

NONFERROUS ALLOYS

- 1. GENERAL  
B 120 VCA is a heat treatable body-centered cubic meta-  
stable beta alloy which is formable in the solution  
treated condition and can be aged to yield strengths of  
170 to 200 ksi. Extreme cold working prior to aging  
has produced tensile strengths as high as 300 ksi in  
small section specimens. The alloy has more than 25  
percent alloy content and stabilizes in a body-centered  
cubic form down to 275F with moderately rapid cooling.  
This structure is retained down to room temperature.  
In this condition the alloy can be strengthened by re-  
heating above 600F where precipitation of the alpha  
phase (close-packed hexagonal structure) and of the  
compound TiCr<sub>2</sub> occurs. The solution treating tempera-  
ture is of particular importance in its influence on tough-  
ness, and temperatures below those commonly used may  
be employed to advantage in this respect. A desirable  
characteristic of the alloy is that it can be air cooled  
from a low solution treatment temperature (1400 to 1450F)  
and yet exhibit good aging response, (1, p.4)(4)(16)(38,  
p. 8, 9).
- 1.01 Commercial Designation  
B 120 VCA Titanium Alloy.
- 1.02 Alternate Designations  
Crucible B 120 VCA,  
Republic RS 120B,  
Ti-13V-11Cr-3Al,  
Beta Ti.
- 1.03 Specifications  
AMS 4917, sheet, strip and plate.  
MIL-T-9046, sheet, strip and plate.
- 1.04 Composition  
Table 1.04.

TABLE 1.04

Source	Crucible (5)		TMCA(2, p. 8)		AMS (20)	
	Percent		Percent		Percent	
	Min	Max	Min	Max	Min	Max
Aluminum	2.50	4.00	2.50	3.50	2.5	4.0
Carbon	-	0.10	-	0.05	-	0.10
Chromium	10.00	12.00	10.00	12.00	10.0	12.0
Iron	-	0.35	-	-	-	0.35
Vanadium	12.50	14.00	12.50	14.50	12.5	14.5
Nitrogen	-	0.05	-	0.08	-	0.05
Hydrogen (Sheet and Wire)	-	-	-	0.02	-	0.02
Hydrogen (Bar and Billet)	-	-	-	0.015	-	-
Oxygen	-	-	-	0.20	-	0.17
Titanium	Balance		Balance		Balance	

- 1.05 Heat Treatment
- 1.051 Solution treat. 1400 to 1450F, 10 to 30 minutes, air cool,  
(4).
- 1.0511 Anneal. Same as solution treat, 1.051. The terms an-  
neal and solution treat can be used interchangeably for  
this alloy as both terms designate one material condition,  
(2, p. 8).

- 1.052 Stress relief. 900F during aging. If aging is not em-  
ployed, 15 minutes at 1000F is recommended, (2, p.10).
- 1.053 Age. Normally a full age is used, 900F, 72 hours.  
However, the mechanical properties are a function of  
aging time and temperature and for special applications  
other aging treatments can be developed, (4)(16).
- 1.06 Hardness
- 1.061 Effect of solution annealing temperature on room tempera-  
ture hardness of sheet, Fig. 1.061.
- 1.062 Effect of aging time on room temperature hardness of  
cold rolled sheet, Fig. 1.062.
- 1.063 Effect of reduction by shear forming on hardness of  
alloy, Fig. 1.063.
- 1.064 Effect of low temperature on hardness of solution treated  
and aged sheet, Fig. 1.064.
- 1.07 Forms and Conditions Available
- 1.071 The alloy is available in a wide range of sizes in the  
solution treated, fully aged, or solution treated and cold  
rolled conditions as sheet, strip, plate and foil. Barstock  
and large billets are supplied in the annealed condition  
for further forging. Small bar, fastener-stock and wire  
is generally supplied in the solution treated condition,  
but is also available in the aged condition. Producers  
are developing production of this alloy as extrusions  
and welded and seamless tubing, (1, p.2)(2, p.11).
- 1.08 Melting and Casting Practice  
Consumable electrode double-vacuum melting, (2, p.8).
- 1.09 Special Consideration

	Ti
13	V
11	Cr
3	Al

B 120 VCA

2. PHYSICAL AND CHEMICAL PROPERTIES

- 2.01 Thermal Properties
- 2.011 Melting range
- 2.012 Phase changes
- 2.0121 Time-temperature-transformation diagram for alloy,  
Fig. 2.0121.
- 2.0122 Phase diagram of alloy with variable chromium content,  
Fig. 2.0122.
- 2.0123 Phase diagram of alloy with variable aluminum content,  
Fig. 2.0123.
- 2.013 Thermal conductivity, Fig. 2.013.
- 2.014 Thermal expansion, Fig. 2.014.
- 2.015 Specific heat, Fig. 2.015.
- 2.016 Thermal diffusivity
- 2.02 Other Physical Properties
- 2.021 Density. 0.175 lb per cu in, 4.85 gr per cu cm, room  
temperature, (1, p. 2).
- 2.022 Electrical resistivity  
RT Ann, 60.2 microhms-in,  
RT STA, 55.8 microhms-in, (25, p. 29).
- 2.023 Magnetic properties
- 2.024 Emissivity
- 2.025 Damping capacity
- 2.03 Chemical Properties
- 2.031 Corrosion resistance. This alloy exhibits excellent  
resistance to sea water and chloride solutions and is also  
resistant to corrosion by both gaseous and liquid  
fluorine at temperatures below 220F. It is susceptible  
to stress corrosion cracking in uninhibited hydrochloric  
acid, (1, p.30)(11, p.7).
- 2.032 Oxidation resistance

3. MECHANICAL PROPERTIES

- 3.01 Specified Mechanical Properties
- 3.011 Producer's specified mechanical properties, Table 3.011.

Ti
13 V
11 Cr
3 Al

B120 VCA

TABLE 3.011

Source	Crucible (1, p.3)			TMCA (2, p.12)					
Alloy	Ti-13V-11Cr-3Al								
Form	Sheet		Sheet and strip			Foil	Bar, billet, forging and fastener stock		
Condition	ST	STA (c)	ST	STA	CR + Aged	STCR	ST	STA	
Thickness - in						< 0.008			
F <sub>tu</sub> min - ksi	125	190	125	190	220	230	125	185	
F <sub>ty</sub> min - ksi	120	170	120	170	200	220	120	170	
e (2 in), min - percent	10	6	10	4 (a), 3 (b)	3	2	-	-	
e (4 D), min - percent	-	-	-	-	-	-	10	4	
Bend factor (radius-t)	3 t	6 t - 8 t	3 t (d), 3.5 t (e)	-	-	-	-	-	
RA, max - percent	40 (c)	10-20	-	-	-	-	-	-	

- (a) > 0.020 in thick (c) Typical properties  
 (b) < 0.020 in thick (d) < 0.071 in thick  
 (e) > 0.071 in thick

3.012 AMS specified mechanical properties, Table 3.012.

TABLE 3.012

Source	(20)	
Alloy	Ti-13V-11Cr-3Al	
Condition	ST	Precipitation HT
Form	Sheet, strip, and plate	
Strain rate	0.003 to 0.007 in/in/min (a)	
Thickness-in	> < 0.250	
F <sub>tu</sub> min-ksi	130	190
F <sub>ty</sub> min-ksi	120	170
e(2in), min-percent	8	5
>0.250 in	10	-
Hardness, RC	36	-

(a) Through yield strength and then increase to produce failure in approx. one minute

3.013 Design mechanical properties of sheet, strip and plate, Table 3.013.

TABLE 3.013

Source	(39)	
Alloy	B120 VCA	
Form	Sheet, strip and plate	
Condition	Ann	ST and aged
Thickness - in	- < 0.250	
Basis	MIL-T-9046 Type IV	
F <sub>tu</sub> -ksi	125	170
F <sub>ty</sub> -ksi	120	160
F <sub>cy</sub> -ksi	120	162
F <sub>su</sub> -ksi	92	105
F <sub>bru</sub> (e/D=1.5) - ksi	207	248
(e/D=2.0) - ksi	270	313
F <sub>bry</sub> (e/D=1.5) - ksi	169	217
(e/D=2.0) - ksi	200	247
e(2 in) - percent	10 (a)	4 (b)

- (a) Thickness of 0.025 and greater  
 (b) Thickness of 0.025 and greater: 3 percent below 0.025 inch

3.02 Mechanical Properties at Room Temperature

- 3.021 Tension  
 3.0211 Stress-strain diagrams. See 3.0311  
 3.0212 Effect of heat treatment on tensile properties.  
 3.02121 Effect of solution treat temperature on room temperature tensile properties of aged sheet, Fig. 3.02121.  
 3.02122 Effect of aging temperature and time on room temperature tensile properties of sheet, Fig. 3.02122.  
 3.02123 Effect of aging time on room temperature tensile properties of cold drawn wire, Fig. 3.02123.  
 3.02124 Effect of aging time on room temperature tensile properties of sheet, cold rolled various amounts after solution treating, Fig. 3.02124.  
 3.0213 Effect of pre-strain on tensile properties.  
 3.02131 Effect of stretching after solution treatment on room temperature tensile properties of subsequently aged sheet, Fig. 3.02131.

- 3.02132 Effect of reduction by shear forming on tensile properties of alloy, Fig. 3.02132.  
 3.02133 Effect of cold work on room temperature tensile properties of solution treated sheet, Fig. 3.02133.  
 3.0214 Effect of exposure on tensile properties.  
 3.02141 Effect of exposure stress and temperature on room temperature tensile properties of sheet in solution treated condition, Fig. 3.02141.  
 3.02142 The effect of exposure time on room temperature tensile properties at various temperatures for sheet, Fig. 3.02142.  
 3.0215 Effect of strain rate on room temperature properties of sheet in solution treated condition, Fig. 3.0215.  
 3.0216 Design tensile properties at room temperature, See Table 3.013.  
 3.022 Compression  
 3.0221 Stress-strain diagrams. See 3.0321.  
 3.0222 Room temperature compressive yield strength for 0.040 inch sheet aged 900F, 60 hours,  
 F<sub>cy</sub>, L = 207.7 ksi,  
 F<sub>cy</sub>, T = 214.3 ksi, (26, p. 1. A.3.5.1).  
 3.0223 Effect of stretching in solution treated condition on room temperature compressive yield strength of aged sheet, (Bauschinger Effect), Fig. 3.0223.  
 3.0224 Design compressive properties at room temperature, see Table 3.013.  
 3.023 Impact, see Section 3.033.  
 3.024 Bending, see Section 4.031.  
 3.025 Torsion and shear  
 3.0251 Effect of reduction by shear forming on ultimate shear strength of alloy, Fig. 3.0251.  
 3.0252 Design shear properties at room temperature, see Table 3.013.  
 3.026 Bearing, see Section 3.034.  
 3.0261 Design bearing properties at room temperature, see Table 3.013.  
 3.027 Stress concentration  
 3.0271 Notch properties  
 3.02711 Effect of stress concentration on tensile strength of aged sheet, Fig. 3.02711.  
 3.02712 Effect of exposure temperature and time on room temperature notch strength of alloy in solution treated condition, Fig. 3.02712.  
 3.02713 Effect of thickness on room temperature notch strength of aged sheet, Fig. 3.02713.  
 3.02714 Effect of aging temperature and time on notched and unnotched room temperature properties of sheet, Fig. 3.02714.  
 3.02715 Effect of stress concentration factor on room temperature notch strength properties of sheet, Fig. 3.02715.  
 3.0272 Fracture toughness  
 3.02721 Effect of solution annealing temperature on room temperature net fracture stress and fracture toughness of sheet, Fig. 3.02721.  
 3.02722 Effect of aging time on room temperature net fracture stress and fracture toughness of sheet, Fig. 3.02722.  
 3.028 Combined properties  
 3.03 Mechanical Properties at Various Temperatures  
 3.031 Tension

- 3.0311 Stress-strain diagrams
- 3.03111 Stress-strain curves for solution treated and aged sheet in tension, Fig. 3.03111.
- 3.03112 Stress-strain curves in tension for solution treated sheet at various temperatures, Fig. 3.03112.
- 3.03113 Stress-strain curves for alloy at very high temperatures, Fig. 3.03113.
- 3.03114 Stress-strain curves at room and low temperatures for solution treated bar in tension, Fig. 3.03114.
- 3.03115 Stress-strain curves at room and low temperatures for solution treated and aged sheet in tension, Fig. 3.03115.
- 3.0312 Effect of test temperature on tensile properties of solution treated sheet and bar, Fig. 3.0312.
- 3.0313 Effect of test temperature on tensile properties of several heats of aged sheet, Fig. 3.0313.
- 3.0314 Effect of test temperature on tensile properties of different gage sheet, Fig. 3.0314.
- 3.0315 Effect of test temperature on tensile properties of sheet, Fig. 3.0315.
- 3.0316 Effect of time of exposure at 550F on tensile properties at room temperature and -110F for 0.040 in sheet, Fig. 3.0316.
- 3.0317 Effect of exposure time at 550F on tensile properties at room temperature and -110F for 0.064 in sheet, Fig. 3.0317.
- 3.0318 Effect of low test temperature on tensile properties of sheet, Fig. 3.0318.
- 3.032 Compression
- 3.0321 Stress-strain diagrams
- 3.03211 Stress-strain curves in compression for solution treated and aged sheet of various thicknesses and test temperatures, Fig. 3.03211.
- 3.0322 Effect of test temperature on compressive yield strength of sheet at room and elevated temperatures, Fig. 3.0322.
- 3.0323 Effect of room and elevated temperature on compressive yield strength of various sheet thicknesses, Fig. 3.0323.
- 3.0324 Effect of test temperature on compressive yield strength of different gage sheet, Fig. 3.0324.
- 3.033 Impact
- 3.0331 Effect of test temperature on impact strength of bar, Fig. 3.0331.
- 3.034 Bending
- 3.035 Torsion and shear
- 3.0351 Effect of test temperature on double shear strength of bar and sheet, Fig. 3.0351.
- 3.0352 Effect of test temperature on shear strength of sheet, Fig. 3.0352.
- 3.0353 Effect of low temperature on shear strength of sheet, Fig. 3.0353.
- 3.036 Bearing
- 3.0361 Effect of test temperature on bearing yield strength of aged sheet at low and elevated temperatures, Fig. 3.0361.
- 3.0362 Effect of test temperature on bearing properties of sheet for  $e/D = 1.5$ , Fig. 3.0362.
- 3.0363 Effect of test temperature on bearing properties for sheet for  $e/D = 2.0$ , Fig. 3.0363.
- 3.037 Stress concentration
- 3.0371 Notch properties
- 3.03711 Effect of test temperature on notch strength of aged sheet, Fig. 3.03711.
- 3.03712 Effect of test temperature and aging time on notch strength ratio for sheet at low and elevated temperatures, Fig. 3.03712.
- 3.03713 Effect of test temperature and thickness on sharp edge notch and smooth tensile strength of solution treated sheet, Fig. 3.03713.
- 3.03714 Effect of exposure time at 550F on notch strength at room temperature and -110F for sheet, Fig. 3.03714.
- 3.03715 Effect of exposure time at 550F on notch strength at room temperature and -110F for sheet, Fig. 3.03715.

