ALLOY K500

Alloy K500 (UNS N05500/ W.Nr. 2.4375) is a nickel-copper alloy which combines the excellent corrosion resistance of Alloy 400 with the added advantages of greater strength and hardness. The increased properties are obtained by adding aluminium and titanium to the nickel-copper base, and by heating under controlled conditions so that submicroscopic particles of Ni3 (Ti, Al) are precipitated throughout the matrix. The thermal processing used to effect precipitation is commonly called age hardening or aging. The composition of the alloy is given in Table 1. Typical applications for Alloy K500 products are chains and cables, fasteners and springs for marine service; pump and valve components for chemical processing; doctor blades and scrapers for pulp processing in paper production; oil well drill collars and instruments, pump shafts and impellers, non-magnetic housings, safety lifts and valves for oil and gas production; and sensors and other electronic components.

PHYSICAL CONSTANTS AN THERMAL PROPERTIES

The nominal physical constants of Alloy K500 are shown in Table 2. Thermal and electrical properties appear in Table 3, and magnetic characteristics in Table 4. Effect of temperature on modulus of elasticity is shown in Figure 1.
A useful characteristic of the alloy is that it is virtually nonmagnetic, even at quite low temperatures (see Table 4). It is possible, however, to develop a magnetic layer on the surface of the material during processing. Aluminium and copper may be selectively oxidized during heating, leaving a magnetic nickel-rich film on the outside of the piece. The effect is particularly noticeable on thin wire or strip where there is a high ratio of surface to weight. The magnetic film can be removed by pickling or bright dipping in acid, and the nonmagnetic properties of the material will be restored. The combination of low magnetic permeability, high strength and good corrosion resistance has been used to advantage in a number of applications, notably oil-well surveying equipment and electronic components. Emittance and solar absorptance of Alloy K500 are given in Figures 2 and 3. Alloy K500 has been found to have exceptionally good dimensional stability, both in long-time exposure tests and in cyclic tests. Results are shown in Table 5. This property of the alloy has led to its use in highprecision devices, such as gyros. Age hardening causes an initial volume contraction.

MECHANICAL PROPERTIES

Tensile Properties and Hardness

The nominal range of room-temperature tensile properties and hardness are shown in Table 6. Approximate relationships between tensile properties and hardness for rods and forgings appear in Figures 4 and 5, and similar relationships for sheet and strip are shown in Figure 6. Notch properties are compared with those of smooth specimens in Table 7. Short-time, high-temperature tensile properties of Alloy K500 rod in various conditions are shown in Figures 7-9. Testing speeds for hot-rolled bar were 0.016 inch per minute through the yield strength and 0.026 inch per minute from there to fracture. The cold-drawn specimens were tested at 0.00075 inch per minute through the yield strength, then 0.075 inch per minute. Effect of temperature on hardness of hot-finished and hot-finished, aged material is shown in Table 8. The low-temperature properties of Alloy K500 are outstanding. Tensile and yield strengths increase with decrease in temperature while ductility and toughness are virtually unimpaired. No ductile-to-brittle transformation occurs even at temperatures as low as that of liquid hydrogen. Thus the alloy is suitable for many cryogenic applications.

Properties of Alloy K500 base metal and welded sheet at temperatures down to -423°F, as reported by the National Aeronautics and Space Administration, are shown in Figures 10-12. Welds can be produced with the strength of age hardened base metal with no serious loss in ductility if aging treatments are performed after welding annealed material. Welding of age hardened material should be avoided because of greatly reduced ductility. Tensile tests on sheet and autogenous welds by Watson *et al* are shown in Table 9.

Torsional Properties
Table 10 contains the results of torsional tests made on Alloy K500 bar in various tempers. These tests were made using reduced-diameter specimens, which were 1-in.-diameter rods turned down to 0.750-in. diameter in the gage section. For making the computations of yield strength and Johnson's apparent elastic limit, it was assumed that the shear stress varied directly from zero at the center of the test piece to a maximum at the outer surface. More data comparing tensile and torsional properties are shown in Table 11.

Shear Properties
Shear strength of Alloy K500 is shown in Table 12. Tests were made in double shear on duplicate 0.050 x 0.250-in. specimens with the cutters set to 0.005-in. clearance. This type of test simulates the service requirements of pins used in shackles or clevises.
Table 13 lists the shear strength of rivet wire. Properties were determined from the load required to produce double shearing of a 0.118 x 1.00-in. wide wire specimen in a tongue and groove jig with 0.002-in. clearance. These data show that rivets can be made to develop exceptionally high strength by partial or full heat treatment prior to driving. The ratio of shear strength to ultimate tensile strength decreases very slightly with increasing hardness, indicating that the longer aging periods increase tensile strength more rapidly than shear strength. Based on these tests, aging for 4 hr at 1080° to 1100°F followed by air cooling is recommended for cold-headed rivets; this treatment is adequate to develop a shear strength of about 85 ksi in the shank.
Bearing strength data are given in Table 14. These were determined with 0.062x1.25x2.5-in. material having a 3/16-in. hole drilled 3/8-in. from the edge. The pin fitted closely into the hole. The maximum load for tearing out of the hole and the load required for a permanent enlargement of the hole diameter by 2% were determined and calculated as ultimate and yield strengths, respectively, in bearing.

Compressive Properties
The results of compressive tests on Alloy K500, made on triplicate samples from the same melt, are given in Table 15.

Impact Strength
Impact strength at room temperature is shown in Table 16 for typical specimens of various tempers. Charpy V-notch impact strength of annealed and aged hot-rolled and cold-drawn rod is in Tables 17 and 18. The effect of low temperature on bending impact and tension impact strength, as determined by the Naval Engineering Experiment Station is shown in Table 19; all samples showed ductile fracture. Charpy impact test results down to -320°F may be found in Table 20.

Fatigue Strength
Fatigue strength (108 cycles) at room temperature of various tempers of Alloy K500 are given in Table 21. The data on rod were developed on high-speed (10,000-rpm) rotating-beam machines using polished specimens and represent average values of a number of tests. Data on strip were reported by Greenall and Gohn. Specimens were subjected to alternate back-and-forth bending as a flat spring; specimens were cut with the longitudinal direction parallel to the direction of rolling. Fatigue strength of wire is shown in Figure 13.
Table 22 shows fatigue of aged Alloy K500 at 1000°F. At low temperatures, fatigue strength increases (see Table 23). The material used in these tests was 0.051-in. sheet, cold-rolled half-hard and aged, with a tensile strength of 182.0 ksi. Tests were in flexure (R = -1) at 1800 cpm except those at -423°F, which were at 3450 cpm.
The effect of surface finish on fatigue strength has been studied. Table 24 shows the detrimental effect of an oxidized surface. These tests indicate that it is advisable to use polished surfaces for parts subject to cyclical stresses. The oxide surface was produced by age hardening in air.

Low-Cycle Fatigue
Cyclic strain fatigue of Alloy K500 is shown in Figure 14. The curve represents a best fit for data on material in different initial conditions but having received the same age hardening treatment (1080°-1100°F/16 hr, F.C. 15°-25°F/hr to 900°F). Also, since data from both axial and completely reversed bending were used to derive the curve, it would be conservative when pure bending is being considered. In Figure 14, S_a, stress amplitude, was calculated from

$$S_a = \frac{\varepsilon_{\tau o \tau}}{2} \times E$$

where $\varepsilon_{\tau o \tau}$ = total strain range applied to the specimen after shakedown, and
E = Young's modulus of the specimen.

Spring Properties
Alloy K500 is useful for corrosion-resistant springs at temperature up to 500°F. Typical usage stresses are shown in Table 25. The recommended aging treatment after cold coiling is 1000°F/10 hr; or 980° to 1000°F/6 hr followed by cooling to 900°F at a rate of 15° to 25°F/hr. Some effects of heat treatment on properties of springs are shown in Table 26. The springs were coiled on standard automatic equipment, cold-pressed to solid height several times, and heat-treated. Relaxation of Alloy K500 springs at 500°F is shown in Figure 15. Using a criterion of 5 to 6% relaxation in 7 days, these data indicate a maximum useful temperature of 500°F.

Creep and Rupture Properties
Typical creep and rupture properties of aged Alloy K500 are shown in Figures 16 and 17.

Bolting Applications
Alloy K500 is approved by the ASME Boiler and Pressure Vessel Code as an acceptable material for use as bolting. Allowable stresses for Section VIII, Division 1 usage up to 500°F are presented in ASME Code Case 1192, latest revision.

MICROSTRUCTURE

Alloy K500 is produced by adding aluminium and titanium to the basic nickel-copper composition. Suitable thermal treatments produce a submicroscopic gamma prime precipitate throughout the matrix. Typical microstructure of hot-rolled, as-rolled Alloy K500 is shown in Figure 18.

