AUTHOR: S. S. MANSON

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

1. GENERAL
Monel alloy K-500 is a corrosion-resistant, nickel-copper base alloy which exhibits high strength and hardness through the addition of aluminum and titanium. The increased properties result from the precipitation of submicroscopic particles of Ni_3 (Al, Ti) throughout the matrix by heating of the alloy under controlled conditions (aging). This alloy has excellent low temperature strength and toughness and is virtually non-magnetic. Dimensional stability is excellent in both long time exposure and in cyclic tests. The alloy is readily machinable in the annealed condition and it can be joined by the usual welding, brazing and soft soldering processes normally employed for nickel-base alloys (1). Monel alloy K-500 is available in a wide variety of forms and sizes and is used for applications requiring a combination of high strength, ductility and corrosion resistance (5)(7). A modified version of this alloy, designed to provide improved machinability, is available as Monel Alloy 501.

1.01 Commercial Designation
Monel Alloy K-500, Monel K-500, UNS N05500.

1.02 Alternate Designation
"K" Monel.

1.03 Specifications
1.031 Rods, forgings, bars - AMS 4676 (41).
Federal Spec. QQ-N-286(Class A) (1).
1.032 Wire. Military Spec. MIL-W-4471 (Comp. A) (1).

1.04 Composition
Table 1.04.

1.05 Heat Treatment
1.051 Anneal. 1600F to 1800F, 1 to 5 minutes, water quench if possible. (See Figure 1.063).
1.0511 Annealing should be performed in a reducing atmosphere.
1.0512 An addition of 2 percent (by volume) of alcohol to quench bath will minimize oxidation and facilitate pickling (5).
1.052 Age harden.
1.0521 Soft material (75-90RB). 1100 to 1125F, 16 hours, furnace cool to 900F, air cool or water quench to room temperature (1).
1.0522 Moderately cold worked material (8-25RC). 1100 to 1125F, 8 hours or longer, furnace cool to 900F, at rate less than 25F per hour air cool or water quench to room temperature (1).
1.0523 Full cold worked material (25-35RC). 980 to 1000F, 6 hours minimum, furnace cool to 900F, at rate less than 25F per hour air cool or water quench to room temperature (1).
1.053 All heating above 1100F should be done in a reducing atmosphere or severe surface damage may occur (1).
1.054 Thermal treatment for cold-coiled spring wire (12).
1.0541 Stress equalizing. 575F, 0.5 to 1 hour, furnace cool.
1.05411 Stress equalizing is not necessary when material is to be age hardened.
1.0542 Age harden. 1000F, 4 to 10 hours, furnace cool.
1.055 Thermal treatment for hot-coiled spring wire (12).
1.0551 Stress equalizing. Not recommended.
1.0552 Age harden. 1100F, 8 to 16 hours, furnace cool.

1.06 Hardness
See also 3.0214, 3.02151.
1.061 Hardness at room and elevated temperatures of hot finished and aged rod, Figure 1.061.
1.062 Effect of time at open annealing temperature on hardness, Figure 1.062.
1.063 Effect of annealing temperature on hardness of water quenched alloy, Figure 1.063.
1.064 Effect of time at 1080 to 1100F on hardness of bar and forging, Figure 1.064.
1.065 Effect of aging time on hardness of hot rolled bar. Figure 1.065.
1.066 Hardness levels associated with various heat treatments after 60 percent cold rolling, and after hydrogen charging in sulfuric acid solution, Table 1.066.

1.07 Forms and Conditions Available
1.071 General. Alloy is available in most conventional forms and sizes.
1.072 Forms. Available as rod, bar, sheet, plate, strip, tubing, pipe and wire. Also as specialty items.
1.073 Conditions. Annealed, hot finished (bar and rod), hot rolled (plate), cold drawn (bar, rod, tube and pipe), cold rolled (sheet and strip), and extruded (tube). See Ref. 1 for further details.

1.08 Melting and Casting Practice
1.081 Casting temperature range, 2650 to 2750F (8).

1.09 Special Considerations
1.091 Alloy is subject to moderate crevice corrosion, see 2.033.
1.092 Hydrogen can substantially degrade tensile properties, but baking to remove hydrogen restores properties; see 3.02171, 3.02172, 3.02173 and 3.0236.

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties
2.011 Melting range, 2400 to 2460F (7).
2.012 Phase changes. Alloy is fcc at all temperatures and is age hardenable.
2.013 Thermal conductivity, Figure 2.013.
2.014 Thermal expansion.
2.0141 Thermal expansion, Figure 2.0141.
2.0142 Thermal expansion at low temperatures, Figure 2.0142.
2.015 Specific heat.
2.0151 Specific heat, Figure 2.0151.
2.016 Thermal diffusivity.
2.0161 Thermal diffusivity, Figure 2.0161.

2.02 Other Physical Properties
2.021 Density.
2.0211 Density, Figure 2.0211.
2.022 Electrical properties.
2.0221 Electrical Resistivity, Figure 2.0221.
2.023 Magnetic properties.
2.0231 Permeability at 0.5 oersteds 1.002 $\pm$ .001 (37, p.6).
2.0232 Alloy shows no tendency to retain induced magnetism (remanence) (37, p.8)
2.0233 Effect of permeability on Curie temp. for annealed, cold drawn and age hardened alloy, Figure 2.0233.
2.0234 Effect of strength level as achieved by several processing procedures on permeability, Figure 2.0234.
2.0235 A program has been conducted by Bureau of Ships to determine the feasibility of using a combination of eddy current tests and hardness to determine elongation potential of K-monel bolt-studs used in submarine construction. It was found that the eddy current test is sensitive to numerous variables including diameter, heat treatment, bar finishing process and chemical composition. The test could not be used to separate the effects of the several variables, nor could it reliably be used to predict acceptability of a given sample with respect to ductility (39).
2.024 Emittance.
2.0241 Normal total emittance, Figure 2.0241.
2.025 Damping capacity.

2.03 Chemical Environments
2.031 General. The corrosion resistance of this alloy is comparable to that of Monel 400 in a wide variety of media including mineral and organic acids, alkalies, salts, potable and industrial waters, food products, organic compounds and oxidizing atmospheres at normal and elevated temperatures (5). Alloy is not resistant to oxidizing acids (8).
2.032 Temperature limits for various environments, Table 2.032
2.033 Alloy heat treated to F_{ty} of 95 ksi and e (2 in) of 17 per-

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0.5	Ti

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cent has satisfactory corrosion fatigue resistance for hydrofoil application, and is not susceptible to stress corrosion cracking when stressed to 90 percent F_{ty}. It is, however, subject to moderate crevice corrosion and exhibits relatively high erosion and cavitation metal loss rates. These factors, together with the marginal strength and the 1400F stress relief temperature required after welding, resulted in the elimination of consideration of alloy for hydrofoil application (38, pp 2.1, 2.2).

2.034 Effects of fluorine.

2.0341 Response to gaseous fluorine at various temperatures and flow states, Table 2.0341.

2.035 Hydrogen effects. See 3.02171, 3.02172, 3.02173, 3.0236, 3.0274.

2.04 <u>Nuclear Environments</u>

2.041 Effect of radiation on tensile and notch properties, Table 2.041.

2.042 Effect of fast neutron irradiation and cryogenic temperature on tensile properties of smooth and notched specimens, Table 2.042.

3. MECHANICAL PROPERTIES

3.01 <u>Specified Mechanical Properties</u>

3.011 AMS specified mechanical properties for bars, forgings and forging stock, Table 3.011. Federal QQ-N-286, Military MIL-N-17506.

3.012 Specified properties of bar, rod, sheet and strip, Table 3.012.

3.013 Specified properties of tube, pipe, plate and wire, Table 3.013.

3.02 <u>Mechanical Properties at Room Temperature</u>

3.021 Tension. See also 3.03.

3.0211 Stress-strain diagrams. See Figures 3.03111 to 3.03114 and 3.03117.

3.0212 Hardness - tensile property relations.

3.02121 Approximate relationship between tensile properties and hardness of age-hardened rod and forgings, Figure 3.02121.

3.02122 Approximate relationship between tensile properties and hardness of hot finished rods and forgings and cold drawn rods, Figure 3.02122.

3.02123 Approximate relationship between tensile strength and hardness of sheet and strip, Figure 3.02123.

3.0213 Cold work effects.

3.02131 Effect of cold work on maximum and minimum tensile properties and hardness, Figure 3.02131.

3.02132 Effect of work hardening and wire thickness on tensile strength of wire rod, Figure 3.02132.

3.0214 Aging effects. See also 3.0251, 3.0254.

3.02141 Effect of aging temperature for 8 and 16 hr ages of tensile properties of sheet, Figure 3.02141.

3.02142 Effect of prior strain on tensile properties of sheet after 8 or 16 hr age at 1090F, Figure 3.02142.

3.02143 Effect of aging time on tensile properties of hot rolled bar, Figure 3.02143.

3.02144 Effect of short time aging at 1100F on tensile properties of cold rolled strip and hot rolled rod, Figure 3.02144.

3.0215 Hydrogen effects.

3.02151 Effect of hydrogen charging on tensile properties of sheet cold worked and heat treated to various hardness levels, Figure 3.02151.

3.02152 Effect of hydrogen charging on tensile properties of 31.5RC sheet, and restoration of initial properties by 500F bake for 24 hrs., Figure 3.02152.

3.02153 Effect of test temperature on tensile yield stress of hydrogen-free and hydrogenated wire, Figure 3.02153.

3.022 Compression.

3.0221 Stress-strain diagrams.

3.0222 Compressive yield strength of rod, Table 3.0222.

3.023 Impact.

3.0231 Charpy keyhole impact energy for hot-finished and cold drawn bar with several heat treatments, Table 3.0231.

3.0232 Charpy-V impact energy of specimens from several sizes of hot rolled rod, Table 3.0232.

3.0233 Charpy-V impact energy of specimens from several sizes of cold drawn rod, Table 3.0233.

3.0234 Impact energy of alloy in several conditions of heat treatment, Table 3.0234.

3.0235 Effect of aging time on Izod impact energy of hot rolled bar, Figure 3.0235.

3.0236 Effect of hydrogen charging for 16 days on Charpy impact energy of alloy in two conditions of hardness, Table 3.0236.

3.024 Bending.

3.025 Torsion and shear.

3.0251 Torsional properties of cold-drawn spring wire, Table 3.0251.

3.0252 Properties of helical spring wire in several conditions of thermal treatment after cold coiling, Table 3.0252.

3.0253 Tensile, hardness and shear properties of rivet wire and hardness of rivets, Table 3.0253.

3.0254 Torsional shear properties of wire and rod in several conditions, Table 3.0254.

3.0255 Shear strength of sheet in several conditions of heat treatment, Table 3.0255.

3.026 Bearing.

3.0261 Bearing strength of sheet in several conditions of heat treatment, Table 3.0261.

3.027 Stress concentration. See also 2.041, 2.042.

3.0271 Notch properties.

3.02711 Effect of section size on notch strength of alloy produced by several processes, Figure 3.02711.

3.02712 Relation between notch strength and ultimate tensile strength for hot rolled, cold drawn, and extruded material containing an aluminum content range from 2.64 to 3.21 percent subjected to several heat treatments, Figure 3.02712.

3.02713 Relation between notch strength and smooth specimen elongation for hot rolled, cold drawn, and extruded material containing an aluminum content range from 2.64 to 3.21 percent subjected to several heat treatments, Figure 3.02713.

3.02714 Notched tensile strength in high pressure nitrogen and hydrogen, Table 3.02714.

3.0272 Fracture toughness.

3.028 Combined properties.

3.03 <u>Mechanical Properties at Various Temperatures</u>

3.031 Tension.

3.0311 Stress-strain diagrams.

3.03111 Stress-strain curves at room and low temperatures for annealed and aged sheet, Figure 3.03111.

3.03112 Stress-strain curves at low and room temperature for cold rolled and aged-hardened alloy, Figure 3.03112.

3.03113 Stress-strain curves at room and low temperatures for aged bar, Figure 3.03113.

3.03114 Stress-strain curve at -321F for hydrogen-free and hydrogenated alloy wire, Figure 3.03114.

3.03115 Elevation of flow stress of wire caused by 300 ppm hydrogenation, Figure 3.03115.

3.03116 True stress-true strain curves for cold-drawn and aged rod from -453F to 392F, Figure 3.03116.

3.0312 Tensile properties at room and low temperature.

3.03121 Alloy displays serrated yielding at -453F. For analysis, see (29).

3.03122 Tensile properties at room and low temperatures for cold drawn and aged alloy, Table 3.03122.

3.03123 Tensile properties of annealed sheet in longitudinal and transverse directions at room and low temperatures, Figure 3.03123.

3.03124 Tensile properties of annealed and aged sheet in longitudinal and transverse directions at room and low temperatures, Figure 3.03124.

3.03125 Tensile properties of annealed and aged sheet having two surface conditions at room and low temperatures, Figure 3.03125.

3.03126 Tensile properties of annealed and aged bar at room and low temperatures, Figure 3.03126.

3.03127 Tensile properties at room and low temperatures for aged bar, Figure 3.03127.

3.03128 Effect of test temperature on ductility of alloy with and without hydrogenation, Figure 3.03128.

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29	Cu
3	Al
0.5	Ti

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3.0313 Tensile properties at room and elevated temperatures, see also 3.02129.
3.03131 Effect of strain rate on ductility at 80F and 400F for alloy with and without hydrogen charge, Figure 3.03131
3.03132 Tensile properties at room and elevated temperatures for annealed and age hardened alloy, Figure 3.03132.
3.03133 Effect of elevated temperature on tensile properties of cold drawn and hot rolled rod, Figure 3.03133.
3.032 Compression.
3.0321 Stress-strain diagrams.
3.033 Impact.
3.0331 Charpy-V impact energy at room and low temperatures for solution treated and aged bar, Figure 3.0331.
3.0332 Effect of low temperature on bending and tension impact energy for notched and smooth specimens, Figure 3.0332.
3.034 Bending.
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration. See also 3.0332.
3.0371 Notch properties.
3.03711 Sustained load failure curves at 350, 400 and 500F for hydrogenated notched specimens, Figure 3.03711.
3.03712 Notch strength ratio at room and low temperatures for sheet in annealed and in aged condition, Figure 3.03712
3.03713 Tensile and notch properties of age hardened sheet at room and low temperatures, Figure 3.03713.
3.0372 Fracture toughness.
3.038 Combined properties.

3.04 Creep and Creep Rupture
3.041 Stress required to produce 0.1 and 1.0 percent creep in 10,000 hrs at temperatures from 750 to 1100F, Table 3.041.
3.042 Minimum creep rate of bar from 750 to 1000F, Figure 3.042.
3.043 Creep relaxation curves at 500F for age-hardened spring stock, Figure 3.043.
3.044 Creep rupture data at 750 to 1100F for bar, Figure 3.044.

3.05 Fatigue Properties
3.051 S-N curves for sheet at room and low temperature, Figure 3.051.
3.052 S-N curves for notched cold rolled sheet at room and low temperatures, Figure 3.052.
3.053 S-N curves for annealed and heat treated sheet at room temperature, Figure 3.053.
3.054 Flexural bending fatigue for annealed and aged sheet with 16 RMS surface finish at room and low temperature, Figure 3.054.
3.055 Flexural bending fatigue for annealed and aged sheet with 90 RMS surface finish at room and low temperature, Figure 3.055.
3.056 Tensile strength and fatigue limit at 10^8 cycles for rod and strip in several conditions, Table 3.056.
3.057 Effect of surface finish on tensile and fatigue strength of bar, Table 3.057.
3.058 S-N curves for hot rolled and cold drawn bar at room temperature, Figure 3.058.
3.059 Axial fatigue of bar at room and low temperatures, Figure 3.059.
3.0510 Rotating bending fatigue of annealed and aged bar at RT and -320F, Figure 3.0510.
3.0511 Low cycle fatigue of plate, Figure 3.0511.
3.0512 Cyclic stress-strain curve, Figure 3.0512.
3.0513 Bend tests in air (180° bends to failure) after exposure to high pressure hydrogen, Table 3.0513.
3.0514 Fatigue crack growth in completely reversed flexure for plate in air and in simulated salt water environment, Figure 3.0514.
3.0515 Torsional fatigue strength of spring wire, Figure 3.0515.

