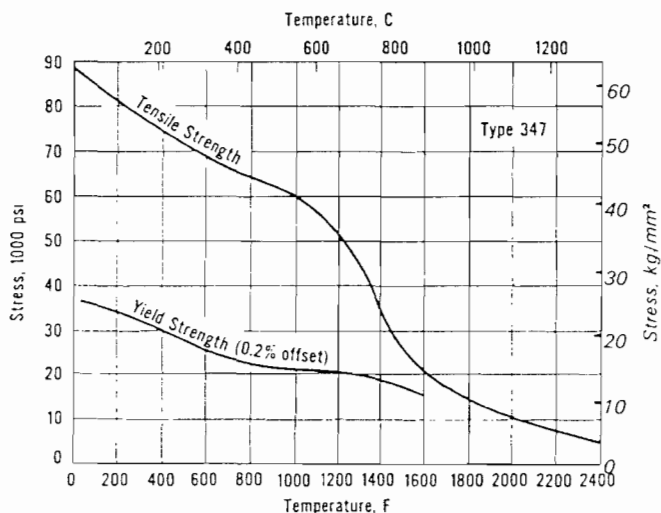


FIG. 7—Effect of temperature on the short time tensile properties of annealed Type 347 stainless steel. Plotted from the data of Simmons and Cross<sup>1</sup>

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.

TABLE I

Tensile, Compressive, and Bearing Properties of Annealed Type 302  
Stainless Steel\* for Various Temperatures and Exposure Times

| Temp, F | C   | Exposure<br>Time, hr** | Yield Strength (0.2% offset), psi    kg/mm <sup>2</sup> |      |             |      |         |      | Ultimate Stress, psi    kg/mm <sup>2</sup> |      |         |       |
|---------|-----|------------------------|---------------------------------------------------------|------|-------------|------|---------|------|--------------------------------------------|------|---------|-------|
|         |     |                        | 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 | 62,400  | 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     | 316 | 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 | 28,700      | 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    | 619 | 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   |
|-----|------|------|------|------|-------|------|------|------|
| .08 | 1.18 | .029 | .012 | 0.36 | 17.48 | 8.44 | 0.11 | 0.16 |

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

Doerr<sup>1</sup>

TABLE II

Tensile, Compressive, and Bearing Properties of Half-Hard Type 301  
Stainless Steel\* for Various Temperatures and Exposure Times

| Temp, F    C | Exposure Time, hr** | Yield Strength (0.2% offset), psi    kg/mm <sup>2</sup> |      |             |      |         |       | Ultimate Stress, psi    kg/mm <sup>2</sup> |       |         |       |  |  |
|--------------|---------------------|---------------------------------------------------------|------|-------------|------|---------|-------|--------------------------------------------|-------|---------|-------|--|--|
|              |                     | 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    316   | 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 |  |  |
| 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  | 60.9  | 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   |
|----|------|------|------|------|-------|------|------|
| 10 | 1.14 | .027 | .017 | 0.39 | 17.38 | 7.46 | 0.10 |

\*\* Time held at temperature prior to testing at indicated temperature. Doerr<sup>2</sup>

TABLE III

## Short Time High Temperature Properties of Cast Chromium-Nickel Stainless Steels\*

| Temperature, F C                                           | ACI Type  |           |           |           |           |           |
|------------------------------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
|                                                            | CF-8      | CF-20     | CF-8C     | CF-8M     | CH-20     | CK-20     |
| <b>Tensile Strength, psi kg/mm<sup>2</sup></b>             |           |           |           |           |           |           |
| 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 |
| <b>Yield Strength (0.2% offset), psi kg/mm<sup>2</sup></b> |           |           |           |           |           |           |
| 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  |
| <b>Elongation, %</b>                                       |           |           |           |           |           |           |
| 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        |
| <b>Reduction of Area, %</b>                                |           |           |           |           |           |           |
| Room                                                       | 74        | 68        | 48        | 70        | 63        | 49        |
| 1000 540                                                   | 53        | 62        | 57        | 68        | —         | —         |
| 1200 650                                                   | 46        | 46        | 50        | 53        | 50        | 34        |
| 1200 760                                                   | 40        | 34        | 41        | 50        | 47        | 21        |
| 1600 870                                                   | —         | —         | —         | —         | 69        | 18        |

\* Water quenched after 2 hr at 2050 F. 1120C

Alloy Casting Institute<sup>3</sup>

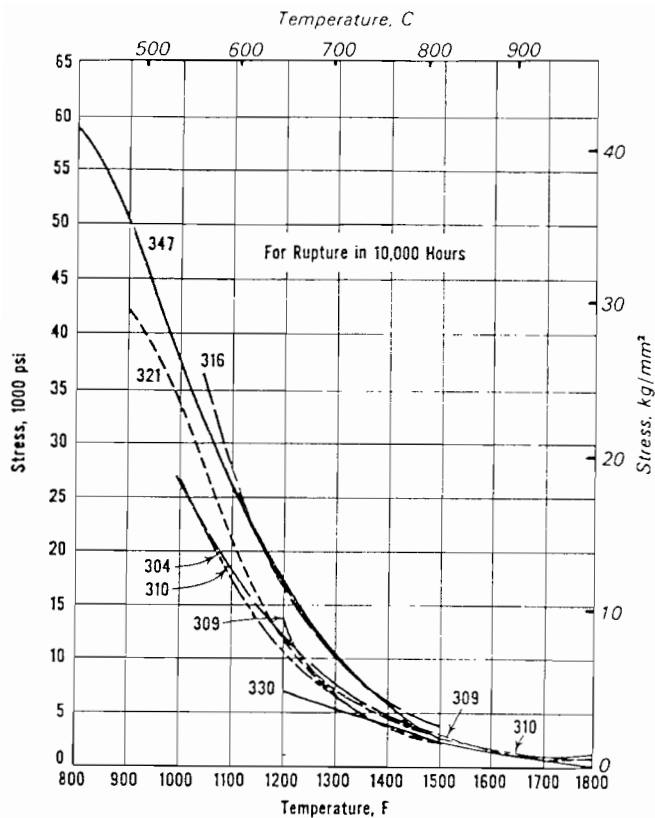


FIG. 8 — Stress-rupture curves for several annealed stainless steels. Simmons and Cross<sup>1</sup>