CORROSION RESISTANCE

The corrosion resistance of Alloy K500 is substantially equivalent to that of Alloy 400 except that, when in the age hardened condition, Alloy K500 has a greater tendency toward stress-corrosion cracking in some environments. Alloy K500 has been found to be resistant to a sour-gas environment. After 6 days of continuous immersion in saturated (3500 ppm) hydrogen sulfide solutions at acidic and basic pHs (ranging from 1.0 to 11.0), U-bend specimens of age hardened sheet showed no cracking. Hardness of the specimens ranged from 28 to 40 Rc. The combination of very low corrosion rates in highvelocity sea water and high strength make Alloy K500 particularly suitable for shafts of centrifugal pumps in marine service. In stagnant or slow-moving sea water, fouling may occur followed by pitting, but this pitting slows down after a fairly rapid initial attack.

WORKING INSTRUCTIONS

HEATING AND PICKLING

Thermal Treatments

Two types of annealing procedures are performed on Alloy K500: solution annealing and process annealing. The treatments are different in both their purpose and procedure.

Solution Annealing - Alloy K500 is hardened by the formation of submicroscopic particles of a secondary phase, Ni3(Ti,Al). Formation of the particles takes place as a solid state reaction during an age hardening (or precipitation hardening) heat treatment. Prior to the aging treatment, the alloy component should be solution-annealed to dissolve any phases that may have formed in the alloy during previous processing. Solution annealing is normally performed by heating hot-finished products to 1800°F and cold-worked products to 1900°F. To avoid excessive grain growth, time at temperature should be kept to a minimum (normally, less than 30 minutes). Heating (ramp) and cooling times must be kept to a minimum to avoid precipitation of detrimental phases. Cooling after solution annealing is normally accomplished by quenching in water.

Process Annealing - During mechanical processing in production and subsequent forming of Alloy K500 products, intermediate process annealing may be required to soften the product. Such anneals recrystallize the structure and are typically conducted at temperatures between 1400°-1600 °F. While higher temperatures will anneal the product, intermediate process annealing temperatures are limited to avoid excessive grain growth. Time at temperature must be limited to avoid the formation of secondary phases which can compromise the hardness of the aged Alloy K500 product. Holding for one hour after the part has reached the set temperature and equalized is normally sufficient to soften the alloy product during processing. The user is cautioned that exposure at temperature for times greater than 1.5 hours is not recommended. Excessive exposure can result in the formation of titanium carbide (TiC). This compound is stable at the aging temperatures used to harden Alloy K500 such that the titanium cannot participate in the hardening reaction, the formation of $Ni_3(Ti,Al)$. Thus, the strength and hardness can be compromised. Obviously, it is best to avoid the formation of the titanium carbide phase. If, however, the phase is formed as a result of improper processing, solution annealing at 2050°F for 30 minutes is required to dissolve the particles.

It should be noted that this heat treatment will result in a large grain size which can somewhat compromise formability. However, the high-temperature solution treatment is necessary if the component is to develop full hardness and strength during the aging treatment.
The Federal Standard for Alloy K500, QQ-N-286, addresses only solution annealing. In-process annealing is left to the discretion of the heat treater. The stated solution annealing temperature range in Revision F is 1600° to 1900°F. Thus, if an Alloy K500 component must be solution annealed at 2050°F because of the presence of titanium carbide, it must subsequently be reduced in section thickness before final heat treatment (solution annealing + age hardening) to comply with the requirements of the specification. Revision G has amended the solution annealing requirement to a minimum annealing temperature of 1600°F. Thus, material solution annealed at 2050°F can be aged without further reduction in section thickness and is acceptable if it meets the other requirements of the specification (mechanical properties, etc.).
For optimum aging response and maximum softness, it is important to obtain an effective water quench from the heating temperature without delay. A delay in quenching or a slow quench can result in partial precipitation of the age hardening phase and subsequent impairment of the aging response. Addition of about 2% by volume of alcohol to the water will minimize oxidation and facilitate pickling. The effect of water quenching from various temperatures is shown in Figure 19.

The following age hardening procedures are recommended for achievement of maximum properties.

1. Soft material (140-180 Brinell, 75-90 Rockwell B).

Hold for 16 hr at 1100° to 1125°F followed by furnace cooling at a rate of 15° to 25°F per hr to 900°F. Cooling from 900°F to room temperature may be carried out by furnace or air cooling, or by quenching, without regard for cooling rate. This procedure is suitable for as-forged and quenched or annealed forgings, for annealed or hot-rolled rods and large cold drawn rods (over 1½ in. diameter) and for soft-temper wire and strip.

2. Moderately cold-worked material (175-250 Brinell, 8-25 Rockwell C).

Hold for 8 hr or longer at 1100° to 1125°F, followed by cooling to 900°F at a rate not to exceed 15° to 25°F per hr. Higher hardnesses can be obtained by holding for as long as 16 hr at temperature, particularly if the material has been coldworked only slightly. As a general rule, material with an initial hardness of 175-200 Brinell should be held the full 16 hr. Material close to the top figure of 250 Brinell (25 Rockwell C) should attain full hardness in 8 hr. These procedures are applicable to colddrawn rods, halfhard strip, cold-upset pieces and intermediate temper wire.

3. Fully cold-worked material (260-325 Brinell, 25-35 Rockwell C).

Hold for 6 hr or longer at 980° to 1000°F followed by cooling to 900°F at a rate not exceeding 15° to 25°F per hr. In some instances slightly higher hardnesses may be obtained (particularly with material near the lower end of the hardness range) by holding 8 to 10 hr at temperature. This procedure is suitable for spring-temper strip, spring wire or heavily cold-worked pieces such as small, cold-formed balls.

NOTE: Cooling may be done in steps of 100°F, holding the furnace 4 to 6 hr at each step. For example, procedure 1 could be 16 hr at 1100°F + 4 to 6 hr at 1000°F + 4 to 6 hr at 900°F. Procedures described under 1, 2, and 3, however, will usually give higher properties. Effects of furnace cooling and step cooling on yield strength of cold-drawn rod are compared in Table 27. In some instances it may be desired to decrease heat treating time, either for cost saving or for obtaining intermediate properties. It is difficult to make specific recommendations which would cover the full range of possibilities. The best procedure is to make pilot tests on specimens which duplicate the cross section of the material to be hardened. Table 28, showing the effect of short-time aging at 1100° and 1000°F, can be used as a guide. More information is given later under "Cold Forming".
Material which has been heated for any appreciable length of time in the temperature range 1100° to 1400°F will be overaged to an extent dependent on time and temperature of exposure. Overaged material will have lower mechanical properties than properly aged metal, and the properties cannot be raised by subsequent aging treatments. In order to strengthen overaged material, it must be solution-annealed (1800°-1900°F) to re-dissolve the age hardening constituents, and then re-aged. All benefits of cold work are lost in annealing. The highest strength obtainable is that corresponding to the annealed and aged condition. Material that has been age hardened to produce maximum hardness will not show an appreciable change in properties if again heated to or held at any temperature up to that at which the original heat treatment was carried out. There may be a small increase in properties if the rate of cooling in the original heat treatment was too rapid between 1050° and 800°F. If the hardened material is subsequently heated above 1100°F and then cooled, there will be a decrease in properties. Hardened Alloy K500 has been subjected to long continued heating at 800°F. A further slow aging occurred during the first month of exposure, but continued heating caused no further significant change in properties. Average data for three typical heats are shown in Table 29.

Hot Forming

Proper temperature during deformation is the most important factor in achievement of hot malleability. Maximum recommended heating temperature for hotworking Alloy K500 is 2100°F. Metal should be charged into a hot furnace and withdrawn when uniformly heated. Prolonged soaking at this temperature is harmful. If a delay occurs, such that the material should be subjected to prolonged soaking, the temperature should be reduced to or held at 1900°F until shortly before ready to work, then brought to 2100°F. When the piece is uniformly heated, it should be withdrawn. In the event of long delay, the work should be removed from the furnace and water-quenched. The hot-working temperature range is 1600° to 2100°F. Heavy work is best done between 1900° and 2100°F; working below 1600°F is not recommended. To produce finer grain in forgings, the final reheat temperature should be 2000°F and at least 30% reduction of area should be taken in the last forging operation. When hot working has been completed, or when it is necessary for Alloy K500 to cool before further hot working, it should not be allowed to cool in air but should be quenched from a temperature of 1450°F or higher. If the piece is allowed to cool slowly it will self-heat-treat (age harden) to some extent, and stress will be set up that may lead to thermal splitting or tearing during subsequent reheating. In addition, quenched material has better response to age hardening, since more of the age hardening constituent is retained in solution.
The surface of the material will be oxidized to a lesser degree and will be easier to pickle if it is quenched in water containing about 2% by volume of alcohol.

Cold Forming
In the annealed condition, Alloy K500 can be cold-worked by standard procedures. Although the alloy requires considerable power to form, it has excellent ductility. Its increase in hardness with increasing cold work, in comparison with other materials, is shown in Figure 20. Figure 21 shows the effect of cold work and cold work plus age hardening on tensile strength and hardness.