3.06 Elastic Properties
3.061 Poisson's ratio. 0.32, (1).
3.062 Modulus of elasticity, Figure 3.062.
3.063 Modulus of rigidity. 9.5×10^3 ksi (1).

4. FABRICATION

4.01 Forming
4.011 General. Alloy can be drawn, formed, upset, swaged or otherwise cold worked in the soft condition. Although the alloy work hardens, its high ductility permits severe deformations without damage (5).
4.012 Hot working. Hot forge in temperature range 1600 to 2100F. Maximum recommended heating temperature for hot working is 2100F. Metal should be charged into a hot furnace and withdrawn when uniformly heated throughout. Prolonged soaking at 2100F is harmful. If a delay occurs, reduce temperature to 1900F until ready to work, then bring to uniform 2100F and withdraw. Avoid exposing hot metal to sulphurous atmosphere (1)(5).
4.0121 Heavy work is best accomplished between 1900 and 2100F. Working below 1600F is not recommended. All heating above 1100F requires a reducing atmosphere (1).
4.0122 To produce finer grain size in forgings, use 2000F for final reheat temperature and take at least 30 percent reduction of area in the last forging operation (1).
4.0123 After hot working, alloy should be quenched from 1450F or higher. Air cooling is not recommended (1).
4.0124 The surface of the part will be less oxidized and easier to pickle if quenched in water containing about 2.0 percent alcohol (by volume).
4.013 Cold work. Alloy can be cold worked by standard procedures in the annealed condition. It has excellent ductility but requires considerable power to form (1).

4.02 Machining and Grinding
4.021 General. Alloy is most readily machined in the annealed condition. Hard material can be cut but production rates are lower. The usual preference is to take heavy cuts prior to age hardening and light finishing cuts after aging (1).
4.022 Machining of material in the aged condition produces a smoother, brighter finish than that obtained on annealed material (1).
4.023 High speed steel (with cobalt), cast non-ferrous and cemented carbide tools are suitable for machining the alloy (5).
4.0231 Recommended cutting speed for single point carbide tip tools. 100-200 fpm (7).
4.024 Monel Alloy 501 exhibits improved machinability characteristics. This alloy is identical to Monel Alloy K-500 except for carbon content.

4.03 Joining
4.031 General. Alloy may be welded by the oxyacetylene, inert-gas tungsten arc, or metallic arc processes, using proper filler rods.
4.032 Oxyacetylene flame should be strongly reducing and the heated end of the filler rod should be kept in the protecting atmosphere of the flame to avoid oxidizing the rod. Monel filler metal 64 should be used for GTA, GMA and oxyacetylene welding. A flux is required for oxyacetylene welding (1, p 47).
4.033 For metallic arc welding, K-Monel No. 134 rod should be used in a shielded arc (5).
4.034 Welding should be performed on annealed material and the welded assembly stress relieved before aging. Welded assembly should be taken through the age hardening range as quickly as possible (1).
4.035 Recommended postweld heat treatment, 1080F after quench from 1400-1800F (31, p 21).
4.036 Alloy can be spot welded, silver or copper brazed or soft-soldered (7).
4.037 Tensile properties of butt-welded sheet with and without aging tested at room and low temperatures, Figure 4.037.
4.038 Weld efficiency of butt welded sheet with and without aging tested at room and low temperatures, Figure 4.038.
4.039 Effect of low test temperature on tensile properties of base metal and butt-welds in sheet, Figure 4.039.
4.0310 Fatigue properties of welded joint Figure 4.0310.

66 Ni
29 Cu
3 Al
0.5 Ti

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4.04 Surface Treating

Source	AMS (41)	
	Percent	
	Minimum	Maximum
Aluminum	2.00	4.00
Carbon	-	0.25
Cobalt	-	1.00(a)
Iron	-	2.00
Lead	-	0.006(a)
Manganese	-	1.50
Nickel	63.00	70.0
Phosphorus	-	0.02(a)
Silicon	-	1.00
Sulfur	-	0.01
Tin	-	0.006(a)
Titanium	0.25	1.00
Zinc	-	0.02(a)
Copper	Balance	

(a) Determinaton not required for routine acceptance.

TABLE 1.04 COMPOSITION

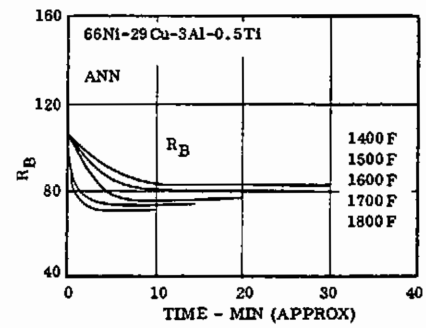

FIG. 1.062 EFFECT OF TIME AT OPEN ANNEALING TEMPERATURE ON HARDNESS. (1, p. 14)

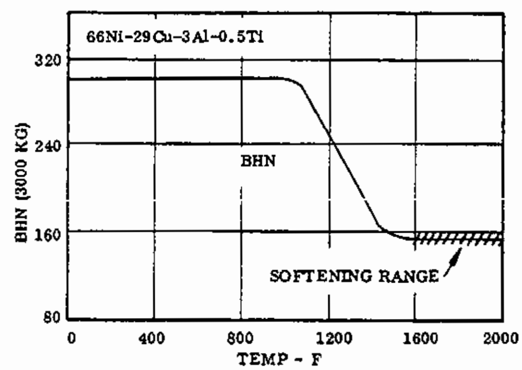

FIG. 1.063 EFFECT OF ANNEALING TEMPERATURE ON HARDNESS OF WATER QUENCHED ALLOY. (1, p. 45)

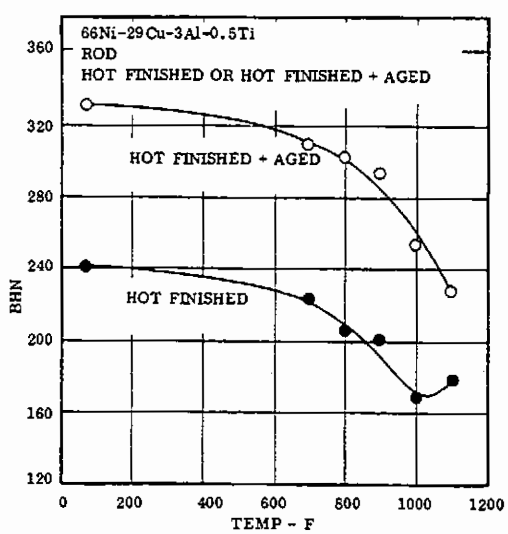

FIG. 1.061 HARDNESS AT ROOM AND ELEVATED TEMPERATURES OF HOT FINISHED AND AGED ROD. (1, p.36)

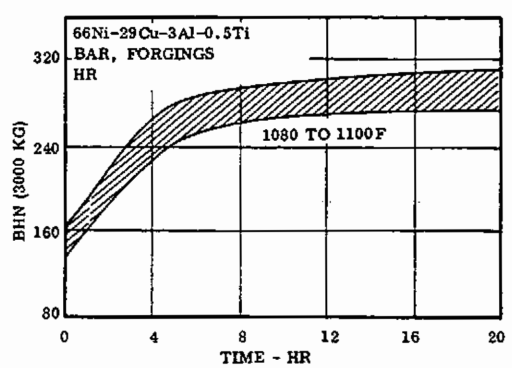

FIG. 1.064 EFFECT OF TIME AT 1080 TO 1100F ON HARDNESS OF BAR AND FORGING. (1, p. 15)

66 Ni
29 Cu
3 Al
0.5 Ti

MONEL ALLOY K-500

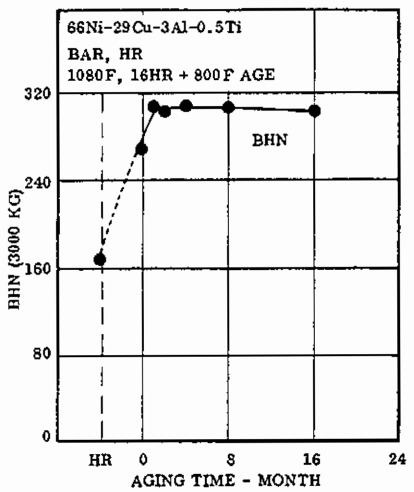

FIG. 1.065 EFFECT OF AGING TIME ON HARDNESS OF HOT ROLLED BAR

(1, p. 15)

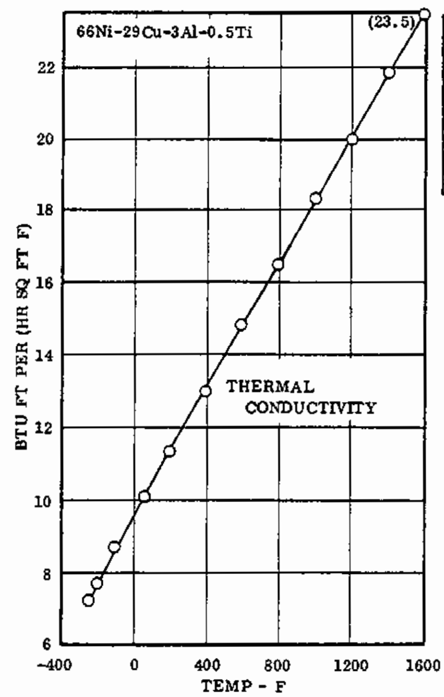

FIG. 2.013 THERMAL CONDUCTIVITY (1, p.32)

Source	(17, p. 58)									
Alloy	66Ni-29Cu-3.5Al-0.5Ti									
Form	.060 inch sheet									
Condition	CR + H.T. as indicated + cathodic charge with H_2 in sol. of 4 percent H_2SO_4 saturated with CS_2.									
Charging Time, Days	0		1		4		9		16	
	H_2 ppm	R_C	H_2 ppm	R_C	H_2 ppm	R_C	H_2 ppm	R_C	H_2 ppm	R_C
CR 60 percent + 1800F, 1/2 hr, WQ + 1100F, 16 hr, F.C. 1000F/6 hr, F.C., 900F/6 hr, AC	-	26.5	49.1(a)	27.0	(b)	26.5	236(a)	26.0	244(a)	26.5
CR 60 percent + 1400F, 1/2 hr, WQ + 1100F/8 hr, F.C. 1000F/6 hr, F.C. 900F/6 hr, AC	-	29.0	51 (a)	30.5	(b)	30.0	210(a)	30.0	324(a)	29.5
CR 60 percent + ann. + 1100F, 16 hr, FC 1000F/6 hr, F.C. 900F/6 hr., AC	-	31.5	61	31.5	75	31.5	127	31.5	(b)	31.5
CR 60 percent + 1100F, 16 hr, FC 1000F/6 hr, FC 900F/6 hr, AC	-	38.5	40(a)	39.5	(b)	39.0	126	38.5	262(a)	39.0
CR 60 percent + 1000F, 16 hr, FC 900F/6 hr, AC	-	40.5	73(a)	41.0	(b)	41.0	154(a)	41.5	309(a)	41.0

(a) Average of 2 tests.
(b) Unsuccessful analysis.

TABLE 1.066 HARDNESS LEVELS ASSOCIATED WITH VARIOUS HEAT TREATMENTS AFTER 60 PERCENT COLD ROLLING AND AFTER HYDROGEN CHARGING IN SULFURIC ACID SOLUTION.

66	Ni
29	Cu
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0.5	Ti

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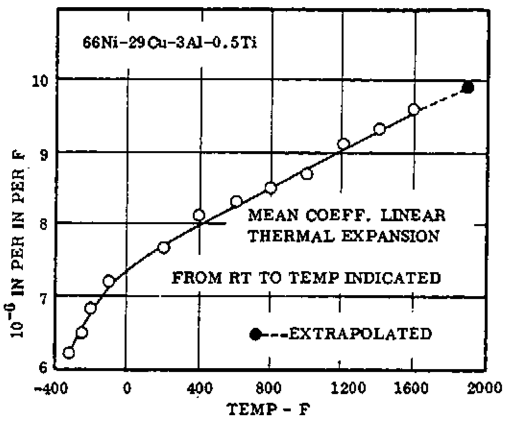

FIG. 2.0141 THERMAL EXPANSION (1, 1. 32)

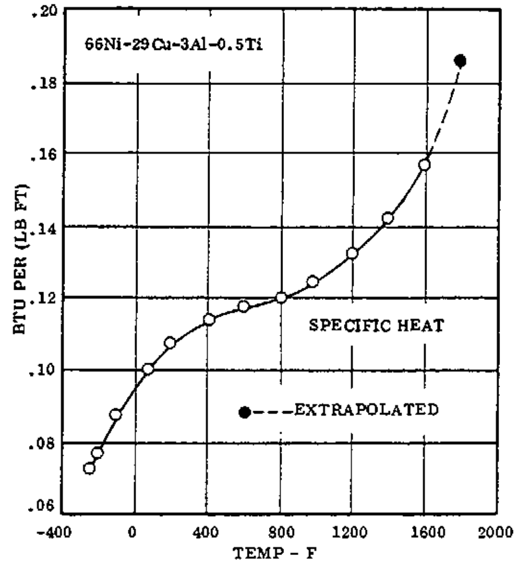

FIG. 2.0151 SPECIFIC HEAT. (1, p. 32)

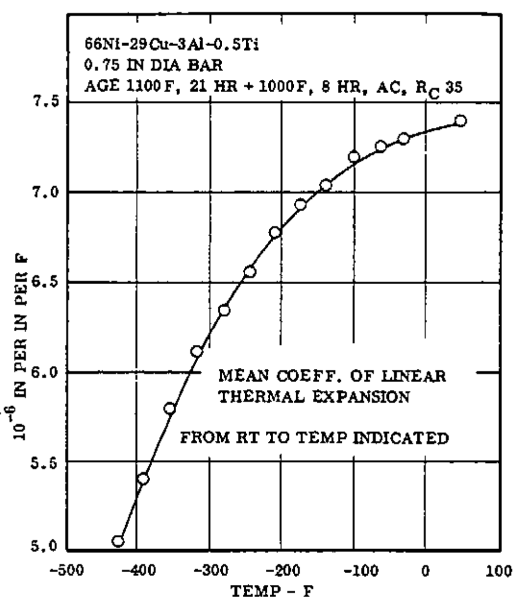

FIG. 2.0142 THERMAL EXPANSION AT LOW TEMPERATURES. (28, p. 234)

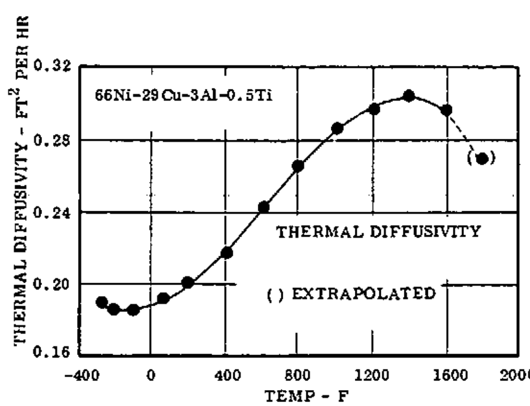

FIG. 2.0161 THERMAL DIFFUSIVITY (14)

