INCOLOY® alloy 925 (UNS N09925) is an age-hardenable nickel-iron-chromium alloy with additions of molybdenum, copper, titanium and aluminum. The alloy's chemical composition, listed in Table 1, is designed to provide a combination of high strength and excellent corrosion resistance. The nickel content is sufficient for protection against chloride-ion stress-corrosion cracking. The nickel, in conjunction with the molybdenum and copper, also gives outstanding resistance to reducing chemicals. The molybdenum aids resistance to pitting and crevice corrosion. The alloy's chromium content provides resistance to oxidizing environments. The titanium and aluminum additions cause a strengthening reaction during heat treatment.

INCOLOY alloy 925 is used in various applications requiring a combination of high strength and corrosion resistance. Because of the alloy's resistance to sulfide stress cracking and stress-corrosion cracking in "sour" ($H_2S$ containing) crude oil and natural gas, it is used for down-hole and surface gas-well components including tubular products, valves, hangers, landing nipples, tool joints and packers. The alloy is also useful for fasteners, marine and pump shafting and high-strength piping systems.

Table 1 - Limiting Chemical Composition (UNS N09925) of INCOLOY alloy 925, %

| | |
|---|---|
| Nickel | 42.0-46.0 |
| Chromium | 19.5-22.5 |
| Iron | 22 min |
| Molybdenum | 2.5-3.5 |
| Copper | 1.5-3.0 |
| Titanium | 1.9-2.4 |
| Aluminum | 0.1-0.5 |
| Manganese | 1.0 max. |
| Silicon | 0.5 max. |
| Niobium | 0.5 max. |
| Carbon | 0.03 max. |
| Sulfur | 0.03 max. |

## Physical Properties

Some physical constants of INCOLOY alloy 925 are given in Table 2. They are room-temperature values except for the melting range. Table 3 provides physical property data for INCOLOY alloy 925 at elevated temperatures. Coefficient of expansion and specific heat data over a range of temperatures are in Table 4. Elevated temperature thermophysical properties are given in Table 5.

Table 2 - Physical Properties of INCOLOY alloy 925

| | |
|---|---|
| Density, lb/in$^3$ | 0.292 |
| g/cm$^3$ | 8.08 |
| Melting Range, F | 2392-2490 |
| C | 1311-1366 |
| Electrical Resistivity, ohm cmil/ft | 701 |
| μΩ m | 1.17 |
| Permeability at 200 oersteds (15.9 kA/m) | 1.001 |

Table 3 - Elevated Temperature Dynamic Young s Modulus and Shear Modulus Values for INCOLOY alloy 925 (hot rolled round, solution-annealed and aged)

| Temperature | | Young s Modulus | | Shear Modulus | | Poisson s Ratio |
|---|---|---|---|---|---|---|
| F | C | $10^3$ ksi | GPa | $10^3$ ksi | GPa | |
| 70 | 21 | 28.9 | 199 | 11.2 | 77 | 0.293 |
| 100 | 38 | 28.8 | 199 | 11.1 | 76 | 0.299 |
| 200 | 93 | 28.3 | 195 | 10.8 | 75 | 0.308 |
| 300 | 149 | 27.8 | 192 | 10.6 | 73 | 0.316 |
| 400 | 204 | 27.3 | 188 | 10.4 | 72 | 0.315 |
| 500 | 260 | 26.8 | 185 | 10.2 | 70 | 0.317 |
| 600 | 316 | 26.3 | 182 | 10.0 | 69 | 0.319 |
| 700 | 371 | 25.9 | 178 | 9.8 | 68 | 0.319 |
| 800 | 427 | 25.4 | 175 | 9.6 | 66 | 0.323 |
| 900 | 482 | 24.9 | 172 | 9.4 | 65 | 0.323 |
| 1000 | 538 | 24.4 | 168 | 9.2 | 64 | 0.324 |
| 1100 | 593 | 23.8 | 164 | 9.0 | 62 | 0.326 |
| 1200 | 649 | 23.2 | 160 | 8.7 | 60 | 0.330 |
| 1300 | 704 | 22.5 | 155 | 8.4 | 58 | 0.334 |
| 1400 | 760 | 21.8 | 150 | 8.2 | 56 | 0.338 |
| 1500 | 816 | 21.0 | 145 | 7.9 | 54 | 0.335 |
| 1600 | 871 | 20.1 | 139 | 7.6 | 52 | 0.330 |
| 1700 | 927 | 19.2 | 132 | 7.2 | 50 | 0.326 |