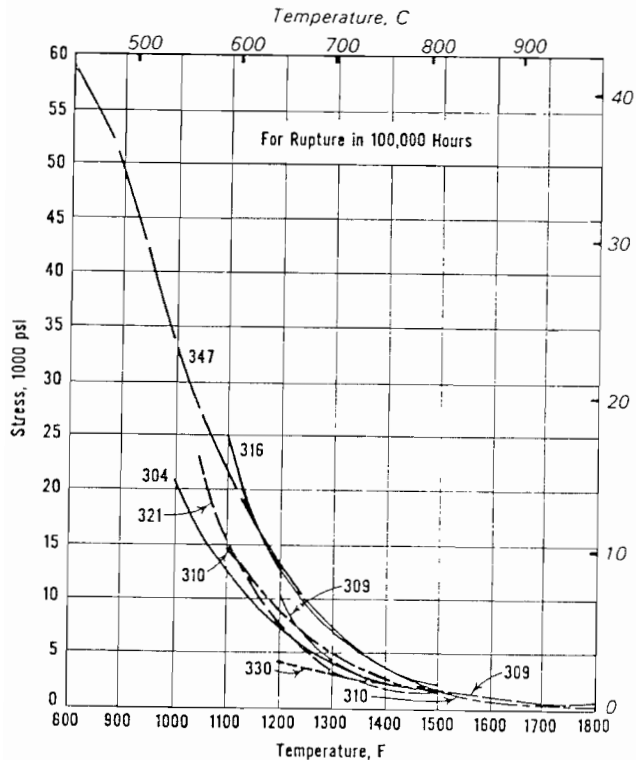


FIG. 9 — Stress-rupture curves for several annealed stainless steels. (Extrapolated data) Simmons and Cross<sup>1</sup>

Stresses that will cause creep at the rates of .0001 and .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.

### 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

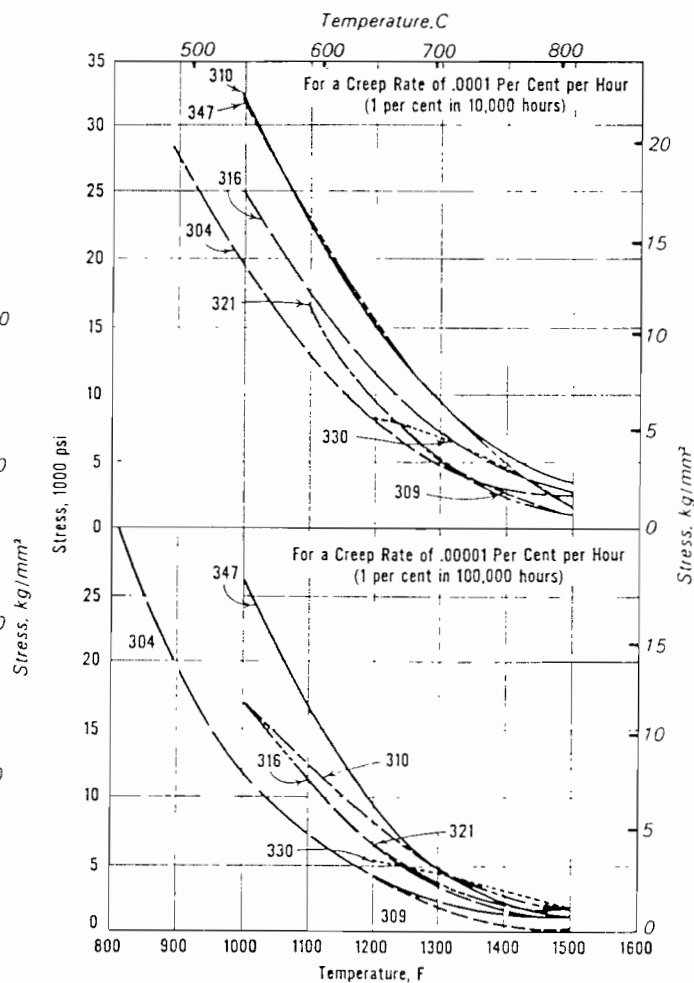


FIG. 10—Creep-rate curves for several annealed stainless steels Simmons and Cross<sup>1</sup>

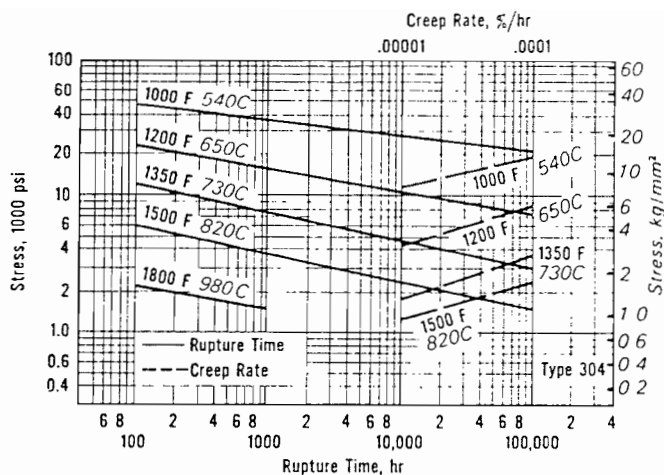


FIG. 11—Stress versus rupture-time and creep-rate curves for annealed Type 304 stainless steel based on average data. Simmons and Cross<sup>1</sup>

