CONVAIR ASTRONAUTICS

REPORT MRG-189

PAGE

MECHANICAL PROPERTIES OF TITANIUM

AND TITANIUM

ALLOYS AT CRYOGENIC TEMPERATURES

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SUBJECT: Mechanical Properties of Titanium and Titanium Alloys at Cryogenic Temperatures

ABSTRACT: This report includes the mechanical property data obtained in the Materials Research Group on titanium and titanium alloys at +78°F, -320°F and -423°F. The data include tensile strengths, 0.2% yield strengths, % elongation, notched tensile strengths, notched/unnotched tensile ratios and charpy impact values on base metal and welded joints (heliarc butt welds and fusion welds with filler metal added). Materials tested include 30% cold-rolled Ti-75A commercially pure titanium (AMS 4901) and the following titanium alloys: 5Al-2.5Sn, 5Al-5Zr-5Sn, 6Al-4Zr-IV, 7Al-12Zr, 8Al-2Cb-1Ta, 5Al-2.75Cr-1.25Fe, 6Al-4V and 13V-11Cr-3Al.

An analysis of the results is included for each alloy which primarily discusses the usefulness of the material for structural applications at cryogenic temperatures. Also, correlations of the materials's mechanical properties are made with its chemistry, impurity content, microstructure, primary working and heat treatment. Recommendations are made concerning the use of titanium and its alloys at cryogenic temperatures and future research work which has been suggested by this program.

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SUBJECT: Mechanical Properties of Titanium and Titanium Alloys at Cryogenic Temperatures.

INTRODUCTION

Very low temperatures are encountered in current and proposed missiles and space vehicles due to the use of cryogenic propellants such as liquid oxygen and liquid hydrogen (boiling points of -297°F and -423°F respectively) and due to the near absolute zero temperatures encountered under certain conditions in outer space. Therefore, the properties of engineering materials at these extreme subzero temperatures are becoming of prime importance to the design engineer.

The primary purpose of this investigation was to determine the mechanical properties of cold-rolled commercially pure titanium and several titanium base alloys in order to evaluate their usefulness for structural applications at cryogenic temperatures. It was also the purpose of this program to correlate mechanical properties with such variables as chemistry, impurity content, microstructure, primary working and heat treatment in order to better understand the mode of deformation and fracture characteristics of titanium and its alloys as a function of temperature. Another purpose was to make definite recommendations for the future development of titanium alloys in order to improve their properties at cryogenic temperatures. The materials tested in this program include cold-rolled 75A commercially pure titanium (AMS 4901) and the following titanium alloys: 5Al-2.5Sn, 5Al-5Zr-5Sn, 6Al-4Zr-1V, 7Al-12Zr, 8Al-2Cb-1Ta, 5Al-1.75Cr-1.25Fe, 6Al-4V, and 13V-11Cr-3Al. These represent the all alpha, the alpha-beta, and the all beta type alloys of which several were tested in various tempers and in various forms (sheet, plate and forging stock).

Many investigations have been made on the low temperature properties of titanium alloys (Refs. 1,2,3,4); however, in addition to the determination of tensile and elastic properties as a function of temperature, notched tensile properties and notched/unnotched tensile ratios and Charpy impact values were determined. The notched/unnotched ratios were determined as a function of temperature in order to evaluate the toughness, which is often referred to in terms of resistance to brittle fracture, or notch sensitivity (Refs. 5, 6, 7). A notched specimen with a stress concentration factor (K_t) of 6.3 was selected for use in this investigation because previous axial fatigue tests of complex welded joints and fatigue and burst tests of pressure vessels made of 301 extra full hard stainless steel exhibited excellent correlation with notched/unnotched tensile ratios obtained with this value of K_t over a range of temperatures from 78° to -423°F (Ref. 8). Data were obtained on specimens with less acute notches (e.g., K_t of 2.5-3.0) and were found to be less discriminatory between tough and brittle materials; in fact notched/unnotched ratios

of near unity were obtained on some materials which were known to be brittle (Ref. 8). At the other extreme, however, stress concentration factors of 15 to 18 have been employed by some investigators (Ref. 4) and these tests in general tend to make all materials appear brittle. Thus, notched/unnotched tensile ratios using a K_t of 6.3 have proven to be both discriminatory between tough and brittle materials and to correlate with service behavior.

MATERIALS, TEST SPECIMENS AND APPARATUS

The titanium alloys used in this investigation and their history and chemical analyses are listed in Table 1. The tensile specimens used in this investigation are shown in Fig. 1 and 2. All tensile specimens were inspected and individually measured for area determination. Notched specimens were inspected and measured by means of an optical comparator, and all specimens out of tolerance were rejected. The stress concentration factor (k_t), as determined by $\sqrt{\frac{1/2 \text{ width between notches}}{\text{radius of the notch}}}$, was 6.3 with "in tolerance" limits of 5.7 to 7.1.

The testing apparatus consisted of a 50,000-lb. Baldwin universal testing machine equipped with a continuous stress-strain recorder and strain pacer. Standard extensometers were used at room temperature and a specially designed cryo-extensometer was used at low temperatures. Specially constructed cryostats were used for testing at sub-zero temperatures; a small open cryostat for -100°F and -320°F, and a gas-tight cryostat insulated by a vacuum chamber, liquid nitrogen jacket and foamed polyurethane, for tensile testing at -423°F. A full description of the cryostat, cryo-extensometer, and accessory equipment, as well as the safety features and rapidity of testing can be found in Ref. 9. The tensile machine, extensometers and accessory equipment were periodically checked and calibrated.

EXPERIMENTAL PROCEDURE

Tensile tests were performed at 72°F (room temperature), -100°F by immersion in a bath of dry ice and alcohol, -320°F by immersion in liquid nitrogen and -423°F by immersion in liquid hydrogen. Tests were conducted after the specimens came to temperature as determined by a copper-constantan thermocouple taped to the test section. Times required to reach temperature were from 3 to 6 minutes after immersion. The smooth tensile specimens were tested at a strain rate of 0.001 in./in/minute to yield, followed by a rate of 0.15 in./minute until fracture. Notched tensile specimens were tested at 0.001 in./in./minute, as determined by extensometers, until fracture. Yield strengths were determined from the continuous stress-strain curves by the 0.2% offset method. Elongations reported herein are total elongations as determined by scribe marks on a surface dye and read at 10X magnification over a 2-in. gage length for flat tensile specimens and a 1-in. gage length for the round test bars. Hardness measurements were made on a Rockwell superficial tester on the 15-N scale at room temperature.