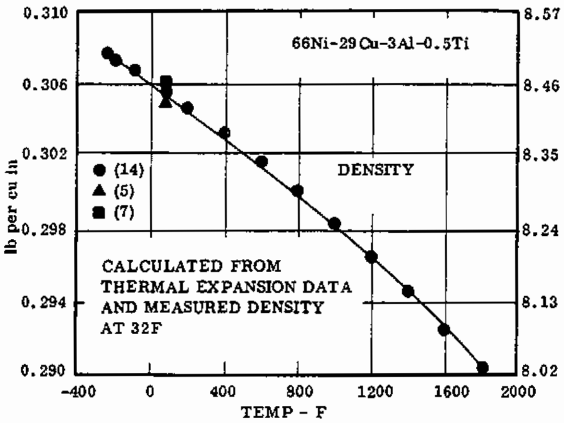

FIG. 2.0211 DENSITY (5)(7)(14)

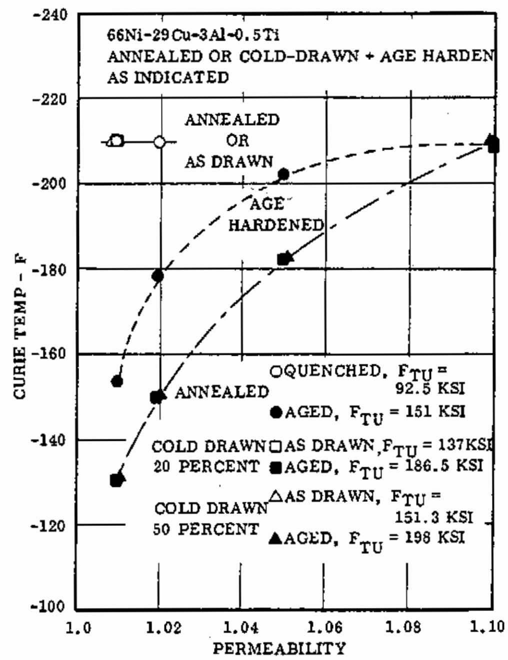

FIG. 2.0233 EFFECT OF PERMEABILITY ON CURIE TEMP. FOR ANNEALED, COLD DRAWN, AND AGE HARDENED ALLOY. (1, p. 32)

66	Ni
29	Cu
3	Al
0.5	Ti

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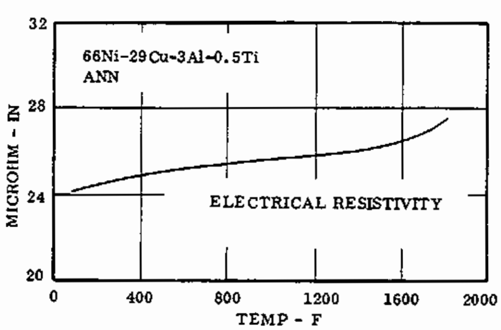


FIG. 2.0221 ELECTRICAL RESISTIVITY (1, p. 4)

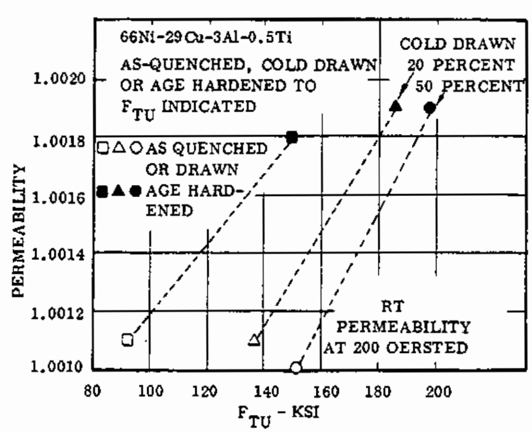


FIG. 2.0234 EFFECT ON PERMEABILITY OF STRENGTH LEVEL AS ACHIEVED BY SEVERAL PROCESSING PROCEDURES. (1, p.32)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

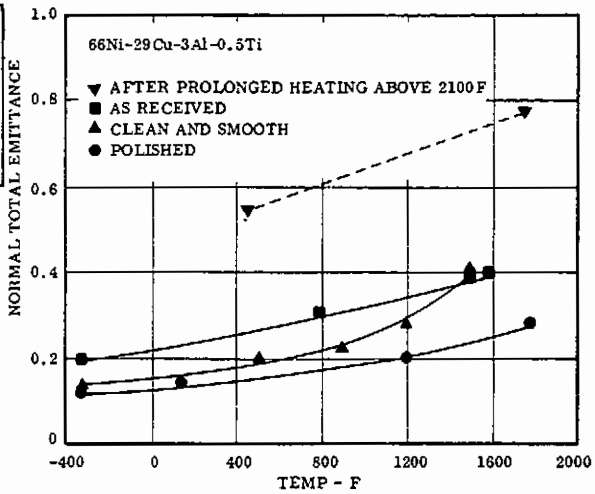


FIG. 2.0241 NORMAL TOTAL EMITTANCE. (9)

Source		(6) (13)	
Alloy		66Ni-29Cu-3Al-0.5Ti	
Test		Tensile - after in-pile radiation	
Condition		Unirradiated	Irradiated (a)
F_{ty}	(ksi)	127.0	133.5
		124.0	134.0
F_{tu}	(ksi)	132.4	167.6
e (2 in)	(percent)	12	19
		9	-
Notch Strength	(ksi)	212.5	195.0
		209.0	-

(a) Specimens were irradiated at 540F for a calculated integrated slow flux of 4 x 10^{19} nvt

TABLE 2.041 EFFECT OF IRRADIATION ON TENSILE AND NOTCH PROPERTIES

Source	(1, p.13)
Alloy	66Ni-29Cu-3Al-0.5Ti
Limit temp - F	Environment
1000	Oxidizing (sulfur free)
800	Steam
600	Oxidizing (sulfur present)
500	Reducing (sulfur present)

TABLE 2.032 TEMPERATURE LIMITS FOR VARIOUS ENVIRONMENTS

Source		(40, pp. 13, 18-20, 65)		
Alloy		66 Ni-29Cu-3Al-0.5Ti		
Condition		Annealed + aged		
Specimen Type		Smooth: 0.125 dia., 1/2 gage length		
		Notched: 0.125 OD, 0.105 ID Center notch, Root radius .0007, K_t = 4		
Irradiation		10^{17} nvt (E > 0.5 Mev) at -430F		
Test Condition (a)		R.T.	-430F	
		Unirrad.	Unirrad.	Irrad.
F_{tu}	(ksi)	154	187	188
F_{ty}	(ksi)	98	121	139
Notch Ten. Str.	(ksi)	180	210	211
Notch strength ratio	$\frac{NS}{F_{tu}}$	1.17	1.20	1.20
e (4D or 1/2 in)	(percent)	28	32	33
RA	(percent)	54	55	51
Fracture Stress	(ksi)			339

(a) Average of 3-5 tests.

TABLE 2.042 EFFECT OF FAST NEUTRON IRRADIATION AND CRYOGENIC TEMPERATURE ON TENSILE PROPERTIES OF SMOOTH AND NOTCHED SPECIMENS.

Source	(33, p.4)
Alloy	66Ni-29Cu-3Al-0.5Ti
Form	0.250 Plate
Test Conditions	0.020 inch diameter drilled passages conducted F_2 gas at 100 psia pressure. Gas and specimen simultaneously heated electrically.

	Threshold Temp. (F)
Static	
a) Significant exotherm	1695
b) Major exotherm, reaching maximum temperature of 2400F, flow passage corroded closed.	1905
Subsonic Flow	
a) Onset of very rapid film buildup	1575
Sonic Flow	
a) Probably onset of rapid film buildup	1520
b) Major exotherm reaching maximum temperature of 2300F, flow passages corroded and restricted	1715

TABLE 2.0341 RESPONSE TO GASEOUS FLUORINE AT VARIOUS TEMPERATURES AND FLOW STATES

Source		AMS 4676 (41)
Alloy		66 Ni-29Cu-3Al-0.5Ti
Form		Bars, Forgings, Forging Stock
Condition		1080-1100F, 16 hr., F.C. @ 15-25F/hr to 900F + 900F to R.T. at all rates
F_{ty}, min.	(ksi)	100
F_{tu}, min.	(ksi)	140
e (2 in or 4D), min., (percent)		
Round bar over 4.25 in dia. and over 12 ft. long		17
All other products		20
BHN Hardness, min. (a)		262

(a) Hardness requirement shall not be cause for rejection if other specifications are met.

TABLE 3.011 AMS SPECIFIED MECHANICAL PROPERTIES FOR BARS, FORGINGS AND FORGING STOCK.

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

Source			(1, p. 35)												
Alloy			66Ni-29Cu-3Al-0.5Ti												
Form			Bar and Rod								Sheet	Strip, Cold Rolled			
Condition			HF	HF + Age(a)	HF + Ann.	HF + Ann + Age(a)	CD	CD + Age(a)	CD + Ann.	CD + Ann + Age(a)	CR + Ann.	Ann.	Ann. + Age(a)	Spring Temper	Spring Temper + Age (a)
F_{tu}	(ksi)	min	90	140	90	130	100	135	90	130	90	90	130	145	170
		max	155	190	110	165	140	185	110	190	105	105	170	165	220
F_{ty}	(ksi)	min	40	100	40	85	70	95	40	85	40	40	90	130	130
		max	110	150	60	120	125	160	60	120	65	65	120	160	195
e	(percent)	min	20	20	25	20	13	15	25	20	25	25	15	3	5
		max	45	30	45	35	35	30	50	30	45	45	25	8	10
Hardness	(RC)	min	-	27	-	24	-	25	-	24	-	-	24	25	34
		max	35	38	-	35	26	41	-	35	-	-	-	-	-
	(RB)	min	75	-	75	-	88	-	75	-	-	-	-	-	-
		max	-	-	90	-	-	-	90	-	85	85	-	-	-
BHN	(3000kg)	min	140	265	140	250	175	255	140	250	-	-	-	-	-
		max	315	346	185	315	260	370	185	315	-	-	-	-	-

(a) Age hardened for max. properties.

TABLE 3.012 SPECIFIED PROPERTIES FOR BAR, ROD, SHEET AND STRIP

Source			(1, p. 35)										
Alloy			66Ni-29Cu-3Al-0.5Ti										
Form			Tube and Pipe - Seamless					Plate		Wire (0.0625 - 0.250 Dia.)			
Condition			Hot Fin (a)	CD + Ann.	CD + Ann + Age(b)	CD as Drawn	CD + Age(b)	Hot Fin	Hot Fin + Age(b)	CD + Ann.	CD + Ann + Age(b)	Spring Temper	Spring Temper + Age(b)
F_{tu}	(ksi)	min	-	90	130	110	140	90	140	80	120	145	160
		max	-	110	180	160	220	135	180	110	150	190	200
F_{ty}	(ksi)	min	-	40	85	85	100	40	100	35	90	130	140
		max	-	65	120	140	200	110	135	65	110	180	190
e	(percent)	min	-	25	15	2	3	20	20	20	15	2	3
		max	-	45	30	15	25	45	30	40	30	5	8
Hardness	(RC)	min	-	-	24	-	27	-	27	-	-	-	-
		max	-	-	36	32	40	26	37	-	-	-	-
	(RB)	min	-	-	-	95	-	75	-	-	-	-	-
		max	-	90	-	-	-	-	-	-	-	-	-
BHN	(3000kg)	min	-	-	-	-	-	140	265	-	-	-	-
		max	-	-	-	-	-	260	337	-	-	-	-

(a) Properties upon request from INCO.
(b) Age hardened for max. properties.

TABLE 3.013 SPECIFIED PROPERTIES FOR TUBE, PIPE, PLATE AND WIRE

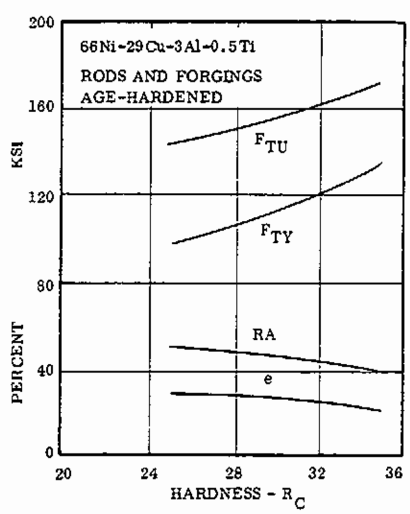


FIG. 3.02121 APPROXIMATE RELATIONSHIP BETWEEN TENSILE PROPERTIES AND HARDNESS OF AGE-HARDENED ROD AND FORGINGS. (1, p. 6)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

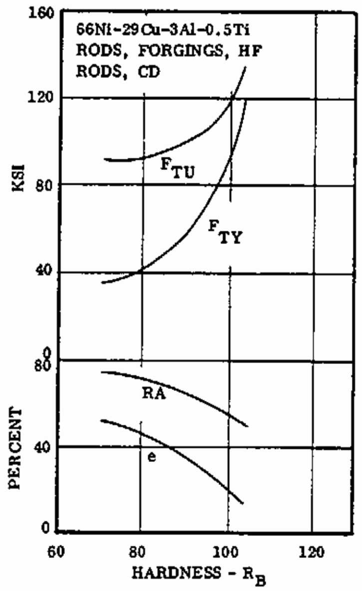


FIG. 3.02122 APPROXIMATE RELATIONSHIP BETWEEN TENSILE PROPERTIES AND HARDNESS OF HOT FINISHED RODS AND FORGINGS AND COLD DRAWN RODS. (1, p. 6)

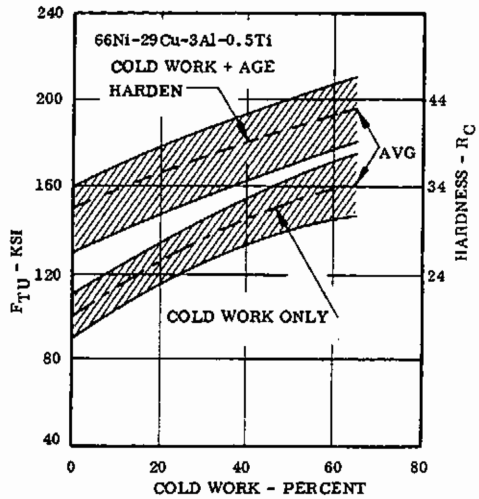


FIG. 3.02131 EFFECT OF COLD WORK ON MAXIMUM AND MINIMUM TENSILE PROPERTIES AND HARDNESS. (1, p. 13)

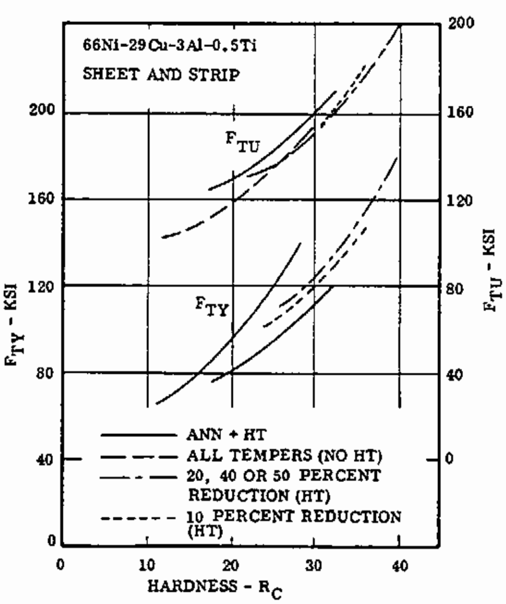


FIG. 3.02123 APPROXIMATE RELATIONSHIP BETWEEN TENSILE STRENGTH AND HARDNESS OF SHEET AND STRIP. (1, p. 6)

