

INCONEL® alloy 718 (UNS N07718/W.Nr. 2.4668) is a high-strength, corrosion-resistant nickel chromium material used at -423° to 1300°F. Typical composition limits are shown in Table 1.

The age-hardenable alloy can be readily fabricated, even into complex parts. Its welding characteristics, especially its resistance to postweld cracking, are outstanding.

The ease and economy with which INCONEL alloy 718 can be fabricated, combined with good tensile, fatigue, creep, and rupture strength, have resulted in its use in a wide range of applications. Examples of these are components for liquid fueled rockets, rings, casings and various formed sheet metal parts for aircraft and land-based gas turbine engines, and cryogenic tankage. It is also used for fasteners and instrumentation parts.

## PHYSICAL CONSTANTS AND THERMAL PROPERTIES

Some physical constants of INCONEL alloy 718 are shown in Table 2. Modulus data appear in Tables 3 and 4, and thermal properties in Table 5. The values in these tables will vary slightly, depending on the composition and condition of the specimen tested. They are typical but are not suitable for specification purposes.

Publication Number SMC-045  
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**Table 1 - Limiting Chemical Composition<sup>a</sup>, %**

|                               |             |
|-------------------------------|-------------|
| Nickel (plus Cobalt) .....    | 50.00-55.00 |
| Chromium .....                | 17.00-21.00 |
| Iron .....                    | Balance*    |
| Niobium (plus Tantalum) ..... | 4.75-5.50   |
| Molybdenum .....              | 2.80-3.30   |
| Titanium .....                | 0.65-1.15   |
| Aluminum .....                | 0.20-0.80   |
| Cobalt .....                  | 1.00 max.   |
| Carbon .....                  | 0.08 max.   |
| Manganese .....               | 0.35 max.   |
| Silicon .....                 | 0.35 max.   |
| Phosphorus .....              | 0.015 max.  |
| Sulfur .....                  | 0.015 max.  |
| Boron .....                   | 0.006 max.  |
| Copper .....                  | 0.30 max.   |

<sup>a</sup>Conforms to AMS specifications

\*Reference to the 'balance' of a composition does not guarantee this is exclusively of the element mentioned but that it predominates and others are present only in minimal quantities.

**Table 2 - Physical Constants**

|                                                           |               |
|-----------------------------------------------------------|---------------|
| Density, lb/in <sup>3</sup>                               |               |
| Annealed .....                                            | 0.296         |
| Annealed and Aged .....                                   | 0.297         |
| Melting Range, °F .....                                   | 2300-2437     |
| °C .....                                                  | 1260-1336     |
| Specific Heat at 70°F, Btu/lb °F (at 21°C, J/kg °C) ..... | 0.104 (435)   |
| Curie Temperature, °F (°C)                                |               |
| Annealed Material .....                                   | <-320 (<-196) |
| Annealed and Aged Material .....                          | -170 (-112)   |
| Permeability at 200 oersted and 70°F                      |               |
| Annealed Material .....                                   | 1.0013        |
| Annealed and Aged Material .....                          | 1.0011        |

**Table 3 - Modulus of Elasticity at Low Temperatures<sup>a</sup>**

| Temperature, °F | Modulus of Elasticity, ksi x 10 <sup>3</sup> |                   | Poisson's Ratio |
|-----------------|----------------------------------------------|-------------------|-----------------|
|                 | Young's Modulus                              | Torsional Modulus |                 |
| -308            | 31.3                                         | 12.5              | 0.25            |
| -86             | 30.6                                         | 11.8              | 0.30            |
| 70              | 29.0                                         | 11.6              | 0.29            |
| 100             | 29.8                                         | 11.5              | 0.30            |
| 200             | 29.4                                         | 11.3              | 0.31            |
| 300             | 28.8                                         | 11.1              | 0.30            |
| 400             | 28.5                                         | 10.9              | 0.31            |
| 500             | 28.0                                         | 10.6              | 0.32            |

<sup>a</sup>Cold-rolled sheet heat-treated in accordance with AMS 5596B.

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Table 4 - Modulus of Elasticity<sup>a</sup>

| Temperature,<br>°F | Modulus of Elasticity, ksi x 10 <sup>3</sup> |                      | Poisson's<br>Ratio <sup>b</sup> | Temperature,<br>°F                                                                                                                                                                                                                                  | Modulus of Elasticity, ksi x 10 <sup>3</sup> |                      | Poisson's<br>Ratio <sup>b</sup> |
|--------------------|----------------------------------------------|----------------------|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|----------------------|---------------------------------|
|                    | Young's<br>Modulus                           | Torsional<br>Modulus |                                 |                                                                                                                                                                                                                                                     | Young's<br>Modulus                           | Torsional<br>Modulus |                                 |
| 70                 | 29.0                                         | 11.2                 | 0.294                           | 1300                                                                                                                                                                                                                                                | 23.0                                         | 8.9                  | 0.292                           |
| 100                | 28.8                                         | 11.2                 | 0.291                           | 1400                                                                                                                                                                                                                                                | 22.3                                         | 8.5                  | 0.306                           |
| 200                | 28.4                                         | 11.0                 | 0.288                           | 1500                                                                                                                                                                                                                                                | 21.3                                         | 8.1                  | 0.321                           |
| 300                | 28.0                                         | 10.9                 | 0.280                           | 1600                                                                                                                                                                                                                                                | 20.2                                         | 7.6                  | 0.331                           |
| 400                | 27.6                                         | 10.8                 | 0.280                           | 1700                                                                                                                                                                                                                                                | 18.8                                         | 7.1                  | 0.334                           |
| 500                | 27.1                                         | 10.6                 | 0.275                           | 1800                                                                                                                                                                                                                                                | 17.4                                         | 6.5                  | 0.341                           |
| 600                | 26.7                                         | 10.5                 | 0.272                           | 1900                                                                                                                                                                                                                                                | 15.9                                         | 5.8                  | 0.366                           |
| 700                | 26.2                                         | 10.3                 | 0.273                           | 2000                                                                                                                                                                                                                                                | 14.3                                         | 5.1                  | 0.402                           |
| 800                | 25.8                                         | 10.1                 | 0.271                           | <sup>a</sup> Hot-rolled flat heat-treated 1800°F/1 hr, A.C. + 1325°F/8 hr, F.C. 20°F/hr to 1150°F, held for total aging time of 18 hr. Dynamic testing involved frequencies of from 813 to 571 cps in bending and from 3110 to 2097 cps in torsion. |                                              |                      |                                 |
| 900                | 25.3                                         | 9.9                  | 0.272                           |                                                                                                                                                                                                                                                     |                                              |                      |                                 |
| 1000               | 24.8                                         | 9.7                  | 0.271                           | <sup>b</sup> Computed from (E-2G)/2G, where E is Young's Modulus and G is torsional modulus.                                                                                                                                                        |                                              |                      |                                 |
| 1100               | 24.2                                         | 9.5                  | 0.276                           |                                                                                                                                                                                                                                                     |                                              |                      |                                 |
| 1200               | 23.7                                         | 9.2                  | 0.283                           |                                                                                                                                                                                                                                                     |                                              |                      |                                 |

Table 5 - Thermal Properties

| Temperature, °F | Thermal Conductivity, <sup>a</sup><br>BTU•in/ft <sup>2</sup> •h•°F |             | Electrical Resistivity, <sup>a</sup><br>ohm circ mil/ft |            | Mean Linear<br>Expansion <sup>b,c</sup> ,<br>in/in/°F x 10 <sup>-6</sup> |
|-----------------|--------------------------------------------------------------------|-------------|---------------------------------------------------------|------------|--------------------------------------------------------------------------|
|                 | Ann. 1800°F/1 hr                                                   | Ann. + Aged | Ann. 1800°F/1 hr                                        | Ann + Aged |                                                                          |
| -320            | -                                                                  | -           | -                                                       | -          | 5.9 <sup>d</sup>                                                         |
| 70              | 77                                                                 | 79          | 753                                                     | 725        | -                                                                        |
| 200             | 86                                                                 | 87          | 762                                                     | 733        | 7.31                                                                     |
| 400             | 98                                                                 | 100         | 772                                                     | 755        | 7.53                                                                     |
| 600             | 111                                                                | 112         | 775                                                     | 768        | 7.74                                                                     |
| 800             | 123                                                                | 124         | 784                                                     | 775        | 7.97                                                                     |
| 1000            | 135                                                                | 136         | 798                                                     | 788        | 8.09                                                                     |
| 1200            | 147                                                                | 148         | 805                                                     | 794        | 8.39                                                                     |
| 1400            | 160                                                                | 161         | 802                                                     | 797        | 8.91                                                                     |
| 1600            | 173                                                                | 173         | 799                                                     | 796        | -                                                                        |
| 1800            | 185                                                                | 186         | 801                                                     | 800        | -                                                                        |
| 2000            | 196                                                                | 199         | 811                                                     | 796        | -                                                                        |

<sup>a</sup>Annealing was 1800°F/1 hr; aging was 1325°F/8 hr, F.C. 20°F/hr to 1150°F, held at 1150°F for total aging time of 18 hr. Conductivity calculated from resistivity values.

<sup>b</sup>From 70°F to temperature shown.

<sup>c</sup>Annealed 1750°F/1 hr and aged 1325°F/8 hr, F.C. to 1150°F/8 hr, A.C.

<sup>d</sup>Samples tested were in both the annealed (1750°F/1 hr, A.C.) and annealed and aged (1750°F/1 hr + 1325°F/8 hr, F.C. to 1150°F, held at 1150°F for 10 hr, A.C.) conditions.

## HEAT TREATING AND MECHANICAL PROPERTIES

For most applications, INCONEL alloy 718 is specified as: solution annealed and precipitation hardened (precipitation hardening, age hardening, and precipitation heat treatment are synonymous terms). Alloy 718 is hardened by the precipitation of secondary phases (e.g. gamma prime and gamma double-prime) into the metal matrix. The precipitation of these nickel-(aluminum, titanium, niobium) phases is induced by heat treating in the temperature range of 1100 to 1500°F. For this metallurgical reaction to properly take place, the aging constituents (aluminum, titanium, niobium) must be in solution (dissolved in the matrix); if they are precipitated as some other phase or are combined in some other form, they will not precipitate correctly and the full strength of the alloy will not be realized. To perform this function, the material must first be solution heat treated (solution annealed is a synonymous term).

Two heat treatments are generally utilized for INCONEL alloy 718:

- Solution anneal at 1700-1850°F followed by rapid cooling, usually in water, plus precipitation hardening at 1325°F for 8 hours, furnace cool to 1150°F, hold at 1150°F for a total aging time of 18 hours, followed by air cooling.
- Solution anneal at 1900-1950°F followed by rapid cooling, usually in water, plus precipitation hardening at 1400°F for 10 hours, furnace cool to 1200°F, hold at 1200°F for a total aging time of 20 hours, followed by air cooling.

If the material is to be machined, formed, or welded, it typically is purchased in the mill annealed or stress relieved condition. The material is then fabricated in its most malleable condition. After fabrication, it can be heat treated as required per the applicable specification.

## 1700°-1850°F Anneal and Age

The 1700°-1850°F anneal with its corresponding aging treatment as shown earlier is the optimum heat treatment for alloy 718 where a combination of rupture life, notch rupture life and rupture ductility is of greatest concern. The highest room-temperature tensile and yield strengths are also associated with this treatment. In addition, because of the fine grain developed, it produces the highest fatigue strength.

Material in this condition will meet the following minimum requirements:

AMS 5596  
Sheet, Strip, & Plate

| Property                             | Room Temperature       | 1200°F                               |
|--------------------------------------|------------------------|--------------------------------------|
| Tensile Strength, ksi                | 180                    | 140 <sup>a</sup><br>145 <sup>b</sup> |
| Yield Strength<br>(0.2% Offset), ksi | 150                    | 115 <sup>a</sup><br>120 <sup>b</sup> |
| Elongation in 2 In., %               | 12                     | 5                                    |
| Hardness                             | Rc 36<br>or equivalent | -                                    |
| Stress Rupture                       |                        |                                      |
| Stress, ksi                          | -                      | 95 <sup>a</sup>                      |
| Life, hr                             | -                      | 100 <sup>b</sup>                     |
| Elongation, %                        | -                      | 23                                   |
|                                      | -                      | 4                                    |

<sup>a</sup>Up to 0.025-in. thickness, inclusive.

<sup>b</sup>Over 0.025-in. thickness.

<sup>c</sup>Longitudinal.

<sup>d</sup>Long transverse for forgings.

<sup>e</sup>Transverse for bars.

<sup>f</sup>Applies up to 5-in.-diam. or thickness, inclusive.

<sup>g</sup>Properties apply only to O.D. of 0.125-in. and over with wall thickness of 0.015-in. and over.

AMS 5662 and 5663  
Bars, Forgings, & Rings

| Property                             | Room Temperature                                         | 1200°F                                                   |
|--------------------------------------|----------------------------------------------------------|----------------------------------------------------------|
| Tensile Strength, ksi                | 185 <sup>c</sup><br>180 <sup>d</sup><br>180 <sup>e</sup> | 145 <sup>c</sup><br>140 <sup>d</sup><br>140 <sup>e</sup> |
| Yield Strength<br>(0.2% Offset), ksi | 150                                                      | 125                                                      |
| Elongation in 2 In., %               | 12 <sup>c</sup><br>10 <sup>d</sup><br>6 <sup>e</sup>     | 12 <sup>c</sup><br>10 <sup>d</sup><br>6 <sup>e</sup>     |
| Reduction of Area, %                 | 15 <sup>c</sup><br>12 <sup>d</sup><br>8 <sup>e</sup>     | 15 <sup>c</sup><br>12 <sup>d</sup><br>8 <sup>e</sup>     |
| Hardness                             | 331 BHN<br>or equivalent                                 | -                                                        |
| Stress Rupture                       |                                                          |                                                          |
| Stress, ksi                          | -                                                        | 100                                                      |
| Life, hr                             | -                                                        | 23                                                       |
| Elongation, %                        | -                                                        | 4 <sup>f</sup>                                           |

AMS 5589  
Seamless Tubing<sup>g</sup>

| Property                             | Room Temperature       | 1300°F |
|--------------------------------------|------------------------|--------|
| Tensile Strength, ksi                | 185                    | -      |
| Yield Strength<br>(0.2% Offset), ksi | 150                    | -      |
| Elongation in 2 In., %               | 12                     | -      |
| Hardness                             | Rc 36<br>or equivalent | -      |
| Stress Rupture                       |                        |        |
| Stress, ksi                          | -                      | 72.5   |
| Life, hr                             | -                      | 23     |
| Elongation, %                        | -                      | 5      |

## 1900°-1950° Anneal and Age

The 1900°-1950° anneal with its corresponding aging treatment as shown above is the treatment preferred in tensile-limited applications because it produces the best transverse ductility in heavy sections, impact strength, and low-temperature notch tensile strength. However, this treatment has a tendency to produce notch brittleness in stress rupture.

After precipitation hardening as shown, material will meet the following requirements:

| Property <sup>a</sup>                | AMS 5664<br>Bars, Forgings, &<br>Rings                                   | AMS 5597<br>Sheet, Strip, &<br>Plate | AMS 5590<br>Seamless<br>Tubing <sup>d</sup> |
|--------------------------------------|--------------------------------------------------------------------------|--------------------------------------|---------------------------------------------|
| Tensile Strength, ksi                | 180                                                                      | 180                                  | 170                                         |
| Yield Strength<br>(0.2% Offset), ksi | 150                                                                      | 150                                  | 145                                         |
| Elongation, %                        | 10 <sup>b</sup><br>12 <sup>c</sup><br>12 <sup>b</sup><br>15 <sup>c</sup> | 15<br>-                              | 15<br>-                                     |
| Reduction of Area, %                 | 341 BHN<br>or equivalent                                                 | Rc 38<br>or equivalent               |                                             |
| Hardness                             |                                                                          |                                      |                                             |

<sup>a</sup>Transverse direction.

<sup>b</sup>Bars.

<sup>c</sup>Forgings and flash-welded rings.

<sup>d</sup>Properties apply only to O.D. of 0.125-in. and over with wall thickness of 0.015-in. and over.