Pickling
Pickling is a standard method for producing a clean surface on Alloy K500.

Fabricating
Alloy K500 is readily fabricated by standard commercial procedures.

Machining
Heavy machining of Alloy K500 is best accomplished when the material is in the annealed condition or hot-worked and quenched condition. Age hardened material, however, can be finish-machined to close tolerances and fine finishes. The recommended practice, therefore, is to machine slightly oversize, age harden, then finish to size. During aging, a slight permanent contraction (about 0.0002 in./in.) takes place, but little warpage occurs because of the low temperatures and slow cooling rates involved.

Joining
Alloy K500 products may be joined by conventional processes and procedures.

Table 1 - Limiting Chemical Composition, %, of Alloy K 500

Nickel (plus Cobalt)	63.0 min.
Carbon	0.25 max.
Manganese	1.5 max.
Iron	2.0 max.
Sulfur	0.01 max.
Silicon	0.5 max.
Copper	27.0 - 33.0
Aluminum	2.30 - 3.15
Titanium	0.35 - 0.85

Table 2 - Physical Constants of Alloy K 500

Density, g/cm^3	8.44
$lb/in.^3$	0.305
Melting Range, °F	2400-2460
°C	1315-1350
Modulus of Elasticity, 10^3 ksi	
Tension	26.0
Torsion	9.5
Poisson's Ratio (aged material at room temperature)	0.32

Table 3 - Thermal Properties of Alloy K 500

Temperature		Mean Linear Expansion[a]		Thermal Conductivity[b]		Specific Heat[b]		Electrical Resistivity[c]	
°F	°C	in/in/°F x 10^{-6}	µm/m•°C	Btu-in/h/ft^2/°F	W/m•°C	Btu/lb/°F	J/kg•°C	ohm-circ mil/ft	µΩ•m
-320	-200	6.2	11.2	–	–	–	–	330.8[d]	0.550
-250	-157	6.5	11.7	86	12.3	0.071	297.3	–	–
-200	-130	6.8	12.2	92	13.1	0.077	322.4	–	–
-100	-70	7.2	13.0	103	14.7	0.087	364.3	–	–
70	21	–	–	121	17.2	0.100	418.7	370	0.615
200	100	7.6	13.7	136	19.4	0.107	448.0	372	0.618
400	200	8.1	14.6	156	22.2	0.114	477.3	378	0.628
600	300	8.3	14.9	178	25.4	0.117	489.9	385	0.640
800	400	8.5	15.3	198	28.2	0.120	502.4	390	0.648
1000	500	8.7	15.7	220	31.4	0.125	523.4	393	0.653
1200	600	9.1	16.4	240	34.2	0.132	552.7	396	0.658
1400	700	9.3	16.7	262	37.3	0.141	590.3	400	0.665
1600	800	9.6	17.3	282	40.2	0.157	657.3	408	0.678
1800	900	–	–	302[e]	43.1	0.186[e]	778.7	418	0.695

[a]Between 70°F (21°C) and temperature shown. Age-hardened material.
[b]Material was in the annealed condition prior to test.
[c]Electrical resistivity is markedly influenced by thermal history because of the age-hardening characteristics of the alloy. The data shown represent values measured on decreasing temperature on material in an equivalent to annealed condition with a small amount of age hardening.
[d]Resistivity of sample from this test tested at room temperature: 355.5 ohm/circ mil/ft.
[e]Extrapolated.

Table 4 - Magnetic Characteristics of Alloy K 500

Condition	Tensile Strength, ksi	Permea-bility[a]	Curie Temperature, °F for Permeability of			
			1.01	1.02	1.05	1.1
Annealed, Quenched	92.5	1.0011	-210	-210	–	–
Annealed, Age-Hardened	151.0	1.0018	-153	-178	-202	-210
Cold-Drawn 20%	137.0	1.0011	-210	–	–	–
Cold-Drawn 20% and Age-Hardened	186.5	1.0019	-130	-150	-182	-210
Cold-Drawn 50%	151.3	1.0010	-210	–	–	–
Cold-Drawn 50% and Age-Hardened	198.0	1.0019	-130	-150	-182	-210

[a]Room temperature, 200 oersted.

Table 5 - Dimensional Stability of Alloy K 500

Condition	Length Change, microinch/inch					Cycled[a]
	Aged at 70°F			Aged at 160°F		
	1 Month	3 Months	12 Months	1 Month	3 Months	
Cold-Drawn	0	-5	-5	–	–	–
Cold-Drawn, Aged[b]	-5	-5	–	0	-5	0

[a]Cycled 10 times between 70°F and -95°F.

[b]1000°F/9 hr, F.C. to 900°F, A.C.

Table 6 - Nominal Mechanical Property Ranges[a] of Alloy K 500

Form and Condition	Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Hardness	
	ksi	MPa	ksi	MPa		Brinell (3000-kg)	Rockwell
Rod and Bar							
Hot-Finished	90-155	621-1069	40-110	276-758	45-20	140-315	75B-35C
Hot-Finished, Aged[b]	140-190	965-1310	100-150	690-1034	30-20	265-346	27-38C
Hot-Finished, Annealed	90-110	621-758	40-60	276-414	45-25	140-185	75-90B
Hot-Finished, Annealed and Aged[b]	130-165	896-1138	85-120	586-827	35-20	250-315	24-35C
Cold-Drawn, As-Drawn	100-140	690-965	70-125	483-862	35-13	175-260	88B-26C
Cold-Drawn, Aged[b]	135-185	931-1276	95-160	655-1103	30-15	255-370	25-41C
Cold-Drawn, Annealed	90-110	621-758	40-60	276-414	50-25	140-185	75-90B
Cold-Drawn, Annealed and Aged[b]	130-190	896-1310	85-120	586-827	30-20	250-315	24-35C
Sheet, Cold-Rolled, Annealed	90-105	621-724	40-65	276-448	45-25	-	85B max.
Strip, Cold-Rolled							
Annealed	90-105	621-724	40-65	276-448	45-25	-	85B max.
Annealed and Aged[b]	130-170	896-1172	90-120	621-827	25-15	-	24C min.
Spring Temper	145-165	1000-1138	130-160	896-1103	8-3	-	25C min.
Spring Temper, Aged[b]	170-220	1172-1517	130-195	896-1345	10-5	-	34C min.
Tube and Pipe, Seamless							
Cold-Drawn, Annealed	90-110	621-758	40-65	276-448	45-25	-	90B max.
Cold-Drawn, Annealed and Aged[b]	130-180	896-1241	85-120	586-827	30-15	-	24-36C
Cold-Drawn, As-Drawn	110-160	758-1103	85-140	586-965	15-2	-	95B-32C
Cold-Drawn, As-Drawn, Aged[b]	140-220	965-1517	100-200	690-1379	25-3	-	27-40C
Plate							
Hot-Finished	90-135	621-931	40-110	276-758	45-20	140-260	75B-26C
Hot-Finished, Aged[b]	140-180	965-1241	100-135	690-981	30-20	265-337	27-37C
Wire, Cold Drawn[c]							
Annealed	80-110	552-758	35-65	241-448	40-20	-	-
Annealed and Aged[b]	120-150	827-1034	90-110	621-758	30-15	-	-
Spring Temper	145-190	1000-1310	130-180	896-1241	5-2	-	-
Spring Temper, Aged[b]	160-200	1103-1379	140-190	965-1310	8-3	-	-

[a]The ranges shown are composites for various product sizes and therefore are not suitable for specification purposes.
[b]Nominal properties for material age-hardened to produce maximum properties.
[c]Properties shown are for sizes 0.0625 - 0.250-in. diameter. Properties for other sizes may vary from these.

Table 7 - Room-Temperature Smooth and Notch Tensile Properties of Alloy K 500

Sample	Temper	Yield Strength (0.2% Offset), ksi	Notched Tensile Strength, ksi	Tensile Strength, ksi	NT/TS[a]	Elongation, %	Reduction of Area, %	Hardness, R_C
Rod (2 5/8-in. Dia.)	Cold-drawn, Annealed & Aged	97.5	185.5	152.5	1.22	25	43.0	28
Rod (3 5/8-in. Dia.)	Hot-Rolled & Aged	119.0	212.0	165.0	1.28	22	45.2	32
Rod (3-in. Dia.)	Cold-Drawn & Aged	122.0	215.0	161.0	1.34	22	43.2	29
Threaded cap screw	Cold-Drawn & Aged	125.5	205.0	169.0	1.21	18	28.5	31
Threaded Stud	Cold-Drawn & Aged	128.0	232.0	165.0	1.41	20	42.0	33
		129.5	237.5	165.5	1.43	20	41.5	32

[a]Ratio of notch tensile strength to smooth tensile strength.