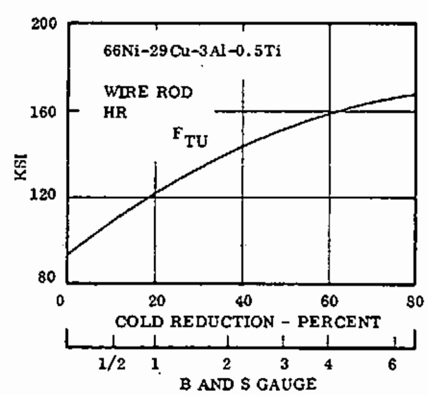


FIG. 3.02132 EFFECT OF WORK HARDENING AND WIRE THICKNESS ON TENSILE STRENGTH OF WIRE ROD. (12, p. 5)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

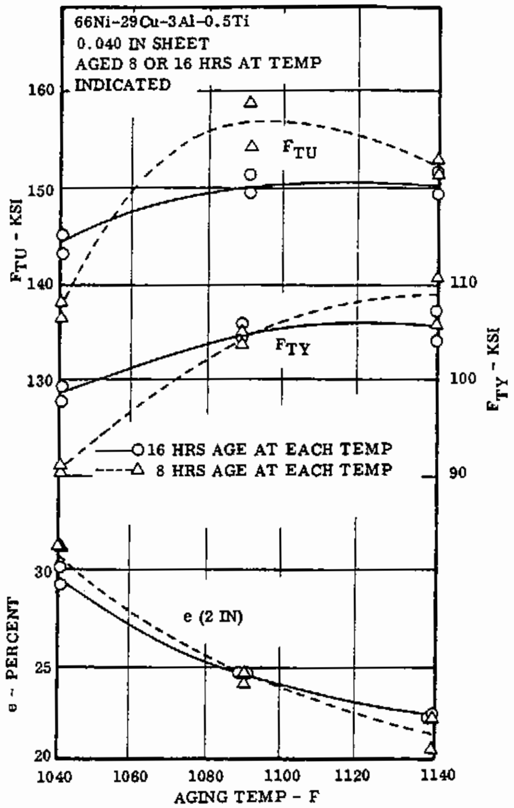


FIG. 3.02141 EFFECT OF AGING TEMPERATURE FOR 8 AND 16 HR AGES ON TENSILE PROPERTIES OF SHEET. (36, p.p. 1.A.7.7.1, 1-7)

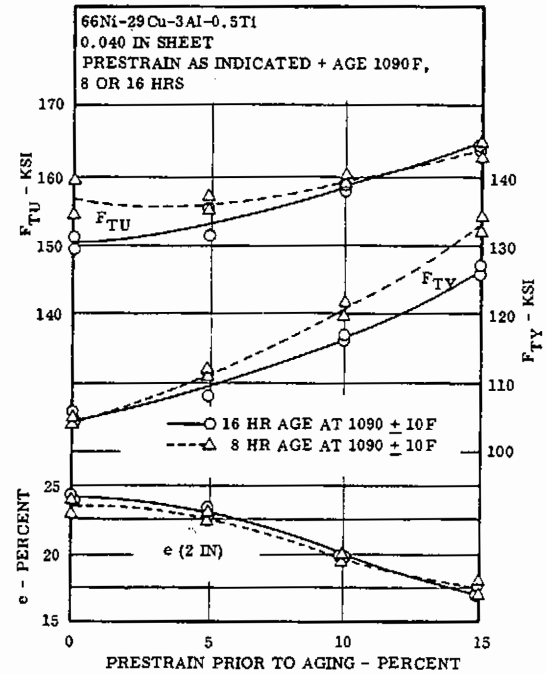


FIG. 3.02142 EFFECT OF PRIOR STRAIN ON TENSILE PROPERTIES OF SHEET AFTER 8 OR 16 HR AGE AT 1090F. (36, p.p. 1·A·7·7·1, 1-7)

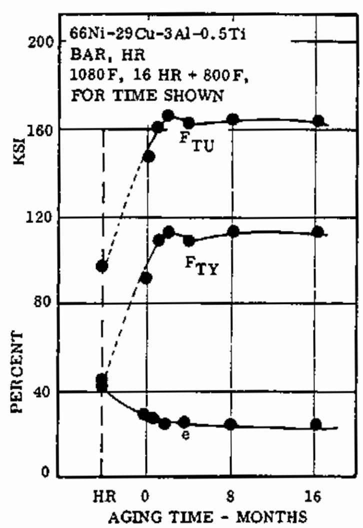


FIG. 3.02143 EFFECT OF AGING TIME ON TENSILE PROPERTIES OF HOT ROLLED BAR. (1, p. 15)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

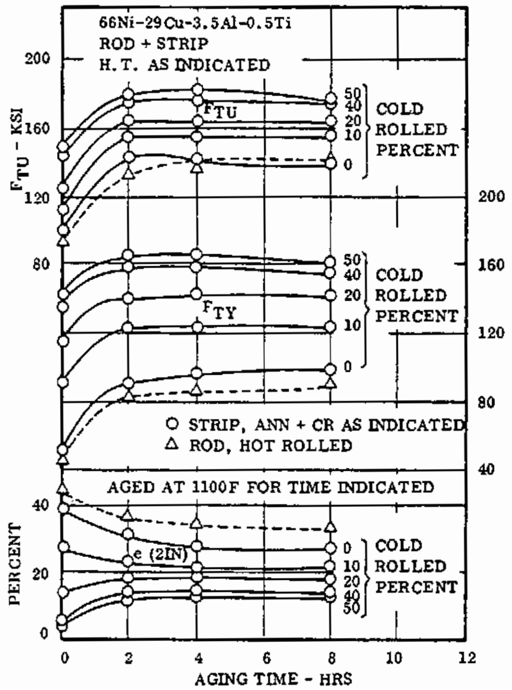


FIG. 3.02144 EFFECT OF SHORT TIME AGING AT 1100F ON TENSILE PROPERTIES OF COLD ROLLED STRIP AND HOT ROLLED ROD. (1, p. 47)

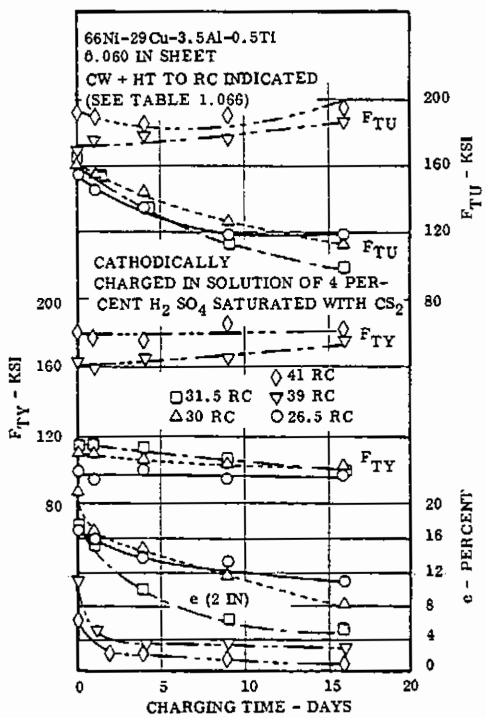


FIG. 3.02151 EFFECT OF HYDROGEN CHARGING ON TENSILE PROPERTIES OF SHEET COLD WORKED AND HEAT TREATED TO VARIOUS HARDNESS LEVELS. (17, p. 58)

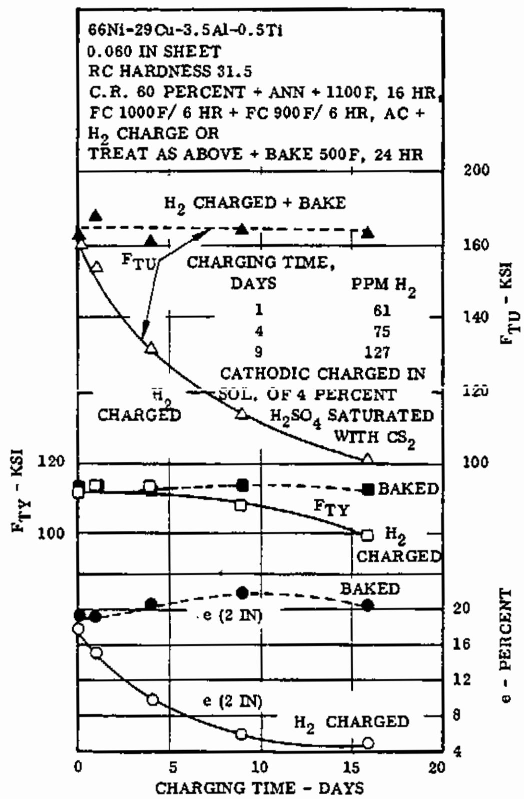


FIG. 3.02152 EFFECT OF HYDROGEN CHARGING ON TENSILE PROPERTIES OF 31.5 RC SHEET, AND RESTORATION OF INITIAL PROPERTIES BY 500F BAKE FOR 24 HRS. (17, p. 58)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

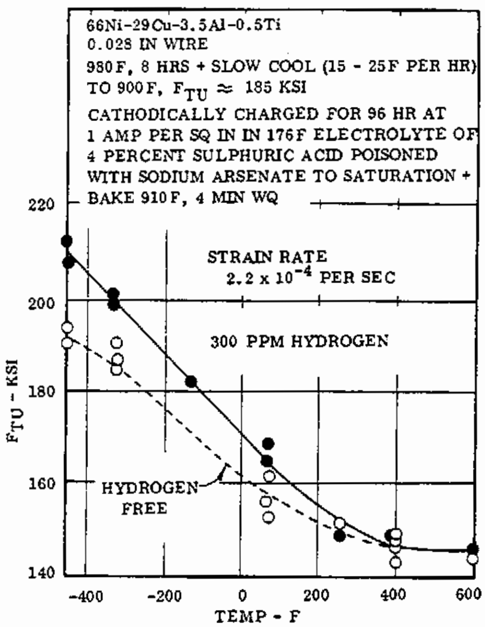


FIG. 3.02153 EFFECT OF TEST TEMPERATURE ON TENSILE YIELD STRESS OF HYDROGEN-FREE AND HYDROGENATED WIRE. (24, p. 39)

Source	(1, p.40)	Charpy Keyhole Impact Energy (ft-lbs)	
Alloy	66Ni-29Cu-3Al-0.5Ti		
Form	Bar		
Condition		L	T
Hot finished		74	51
Hot finished + 1800F, 1 hr, WQ		75	48
Hot finished + 1100F, 16 hr, AC (a)		39	23
Hot finished + 1100F, 16 hr, FC 15F per hr to 900F, AC (a)		25	20
Hot finished + 1800F, 1 hr, WQ + 1100F, 16 hr, FC 15F per hr to 900F, AC (a)		38	22
Cold drawn		40	-
Cold drawn + 1800F, 1 hr, WQ		90	-
Cold drawn + 1100F, 16 hr, AC (a)		26	-
Cold drawn + 1100F, 16 hr, FC 15F per hr to 900F, AC (a)		20	-
Cold drawn + 1800F, 1 hr, WQ + 1100F, 16 hr, FC 15F per hr to 900F, AC (a)		46	-

(a) Specimen fractured completely.

TABLE 3.0231 CHARPY KEYHOLE IMPACT ENERGY FOR HOT FINISHED AND COLD DRAWN BAR WITH SEVERAL HEAT TREATMENTS

Source	(1, p.40)	
Alloy	66Ni-29Cu-3Al-0.5Ti	
Form	Hot Rolled Rod of Dia. Indicated	
Condition	1800F, 1/2 hr + 1100F 16 hr., FC to 1000F in 6 hr., FC to 900F in 6 hr, AC	
Diameter (in) (a)	F_{ty} (ksi)	Charpy V Impact Energy (ft-lbs)
1.250	97.3	54
1.250	92.5	72
0.875	109.3	45
1.00	111	38

(a) Each diameter from a different heat.

TABLE 3.0232 CHARPY-V IMPACT ENERGY OF SPECIMENS FROM SEVERAL SIZES OF HOT ROLLED ROD

Source		(1, p.40)			
Alloy		66Ni-29Cu-3Al-0.5Ti			
Form		Rod			
Condition		Hot Rolled		Cold Drawn	
		As Rolled	Aged	As Drawn	Aged
Compression					
F_{cy} (0.2 percent)	(ksi)	40	121	76	121
F_{cy} (0.01 percent)	(ksi)	34	96	55	102
Tension					
F_{tu}	(ksi)	100	151	106	158
F_{ty}	(ksi)	47	111	85	120
e (2 in)	(percent)	42.5	30	26.5	22
Hardness	(RC)	5	33	23	35

TABLE 3.0222 COMPRESSIVE YIELD STRENGTH OF ROD

Source	(1, p.41)	
Alloy	66Ni-29Cu-3Al-0.5Ti	
Form	Cold drawn rod of dia. indicated	
Condition	1900F, 1/2 hr, + 1100F, 16 hr, FC to 1000F in 6 hr, FC to 900F in 6 hr, AC	
Diameter (in) (a)	F_{ty} (ksi)	Charpy V Impact Energy (ft-lbs)
1.250	92.5	76.3
0.812	103	43.8
0.687	110.6	39.5

(a) Each diameter from a different heat. Average of 2 tests.

TABLE 3.0233 CHARPY-V IMPACT ENERGY OF SPECIMENS FROM SEVERAL SIZES OF COLD DRAWN ROD

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

Source	(5)	
Alloy	66Ni-29Cu-3Al-0.5Ti	
Temp - F	RT	
Type of Test	Impact	
	Impact energy, ft-lbs	
Condition	Izod	Charpy U-notch
HR	120+	170
HR + Age	40 (a)	61 (a)
CD	56 (a)	71 (a)
CD + Age	26 (a)	42 (a)

(a) Specimens fractured completely.

TABLE 3.0234 IMPACT ENERGY OF ALLOY IN SEVERAL CONDITIONS OF HEAT TREATMENT

Source	(12)		
Alloy	66Ni-29Cu-3Al-0.5Ti		
Form	(a) 0.080-0.148 in dia. CD Spring Wire		
Temp - F	RT		
	Tension		Torsion
Condition	F_{tu} (ksi)	F_{ty} (ksi)	Breaking strength (ksi)
As drawn	172	165	115
Stress equal, 575F, 1 hr	181	179	122
Stress equal, 650F, 1 hr	181	179	123
Aged, 1000F, 4 hr, AC	204	195	138
Aged, 1000F, 6 hr, FC	209	203	142
Aged, 1000F, 6 hr, (b)	213	206	148

(a) Cold drawn 75 percent reduction.
(b) Slow cool, 15F per hr to 900F, AC.

TABLE 3.0251 TORSIONAL PROPERTIES OF COLD-DRAWN SPRING WIRE

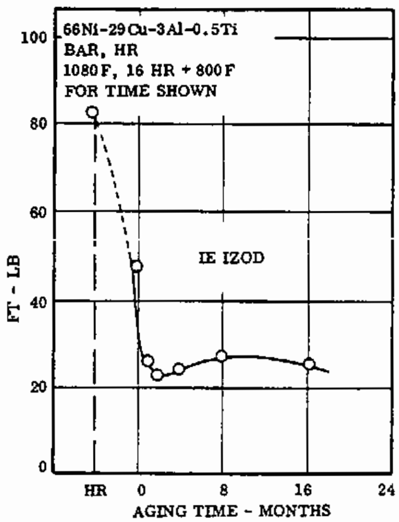


FIG. 3.0235 EFFECT OF AGING TIME ON IZOD IMPACT ENERGY OF HOT ROLLED BAR. (1, p. 15)

Source	(1, p.43)		
Alloy	66Ni-29Cu-3Al-0.5Ti		
Form	0.148 Dia. Spring Temper Wire, 65 percent Reduction		
Condition After Cold Coiling	As Drawn	525F, 3 hr. (Stress equalized)	Aged 980F, 6 hr + 900F, 6 hr
F_{tu} (ksi)	162.5	171.8	197
F_{su} (ksi)	106.3	107.2	137.2
F_{sy} (ksi)	67.5	67.5	74.6

TABLE 3.0252 PROPERTIES OF HELICAL SPRING WIRE IN SEVERAL CONDITIONS OF THERMAL TREATMENT AFTER COLD COILING

Source	(17, p.62)			
Alloy	66Ni-29Cu-3.5Al-0.5Ti			
Form	Charpy-V Specimen			
Condition	RC Values as indicated			
	RC 17		RC 31	
	No H_2	Charged 16 days(a)	No H_2	Charged 16 days(a)
Charpy-V Impact Strength (ft-lbs)	86, 89	67, 67	58, 64	44, 49

(a) Charged cathodically in 4 percent H_2SO_4 solution saturated with CS_2. Approx. H_2 content in 16 days - 275 ppm.