EXPERIMENTAL RESULTS

The mechanical properties (tensile strengths, .2% yield strengths and elongations) of 30% cold-rolled 75-A commercially pure titanium from +78°F to -423°F are reported in Table II. Tables III thru VI present the mechanical properties of four different heats of 5Al-2.5Sn titanium alloy (A-110AT) at 78, -100, -320 and -423°F. These tables include the tensile properties of heliarc butt welded joints as well as base metal and notched data. Tables VII thru XI report the mechanical property data obtained on 5Al-5Zr-5Sn, 6Al-4Zr-1V, 7Al-12Zr, 8Al-2Cb-1Ta, and 5Al-2.75Cr-1.25Fe titanium alloys. Tables XII thru XIX contain tensile and Charpy impact data on 6Al-4V alloy in the annealed, solution treated, and solution treated and aged conditions. Data on the all beta titanium alloy, 13V-11Cr-3Al (B-120VCA) are presented in Tables XX thru XXII.

DISCUSSION OF RESULTS

Since the behavior of titanium and its alloys at cryogenic temperatures is not subject to generalizations, each alloy will be discussed separately.

30% Cold-Rolled Ti-75A Commercially Pure Titanium

The mechanical properties of the base metal are reported in Table II. Of immediate interest is the fact that the room temperature tensile and yield strengths have been considerably increased by cold-rolling the material 30%. However, the fact that the notched tensile strengths and notched/unnotched tensile ratios sharply decline with reduction in testing temperature indicates that the material is not suitable for structural applications at cryogenic temperatures. It is felt that the low temperature embrittlement of this material is partly due to the high interstitial (C, O_2, N_2, H_2) and impurity content present as well as the cold-rolling. Further research on the low temperature mechanical properties of Ti-45A and Ti-55A (AMS 4900 and AMS 4902) commercially pure material in the annealed condition is being planned.

5Al-2.5Sn Titanium (A-110AT)

Tables III thru VI present the data obtained on base metal and weld joints of 5Al-2.5Sn titanium alloy from 78°F to -423°F. Four different heats of material have been tested all in the mill annealed condition with sheet thicknesses ranging from 0.020 to 0.063 inches.

It is significant to note that the notched/unnotched tensile ratios are quite high for all four heats down to -320°F. Also, the notched tensile strengths continue to increase to -320°F. However, the .027 and .063 inch sheet materials (Tables IV and VI) experience a decrease in notched tensile strengths and notched/unnotched tensile ratios from -320 to -423°F. This indicates some degree of embrittlement of these materials at -423°F. Notch tensile strengths of the .020 and .040 inch sheet materials (Tables III and V) continue

to increase down to -423°F and the notched/unnotched tensile ratios remain quite high (0.97 and 0.86). The reason for the partial embrittlement of the before material heats is felt to be due to their higher interstitial content (C, O_2, N_2, H_2), which also explains why their room temperature tensile and yield strengths are higher than for the low interstitial content heats.

Mechanical properties of heliarc butt welded joints (no post heat treatment or doublers attached) show nearly 100% weld joint tensile efficiency and appreciable ductility down to -423°F.

Repeated loading tests of large welded joints (38" long coupon 4" in width with transverse heliarc butt joint made with no filler metal added, and in as-welded condition) were run on the 0.020 inch sheet material (Table V) at +78, -320 and -423°F. The specimens were axially loaded to 90% of their typical yield strength at each temperature. More than 2000 cycles were obtained at room temperature (maximum stress of 100,000 psi) and at -320°F (stress level of 1[illegible],000 psi) without failure or indication of failure (cracking). 539 cycles were obtained at -423°F (stress level of 205,000 psi) without failure in the test section (specimen failed in end doubler due to the nature of the test equipment). These tests validate three important points. First, that 5Al-2.5Sn titanium alloy retains sufficient toughness for structural applications at -423°F. Secondly, that straight heliarc butt welds without post treatment or doublers is 100% efficient down to -423°F. And, third, that the very large increase in tensile and yield strengths (100% increase from +78 to -423°F) may be used to advantage in those structures which see maximum stress only while at low temperature.

Of the large number of titanium alloys tested, the 5Al-2.5Sn alloy is the only one being recommended at this time for structural use in liquid hydrogen (-423°F). It is possible that the annealed 6Al-4V-titanium alloy may possess good toughness at -423°F if the interstitial content were kept very low, lower than presently found in commercial heats. This point is being further investigated. The 5Al-2.5Sn titanium alloy is readily available in gauges 0.020 inches and thicker and an effort to produce 0.010 inch material by rolling rather than chemical milling is presently being made. Resistance spot or fusion welding of the 5Al-2.5Sn alloy to itself or to commercially pure titanium is considered excellent. Present CV-A production welding equipment used in the Atlas and Centaur programs is capable of resistance spot welding this alloy with no equipment changes required. Fusion welding may also be accomplished on present equipment with minor modifications, in particular, an increase in inert gas shielding. Corrosion resistance of the base metal and fusion welds is excellent. Also, the alloy is compatible with liquid oxygen, liquid hydrogen, and many storable propellants, such as pentaborane, hydrazine, UDMH and nitrogen tetroxide. Further information on the physical properties (thermal, elastic, etc.), formability, machineability, etc., are available in the Materials Research Group.

5Al-5Zr-5Sn Titanium Alloy

The mechanical properties of the base metal and heliarc butt welded joints of this alloy are presented in Table VII. Notched tensile strengths and notched/unnotched tensile ratios indicate sufficient toughness to -320°F but partial embrittlement at -423°F. Welded joints were nearly 100% efficient at all testing temperatures. The microstructure of this alloy showed a small amount of beta phase present which may account for the embrittlement at -423°F, although recent information indicates that the zirconium alloying may be responsible for the low temperature embrittlement.