Table 4 - Thermal Properties of INCOLOY alloy 925

| Temperature | Coefficient of Expansion[a] | Specific Heat |
|---|---|---|
| F | $10^{-6}$ in/in F | Btu/lb F |
| 70 | - | 0.104 |
| 200 | 7.8 | 0.109 |
| 400 | 8.1 | 0.116 |
| 600 | 8.4 | 0.122 |
| 800 | 8.5 | 0.129 |
| 1000 | 8.7 | 0.136 |
| 1200 | 9.0 | 0.143 |
| 1400 | 9.5 | 0.150 |
| 1600 | - | 0.157 |
| Temperature | Coefficient of Expansion[a] | Specific Heat |
| C | µm/m C | J/kg C |
| 20 | - | 435 |
| 100 | 13.2 | 456 |
| 200 | 14.2 | 486 |
| 300 | 14.7 | 507 |
| 400 | 15.0 | 532 |
| 500 | 15.3 | 561 |
| 600 | 15.7 | 586 |
| 700 | 16.3 | 611 |
| 800 | 17.2 | 641 |
| 900 | - | 666 |

[a]Expansion testing in accordance with ASTM E228.
Reference temperature = 77 F (25 C).

Table 5 - Elevated Temperature Thermophysical Properties of INCOLOY alloy 925 (hot rolled round, solution-annealed and aged)

| Temperature | | Thermal Conductivity | |
|---|---|---|---|
| C | F | W/m C | BTU in/ft$^2$ h F |
| 23 | 73 | 12.0 | 83.1 |
| 100 | 212 | 12.9 | 89.2 |
| 200 | 392 | 14.3 | 99.2 |
| 300 | 572 | 15.9 | 110.0 |
| 400 | 752 | 17.4 | 120.9 |
| 500 | 932 | 19.3 | 133.8 |
| 600 | 1112 | 22.2 | 153.7 |
| 700 | 1292 | 24.0 | 166.7 |
| 800 | 1472 | 28.2 | 195.8 |
| 900 | 1652 | 27.7 | 192.3 |
| 1000 | 1832 | 24.6 | 170.7 |
| 1100 | 2012 | 26.0 | 180.2 |
| 1150 | 2102 | 26.9 | 186.8 |

## Mechanical Properties

Mechanical properties at room temperature of solution-annealed and solution-annealed plus aged products are given in Table 6. Mechanical properties limits for specification purposes are shown in Table 7 (Special Metals Corporation internal specification HA 46).

As shown in Figure 1, INCOLOY alloy 925 retains a substantial portion of its strength at temperatures up to about 1200°F (650°C).

Figure 2 shows rotating beam fatigue data for INCOLOY alloy 925 and MONEL alloy K-500.

Figure 3 shows mean axial stress vs. cycles of fatigue in the 1365°F (740°C) dual aged condition. The compression test result, at room temperature, for a solution-annealed and aged bar was 122.7 ksi (846 MPa) and the yield strength tension test result was 123.5 ksi (851 MPa)