## Other Heat Treatments

Special Metals produces INCONEL alloy 718 for use in oil field applications. This material is produced under the NACE specification MR0175 which requires the solution annealed and aged material to meet a maximum hardness value of 40 Rockwell “C”. Such material is typically solution heat treated at 1850-1900 °F and aged at 1450°F for six to eight hours and air cooled. Table 6 shows the mechanical properties this material will meet. Numerous proprietary heat treatments are used for INCONEL alloy 718 depending on the properties required. Such heat treatment sequences are usually developed by companies or agencies independent of the material supplier; consequently, discussion of procedures, tolerances, and resulting properties should be with that company or agency.

All the data shown in the following sections are typical but not to be used for specification purposes.

**Table 6** - Mechanical Properties Aged Material for Oil Tool Applications  
Room Temperature Tensile and Hardness, and Room Temperature and -75°F Impact

| Condition                             | Diameter, in.(mm)                  | Tensile Strength, ksi (Kg/cm <sup>2</sup> ) min. | Yield Strength (0.2% Offset), ksi (Kg/cm <sup>2</sup> ) |            | Elongation in 2 in. (50.8 mm) or 4D% minimum | Reduction of Area, % minimum | Impact Strength, ft•lb (Kg•m) min. aver. | Hardness, Rockwell C |         |
|---------------------------------------|------------------------------------|--------------------------------------------------|---------------------------------------------------------|------------|----------------------------------------------|------------------------------|------------------------------------------|----------------------|---------|
|                                       |                                    |                                                  | minimum                                                 | maximum    |                                              |                              |                                          | minimum              | maximum |
| Cold worked, solution annealed & aged | 0.5 (12.7) to 3 (76.2), inclusive  | 150 (10,545)                                     | 120 (8436)                                              | 140 (9842) | 20                                           | 25                           | 40 (5.55)                                | 30                   | 40      |
| Hot worked, solution annealed & aged  | 0.5 (12.7) to 8 (203.2), inclusive | 150 (10,545)                                     | 120 (8436)                                              | 140 (9842) | 20                                           | 25                           | 40 (5.55)                                | 30                   | 40      |
| Hot worked, solution annealed & aged  | 8 (203.2) to 10 (254), inclusive   | 150 (10,545)                                     | 120 (8436)                                              | 140 (9842) | 20                                           | 25                           | 40 (5.55)                                | 30                   | 40      |

## ROOM TEMPERATURE TENSILE PROPERTIES

The following data are representative of the effects of the above annealing and aging treatments on room-temperature properties of a variety of products. More properties are shown under the section, High- and Low-Temperature Tensile Properties, Fatigue Strength, and Weld Properties.

## Hot-Finished Products

Table 7 shows properties of hot-rolled round annealed at 1750° or 1950°F. The effects of annealing at 1750° or 1950°F and the associated aging treatments on bar of a range of diameters are given in Table 8. Properties produced by the two different annealing and aging schedules in hot-rolled round are compared in Table 9.

The effect of direct aging (1325°F/time at temperature, 8 hours, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours) on various sizes of samples is given in Table 10.

Properties of a pancake forging with samples taken from various locations, annealed at 1700°F and aged, are shown in Table 11. Properties of forged products given the 1950°F anneal and aged are shown in Tables 12 and 13. The effects of the two annealing and aging treatments on a forged pancake are compared in Table 14.

Table 7 - Room-Temperature Tensile Properties of Annealed Hot-Rolled Round

| Diameter <sup>a</sup> ,<br>in. | Annealing<br>Temperature <sup>b</sup> , °F | Test Orientation <sup>c</sup> | Tensile Strength,<br>ksi | Yield Strength<br>(0.2% Offset), ksi | Elongation, % | Reduction of<br>Area, % | Hardness |
|--------------------------------|--------------------------------------------|-------------------------------|--------------------------|--------------------------------------|---------------|-------------------------|----------|
| 2.5                            | 1750                                       | L                             | 135.5                    | 77.5                                 | 45            | 49                      | -        |
|                                |                                            | T                             | 129.5                    | 73.5                                 | 32            | 29                      | -        |
|                                | 1950                                       | L                             | 114.0                    | 50.4                                 | 62            | 65                      | -        |
|                                |                                            | T                             | 112.0                    | 49.8                                 | 53            | 49                      | -        |
| 4                              | 1750                                       | L                             | 117.5                    | 55.0                                 | 53            | 52                      | 90 Rb    |
|                                |                                            | T                             | 119.0                    | 56.5                                 | 50            | 46                      | 88 Rb    |
|                                | 1950                                       | L                             | 112.5                    | 48.0                                 | 60            | 63                      | 87 Rb    |
|                                |                                            | T                             | 114.0                    | 50.0                                 | 61            | 55                      | 84 Rb    |
| 4                              | 1750                                       | L                             | 125.5                    | 71.5                                 | 45            | 49                      | 97 Rb    |
|                                |                                            | T                             | 123.5                    | 67.0                                 | 46            | 43                      | 93 Rb    |
|                                | 1950                                       | L                             | 115.0                    | 47.0                                 | 59            | 65                      | 85 Rb    |
|                                |                                            | T                             | 99.5                     | 47.5                                 | 32            | 31                      | 84 Rb    |
| 4                              | 1750                                       | L                             | 126.0                    | 71.5                                 | 45            | 47                      | 96 Rb    |
|                                |                                            | T                             | 114.0                    | 60.0                                 | 26            | 25                      | 90 Rb    |
|                                | 1950                                       | L                             | 114.5                    | 53.0                                 | 58            | 61                      | 87 Rb    |
|                                |                                            | T                             | 105.0                    | 47.0                                 | 34            | 29                      | 83 Rb    |
| 4                              | 1750                                       | L                             | 122.0                    | 63.0                                 | 51            | 51                      | 92 Rb    |
|                                |                                            | T                             | 109.0                    | 56.5                                 | 32            | 31                      | 89 Rb    |
|                                | 1950                                       | L                             | 112.5                    | 50.0                                 | 62            | 62                      | 86 Rb    |
|                                |                                            | T                             | 106.5                    | 49.5                                 | 38            | 33                      | 84 Rb    |
| 4                              | 1750                                       | L                             | 119.0                    | 56.5                                 | 51            | 54                      | 91 Rb    |
|                                |                                            | T                             | 114.5                    | 54.0                                 | 45            | 38                      | 85 Rb    |
|                                | 1950                                       | L                             | 110.5                    | 47.0                                 | 60            | 62                      | 86 Rb    |
|                                |                                            | T                             | 108.5                    | 45.5                                 | 58            | 53                      | 83 Rb    |
| 4                              | 1750                                       | T                             | 111.0                    | 54.5                                 | 41            | 35                      | -        |
|                                | 1950                                       | T                             | 99.0                     | 46.0                                 | 36            | 36                      | -        |

<sup>a</sup>Eight separate heats represented.<sup>b</sup>Annealing for 1 hr, A.C.<sup>c</sup>L is longitudinal test orientation; T, transverse.

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**Table 8 - Room-Temperature Tensile Properties of Hot-Rolled Bar**

| Diameter <sup>a</sup> , in. | Heat Treatment <sup>b</sup> | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Reduction of Area, % | Hardness |
|-----------------------------|-----------------------------|-----------------------|-----------------------------------|---------------|----------------------|----------|
| 0.625                       | As-Rolled                   | 140.0                 | 85.7                              | 46            | 58                   | 23 Rc    |
|                             | 1750°F/1 hr                 | 140.0                 | 83.0                              | 45            | 49                   | 99 Rb    |
|                             | 1950°F/1 hr                 | 117.5                 | 48.5                              | 58            | 64                   | 85 Rb    |
|                             | 1750°F/1 hr, Age            | 208.0                 | 180.0                             | 21            | 39                   | 46 Rc    |
|                             | 1950°F/1 hr, Age            | 194.0                 | 157.0                             | 23            | 34                   | 45 Rc    |
| 0.625                       | As-Rolled                   | 139.0                 | 78.5                              | 46            | 62                   | 98 Rb    |
|                             | 1750°F/1 hr                 | 138.0                 | 75.5                              | 54            | 49                   | 97 Rb    |
|                             | 1950°F/1 hr                 | 115.5                 | 48.0                              | 64            | 67                   | 85 Rb    |
|                             | 1750°F/1 hr, Age            | 208.5                 | 179.5                             | 20            | 39                   | 45 Rc    |
|                             | 1950°F/1 hr, Age            | 194.5                 | 158.0                             | 20            | 26                   | 44 Rc    |
| 1.0                         | As-Rolled                   | 130.0                 | 65.0                              | 54            | 67                   | 95 Rb    |
|                             | 1750°F/1 hr                 | 129.0                 | 64.5                              | 55            | 61                   | 94 Rb    |
|                             | 1950°F/1 hr                 | 112.5                 | 52.0                              | 64            | 68                   | 87 Rb    |
|                             | 1750°F/1 hr, Age            | 201.5                 | 175.0                             | 20            | 36                   | 46 Rc    |
|                             | 1950°F/1 hr, Age            | 188.0                 | 152.0                             | 21            | 34                   | 45 Rc    |
| 1.5                         | As-Rolled                   | 147.0                 | 105.5                             | 40            | 52                   | 32 Rc    |
|                             | 1750°F/1 hr                 | 141.5                 | 72.5                              | 46            | 45                   | 97 Rb    |
|                             | 1950°F/1 hr                 | 120.0                 | 55.0                              | 58            | 60                   | 89 Rb    |
|                             | 1750°F/1 hr, Age            | 205.0                 | 167.5                             | 20            | 28                   | 46 Rc    |
|                             | 1950°F/1 hr, Age            | 191.0                 | 153.0                             | 24            | 36                   | 43 Rc    |
| 4.0                         | 1750°F/1 hr                 | 117.5                 | 55.0                              | 53            | 52                   | 90 Rb    |
|                             | 1950°F/1 hr                 | 112.5                 | 48.0                              | 60            | 63                   | 87 Rb    |
|                             | 1750°F/1 hr, Age            | 192.0                 | 165.0                             | 17            | 24                   | 46 Rc    |
|                             | 1950°F/1 hr, Age            | 195.5                 | 165.0                             | 21            | 34                   | 43 Rc    |

<sup>a</sup>Five separate heats represented. All tests are longitudinal.

<sup>b</sup>When annealing is at 1750°F, aging is 1325°F/8 hr, F.C. to 1150°F for total aging time of 18 hr. When annealing is at 1950°F, aging is 1400°F/10 hr, F.C. to 1200°F for total aging time of 20 hr.

**Table 9 - Tensile Properties of Hot-Rolled Round (4-in. Diameter)**

| Test Temperature, °F                                                                                                       | Test Orientation | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Reduction of Area, % | Hardness, Rc |
|----------------------------------------------------------------------------------------------------------------------------|------------------|-----------------------|-----------------------------------|---------------|----------------------|--------------|
| Heat Treatment: 1750°F/1 hr, A.C. + 1325°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Aging Time of 18 hr <sup>a</sup> |                  |                       |                                   |               |                      |              |
| Room                                                                                                                       | Longitudinal     | 199.5                 | 178.0                             | 15.0          | 24.0                 | 44           |
| Room                                                                                                                       | Transverse       | 198.5                 | 173.5                             | 12.0          | 16.0                 | 40           |
| 1200                                                                                                                       | Longitudinal     | 167.0                 | 152.5                             | 13.0          | 24.0                 | -            |
| Heat Treatment: 1950°F/1 hr, A.C. + 1400°F/10 hr, F.C. to 1200°F, Hold at 1200°F for Total Aging Time of 20 hr             |                  |                       |                                   |               |                      |              |
| Room                                                                                                                       | Longitudinal     | 197.0                 | 164.0                             | 17.0          | 23.0                 | 44           |
| Room                                                                                                                       | Transverse       | 192.0                 | 165.0                             | 19.0          | 24.0                 | 44           |

<sup>a</sup>In stress-rupture tests under conditions of 1300°F and 75 ksi, results were: 68.2 hr life, 10.0% elongation and 13.0% reduction of area.

**Table 10 - Room-Temperature Tensile Properties of Material Hot-Rolled and Aged (1325°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Aging Time of 18 hr)**

| Sample                | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Reduction of Area, % | Hardness, Rc |
|-----------------------|-----------------------|-----------------------------------|---------------|----------------------|--------------|
| 0.65625-in. Diam.     | 206.5                 | 189.5                             | 19.0          | 34.5                 | 42           |
| 0.625-in.-Diam.       | 206.5                 | 179.5                             | 22.0          | 45.5                 | 41           |
| 0.625-in.-Diam.       | 210.0                 | 184.0                             | 22.0          | 44.5                 | 42           |
| 13/16-in.-Diam.       | 209.0                 | 181.0                             | 22.0          | 43.0                 | 43           |
| 1.25- x 1.25-in. Flat | 227.5                 | 210.0                             | 17.0          | 40.8                 | 44           |
| 1.5- x 175-in. Flat   | 215.0                 | 172.0                             | 19.0          | 35.0                 | 42           |
| 0.625- x 1-in. Flat   | 215.5                 | 184.0                             | 24.0          | 45.5                 | 44           |

**Table 11** - Room-Temperature Tensile Properties of Pancake Forging (1700°F/1 hr plus 1325°F/8 hr, F.C. to 1150°F, Hold at 1150° for Total Aging Time of 18 hr)<sup>a</sup>

| Sample                     | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation in 2 Inches, % | Reduction of Area, % | Charpy Keyhole Impact Strength, ft•lb |
|----------------------------|-----------------------|-----------------------------------|---------------------------|----------------------|---------------------------------------|
| Radial center, top edge    | 182.0                 | 159.0                             | 10.0                      | 10.5                 | -                                     |
| Radial center, center      | 196.0                 | 160.0                             | 24.0                      | 33.0                 | -                                     |
| Radial center, bottom edge | 186.5                 | 159.5                             | 16.0                      | 19.0                 | -                                     |
| Tangential, top edge       | 209.0                 | 181.0                             | 19.0                      | 27.5                 | 17-21                                 |
| Tangential, bottom edge    | 210.0                 | 179.0                             | 18.0                      | 29.5                 | 21                                    |

<sup>a</sup>Piece 6.75-in. long by 4.5-in. octagon, heated at 2050°F, upset to 4.5-in. thick; heated at 1800°F, upset to 2.25-in. thick by 8-in. diameter pancake.

**Table 12** - Room-Temperature Tensile Properties of Forged Flats (1 x 2-in. Thick, Annealed 1950°F/1 hr, A.C. and Aged)<sup>a</sup>

| Sample       | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Reduction of Area, % | Hardness, Rc |
|--------------|-----------------------|-----------------------------------|---------------|----------------------|--------------|
| Longitudinal | 191.5                 | 159.0                             | 20            | 32                   | 40           |
| Transverse   | 187.0                 | 153.0                             | 13            | 16                   | 40           |
| Longitudinal | 191.1                 | 160.0                             | 19            | 29                   | 42           |
| Transverse   | 185.5                 | 152.0                             | 14            | 14                   | 42           |
| Longitudinal | 194.0                 | 162.0                             | 17            | 26                   | 43           |
| Transverse   | 192.5                 | 160.0                             | 17            | 25                   | 43           |
| Longitudinal | 195.0                 | 165.0                             | 18            | 23                   | 43           |
| Transverse   | 195.0                 | 163.0                             | 16            | 18                   | 43           |
| Longitudinal | 193.0                 | 164.0                             | 17            | 22                   | 42           |
| Transverse   | 191.5                 | 159.0                             | 16            | 23                   | 42           |
| Longitudinal | 193.5                 | 166.0                             | 15            | 21                   | 42           |
| Transverse   | 190.0                 | 158.5                             | 14            | 22                   | 42           |
| Longitudinal | 199.5                 | 171.0                             | 17            | 26                   | 44           |
| Transverse   | 200.0                 | 167.5                             | 19            | 28                   | 44           |
| Longitudinal | 195.0                 | 165.0                             | 18            | 26                   | 42           |
| Transverse   | 195.0                 | 160.0                             | 20            | 28                   | 42           |
| Longitudinal | 198.0                 | 170.0                             | 20            | 33                   | 43           |
| Transverse   | 192.5                 | 163.0                             | 15            | 29                   | 43           |
| Longitudinal | 198.0                 | 174.0                             | 21            | 34                   | 43           |
| Transverse   | 196.5                 | 170.0                             | 18            | 25                   | 43           |
| Longitudinal | 200.0                 | 170.0                             | 17            | 24                   | 43           |
| Transverse   | 193.0                 | 158.0                             | 17            | 30                   | 43           |
| Longitudinal | 189.0                 | 157.5                             | 21            | 35                   | 42           |
| Transverse   | 189.0                 | 157.0                             | 18            | 27                   | 42           |

<sup>a</sup>1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for total aging time of 20 hours.