6Al-4Zr-1V Titanium Alloy

Table VIII presents the mechanical properties of this alloy. This material exhibits embrittlement at -320 and at -423°F as determined by notched tensile testing. The substantial amount of beta present in the microstructure and the combination of zirconium and vanadium is probably the cause for low temperature embrittlement.

7Al-12Zr Titanium Alloy

As may be seen in Table IX, this alloy also experiences some embrittlement at -320 and -423°F. The zirconium alloying content is felt to be much too high for cryogenic applications. Note in Table I that the interstitial content (C, O_2, N_2, H_2) of this material is quite low, which is further evidence that high zirconium contents in titanium cause low temperature embrittlement.

8Al-2Cb-1Ta Titanium Alloy

This alloy retains sufficient toughness for structural applications to -320°F but experiences some embrittlement at -423°F (see Table X). The tensile and yield strength of this alloy is 15-20% higher than for the low interstitial 5Al-2.5Sn alloy, therefore there is interest in further development of this material. As may be seen in Table I, the interstitial content of this material is very low; however it is felt that a small change in the alloying contents of this material may show improved toughness at -423°F. Another alloy, 8Al-1Mo-1V, is presently being evaluated for low temperature use.

5Al-2.75Cr-1.25Fe Titanium Alloy (RS-140)

Tensile properties and Charpy impact values of annealed and heat treated material are presented in Table XI. It is felt that further testing is required to fully evaluate this alloy, however Charpy impact values indicate an appreciable decrease in toughness of the annealed material with reduction in testing temperature.

6Al-4V-Titanium Alloy

Mechanical property data on this alloy are presented in Tables XII thru XIX. Data have been obtained on this alloy in the mill annealed, in the solution

treated and in the solution treated and aged conditions. Typical properties of four heats of annealed 6Al-4V are given in Tables XII thru XV. Notched tensile data and notched/unnotched tensile ratios indicate good toughness to -320°F with partial embrittlement at -423°F. Titanium Metals Corporation of America has arranged to provide CV-A with high purity samples of annealed 6Al-4V-Ti alloy sheet having very low interstitial contents to determine if the moderately high O_2 content of commerical quality 6Al-4V-Ti alloy is responsible for the embrittlement observed at -423°F.

Heliarc butt welds are nearly 100% efficient at all testing temperatures. Data on the solution treated alloy are given in Table XVI. Notched tensile data indicate a higher degree of embrittlement at cryogenic temperatures than observed in the annealed condition. Tables XVII and XVIII present data on solution quenched and aged 6Al-4V titanium alloy. Test specimens were prepared from the 24 "O.D." spherical storage bottles used for helium pressurization in the Atlas ICBM pneumatics system. Both notched tensile data and Charpy impact values indicate this alloy retains sufficient toughness for structural use at -320°F. Table XIX presents information obtained on 6Al-4V fusion welds using three different filler metals (6Al-4V, 3.5Al-2.5V, and 75A commercially pure titanium) and tested in the stress relieved and heat treated conditions. Tensile data and Charpy impact values are reported. Choice of filler metal would be dependent upon application.

13V-11Cr-3Al Titanium Alloy (B 120 VCA)

This is an all-beta type titanium alloy known for its high strength/density ratio at room temperature after aging. Tables XX thru XXII present data on both solution annealed and solution annealed and aged material at room and cryogenic temperatures. Notched tensile data and Charpy impact values indicate that the material is very brittle at -320°F, therefore this alloy is not recommended for structural applications at extreme sub-zero temperatures.

RECOMMENDATIONS

Based upon present information the following recommendations are made concerning the use of titanium alloys for structural applications at cryogenic temperatures. The only titanium alloy which is recommended at this time for use at liquid hydrogen temperatures is the 5Al-2.5Sn alloy. However, careful control over interstitial content is required to insure adequate toughness at -423°F. Several titanium alloys may be employed for structural use as low as -320°F. These include 6Al-4V (both annealed and heat treated), 8Al-2Cb-1Ta and 5Al-5Zr-5Sn titanium alloys (annealed condition). Again it is pointed out that low interstitial levels are required in all the titanium alloys as well as commercially pure titanium in order to achieve maximum toughness at sub-zero temperatures.

It is apparent from the data obtained in this program that several metallurgical factors affect the low temperature brittle fracture characteristics of titanium and its alloys. Of primary importance are microstructure chemistry, and impurity (including interstitials) content of the material. There is some

evidence that certain alloying elements (such as zirconium) adversely affect the low temperature toughness of titanium alloys. Also, it is quite apparent from this investigation as well as several other studies that high interstitials and certain impurities promote brittle fracture in titanium and its alloys. Alloys having an all-beta microstructure are brittle at reduced temperatures. A study of photomicrographs obtained on fractured surfaces of tensile specimens indicated that those materials with fine grained equiaxed structure (either alpha or alpha-beta) retained greater toughness at cryogenic temperatures than those materials with a coarse grained transformed structure (e.g. the solution treated 6Al-4V and 13V-11Cr-3Al alloys). The poor toughness of the cold-rolled 75A commercially pure titanium seems to indicate that cold-rolling may have a deleterious effect on the fracture properties of titanium at sub-zero temperatures.

It is recommended that further research be conducted, particularly in the field of alloy development, to produce high strength titanium alloys for structural use at cryogenic temperatures.

CONCLUSIONS

1. The 5Al-2.5Sn titanium alloy retains sufficient toughness in both base metal and weld joints for structural application down to liquid hydrogen temperatures (-423°F) provided that careful control over interstitial content is maintained. The large increase in tensile and yield strength of the 5Al-2.5 Sn alloy with reduction in temperature may be used to advantage in missile structures when maximum stress occurs while the material is subjected to sub-zero temperatures, such that low temperature design allowables can be used.

2. The following titanium alloys may be used for structural applications as low as -320°F but not at -423°F: 6Al-4V (both annealed and solution quenched and aged), 8Al-2Cb-1Ta, and 5Al-5Zr-5Sn.