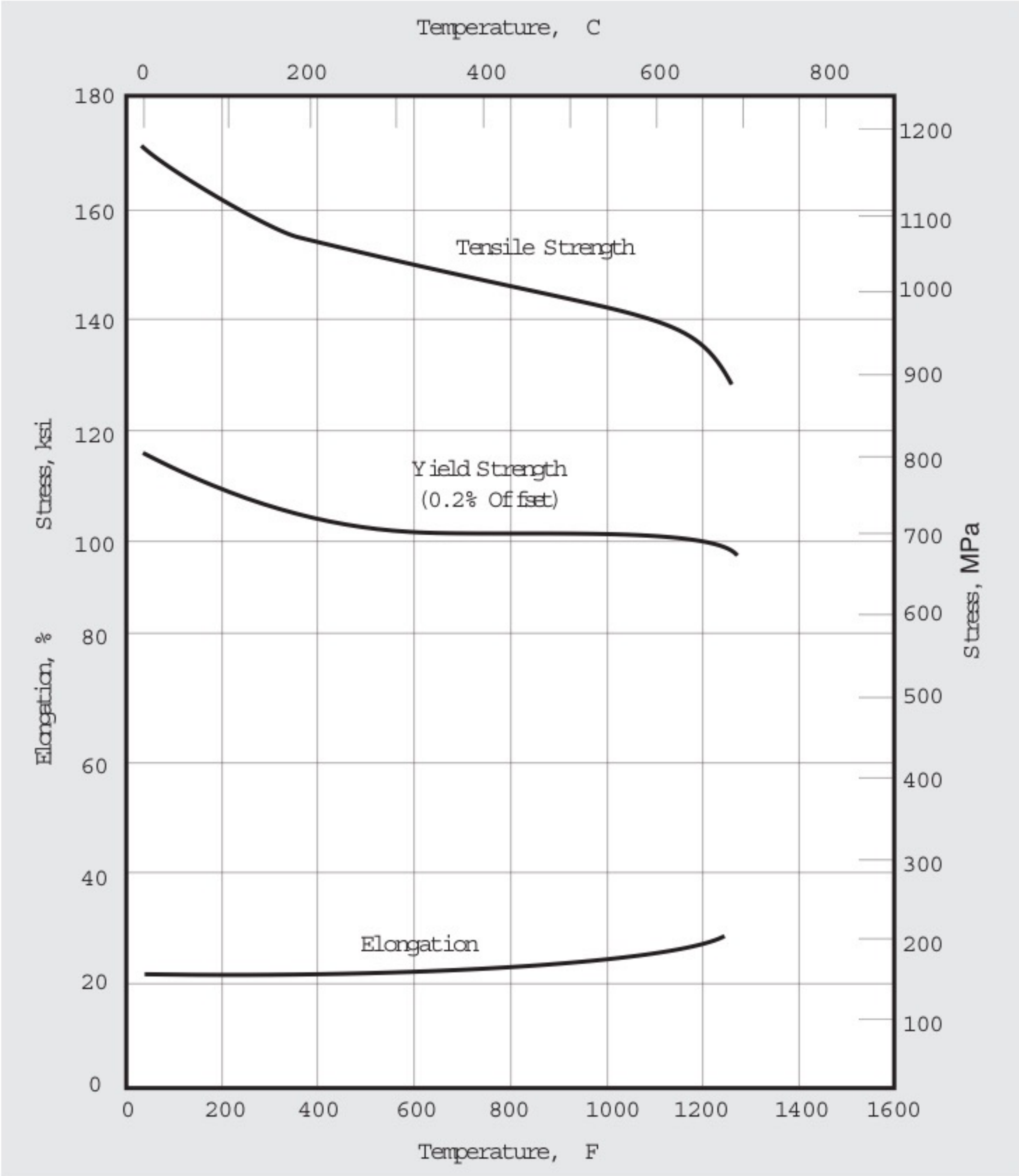


Figure 1. Tensile properties at high temperatures of solution-annealed and aged INCOLOY alloy 925.

Table 6 - Tensile Properties of INCOLOY alloy 925

| Form/Condition | Tensile Strength | | Yield Strength (0.2% Offset) | | Elongation | Hardness* |
|---|---|---|---|---|---|---|
| | ksi | MPa | ksi | MPa | % | Rockwell |
| Round/Solution-Annealed | 99.3 | 685 | 39.3 | 271 | 56 | 76 B |
| Round/Solution-Annealed and Aged | 167.3 | 1154 | 120.6 | 832 | 27 | 32 C |
| Cold Drawn Tubing/Solution-Annealed and Aged | 172.5 | 1189 | 120.4 | 830 | 27 | 35 C |

*All values meet the requirements of NACE Standard MR0175.

Table 7 - Mechanical Property Limits for INCOLOY alloy 925, Solution-Annealed and Aged Material (SMC internal specification HA 46)

| Condition | Diameter | | Tensile Strength minimum | | Yield Strength (0.2% offset) minimum | | Elongation in 2 in (50.8 mm) or 4D min. | Reduction of Area minimum | Impact Strength[1] min. average | | Hardness[2] Rockwell C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | in | mm | ksi | MPa | ksi | MPa | % | % | ft lbf | kgf m | min. | max. |
| Cold Worked | 5/8 to 3.0 | 15.9 to 76.2 | 140 | 965 | 105 | 724 | 18 | 25 | 35 | 4.85 | 26 | 38 |
| Hot Worked | 1 to 10 | 25.4 to 254 | 140 | 965 | 110 | 758 | 18 | 25 | 35 | 4.85 | 26 | 38 |

[1]Charpy V-Notch - Impact tests performed at -75 F (-60 C), in accordance with ASTM E23. Capability of meeting the strengths shown at room temperature is guaranteed.