- 3.03716 Effect of low test temperature on notch strength of sheet, Fig. 3.03716.
- 3.03717 Effect of test temperature on net fracture stress of center notch sheet specimens, Fig. 3.03717.
- 3.0372 Fracture toughness
- 3.03721 Effect of test temperature on net fracture stress and plane strain fracture toughness of bar and sheet, Fig. 3.03721.
- 3.038 Combined properties
- 3.04 Creep and Creep Rupture Properties
- 3.041 Creep rupture curves for aged sheet at 800F, Fig. 3.041.
- 3.042 Creep curves for aged sheet at 600 and 700F, Fig. 3.042.
- 3.05 Fatigue Properties
- 3.051 S-N curves for solution treated bar, Fig. 3.051.
- 3.052 S-N curves for solution treated and aged sheet at room and low temperatures, Fig. 3.052.
- 3.06 Elastic Properties
- 3.061 Poisson's ratio at room and elevated temperatures, Fig. 3.061.
- 3.062 Modulus of elasticity
- 3.0621 Modulus of elasticity at low and elevated temperatures, Fig. 3.0621.
- 3.0622 Effect of test temperature on modulus of elasticity for sheet in compression, Fig. 3.0622.
- 3.0623 Modulus of elasticity for 0.040 in sheet aged at 600F in compression, 60 hours,  $E_c = 16.3 \times 10^3$  ksi, (26, p. 1. A.3.5.1).
- 3.063 Modulus of rigidity at room temperature,  $6.2 \times 10^3$  ksi, (25, p. 29).
- 3.064 Tangent modulus
- 3.0641 Tangent modulus curves in tension for solution treated and aged sheet at room and elevated temperatures, Fig. 3.0641.
- 3.0642 Tangent modulus curves at room and elevated temperatures for solution treated and aged sheet in compression, Fig. 3.0642.
- 3.065 Secant modulus curves at room and elevated temperatures for solution treated and aged sheet in compression, Fig. 3.065.

4. FABRICATION

4.01 Formability

- 4.011 General.  
Although requiring higher work forces, this alloy in the solution treated condition is more amenable to cold forming than any other of the high strength titanium alloys and it has good cold heading properties. In very severe cold forming such as spinning or deep drawing, intermediate anneals may be advisable. Forming by all conventional methods is possible, (1, p. 20).
- 4.0111 Effect of test temperature on bend properties of solution treated sheet at room and elevated temperatures, Fig. 4.0111.
- 4.012 Forging. Hot forging temperature 1850F. Warm forging below 1400F promotes more rapid aging and results in a stronger and more ductile alloy after aging. Reductions up to 50 percent are possible between anneals in open and closed die forgings, (1, p. 20)(13, p. 76).
- 4.0121 Effect of aging after forging at two temperatures, Fig. 4.0121.
- 4.013 Splitting limits for brake forming at 1000F and 1200F, Fig. 4.013.
- 4.014 Limit curve for deep drawing at 1200F, Fig. 4.014.
- 4.015 Limit curves for linear stretch at 500F, Fig. 4.015.

4.02 Machining

This alloy is somewhat more difficult to machine than other titanium alloys. Sulfurized oils can be used as cutting fluids with high speed steel tools. Maintain slow speeds and coarse feeds for all machining operations. Grind wet to minimize fire hazard, using aluminum oxide wheels, (4).

	Ti
13	V
11	Cr
3	Al

B 120 VCA

13	Ti
11	V
3	Cr
3	Al

4.03 **Welding**  
 This alloy can be satisfactorily welded using inert gas shielded tungsten arc method without filler, or using B-120 VCA as a filler. Consumable electrode welding may be accomplished with B120 VCA wire as filler. Resistance, seam, spot or flash welding methods are also applicable, (1, p. 24).

4.031 Room temperature bend properties (single point) of weld joints, Table 4.031.

B120 VCA

TABLE 4.031

Source	(14, p.10)			
Alloy	Ti-13V-11Cr-3Al			
Form and Condition	Sheet * solution treated and aged 900 F, 25 hr			
Filler wire	ST, welded and aged		ST, welded and aged	
	Fract defl, in	Rupture modulus, ksi	Fract defl, in	Rupture modulus, ksi
Unwelded base alloy	1.70	286.3	1.70	286.3
Ti-75A	1.46	247.7	1.55	227.9
Ti-3Al	1.54	268.1	1.66	239.4
Ti-6Al-4V	1.28	270.1	1.70	210.4
RS-140	1.30	292.2	1.52	248.5
Ti-4Al-3Mo-1V	1.54	267.9	1.62	225.0
Ti-2.5Al-16V	1.02	278.6	1.59	215.4
A-110AT	1.28	286.5	1.60	230.6
Ti-3Al-6Mo	1.04	267.1	1.58	235.8
Ti-13V-11Cr-3Al	1.28	231.2	1.58	230.8

\* Sheet specimen 1 1/2 in wide x 4 1/2 in long. Punch nose radius 0.125 in, 105° Anvil

4.032 **Weldability** is excellent in annealed condition, but weld metal ages at different rate than bare metal resulting in low joint efficiencies. Large grain size and micro-segregation of alloying constituents develop at weld-metal grain boundaries during the fusion process. These adversely effect the properties of the joint after aging. The ductility and toughness of aged weldments are generally low when large grains and grain boundary precipitates are present, (38, p.9).

4.04 **Heat Treatment**  
 Before heat treatment remove all hydrocarbons, carbonaceous materials, chloride cleaner residuals. Final cleaning using light acid pickle is recommended. Heating in air at temperatures above about 800F contaminates the surface. If inert atmosphere cannot be used the contaminated layer must be removed by surface treatment, (1, p.30).

4.05 **Surface Treatment**

4.051 Scale removal can be accomplished by oxidizing molten salt baths, by grinding, by grit and vapor blasting and by pickling in 20 to 30 percent nitric acid plus 2 percent hydrofluoric acid at 130F, (1, p. 30).

4.052 Brightening dip by immersion in 10 percent nitric acid plus 1/4 percent hydrofluoric acid, (4).

4.053 Finger stains are removed by most detergents, (4).

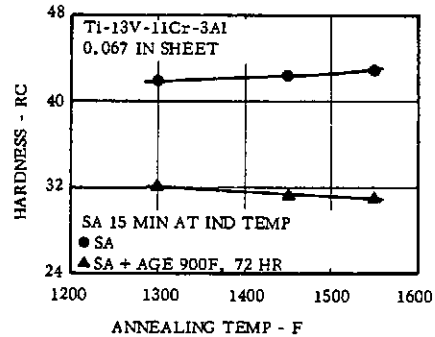


FIG. 1.061 EFFECT OF SOLUTION ANNEALING TEMPERATURE ON ROOM TEMPERATURE HARDNESS OF SHEET (24, p. 154)

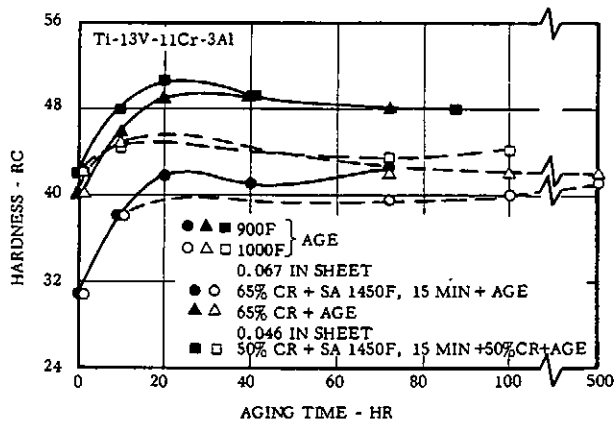


FIG. 1.062 EFFECT OF AGING TIME ON ROOM TEMPERATURE HARDNESS OF COLD ROLLED SHEET (24, p. 160, 177)

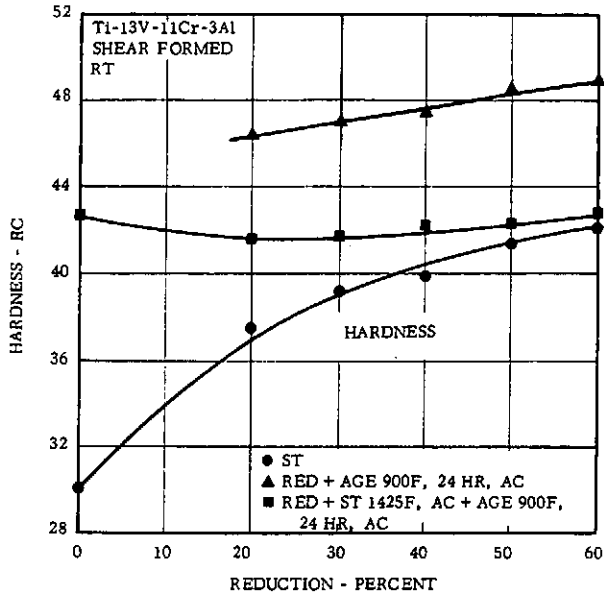


FIG. 1.063 EFFECT OF REDUCTION BY SHEAR FORMING ON HARDNESS OF ALLOY (27, p. 217-221)

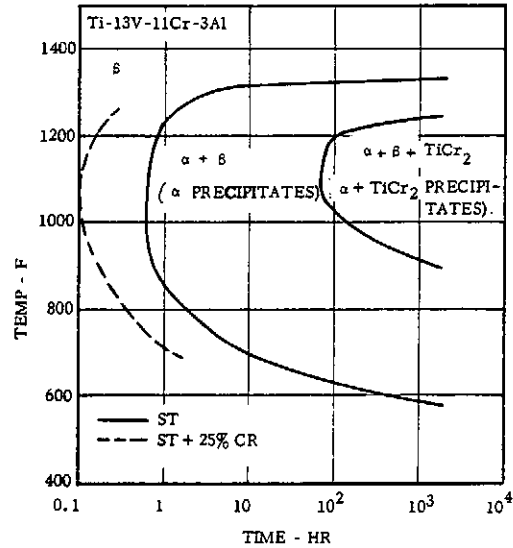


FIG. 2.0121 TIME-TEMPERATURE-TRANSFORMATION DIAGRAM FOR ALLOY (3)

Ti	13
V	11
Cr	3
Al	3

B120 VCA

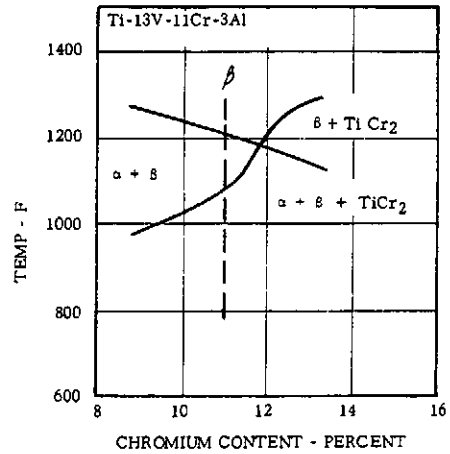


FIG. 2.0122 PHASE DIAGRAM OF ALLOY WITH VARIABLE CHROMIUM CONTENT (3, p. 11)

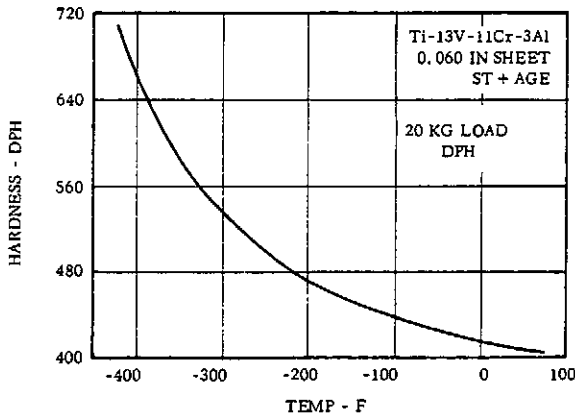


FIG. 1.064 EFFECT OF LOW TEMPERATURES ON HARDNESS OF SOLUTION TREATED AND AGED SHEET (37, p. C. 8. k)

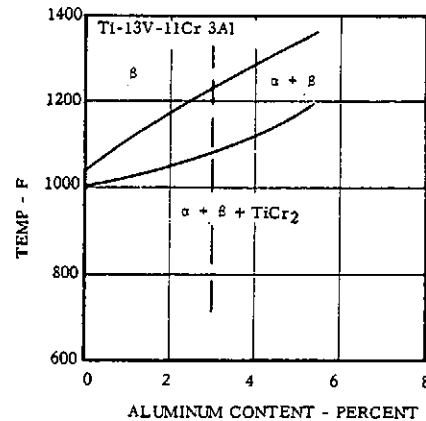


FIG. 2.0123 PHASE DIAGRAM OF ALLOY WITH VARIABLE ALUMINUM CONTENT (3, p. 12)

Ti
13 V
11 Cr
3 Al

B120 VCA

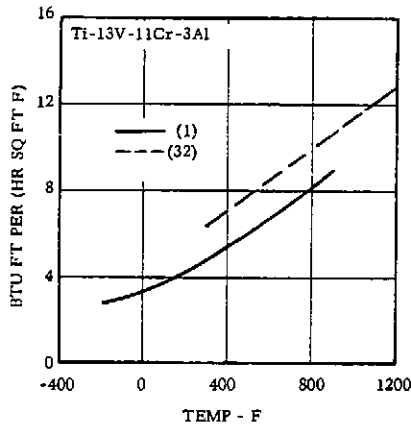


FIG. 2.013 THERMAL CONDUCTIVITY (1, p. 2)(32, p. 65)