3. The 13V-11Cr-3Al titanium alloy offers a high strength/density material at room temperature but is not recommended for sub-zero applications because of excessive embrittlement at low temperatures.

4. Several metallurgical factors affect the fracture characteristics of titanium and its alloys at cryogenic temperatures. High interstitial contents adversely affects the toughness at cryogenic temperatures as well as certain alloying elements (e.g. zirconium). Greater toughness is obtained on materials with fine grained equiaxed microstructures than with coarse grained transformed microstructures. Cold-rolling has a deleterious effect on low temperature toughness.

5. Further research should be conducted, particularly in the area of alloy development, to provide more titanium alloys with improved strength and toughness for structural applications at cryogenic temperatures.

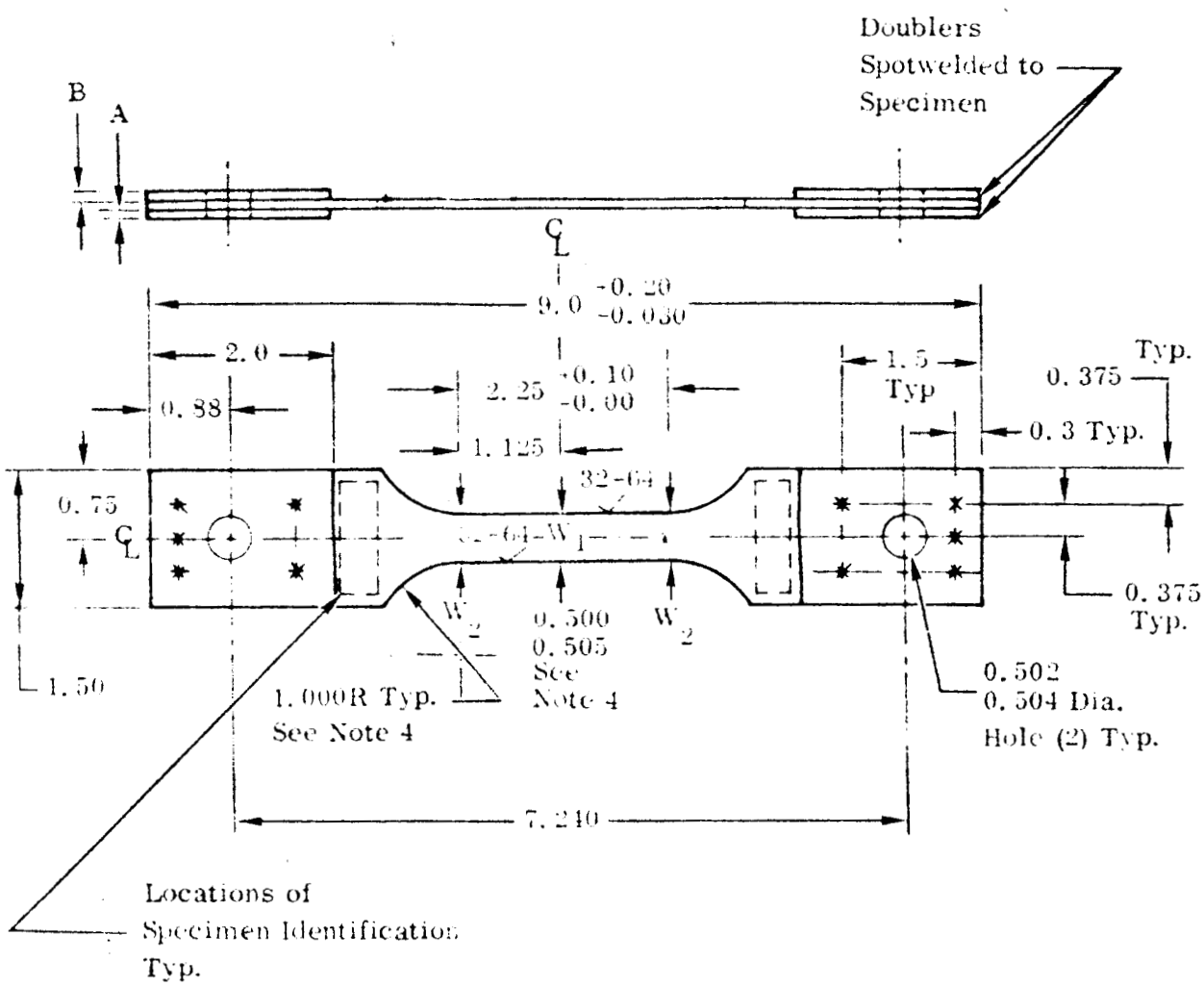

Fig. 1. Flat tensile specimen (standard).