**Table 13** - Room-Temperature Tensile Properties of 1-in. Thick Pancake<sup>a</sup>

| Sample     | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Reduction of Area, % | Hardness, Rc |
|------------|-----------------------|-----------------------------------|---------------|----------------------|--------------|
| Radial     | 186.0                 | 153.0                             | 20            | 31                   | 43           |
| Tangential | 186.5                 | 154.0                             | 18            | 29                   | 43           |
| Radial     | 195.0                 | 151.0                             | 20            | 33                   | 43           |
| Tangential | 184.5                 | 152.5                             | 20            | 29                   | 43           |
| Radial     | 189.0                 | 155.0                             | 15            | 24                   | 44           |
| Tangential | 185.0                 | 154.0                             | 19            | 23                   | 44           |
| Radial     | 188.0                 | 153.0                             | 20            | 31                   | 43           |
| Tangential | 185.0                 | 152.5                             | 18            | 28                   | 43           |

<sup>a</sup>Upset-forged 3 to 1 reduction from a 4.0-in. diameter round. Forging temperature, 2000°F. Heat treatment: 1950°F/1-2 hr, plus 1400°F/10 hr, F.C. to 1200°F. Hold at 1200°F for a total aging time of 20 hr. Samples are from 4 separate heats.

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**Table 14** - Tensile Properties of Pancake Forging<sup>a</sup>

| Heat Treatment                                                                                 | Test Temperature, °F | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Reduction of Area, % | Hardness, Rc |
|------------------------------------------------------------------------------------------------|----------------------|-----------------------|-----------------------------------|---------------|----------------------|--------------|
| 1800°F/1 hr, W.Q. + 1325°F/8 hr, F.C. to 1150°F, hold at 1150 °F for total aging time of 18 hr | Room                 | 204.5                 | 176.0                             | 16.0          | 23.0                 | 38           |
|                                                                                                | Room                 | 201.0                 | 168.0                             | 21.0          | 28.3                 | 41           |
|                                                                                                | 1200                 | 163.0                 | 145.5                             | 26.0          | 47.4                 | -            |
| 1950°F/1 hr, W.Q. + 1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for total aging time of 20 hr | Room                 | 190.0                 | 152.0                             | 18.0          | 24.3                 | 35           |

<sup>a</sup>Pieces 4-in. diameter by 2-in. length heated at 1900°F and upset-forged to 5.5-in.-diameter by 1-in.-thickness pancake. Tests are transverse center-to-midsection.

## Cold-Finished Products

Properties of cold-rolled sheet aged at 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours are shown in Table 15. Table 16 gives the effect of the heat treatment specified by AMS 5597 on material of various thickness. Some properties of tubing are given in Table 17.

**Table 15** - Room-Temperature Tensile Properties of Cold-Rolled Sheet

| Thickness, in. | Cold Reduction, % | Condition <sup>a</sup> | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation in 2 In., % |
|----------------|-------------------|------------------------|-----------------------|-----------------------------------|------------------------|
| 0.025          | 27                | As Cold-Rolled         | 155.0                 | 130.0                             | 14                     |
|                |                   | Cold-Rolled, Aged      | 209.0                 | 190.0                             | 10                     |
|                |                   | As Cold-Rolled         | 154.0                 | 128.0                             | 15                     |
|                |                   | Cold-Rolled, Aged      | 223.5                 | 209.5                             | 10                     |
|                |                   | As Cold-Rolled         | 154.0                 | 132.0                             | 14                     |
|                |                   | Cold-Rolled, Aged      | 211.5                 | 194.0                             | 8                      |
|                |                   | As Cold-Rolled         | 156.0                 | 132.0                             | 14                     |
|                |                   | Cold-Rolled, Aged      | 216.0                 | 195.0                             | 13                     |
| 0.050          | 21                | As Cold-Rolled         | 138.0                 | 112.0                             | 22                     |
|                |                   | Cold-Rolled, Aged      | 208.0                 | 189.0                             | 9                      |
|                |                   | As Cold Rolled         | 143.5                 | 117.5                             | 19                     |
|                |                   | Cold-Rolled, Aged      | 212.5                 | 196.0                             | 10                     |
| 0.093          | 18                | As Cold-Rolled         | 140.5                 | 115.0                             | 26                     |
|                |                   | Cold-Rolled, Aged      | 210.0                 | 188.5                             | 16                     |
| 0.125          | 26                | As Cold-Rolled         | 158.5                 | 137.0                             | 11                     |
|                |                   | Cold-Rolled, Aged      | 219.0                 | 206.5                             | 8                      |
| 0.125          | 23                | As Cold-Rolled         | 140.5                 | 120.0                             | 21                     |
|                |                   | Cold-Rolled, Aged      | 204.0                 | 186.5                             | 12                     |
| 0.074          | 18.5              | As Cold-Rolled         | 145.0                 | 116.5                             | 25                     |
| 0.062          | 28                | As Cold-Rolled         | 159.5                 | 134.0                             | 11                     |

<sup>a</sup>Aging--1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours.

**Table 16** - Room-Temperature tensile properties of Sheet Annealed and Aged in Accordance with AMS 5597

| Thickness, in | Tensile Strength, ksi | Yield Strength, ksi | Elongation, % |
|---------------|-----------------------|---------------------|---------------|
| 0.010         | 192.5                 | 172.5               | 17            |
| 0.012         | 204.0                 | 169.5               | 19            |
| 0.015         | 198.0                 | 162.0               | 19            |
| 0.016         | 196.0                 | 163.5               | 19            |
| 0.018         | 196.5                 | 155.5               | 21            |
| 0.021         | 202.5                 | 169.0               | 20            |
| 0.025         | 199.0                 | 162.5               | 20            |
| 0.031         | 197.0                 | 160.0               | 21            |
| 0.040         | 208.0                 | 172.0               | 16            |
| 0.047         | 199.0                 | 166.5               | 20            |
| 0.050         | 211.0                 | 177.0               | 16            |
| 0.062         | 203.5                 | 171.0               | 18            |
| 0.078         | 192.0                 | 158.5               | 17            |
| 0.080         | 200.0                 | 163.5               | 20            |
| 0.093         | 199.0                 | 167.0               | 19            |
| 0.100         | 208.0                 | 176.0               | 18            |
| 0.109         | 204.0                 | 171.0               | 19            |
| 0.125         | 203.5                 | 172.0               | 16            |
| 0.156         | 196.5                 | 161.0               | 21            |
| 0.187         | 207.5                 | 182.0               | 18            |
| 0.210         | 194.5                 | 160.0               | 22            |
| 0.250         | 205.0                 | 170.5               | 19            |

**Table 17** - Effect of Aging on Room-Temperature Properties of Tube Reduced 70% to 0.133-in. Wall, 1.513-in. O.D.

| Condition                                                   | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Hardness, Rc |
|-------------------------------------------------------------|-----------------------|-----------------------------------|---------------|--------------|
| As-Tube Reduced                                             | 247.0                 | 211.0                             | 6.0           | 42.0         |
| Aged 1325°F/8 hr, F.C.<br>100°F/hr to 1150°F/<br>8 hr, A.C. | 266.0                 | 261.0                             | 4.0           | 51.5         |

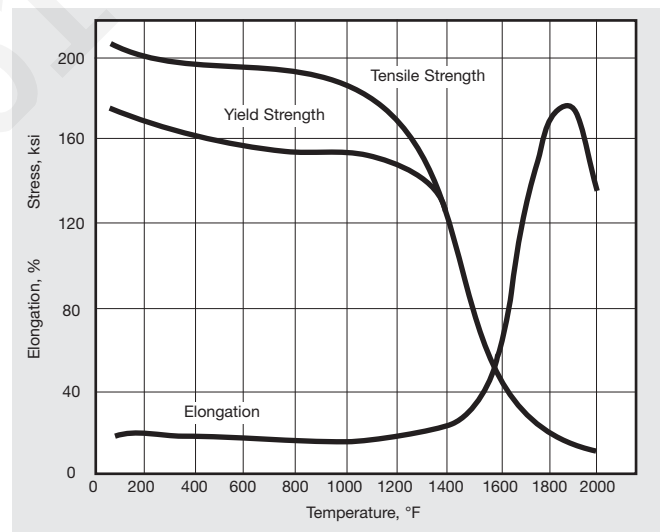
## HIGH- AND LOW-TEMPERATURE PROPERTIES

### Hot Finished Products

Properties of hot-rolled bar annealed at 1800°F and aged are shown in Figure 1. Table 18 shows room-temperature properties of hot-rolled plate annealed and aged per AMS 5596H. Properties of hot-rolled round annealed at 1950°F and aged are in Table 19. Data on hot-rolled round (annealed at 1800°F and aged ) for the range of -320°F to 1300°F are given in Table 20.

Table 21 compares low-temperature properties (short transverse tests) of specimens machined from a forging and given the 1800°F anneal and age with those given the 1950°F anneal and age.

Table 22 shows room and 1200°F and 1300°F properties of a variety of hot-finished products annealed at 1800°F and aged.



**Figure 1.** High-temperature properties of ½-in. diameter hot-rolled, annealed (1800°F/1 hr) and aged (1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours) bar.

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**Table 18** - Room-Temperature Tensile Properties of Hot-Rolled Plate Annealed and Aged in Accordance with AMS 5596H

| Thickness, in. <sup>a</sup> | Tensile Strength, ksi | Yield Strength, ksi | Elongation, % | Hardness, Rc |
|-----------------------------|-----------------------|---------------------|---------------|--------------|
| 0.5                         | 206                   | 177                 | 18            | 43           |
| 0.75                        | 204                   | 170                 | 19            | 42           |
| 1                           | 204                   | 173                 | 17            | 42           |

<sup>a</sup>Values for each thickness are average of six samples, different heats.

**Table 19** - High-Temperature Tensile Properties of Hot-Rolled Round, Annealed and Aged (1950°F/1 hr, plus 1400°F/10 hr, F.C. 100°F/hr to 1200°F, hold at 1200°F for 8 hr)<sup>a</sup>

| Test Temperature, °F | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Reduction of Area, % |
|----------------------|-----------------------|-----------------------------------|---------------|----------------------|
| Room                 | 198.0                 | 163.0                             | 21            | 30                   |
| 600                  | 183.5                 | 156.0                             | 16            | 34                   |
| 1000                 | 173.0                 | 148.0                             | 16            | 30                   |
| 1200                 | 160.0                 | 140.0                             | 15            | 25                   |
| 1300                 | 146.0                 | 135.0                             | 8             | 10                   |
| 1400                 | 123.5                 | 116.0                             | 5             | 10                   |
| 1500                 | 105.0                 | 100.0                             | 15            | 20                   |

<sup>a</sup>Round, 4-in. diameter, from single heat.

**Table 20** - Effect of Temperature on Tensile Properties of Hot-Rolled Round (5/8-in. Diameter, Annealed 1800°F/1 hr and Aged)<sup>a</sup>

| Temperature, °F | Tensile Strength, ksi | Yield Strength, ksi | Elongation, % | Reduction of Area, % |
|-----------------|-----------------------|---------------------|---------------|----------------------|
| -320            | 237.0                 | 173.5               | 26.0          | 27.0                 |
| -60             | 201.5                 | 158.0               | 23.0          | 33.5                 |
| 80              | 190.5                 | 153.5               | 22.0          | 32.5                 |
| 1200            | 164.5                 | 145.0               | 28.0          | 59.2                 |
| 1300            | 145.5                 | 133.0               | 22.0          | 34.0                 |

<sup>a</sup>1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.

**Table 21** - Low-Temperature Properties of Forging (Short Transverse Tests)<sup>a</sup>

| Test Temperature, °F                                                                                | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation in 4D, % | Reduction of Area, % | Notch Strength, Tensile Strength Ratio <sup>b</sup> |
|-----------------------------------------------------------------------------------------------------|-----------------------|-----------------------------------|---------------------|----------------------|-----------------------------------------------------|
| 1800°F/45 min, A.C. plus 1325°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Aging Time of 18 hr  |                       |                                   |                     |                      |                                                     |
| Room                                                                                                | 187.0                 | 165.9                             | 17.0                | 23.0                 | 1.45                                                |
| -110                                                                                                | 198.9                 | 174.4                             | 17.2                | 20.0                 | 1.37                                                |
| -320                                                                                                | 229.0                 | 186.8                             | 14.0                | 14.0                 | 1.30                                                |
| -423                                                                                                | 237.2                 | 194.9                             | 13.5                | 11.5                 | 1.30                                                |
| 1950°F/45 min, A.C. plus 1400°F/10 hr, F.C. to 1200°F, Hold at 1200°F for Total Aging Time of 20 hr |                       |                                   |                     |                      |                                                     |
| Room                                                                                                | 181.5                 | 147.7                             | 19.0                | 24.5                 | 1.37                                                |
| -110                                                                                                | 195.9                 | 158.1                             | 15.0                | 18.5                 | 1.41                                                |
| -320                                                                                                | 228.7                 | 176.7                             | 17.5                | 19.5                 | 1.28                                                |
| -423                                                                                                | 244.2                 | 186.8                             | 16.5                | 18.0                 | 1.19                                                |

<sup>a</sup>Specimens machined from forging with dimensions 4 by 9 by 15-in.

<sup>b</sup>Notch concentration factor K<sub>t</sub>, 6.3.

**Table 22** - High-Temperature Tensile Properties of Annealed and Aged Hot-Finished Material  
(1800°F/1 hr, plus 1325°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Aging Time of 18 hours)

| Form                           | Temperature, °F | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Reduction of Area, % | Hardness, Rc |
|--------------------------------|-----------------|-----------------------|-----------------------------------|---------------|----------------------|--------------|
| Forged Pancake <sup>a</sup>    |                 |                       |                                   |               |                      |              |
| Radial Center                  | Room            | 196.0                 | 160.0                             | 24            | 33                   | -            |
| Tang. Mid.Rad.                 | 1200            | 162.0                 | 138.5                             | 23            | 38                   | -            |
|                                | 1300            | 146.0                 | 135.0                             | 30            | 62                   | -            |
| Hot Rolled, 0.625-in.-Diam.    | Room            | 201.0                 | 171.0                             | 26            | 50                   | 41           |
|                                | 1200            | 164.5                 | 145.0                             | 28            | 59                   | -            |
|                                | 1300            | 145.5                 | 133.0                             | 22            | 34                   | -            |
| Forged Rod, 6-in.-Diam.        | Room            | 184.5                 | 152.0                             | 28            | 42                   | -            |
|                                | 1300            | 129.0                 | 113.0                             | 14            | 16                   | -            |
| Hot-Rolled, 0.5-in.-Diam.      | Room            | 211.0                 | 174.0                             | 23            | 40                   | -            |
|                                | 1200            | 168.0                 | 148.8                             | 22            | 32                   | -            |
|                                | 1300            | 145.0                 | 136.5                             | 20            | 27                   | -            |
| Hot-Rolled, 0.5-in.-Diam.      | Room            | 207.5                 | 172.0                             | 25            | 44                   | 40           |
|                                | 1200            | 163.5                 | 145.0                             | 26            | 49                   | -            |
|                                | 1300            | 137.0                 | 126.0                             | 25            | 25                   | -            |
| Forged Square, 1- x 1-in.      | Room            | 180.0                 | 152.0                             | 23            | 40                   | -            |
|                                | 1200            | 159.0                 | 138.0                             | 20            | 28                   | -            |
|                                | 1300            | 140.0                 | 129.0                             | 26            | 44                   | -            |
| Forged Flat, 1- x 2-in.        | Room            | 184.5                 | 154.0                             | 24            | 42                   | 44           |
|                                | 1200            | 150.0                 | 132.5                             | 21            | 38                   | -            |
|                                | 1300            | 140.0                 | 125.5                             | 17            | 22                   | -            |
| Hot-Rolled, 2-in.-Diam.        | Room            | 190.0                 | 152.0                             | 22            | 37                   | 42           |
|                                | 1200            | 153.0                 | 130.0                             | 30            | 46                   | -            |
|                                | 1300            | 131.5                 | 117.0                             | 23            | 34                   | -            |
| Forged Round, 6-in.-Diam.      | Room            | 187.0                 | 155.0                             | 20            | 37                   | 42           |
|                                | 1200            | 156.0                 | 134.0                             | 18            | 24                   | -            |
|                                | 1300            | 136.5                 | 123.0                             | 12            | 13                   | -            |
| Forged Flat, 0.625- x 0.75-in. | Room            | 204.0                 | 162.5                             | 18            | 33                   | 44           |
|                                | 1200            | 165.5                 | 147.0                             | 26            | 61                   | -            |
|                                | 1300            | 138.0                 | 126.0                             | 32            | 68                   | -            |

<sup>a</sup>6.75-in. long by 4.5-in octagonal heated at 2050°F, upset-forged to 4.5-in. thick; reheated at 1800°F, upset-forged to 2.25-in. thick pancake.