Table 8 - Hot Hardness of Alloy K 500 Rod

Condition	Hardness, Brinell					
	70°F (21°C)	700°F (371°C)	800°F (427°C)	900°F (482°C)	1000°F (538°C)	1100°F (593°C)
Hot-Finished	241	223	207	201	170	179
Hot-Finished, Aged	331	311	302	293	255	229

Table 9 - Tensile Properties of Alloy K 500 Sheet

Test Temperature, °F	Sheet				Weld		
	Tensile Strength, ksi	Yield Strength, ksi	Elongation, %	NT/TS[a]	Tensile Strength, ksi	Joint Efficiency, %	Elongation, %
78	154	97.3	22	0.93	141	92	11
-100	166	107	24	0.93	154	93	14
-320	183	120	30	0.95	170	93	15
-423	200	136	28	0.99	190	95	14

[a]Ratio of notch tensile strength to smooth tensile strength, K_t=6.3.

Table 10 - Torsional Properties of Alloy K 500 Bar

Condition	Yield Strength (0.00% Offset), ksi [a]	Johnson's Apparent Elastic Limit, ksi	Angle of Twist, deg/in.
Hot-Rolled	27	29	620
Hot-Rolled, Aged	57	67	104
Cold-Drawn	48	55	360
Cold-Drawn, Aged	62	71	76

[a] $S_s = \frac{5.08\ M_t}{d^3}$, where S_s = torsional stress on the outer fiber, psi
M_t = Torsional moment, in.-lb
d = specimen diameter, in.

Table 12 - Shear Strength of Alloy K 500

Condition	Maximum Strength, ksi	Deflection at Maximum Strength, ksi	Tensile Strength, ksi	Elongation %	Hardness, Rockwell C
Annealed	65.3	0.08	97.5	49.0	84B
Annealed, aged	96.5	0.06	147.2	29.0	29
Half-hard	71.0	0.04	122.0	12.5	25
Half-hard, aged	98.8	0.05	155.6	24.0	31
Full-hard	89.5	0.04	151.5	16.5	33
Full-hard, aged	98.5	0.04	168.5	12.5	37

Table 11 - Comparison of Tensile and Torsional Properties of Alloy K 500 Rod and Wire

Form	Condition	Tensile		Torsional		Ratios		
		Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Breaking Strength, ksi	Proportional Limit, ksi	Torsional Breaking Strength/ Tensile Strength	Torsional Proportional Limit/ Tensile Strength	Torsional Proportional Limit/Torsion -al Breaking Strength
Wire (0.148-in. Dia.)	Cold-Drawn 50%	163	-	107	68	0.657	0.417	0.635
	Cold-Drawn 50%, Age-Hardened	197	-	137	75	0.696	0.380	0.547
Rod (1-in. Dia.)	Hot-Rolled	98	45	69	18	0.704	0.184	0.261
	Hot-Rolled, Age-Hardened	-	-	-	62	-	-	-
	Cold-Drawn 20%	134	103	80	45	0.597	0.336	0.562
	Cold-Drawn 20%, Age-Hardened	155	125	102	50	0.658	0.373	0.490

Table 13 - Properties of Alloy K 500 Rivet Wire and Rivets

Property	Condition				
	As Received	Aged 2 Hours[a]	Aged 4 Hours[b]	Aged 8 Hours[c]	Aged 16 Hours[d]
	Rivet Wire				
Average Shear Stress, ksi	69.3	83.2	85.3	85.0	89.2
Ultimate Tensile Stress, ksi	107.3	133.0	137.6	–	147.0
Ratio	0.64	0.63	0.62	–	0.61
Hardness, R_C	13	24	26	26	32
	Rivets[e]				
Hardness, R_C					
Head	34	40	40	40	40
Shank	23	30	32	30	34

[a]1080°F/2 hr, A.C.
[b]1080°F/4 hr, A.C.
[c]1080°F/8 hr, A.C.
[d]1080°F/16 hr, furnace cool to 900°F at the rate of 15°F/hr, A.C.
[e]1/8-in. diameter x 1/4-in. long.

Table 14 - Bearing Strength of Alloy K 500

Condition	Tensile Properties			Bearing Strength		Ratio, Bearing Strength/	
	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elongation. %	Ultimate Strength,[a] ksi	Yield Strength,[b] ksi	Ultimate Strength	Yield Strength
Annealed	92.2	38.5	49.0	178.0	68.8	1.93	1.79
Annealed, Aged	145.5	98.5	31.0	295.0	162.0	2.03	1.65
Hard	145.9	139.0	5.0	294.0	190.0	1.72	1.37
Hard, Aged	195.5	177.0	10.0	358.0	262.0	1.83	1.48

[a]Tearing out.
[b]2% enlargement of hole dia. in sheet.

Table 15 - Compressive Strength of Alloy K 500 Rod

Property	Hot-Rolled		Cold-Drawn	
	As-Rolled	Aged	As-Drawn	Aged
Hardness				
Brinell (3000 kg)	165	300	205	330
Rockwell C	5	33	23	35
Vickers (30 kg - Diamond pyramid)	167	316	210	336
Tension				
Tensile Strength, ksi	100.0	151.0	106.0	158.0
Yield Strength (0.2% offset), ksi	47.0	111.0	85.0	120.0
Elongation, %	42.5	30.0	26.5	22.0
Compression				
Yield Strength (0.2% offset), ksi	40.0	121.0	76.0	121.0
Yield Strength (0.1% offset), ksi	34.0	96.0	55.0	102.0

Table 16 - Impact Strength of Alloy K 500

Condition	Test Orientation	Charpy Keyhole Impact Strength, ft-lb
Hot-Finished	Longitudinal	74
	Transverse	51
Hot-Finished, Annealed[a]	Longitudinal	75
	Transverse	48
Hot-Finished, Aged[b]	Longitudinal	39*
	Transverse	23*
Hot-Finished, Aged[c]	Longitudinal	25*
	Transverse	20*
Hot-Finished, Annealed & Aged[d]	Longitudinal	38*
	Transverse	22*
Cold-Drawn	Longitudinal	40
Cold-Drawn, Annealed[a]	Longitudinal	90
Cold-Drawn, Aged[b]	Longitudinal	26*
Cold-Drawn, Aged[c]	Longitudinal	20*
Cold-Drawn, Annealed & Aged[d]	Longitudinal	46*

* Specimen fractured completely.
[a] 1800°F/1 hr, W. Q.
[b] 1100°F/16 hr, A.C.
[c] 1100°F/16 hr, F.C. 15°F/hr to 900°F.
[d] Anneal (a) + age (c).

Table 17 - Properties of Hot-Rolled Alloy K 500 Rod (Annealed 1800°F/½ hr and aged 1100°F/16 hr, F.C. to 1000°F/6 hr, F.C. to 900°F/6 hr, A.C.)

Diameter, [a] in.	Yield Strength (0.2% offset), ksi	Charpy V-Notch Impact Strength, ft-lb
1.250	97.3	54
1.250	92.5	72
0.875	109.3	45
1.00	111.0	38

[a] Each diameter from different heat.

Table 18 - Properties of Cold-Drawn Alloy K 500 Rod (Annealed 1900°F/½ hr and aged 1100°F/16 hr, F.C. to 1000°F/6 hr, F.C. to 900°F/6 hr, A.C.)

Diameter, [a] in.	Yield Strength (0.2% offset), ksi	Charpy V-Notch Impact Strength, ft-lb
1.250	92.5	76.25
0.812	103.0	43.75
0.687	110.6	39.5

[a] Each diameter from different heat. Data are averages of 2 tests.

Table 19 - Impact Properties of Alloy K 500

Condition	Average Energy Absorbed, ft-lb					
	Smooth Specimen			Notched Specimen[a]		
	-200°F	-120°F	+80°F	-200°F	-120°F	+80°F
	Tension Test					
Hot-Finished, Aged	158	145	141	37	37	35
Cold-Drawn, Aged	127	108	117	34	28	29
	Bending test					
Hot-Finished, Aged	–	–	–	42	50	55
Cold-Drawn, Aged	–	–	185	30	30	32

[a] In tension test, K_t = 3.00; in bending test, K_t = 4.00.

Table 20 - Charpy V-Notch Impact Strength of Alloy K 500[a] at Low Temperatures

Temperature, °F	Impact Strength, ft-lb
Room	37.0
-110	34.0
-320	31.0

[a] ¾-in. bar, aged 1100°F/21 hr, 1000°F/8 hr, A.C.