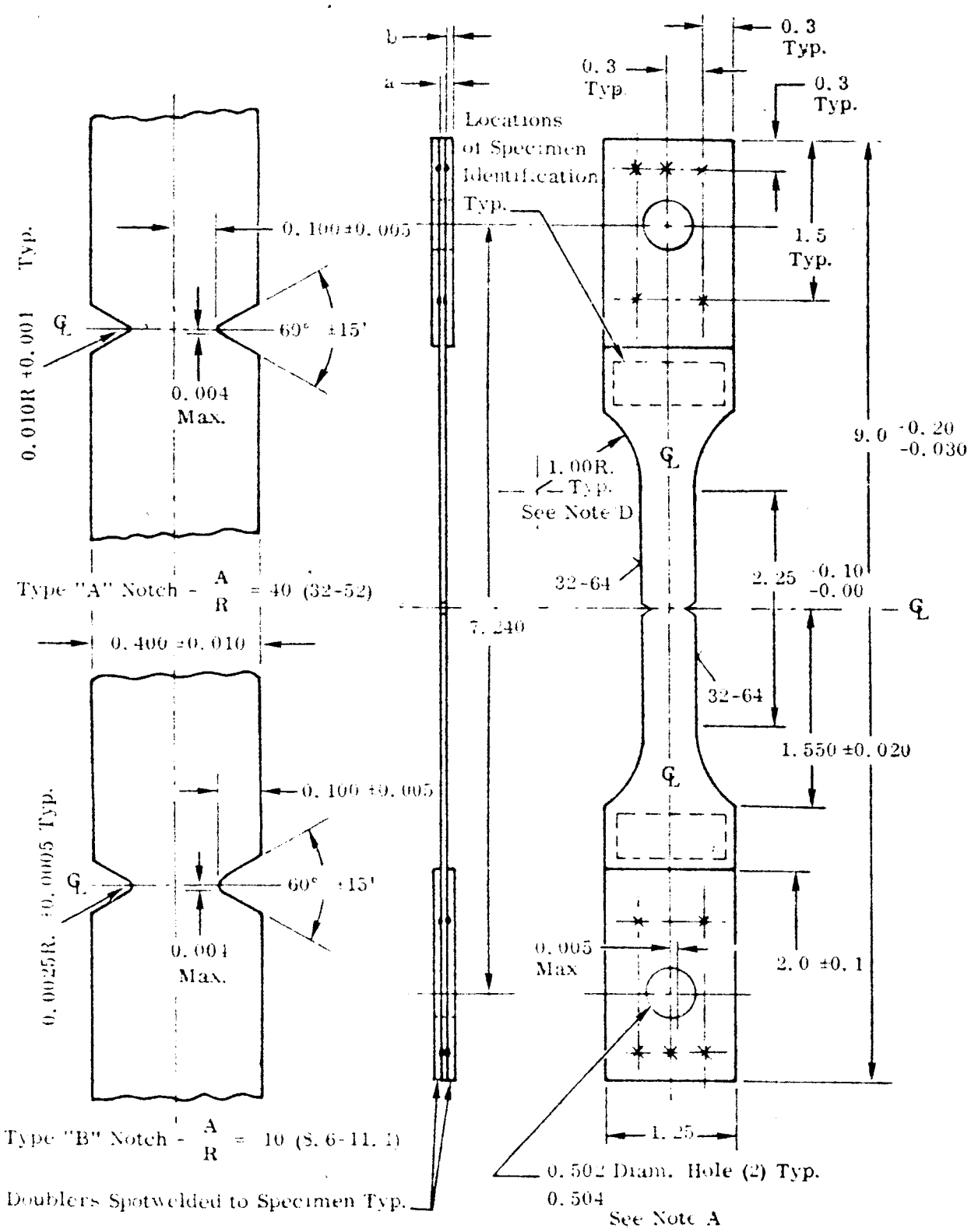

Fig. 2. Notched tensile specimens.

History and Chemical Analysis of Titanium Base Alloys

TABLE	MATERIAL	TEMPER	THICKNESS (IN.)	HARDNESS 15-N SUPERFICIAL	HEAT NO.	PRODUCT	CHEMISTRY Al	Cb	Cr	Fe	Sn	Ta	V	Zr	C	H_2	N_2	O_2
II	75A (Commercially)	30% Cold Rolled	0.012	74	M-9656	TMCA	5.8			0.09	2.4				0.017	0.0108	0.010	0.103
III	5Al-2.5 Sn	Annealed	0.040	78	M-8465	TMCA	5.4			0.21	2.5				0.021	0.015	0.010	
IV	5Al-2.5 Sn	Annealed	0.027	78	M-9048	TMCA	4.9				2.4				0.03	0.0061	0.03	
V	5Al-2.5 Sn	Annealed	0.020	78	31387	Reactive Metals	4.8			0.045	4.7			4.8	0.02	0.005	0.014	0.06
VI	5Al-2.5 Sn	Annealed	0.063	80	D-2073		5.8						0.087	3.6	0.020	84ppm	0.024	
VII	5Al-5Zr-5Sn	Annealed	0.062	76	V-1464	TMCA	7.0							11.5	0.01	0.012	0.01	0.09
VIII	6Al-4Zr-1V	Annealed	0.090	80	V-1166	TMCA	7.67	1.89		0.19		0.96			0.02	135ppm		0.001
IX	7Al-12Zr	Annealed	0.050	80	R-98321	Crucible	4.90		2.70	1.05					0.031		0.010	
X	8Al-2Cb-1Ta	Annealed	0.026	79	23732	Reactive Metals	5.89			0.09			4.1		0.028	0.005	0.008	
XI	5Al-2.75Cr-1.25 Fe	Given in Table XI			R-11730	Crucible	6.1			0.09			3.9		0.028	0.0049	0.022	0.11
XII	6Al-4V	Annealed	0.090	74	M-8619	TMCA	6.21			0.16			3.81		0.007	0.0118	0.010	
XIII	6Al-4V	Annealed	0.063	76	M-8907	TMCA	5.92			0.41			4.06		0.016	0.0435	0.013	
XIV	6Al-4V	Annealed	0.063	78	B-23132	-	3.2		10.6				13.3		0.03	212ppm	0.01	
XV	6Al-4V	Annealed	0.063	76	M-23262	-	3.2		10.6				13.3		0.03	212ppm	0.01	
XVI	6Al-4V	Solution Treated	0.020	80	—	-	5.3		9.9				12.5		0.03	0.0184	0.02	
XX	13V-11Cr-3Al	Solution Annealed	0.062	75	—	Crucible												
XXI	13V-11Cr-3Al	Solution Treated and Aged	0.062	80	—	Crucible												
XXII	13V-11Cr-3Al	Given Table XXII	0.250		R-98103	Crucible												

TABLE II

Mechanical Properties of Titanium, 75-A Commercially Pure

0.012" Sheet, TMCA, Heat M-9656, 30% Cold Rolled

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/UNNOTCHED TENSILE RATIO
+78°F	Long.	121	138	5	149	
	Long.	121	136	5	141	
	Ave.	121	137	5	145	1.06
+78°F	Trans.	122	145	5	165	
	Trans.	122	147	5	163	
	Ave.	122	146	5	164	1.12
-60°F	Long.	-	154	-	145	
	Long.				147	
	Ave.	-	154	-	146	0.95
-60°F	Trans.	-	171	-	117	
	Trans.	-	172	-		
	Ave.	-	172	-	117	0.68
-320°F	Long.	-	211	5	151	
	Long.	-	212	5	155	
	Ave.	-	212	5	153	0.72
-320°F	Trans.	-	210	3	122	
	Trans.	-	212	3	137	
	Ave.	-	211	3	130	0.62
-423°F	Long.	217	233	1	128	
	Long.	-	241	1	130	
	Long.		228		122	
	Ave.	217	234	1	127	0.54
-423°F	Trans.	-	237	1	121	
	Trans.	-	241	1	125	
	Trans.				102	
	Ave.	-	239	1	116	0.49