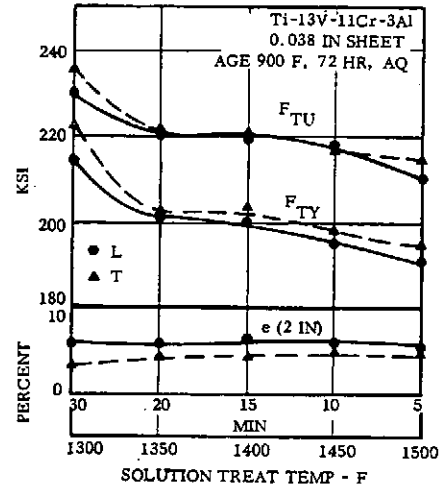


FIG. 3.02121 EFFECT OF SOLUTION TREAT TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF AGED SHEET (1, p. 3)

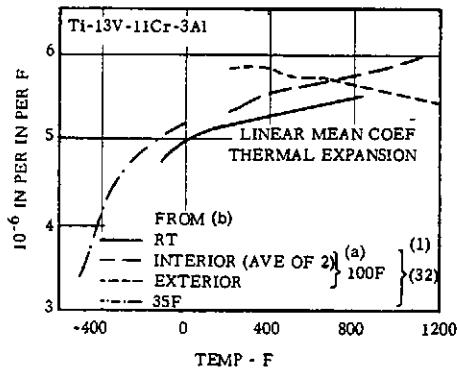


FIG. 2.014 THERMAL EXPANSION (1, p. 2)(32, p. 63, 64)  
(a) Location of test specimen  
(b) To temperature indicated

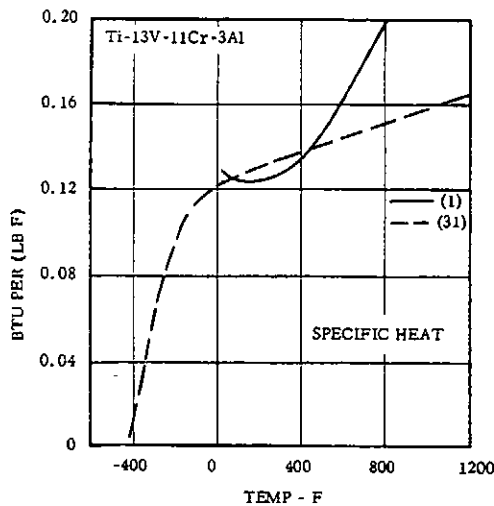


FIG. 2.015 SPECIFIC HEAT (1, p. 2)(31, p. 236)

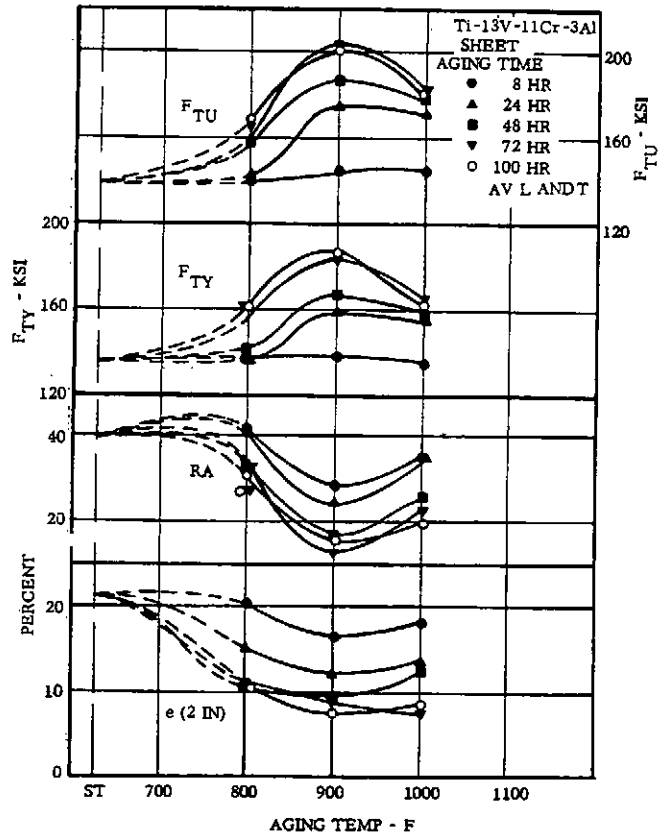


FIG. 3.02122 EFFECT OF AGING TEMPERATURE AND TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF SHEET (3, p. 27)

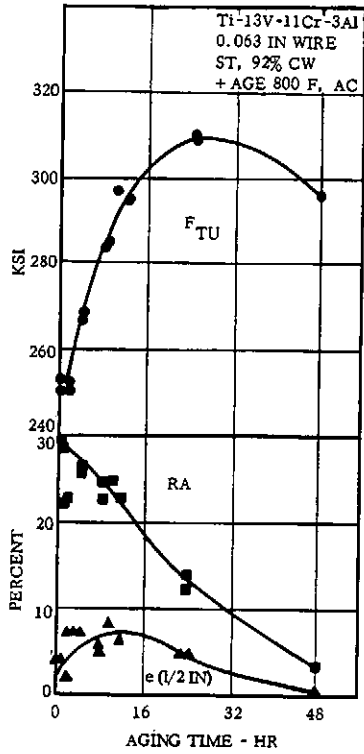


FIG. 3.02123 EFFECT OF AGING TIME ON ROOM TEMPERATURE TENSILE PROPERTIES OF COLD DRAWN WIRE (1, p. 20)

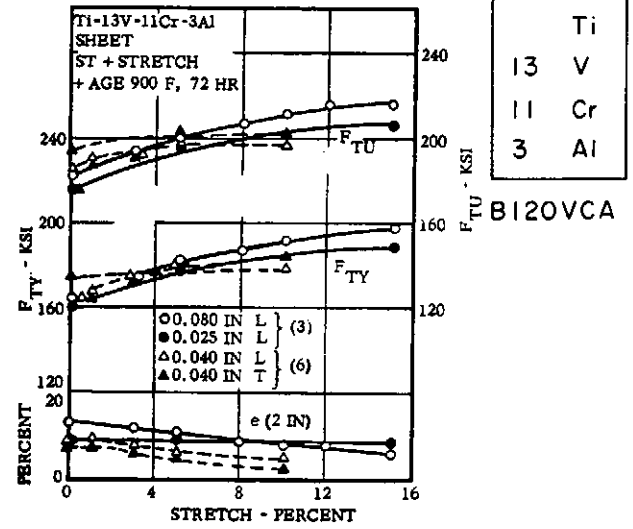


FIG. 3.02131 EFFECT OF STRETCHING AFTER SOLUTION TREATMENT ON ROOM TEMPERATURE TENSILE PROPERTIES OF SUBSEQUENTLY AGED SHEET (3, p. 41) (6, p. 513)

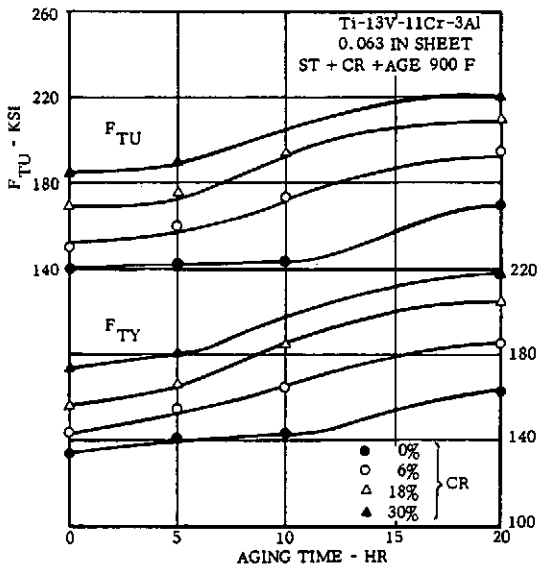


FIG. 3.02124 EFFECT OF AGING TIME ON ROOM TEMPERATURE TENSILE PROPERTIES FOR SHEET COLD ROLLED VARIOUS AMOUNTS AFTER SOLUTION TREATING (16)

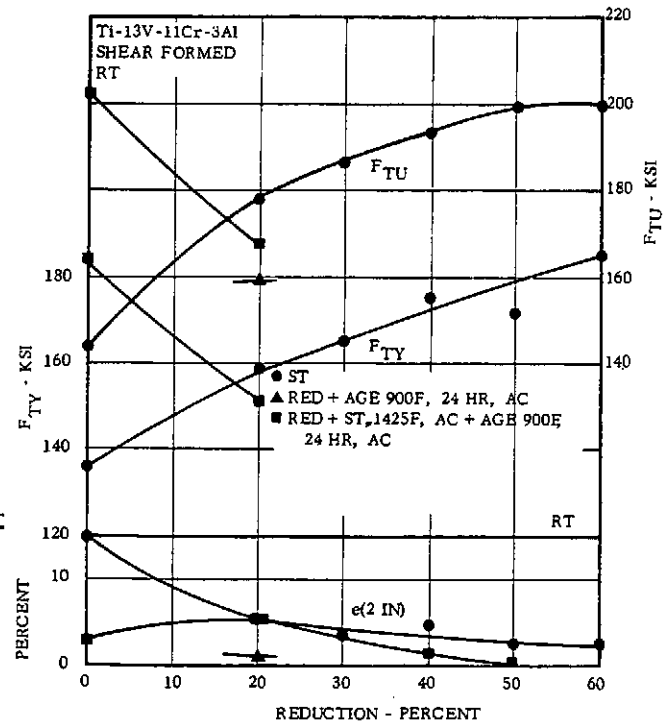


FIG. 3.02132 EFFECT OF REDUCTION BY SHEAR FORMING ON TENSILE PROPERTIES OF ALLOY (27, p. 217-221)

	Ti
13	V
11	Cr
3	Al

B120 VCA

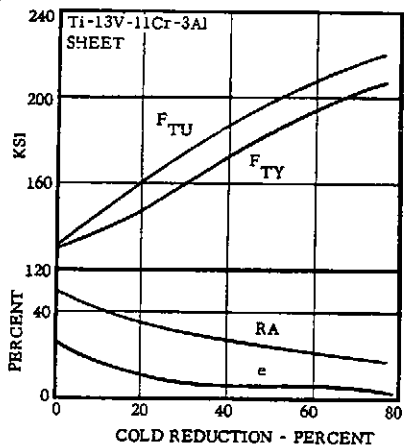


FIG. 3.02133 EFFECT OF COLD WORK ON ROOM TEMPERATURE TENSILE PROPERTIES OF SOLUTION TREATED SHEET (1, p. 23)

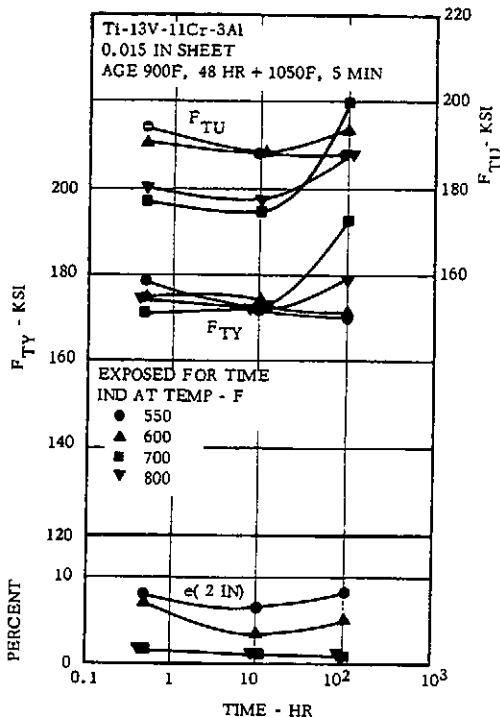


FIG. 3.02142 THE EFFECT OF EXPOSURE TIME ON ROOM TEMPERATURE TENSILE PROPERTIES AT VARIOUS TEMPERATURES FOR SHEET (26, p. 1.A.3.5.1)

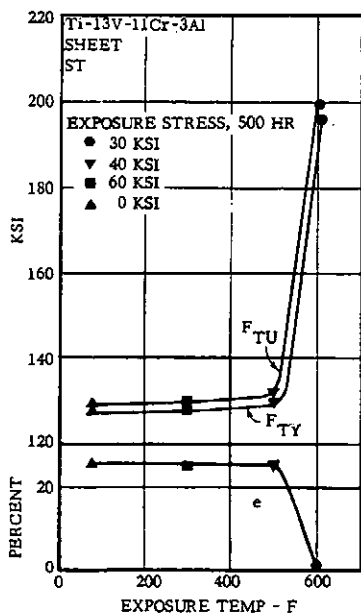


FIG. 3.02141 EFFECT OF EXPOSURE STRESS AND TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF SHEET IN SOLUTION TREATED CONDITION (3, p. 94)

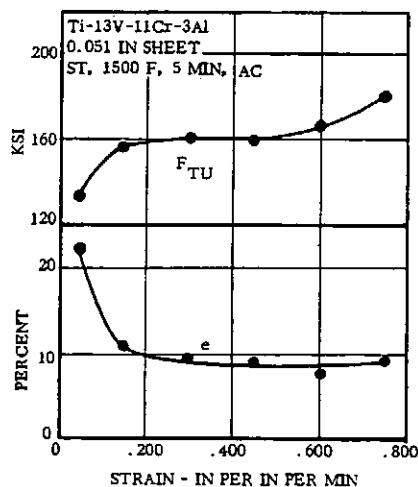


FIG. 3.0215 EFFECT OF STRAIN RATE ON ROOM TEMPERATURE PROPERTIES OF SHEET IN SOLUTION TREATED CONDITION (1, p. 5)

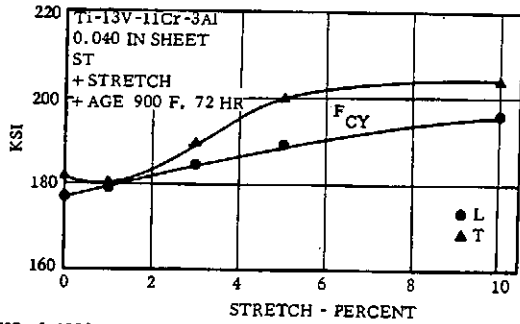


FIG. 3.0223 EFFECT OF STRETCHING IN SOLUTION TREATED CONDITION ON ROOM TEMPERATURE COMPRESSIVE YIELD STRENGTH OF AGED SHEET (BAUSCHINGER EFFECT) (6, p.512-514)