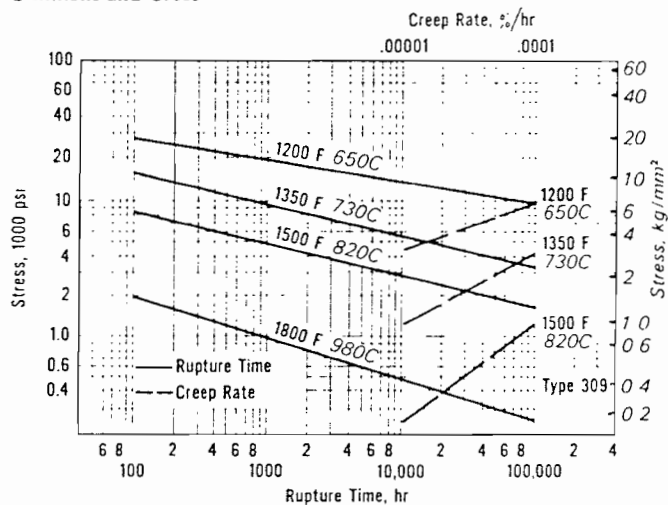


FIG. 12—Stress versus rupture-time and creep-rate curves for annealed Type 309 stainless steel based on average data. Simmons and Cross<sup>1</sup>

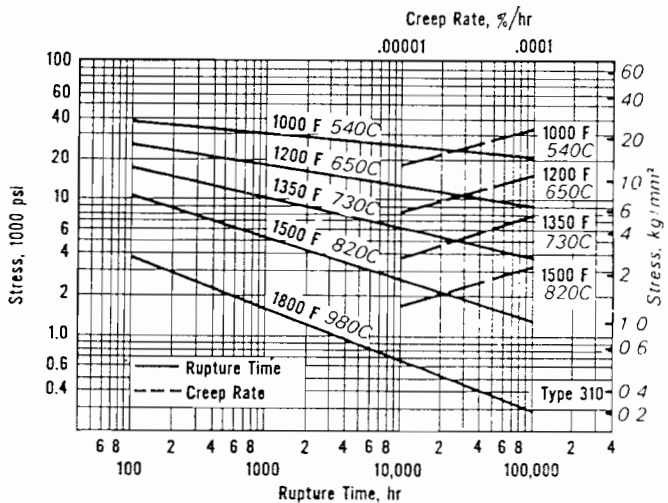


FIG. 13—Stress versus rupture-time and creep-rate curves for annealed Type 310 stainless steel based on average data. Simmons and Cross<sup>1</sup>

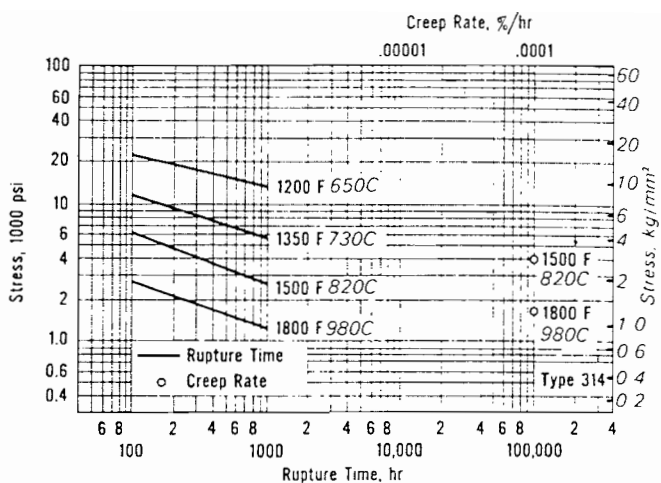


FIG. 14—Stress versus rupture-time and creep-rate curves for annealed Type 314 stainless steel based on average data. Simmons and Cross<sup>1</sup>

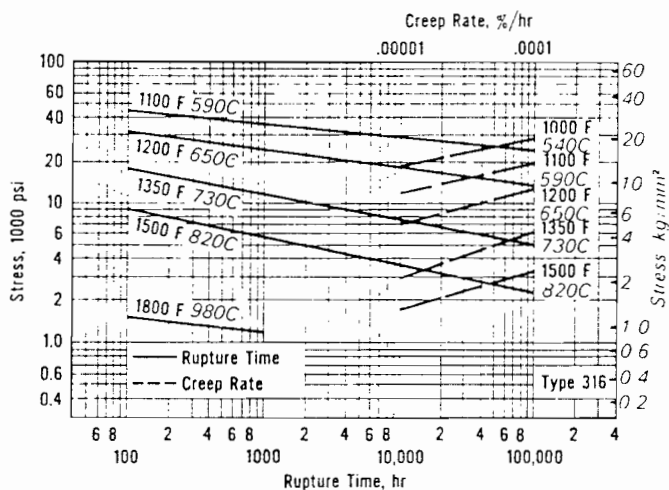


FIG. 15—Stress versus rupture-time and creep-rate curves for annealed Type 316 stainless steel based on average data. Simmons and Cross<sup>1</sup>

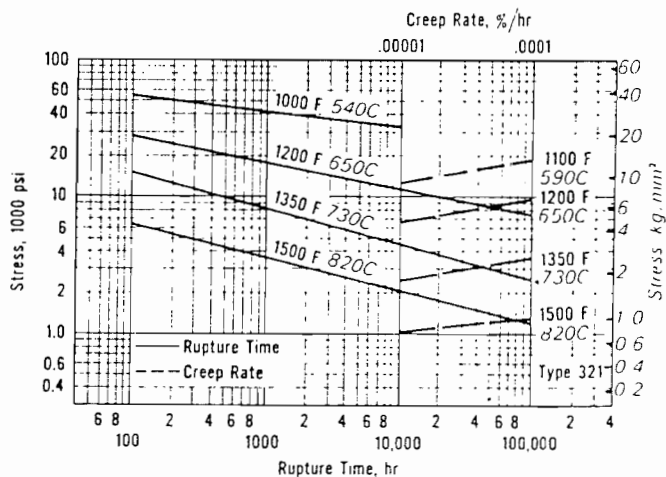


FIG. 16—Stress versus rupture-time and creep-rate curves for annealed Type 321 stainless steel based on average data. Simmons and Cross<sup>1</sup>