TABLE III

Mechanical Properties of Titanium 5Al-2.5 Sn Alloy

0.040" Sheet, TMCA, Heat M-8465, Mill Annealed

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/ UNNOTCHED TENSILE RATIO	HELIARC BUTT WELD T.S., ksi	WELD EL %	JOINT EFF %
+78°F	Long.	113	118	19	154		122	11	
	Long.	111	118	19	153		121	13	
	Long.	114	117	19	162		120	13	
	Long.	113	119	19	163				
	Long.	111	119	19					
	Ave.	113	118	19	158	1.34	121	12	100
+78°F	Trans.	114	120	14	159				
	Trans.	115	120	13					
	Ave.	115	120	14	159	1.33			
-100°F	Long.	134	140	17	174		141	10	
	Long.	136	144	20	174		142	12	
	Long.	135	143	19	176				
	Ave.	135	142	18	175	1.23	142	11	100
-100°F	Trans.	137	144	11					
	Trans.	137	143	11					
	Ave.	137	144	11					
-320°F	Long.	184	197	11	224		190	2	
	Long.	185	196	18	227		193	11	
	Long.	182	195	18	222		194	11	
	Long.	184	191	15	229				
	Long.	186	197	16					
	Ave.	184	196	15	226	1.15	192	8	98
-320°F	Trans.	186	197	11	219				
	Trans.	184	200	11	221				
	Ave.	185	199	11	220	1.11			
-423°F	Long.	227	248	14	235		234	3	
	Long.	237	246	14	244		225	0	
	Long.	226	244	-	232		240	8	
	Long.	225	248	15	221				
	Long.	234	251	15	234				
	Ave.	230	247	15	239	0.97	233	4	94
-423°F	Trans.	-	243	9	202				
	Trans.	-	244	10	213				
	Trans.	225	248	15					
	Trans.	234	251	-					
	Ave.	230	244	11	208	0.85			

TABLE IV

Mechanical Properties of Titanium 5Al-2.5Sn

0.027" Sheet, TMCA, Heat M-9048, Mill Annealed

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (Kt=6.3) ksi	NOTCHED/UNNOTCHED TENSILE RATIO
+78°F	Long.	123	133	15	178	
	Long.	123	133	15		
	Long.	123	133	16		
	Ave.	123	133	15	178	1.34
+78°F	Trans.	124	131	14	176	
	Trans.	124	133	14	177	
	Ave.	124	132	14	177	1.34
-100°F	Long.	141	159	15	195	
	Long.	148	160	15		
	Long.	149	161	15		
	Ave.	146	160	15	195	1.22
-100°F	Trans.	146	156	14	189	
	Trans.	148	157	14	190	
	Ave.	147	157	14	190	1.21
-320°F	Long.	195	210	17	247	
	Long.	195	209	17		
	Long.	194	210	16		
	Ave.	195	210	17	247	1.18
-320°F	Trans.	191	207	13	235	
	Trans.	204	216	15	241	
	Trans.				238	
	Ave.	198	212	14	238	1.12
-423°F	Long.	236	259	9	223	
	Long.	244	259	12	194	
	Long.	234	259	5		
	Ave.	238	259	9	209	0.81
-423°F	Trans.	232	255	7	216	
	Trans.	230	254	9	211	
	Trans.				213	
	Ave.	231	255	8	213	0.84

TABLE IV

Mechanical Properties of Titanium 5Al-2.5 Sn

0.020" Sheet, Reactive Metals, Heat 31387, Mill Annealed

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/ UNNOTCHED TENSILE RATIO	HELIARC BUTT WELD T.S., ksi	WELD EL %	JOINT EFF %
+78°F	Long.	111	122	12	154		118	7	
	Long.	111	123	12	147		124	10	
	Long.						122	9	
	Ave.	111	123	12	151	1.23	121	9	98
-423°F	Long.	230	245	5	227		252	2	
	Long.	247	260	3	207		299	1	
	Long.						249	2	
	Ave.	239	253	4	217	0.86	267	2	100

TABLE VI

Mechanical Properties of Titanium 5Al-2.5 Sn Alloy

0.063" Sheet, Crucible, Heat D-2073, Mill Annealed

TEST TEMP.	DIRECTION		F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/UNNOTCHED TENSILE RATIO
+78°F	Long		122	130	17	174	
	Long.		122	129	17	174	
		Ave.	122	130	17	174	1.34
+78°F	Trans.					175	
-100°F	Long.		146	153	17	202	
	Long.					200	
		Ave.	146	153	17	201	1.31
-320°F	Long.		201	212	13	248	
	Long.		205	216	13	244	
		Ave.	203	214	13	246	1.15
-423°F	Long.		257	262	2	181	
	Long.		258	264	-	179	
	Long.					197	
		Ave.	258	263	2	186	0.71
-423°F	Trans.					164	