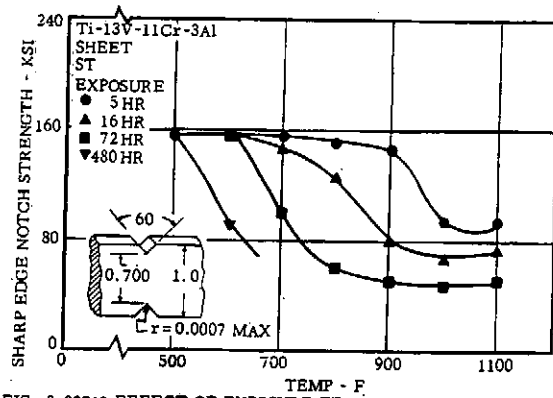


FIG. 3.02712 EFFECT OF EXPOSURE TEMPERATURE AND TIME ON ROOM TEMPERATURE NOTCH STRENGTH OF ALLOY IN SOLUTION TREATED CONDITION (19, p.11)

Ti	13	V
	11	Cr
	3	Al

B120 VCA

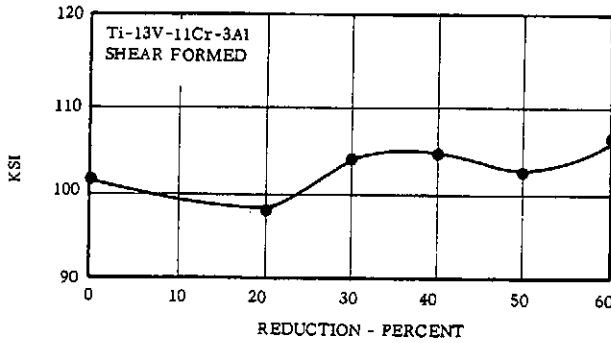


FIG. 3.0251 EFFECT OF REDUCTION BY SHEAR FORMING ON ULTIMATE SHEAR STRENGTH OF ALLOY (27, p. 302-307)

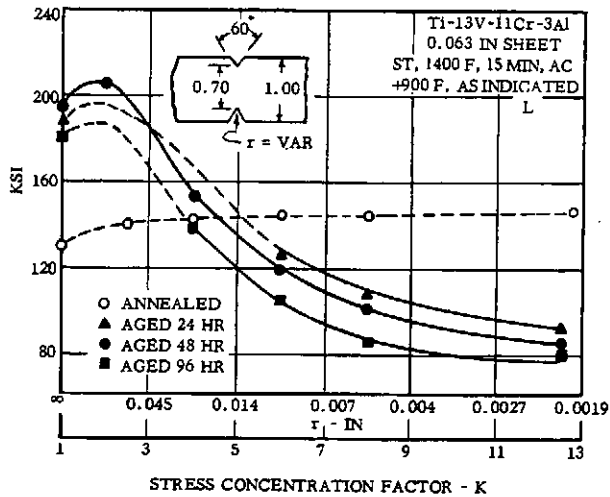


FIG. 3.02711 EFFECT OF STRESS CONCENTRATION ON TENSILE STRENGTH OF AGED SHEET (7, p. 20, 21)

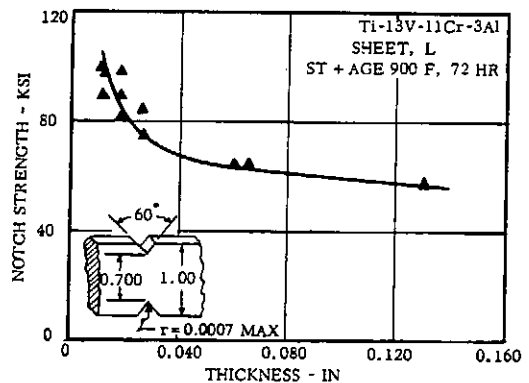


FIG. 3.02713 EFFECT OF THICKNESS ON ROOM TEMPERATURE NOTCH STRENGTH OF AGED SHEET (18, p.7)

	Ti
13	V
11	Cr
3	Al

B120 VCA

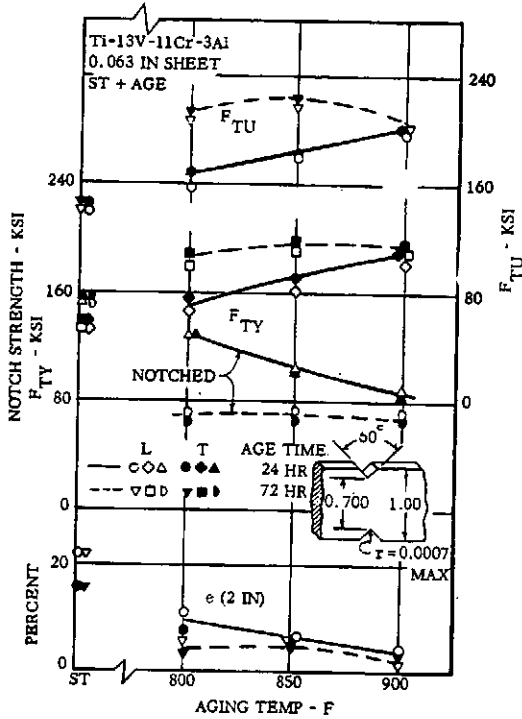


FIG. 3.02714 EFFECT OF AGING TEMPERATURE AND TIME ON NOTCHED AND UNNOTCHED ROOM TEMPERATURE-TENSILE PROPERTIES OF SHEET (17, p. 81)

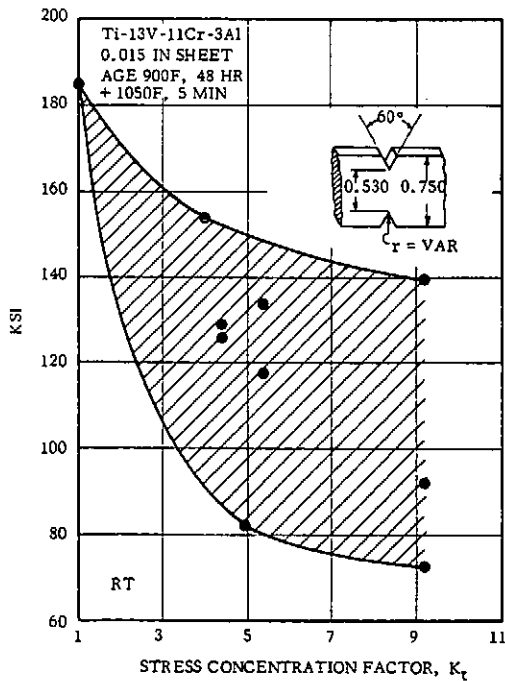


FIG. 3.02715 EFFECT OF STRESS CONCENTRATION FACTOR ON ROOM TEMPERATURE NOTCH STRENGTH PROPERTIES OF SHEET (26, p. 1.A.3.5.1)

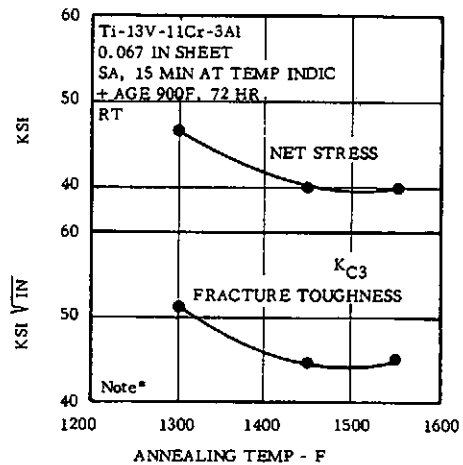


FIG. 3.02721 EFFECT OF SOLUTION ANNEALING TEMPERATURE ON ROOM TEMPERATURE NET FRACTURE STRESS AND FRACTURE TOUGHNESS OF SHEET (24, p. 154)

\* Center notched by spark discharge machining fatigue cracked 0.7 inch long by tension-tension cycling.

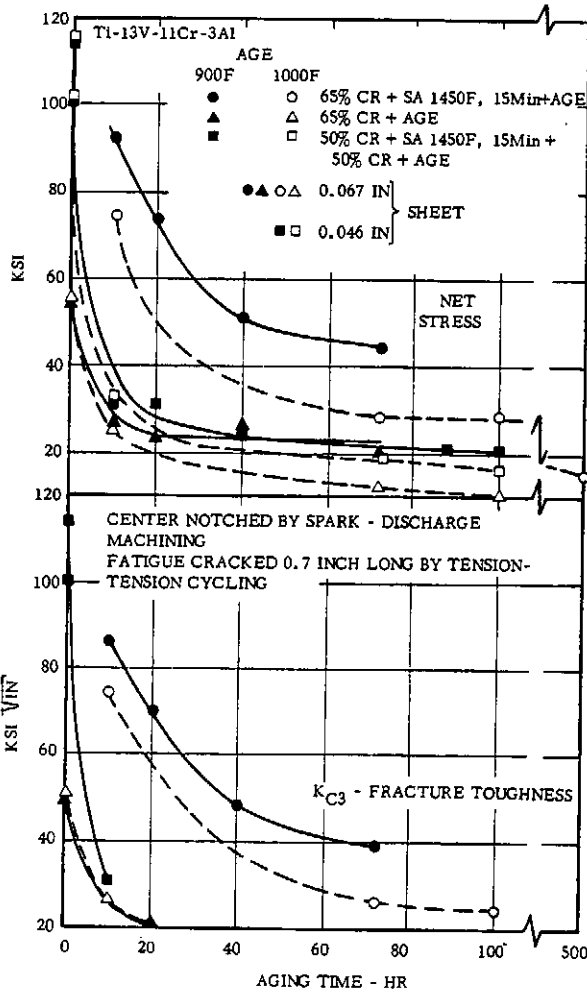


FIG. 3.02722 EFFECT OF AGING TIME ON ROOM TEMPERATURE NET FRACTURE STRESS AND FRACTURE TOUGHNESS OF SHEET (24, p. 160, 177)

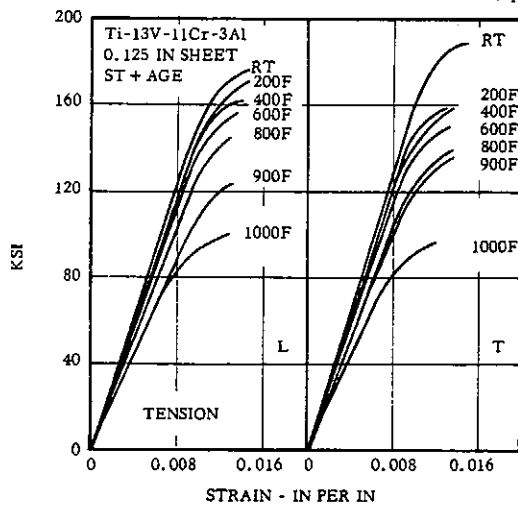


FIG. 3.03111 STRESS-STRAIN CURVES FOR SOLUTION TREATED AND AGED SHEET IN TENSION (33, p. 128-130)

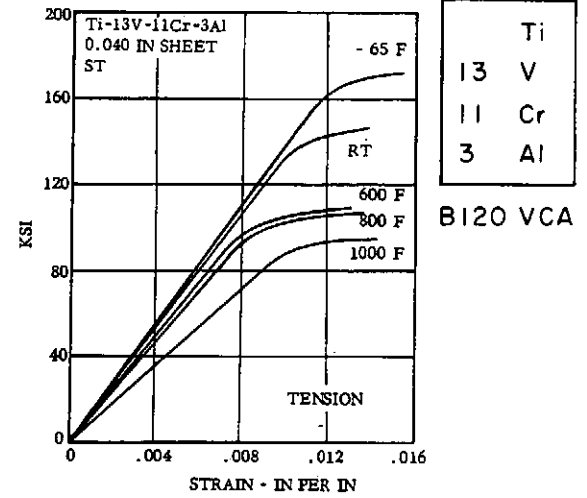


FIG. 3.03112 STRESS STRAIN CURVES IN TENSION FOR SOLUTION TREATED SHEET AT VARIOUS TEMPERATURES (1, p.5)

Ti
13 V
11 Cr
3 Al

B120 VCA

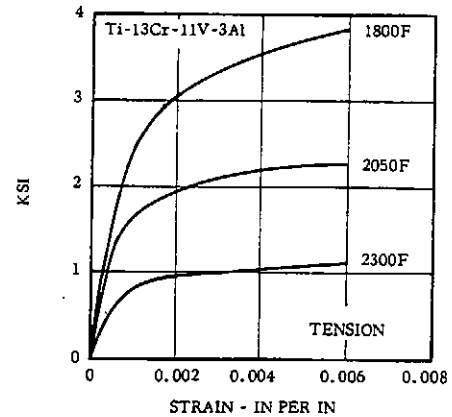


FIG. 3.03113 STRESS-STRAIN CURVES FOR ALLOY AT VERY HIGH TEMPERATURES (34, p. 15-17)

Ti  
13 V  
11 Cr  
3 Al  
B120 VCA

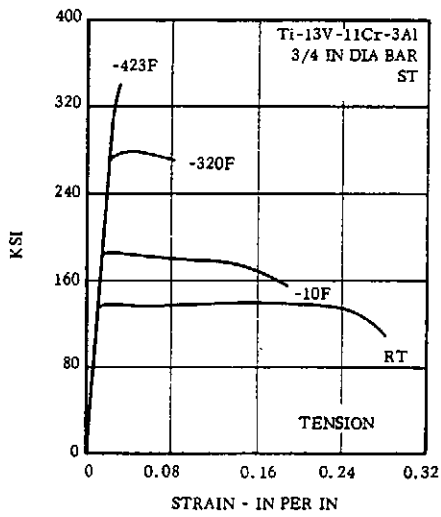


FIG. 3.03114 STRESS-STRAIN CURVES AT ROOM AND LOW TEMPERATURES FOR SOLUTION TREATED BAR IN TENSION (37, p. C.8.h)