TABLE 3.0236 EFFECT OF HYDROGEN CHARGING FOR 16 DAYS ON CHARPY IMPACT ENERGY OF ALLOY IN TWO CONDITIONS OF HARDNESS

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

Source	(1, pp 38, 39)				
Alloy	66Ni-29Cu-3Al-0.5Ti				
Form (a)	0.113 in. dia. rivet wire and 1/8 in dia. x 1/4 in long rivets				
Condition	As Rec.	Aged 1080F 2 hr, AC	Aged 1080F 4 hr., AC (b)	Aged 1080F 16 hr., AC	Aged 1080F, 16 hr, FC to 900F at 15F per hr., AC
Rivet Wire					
Hardness (RC)	13	24	26	26	32
F_{tu} (ksi)	107.3	133	137.6	-	147
F_{su} (ksi)	69.3	83.2	85.3	85	89.2
Rivet Hardness					
Head (RC)	34	40	40	40	40
Shank (RC)	23	30	32	30	34

(a) Tested in double shear, using 1 inch wire in tongue and groove jig with .002 inch clearance.
(b) Recommended treatment by INCO for cold-headed rivets.

TABLE 3.0253 TENSILE, HARDNESS AND SHEAR PROPERTIES OF RIVET WIRE AND HARDNESS OF RIVETS

Source	(1, p.39)					
Alloy	66Ni-29Cu-3Al-0.5Ti					
Form	0.148 Dia. Wire		1 In Dia. Rod			
and Condition	CD 5 percent	CD 50 percent + Age	Hot Rolled	Hot Rolled + Age	CD 20 percent	CD 20 percent + Age
F_{ty} (ksi)	-	-	45	-	103	125
F_{tu} (ksi)	163	197	98	-	134	155
Prop. Limit, in Torsion (ksi)	68	75	18	62	45	50
F_{su} (ksi)	107	137	69	-	80	102

TABLE 3.0254 TORSIONAL SHEAR PROPERTIES OF WIRE AND ROD IN SEVERAL CONDITIONS

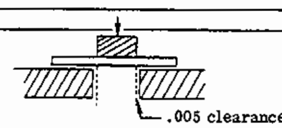
Source	(1, p.38, 39)					
Alloy	66Ni-29Cu-3Al-0.5Ti					
Form	0.050 x 0.250 in sheet 					
Condition	Annealed		Half Hard		Full Hard	
	As Ann	Ann + Age	As Hardened	Aged	As Hardened	Aged
F_{tu} (ksi)	97.5	147.2	122	155.6	151.5	168.5
e (2 in) (percent)	49	29	12.5	24	16.5	12.5
Hardness (R_C)	87 (R_B)	29	25	31	33	37
F_{su} (ksi)	65.3	96.5	71	98.8	89.5	98.5

TABLE 3.0255 SHEAR STRENGTH OF SHEET IN SEVERAL CONDITIONS OF HEAT TREATMENT

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL
ALLOY
K-500

Source	(1, p. 40)			
Alloy	66Ni-29Cu-3Al-0.5Ti			
Form	0.062 in sheet; 2.5; 1.25; 3/16 Dia; 3/8 (a)			
Condition	Annealed		Hard	
	As Ann.	Ann + Age	As Hardened	Hard + Age
F_{bry} (b) (ksi)	68.8	162	190	262
F_{bru} (c) (ksi)	178	295	294	358
F_{ty} (ksi)	38.5	98.5	139	177
F_{tu} (ksi)	92.2	145.5	145.9	195.5
e (2 in) (percent)	49	31	5	10

(a) Determined by loading close fitting pin in hole.
(b) 2 percent enlargement of hole in sheet.
(c) Tear-out.

TABLE 3.0261 BEARING STRENGTH OF SHEET IN SEVERAL CONDITIONS OF HEAT TREATMENT

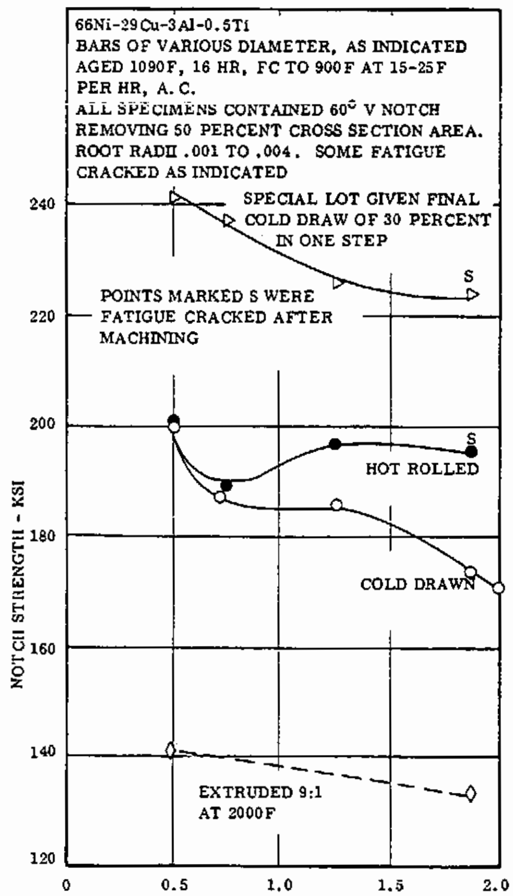


FIG. 3.02711 EFFECT OF SECTION SIZE ON NOTCH STRENGTH OF ALLOY PRODUCED BY SEVERAL PROCESSES. (30, p. 382)

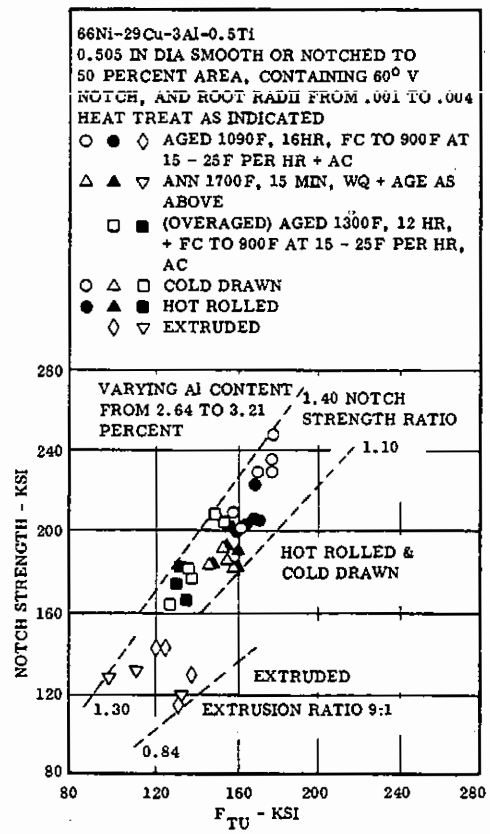


FIG. 3.02712 RELATION BETWEEN NOTCH STRENGTH AND ULTIMATE TENSILE STRENGTH FOR HOT ROLLED, COLD DRAWN, AND EXTRUDED MATERIAL CONTAINING AN ALUMINUM CONTENT RANGE FROM 2.64 TO 3.21 PERCENT SUBJECTED TO SEVERAL HEAT TREATMENTS. (30, p.p. 377-379)

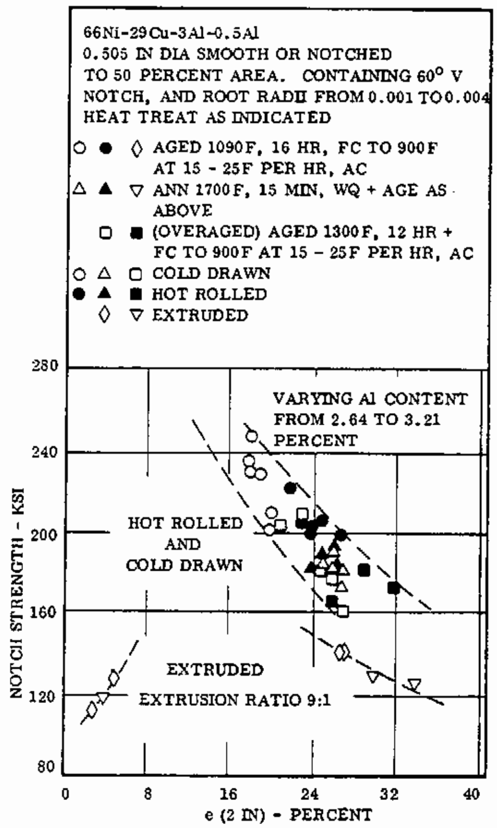


FIG. 3.02713 RELATION BETWEEN NOTCH STRENGTH AND SMOOTH SPECIMEN ELONGATION FOR HOT ROLLED, COLD DRAWN, AND EXTRUDED MATERIAL CONTAINING AN ALUMINUM CONTENT RANGE FROM 2.64 TO 3.21 PERCENT SUBJECTED TO SEVERAL HEAT TREATMENTS. (30, p.p. 377-380)

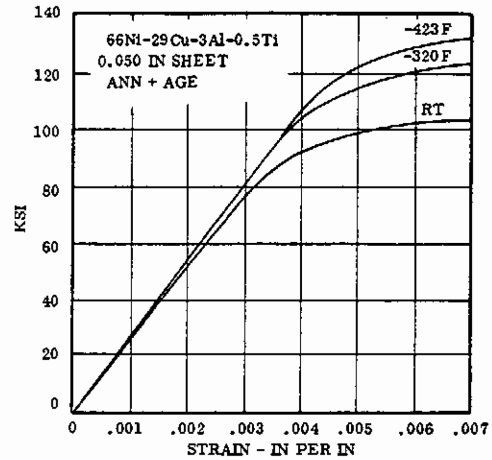


FIG. 3.03111 STRESS - STRAIN CURVES AT ROOM AND LOW TEMPERATURES FOR ANNEALED AND AGED SHEET. (15, p. K-9)

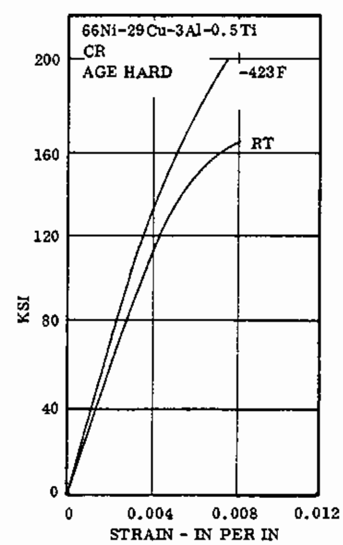


FIG. 3.03112 STRESS-STRAIN CURVES AT LOW AND ROOM TEMPERATURE FOR COLD ROLLED AND AGED-HARDENED ALLOY. (4, p. 13)

Source	(23) (19, p.63)	
Alloy	66Ni-29Cu-3.5Al-0.5Ti	
Form	Notched Spec. $K_t = 4.0$	
Condition	Annealed F_{tu} of smooth spec. in air = 100 ksi	Aged F_{tu} of smooth spec. in air = 139 ksi
NTS in 10 ksi N_2	144	251
NTS in 10 ksi H_2	105	113
Ratio $\frac{NTS, H_2}{NTS, N_2}$	0.73	0.45

TABLE 3.02714 NOTCHED TENSILE STRENGTH IN HIGH PRESSURE NITROGEN AND HYDROGEN

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

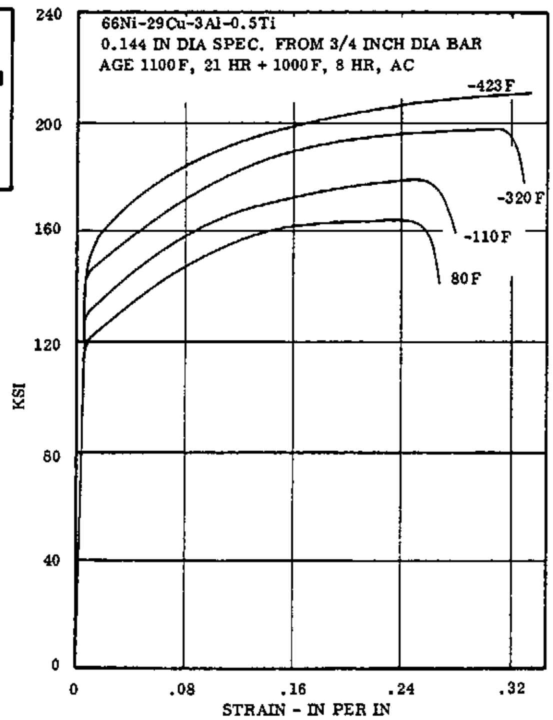


FIG. 3.03113 STRESS-STRAIN CURVES AT ROOM AND LOW TEMPERATURES FOR AGED BAR. (26, p. 47)

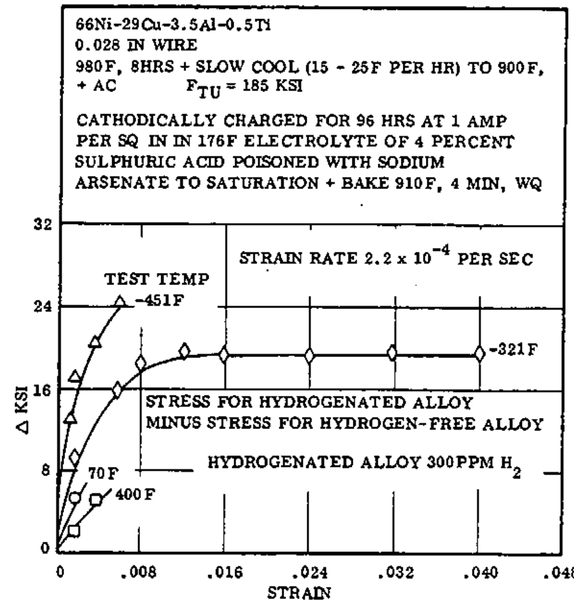


FIG. 3.03115 ELEVATION OF FLOW STRESS OF WIRE CAUSED BY 300PPM HYDROGENATION. (24, p. 41)

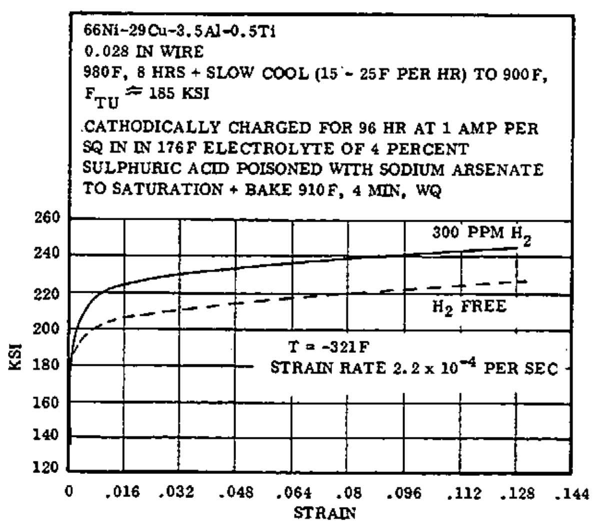


FIG. 3.03114 STRESS-STRAIN CURVE AT -321 FOR HYDROGEN-FREE AND HYDROGENATED ALLOY WIRE. (24, p. 40)

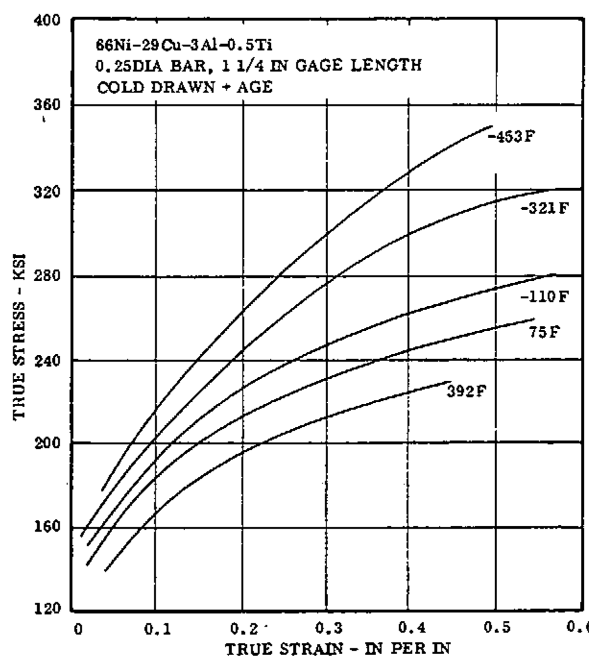


FIG. 3.03116 TRUE STRESS - TRUE STRAIN CURVES FOR COLD-DRAWN AND AGED ROD FROM -453F TO 392F. (29, p. 3)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

Source		(5)		
Alloy		66Ni-29Cu-3Al-0.5Ti		
Condition		CD + Aged		
Type of Test		Tensile		
Temp - F		RT	RT(a)	-110F
F_{tu}	(ksi)	157.3	157.4	171.6
F_{ty}	(ksi)	125.9	125.9	134.6
e (2 in)	(percent)	15.5	14.8	17.3
RA	(percent)	37.4	37.2	41.1
Hardness	(RC)	33	33	36

(a) Specimens cooled to -110F for several hours prior to testing at room temperature.