TABLE VII

Mechanical Properties of Titanium 5Al-5Zr-5 Sn Alloy

0.062" Sheet, TMCA, Heat V-1464, Mill Annealed

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/ UNNOTCHED TENSILE RATIO	HELIARC BUTT WELD T.S., ksi	WELD EL %	JOINT EFF. %
+78°F	Long.	120	125	18	155		126	17	
	Long.	120	127	17	155		126	10	
	Long.	122	126	17	155		127	15	
	Ave.	121	126	17	155	1.23	126	14	100
+78°F	Trans.	120	123	17	155				
	Trans.	120	123	17	156				
	Ave.	120	123	17	156	1.27			
-100°F	Long.	146	151	17	181		151	7	
	Long.	145	150	17	182		151	16	
	Long.	144	150	18	181		151	16	
	Ave.	145	150	17	181	1.21	151	13	100
-100°F	Trans.	143	149	16	181				
	Trans.	143	148	17	180				
	Ave.	143	149	17	181	1.21			
-320°F	Long.	192	209	16	204		207	5	
	Long.	192	209	17	190		209	7	
	Long.	193	208	17	202		210	9	
	Ave.	192	209	17	199	0.95	209	7	100
-320°F	Trans.	188	204	15	185				
	Trans.	186	203	15	191				
	Ave.	187	204	15	188	0.92			
-423°F	Long	230	254	11	181		242	2	
	Long.	239	265	11	178		242	3	
	Long.	236	268	11	189		242	2	
	Ave.	235	262	11	183	0.70	242	2	92
-423°F	Trans.	225	256	10	161				
	Trans.	216	251	8	165				
	Ave.	221	254	9	163	0.64			

TABLE VIII

Mechanical Properties of Titanium 6Al-4Zr-1V Alloy

0.090" Sheet, TMCA, Heat V-1166, Mill Annealed

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3)	NOTCHED/UNNOTCHED TENSILE RATIO
+78°F	Long.	137	142	16	173	
	Long.	136	141	16	173	
	Ave.	137	142	16	173	1.22
+78°F	Trans.	137	139	16	173	
	Trans.	136	139	16	173	
	Ave.	137	139	16	173	1.24
-100°F	Long.	160	167	15	197	
	Long.	159	167	15	197	
	Long.				195	
	Ave.	160	167	15	196	1.17
-320°F	Long.	-	227	9	186	
	Long.	207	228	12	184	
	Long.	216	227	10		
	Ave.	212	227	10	185	0.81
-320°F	Trans.	218	226	12	169	
	Trans.				172	
	Ave.	218	226	12	171	0.76
-423°F	Long.	266	279	5	151	
	Long.	261	279	5	149	
	Ave.	264	279	5	150	0.54
-423°F	Trans.	264	277	4	157	
	Trans.				152	
	Ave.	264	277	0	155	0.56

TABLE IX

Mechanical Properties of Titanium 7Al-12Zr Alloy

0.050" Sheet, Crucible, Heat R-98321, Mill Annealed 1650°F, 1 Hr.

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/UNNOTCHED TENSILE RATIO
+78°F	Long.	134	146	11	179	
	Long.	133	142	11	179	
	Long.	132	141	10	176	
	Ave.	133	143	11	178	1.24
+78°F	Trans.	133	139	16	179	
	Trans.	132	138	12	180	
	Ave.	133	139	14	180	1.29
-100°F	Long.	148	159	10	155	
	Long.	146	157	12	-	
	Ave.	147	158	11	155	0.98
-100°F	Trans.	149	158	11	193	
	Trans.	148	158	11	198	
	Trans.	150	158	11		
	Ave.	149	158	11	196	1.24
-320°F	Long.	197	214	11	173	
	Long.	196	214	13	162	
	Ave.	197	214	12	168	0.79
-320°F	Trans.	194	209	16	190	
	Trans.	195	212	12	196	
	Trans.	194	212	14		
	Ave.	194	211	14	193	0.91
-423°F	Long.	241	252	7	131	
	Long.	239	251	5	150	
	Long.	239	249	-		
	Ave.	240	251	6	141	0.56
-423°F	Trans.	239	251	4	161	
	Trans.	230	247	5	151	
	Ave.	235	249	5	156	0.63

TABLE X

Mechanical Properties of Titanium 8Al-2Cb-1Ta Alloy

0.026" Sheet, Reactive Metals, Heat No. 23732, Mill Annealed

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/UNNOTCHED TENSILE RATIO
+78°F	Long.	131	141	12	172	
	Long.	130	143	12	175	
	Long.	132	143	12	160	
	Ave.	131	142	12	169	1.19
+78°F	Trans.	129	143	14	169	
	Trans.	129	137	14	166	
	Ave.	129	140	14	168	1.20
-100°F	Long	156	165	13	196	
	Long.	156	165	13	198	
	Long.	155	165	12	199	
	Ave.	156	165	13	198	1.20
-100°F	Trans.	151	161	9	191	
	Trans.	—	—	—	191	
	Ave.	151	161	9	191	1.19
-320°F	Long.	195	207	13	240	
	Long.	204	221	12	248	
	Long.	214	223	13	245	
	Ave.	204	217	13	244	1.12
-320°F	Trans.	—	—	—	204	
	Ave.				204	
-423°F	Long.	252	266	0	207	
	Long.	248	264	1	243	
	Long.	—	—	—	230	
	Ave.	250	265	1	227	0.86
-423°F	Trans.	215	248	0	158	
	Trans.	-	278	1	201	
	Ave.	215	263	1	180	0.68

TABLE XI

Mechanical Properties of Titanium 5AL-2.75 Cr-1.25 Fe, Alloy

0.250" Plate, Crucible, Heat R-11730

CONDITION	TEST TEMP.	YIELD STRENGTH 0.02% OFFSET psi	TENSILE STRENGTH psi (1)	% ELONG	% R.A.	V-NOTCH CHARPY IMPACT FT. LBS. (2)
Annealed 1425°F, 1 hr. air cooled	+70°F	147,300 (3)	157,900	15.9	43.6	27.5 (4)
	-320°F	234,700 (4)	244,100	13.1	18.8	7.7 (4)
Heat Treated, 1450°F 1 hr. water quenched, 900°F, 6 hrs. air cool	+70°F	163,500 (4)	184,000	7.7	13.3	4.0 (4)
	-320°F	256,000 (4)	269,900	2.2	4.0	3.4 (4)

(1) Tensile test specimens were 0.113" diameter round shank, with 0.45" gage length.

(2) V-Notch Charpy impact specimens were twice standard width (0.788"), 1/2 standard thickness (0.197"), and 1/2 standard notch depth (0.039"), but with standard notch contour.

(3) Average of 5 tests; longitudinal to grain direction.

(4) Average of 2 tests; longitudinal to grain direction.