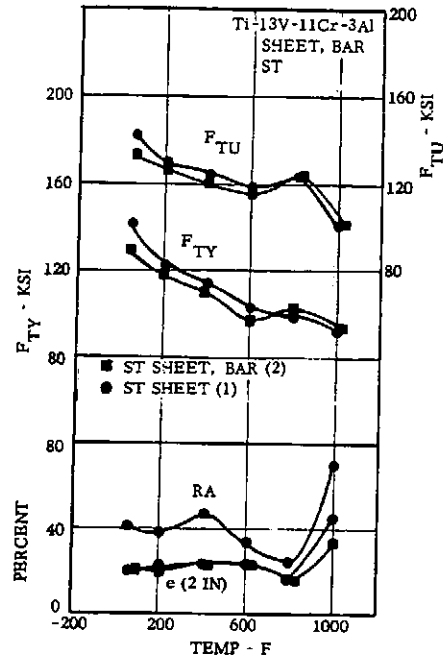


FIG. 3.0312 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SOLUTION TREATED SHEET AND BAR (1, p.5) (2, p.13)

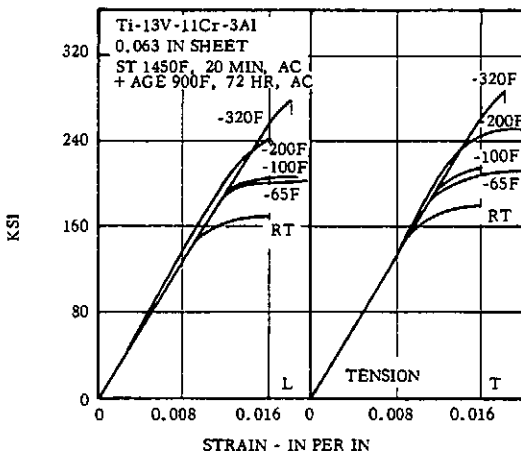


FIG. 3.03115 STRESS-STRAIN CURVES AT ROOM AND LOW TEMPERATURES FOR SOLUTION TREATED AND AGED SHEET IN TENSION (31, p. 232, 233)

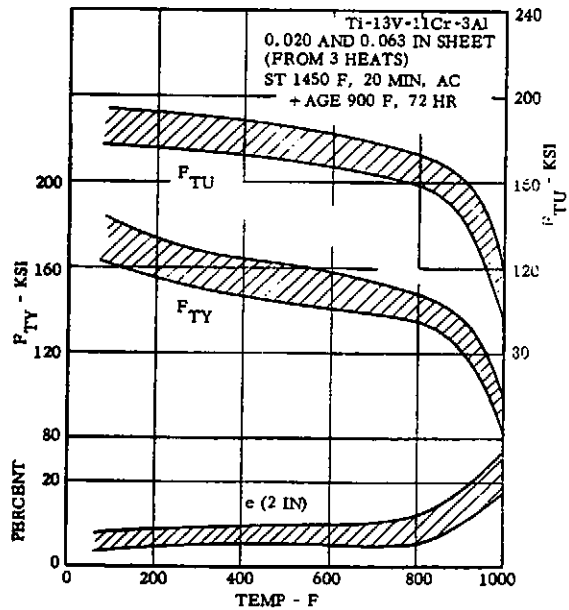


FIG. 3.0313 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SEVERAL HEATS OF AGED SHEET (8, p.8, 8A) (9, p. A3-A12) (10, p. A3-A16)

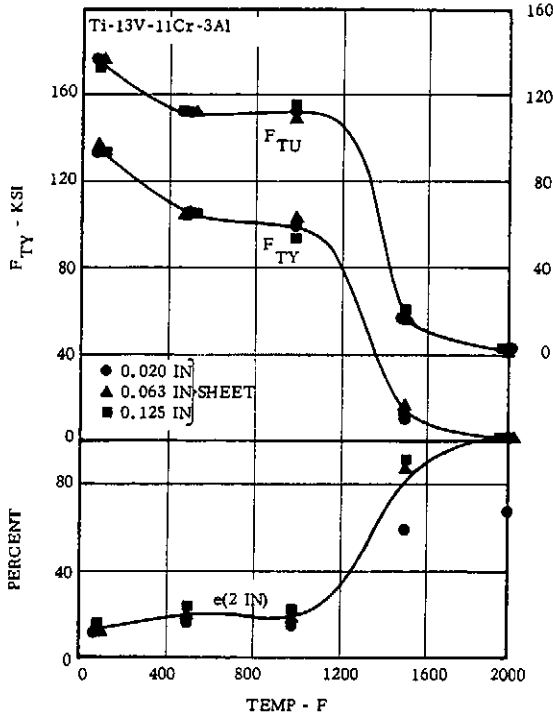
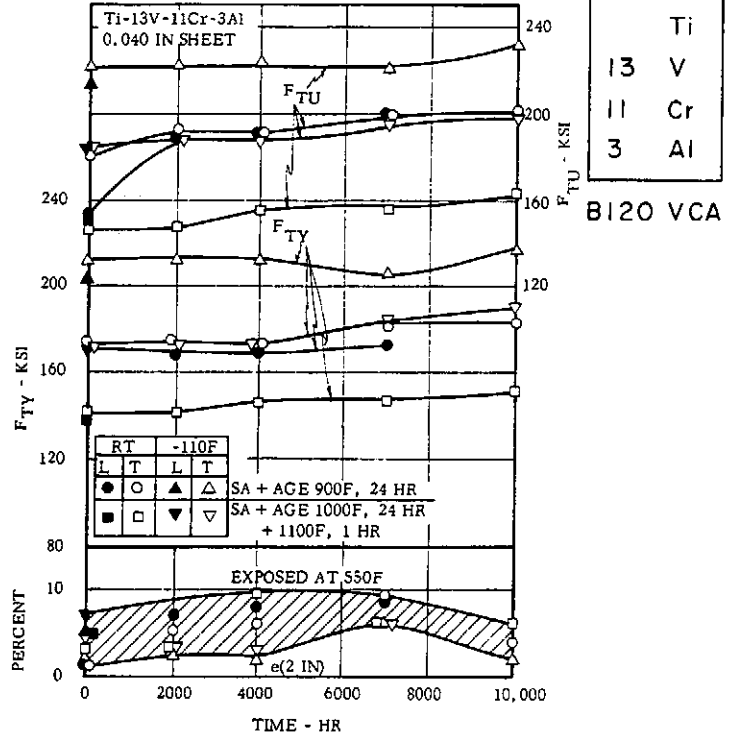


FIG. 3.0314 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF DIFFERENT GAGE SHEET (29, p. 61, 26, 29, 70)



Ti  
13 V  
11 Cr  
3 Al  
B120 VCA

FIG. 3.0316 EFFECT OF EXPOSURE TIME AT 550F ON TENSILE PROPERTIES AT ROOM TEMPERATURE AND -110F FOR SHEET (21, p. 26, 27)

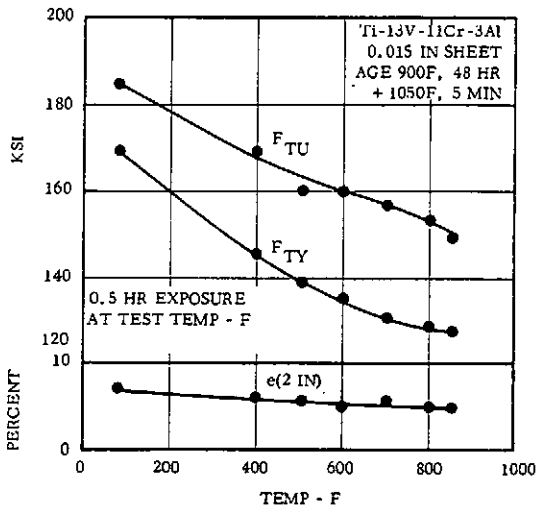


FIG. 3.0315 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SHEET (26, p. 1.A.3.5)

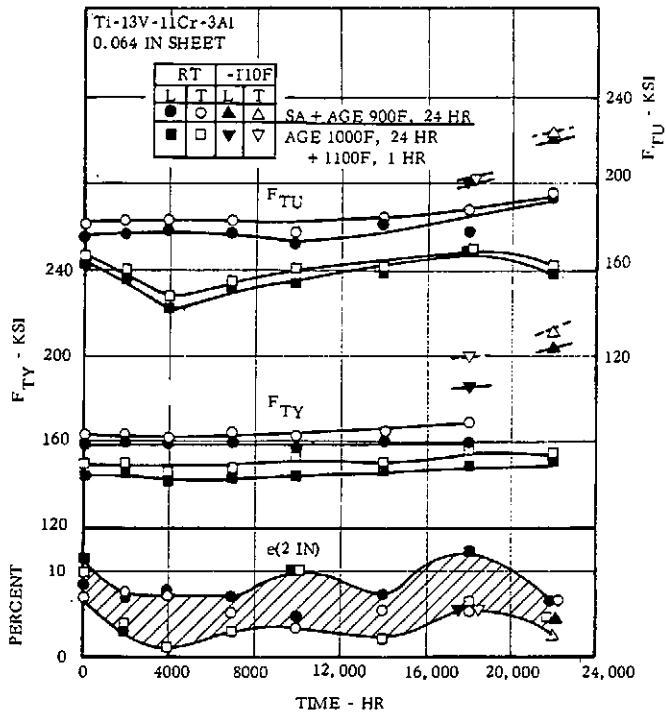


FIG. 3.0317 EFFECT OF EXPOSURE TIME AT 550F ON TENSILE PROPERTIES AT ROOM TEMPERATURE AND -110F FOR 0.064 IN SHEET (21, p. 24, 25)

Ti  
13 V  
11 Cr  
3 Al  
B120 VCA

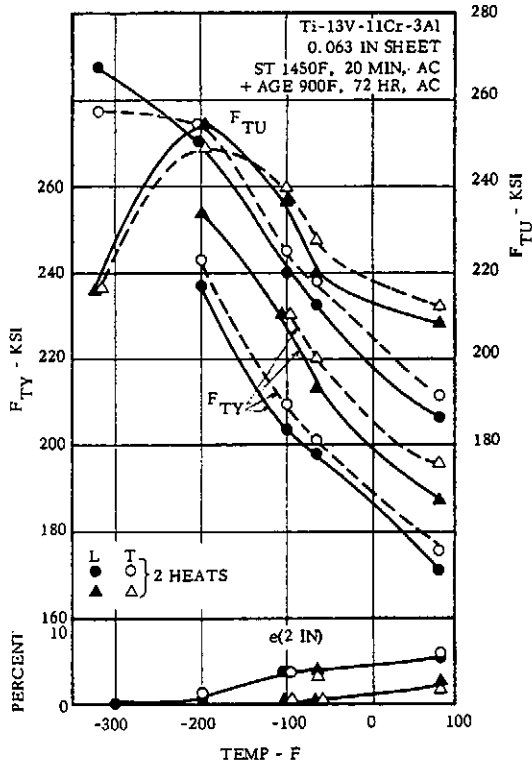


FIG. 3.0318 EFFECT OF LOW TEST TEMPERATURES ON TENSILE PROPERTIES OF SHEET (32, p. 61,62)

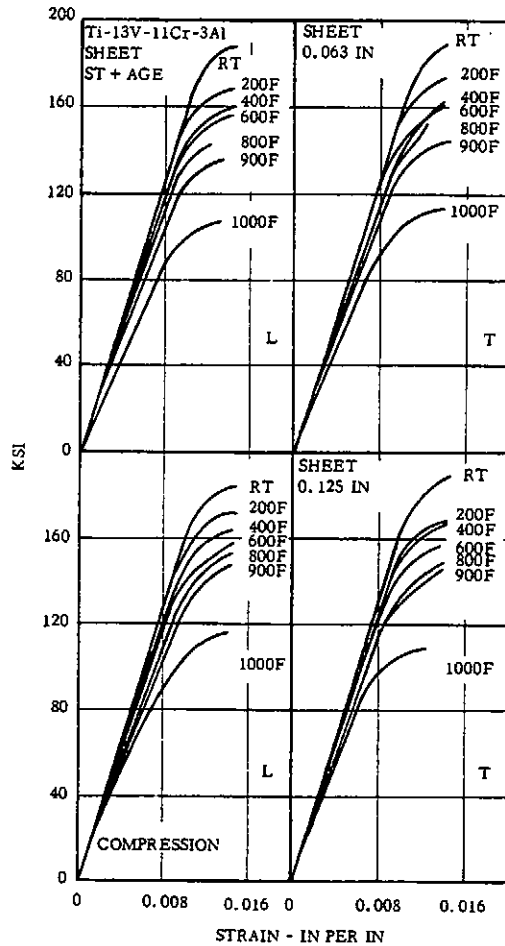


FIG. 3.03211 STRESS-STRAIN CURVES IN COMPRESSION FOR SOLUTION TREATED AND AGED SHEET OF VARIOUS THICKNESS AND TEST TEMPERATURES (33, p. 131-132)

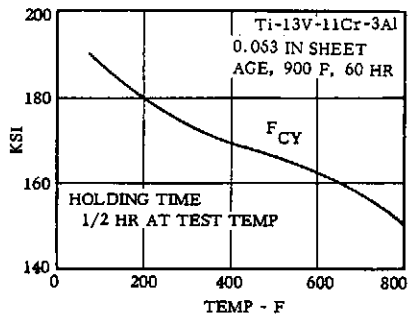
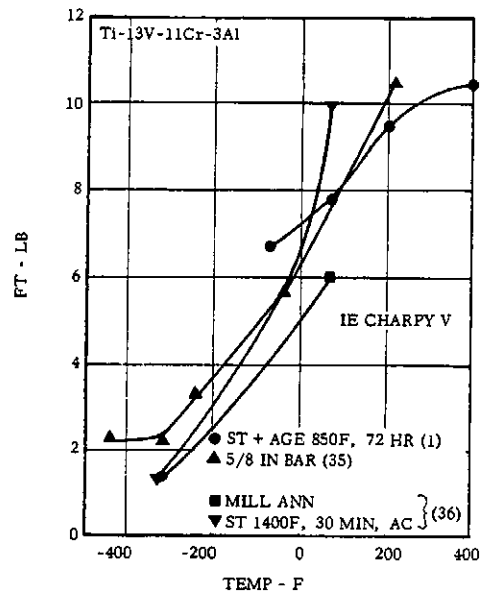