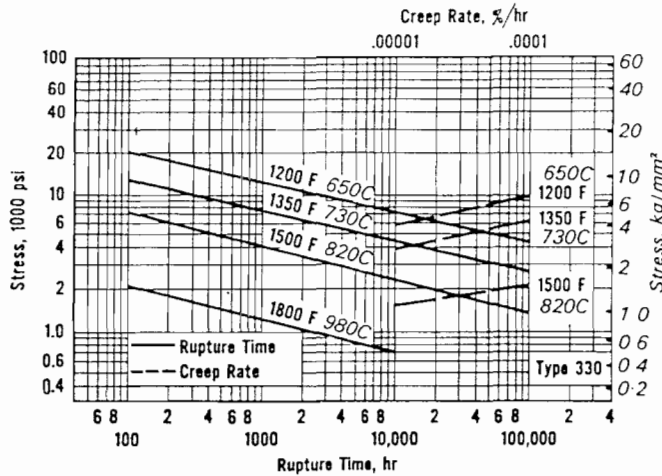


FIG. 17 - Stress versus rupture-time and creep-rate curves for annealed Type 330 stainless steel based on average data. Simmons and Cross<sup>1</sup>

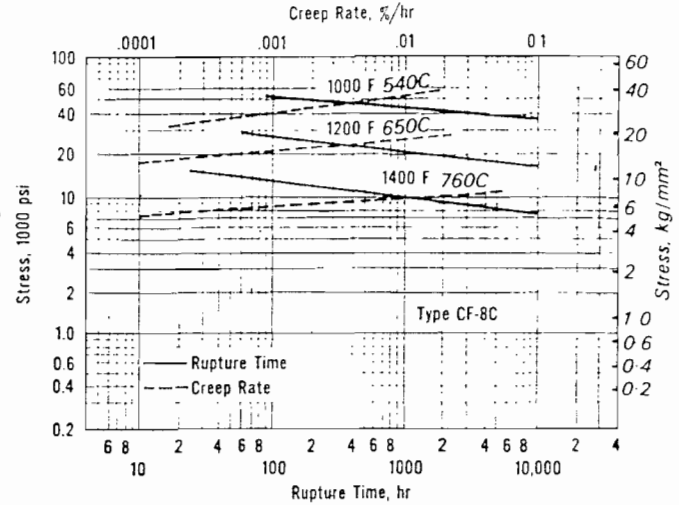


FIG. 20 - Stress versus rupture-time and creep-rate curves for annealed Type CF-8C stainless steel. Alloy Casting Institute<sup>3</sup>

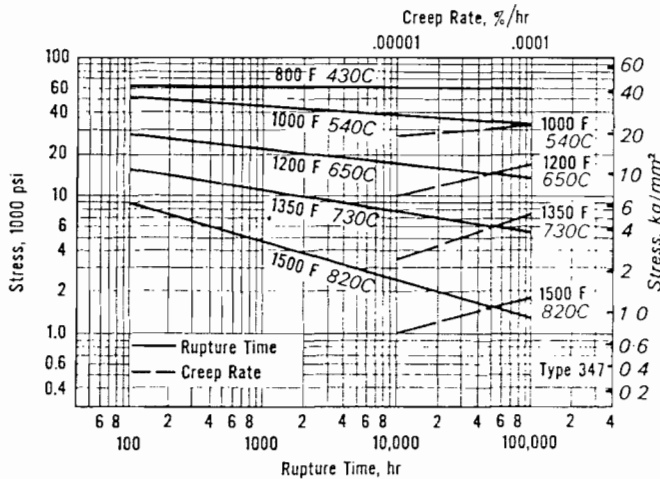


FIG. 18 - Stress versus rupture-time and creep-rate curves for annealed Type 347 stainless steel based on average data. Simmons and Cross<sup>1</sup>

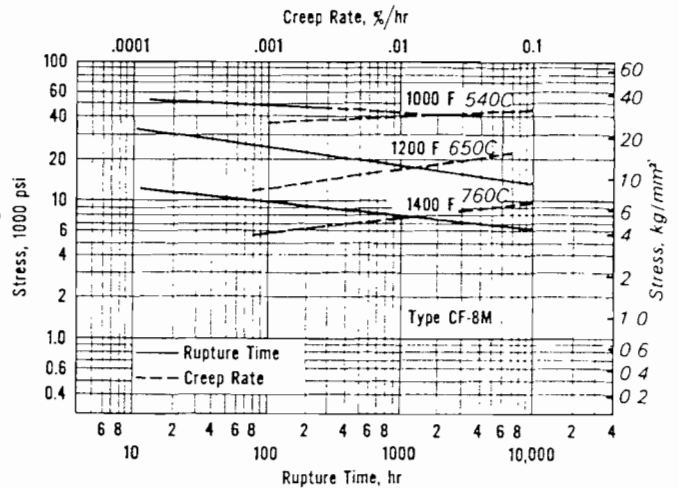


FIG. 21 - Stress versus rupture-time and creep-rate curves for annealed Type CF-8M stainless steel. Alloy Casting Institute<sup>1</sup>