[2]Hardness testing in accordance with ASTM E 18.

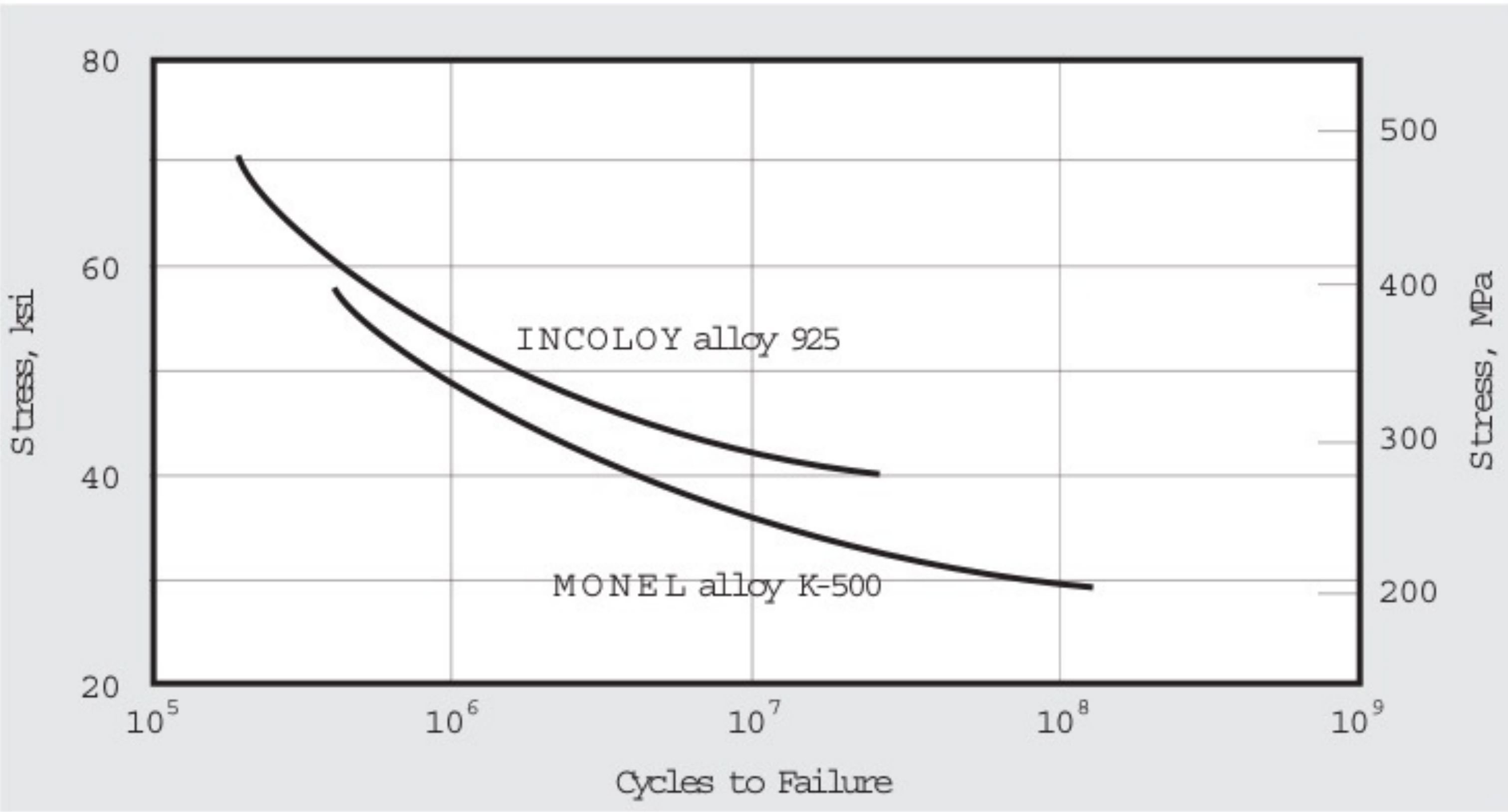


Figure 2. Rotating beam fatigue data for INCOLOY alloy 925 and MONEL alloy K-500.