Table 21 - Room-Temperature Fatigue Strength of Alloy K 500

Form and Condition		Fatigue Strength (10^8 cycles) ksi	Tensile Strength, ksi	Ratio, Fatigue Strength/Tensile Strength
Rod,	Annealed	38	88	0.43
	Hot-Rolled	43	99	0.43
	Hot-Rolled, Aged	51	155	0.33
	Cold-Drawn	45	120	0.37
	Cold-Drawn, Aged	47	170	0.28
Strip,	Annealed	27	88	0.31
	Spring-Temper, Aged	37	153	0.24

Table 22 - Fatigue Strength of Alloy K 500 at Elevated Temperature

Condition	Temperature, °F	Fatigue Strength, (10^8 cycles), ksi
Hot-Finished, Aged	80	46.0
	1000	43.0
Cold-Drawn, Aged	80	52.0
	1000	48.0

Table 23 - Fatigue Strength of Alloy K 500 at Low Temperature

Temperature, °F	Stress, ksi, for a Fatigue Life of		
	10^5 cycles	10^6 cycles	10^7 cycles
70	90	55	37
-110	99	67	–
-320	105	69	–
-423	143	101	–

Table 24 - Effect of Surface Finish on Fatigue Strength of Alloy K 500[a]

Condition	Surface Finish	Tensile Strength, ksi	Fatigue Strength (10^8 cycles), ksi	Ratio, Fatigue Strength/Tensile Strength
Hot-Rolled, Aged	Polished	171.0	50.0	0.29
	Oxidized	172.5	39.5	0.23
Cold-Drawn, Aged	Polished	174.5	57.0	0.33
	Oxidized	167.5	39.5	0.24

[a] R.R. Moore rotating-beam specimens.

Table 25 - Typical Usage Stresses for Alloy K500 Springs [a]

Temper and Diameter, in.	Method of Coiling	Aging Treatment After Coiling	Maximum Shearing Stress, ksi, for Metal Temperature		
			Up to 400°F	400° to 450°F	450° to 500°F
Spring 5/8 and under[b]	Cold	1000°F/10 hr, A.C.	65	65	50
Hot-Rolled 1/2 and over[b]	Hot	1100°F/8 hr, A.C.	65	65	55

[a] All values include the Wahl Curvature Correction Factor and are based on 5% relaxation maximum at stress and temperature after 7 days. Stresses at temperature are adjusted for modulus (G) at temperature.

[b] Selection of break in size for hot or cold winding will be governed largely by the spring index and processing.

Table 26 - Properties of Alloy K500 Helical Springs (0.148-in. dia. Spring-Temper Wire, 65% Reduction)

Thermal Treatment after Cold Coiling	Properties of Wires			Fatigue Strength or Stress Range of Springs, ksi (Curvature Correction Factor included)		
	Tensile Strength, ksi	Torsional Breaking Strength, ksi	Torsional Proportional Limit, ksi	10^6 Cycles	10^7 Cycles	10^8 Cycles
				Initial Stress - 10.0 ksi		
As-Drawn	162.5	106.3	67.5	–	–	–
Stress-Equalized 525°F/3 hr	171.8	107.2	67.5	–	–	–
Aged 980°F/6 hr, plus 900°F/6 hr	197.0	137.2	74.6	55.0	44.0	39.5
				Initial Stress - 20.0 ksi		
				59.5	51.0	47.0

Table 27 - Properties of Alloy K500 Cold Drawn Rod (Annealed 1900°F/1/2 hr, W.Q. and Aged 1100°F/16 hr, F.C. 15°F/hr to 900°F, A.C.)

Diameter, [a] in.	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elongation, %	Reduction of Area, %	Hardness, R_C	Yield Strength (0.2% offset),[b] ksi
3 1/4	156.5	98.0	26	42	29	94.5
3	154.0	95.0	24	39	29	94.0
3	152.0	96.5	26	46	28	95.5
2 3/4	149.0	91.5	26	45	27	90.0
2 5/8	156.0	99.0	25	45	29-30	98.0
1 1/2	160.5	102.0	26	42	29	98.5
1 1/2	152.0	100.5	26	49	29	98.5
1 3/8	153.0	100.5	26	47	28	97.5
1 1/4	150.0	96.5	26	51	27	96.0
1 1/4	153.0	100.0	26	49	28	100.0
1	155.5	99.5	26	45	29	99.0
1	156.5	101.5	25	45	29	101.5
5/8	156.0	100.5	27	46	28	97.5
5/8	155.0	99.5	27	47	26	97.0

[a]Each diameter from different melt.

[b]Aged by step procedure: 1100°F/16 hr, +1000°F/6 hr, +900°F/6 hr, A.C.

Table 28 - Effect of Short-Time Aging on Properties of Alloy K 500[a]

Condition	Thermal Treatment		Tensile Properties			
	Temperature, °F	Time, hr	Tensile Strength, ksi	Yield Strength (0.2% offset), ksi	Elongation, %	Hardness, Rockwell C
Rod, Hot-Rolled	–	0	93	45	44	82B
	1100	2	132	82	36	17
		4	136	86	34	20
		8	142	90	33	22
Strip, Annealed	–	0	100	50	39	85B
	1100	2	142	90	31	24
		4	141	96	27	25
		8	140	98	27	26
Strip, Cold-Rolled 10%	–	0	111	90	27	19
	1100	2	155	122	23	31
		4	155	122	21	31
		8	156	123	21	31
	1000	2	141	124	24	31
		4	144	123	23	31
		8	149	129	22	32
Strip, Cold-Rolled 20%	–	0	125	115	14	23
	1100	2	163	140	18	34
		4	163	142	18	33
		8	163	141	18	33
	1000	2	169	143	17	34
		4	170	143	18	34
		8	174	148	18	35
Strip, Cold-Rolled 40%	–	0	143	136	5	27
	1100	2	175	159	14	37
		4	176	159	14	36
		8	174	156	14	36
	1000	2	182	165	11	37
		4	183	164	14	37
		8	184	167	13	38
Strip, Cold-Rolled 50%	–	0	148	141	4	29
	1100	2	179	166	12	38
		4	181	165	12	38
		8	177	161	13	38
	1000	2	187	173	10	39
		4	189	174	13	39
		8	189	174	11	39

[a]These data are offered as a guide to short-time aging treatments and are not suitable for specification purposes.

Table 29 - Long-Time Aging of Hot-Rolled Alloy K 500 Rod

Thermal Treatment	Tensile Strength, ksi	Yield Strength (0.2% Offset), ksi	Elongation, %	Izod Impact, ft-lb	Hardness, Brinell, (3000-kg)
Hot-Rolled	97.5	40.5	44.0	83	169
1080°F/16 hr	147.0	92.0	28.0	48	270
1080°F/16 hr + 800°F/1 month	161.5	109.0	26.0	26	310
1080°F/16 hr + 800°F/2 months	165.0	112.0	25.0	23	307
1080°F/16 hr + 800°F/4 months	162.3	109.2	25.5	24	310
1080°F/16 hr + 800°F/8 months	164.3	113.2	23.1	27	308
1080°F/16 hr + 800°F/16 months	163.5	112.0	24.5	25	305

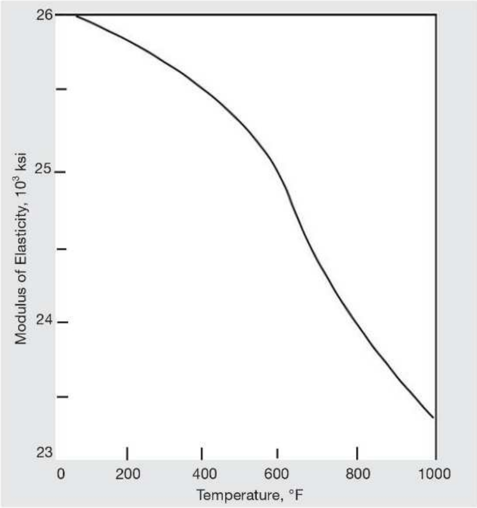

Figure 1. Effect of temperature on modulus of elasticity in tension of Alloy K 500 (determined by dynamic method).

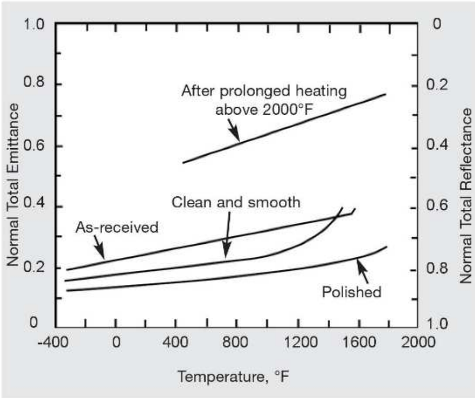

Figure 2 - Normal total emittance of Alloy K 500 (Total radiation detector; comparison blackbody. Measured in a 10-micron pressure of helium.)

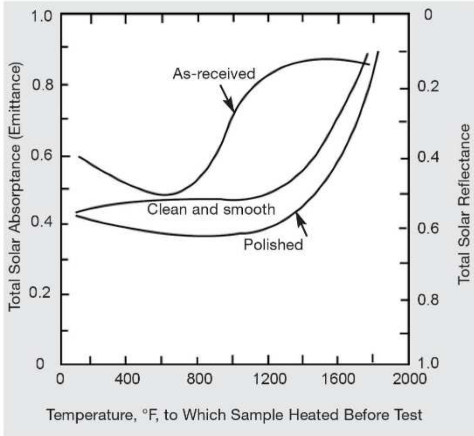

Figure 3 - Total solar absorptance at 100°F of Alloy K 500 (Comparison standards; comparison pyroheliometer. Measured in air.)