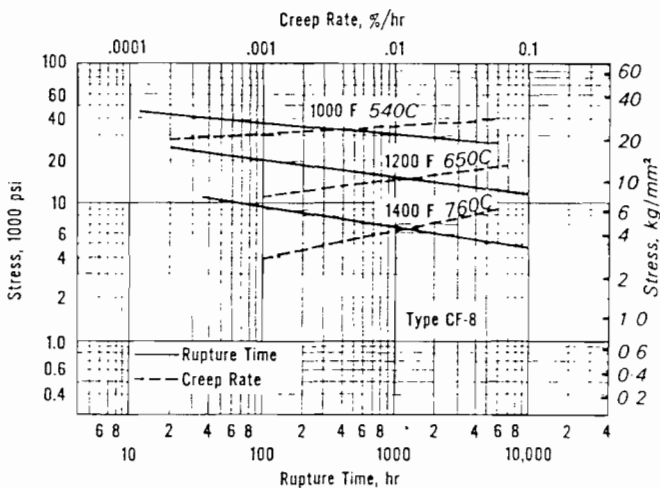


FIG. 19 - Stress versus rupture-time and creep-rate curves for annealed Type CF-8 stainless steel. Alloy Casting Institute<sup>3</sup>

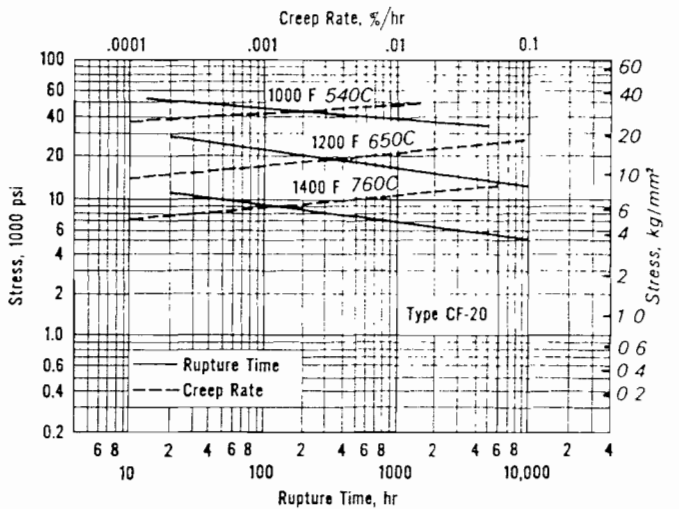


FIG. 22 - Stress versus rupture-time and creep-rate curves for annealed Type CF-20 stainless steel. Alloy Casting Institute<sup>3</sup>

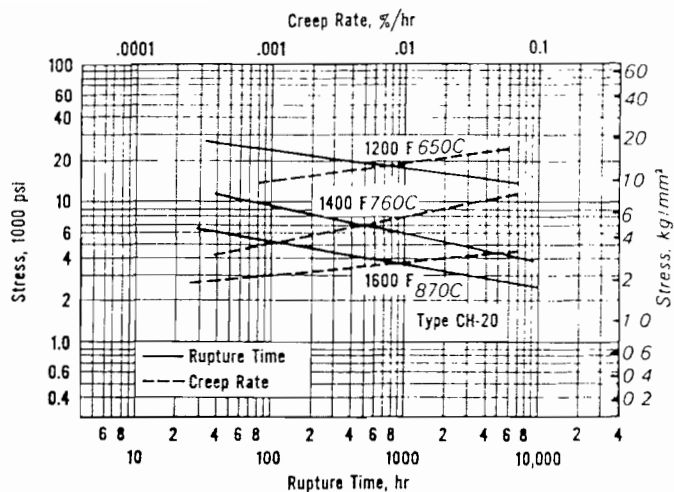


FIG. 23 — Stress versus rupture-time and creep-rate curves for annealed Type CH-20 stainless steel. Alloy Casting Institute<sup>1</sup>

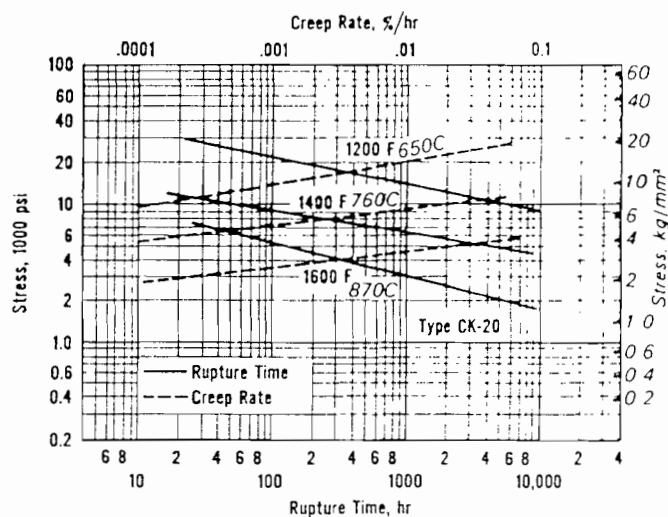


FIG. 24 — Stress versus rupture-time and creep-rate curves for annealed Type CK-20 stainless steel. Alloy Casting Institute<sup>1</sup>

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.

### 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.

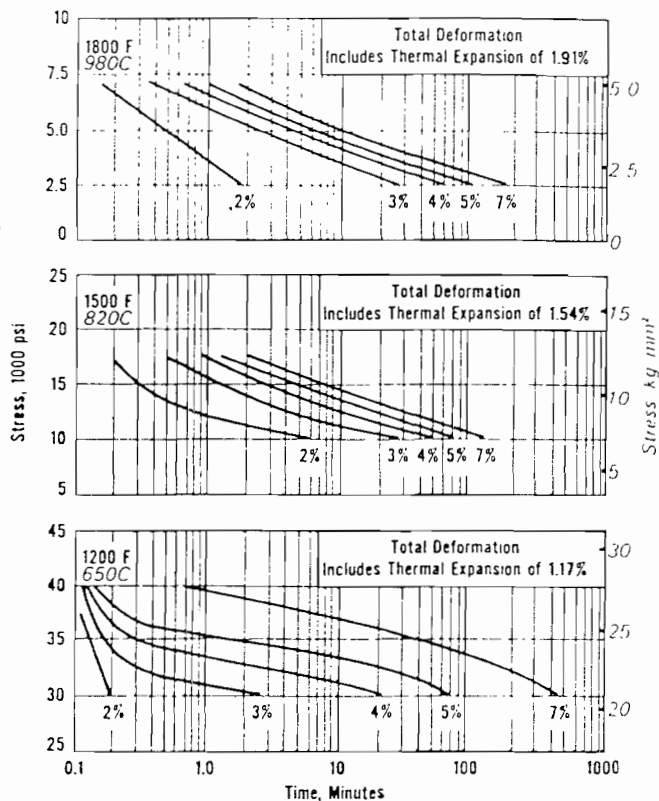


FIG. 25—Design curves for Type 304 stainless steel sheet (heating rate 125°F/sec). Cross, McMaster, Simmons, and Van Echo<sup>4</sup> 70 C/sec