TABLE 3.03122 TENSILE PROPERTIES AT ROOM AND LOW TEMPERATURES FOR COLD DRAWN AND AGED ALLOY

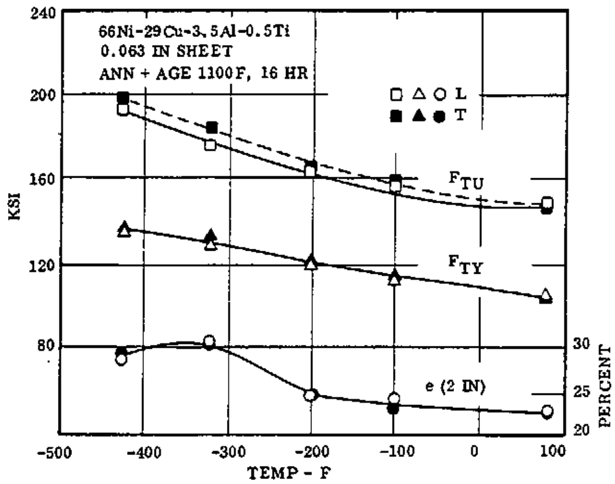


FIG. 3.03124 TENSILE PROPERTIES OF ANNEALED AND AGED SHEET IN LONGITUDINAL AND TRANSVERSE DIRECTIONS AT ROOM AND LOW TEMPERATURES. (16, p. 47)

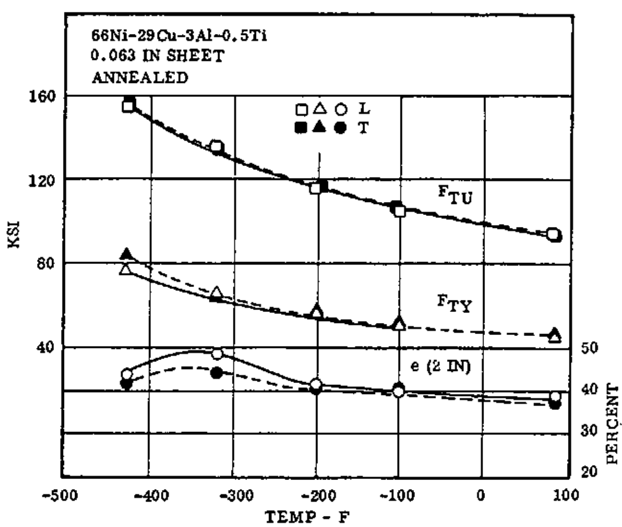


FIG. 3.03123 TENSILE PROPERTIES OF ANNEALED SHEET IN LONGITUDINAL AND TRANSVERSE DIRECTIONS AT ROOM AND LOW TEMPERATURES. (16, p. 47)

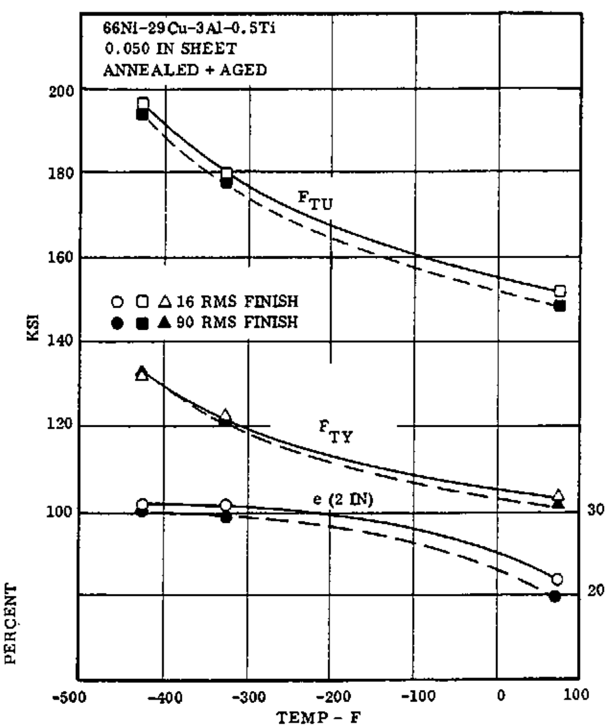


FIG. 3.03125 TENSILE PROPERTIES OF ANNEALED AND AGED SHEET HAVING TWO SURFACE CONDITIONS AT ROOM AND LOW TEMPERATURES. (15, p. K-7)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

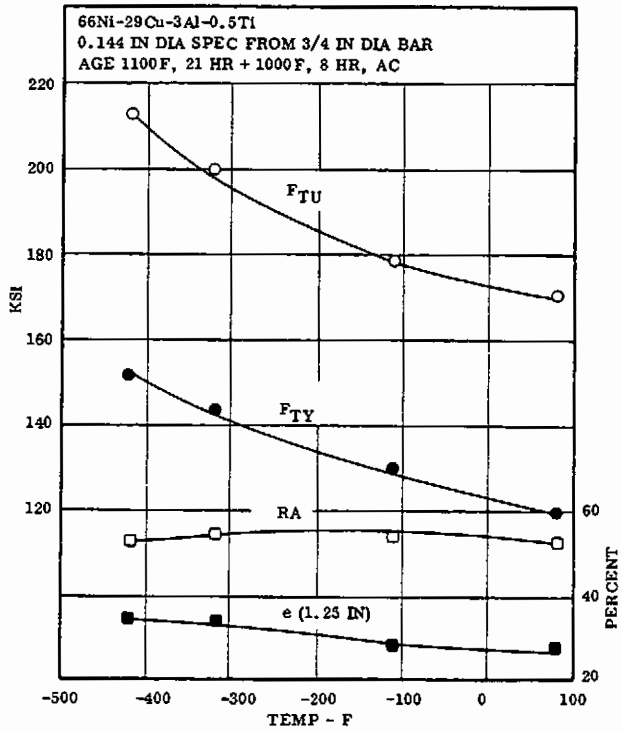


FIG. 3.03127 TENSILE PROPERTIES AT ROOM AND LOW TEMPERATURES FOR AGED BAR. (26, p. 24)

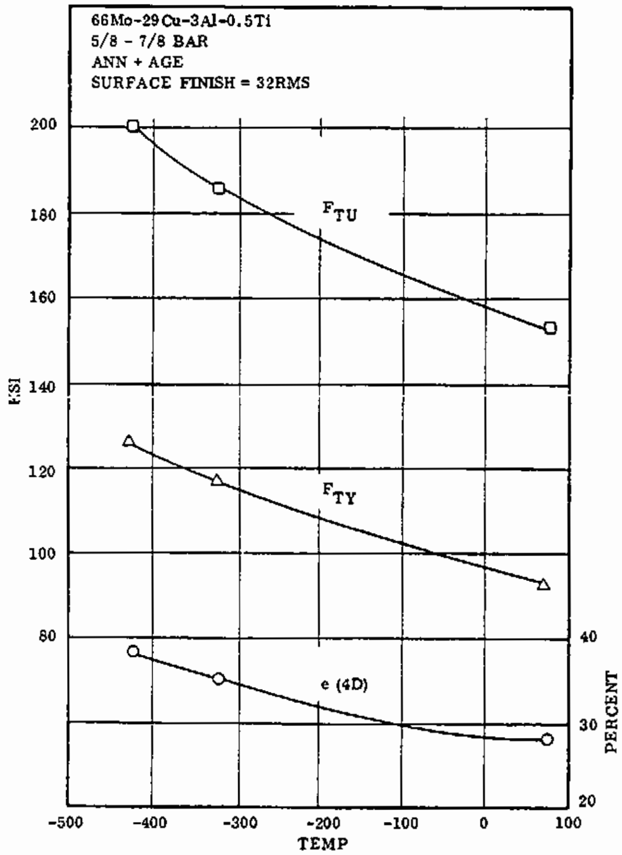


FIG. 3.03126 TENSILE PROPERTIES OF ANNEALED AND AGED BAR AT ROOM AND LOW TEMPERATURES. (15, p. K-13)

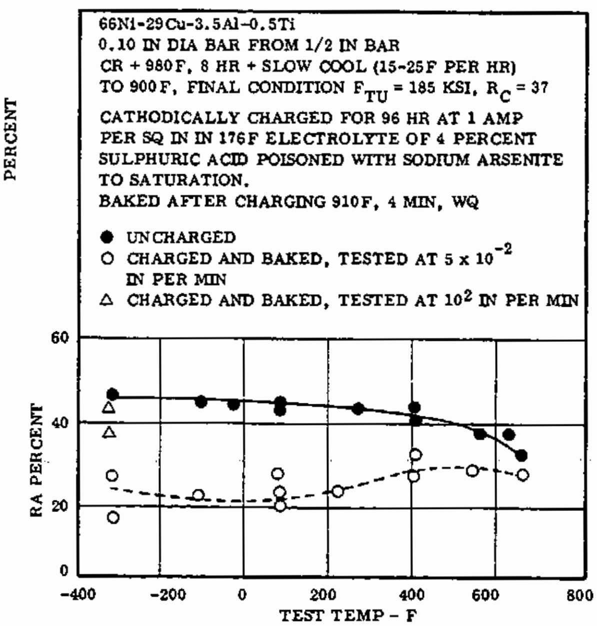


FIG. 3.03128 EFFECT OF TEST TEMPERATURE ON DUCTILITY OF ALLOY WITH AND WITHOUT HYDROGENATION. (24, p.28)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

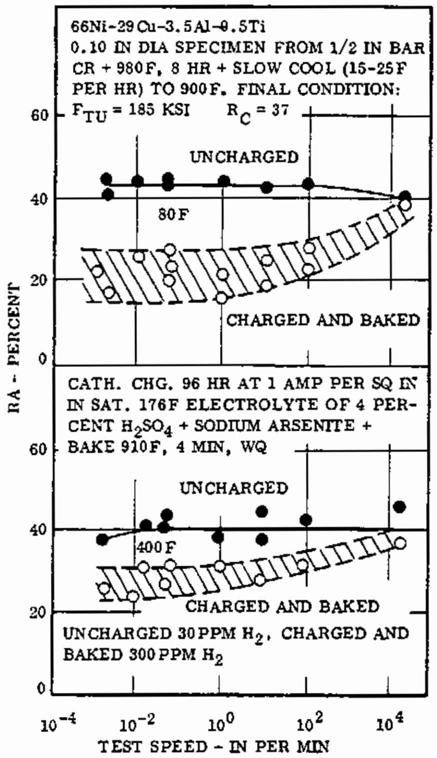


FIG. 3.03131 EFFECT OF STRAIN RATE ON DUCTILITY AT 80F AND 400F FOR ALLOY WITH AND WITHOUT HYDROGEN CHARGE. (24, p.27)

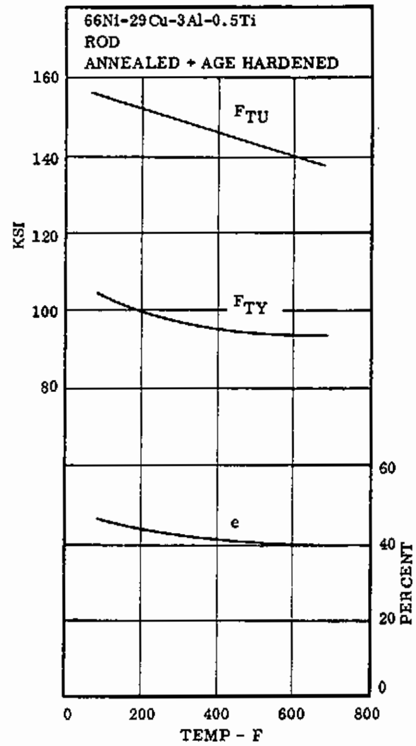


FIG. 3.03132 TENSILE PROPERTIES AT ROOM AND ELEVATED TEMPERATURES FOR ANNEALED AND AGE HARDENED ALLOY (1, p. 37)

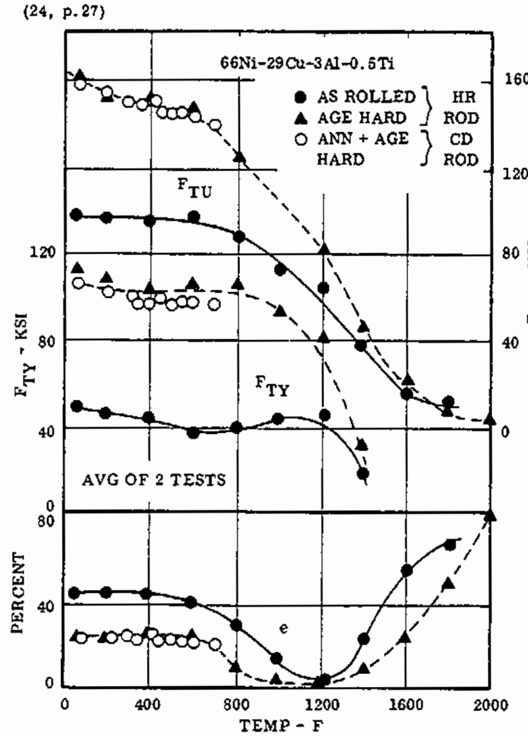


FIG. 3.03133 EFFECT OF ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF COLD DRAWN AND HOT ROLLED ROD. (1, p.8)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