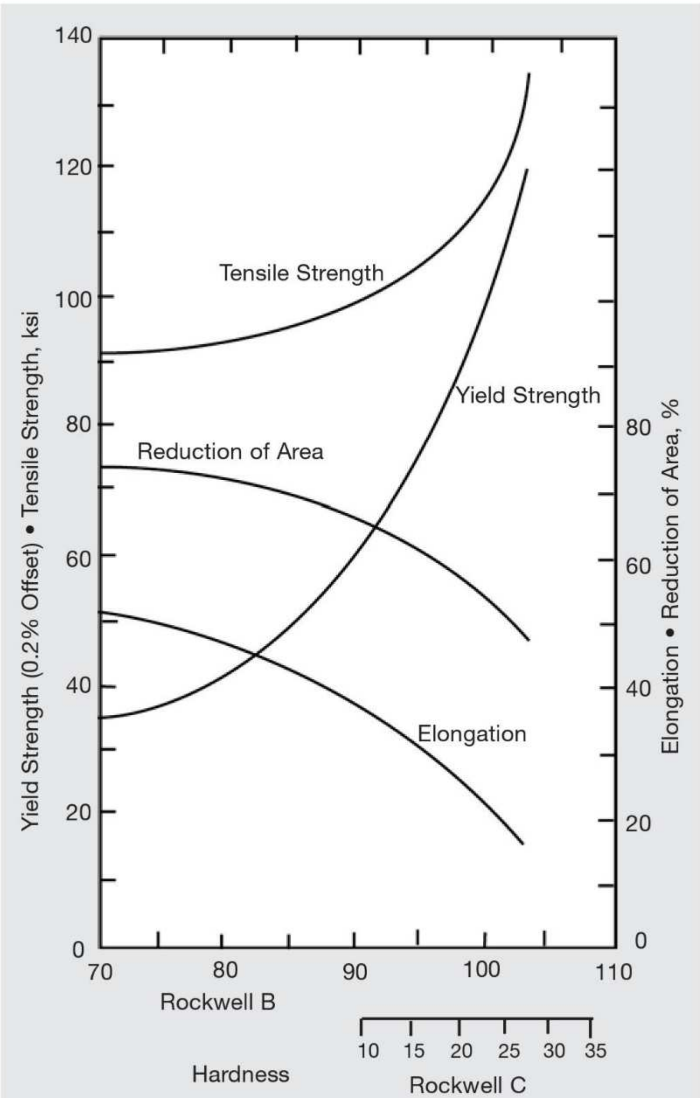

Figure 4 - Approximate relationships between tensile properties and hardness of Alloy K 500 hot-finished rods and forgings and cold-drawn rods.

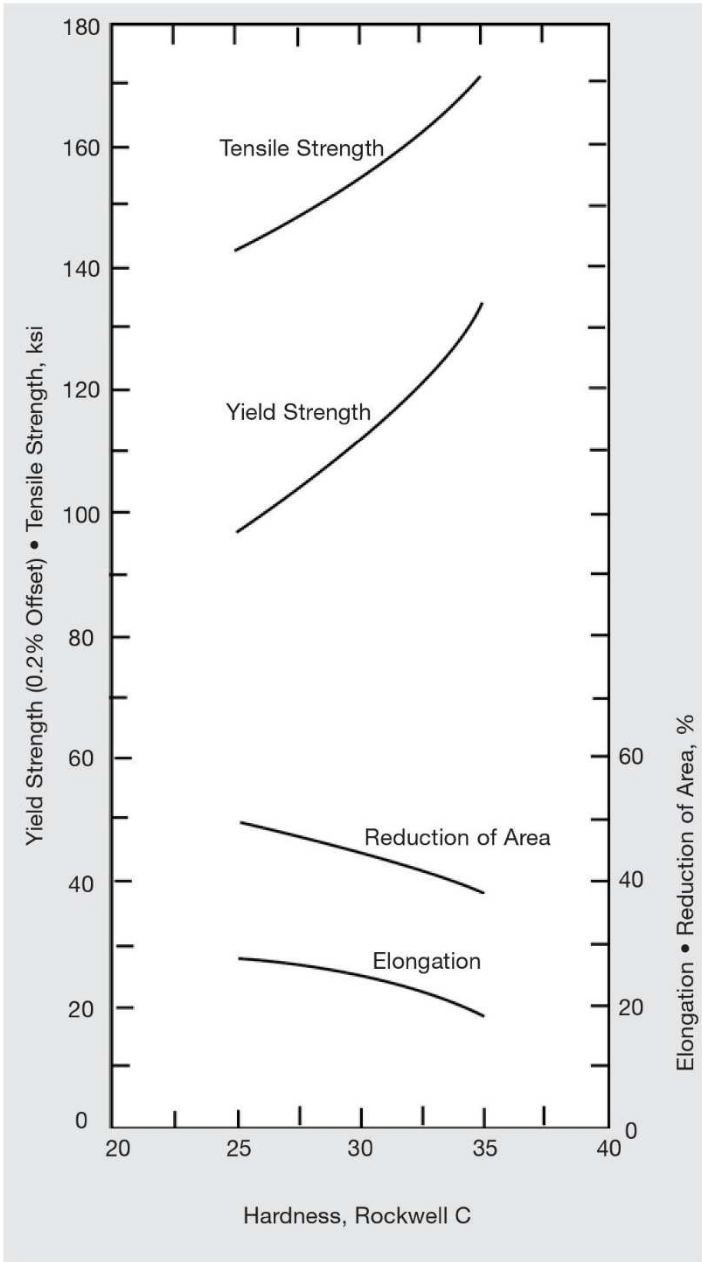

Figure 5 - Approximate relationships between tensile strength and hardness of Alloy K 500 age-hardened rods and forgings.

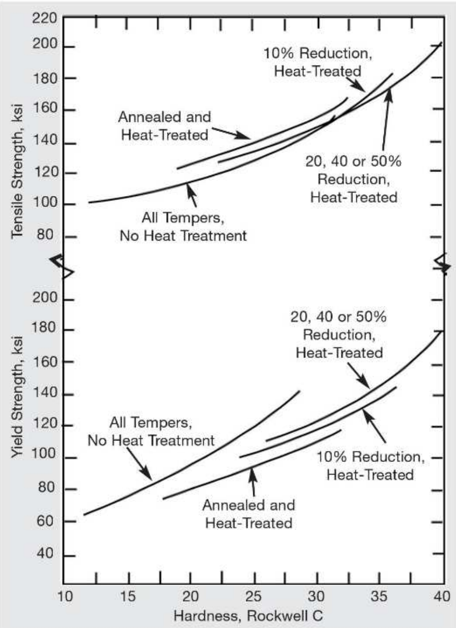

Figure 6. Approximate relationships between tensile properties and hardness of Alloy K 500 strip and sheet.

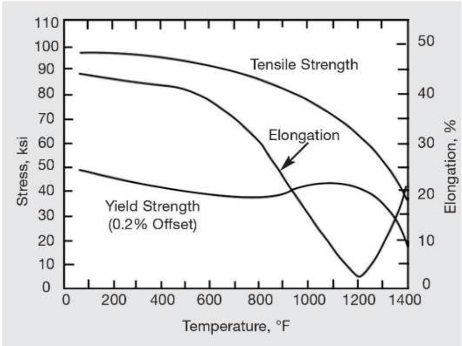

Figure 7 - High-temperature tensile properties of Alloy K 500 rod (hot-rolled, as-rolled).

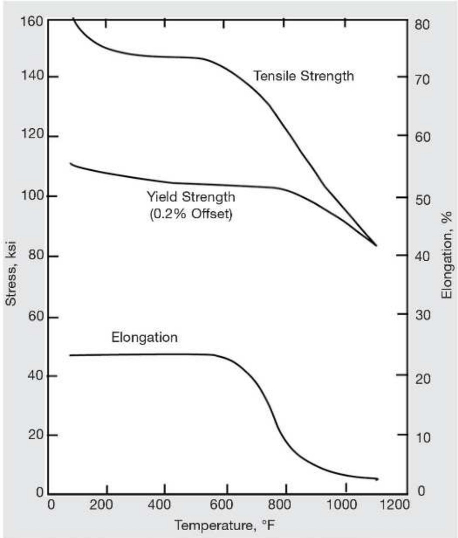

Figure 8. High-temperature tensile properties of hot-finished age-hardened Alloy K 500