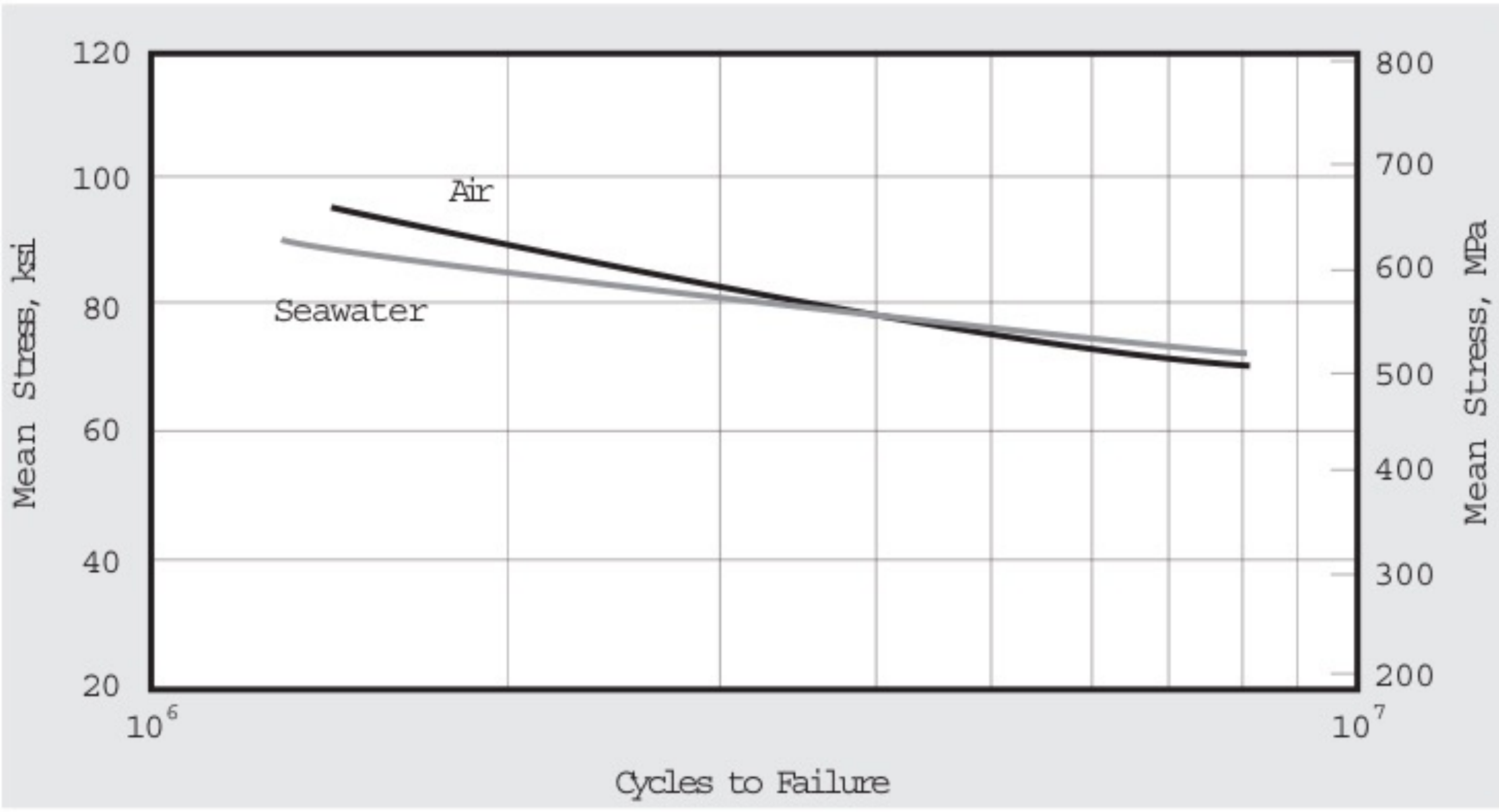


Figure 3. Mean axial stress vs. cycles of fatigue for INCOLOY alloy 925 in the 1365 F (740 C) dual aged condition. Tension-tension test.

## Metallurgy

INCOLOY alloy 925 is an austenitic nickel-iron-chromium alloy made precipitation hardenable by additions of titanium and aluminum. The precipitation-hardening (age-hardening) heat treatment causes precipitation of gamma prime phase, $Ni_3$ (Al, Ti). The phase greatly increases both the hardness and strength of the alloy.

Exposure to elevated temperatures also causes formation of other phases, including eta and sigma. Figure 4 is a time-temperature-transformation diagram, and Figure 5 shows effects of the phases on impact strength of the solution-annealed plus aged alloy.