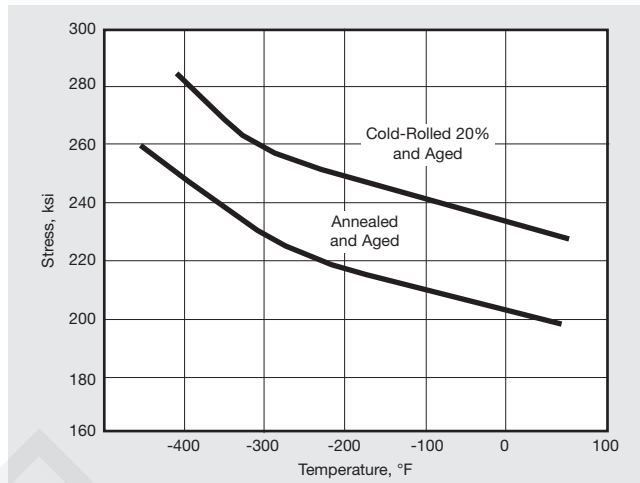
## Cold-Finished Products

High-temperature tensile properties of cold-rolled sheet annealed in accordance with AMS 5596 are shown in Table 23. More data on 5596-processed material appear in Table 24.

Table 25 shows room-temperature tensile properties of sheet annealed and aged per AMS 5596. Low-temperature properties of sheet processed in accordance with AMS 5596 are shown in Table 26. These data indicate the effects of sheet thickness as well as annealing and aging treatment. Large increases in strength are achieved by cold working and aging. Additional data on notch tensile strength are shown in Figure 2.

Table 27 compares data on annealed and aged sheet with direct-aged sheet over a temperature range from -110° to 1000°F.

More data on sheets of various thicknesses are shown in Table 28.



**Figure 2.** Notch tensile strength of 0.031-in. sheet, heat-treated in accordance with AMS 5596 ( $K_t=7.2$ ; transverse tests).

**Table 23** - High-Temperature Tensile Properties of Cold-Rolled 0.054-in. Sheet Annealed in Accordance with AMS 5596

| Temperature, °F | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % |
|-----------------|-----------------------|-----------------------------------|---------------|
| Room            | 135.0                 | 76.0                              | 44.5          |
| 1000            | 119.5                 | 55.5                              | 43.0          |
| 1200            | 120.0                 | 72.0                              | 32.0          |
| 1400            | 103.0                 | 64.5                              | 7.0           |
| 1600            | 74.5                  | 52.5                              | 39.0          |

**Table 24** - Tensile Properties of 0.065-in. Cold-Rolled Sheet

| Condition <sup>a</sup>         | Grain Size, ASTM No. | Test Temperature, °F | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Hardness |
|--------------------------------|----------------------|----------------------|-----------------------|-----------------------------------|---------------|----------|
| Annealed                       | 7                    | Room                 | 141.0                 | 73.0                              | 38.0          | 99 Rb    |
| Annealed and Aged <sup>b</sup> | -                    | Room                 | 214.0                 | 188.5                             | 15.0          | 46 Rc    |
| Annealed and Aged              | -                    | 1200                 | 166.0                 | 149.5                             | 13.5          | -        |

<sup>a</sup>In accordance with AMS 5596.

<sup>b</sup>Stress-rupture properties at 1300°F and 72.5 ksi: 35.3 hr life, 22.0% elongation.

**Table 25** - Room-Temperature Tensile Properties of Cold-Rolled Sheet, Annealed and Aged in Accordance with AMS 5596<sup>a</sup>

| Thickness, in. | Tensile Strength, ksi | Yield Strength, ksi | Elongation, % | Hardness, Rc |
|----------------|-----------------------|---------------------|---------------|--------------|
| 0.187          | 205                   | 177                 | 20            | 44           |
| 0.156          | 207                   | 180                 | 20            | 44           |
| 0.125          | 206                   | 178                 | 19            | 44           |
| 0.100          | 209                   | 183                 | 19            | 44           |
| 0.063          | 205                   | 179                 | 19            | 44           |
| 0.035          | 208                   | 184                 | 18            | 44           |
| 0.025          | 203                   | 177                 | 19            | 44           |

<sup>a</sup>Each size average of four samples, four heats.

**Table 26** - Tensile Properties of Cold-Rolled Sheet (Annealed and Aged in Accordance with AMS 5596; Transverse Tests)

| Thickness,<br>in.                     | Temperature, °F | Tensile<br>Strength,<br>ksi | Yield Strength<br>(0.2% Offset),<br>ksi | Elongation,<br>% | Hardness,<br>Rc | Notch Tensile<br>Strength, ksi<br>(K <sub>t</sub> =6.3) | Notch/Unnotch<br>Tensile Strength<br>Ratio |
|---------------------------------------|-----------------|-----------------------------|-----------------------------------------|------------------|-----------------|---------------------------------------------------------|--------------------------------------------|
| 0.025                                 | Room            | 204.5                       | 177.0                                   | 14.0             | 48              | -                                                       | -                                          |
|                                       | -320            | 253.5                       | 203.0                                   | 12.5             | 48              | 215.5                                                   | 0.85                                       |
| 0.062<br>(30% Reduction) <sup>a</sup> | Room            | 205.75                      | 174.5                                   | 19.0             | 45              | 204.0                                                   | 0.99                                       |
|                                       | -320            | 254.25                      | 200.0                                   | 20.0             | 45              | 219.5                                                   | 0.86                                       |
| 0.075<br>(10% Reduction) <sup>a</sup> | Room            | 201.0                       | 170.25                                  | 18.0             | 44              | 213.25                                                  | 1.06                                       |
|                                       | -320            | 249.25                      | 194.25                                  | 18.0             | 44              | 233.25                                                  | 0.94                                       |
| 0.93                                  | Room            | 202.0                       | 170.5                                   | 16.0             | 41              | -                                                       | -                                          |
|                                       | -320            | 251.0                       | 189.5                                   | 22.5             | 45              | 244.0                                                   | 0.97                                       |
| 0.125                                 | Room            | 205.5                       | 181.0                                   | 13.5             | 47              | -                                                       | -                                          |
|                                       | -320            | 262.5                       | 208.5                                   | 18.0             | 46              | 255.0                                                   | 0.97                                       |

<sup>a</sup>Values for these specimens are averages of 2 tests.

**Table 27** - Tensile Properties of 0.027-in. Sheet Reduced 20% (Transverse Tests)

| Sample                                                           | Test<br>Temperature,<br>°F | Tensile<br>Strength, ksi | Yield<br>Strength<br>(0.2%<br>Offset),<br>ksi | Elongation,<br>% | Notch<br>Tensile<br>Strength, ksi<br>(K <sub>t</sub> =6.3) | Tensile<br>Strength/<br>0.297<br>lb/cu. in. <sup>a</sup> | Ratio of Notch Tensile<br>Strength to |                   |
|------------------------------------------------------------------|----------------------------|--------------------------|-----------------------------------------------|------------------|------------------------------------------------------------|----------------------------------------------------------|---------------------------------------|-------------------|
|                                                                  |                            |                          |                                               |                  |                                                            |                                                          | Tensile<br>Strength                   | Yield<br>Strength |
| Cold-Rolled, Annealed<br>and Aged in Accordance<br>with AMS 5596 | -110                       | 212.0                    | 168.5                                         | 25.0             | 195.0                                                      | 714,000                                                  | 0.92                                  | 1.16              |
|                                                                  | 85                         | 196.0                    | 163.0                                         | 21.0             | 183.0                                                      | 660,000                                                  | 0.93                                  | 1.12              |
|                                                                  | 85 <sup>b</sup>            | 197.0                    | 162.5                                         | 21.0             | 178.0                                                      | -                                                        | 0.91                                  | 1.10              |
|                                                                  | 350                        | 191.0                    | 153.0                                         | 20.0             | -                                                          | -                                                        | -                                     | -                 |
|                                                                  | 650                        | 171.5                    | 141.5                                         | 20.0             | 158.0                                                      | 578,000                                                  | 0.92                                  | 1.11              |
|                                                                  | 650 <sup>b</sup>           | 172.0                    | 137.5                                         | 23.0             | 163.0                                                      | -                                                        | 0.95                                  | 1.19              |
|                                                                  | 800                        | 188.0                    | 141.0                                         | 23.0             | 156.0                                                      | -                                                        | 0.83                                  | 1.11              |
|                                                                  | 1000                       | 169.0                    | 135.0                                         | 24.0             | 143.0                                                      | 570,000                                                  | 0.85                                  | 1.06              |
| Cold-Rolled and Aged<br>in Accordance with<br>AMS 5596           | -320                       | 260.5                    | 229.0                                         | 13.0             | 236.5                                                      | 877,000                                                  | 0.91                                  | 1.03              |
|                                                                  | -110                       | 232.0                    | 206.5                                         | 17.0             | 209.0                                                      | 781,000                                                  | 0.88                                  | 1.01              |
|                                                                  | 85                         | 221.0                    | 198.5                                         | 12.0             | 196.5                                                      | 745,000                                                  | 0.89                                  | 0.99              |
|                                                                  | 85 <sup>b</sup>            | 212.0                    | 195.5                                         | 13.0             | 199.0                                                      | -                                                        | 0.94                                  | 1.02              |
|                                                                  | 350                        | 205.0                    | 188.5                                         | 12.0             | 179.0                                                      | -                                                        | 0.88                                  | 0.96              |
|                                                                  | 650                        | 193.5                    | 179.0                                         | 12.0             | 173.5                                                      | 652,000                                                  | 0.90                                  | 0.97              |
|                                                                  | 650 <sup>b</sup>           | 198.5                    | 182.0                                         | 13.0             | 172.0                                                      | -                                                        | 0.87                                  | 0.95              |
|                                                                  | 800                        | -                        | -                                             | -                | 169.0                                                      | -                                                        | -                                     | -                 |
|                                                                  | 1000                       | 180.5                    | 165.3                                         | 10.0             | 166.5                                                      | 608,000                                                  | 0.92                                  | 1.01              |

<sup>a</sup>Room-temperature density.

<sup>b</sup>Stressed at 40 ksi for 1000 hr at 650°F prior to testing.

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**Table 28** - Low-Temperature Tensile Properties of Sheet (Heat-Treated in Accordance with 5596)

| Test Temperature,<br>°F                                      | Test Orientation <sup>a</sup> | Tensile Strength,<br>ksi | Yield Strength, ksi | Elongation,<br>% | Notch Tensile<br>Strength <sup>b</sup> ,<br>psi | Notch/Unnotch<br>Tensile Strength<br>Ratio |
|--------------------------------------------------------------|-------------------------------|--------------------------|---------------------|------------------|-------------------------------------------------|--------------------------------------------|
| 0.010-in. Material - Annealed (Heat 1)                       |                               |                          |                     |                  |                                                 |                                            |
| 75                                                           | L                             | 114.0                    | 47.3                | 43               | 89.2                                            | 0.78                                       |
|                                                              | T                             | 116.0                    | 47.0                | 49               | 88.8                                            | 0.77                                       |
| -320                                                         | L                             | 152.0                    | 70.7                | 50               | 121.0                                           | 0.80                                       |
|                                                              | T                             | 157.0                    | 75.8                | 43               | 118.0                                           | 0.75                                       |
| -423                                                         | L                             | 187.0                    | 97.3                | 49               | 146.0                                           | 0.78                                       |
|                                                              | T                             | 176.0                    | 91.8                | 40               | 142.0                                           | 0.81                                       |
| 0.010-in. Material - Annealed and Aged (Heat 1)              |                               |                          |                     |                  |                                                 |                                            |
| 75                                                           | L                             | 192.0                    | 155.0               | 21               | 198.0                                           | 1.03                                       |
|                                                              | T                             | 189.0                    | 154.0               | 20               | 196.0                                           | 1.04                                       |
| -320                                                         | L                             | 243.0                    | 186.0               | 26               | 234.0                                           | 0.96                                       |
|                                                              | T                             | 239.0                    | 181.0               | 22               | 229.0                                           | 0.96                                       |
| -423                                                         | L                             | 267.0                    | 200.0               | 21               | 254.0                                           | 0.95                                       |
|                                                              | T                             | 262.0                    | 195.0               | 21               | 259.0                                           | 0.99                                       |
| 0.031-in. Material - Annealed and Aged (Heat 2)              |                               |                          |                     |                  |                                                 |                                            |
| 75                                                           | L                             | 195.0                    | 157.0               | 20               | 207.0                                           | 1.06                                       |
|                                                              | T                             | 194.0                    | 157.0               | 20               | 206.0                                           | 1.06                                       |
| -100                                                         | L                             | 214.0                    | 171.0               | 23               | 221.0                                           | 1.03                                       |
|                                                              | T                             | 213.0                    | 170.0               | 23               | 223.0                                           | 1.04                                       |
| -320                                                         | L                             | 232.0                    | 185.0               | 33               | 214.0                                           | 0.92                                       |
|                                                              | T                             | 247.0                    | 192.0               | 26               | 229.0                                           | 0.93                                       |
| -423                                                         | L                             | 278.0                    | 205.0               | 28               | 276.0                                           | 0.99                                       |
|                                                              | T                             | 276.0                    | 204.0               | 27               | 269.0                                           | 0.97                                       |
| 0.031-in. Material - 20% Cold-Rolled and Aged (Heat 2)       |                               |                          |                     |                  |                                                 |                                            |
| 75                                                           | L                             | 214.0                    | 197.0               | 15               | 238.0                                           | 1.11                                       |
|                                                              | T                             | 204.0                    | 183.0               | 13               | 226.0                                           | 1.11                                       |
| -320                                                         | L                             | 268.0                    | 227.0               | 25               | 272.0                                           | 1.01                                       |
|                                                              | T                             | 254.0                    | 214.0               | 21               | 262.0                                           | 1.03                                       |
| -423                                                         | L                             | 286.0                    | 239.0               | 28               | 293.0                                           | 1.02                                       |
|                                                              | T                             | 281.0                    | 228.0               | 22               | 286.0                                           | 1.02                                       |
| 0.018-0.025-in. Material - 30% Cold-Rolled and Aged (Heat 3) |                               |                          |                     |                  |                                                 |                                            |
| 75                                                           | L                             | 230.0                    | 218.0               | 7                | 248.0                                           | 1.08                                       |
|                                                              | T                             | 223.0                    | 206.0               | 7                | 248.0                                           | 1.11                                       |
| -100                                                         | L                             | 249.0                    | 230.0               | 11               | 267.0                                           | 1.07                                       |
|                                                              | T                             | 242.0                    | 218.0               | 8                | 262.0                                           | 1.08                                       |
| -320                                                         | L                             | 292.0                    | 259.0               | 16               | 292.0                                           | 1.00                                       |
|                                                              | T                             | 273.0                    | 238.0               | 13               | 285.0                                           | 1.04                                       |
| -423                                                         | L                             | 309.0                    | 269.0               | 15               | 309.0                                           | 1.00                                       |
|                                                              | T                             | 295.0                    | 251.0               | 16               | 301.0                                           | 1.02                                       |
| 0.018-0.025-in. Material - 50% Cold-Rolled and Aged (Heat 3) |                               |                          |                     |                  |                                                 |                                            |
| 75                                                           | L                             | 240.0                    | 231.0               | 6                | 261.0                                           | 1.09                                       |
| -320                                                         | L                             | 297.0                    | 274.0               | 9                | 304.0                                           | 1.02                                       |
| -423                                                         | L                             | 337.0                    | 287.0               | 12               | 320.0                                           | 0.95                                       |

<sup>a</sup>L, longitudinal; T, transverse.

<sup>b</sup>Notch concentration, K<sub>t</sub>, 6.3

## IMPACT STRENGTH

Room-temperature impact strength of some hot-finished products are shown in comparison with their tensile properties in Table 29. The data also point out the effect of annealing at 1750°F and aging at 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours versus annealing at 1950°F and aging at 1400°F/10 hr, F.C. to 1200°F for total aging time of 20 hours. Some impact properties of a pancake forging are shown in Table 11 (page 7).