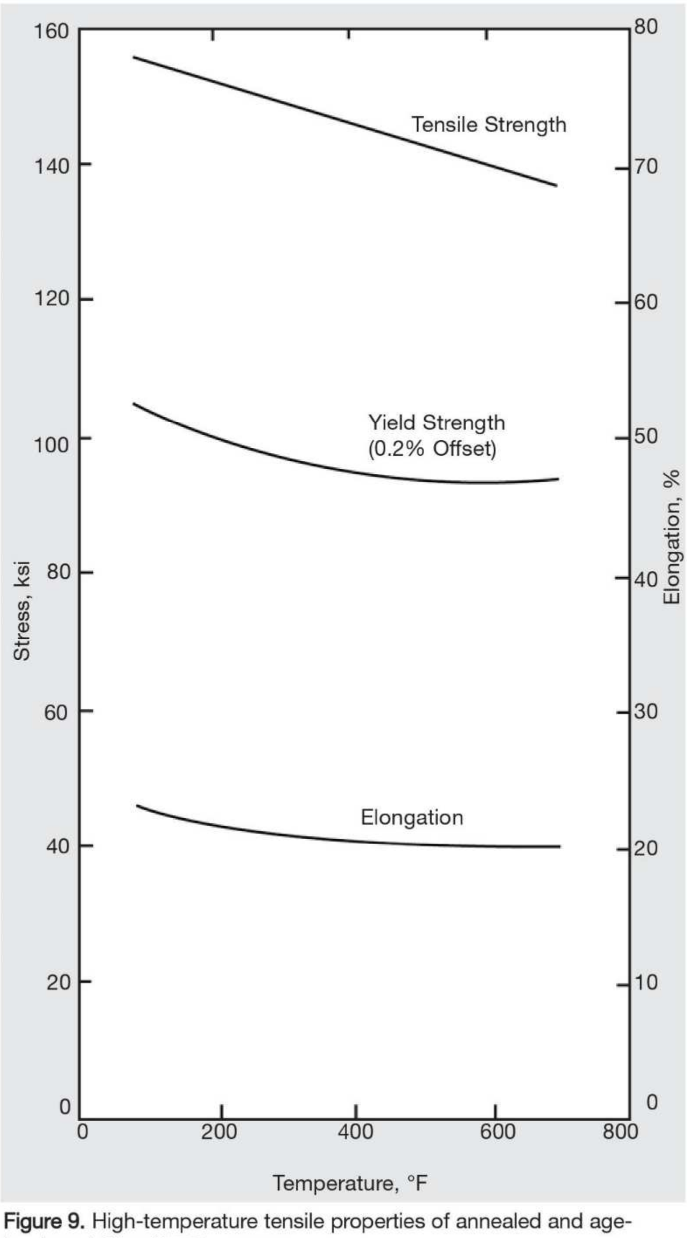

Figure 9. High-temperature tensile properties of annealed and age-hardened Alloy K 500

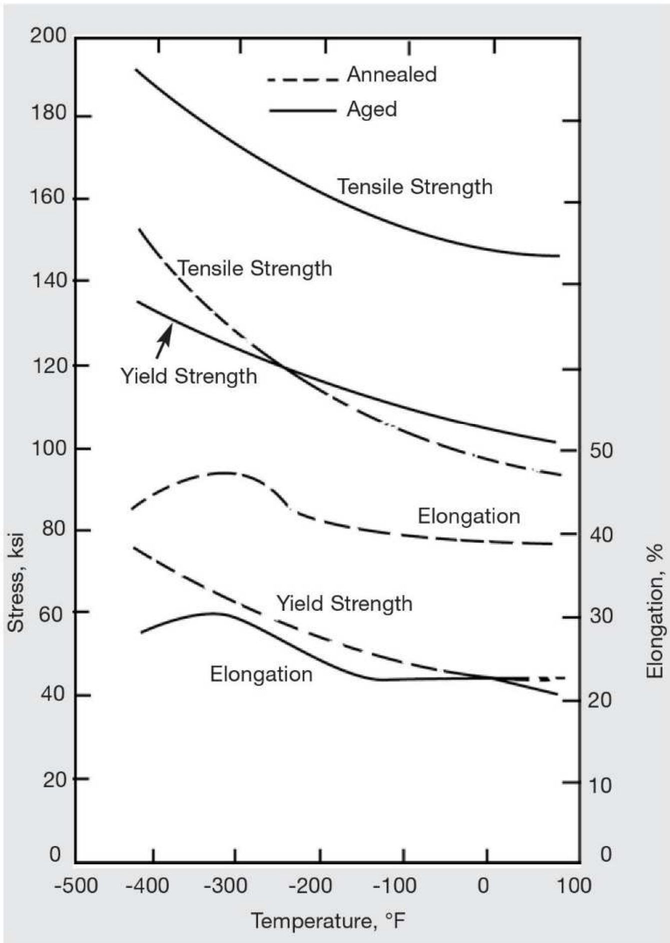

Figure 10. Low-temperature tensile properties of Alloy K 500 (0.063-in. sheet).

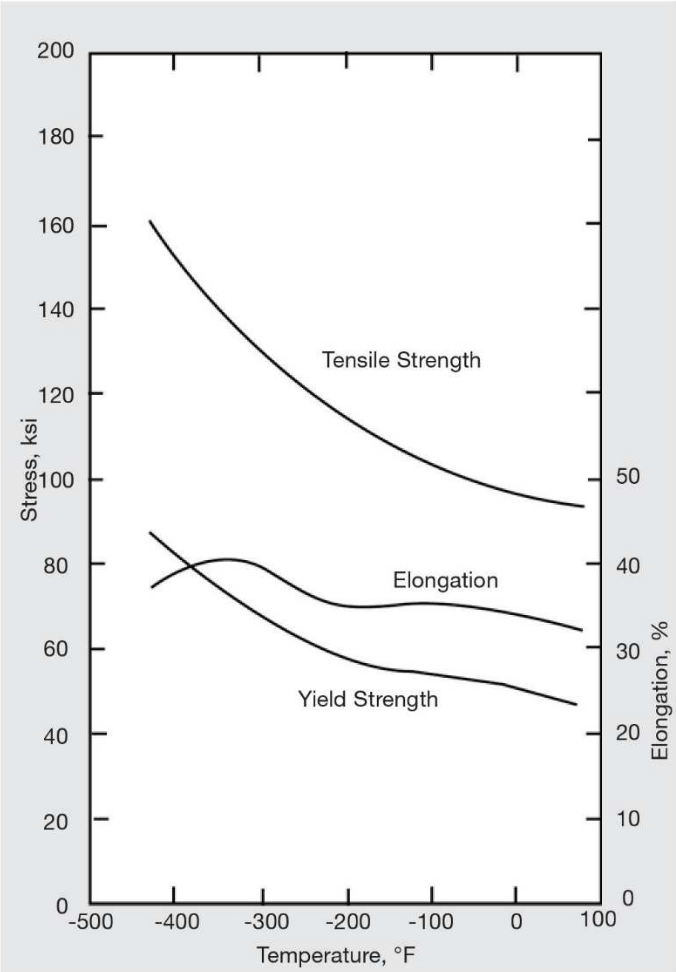

Figure 11 - Low-temperature tensile properties of Alloy K 500 welded and annealed

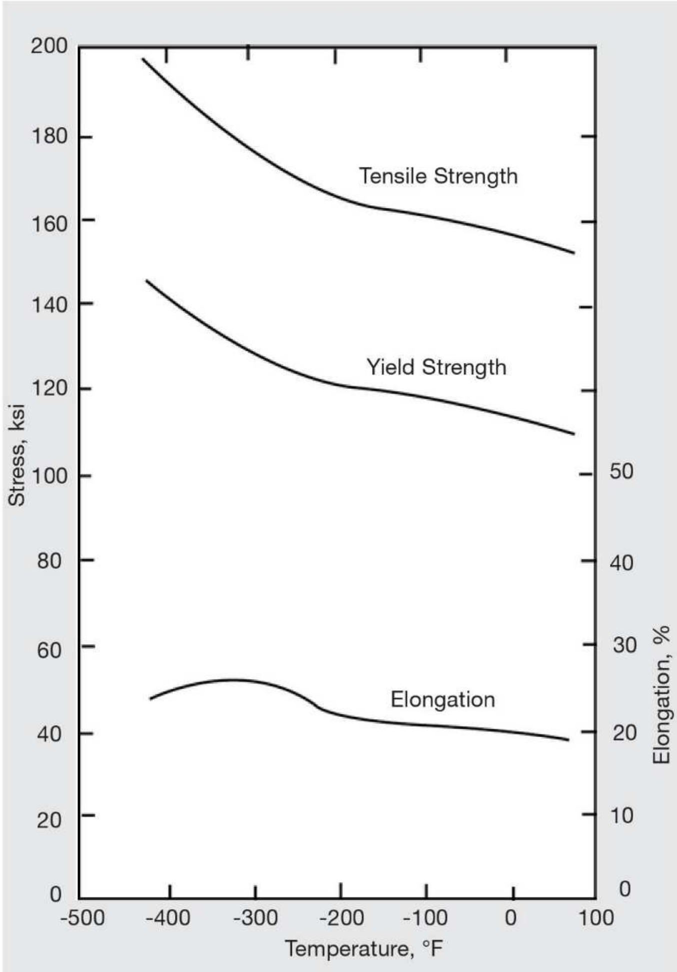

Figure 12 - Low-temperature tensile properties of Alloy K 500 welded and age-hardened

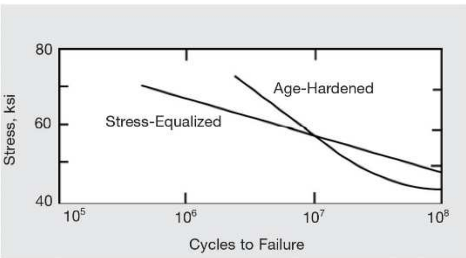

Figure 13 - Fatigue strength of commercially produced Alloy K 500 wire (0.0375-in. diameter, cold-drawn 75% after final anneal). Tested in processed condition. Data determined with a rotating-wire (5000 rpm) arc-fatigue machine.