FIG. 3.0322 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF SHEET AT ROOM AND ELEVATED TEMPERATURES (2, p. 13)



Ti
13 V
11 Cr
3 Al

B120 VCA

FIG. 3.0331 EFFECT OF TEST TEMPERATURE ON IMPACT STRENGTH OF BAR (1, p. 18, 19)(35, p. 4)(36, p. 32)

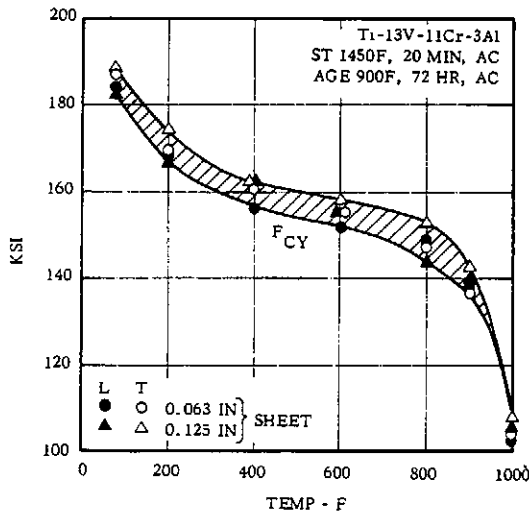


FIG. 3.0323 EFFECT OF ROOM AND ELEVATED TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF VARIOUS SHEET THICKNESSES (32, p. 15-20)

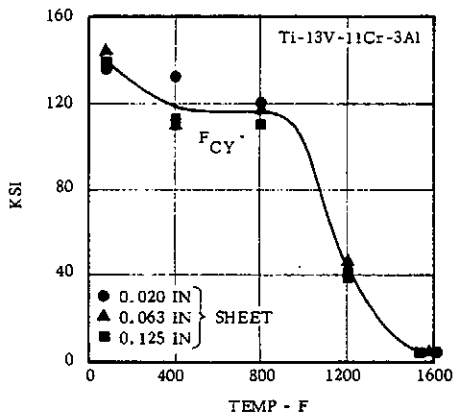


FIG. 3.0324 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF DIFFERENT GAGE SHEET (28, p. 79)

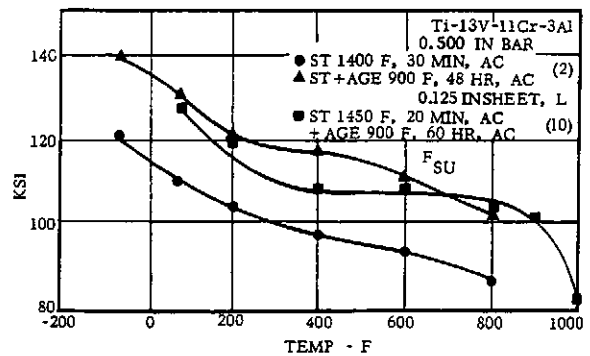


FIG. 3.0351 EFFECT OF TEST TEMPERATURE ON DOUBLE SHEAR STRENGTH OF BAR AND SHEET (2, p. 14) (10, p. A35-A37)

Ti
13 V
11 Cr
3 Al

B 120 VCA

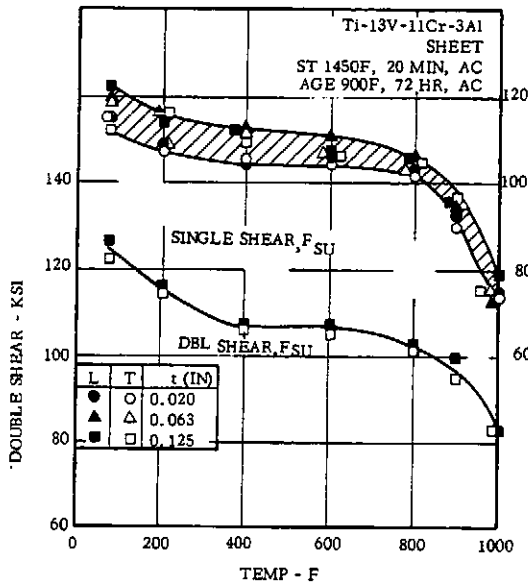


FIG. 3.0352 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF SHEET (32, p. 51-54)

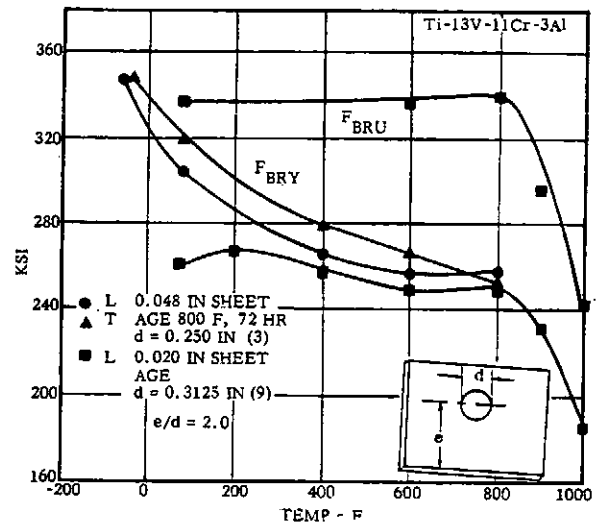


FIG. 3.0361 EFFECT OF TEST TEMPERATURE ON BEARING YIELD STRENGTH OF AGED SHEET AT LOW AND ELEVATED TEMPERATURES (3, p. 86) (9, p. A33-A35)

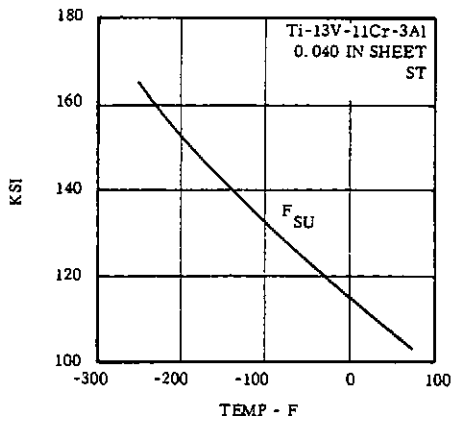


FIG. 3.0353 EFFECT OF LOW TEMPERATURES ON SHEAR STRENGTH OF SHEET (37, p. C. 8, p)

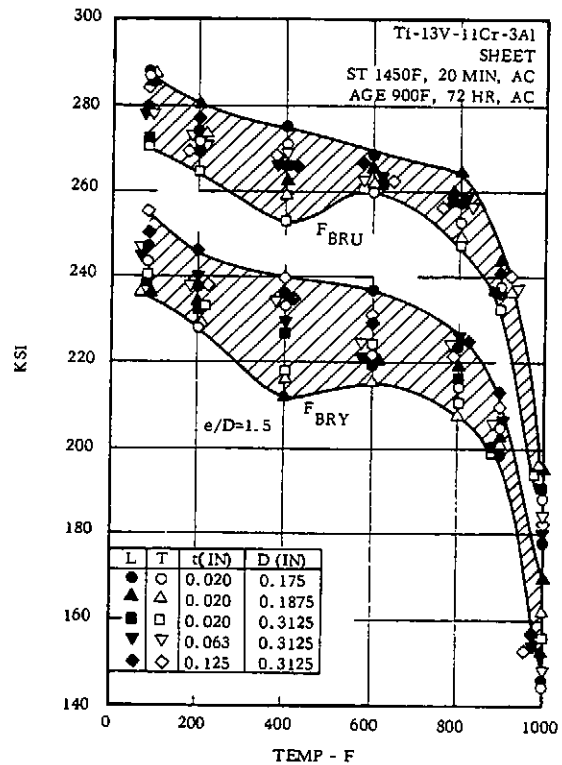


FIG. 3.0362 EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF SHEET FOR e/D = 1.5 (32, p. 21-35)

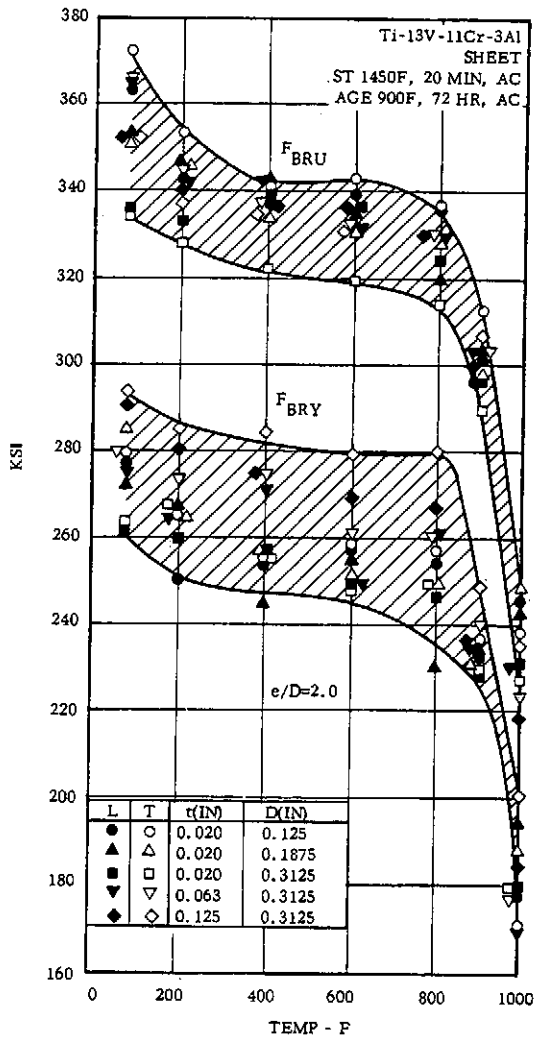


FIG. 3.0363 EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF SHEET FOR  $e/D = 2.0$  (32, p. 36-50)

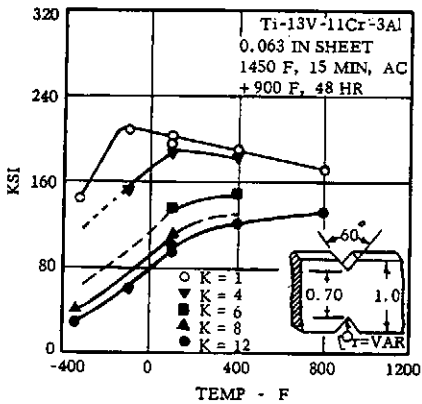


FIG. 3.03711 EFFECT OF TEST TEMPERATURE ON NOTCH STRENGTH OF AGED SHEET (7, p. 26)

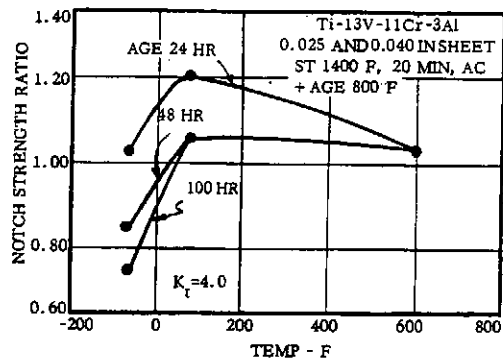


FIG. 3.03712 EFFECT OF TEST TEMPERATURE AND AGING TIME ON NOTCH STRENGTH RATIO FOR SHEET AT LOW AND ELEVATED TEMPERATURES (4)

Ti  
13 V  
11 Cr  
3 Al  
B120 VCA

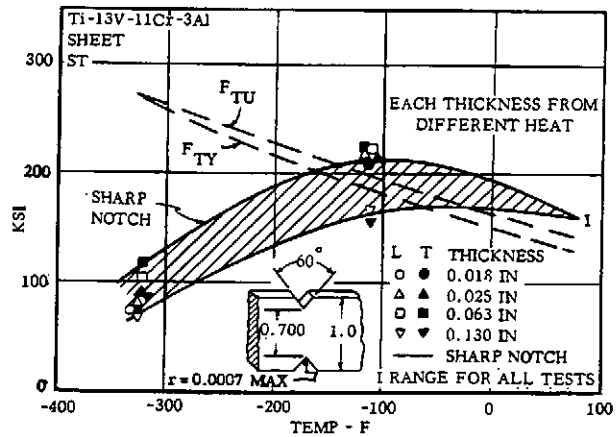


FIG. 3.03713 EFFECT OF TEST TEMPERATURE AND THICKNESS ON SHARP EDGE NOTCH AND SMOOTH TENSILE STRENGTH OF SOLUTION TREATED SHEET (18, p.15)

	Ti
13	V
11	Cr
3	Al

B120 VCA

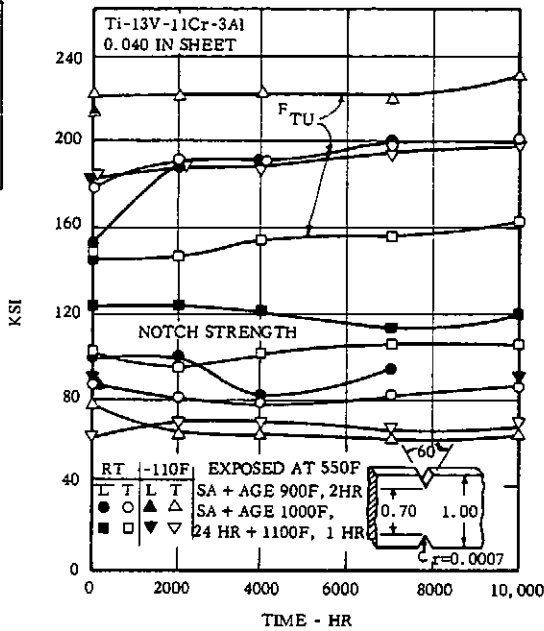


FIG. 3.03714 EFFECT OF EXPOSURE TIME AT 550F ON NOTCH STRENGTH AT ROOM TEMPERATURE AND -110F FOR SHEET (21, p. 26, 27)