Low-temperature impact strength of plate is shown in Table 30.

**Table 30** - Impact Strength of 1-in. Plate (Annealed and Aged in Accordance with AMS 5596)

| Temperature, °F | Impact Strength, ft•lb |                  |
|-----------------|------------------------|------------------|
|                 | Charpy Keyhole         | Charpy V-Notch   |
| Room            | 15.5, 16.0, 17.0       | 19.5, 20.5, 22.5 |
| -320            | 13.5, 13.5, 15.0       | 18.5, 19.0, 19.5 |

**Table 29** - Room-Temperature Impact Strength of Hot-Finished Products

| Diameter <sup>a</sup> ,<br>in.                                                                                         | Tensile Properties (Longitudinal Orientation) |                                      |                  |                         | Charpy V-Notch<br>Impact Strength, ft•lb |
|------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|--------------------------------------|------------------|-------------------------|------------------------------------------|
|                                                                                                                        | Tensile Strength,<br>ksi                      | Yield Strength<br>(0.2% Offset), ksi | Elongation,<br>% | Reduction of Area,<br>% |                                          |
| Heat Treatment: 1750°F/1 hr, A.C. + Aged 1325°F/8 hr, F.C. to 1150°F, Hold at 1150°F for Total Aging Time of 18 hours  |                                               |                                      |                  |                         |                                          |
| 0.625                                                                                                                  | 208.0                                         | 180.0                                | 21.0             | 39.0                    | 18.5                                     |
| 1                                                                                                                      | 209.0                                         | 174.0                                | 20.0             | 24.8                    | 10.0                                     |
| 1.5                                                                                                                    | 204.0                                         | 165.5                                | 19.0             | 24.5                    | 11.0                                     |
| 8                                                                                                                      | 209.0                                         | 183.5                                | 17.0             | 32.0                    | 13.0 <sup>b</sup>                        |
| 12                                                                                                                     | 196.0                                         | 165.0                                | 25.0             | 39.1                    | 24.0 <sup>b</sup>                        |
| Heat Treatment: 1950°F/1 hr, A.C. + Aged 1400°F/10 hr, F.C. to 1200°F, Hold at 1200°F for Total Aging Time of 20 hours |                                               |                                      |                  |                         |                                          |
| 0.625                                                                                                                  | 194.0                                         | 157.0                                | 23.0             | 34.0                    | 26.0                                     |
| 1                                                                                                                      | 188.0                                         | 152.0                                | 21.0             | 34.0                    | 33.0                                     |
| 1.5                                                                                                                    | 191.0                                         | 153.0                                | 24.0             | 36.0                    | 28.5                                     |
| 8                                                                                                                      | 194.5                                         | 160.0                                | 22.0             | 34.3                    | 35.0 <sup>b</sup>                        |
| 12                                                                                                                     | 192.5                                         | 162.0                                | 27.0             | 42.0                    | 39.0 <sup>b</sup>                        |

<sup>a</sup>Diameters of 8- and 12-in. were forged; others are hot-rolled.

<sup>b</sup>Average of 2 tests.

## FATIGUE STRENGTH

Room-temperature fatigue properties of annealed and annealed and aged (1750°F, plus 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours) forging specimens are shown in Table 31. Table 32 presents fatigue strength of hot-rolled plate annealed and aged in accordance with AMS 5596.

Fatigue strength of cold-rolled sheet is shown in Figure 3.

If fatigue strength is of prime importance, INCONEL alloy 718 forgings can be used in the annealed rather than the annealed and aged condition; aging raises fatigue strength

only slightly (less than 4 ksi in Table 31).

Grain size is a major factor in achievement of high fatigue strength. Its effect can be seen in Figure 4. The low-temperature heat-treatment schedule (such as that in AMS 5596) will promote the requisite fine grain. See also Tables 31 and 32. High-temperature fatigue strength of annealed and aged bar is shown in Table 33.

Low-cycle fatigue life of INCONEL alloy 718 is the same whether tested in fully reversed bending or in zero-to-maximum bending. Test results are shown in Figure 5.

**Table 31** - Room-Temperature Fatigue Strength of 6- by 9-in. Forging<sup>a</sup>

| Condition <sup>b</sup> | Tensile Properties    |                                   |                 |                      | Grain Size, in.     | Fatigue Strength, ksi  |                        |                        |
|------------------------|-----------------------|-----------------------------------|-----------------|----------------------|---------------------|------------------------|------------------------|------------------------|
|                        | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, %   | Reduction of Area, % |                     | 10 <sup>6</sup> Cycles | 10 <sup>7</sup> Cycles | 10 <sup>8</sup> Cycles |
| Annealed               | 143.0 <sup>c</sup>    | 99.5 <sup>c</sup>                 | 32 <sup>c</sup> | 32 <sup>c</sup>      | 0.0023 <sup>c</sup> | 74.0                   | 67.5                   | 66.5                   |
| Annealed and Aged      | 191.25                | 169.5                             | 10.5            | 20                   | 0.0021              | 77.5                   | 71.0                   | 69.5                   |

<sup>a</sup>Rotating-beam fatigue tests. Values are average of 2 samples (polished specimens)--center short transverse and mid short transverse.

<sup>b</sup>Annealing at 1750°F/1 hr Aging at 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.

<sup>c</sup>Values for center short transverse only.

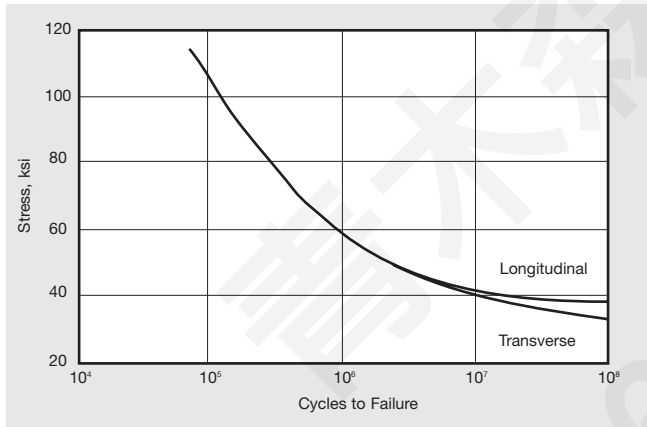
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**Table 32** - Room-Temperature Fatigue Strength of 1.125-in. Hot-Rolled Plate<sup>a</sup>

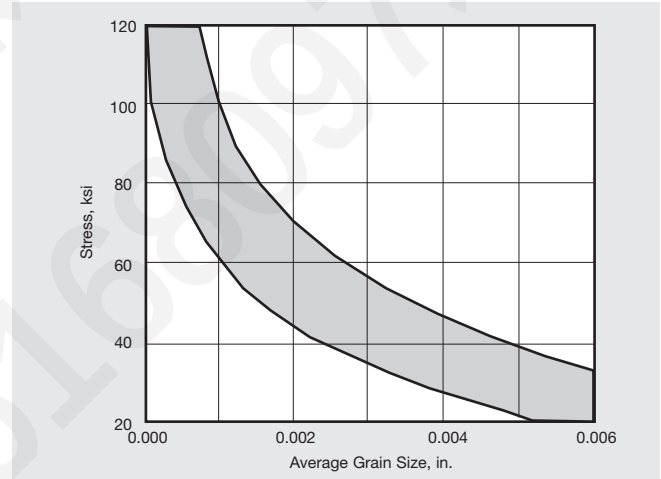
| Heat Treatment <sup>b</sup> | Test Orientation | Tensile Properties    |                                   |               |                      | Grain Size, in. | Fatigue Strength, ksi  |                        |                        |
|-----------------------------|------------------|-----------------------|-----------------------------------|---------------|----------------------|-----------------|------------------------|------------------------|------------------------|
|                             |                  | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Reduction of Area, % |                 | 10 <sup>6</sup> Cycles | 10 <sup>7</sup> Cycles | 10 <sup>8</sup> Cycles |
| Annealed                    | Longitudinal     | 132.5                 | 58.0                              | 46            | 46.6                 | 0.0008          | 73.0                   | 70.0                   | 70.0                   |
| Annealed and Aged           | Longitudinal     | 201.5                 | 159.5                             | 26            | 46.0                 | 0.0005          | 96.0                   | 81.0                   | 78.0                   |
|                             | Transverse       | 199.0                 | 158.0                             | 24            | 38.0                 | 0.0007          |                        |                        |                        |
| Annealed and Aged           | Longitudinal     | 202.0                 | 160.5                             | 26            | 44.5                 | 0.0015          | 96.0                   | 88.0                   | 85                     |
|                             | Transverse       | 197.5                 | 159.0                             | 24            | 41.0                 | 0.0005          |                        |                        |                        |
| Annealed and Aged           | Longitudinal     | 196.5                 | 158.0                             | 27            | 48.5                 | 0.0009          | 91.0                   | 82.0                   | 77.0                   |
|                             | Transverse       | 196.5                 | 158.0                             | 27            | 43.0                 | 0.0008          |                        |                        |                        |
| Annealed and Aged           | Longitudinal     | 191.0                 | 153.5                             | 28            | 41.5                 | 0.0014          | 90.0                   | 81.0                   | 74.0                   |
|                             | Transverse       | 188.5                 | 151.5                             | 28            | 41.5                 | 0.0013          |                        |                        |                        |
| Aged                        | Longitudinal     | 215.0                 | 193.5                             | 20            | 39.1                 | 0.0008          | 95.0                   | 84.0                   | 80.0                   |
|                             | Transverse       | 210.0                 | 187.0                             | 17            | 37.5                 | 0.0012          |                        |                        |                        |

<sup>a</sup>Fatigue tests run on R.R. Moore rotating-beam fatigue machines at 10,000. Specimens were 0.300-in. diameter polished longitudinally.

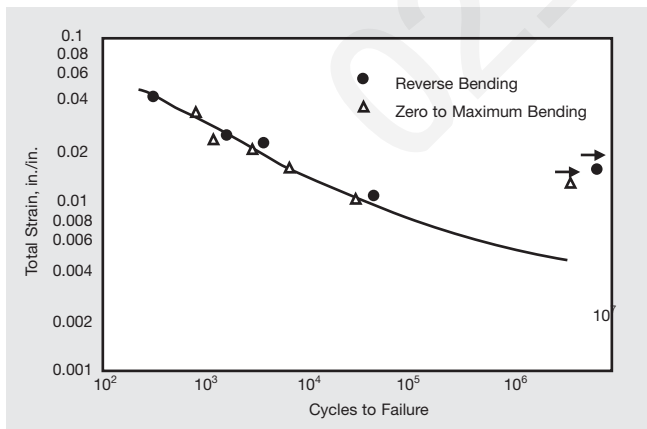
<sup>b</sup>In accordance with AMS 5596.



**Figure 3.** Room-temperature fatigue strength of 0.068-in. cold-rolled sheet annealed and aged in accordance with AMS 5596 (Krouse tests). Average grain size, 0.002 in.



**Figure 4.** Effect of grain size on endurance limit (10<sup>8</sup> cycles) of plate annealed and aged in accordance with AMS 5596.



**Figure 5.** Low-cycle life of plate annealed and aged in accordance with AMS 5596. (Test orientation parallel to rolling direction). Grain size, 0.0021-in. Modified Krouse plate fatigue machine.

**Table 33** - High-Temperature Fatigue Strength of Hot-Rolled Bar (Annealed 1750°F/1 hr, A.C. and Aged)<sup>a</sup>

| Test Temperature,<br>°F | Fatigue Strength, ksi     |                           |                           |                           |
|-------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
|                         | 10 <sup>6</sup><br>Cycles | 10 <sup>6</sup><br>Cycles | 10 <sup>7</sup><br>Cycles | 10 <sup>8</sup><br>Cycles |
| Room                    | 132.0                     | 101.0                     | 92.0                      | 90.0                      |
| 600                     | 115.0                     | 110.0                     | 110.0                     | 110.0                     |
| 1000                    | 111.0                     | 102.0                     | 95.0                      | 90.0                      |
| 1200                    | 100.0                     | 94.0                      | 88.0                      | 72.0                      |

<sup>a</sup>Rotating-beam tests. Average grain size, 0.0008-in. Aging--1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.

## RUPTURE AND CREEP PROPERTIES

For creep-limited and rupture-limited applications INCONEL alloy 718 is annealed at 1700°F-1850°F and aged at 1325°F/8 hr, F.C. to 1150°F, hold for total aging time of 18 hours (or an equivalent treatment such as in AMS 5596). Rupture and creep properties shown in this bulletin are typical of material receiving this low-temperature treatment.

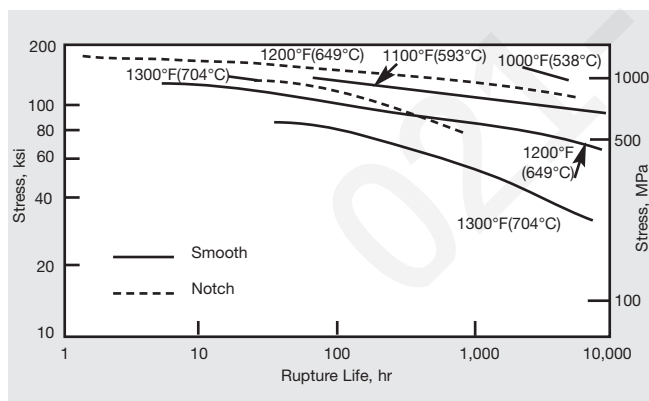
Figure 6, a plot of high-temperature rupture life, also shows the excellent properties at 1200° and 1300°F of notch specimens of small-diameter bar.

Figure 7 shows creep strength of annealed and aged hot-rolled bar.

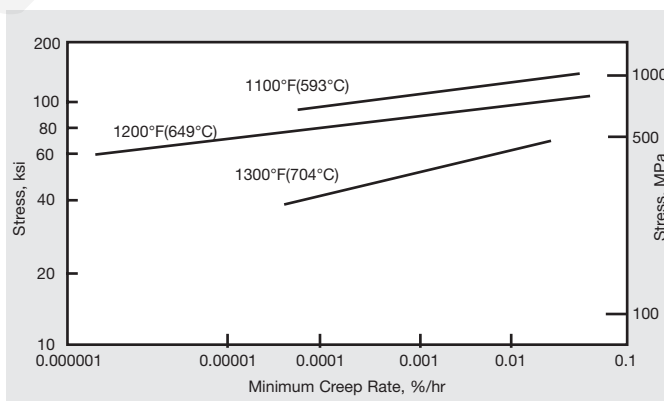
These rupture and creep data have been used for construction of Larson-Miller and Manson-Haferd parameter plots (Figures 8 and 9). For convenience in design, the typical properties are also shown on the basis of 100, 1000, and 10,000 hours (Figures 10, 11 and 12).

Rupture properties of annealed and aged cold-rolled sheet are shown in the form of a Larson-Miller parameter plot (Figure 13). As indicated by the specifications, thickness will influence rupture life.

Rupture life of round and sheet in comparison with tensile properties is shown in Tables 9 (page 6) and 24 (12).

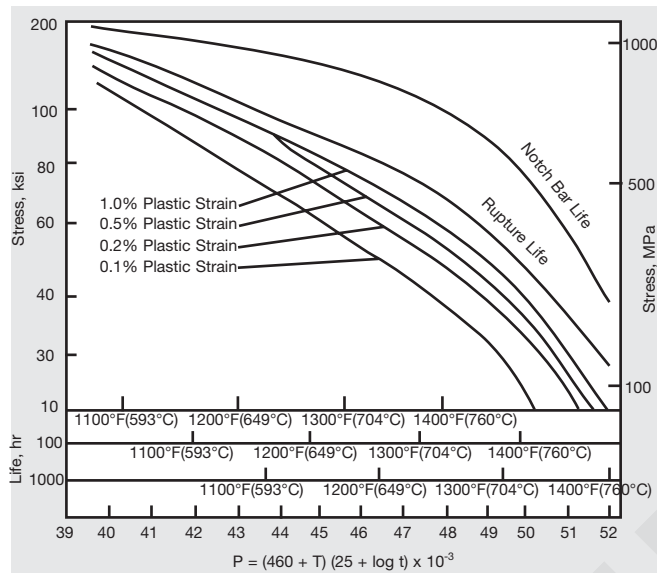


**Figure 6.** Smooth and notch rupture life of hot-rolled bar, 0.625-in. (15.9 mm) diameter (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr),  $K_t=4$ .