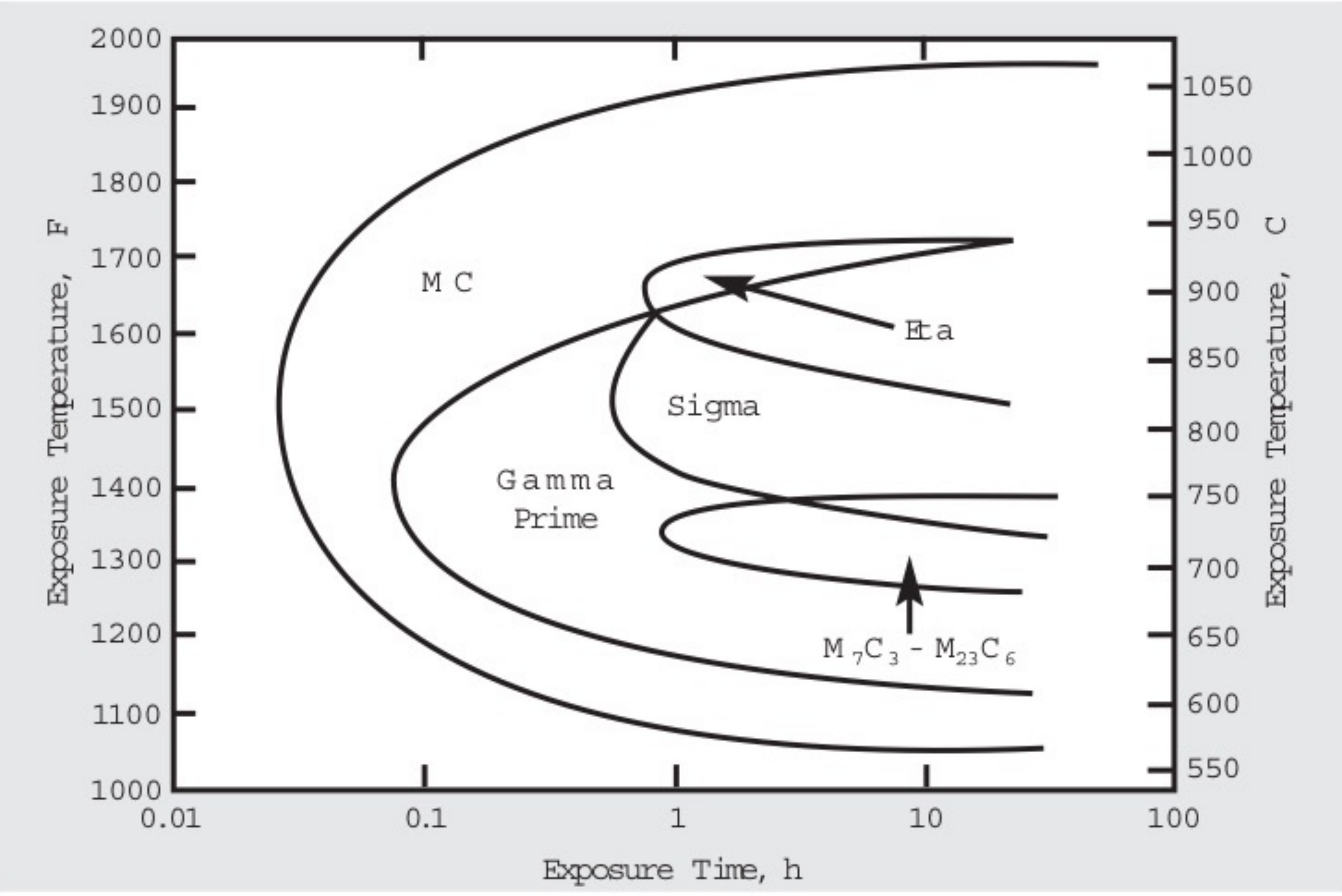


Figure 4. Time-temperature-transformation diagram for initially solution-annealed INCOLOY alloy 925 material.