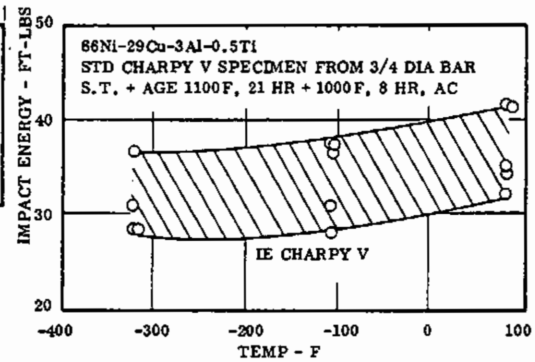


FIG. 3.0331 CHARPY V IMPACT ENERGY AT ROOM AND LOW TEMPERATURES FOR SOLUTION TREATED AND AGED BAR. (26, p. 24)

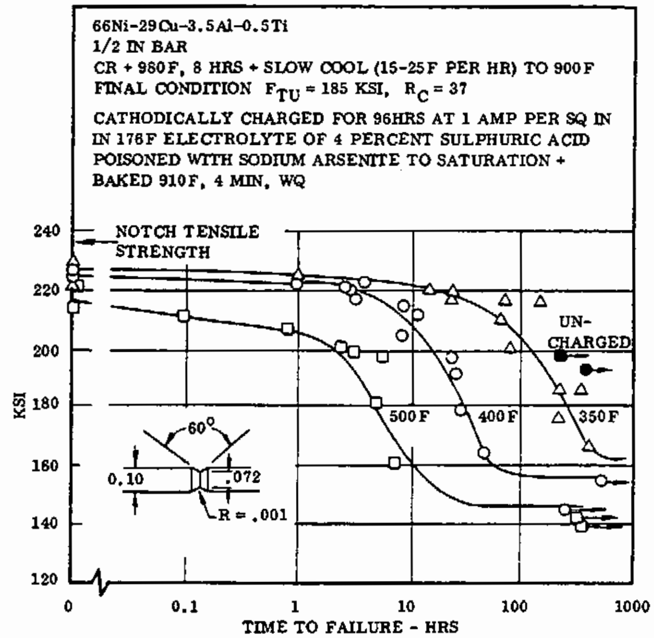


FIG. 3.03711 SUSTAINED LOAD FAILURE CURVES AT 350, 400, AND 500F FOR HYDROGENATED NOTCHED SPECIMENS. (24, p. 25)(25)

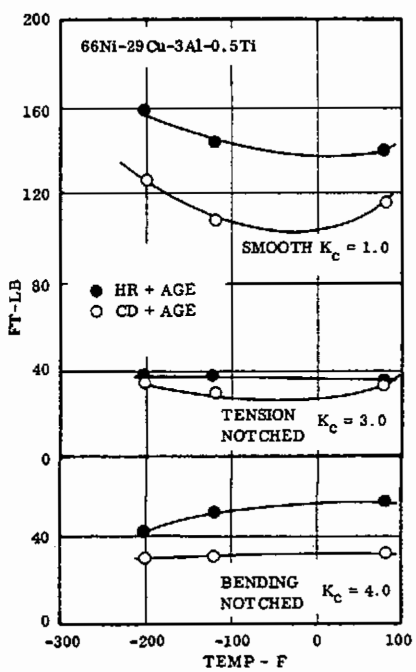


FIG. 3.0332 EFFECT OF LOW TEMPERATURE ON BENDING AND TENSION IMPACT ENERGY FOR NOTCHED AND SMOOTH SPECIMENS. (1, p.9)

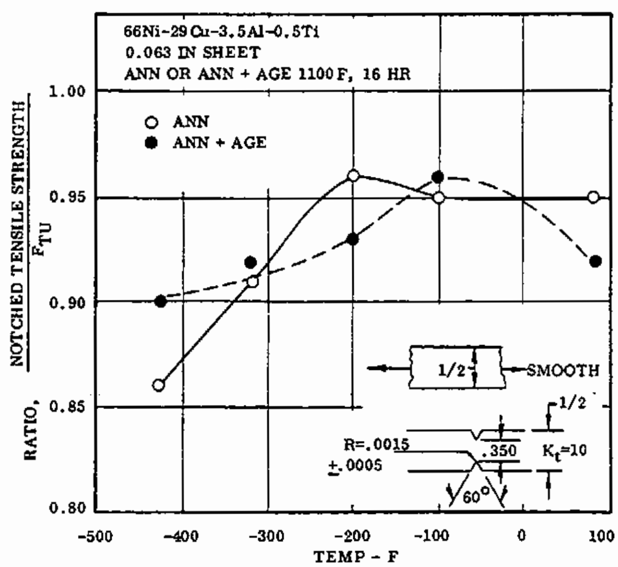


FIG. 3.03712 NOTCH STRENGTH RATIO AT ROOM AND LOW TEMPERATURES FOR SHEET IN ANNEALED AND IN AGED CONDITION. (16, p.47)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

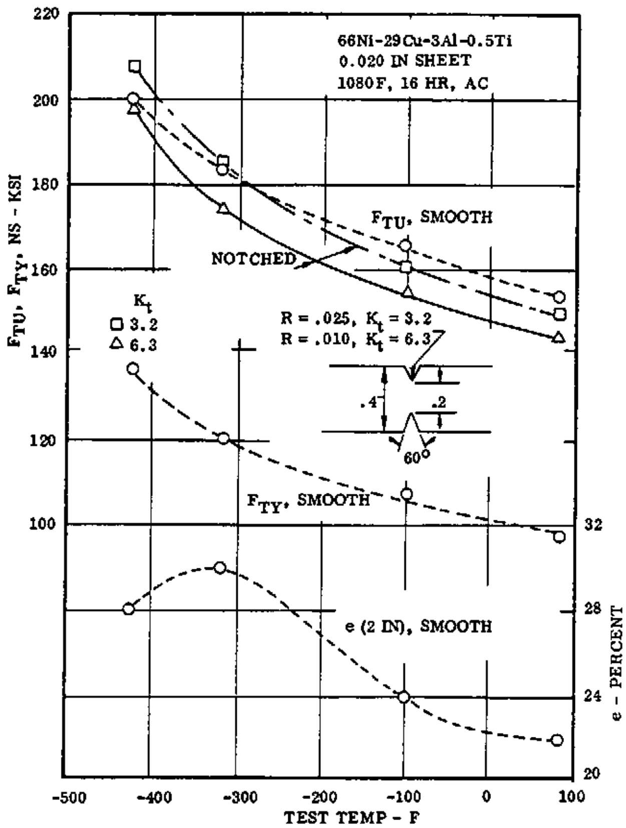


FIG. 3.03713 TENSILE AND NOTCH PROPERTIES OF AGE HARDENED SHEET AT ROOM AND LOW TEMPERATURES. (2, TABLE 35)

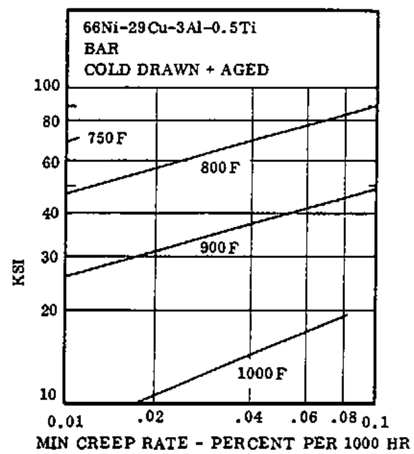


FIG. 3.042 MINIMUM CREEP RATE OF BAR FROM 750 TO 1000F. (1, p. 44)

Source	(1, p.8)	
Alloy	66 Ni-29Cu-3Al-0.5Ti	
Condition	CD + Aged	
Type of Test	Creep	
	Stress, ksi, for creep rate of	
Temp - F	0.10 percent in 10,000 hr	1.0 percent in 10,000 hr
750	68	
800	47	88
900	25	48
1000	8.2	21
1100		9.1

TABLE 3.041 STRESS REQUIRED TO PRODUCE 0.1 AND 1.0 PERCENT CREEP IN 10,000 HRS AT TEMPERATURES FROM 750 TO 1100F.

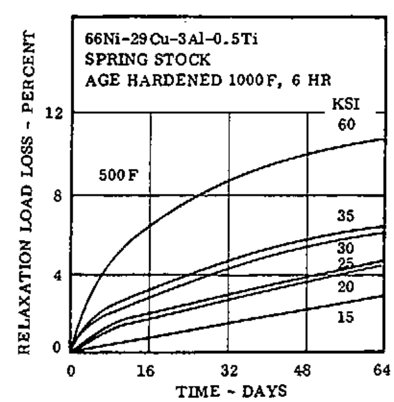


FIG. 3.043 CREEP RELAXATION CURVES AT 500F FOR AGE HARDENED SPRING STOCK. (1, p.43)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

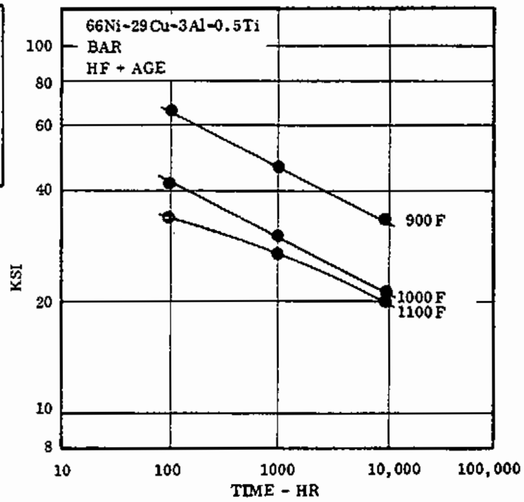


FIG. 3.044 CREEP RUPTURE DATA AT 750 TO 1100F FOR BAR. (1, p. 44)

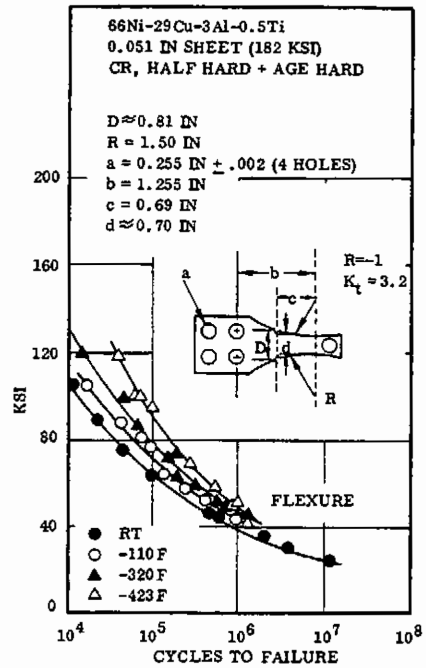


FIG. 3.052 S-N CURVES FOR NOTCHED COLD ROLLED SHEET AT ROOM AND LOW TEMPERATURES. (4, p. 55)

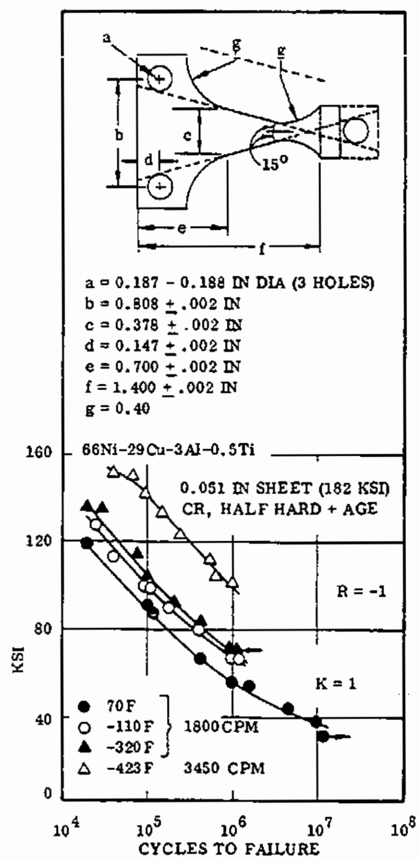


FIG. 3.051 S-N CURVES FOR SHEET AT LOW AND ROOM TEMPERATURE. (1, p. 9)(4, FIG. 28)

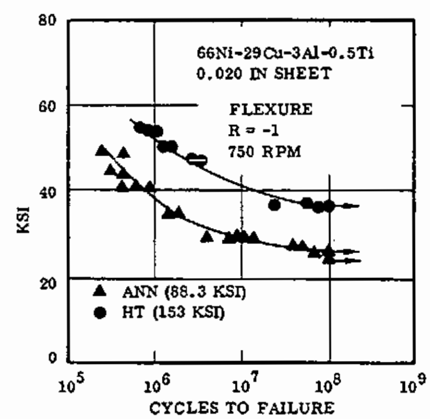


FIG. 3.053 S-N CURVES FOR ANNEALED AND HEAT TREATED SHEET AT ROOM TEMPERATURE. (11)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

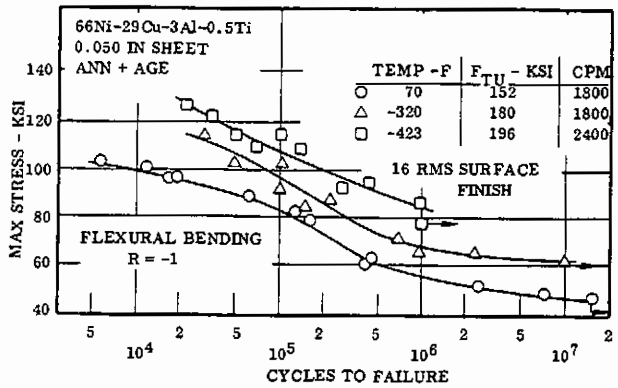


FIG. 3.054 FLEXURAL BENDING FATIGUE FOR ANNEALED AND AGED SHEET WITH 16 RMS SURFACE FINISH AT ROOM AND LOW TEMPERATURE. (15, p. K-4, 5)

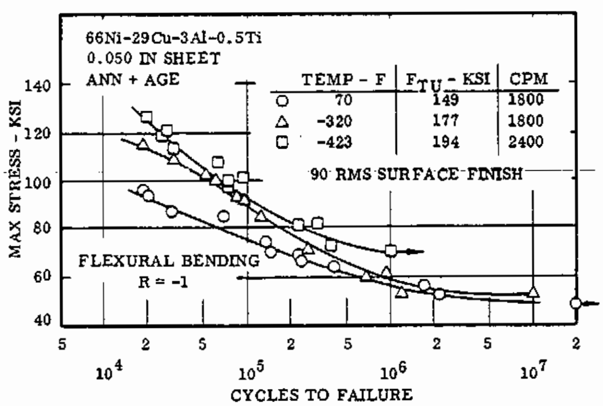


FIG. 3.055 FLEXURAL BENDING FATIGUE FOR ANNEALED AND AGED SHEET WITH 90 RMS SURFACE FINISH AT ROOM AND LOW TEMPERATURE. (15, p. K-4,5)

Source	(1, p.40) (35)		
Alloy	66Ni-29Cu-3Al-0.5Ti		
Form and Condition	F_{tu} (ksi)	Fatigue Limit 10^8 cycles (ksi)	Ratio: Fatigue limit / F_{tu}
Rod (a)			
Annealed	88	38	0.43
Hot Rolled	99	43	0.43
Hot Rolled, Aged	155	51	0.33
Cold Drawn	120	45	0.37
Cold Drawn, Aged	170	47	0.28
Strip (b)			
Annealed	88	27	0.31
Spring-Temper Aged	153	37	0.24

(a) R.R. Moore specimens at 10,000 rpm.
(b) Longitudinal flat strip, flexure, R = -1.

TABLE 3.056 TENSILE STRENGTH AND FATIGUE LIMIT AT 10^8 CYCLES FOR ROD AND STRIP IN SEVERAL CONDITIONS

Source	(1, p.42)			
Alloy	66Ni-29Cu-3Al-0.5Ti			
Form	Bar			
	Hot Rolled, Aged		Cold Drawn, Aged	
Condition	Polished	Oxidized (a)	Polished	Oxidized
F_{tu}, ksi	171	172.5	174.5	167.5
Fatigue strength at 10^8 cycles (R.R. Moore, R = -1), ksi	50	39.5	57	39.5
Ratio, Fatigue strength / Tensile strength	0.29	0.23	0.33	0.24

(a) Oxide surface produced by age hardening in air.