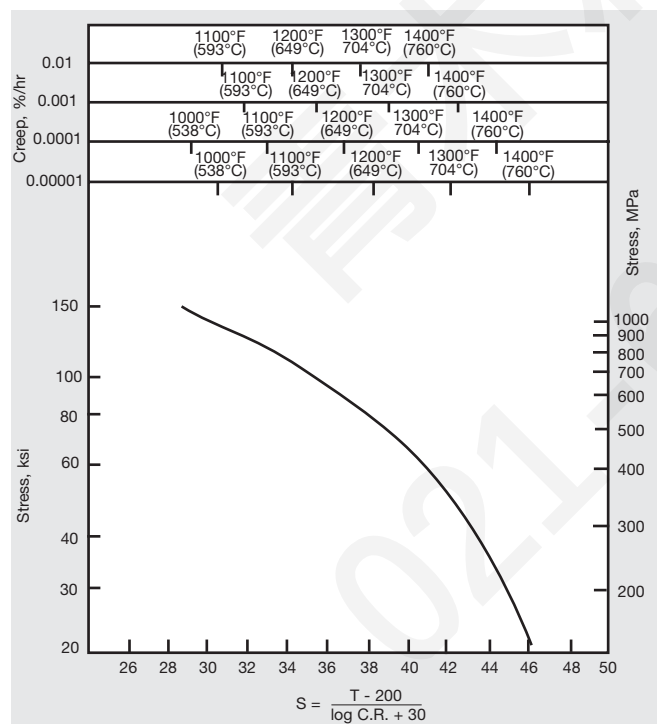


**Figure 7.** Creep strength of hot-rolled bar 0.625-in. (15.9 mm) diameter (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr).

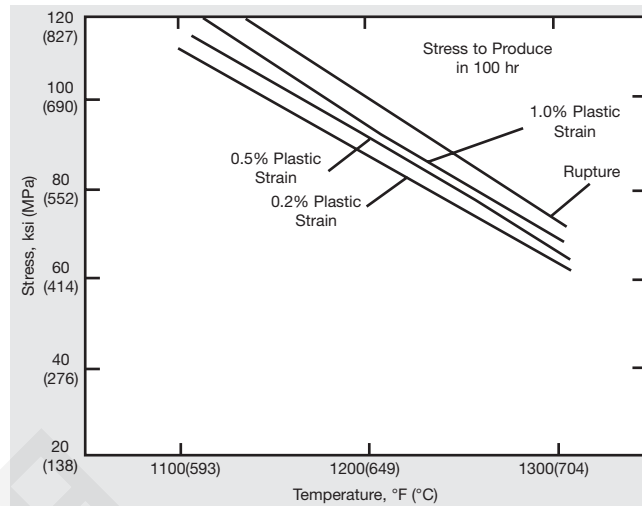
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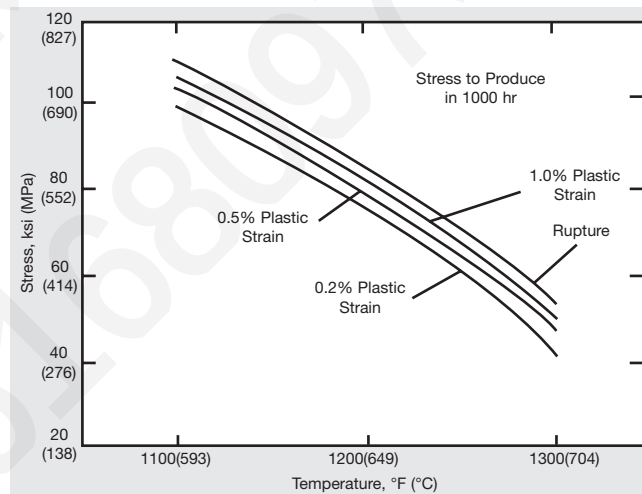
**Figure 8.** Larson-Miller parameter plot of rupture life of hot-rolled, 0.625-in. (15.9 mm) diameter bar (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hours). In the Larson Miller parameter,  $P$ ,  $T$  is temperature, °F, and  $t$  is time, hr.



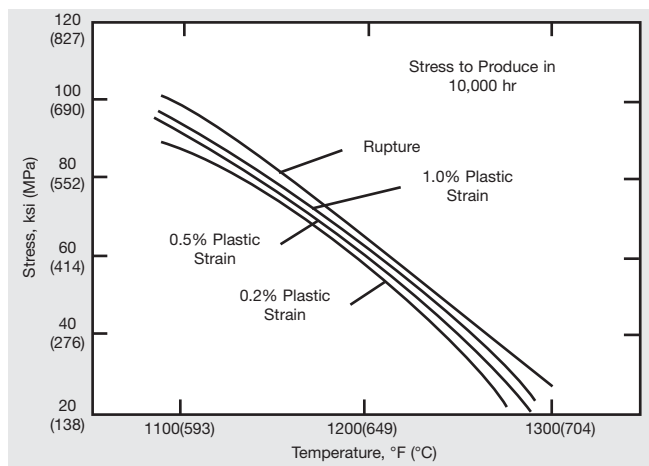
**Figure 9.** Manson-Haferd parameter plot of minimum creep rate of hot-rolled bar, 0.625-in. (15.9 mm) diameter (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr). In the Manson-Haferd parameter,  $S$ ,  $T$  is temperature, °F, and C.R. is creep rate.



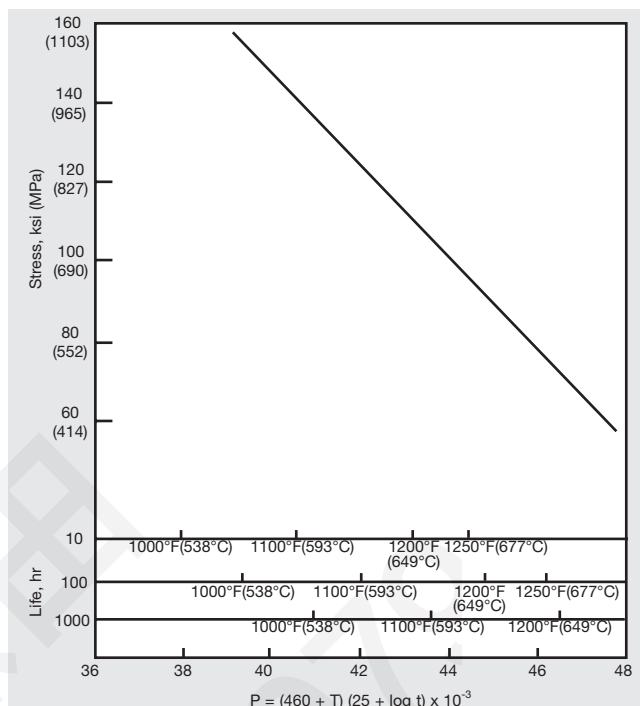
**Figure 10.** Creep-rupture properties (100 hr) of hot-rolled, 0.625-in. (15.9 mm) diameter bar (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr).



**Figure 11.** Creep-rupture properties (1000 hr) of hot-rolled, 0.625-in. (15.9 mm) diameter bar (1800°F(982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr).



**Figure 12.** Creep-rupture properties (10,000 hr) of hot-rolled, 0.625-in. (15.9 mm) diameter bar (1800°F/982°C)/1 hr, W.Q. and aged 1325°F(718°C)/8 hr, F.C. to 1150°F(621°C), hold at 1150°F(621°C) for total aging time of 18 hr.



**Figure 13.** Larson-Miller parameter plot of rupture life of cold-rolled sheet, 0.025-0.250 in. (0.64-6.35 mm) (Annealed and aged in accordance with AMS 5596). In the Larson-Miller parameter, P, T is temperature, °F, and t is time, hr.

## WELD PROPERTIES

INCONEL alloy 718 is readily welded by the gas tungsten-arc (TIG) process using INCONEL Filler Metal 718. Composition of this filler metal is shown in Table 34. Mechanical properties of its all-weld metal specimens are shown in Table 35. These test data show the effect of postwelding treatment on tensile properties. Highest room-temperature ductility is obtained by annealing at 1950°F prior to aging.

Slow response of alloy 718 to age hardening enables parts to be welded and directly age-hardened without an intermediate stress relief. Joint efficiencies very close to 100% were realized in the tests shown in Table 38; these specimens were from plate that had been annealed, then welded and aged. Better properties, however, are obtained by re-annealing after welding prior to aging.

Silver brazing compounds are known to cause stress cracking in nickel-based alloys. If alloy 718 is cold-worked and/or precipitation-hardened, silver brazing compounds should not be used. Also, brazing alloys containing cadmium are best avoided; while cadmium has not been shown to cause cracking by itself, it can aggravate cracking from other sources.

**Table 34 -** Composition, %, of INCONEL Filler Metal 718

|                               |             |
|-------------------------------|-------------|
| Nickel (plus Cobalt) .....    | 50.00-55.00 |
| Copper .....                  | 0.30 max.   |
| Manganese .....               | 0.35 max.   |
| Iron .....                    | Balance     |
| Silicon .....                 | 0.35 max.   |
| Carbon .....                  | 0.08 max.   |
| Sulfur .....                  | 0.015 max.  |
| Titanium .....                | 0.65-1.15   |
| Aluminum .....                | 0.20-0.80   |
| Niobium (plus Tantalum) ..... | 4.75-5.50   |
| Chromium .....                | 17.0-21.0   |
| Molybdenum .....              | 2.80-3.30   |
| Phosphorus .....              | 0.015 max.  |
| Cobalt .....                  | 1.00 max.   |
| Boron .....                   | 0.006 max.  |

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**Table 35** - Effect of Postwelding Heat Treatment on Tensile Properties of INCONEL Filler Metal 718 All-Weld Metal  
(Manual Gas Tungsten-Arc Process between 0.5-in. Plates) (Average of 2 Tests)

| Filler Metal Diameter, in. <sup>a</sup> | Heat Treatment <sup>b</sup> | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Reduction of Area, % |
|-----------------------------------------|-----------------------------|-----------------------|-----------------------------------|---------------|----------------------|
| 0.045                                   | As-Welded <sup>c</sup>      | 125.50                | 84.30                             | 28.0          | 30.0                 |
|                                         | 1750°F, Age                 | 180.25                | 148.50                            | 7.8           | 12.3                 |
|                                         | 1950°F, Age                 | 197.25                | 162.75                            | 18.8          | 26.5                 |
|                                         | 1325°F, Age                 | 186.00                | 153.50                            | 11.0          | 13.5                 |
| 0.045                                   | As-Welded                   | 120.75                | 82.30                             | 28.0          | 30.5                 |
|                                         | 1750°F, Age                 | 169.50                | 144.00                            | 7.8           | 12.0                 |
|                                         | 1950°F, Age                 | 193.50                | 164.85                            | 13.3          | 17.0                 |
|                                         | 1325°F, Age                 | 180.50                | 147.75                            | 7.8           | 10.3                 |
| 0.09375                                 | As-Welded                   | 123.75                | 84.00                             | 28.0          | 31.3                 |
|                                         | 1750°F, Age                 | 174.50                | 145.25                            | 7.7           | 12.5                 |
|                                         | 1950°F, Age <sup>c</sup>    | 197.00                | 168.50                            | 10.0          | 18.0                 |
|                                         | 1325°F, Age <sup>c</sup>    | 166.50                | 150.50                            | 4.0           | 4.0                  |
| 0.062                                   | As-Welded <sup>c</sup>      | 125.20                | 83.50                             | 28.0          | 37.5                 |
|                                         | 1750°F, Age                 | 174.50                | 152.00                            | 4.9           | 7.0                  |
|                                         | 1950°F, Age                 | 198.00                | 179.25                            | 13.8          | 21.5                 |
|                                         | 1325°F, Age <sup>c</sup>    | 175.50                | 151.00                            | 4.0           | 7.5                  |
| 0.062                                   | As-Welded                   | 123.25                | 75.05                             | 34.3          | 35.3                 |
|                                         | 1750°F, Age                 | 180.00                | 144.00                            | 12.6          | 18.0                 |
|                                         | 1950°F, Age <sup>c</sup>    | 196.50                | 161.00                            | 16.0          | 31.0                 |
|                                         | 1325°F, Age                 | 176.75                | 140.00                            | 15.5          | 22.5                 |

<sup>a</sup>Each separate size shown represents test run on separate heat.

<sup>b</sup>Heat treatments: 1750°F, Age is 1750°F anneal plus age at 1325°F/8 hr, F.C. 100°F/hr to 1150°F, hold at 1150°F for a total of 18 hours. 1950°F, Age is 1950°F anneal plus age at 1400°F/10 hr, F.C. 100°F/hr to 1200°F, hold at 1200°F for a total aging time of 20 hours. 1325°F, Age is at 1325°F/8 hr, F.C. 100°F/hr to 1150°F, hold at 1150°F for total aging time of 18 hr.

<sup>c</sup>One test only.

**Table 36** - Weld-Patch Testing of Cold-Rolled, Annealed Sheet<sup>a</sup>  
(Procedure: Anneal plus Weld plus Age plus Repair-Weld plus Re-Age)

| Sheet Thickness, in. | Heat Treatment | Patch Test Assembly <sup>b</sup> | Condition After   |                             |
|----------------------|----------------|----------------------------------|-------------------|-----------------------------|
|                      |                |                                  | Welding and Aging | Repair Welding and Re-Aging |
| 0.028                | AMS 5596       | 1                                | Crack-Free        | Crack-Free                  |
| 0.030                |                | 1                                | Crack-Free        | Crack-Free                  |
| 0.030                |                | 1                                | Crack-Free        | Crack-Free                  |
| 0.035                |                | 1                                | Crack-Free        | Crack-Free                  |
| 0.035                |                | 2                                | Crack-Free        | Cracked                     |
| 0.062                |                | 2                                | Crack-Free        | Crack-Free                  |
| 0.062                | AMS 5597       | 2                                | Crack-Free        | Cracked                     |
| 0.062                |                | 1                                | Crack-Free        | Crack-Free                  |
| 0.062                |                | 1                                | Crack-Free        | Crack-Free                  |
| 0.062                |                | 2                                | Crack-Free        | Crack-Free                  |
| 0.078                |                | 1                                | Crack-Free        | Cracked                     |
| 0.093                |                | 2                                | Crack-Free        | Cracked                     |
| 0.109                |                | 2                                | Crack-Free        | Crack-Free                  |

<sup>a</sup>Seven different heats represented in these tests.

<sup>b</sup>See Figure 15.

**Table 37** - Room-Temperature Tensile Properties<sup>a</sup>  
(Transverse Tests) of Welds in 0.5-in. Plate  
(Gas Tungsten-Arc Process Using INCONEL Filler Metal 718)

| Postweld Heat Treatment <sup>b</sup> | Tensile Strength, ksi | Yield Strength (0.2 % Offset), ksi | Elongation in 1 in., % | Reduction of Area, % |
|--------------------------------------|-----------------------|------------------------------------|------------------------|----------------------|
| Direct Age                           | 185.0                 | 158.0                              | 6.5                    | 15.8                 |
| Annealed and Aged                    | 190.0                 | 163.3                              | 7.5                    | 13.9                 |
| Annealed and Aged                    | 191.5                 | 164.5                              | 9.5                    | 16.3                 |

<sup>a</sup>Average of 2 tests.

<sup>b</sup>According to AMS 5596.