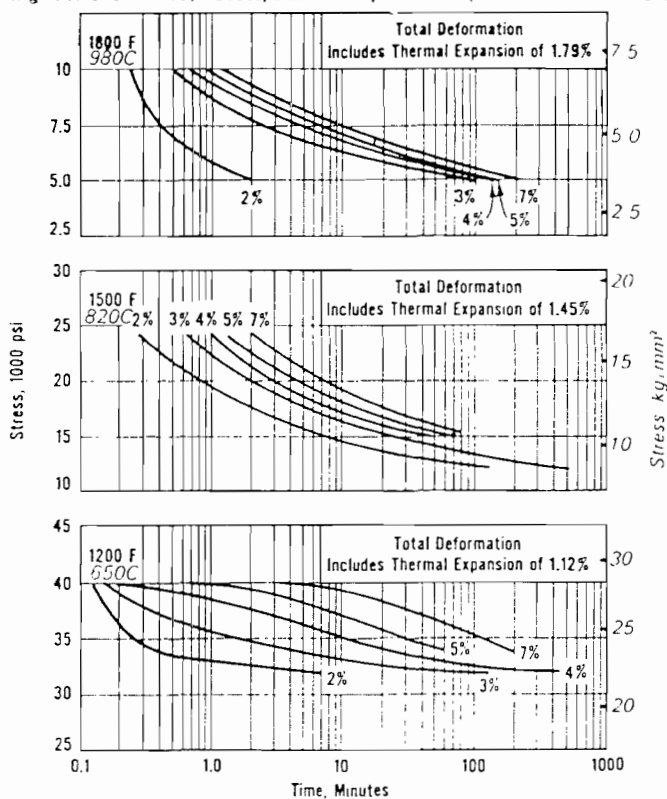


FIG. 26—Design curves for Type 314 stainless steel sheet (heating rate 125°F/sec). Cross, McMaster, Simmons, and Van Echo<sup>4</sup> 70 C/sec

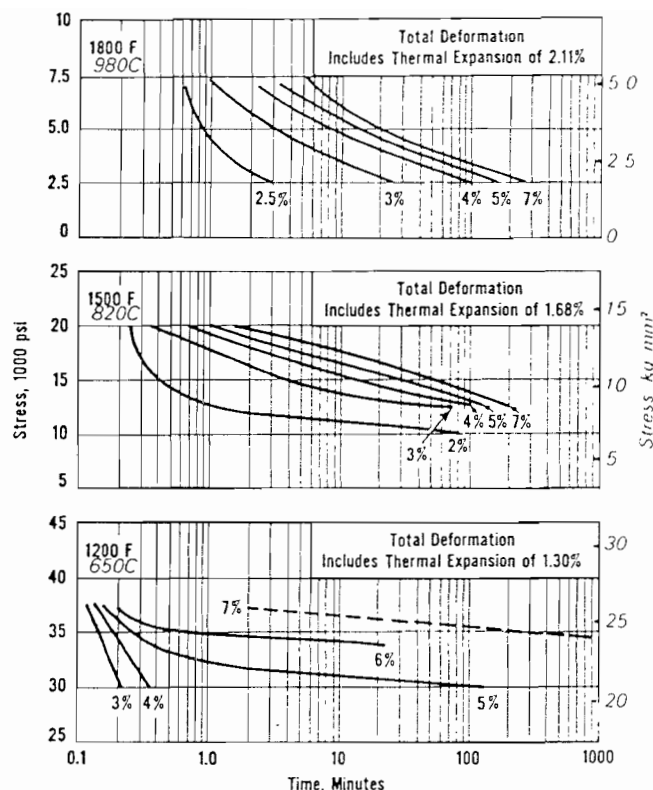


FIG. 27—Design curves for Type 347 stainless steel sheet (heating rate 125°F/sec). Cross, McMaster, Simmons, and Van Echo<sup>4</sup>

## 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 IV, V and VI.

### 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 VII.

### THERMAL PROPERTIES

#### Specific Heat

Table VIII 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.