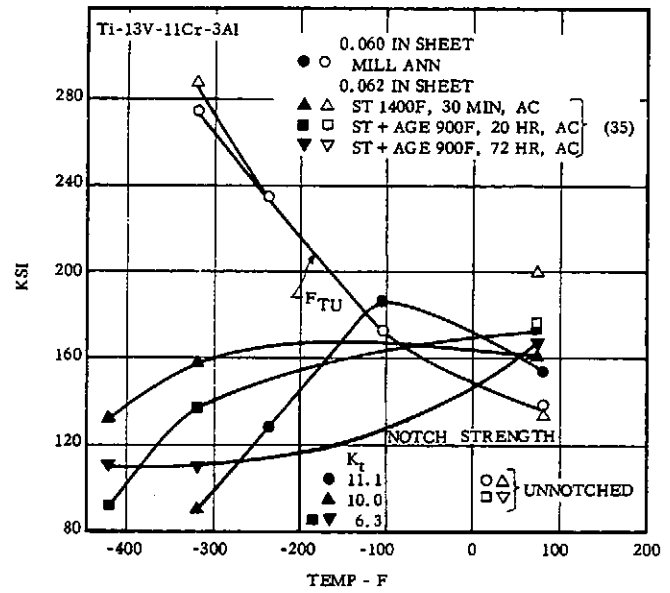


FIG. 3.03716 EFFECT OF LOW TEST TEMPERATURE ON NOTCH STRENGTH OF SHEET (34, p. 5)(35, p. 30, 31)

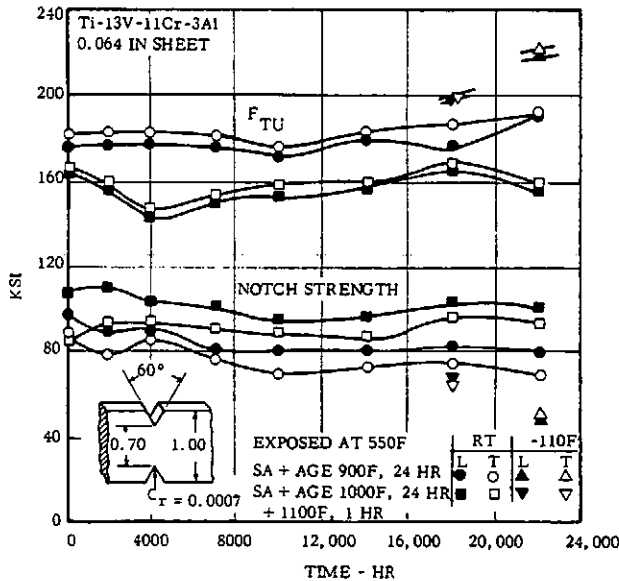


FIG. 3.03715 EFFECT OF EXPOSURE TIME AT 550F ON NOTCH STRENGTH AT ROOM TEMPERATURE AND -110F FOR SHEET (21, p. 24, 25)

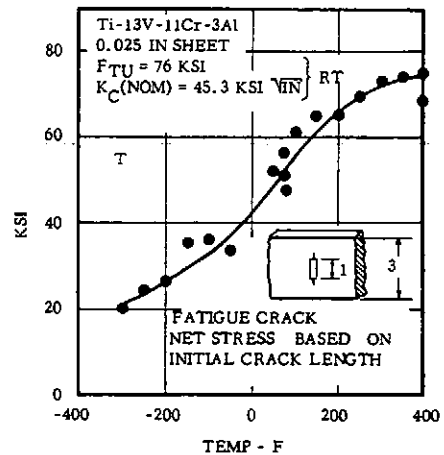


FIG. 3.03717 EFFECT OF TEST TEMPERATURE ON NET FRACTURE STRESS OF CENTER NOTCH SHEET SPECIMENS (22, Tabl. 26)

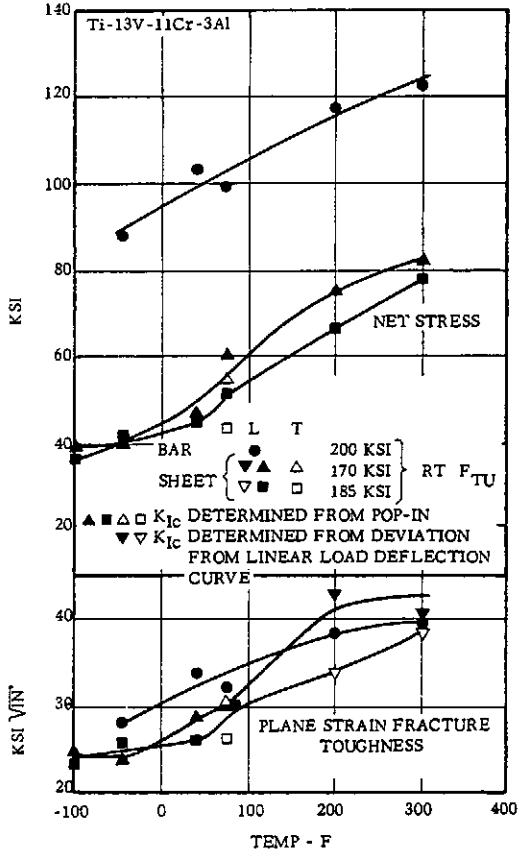


FIG. 3.03721 EFFECT OF TEST TEMPERATURE ON NET FRACTURE STRESS AND PLANE STRAIN FRACTURE TOUGHNESS OF BAR AND SHEET (28, Tbls. 33-35)

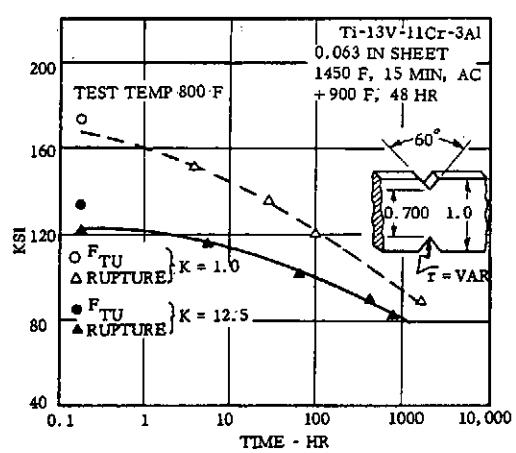


FIG. 3.041 CREEP RUPTURE CURVES FOR AGED SHEET AT 800 F (7, p. 29)

Ti
13 V
11 Cr
3 Al

B120 VCA

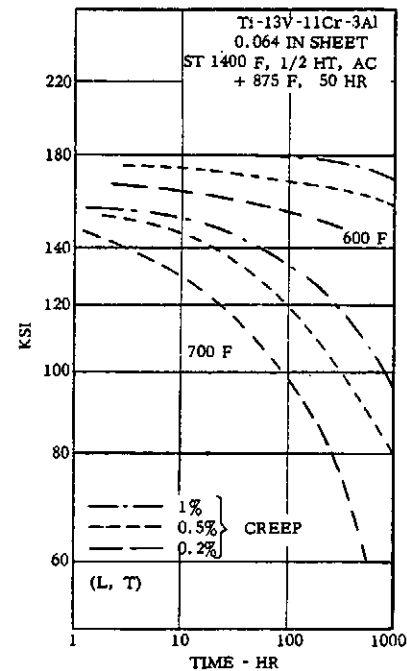
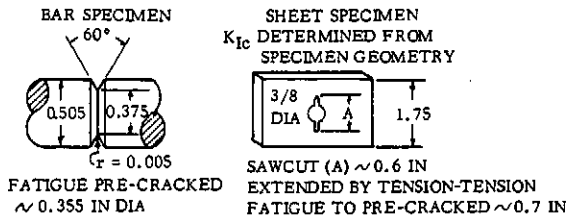


FIG. 3.042 CREEP CURVES FOR AGED SHEET AT 600 AND 700 F (15, p. 28-32)

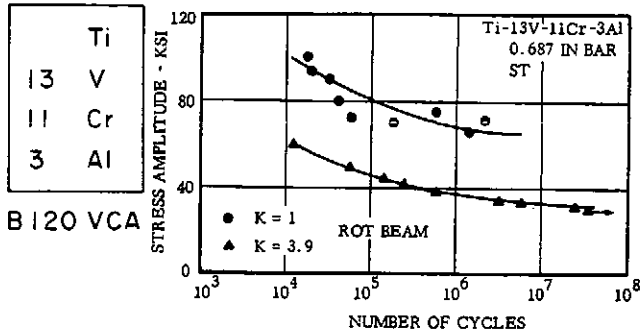


FIG. 3.051 S-N CURVES FOR SOLUTION TREATED BAR (1, p. 19)

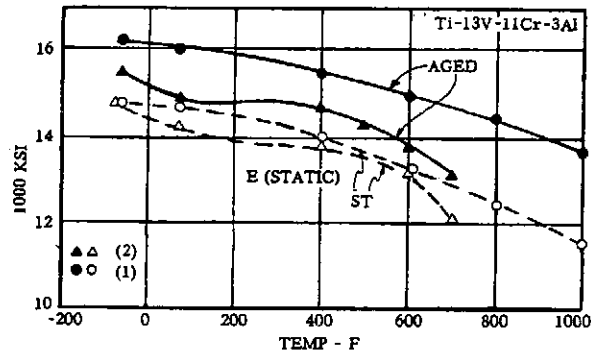


FIG. 3.0621 MODULUS OF ELASTICITY AT LOW AND ELEVATED TEMPERATURES (1, p. 2) (2, p. 8)

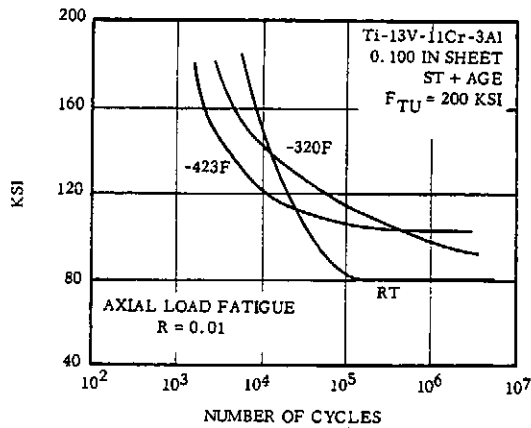


FIG. 3.052 S-N CURVE FOR SOLUTION TREATED AND AGED SHEET AT ROOM AND LOW TEMPERATURES (37, p. C. 8. o)

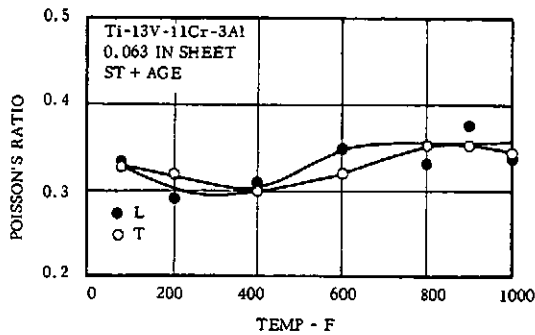


FIG. 3.061 POISSON'S RATIO AT ROOM AND ELEVATED TEMPERATURE (31, p. 181)

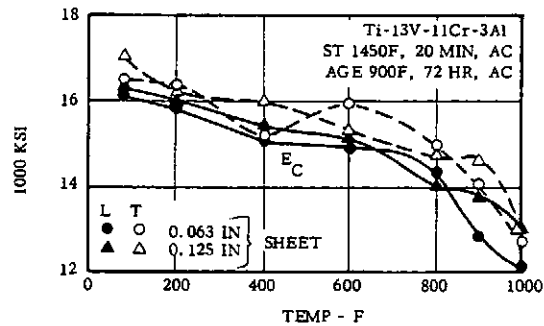


FIG. 3.0622 EFFECT OF TEST TEMPERATURE ON COMPRESSION MODULUS OF ELASTICITY FOR SHEET (32, p. 15-20)

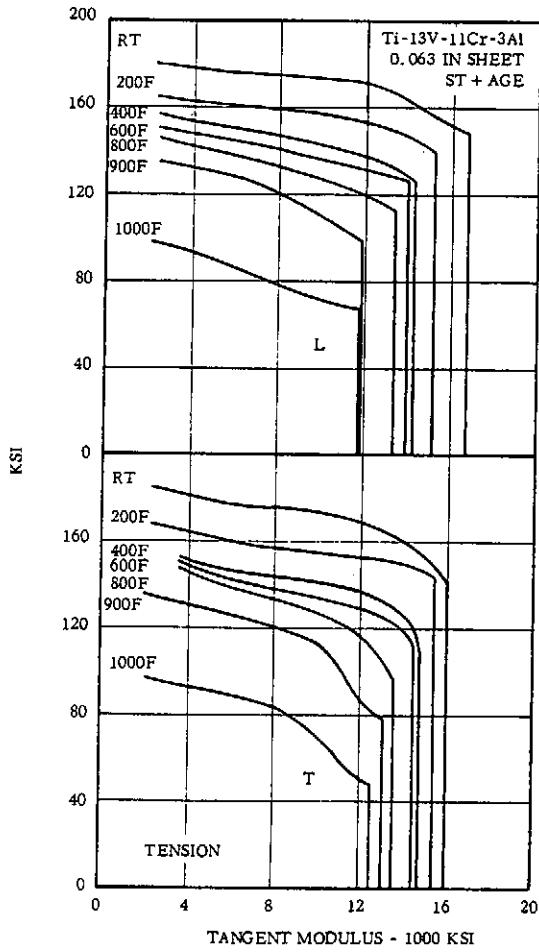


FIG. 3.0641 TANGENT MODULUS CURVES AT ROOM AND ELEVATED TEMPERATURES FOR SOLUTION TREATED AND AGED SHEET IN TENSION (23, p. 122)