**Table 38** - Room Temperature Tensile Properties of Welds (Aged 1325°F/8 hr, F.C. to 1150°F, Held at 1150°F for Total Aging Time of 18 Hours)<sup>a</sup>

| Tensile Strength, ksi          | Yield Strength (0.2% Offset), ksi | Elongation in 1 in., % | Reduction of Area, % |
|--------------------------------|-----------------------------------|------------------------|----------------------|
| Transverse Tests Across Joints |                                   |                        |                      |
| 183.0                          | 159.5                             | 8.0                    | 19.0                 |
| 183.5                          | 158.5                             | 7.0                    | 16.0                 |
| 186.5                          | 162.0                             | 6.0                    | 12.8                 |
| 185.5                          | 163.0                             | 6.0                    | 21.0                 |
| 184.0                          | 163.0                             | 6.0                    | 16.5                 |
| 192.5                          | 166.0                             | 9.0                    | 17.5                 |
| 191.5                          | 164.0                             | 6.0                    | 12.5                 |
| 182.0                          | 156.5                             | 4.0                    | 6.8                  |
| 188.5                          | 168.0                             | 4.0                    | 11.5                 |
| 188.0                          | 170.0                             | 5.0                    | 10.0                 |
| Average 186.5                  | 163.0                             | 6.0                    | 14.4                 |
| All-Weld Metal Tests           |                                   |                        |                      |
| 180.5                          | 157.5                             | 10.0                   | 16.0                 |
| 182.5                          | 162.0                             | 8.0                    | 14.0                 |
| 178.0                          | 154.0                             | 11.0                   | 12.5                 |
| 177.5                          | 150.0                             | 14.0                   | 18.5                 |
| 180.0                          | 153.5                             | 10.0                   | 22.0                 |
| 180.0                          | 158.5                             | 7.0                    | 11.5                 |
| 183.5                          | 160.5                             | 6.0                    | 8.5                  |
| Average 180.0                  | 156.5                             | 9.0                    | 15.0                 |

<sup>a</sup>0.252-in.-diameter specimens prepared from TIG-welded 0.500-in. plate. Plate annealed in accordance with AMS 5596 prior to welding. All tests broke in weld. Filler metal was INCONEL 718.

**Table 39** - Room-Temperature Tensile Properties<sup>a</sup> of Welds in 0.5-in. Plate (Gas Tungsten-Arc Process Using INCONEL Filler Metal 718)

| Sample                  | Postweld Heat Treatment <sup>b</sup> | Tensile Strength, ksi | Yield Strength (0.2 % Offset), ksi | Elongation in 0.5 in., % | Reduction of Area, % |
|-------------------------|--------------------------------------|-----------------------|------------------------------------|--------------------------|----------------------|
| All-Weld Metal          | Direct Age                           | 174.50                | 139.25                             | 18.3                     | 21.5                 |
|                         | 1950°F/1 hr, Age                     | 185.75                | 155.50                             | 22.0 <sup>c</sup>        | 31.8                 |
| Transverse <sup>d</sup> | Direct Age                           | 183.50                | 149.50                             | 12.0                     | 24.8                 |
|                         | 1950°F/1 hr, Age                     | 192.25                | 160.75                             | 17.3                     | 23.5                 |

<sup>a</sup>Average of 2 tests.

<sup>b</sup>Age--1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for total aging time of 20 hours.

<sup>c</sup>One test.

<sup>d</sup>All fractures were in weld.

## Weld Tensile Properties

Room-temperature properties of welds receiving the low-temperature anneal and/or age can be compared with results of the high-temperature anneal and/or age in Tables 38 and 39.

Additional properties of welds annealed at 1950°F/15 min. and aged at 1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for a total aging time of 20 hours are shown in Table 40. Welding was by the manual gas tungsten-arc process, using Filler Metal 718. These welds were found satisfactory in bend tests and radiographic examination. Slightly better results were obtained when helium was used as the torch gas. Notch strength of butt-welded sheet in both the heat-affected zone and weld is shown in Table 41. These welds were heat-treated by the low-temperature schedule.

Another laboratory using the high-temperature heat treatment has found that notch toughness of the parent metal and that of the weld metal are quite consistent and exceed a notch-to-smooth bar tensile ratio of 1.30 throughout the test-temperature range of -423°F to 1200°F. Test data are shown in Table 42. The weld joint efficiency is approximately 93% at -423°F and 95% at room temperature and 1200°F.

**Table 40** - Room-Temperature Tensile Properties of Annealed and Aged Welds in 0.063-in. Sheet<sup>a</sup>

| Weld                             | Tensile Strength, ksi | Elongation In 1 in., % |
|----------------------------------|-----------------------|------------------------|
| Argon Torch Gas; Helium Root Gas |                       |                        |
| 1                                | 188.00                | 11.7                   |
| 2                                | 184.20                | 10.0                   |
| 3                                | 184.50                | 10.0                   |
| 4                                | 190.20                | 14.3                   |
| 5                                | 192.70                | 17.3                   |
|                                  | Average 187.92        | 12.7                   |
| Helium Torch Gas; Argon Root Gas |                       |                        |
| 6                                | 189.20                | 11.7                   |
| 7                                | 191.00                | 15.3                   |
| 8                                | 187.80                | 12.7                   |
| 9                                | 191.70                | 18.3                   |
| 10                               | 194.00                | 18.7                   |
|                                  | Average 190.74        | 15.3                   |

<sup>a</sup>Welded manually with INCONEL Filler Metal 718. One bead. Average of 3 tests. All sheet from same heat. Heat treatment after welding: 1950°F/15 min., plus 1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for total aging time of 20 hr.

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**Table 42** - Tensile Properties of Ring-Forging Specimens Gas-Tungsten-Arc Welded with INCONEL filler Metal 718  
(Weldments Annealed 1950°F/1 hr and Aged 1400°/10 hr, F.C. to 1200°F, Hold at 1200°F for Total Aging Time of 20 hours)<sup>a</sup>

| Specimen     | Tensile Strength, ksi | Yield Strength (0.2% Offset), ksi | Elongation, % | Reduction of Area, % | Notch Tensile Strength <sup>b</sup> , ksi | Notch/Unnotch Tensile Strength Ratio |
|--------------|-----------------------|-----------------------------------|---------------|----------------------|-------------------------------------------|--------------------------------------|
| Room Temp.   |                       |                                   |               |                      |                                           |                                      |
| Parent Metal | 197.5                 | 163.8                             | 25.5          | 38.5                 | 272.8                                     | 1.38                                 |
| Weld         | 189.7                 | 165.6                             | 19.3          | 38.1                 | 263.1                                     | 1.39                                 |
| -423°F       |                       |                                   |               |                      |                                           |                                      |
| Parent Metal | 245.9                 | 203.6                             | 22.5          | 33.1                 | 323.8                                     | 1.32                                 |
| Weld         | 237.9                 | 201.0                             | 19.7          | 30.7                 | 308.7                                     | 1.30                                 |
| 1200°F       |                       |                                   |               |                      |                                           |                                      |
| Parent Metal | 143.8                 | 125.7                             | 21.1          | 40.7                 | 207.4                                     | 1.44                                 |
| Weld         | 147.3                 | 127.3                             | 11.9          | 30.2                 | 204.2                                     | 1.39                                 |

<sup>a</sup>Data are averages of 2-5 tests.

<sup>b</sup>Notch concentration factor,  $K_t$ , 6.3

**Table 41** - Notch-Strength of Butt-Welded, 0.051-in. Cold-Rolled, Annealed Sheet

| Treatment of Weld <sup>a</sup> | Notch Strength <sup>b</sup> , ksi |       |
|--------------------------------|-----------------------------------|-------|
|                                | Heat-Affected Zone                | Weld  |
| Aged                           | 154.0                             | 129.0 |
|                                | 183.8                             | 133.5 |
| Annealed                       | 175.0                             | 132.3 |
| 1800°F/1 hr and Aged           | 163.3                             | 136.0 |

<sup>a</sup>Aging--1325°F/8 hr, F.C. to 1150°F, hold for total aging time of 18 hr, A.C. All welds milled flush to parent metal. Welds made by automatic gas tungsten-arc process with INCONEL Filler Metal 718.

<sup>b</sup>Average of 2 values. Notches were milled in the center of the weld and in the parent metal about 0.025-in. from the fusion zone  $K_t$ , approximately 24.

## Weld Fatigue Properties

Weldments were found to have a room-temperature fatigue strength ( $10^8$  cycles) of approximately 62.5 ksi (tested in R.R. Moore rotating-beam apparatus). They were made from hot-rolled, annealed (per AMS 5596) 0.500-in. plate, joined with 0.125-in.-diameter INCONEL Filler Metal 718 by the gas tungsten-arc process. Samples were aged 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours and tested as polished specimens. In comparable tests, alloy 718 bar had a fatigue strength ( $10^8$  cycles) of 89.0 ksi.

## Weld Shear Properties

Shear strength of as-deposited Filler Metal 718 is shown in Table 43. The test specimens were taken from a 0.625-in. thick overlay made by the automatic gas tungsten-arc process using 0.062-in.-diameter INCONEL Filler Metal 718.

**Table 43** - Shear Strength of As-Welded INCONEL Filler Metal 718 Overlay on INCONEL Alloy 718

| Specimen <sup>a</sup> | Shear Strength <sup>b</sup> , ksi | Tensile Strength, ksi | Yield Strength, ksi | Elongation, % | Reduction of Area, % |
|-----------------------|-----------------------------------|-----------------------|---------------------|---------------|----------------------|
| A                     | 86.0                              | 121.0                 | 73.5                | 27.0          | 30.0                 |
| B                     | 86.5                              | 120.0                 | 73.4                | 28.0          | 26.5                 |
| C                     | 80.0                              | 120.0                 | 72.0                | 30.0          | 33.8                 |

<sup>a</sup>Specimens from 0.625-in. thick, 3-in. wide, 6-in. long overlay. Axes were parallel to direction of welding. Gage diam. of tensile specimen, 0.252-in.; gage length, 4 x diam. Double-shear test specimens 0.250-in. diam., 1.5-in. long.

<sup>b</sup>Double shear.

## Weld Rupture Properties

Rupture strength at 1200° and 1300°F of heat-treated weldments in sheet is compared with parent metal in Table 44. In other tests, welds whose process steps were age, weld, and age had lives of 0.3 hr (1200°F, 100.0 ksi) and 4.9 hr (1300°F, 72.5 ksi) ; fractures were in the heat-affected zone. Notch-bar life at 1300°F and 75.0 ksi is shown in Table 45.

**Table 44** - Rupture Strength of Butt Joints in Annealed Sheet<sup>a</sup>

| Treatment of Weld              | Test Temperature, °F | Stress, ksi | Life, hr | Elongation, % | Location of Fracture |
|--------------------------------|----------------------|-------------|----------|---------------|----------------------|
| Parent Metal Annealed and Aged | 1200                 | 100.0       | 47.3     | 85.0          | -                    |
|                                | 1300                 | 72.5        | 26.1     | 11.0          | -                    |
| Annealed and Aged              | 1200                 | 100.0       | 10.8     | 1.0           | Weld                 |
|                                | 1300                 | 72.5        | 9.4      | 1.0           | Weld                 |
| Aged                           | 1200                 | 100.0       | 16.4     | 1.0           | Weld                 |
|                                | 1300                 | 72.5        | 15.8     | 2.0           | Weld                 |

<sup>a</sup>0.060-in. sheet, welded with INCONEL Filler Metal 718. Parent metal and weld heat-treated in accordance with AMS 5596. Welds ground flush.

**Table 45** - Rupture Strength of Welds<sup>a</sup> (Test Conditions: 1300°F and 75.0 ksi)

| Specimen                      | Heat Treatment <sup>b</sup> | Life, hr | Elongation, %    | Reduction of Area, % | Notch Bar Life, hr |
|-------------------------------|-----------------------------|----------|------------------|----------------------|--------------------|
| All-Weld Metal                | Aged                        | 11.7     | 4.0              |                      | 6.0 14.1           |
|                               | Annealed and Aged           | 12.2     | 5.0              |                      | 7.5 45.5           |
| Transverse Joint <sup>c</sup> | Aged                        | 25.5     | 4.0 (in 0.5 in.) | 5.0                  | 30.1               |
|                               | Annealed and Aged           | 15.3     | 3.0 (in 0.5 in.) | 8.5                  | 25.1               |

<sup>a</sup>Weld deposit by gas tungsten-arc process between 0.5-in. plates using INCONEL Filler Metal 718.

<sup>b</sup>In accordance with AMS 5596.

<sup>c</sup>All fractures in weld.

## SPRING PROPERTIES

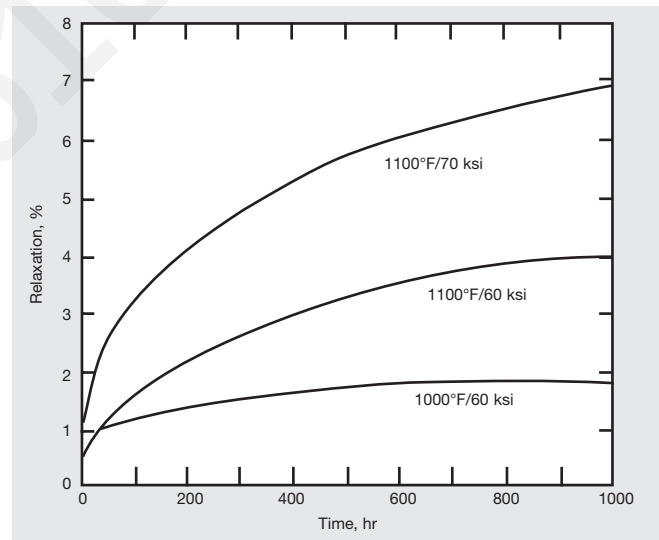
The excellent relaxation resistance of INCONEL alloy 718 is a factor in its successful use for springs at temperatures up to 1100°F. Some relaxation data are shown in Figure 14.

## BOLTING

INCONEL alloy 718 combines excellent mechanical properties over a wide temperature range with superior oxidation and corrosion resistance. Because of these properties it is specified for many fastener applications where superior performance is required under varying environmental conditions.

INCONEL alloy 718 can be strengthened in two ways: (1) by solution treating and age hardening or (2) by cold working and age hardening only. See Table 46.

The use of alloy 718 for bolting applications is addressed under Section I and Section VIII, Division I of the ASME Code by Code Case 1993.



**Figure 14.** Relaxation of helical coil springs made from 0.148-in.-diameter cold-drawn No. 1 Temper wire. (Springs annealed 1800°F/1 hr and aged 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.

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Table 46 - Cold Working and Age Hardening<sup>a</sup>

| Diameter,<br>in                                                                                                                              | Yield Strength<br>(0.2% Offset), ksi | Tensile Strength,<br>ksi | Elongation,<br>% | Hardness,<br>Rc |
|----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|--------------------------|------------------|-----------------|
| As Cold Drawn                                                                                                                                |                                      |                          |                  |                 |
| 0.51                                                                                                                                         | -                                    | -                        | -                | -               |
| 0.76                                                                                                                                         | 161                                  | 178                      | 16               | 41              |
| 1.01                                                                                                                                         | 150                                  | 176                      | 15               | 38              |
| 1.51                                                                                                                                         | -                                    | -                        | -                | -               |
| Cold Drawn and Aged (1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr)                                              |                                      |                          |                  |                 |
| 0.51                                                                                                                                         | 227                                  | 243                      | 11               | 48              |
| 0.76                                                                                                                                         | 223                                  | 234                      | 11               | 47              |
| 1.01                                                                                                                                         | 222                                  | 237                      | 11               | 47              |
| 1.51                                                                                                                                         | 229                                  | 244                      | 11               | 46              |
| Cold Drawn, Solution Annealed and Aged<br>(1750°F/1 hr, A.C. then 1325°F/8 hr F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr.) |                                      |                          |                  |                 |
| 0.51                                                                                                                                         | 168                                  | 211                      | 20               | 42              |
| 0.76                                                                                                                                         | 165                                  | 208                      | 21               | 42              |
| 1.01                                                                                                                                         | 165                                  | 212                      | 20               | 42              |
| 1.51                                                                                                                                         | -                                    | -                        | -                | -               |

<sup>a</sup>Average of minimum five samples from five different heats.

## METALLOGRAPHY

INCONEL alloy 718 is an age-hardenable austenitic material. Strength is largely dependent on the precipitation of a gamma prime phase during heat treatment.

A major part of the development effort with this alloy was concerned with establishment of the proper heat treatments for producing optimum properties. These heat treatments and the applications for which they are intended are described in the section, Mechanical Properties.

The microstructure of alloy 718, especially with regard to the effects of heat treatment, has been extensively studied and reported. The literature should be consulted for detailed discussions on the various phases developed by various heat treatments and other metallurgical investigations.

## CORROSION RESISTANCE

INCONEL alloy 718 has excellent corrosion resistance to many media. This resistance, which is similar to that of other nickel-chromium alloys, is a function of its composition. Nickel contributes to corrosion resistance in many inorganic and organic, other than strongly oxidizing, compounds throughout wide ranges of acidity and alkalinity. It also is useful in combating chloride-ion stress-corrosion cracking. Chromium imparts an ability to withstand attack by oxidizing media and sulfur compounds. Molybdenum is known to contribute to resistance to pitting in many media.

## WORKING INSTRUCTIONS

### Heating and Pickling

When INCONEL alloy 718 is heated care must be taken to maintain both the furnace and the material being heated at correct temperatures.