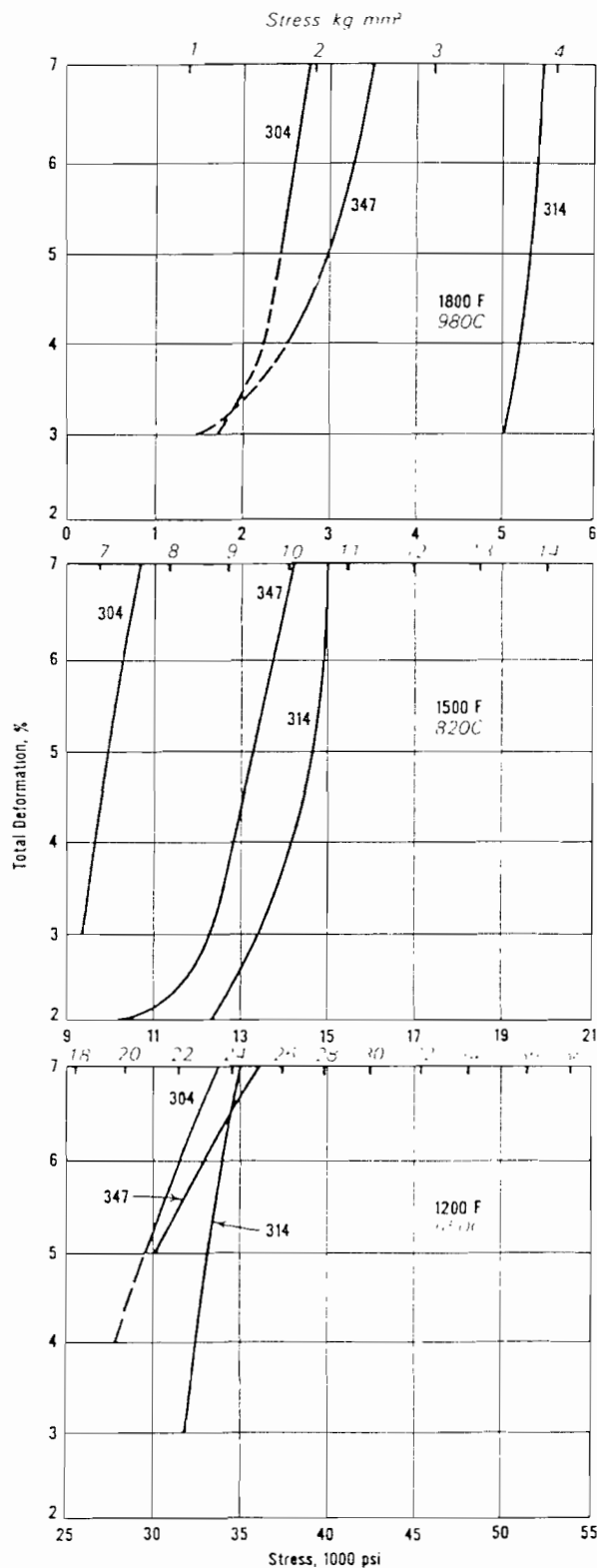


FIG. 28—Stress-deformation curves for stainless steel sheets under load for 100 minutes. Cross, McMaster, Simmons, and Van Echo<sup>4</sup>

**TABLE IV**  
**Modulus of Elasticity at Various Temperatures**

| Temp, F C | Modulus of Elasticity (Tension), $10^6$ psi $10^3$ kg/mm <sup>2</sup> |           |           |           |           |           |           |
|-----------|-----------------------------------------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
|           | 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   | 26.0 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 <sup>5</sup>, Garofalo <sup>6</sup>

**TABLE V**  
**Modulus of Rigidity at Various Temperatures**

| Temp, F C | Modulus of Rigidity (Shear), $10^6$ psi $10^3$ kg/mm <sup>2</sup> |          |          |          |          |          |
|-----------|-------------------------------------------------------------------|----------|----------|----------|----------|----------|
|           | 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 4.6  | —        | —        | 6.9 4.9  |

Fredericks <sup>5</sup>, Garofalo <sup>6</sup>

**TABLE VI**  
**Poisson's Ratio at Various Temperatures**

| Temp, F °C | Poisson's Ratio |          |          |          |          |          |
|------------|-----------------|----------|----------|----------|----------|----------|
|            | 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     | 0.29     |
| 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 <sup>7</sup>

**TABLE VII**  
**Density of Annealed Austenitic Stainless Steels at Various Temperatures**

| Temp, F °C | Density, lb/cu in. g/cm <sup>3</sup> |      |          |      |          |      |
|------------|--------------------------------------|------|----------|------|----------|------|
|            | 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                               | 7.89 | 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 <sup>7</sup>

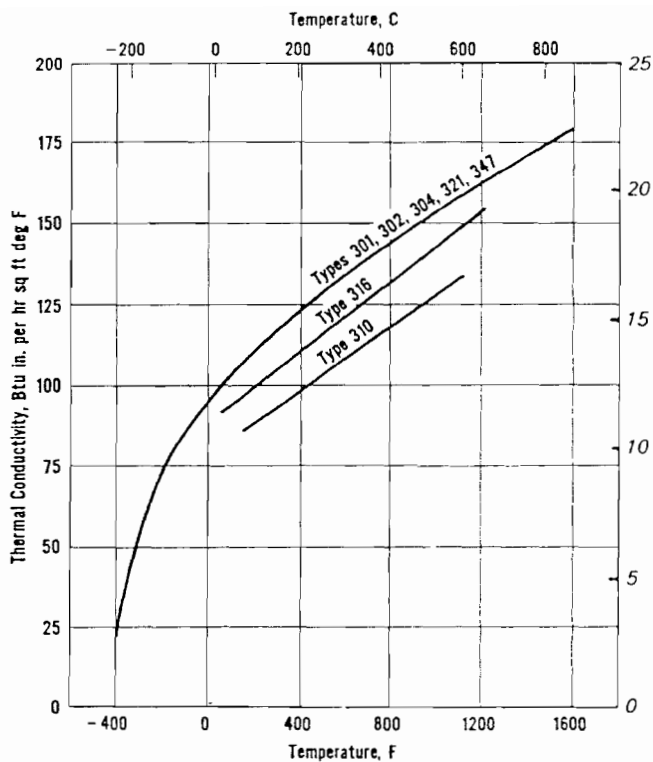


FIG. 29 — Effect of temperature on the thermal conductivity of chromium-nickel stainless steels.