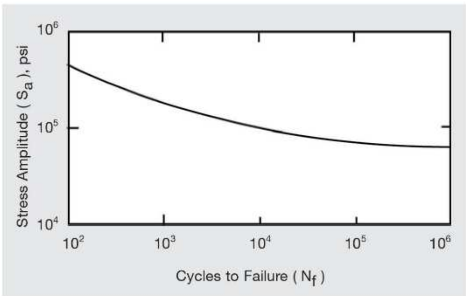

Figure 14 - Cyclic-strain fatigue of age-hardened Alloy K 500

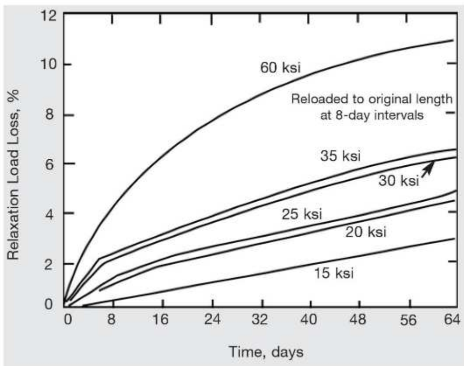

Figure 15 - Relaxation at 500°F of Alloy K 500 springs, age-hardened at 1000°F/6 hr. All stresses are shearing stresses corrected for curvature; modulus corrected for temperature.

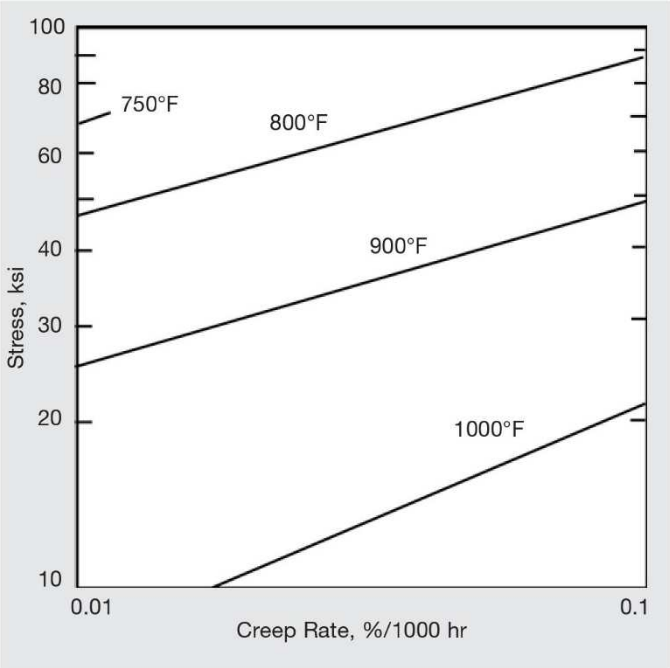

Figure 16 - Creep properties of Alloy K500 (cold-drawnaged).

Figure 18 - Microstructure of hot-rolled, as-rolled Alloy K500

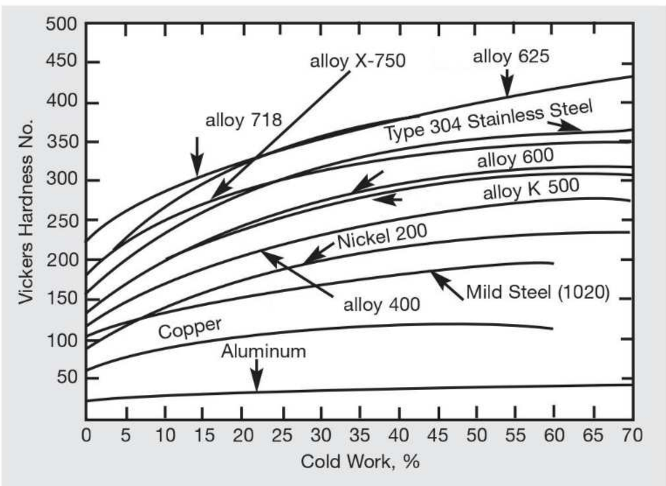

Figure 20. Effect of cold work on hardness.

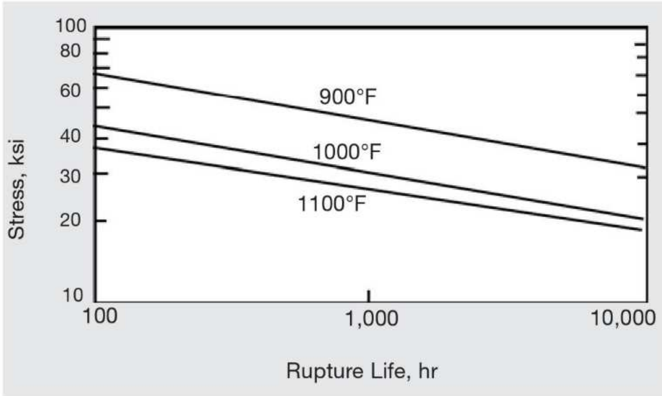

Figure 17 - Rupture life of hot-finished aged Alloy K500

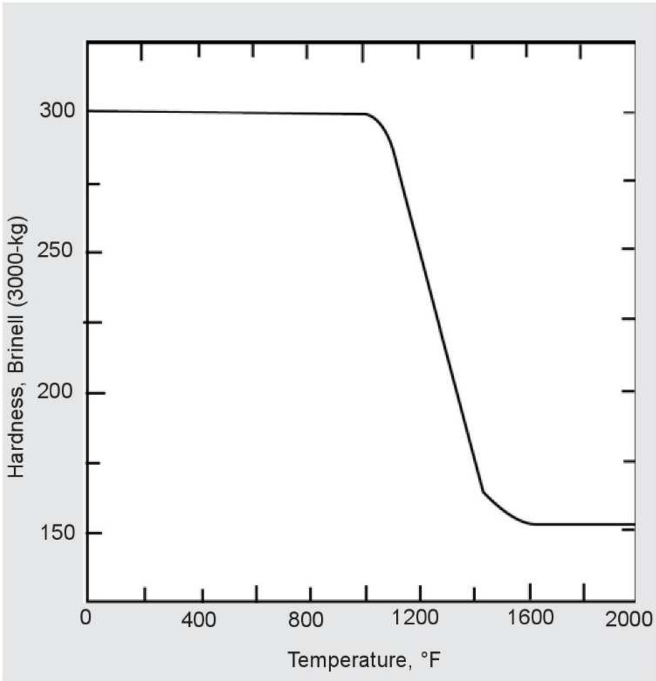

Figure 19 - Effect of water quenching from various annealing temperatures on hardness of Alloy K500

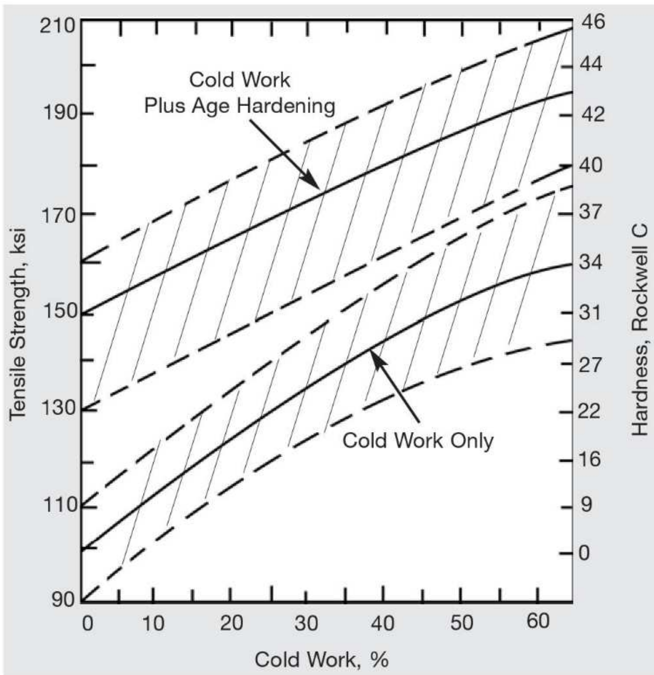

Figure 21 - Effect of cold work and age hardening on properties of Alloy K500