Fuels used for heating must be extremely low in sulfur. The alloy must be absolutely clean and free from all oil, paint, grease, and shop soil when charged into the furnace.

The furnace atmosphere for forging or open annealing should be slightly reducing, containing at least 2% carbon monoxide. A slight positive pressure should be maintained in the furnace to prevent air infiltration.

When alloy 718 is heated in a reducing atmosphere, a thin, adherent green-black film of oxide will be left on the surface of the material. In oxidizing atmospheres, a heavy black scale is produced that is very difficult to remove. Every precaution should be taken in heating so that only the green-black film is formed.

## Hot Forming

Because of its strength, INCONEL alloy 718 is more resistant than most materials to deformation during hot forming. Its relative resistance is shown by pressures developed in the roll gap at 20% reduction (Table 47). It is readily hot-worked if sufficiently powerful equipment is used.

Hot forming is performed in the 1650°-2050°F temperature range. In the last operation, the metal should be worked uniformly with a gradually decreasing temperature, finishing with some light reduction in the 1650°-1750°F range. This procedure is necessary to ensure notch ductility in stress-rupture applications when material has been annealed and aged. (See below). In heating for hot working, the material should be brought up to temperature, allowed to soak a short time to ensure uniformity, and withdrawn.

To avoid duplex grain structure INCONEL alloy 718 should be given uniform reductions. Final reductions of 20% minimum should be used for open-die work and 10% minimum for closed-die work. Parts should generally be air-cooled from the hot-working temperature rather than water-quenched.

Care should be taken to avoid overheating the metal by heat buildup due to working. Also, the piece should be reheated when any portion has cooled below 1650°F. Preheating tools and dies to 500°F is recommended. Any

ruptures appearing on the surface of the workpiece must be removed at once.

Data shown in Table 48 show the importance of a 1650°F-1750°F finish-forging temperature for achievement of notch ductility in large forgings in stress-rupture applications. In these tests, 0.75-in. square forged bar was cut into 12-in. lengths, heated to the rolling temperatures shown in Table 48, and given 25% reduction in one pass. Following annealing and aging, specimens were rupture-tested at 1200°F and 100 ksi. Success in achieving notch-rupture ductility with forgings of alloy 718 through this type of procedure has also been reported by others.

**Table 47** - Pressure, ksi, Developed in Roll Gap at 20% Reduction

| Material                 | Pressure, ksi               |      |      |      |
|--------------------------|-----------------------------|------|------|------|
|                          | Hot-Forming Temperature, °F |      |      |      |
|                          | 1800                        | 1900 | 2000 | 2100 |
| Mild Steel (1020)        | 22.4                        | 18.3 | 14.3 | 10.3 |
| Type 302 Stainless Steel | 27.8                        | 24.3 | 21.4 | 18.0 |
| INCONEL alloy 600        | 40.8                        | 34.6 | 28.3 | 22.3 |
| INCONEL alloy X-750      | 48.6                        | 43.3 | 38.4 | 33.3 |
| INCONEL alloy 718        | 63.3                        | 55.8 | 48.3 | 41.0 |

**Table 48** - Effect of Hot-Forming Temperature on Rupture Properties<sup>a</sup> (1200°F, 100 ksi)

| Hot-Forming Temperature, °F | Heat Treatment <sup>b</sup> | ASTM Grain Size                  | Smooth Bar |               |                      |              | Notch Bar Life <sup>c</sup> , hr |
|-----------------------------|-----------------------------|----------------------------------|------------|---------------|----------------------|--------------|----------------------------------|
|                             |                             |                                  | Life, hr   | Elongation, % | Reduction of Area, % | Hardness, Rc |                                  |
| 2050                        | A                           | 20% 0.5, 30% 4.5, 40% 6.5, 10% 9 | 193.5      | 3             | 6.5                  | 45           | 16.2                             |
|                             | B                           | 100% 1.5                         | 209.5      | 4             | 8.5                  | 46           | 16.5                             |
| 1950                        | A                           | 70% 8, 30% 3                     | 274.5      | 7             | 9.0                  | 45           | 55.1                             |
|                             | B                           | 60% 3, 30% 8, 10% 7              | 291.4      | 8             | 10.0                 | 45           | 56.7                             |
| 1850                        | A                           | 95% 4.5, 5% 9                    | 193.3      | 11            | 16.0                 | 46           | 123.9                            |
|                             | B                           | 35% 4.5, 60% 9, 5% 7             | 231.6      | 10            | 13.0                 | 46           | 99.2                             |
| 1750                        | A                           | 20% 6, 20% 7, 60% 10             | 121.3      | 13            | 22.0                 | 46           | 131.4                            |
|                             | B                           | 40% 7, 55% 9, 5% 5               | 248.3      | 14            | 16.0                 | 46           | 179.6                            |
| 1650                        | A                           | 100% 9.5                         | 48.0       | 33            | 53.5                 | 46           | 426.2 <sup>d</sup>               |
|                             | B                           | 100% 9.5                         | 124.3      | 28            | 43.5                 | 46           | 426.1 <sup>d</sup>               |

<sup>a</sup>Hot-finished, 25% reduction, one pass.

<sup>b</sup>A--1750°F/1 hr, A.C., + 1325°F/8 hr, F.C. 100°F/hr to 1150°F, hold at 1150°F/8 hr, A.C.

B--1800°F/1 hr, A.C., + 1325°F/8 hr, F.C. 100°F/hr to 1150°F, hold at 1150°F/8 hr, A.C.

<sup>c</sup>K<sub>t</sub>, 3.5 to 4.0; root diameter, 0.252-in.

<sup>d</sup>Test discontinued.

## INCONEL® alloy 718

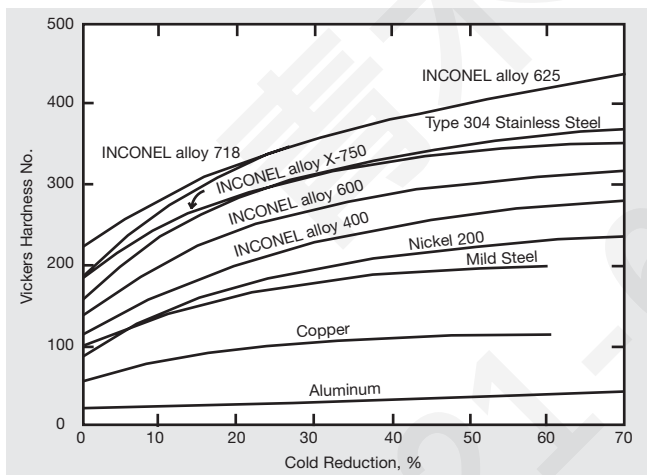
**Table 49** - Effect of Cold Reduction on Properties of Sheet

| Cold Reduction,<br>%                                                                                      | Tests at Room Temperature |                                         |                  |                 | Tests at -320°F          |                                         |                  |
|-----------------------------------------------------------------------------------------------------------|---------------------------|-----------------------------------------|------------------|-----------------|--------------------------|-----------------------------------------|------------------|
|                                                                                                           | Tensile Strength,<br>ksi  | Yield Strength<br>(0.2% Offset),<br>ksi | Elongation,<br>% | Hardness,<br>Rc | Tensile Strength,<br>ksi | Yield Strength<br>(0.2% Offset),<br>ksi | Elongation,<br>% |
| 0                                                                                                         | 117.0                     | 44.0                                    | 60.0             | 87 Rb           | -                        | -                                       | -                |
| 5.9                                                                                                       | 115.0                     | 68.2                                    | 45.0             | 19              | 161.0                    | 103.0                                   | 38.0             |
| 18.5                                                                                                      | 145.0                     | 116.5                                   | 25.0             | 33              | 189.0                    | 153.0                                   | 24.0             |
| 27.9                                                                                                      | 159.5                     | 134.0                                   | 10.5             | 36              | 204.0                    | 169.0                                   | 15.0             |
| 48.3                                                                                                      | 191.0                     | 165.0                                   | 7.0              | 40              | 231.0                    | 204.0                                   | 15.0             |
| Aged 1325°F/8 hr, F.C. 100°F/1 hr to 1150°F (Held for Total Aging Time of 18 hr, A.C.) after Cold Rolling |                           |                                         |                  |                 |                          |                                         |                  |
| 0                                                                                                         | 187.0                     | 172.5                                   | 19.5             | 44              | 248.0                    | 188.5                                   | 26.0             |
| 5.9                                                                                                       | 203.0                     | 175.5                                   | 22.0             | 45              | 255.0                    | 211.0                                   | 13.0             |
| 18.5                                                                                                      | 217.0                     | 201.0                                   | 16.0             | 47              | 270.0                    | 235.0                                   | 12.5             |
| 48.3                                                                                                      | 244.0                     | 232.5                                   | 4.0              | 49              | 289.0                    | 269.0                                   | 2.5              |

### Cold Forming

INCONEL alloy 718 can be cold-formed by standard procedures used for steel and stainless steel. Figure 16 shows its rate of work hardening in comparison with other materials.

The effect of cold reduction on the tensile properties of sheet in the cold-rolled and cold-rolled and aged conditions is shown in Table 49.



**Figure 16.** Effect of cold work on hardness.

### Machining

INCONEL alloy 718 can be readily machined, but its high strength and work-hardening characteristics must be considered in the selection and use of proper tool materials and design, operating speeds, and coolants.

When machined in the age-hardened condition the alloy will have a slightly better finish; chip action on chipbreaker tools will be better. The use of annealed material, however, provides easier machining and longer tool life.

### Super-Plastic Forming

A special grade of alloy 718 that is specifically designed for the super-plastic forming process is manufactured by Special Metals. This alloy, designated INCONEL alloy 718SPF, is available as annealed sheet in thicknesses from 0.02 to 0.08 inches (0.5 to 2.0 mm) in widths up to 36 inches (914 mm). The specification SAE AMS 5950 was developed to define the requirements for the alloy. Complete information describing the properties of alloy 718SPF and how it is formed is available in the technical bulletin for the alloy on the website [www.specialmetals.com](http://www.specialmetals.com).

### Bending

A guide to the minimum bend diameters of hot-rolled and annealed plate and annealed sheet and strip is given in Table 50. In the determination of those diameters a sample is judged to have passed the 180°-bend test if its surface shows no ductile fracturing. Because of the effect of various surface conditions and heat treatments on bendability, the bends cannot be guaranteed. Many of the materials can nevertheless be bent in stages to tighter bends than those that are suggested in Table 50, provided that the initial bend is not severe.

**Table 50** - Minimum Bend Diameters for Annealed Sheet and Strip and Hot-Rolled and Annealed Plate in 180° Bend

| Alloy                          | Thickness (T)   |                 | Minimum Diameter <sup>a</sup> |
|--------------------------------|-----------------|-----------------|-------------------------------|
|                                | in.             | mm              |                               |
| INCONEL alloy 718 <sup>b</sup> | Sheet and Strip | Sheet and Strip | 1T                            |
|                                | 0.012-0.049     | 0.30-1.24       | 2T                            |
|                                | 0.050-0.250     | 1.27-6.35       |                               |

<sup>a</sup>Bend tests were performed according to ASTM Standard Method E 290-77 with a guided-bed jig as described in ASTM Standard Method E 190-64 (Reapproved 1976).

<sup>b</sup>Sheared edges of samples of INCONEL alloy 718 were ground or machined.

## Annealing and Age Hardening

For most applications, INCONEL alloy 718 receives one of the following treatments:

Anneal at 1700°-1850°F, A.C. and age at 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hr, or

Anneal at 1900°-1950°F, A.C. and age at 1400°F/10 hr, F.C. to 1200°F, hold at 1200°F for total aging time of 20 hr.

Rate of furnace cooling during aging is not critical, but a rate of 100°F/hr is sometimes specified. Recommended total times should be observed. Properties of material receiving these heat treatments are shown in the section, Mechanical Properties.

The effect of annealing for 30 minutes at various temperatures on the grain size of sheet is shown in Figure 17.

Aging response of niobium-aluminum-titanium-hardened INCONEL alloy 718 is rather slow in comparison with that of aluminum-titanium-hardened alloys. Thus, in most sizes, the alloy can be heated and cooled through the aging temperature range at normal speeds yet retain softness and ductility.

Figure 18 shows the effect of aging time and temperature on the hardness of annealed sheet. Virtually no hardening occurs during the first 2-3 minutes of exposure. This is ample time to permit air cooling after welding or annealing. An aluminum-titanium-hardened alloy having sufficient hardener content to approach the strength level of INCONEL alloy 718 would develop almost full hardness in the same period of time.

## AVAILABLE PRODUCTS AND SPECIFICATIONS

INCONEL alloy 718 is designated at UNS N07718, UNS N07719, and Werkstoff Nr. 2.4668. It is listed in NACE MR-01-75 for oil and gas service. Alloy 718 is available as pipe, tube, sheet, strip, plate, round bar, flat bar, forging stock, hexagon, wire and extruded section.

**Rod, Bar, Wire and Forging Stock** - ASTM B 637, ASME SB 637, SAE AMS 5662, SAE AMS 5663, SAE AMS 5664, SAE AMS 5832, SAE AMS 5914, SAE AMS 5962, ASME Code Case 1993, ASME Code Case 2206, ASME Code Case 2222, AECMA PrEN 2404, AECMA PrEN 2405, AECMA PrEN 2952, AECMA PrEN 2961, AECMA PrEN 3219, AECMA PrEN 3666, ISO 9723, ISO 9724, ISO 9725, DIN 17752-17754

**Plate, Sheet and Strip** - ASTM B 670, ASTM B 906, ASME SB 670, ASME SB 906, SAE AMS 5596, SAE AMS 5597, SAE AMS 5950, AECMA PrEN 2407, AECMA PrEN 2408, ISO 6208, DIN 17750

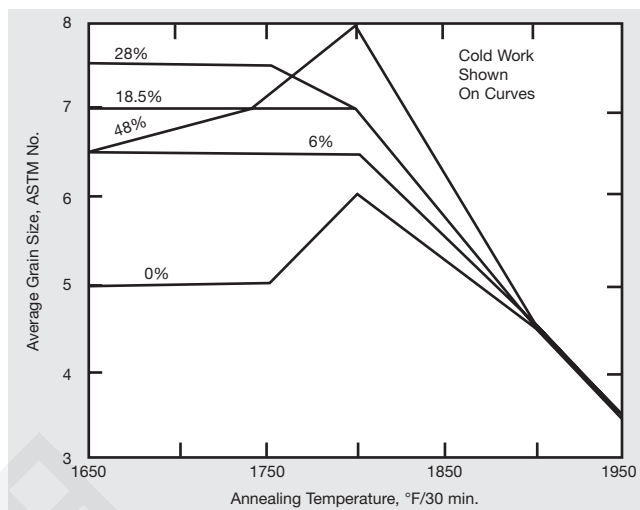


Figure 17. Effect of annealing temperature on grain size of sheet.

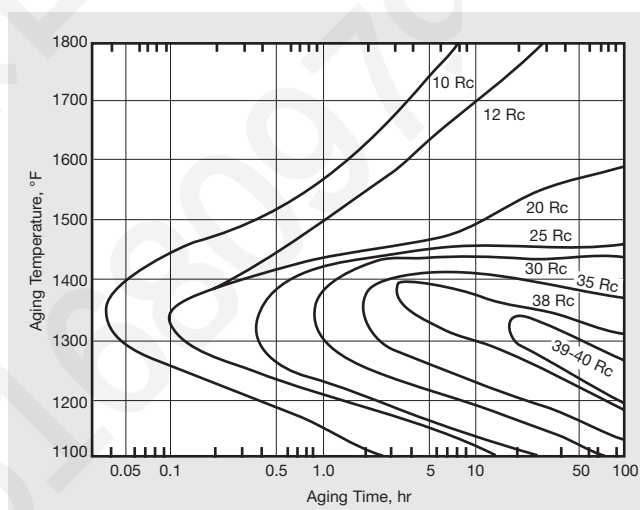


Figure 18. Effect of aging conditions on hardness of annealed sheet. (Initial hardness, as-annealed condition, Rc 4.)

**Pipe and Tube** - SAE AMS 5589, SAE AMS 5590, ASME Code Case N-253, DIN 17751

**Welding Product** - INCONEL Filler Metal 718 - AWS 5.14 / ERNiFeCr-2

**Others** - ASME Code Case N-62, ASME Code Case N-208, DIN 17744