### 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.

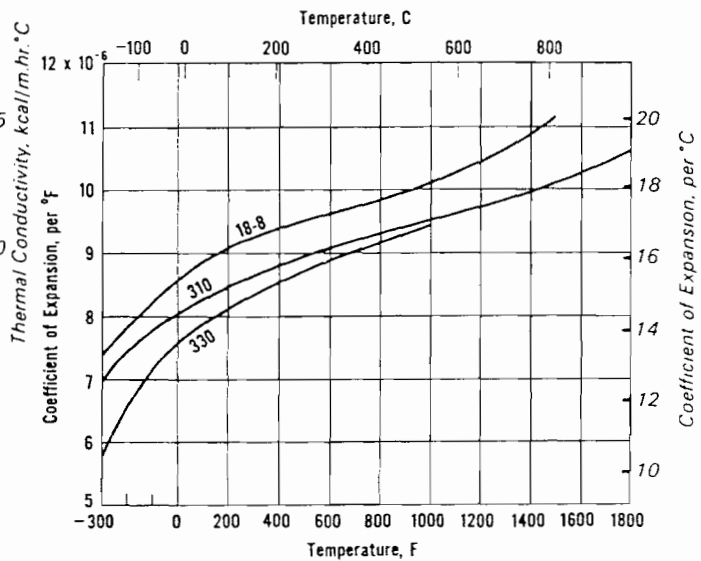


FIG. 31 — Approximate average coefficients of expansion of chromium-nickel stainless steels between 70 F and the indicated temperatures.

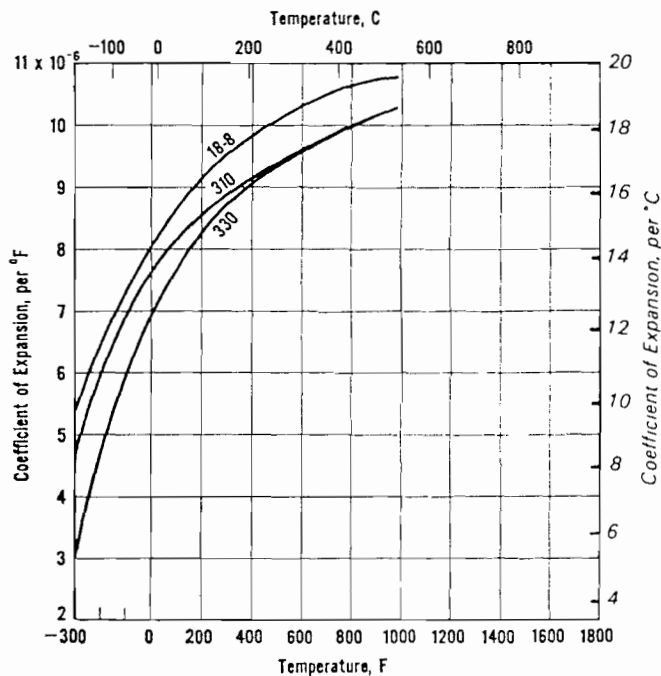


FIG. 30 — Average instantaneous coefficients of expansion of chromium-nickel stainless steels.

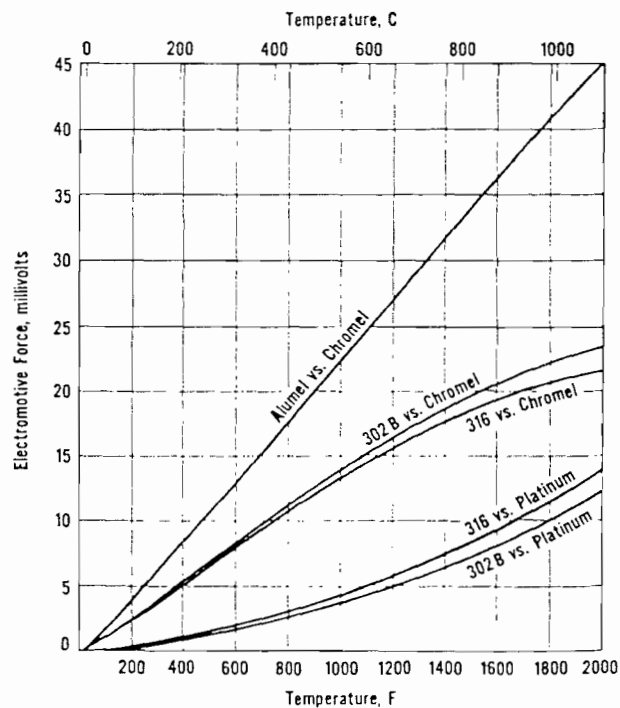


FIG. 32 — Thermo-electric properties of Types 302 B and 316 stainless steels Dahl and Lonberger<sup>8</sup>

TABLE VIII

Specific Heats of Annealed Austenitic Stainless Steels at Various Temperatures

| Temp, F | C    | Specific Heat, Btu/lb/°F    J/kgK |                        |                        |
|---------|------|-----------------------------------|------------------------|------------------------|
|         |      | Type 301                          | Type 316               | Type 347               |
| -250    | -160 | .080 335                          | .079 331               | .080 335               |
| -200    | -130 | .086 360                          | .085 356               | .085 356               |
| -100    | 70   | .096 402                          | .094 394               | .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 <sup>a</sup> 678            | 0.165 <sup>a</sup> 691 | 0.175 <sup>a</sup> 733 |

<sup>a</sup> Extrapolated. Garofalo, Malenock and Smith <sup>7</sup>

TABLE IX

Diffusivity of Annealed Austenitic Stainless Steels at Various Temperatures

| Temp, F | C    | Diffusivity, sq ft/hr    cm <sup>2</sup> /hr |                        |                        |
|---------|------|----------------------------------------------|------------------------|------------------------|
|         |      | 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    | 70   | 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 <sup>a</sup> 197                       | 0.195 <sup>a</sup> 181 | 0.194 <sup>a</sup> 180 |

<sup>a</sup> Extrapolated. Garofalo, Malenock and Smith <sup>7</sup>

TABLE X

Electrical Resistivity of Annealed Stainless Steels at Various Temperatures

| Temp, F | C    | Electrical Resistivity, microhm-cm |          |          |          |          |          |          |          |          |
|---------|------|------------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|
|         |      | 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 IX. The data were calculated by the equation

$$D = \frac{K}{C_p d}$$

K = thermal conductivity

C<sub>p</sub> = specific heat

d = density

## ELECTRICAL PROPERTIES

### Resistivity

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

### Thermo-electric Properties

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

\* Trade mark

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