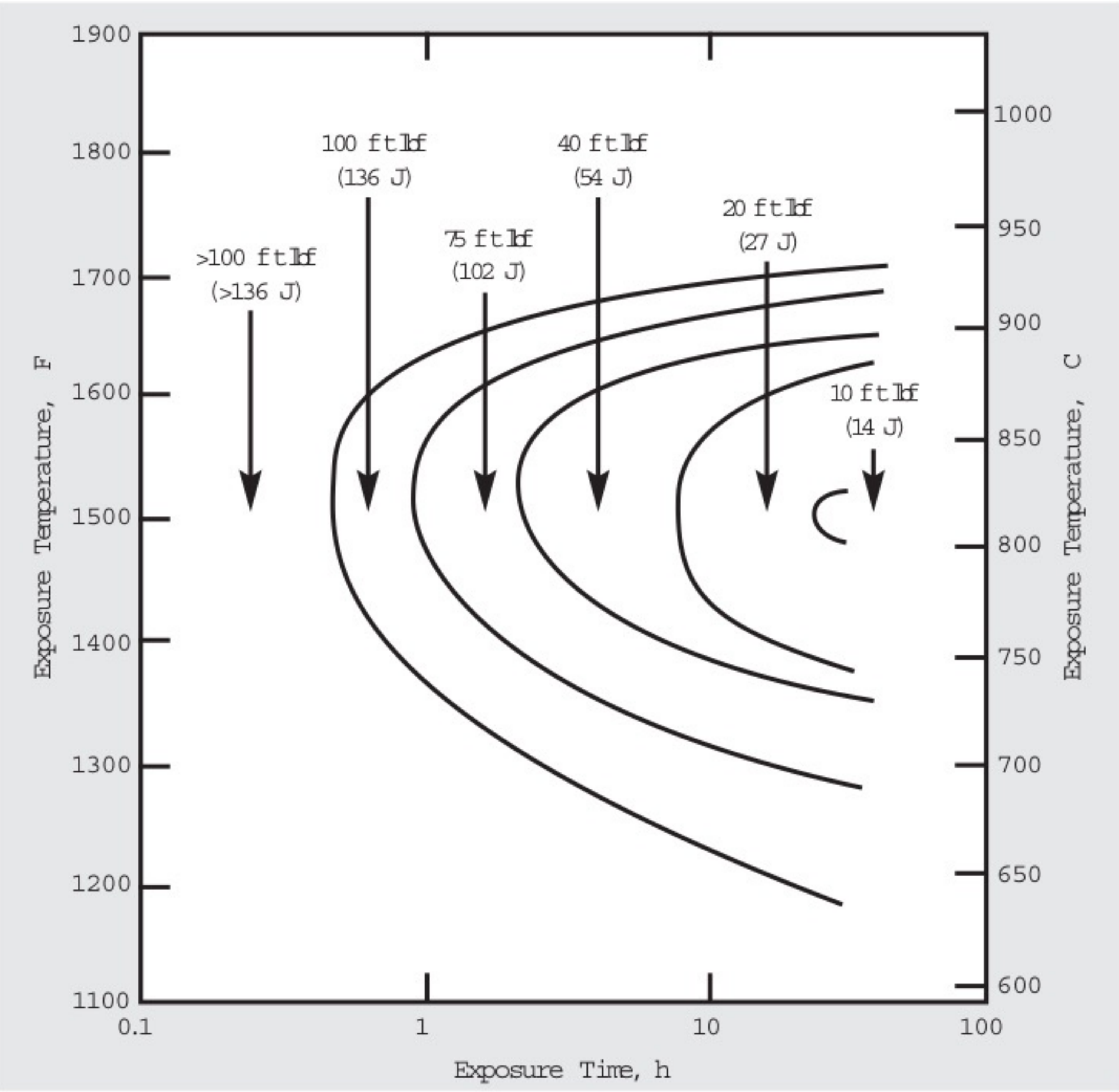


Figure 5. Effect of high-temperature exposure on impact strength of solution-annealed INCOLOY alloy 925 material. Base impact strength was 236 ft lbf (320 J).

## Corrosion Resistance

INCOLOY alloy 925 has a high level of corrosion resistance. In both reducing and oxidizing environments, the alloy resists general corrosion, pitting, crevice corrosion, intergranular corrosion and stress-corrosion cracking. Some environments in which INCOLOY alloy 925 is particularly useful are "sour" ($H_2S$ containing) crude oil and natural gas, sulfuric acid, phosphoric acid, and seawater.

The performance of INCOLOY alloy 925 under conditions representing sour gas wells is indicated in Figure 6 and Tables 8, 9 and 10. Figure 6 shows resistance to stress-corrosion cracking in a sour environment at high pressure and temperature. Table 8 shows that the alloy resists sulfide stress cracking, a form of hydrogen embrittlement. The tests involve exposure of stressed C-ring specimens (made from a portion of tubing cross section) to a solution containing hydrogen sulfide, sodium chloride and acetic acid.