	Ti
13	V
11	Cr
3	Al

B120 VCA

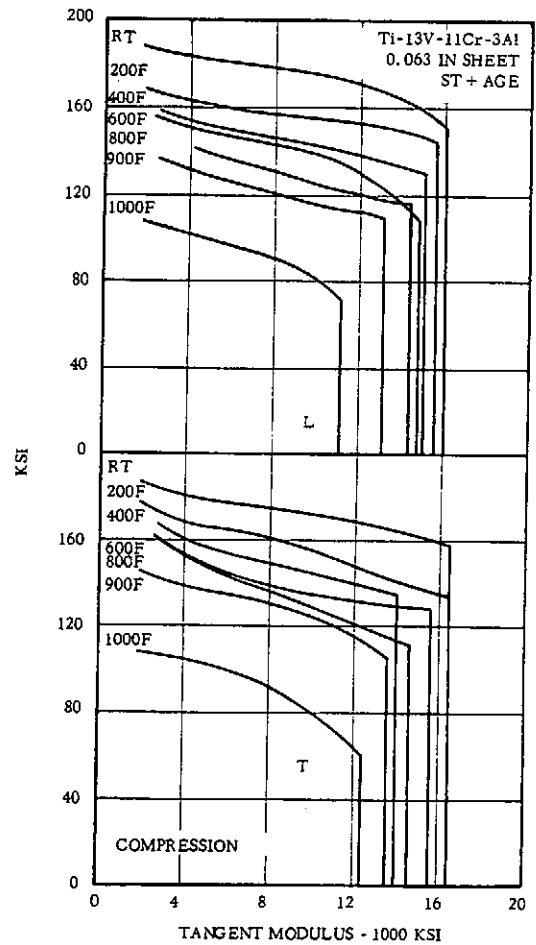


FIG. 3.0642 TANGENT MODULUS CURVES AT ROOM AND ELEVATED TEMPERATURES FOR SOLUTION TREATED AND AGED SHEET IN COMPRESSION (33, p. 124)

	Ti
13	V
11	Cr
3	Al

B120 VCA

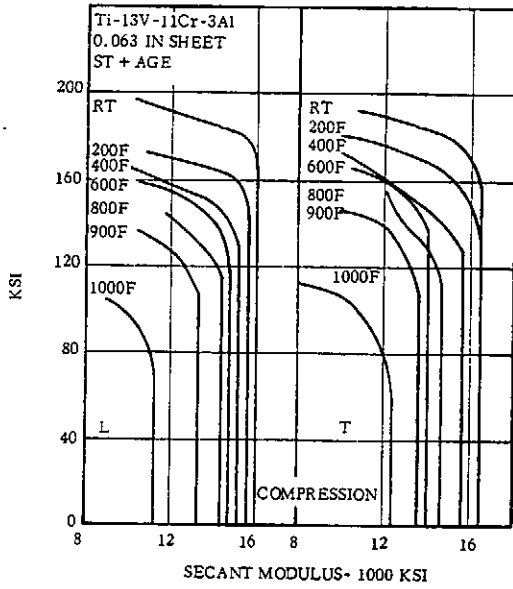


FIG. 3.065 SECANT MODULUS CURVES AT ROOM AND ELEVATED TEMPERATURES FOR SOLUTION TREATED AND AGED SHEET IN COMPRESSION (33, p.126)

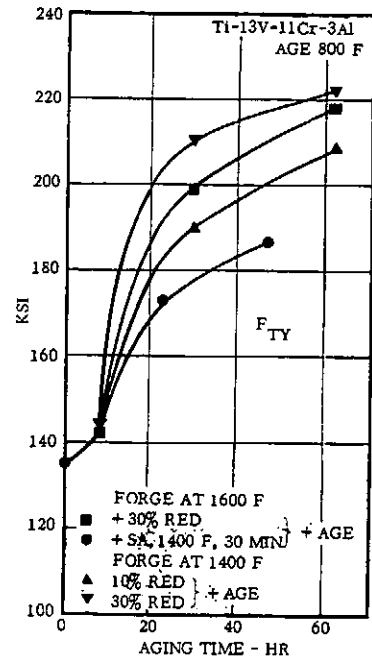


FIG. 4.0121 EFFECT OF AGING AFTER FORGING AT TWO TEMPERATURES (13, p.77)

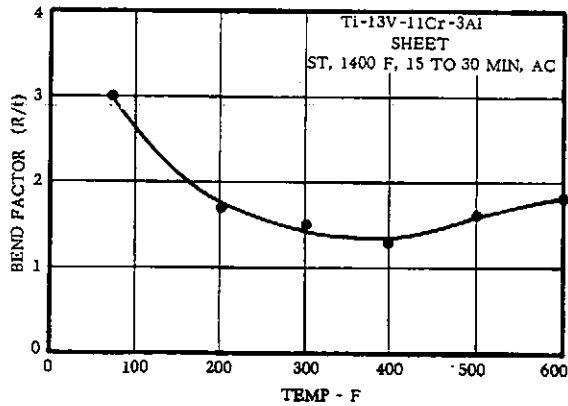


FIG. 4.0111 EFFECT OF TEST TEMPERATURE ON BEND PROPERTIES OF SOLUTION TREATED SHEET AT ROOM AND ELEVATED TEMPERATURES (12, p.4)

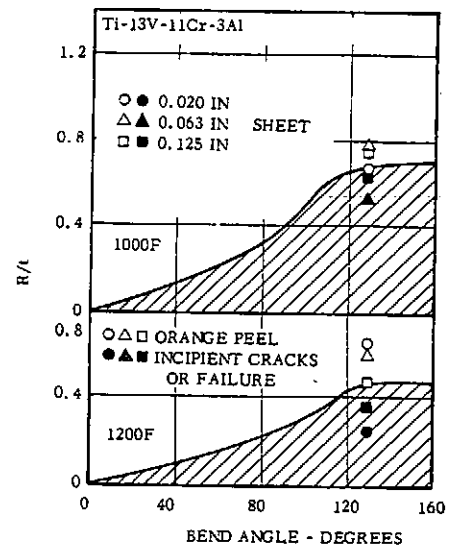
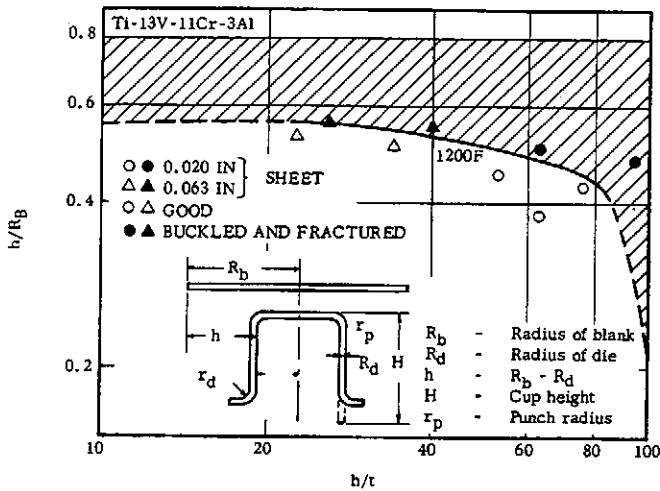


FIG. 4.013 SPLITTING LIMITS FOR BRAKE FORMING AT 1000F AND 1200F (29, p. 93-95)



	Ti
13	V
11	Cr
3	Al

B120 VCA

FIG. 4.014 LIMIT CURVE FOR DEEP DRAWING AT 1200F (29, p.121,122)

REFERENCES

- Crucible Steel Co. of America, Data Sheet B 120 VCA, Titanium Alloy Issue #2, TDS-2007-5M-(1960), (Dec. 1960)
- Titanium Metals Corp. of America, "Properties of Ti-13V-11Cr-3Al", Titanium Engineering Bulletin No. 9, (June 1960)
- Wood, R. A. and Ogden, H. R., "The All-Beta Titanium Alloy", DMIC Rep. No. 110, (April 17, 1959)
- Alloy Digest, "Crucible B-120 VCA", Filing Code: Ti-28, Titanium Alloy, (Dec. 1960)
- Durstein, R. C., Crucible Steel Co., "Personal Communication", (Oct. 23, 1959)
- Carpenter, S. R., Woodward, R. D., Alesch, C. W. and Green, E. D., Convair, "Titanium Development Study Program", Interim Engineering Rep. No. IX, (Jan. thru March, 1960)
- Sachs, G. and Sessler, J. G., "Effect of Stress Concentration on Tensile Strength of Titanium and Steel Alloy Sheet at Various Temperatures", Symposium on Low-Temperature Properties of High-Strength Aircraft and Missile Materials, ASTM STP No. 287, p. 122, (1960)
- White, D. L., McGee, W. M., Mathews, B. R., and Watson, H. T., Lockheed Aircraft Corp., "The Determination of the Mechanical Property Design Data for Heat Treated Titanium Alloys Being Produced by the DOD Sheet Rolling Program", Progress Rep. No. 9, ER-3830, Vol. 9, (June 1961)
- Hughes, P. J., McGee, W. M. and White, D. L., Lockheed Aircraft Corp., "The Determination of the Mechanical Property Design Data for Heat Treated Titanium Alloys Being Produced by the DOD Sheet Rolling Program", Progress Rep. No. 7, ER-3830, Vol. 7, (Dec. 1960)
- Hughes, P. J., McGee, W. M. and Johnson, R. W., Lockheed Aircraft Corp., "The Determination of the Mechanical Property Design Data for Heat Treated Titanium Alloys Being Produced by the DOD Sheet Rolling Program", Progress Rep. No. 8, ER-3830, Vol. 8, (March 1961)
- Ericson, G. L., Boyd, W. K. and Miller, P. D., "Corrosion of Titanium and Titanium Base Alloys in Liquid and Gaseous Fluorine", TML-BMI Memo, (April 30, 1958)
- Crucible Steel Co., Titanium Div., "Tentative Data Sheet Crucible B-120 VCA, an FA-Formageable Beta Titanium Alloy", Brochure (June 23, 1958)
- Henning, H. J. and Frost, P. D., "Titanium Alloy Forgings", DMIC Rep. No. 141, (Dec. 19, 1960)

	Ti	14
13	V	15
11	Cr	16
3	Al	16

B 120 VCA

- 14 Brothers, A. J., Martens, H. E. and Wood, A. L., "Bend Properties of Welded High Strength Titanium Alloy Sheet", Jet Propulsion Laboratory TR No. 32-39, (Jan. 30, 1961)
- 15 Horne, E. L. and Harden, W. D., "Elevated Temperature Creep Properties of B 120 VCA Sheet Material", WADD-TR 60-525, (Nov. 1960)
- 16 Brown, W. F., Jr., Personal Communications, (Aug. 1961 and Jan. 1962)
- 17 Espey, G. B., Jones, M. H. and Brown, W. F., Jr., "Sharp Edge Notch Tensile Characteristics of Several High-Strength Titanium Sheet Alloys at Room and Cryogenic Temperatures", Symposium on Low Temperature Properties of High Strength Aircraft and Missile Materials, ASTM STP No. 287, (1960)
- 18 Repko, A. J., Jones, M. H. and Brown, W. F., Jr., "Influence of Sheet Thickness on Sharp Edge Notch Properties of a Titanium Alloy at Room and Low Temperatures", ASTM Preprint No. 80 b, (1961)
- 19 Brown, W. F., Jr., Espey, G. B. and Jones, M. H., "Considerations in Selection of Wing and Fuselage Sheet Materials for Transonic Transports", SAE Preprint No. 341 D, (1961)
- 20 "Titanium Alloy Sheet, Strip and Plate", Aerospace Material Specification AMS 4917, issued (Jan. 15, 1963)
- 21 Heimerl, G. J., Baucom, R. M., Manning, C. R., Jr. and Braski, D. N., "Stability of Four Titanium-Alloy and Four Stainless Steel Sheet Materials after Exposures up to 22,000 Hours at 350 F", NASA TN D-2607, (Feb. 1965)
- 22 Viglione, J., Worden, W. F., Erthal, J. F. and Williams, F. S., "Fracture Toughness Properties of Some Alloy Steels and Aluminum and Titanium Alloys", U. S. Naval Air Engineering Center, Report No. NAEC-AML-2111, (March 4, 1965)
- 23 Hanna, G. L. and Steigerwald, E. A., "Fracture Characteristics of Structural Metals", Thompson-Ramo Wooldridge, Inc., ER-5426, (June 30, 1963)
- 24 Banerjee, B. R. and Hauser, J. T., "Fracture Micro-mechanics in High-Strength Steels and Titanium", ML-TDR-64-182, (July 31, 1964)
- 25 "Basic Design Facts about Titanium", Reactive Metals, Inc., Niles, Ohio, (Feb. 1965)
- 26 "Compilation of Unpublished Materials Information - 3rd Quarterly Report", Republic Aviation Corp., Rep. No. 357-3, (Jan. 12, 1962)
- 27 Jacobs, F., "Mechanical Properties of Materials Fabricated by Shear Forming", ASD TDR-62-830, (Feb. 1963)
- 28 Wood, W. W., et al, "Advanced Theoretical Formability Manufacturing Technology, Interim Report Part II", ASD-TR-8-143(II), (1964)
- 29 Wood, W. W., et al, "Advanced Theoretical Formability Manufacturing Technology, Interim Report Part III", ASD-TR-8-143(III), (1964)
- 30 Wood, W. W., et al, "Advanced Theoretical Formability Manufacturing Technology, Interim Report Part IV", ASD-TR-8-143(IV), (1964)
- 31 McGee, W. M. and Mathews, B. R., "Determination of Design Data for Heat Treated Titanium Alloy Sheet, Vol. 2 a", ASD TDR-62-335, Vol. 2 a, (May 1962)
- 32 Lockheed-Georgia Co., "Determination of Design Data for Heat Treated Titanium Alloy Sheet, Vol. 3", ASD-TDR-62-335, Vol. 3, (May 1962)
- 33 Hughes, P. J., "Determination of Design Data for Heat Treated Titanium Alloy Sheet, Vol. I", ASD-TDR-62-335, Vol. I, (May 1962)
- 34 Moorhead, P. E., "Tensile and Creep Properties of Columbium, Tantalum and Titanium Alloys at Elevated Temperatures", Bell Laboratory Report BLR-62-26M, (Dec. 1962)
- 35 Hickey, C. F., Jr., "Mechanical Properties of Titanium and Aluminum Alloys at Cryogenic Temperatures", ASTM, Preprint No. 78, (1962)
- 36 Christian, J. L., "Mechanical Properties of Titanium and Titanium Alloys at Cryogenic Temperatures", Convair Astronautics, MRG-189, (Oct. 14, 1960)
- 37 Schwartzberg, F. R., Osgood, S. H., Keys, R. D. and Kiefer, T. F., "Cryogenic Materials Data Handbook, Progress Report No. 1", ML-TDR-64-280, Suppl., (Feb. 1965)
- 38 "A Review and Comparison of Alloys for Future Solid Propellant Rocket-Motor Cases", Defense Metals Information Center, Battelle Memorial Institute, DMIC Memo 184, (Nov. 15, 1963)
- 39 Military Handbook - 5, "Metallic Materials and Element for Flight Vehicle Structures", FSC 1500, Dept. of Defense, (August 1962)