TABLE 3.057 EFFECT OF SURFACE FINISH ON TENSILE AND FATIGUE STRENGTH OF BAR

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

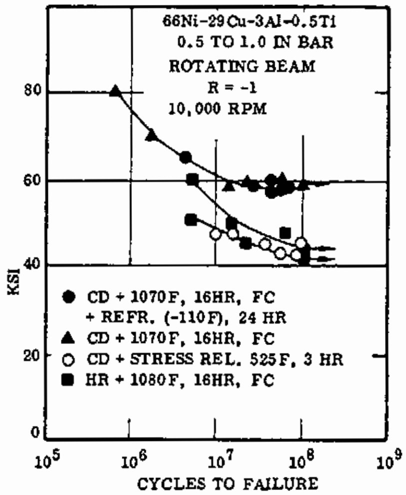


FIG. 3.058 S-N CURVES FOR HOT ROLLED AND COLD DRAWN BAR AT ROOM TEMPERATURE. (10, p. 74-77)

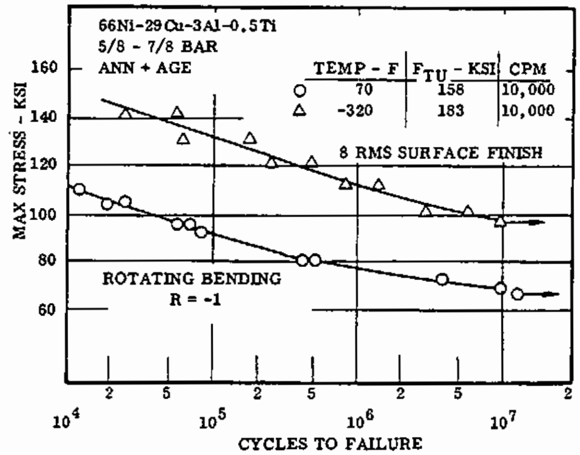


FIG. 3.0510 ROTATING BENDING FATIGUE OF ANNEALED AND AGED BAR AT RT AND -320F. (15, p. K-15)

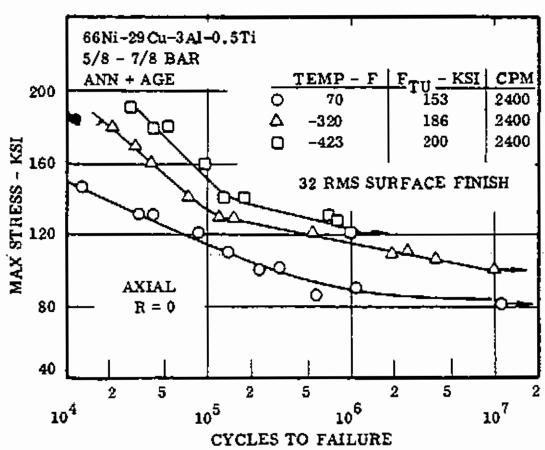


FIG. 3.059 AXIAL FATIGUE OF BAR AT ROOM AND LOW TEMPERATURES. (15, p. K-11)

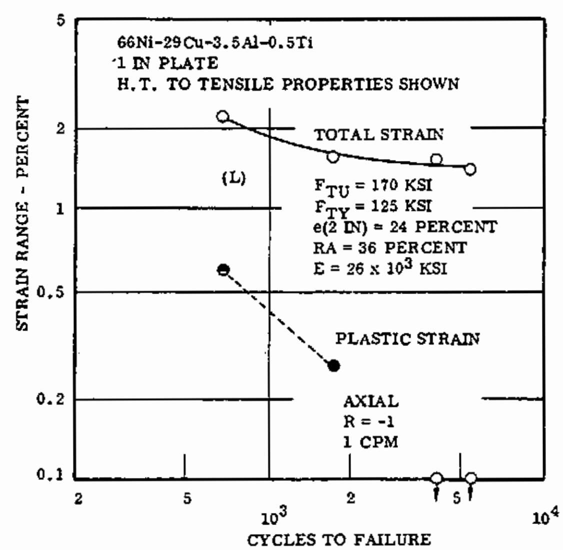


FIG. 3.0511 LOW CYCLE FATIGUE OF PLATE. (18, p. A-7)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

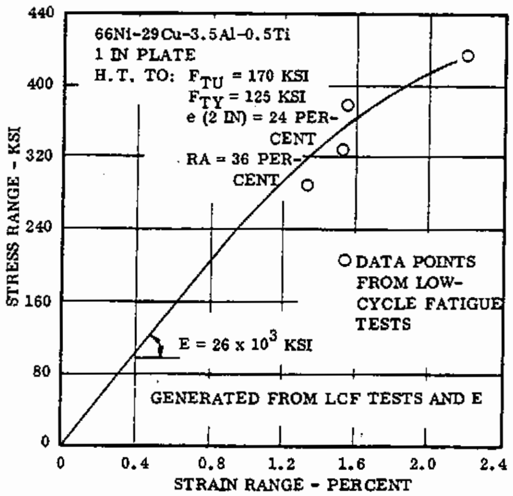


FIG. 3.0512 CYCLIC STRESS - STRAIN CURVE. (18, p. A-7)

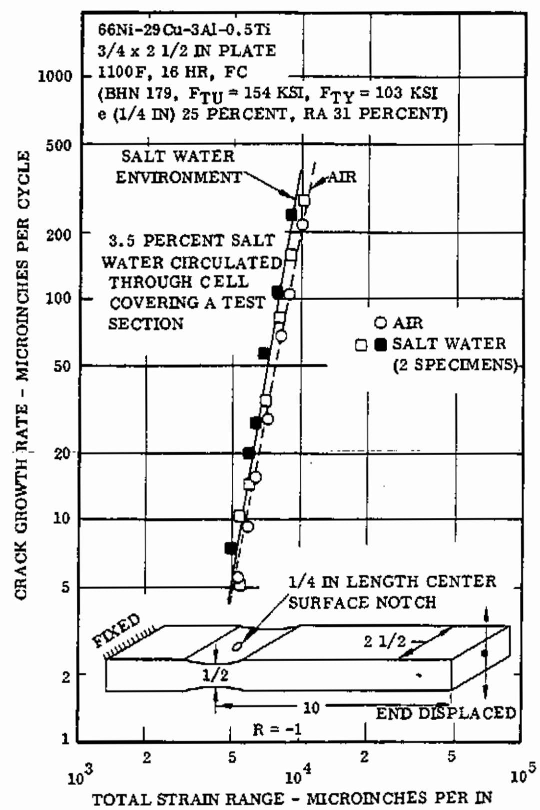


FIG. 3.0514 FATIGUE CRACK GROWTH IN COMPLETELY REVERSED FLEXURE FOR PLATE IN AIR AND IN SIMULATED SALT WATER ENVIRONMENT. (27, p.p. 3,6,9)

Source	(19, p.26) (20)(21)	
Alloy	66Ni-29Cu-3Al-0.5Tu	
Condition	Not Specified	
Form	Sheet Strip, 4 x 1/2 x 1/16	
	(20) Cycles of 180° Bend	(21) Cycles of 180° Bend
Exposure Conditions		
None	45	32
13 hr, 29.4 ksi	31	-
18 hr, 58.8 ksi	31	-
20 days, 7.8 ksi	–	16
4 days, 52 ksi	–	18
60 days, 52 ksi	–	2

TABLE 3.0513 BEND TESTS IN AIR (180° BENDS TO FAILURE) AFTER EXPOSURE TO HIGH PRESSURE HYDROGEN

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

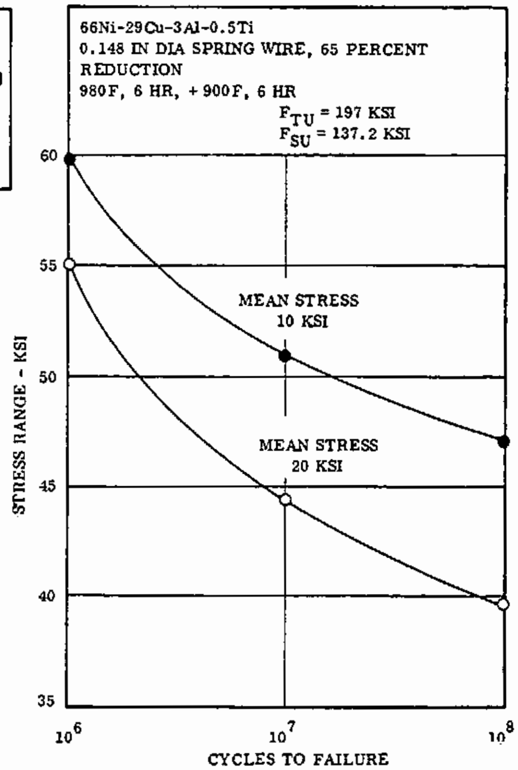


FIG. 3.0515 TORSIONAL FATIGUE STRENGTH OF SPRING WIRE. (1, p. 43)

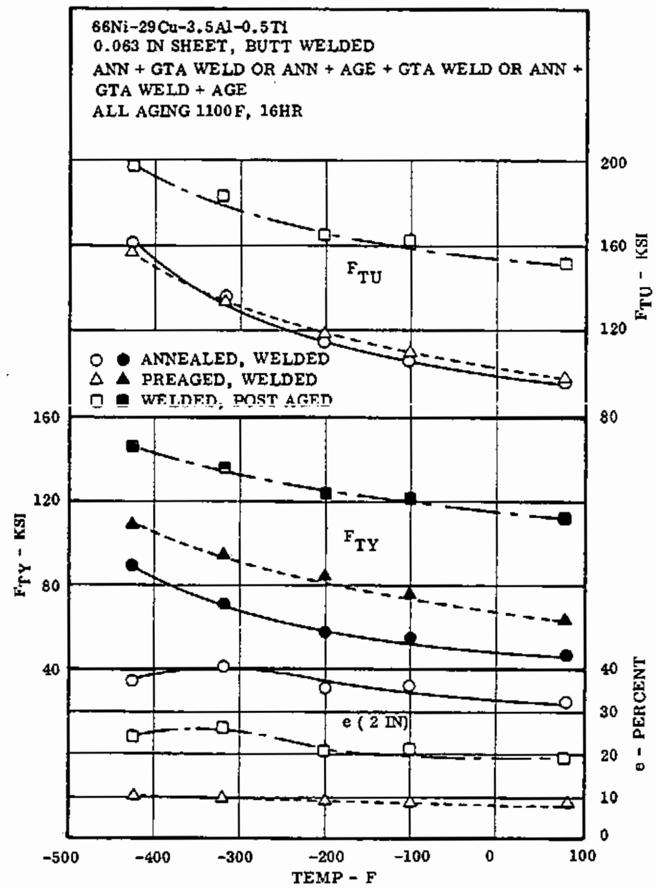


FIG. 4.037 TENSILE PROPERTIES OF BUTT-WELDED SHEET WITH AND WITHOUT AGING TESTED AT ROOM AND LOW TEMPERATURES. (16, p.p. 45, 46)

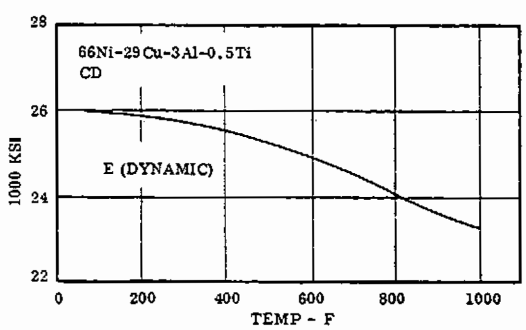


FIG. 3.062 MODULUS OF ELASTICITY. (1, p. 9)

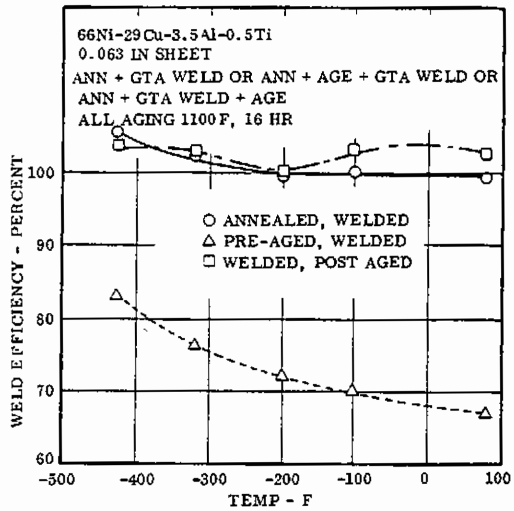


FIG. 4.038 WELD EFFICIENCY OF BUTT WELDED SHEET WITH AND WITHOUT AGING TESTED AT ROOM AND LOW TEMPERATURES. (16, p.p. 45, 46)

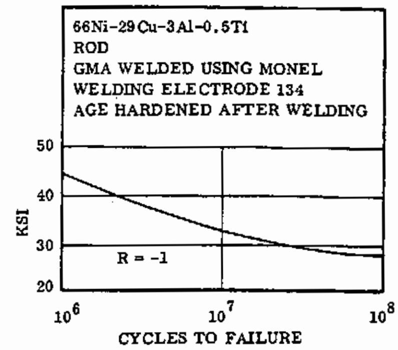


FIG. 4.0310 FATIGUE PROPERTIES OF WELDED JOINT. (1, p. 48)

66	Ni
29	Cu
3	Al
0.5	Ti

MONEL ALLOY K-500

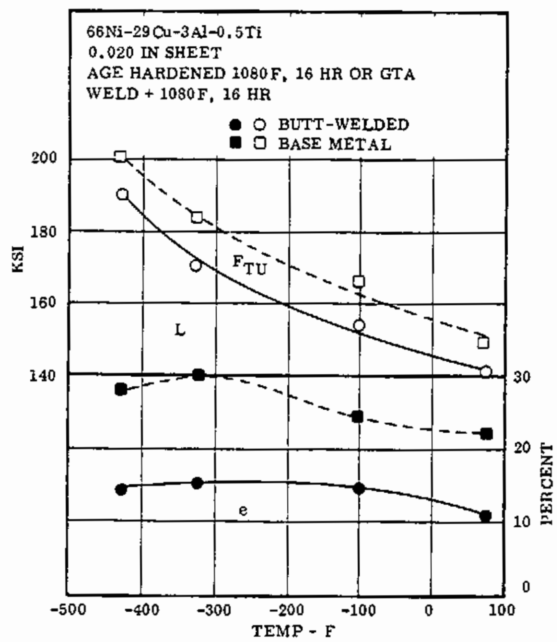


FIG. 4.039 EFFECT OF LOW TEST TEMPERATURE ON TENSILE PROPERTIES OF BASE METAL AND BUTT-WELDS IN SHEET. (1, p. 37)

REFERENCES

1. International Nickel Co., Inc., "Monel, Nickel-Copper Alloys" (including some data from Bulletin T-9, Huntington Alloy Products Div., 1963) (1972).
2. Watson, J.F., Christian, J.L. and Hertz, J., "Selection of Materials for Cryogenic Applications in Missiles and Aerospace Vehicles", Convair Astronautics Rep. MRG-132-1 (February 1960).
3. International Nickel Company, Inc., "Fabrication and Design of Nickel and High-Nickel Alloy Pipe and Tubing", Technical Bulletin T-17 (July 1955).
4. Gideon, D.N., Favor, R.J., Koppenhafer, A., Grover H.J. and McClure, G.M., "Investigation of Notch Fatigue Behavior of Certain Alloys in the Temperature Range of Room Temperature to -423F), ASD-TDR-62-351 (August 1962).
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66	Ni
29	Cu
3	Al
0.5	Ti

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