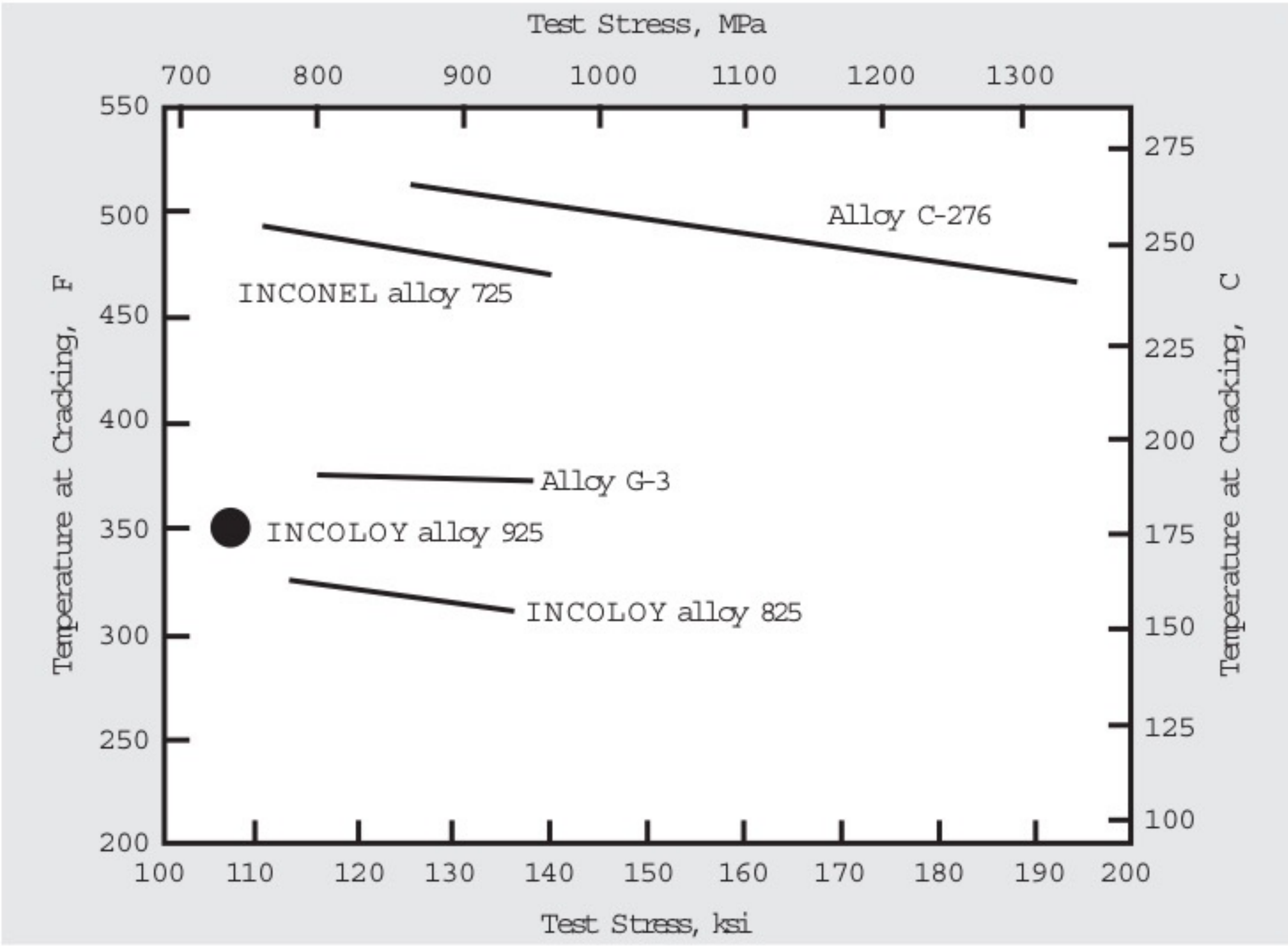


Figure 6. Results of autoclave C-ring tests in a solution of distilled water containing 25% sodium chloride, 0.5% acetic acid and 1 g/l sulfur with pressure of 120 psi (827 kPa) hydrogen sulfide. Test stresses were 100% of yield strength (0.2% offset).