TABLE XII

Mechanical Properties of Titanium 6Al-4V Alloy

0.090" Sheet, TMCA, Heat M-8619, Mill Annealed

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/UNNOTCHED TENSILE RATIO
+78°F	Long.	127	137	13	163	
	Long.	127	136	13	162	
	Long.	128	136	13	161	
	Ave.	127	136	13	162	1.19
+78°F	Trans.	128	136	13	168	
	Trans.	128	135	13	168	
	Ave.	128	136	13	168	1.24
-320°F	Long.	209	215	12	231	
	Long.	210	215	12	231	
	Long.	209	216	13	236	
	Ave.	209	215	12	233	1.08
-320°F	Trans.	210	214	12	246	
	Trans.	210	214	13		
	Ave.	210	214	13	246	1.15
-423°F	Long.	260	260	2	163	
	Long.	259	259	2	162	
	Long.	260	260	2	161	
	Ave.	260	260	2	162	0.62
-423°F	Trans.	244	262	4	168	
	Trans.	251	258	2	168	
	Ave.	248	260	3	168	0.65

TABLE XIII

Mechanical Properties of Titanium 6Al-4V Alloy

0.063" Sheet, TMCA, Heat M-8907, Mill Annealed

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/ UNNOTCHED TENSILE RATIO	HELIARC BUTT WELD T.S., ksi	WELD EL %	JOINT EFF %
+78°F	Long.	128	141	11	157		142	10	
	Long.	130	141	12	156		142	10	
	Long.	129	140	11			142	10	
	Ave.	129	141	11	157	1.11	142	10	100
+78°F	Trans.	135	145	13	169				
	Trans.	137	146	12	169				
	Ave.	136	146	13	169	1.16			
-100°F	Long.	157	166	9	170		168	9	
	Long.	158	166	12	164		168	10	
	Long.						169	10	
	Ave.	158	166	11	167	1.01	168	10	100
-100°F	Trans.	161	168	10	186				
	Trans.	160	169	11	183				
	Ave.	161	169	11	185	1.09			
-320°F	Long.	212	220	11	200		221	8	
	Long.	211	219	11	181		221	11	
	Long.	210	217	8			221	12	
	Ave.	211	219	10	191	0.87	221	10	100
-320°F	Trans.	213	218	8	182				
	Trans.	217	222	11	191				
	Trans.	214	218	11					
	Ave.	215	219	10	187	0.85			
-423°F	Long.	249	258	-	185		270	5	
	Long.	248	256	2	181		292	3	
	Long.	239	249	2			263	3	
	Ave.	245	253	2	183	0.72	275	4	100
-423°	Trans.	245	254	2	182				
	Trans.	251	261	2	191				
	Trans.	-	250	1					
	Ave.	248	255	2	187	0.73			

TABLE XIV

Mechanical Properties of Titanium 6Al-4V Alloy

0.063" Sheet, Heat B-23132, Mill Annealed

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/UNNOTCHED TENSILE RATIO
+78°F	Long.	121	133	10	151	
	Long.	121	134	11	149	
	Ave.	121	134	11	150	1.12
+78°F	Trans.	137	145	10	167	
	Trans.	138	145	11	167	
	Ave.	138	145	11	167	1.15
-320°F	Long.	208	217	10		
	Long.					
	Long.					
	Ave.	—	—	—		
-423°F	Long.	262	269	2	185	
	Long.	263	273	2	179	
	Long.					
	Ave.	263	271	2	182	0.67
-423°F	Trans.	242	255	2	177	
	Trans.	242	255	2	172	
	Ave.	242	255	2	175	0.69

TABEL XV

Mechanical Properties of Titanium 6Al-4V Alloy

0.063" Sheet, Heat M-23262, Mill Annealed

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/UNNOTCHED TENSILE RATIO
+78°F	Long.	98	137	11	154	
	Long.	104	141	12	144	
	Long.	115	145	9	148	
	Ave.	106	141	11	149	1.06
+78°F	Trans.	127	157	8	168	
	Trans.	127	157	8	167	
	Ave.	127	157	8	168	1.07
-100°F	Long.	125	171	11	162	
	Long.	123	171	11	154	
	Long.	122	171	11	161	
	Ave.	123	171	11	159	0.93
-100°F	Trans.	145	177	6	174	
	Trans.	144	171	-	171	
	Ave.	145	174	6	173	0.99
-320°F	Long.	177	223	11	193	
	Long.	166	215	8	200	
	Long.	177	219	7	193	
	Ave.	173	219	9	195	0.89
-320°F	Trans.	198	215	3	191	
	Trans.	195	217	5	184	
	Ave.	197	216	4	188	0.87
-423°F	Long.	227	256	2	174	
	Long.	230	248	0	173	
	Long.	203	236	2	182	
	Ave.	220	247	1	176	
-423°F	Trans.	227	254	7	162	
	Trans.	-	231	0	161	
	Ave.	227	243	4	162	0.67

TABLE XVI

Mechanical Properties of Titanium 6Al-4V Alloy

0.020" Sheet, Solution Treated (1725°F, 30 Min., WQ)

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/UNNOTCHED TENSILE RATIO
+78°F	Long.	130	160	7	170	
	Long.	130	159	8	182	
	Long.	128	156	8	182	
	Ave	129	158	8	178	1.13
+78°F	Trans.	126	157	10	180	
	Trans.	128	160	11	170	
	Ave	127	159	11	175	1.10
-100°F	Long.	154	195	9	187	
	Long.	148	187	11	190	
	Ave	151	191	10	189	0.99
-100°F	Trans.	145	189	12	179	
	Trans.	145	189	12		
	Ave	145	189	12	179	0.95
-320°F	Long.	-	246	7	190	
	Long.	207	239	5	198	
	Ave	207	243	6	194	0.80
-320°F	Trans.	207	244	11	179	
	Trans.	195	240	11	169	
	Ave	201	242	11	174	0.72
-423°F	Long.	224	259	0	152	
	Long.	236	-	-	152	
	Long.	234	259	0	169	
	Ave	231	259	0	158	0.61
-423°F	Trans.	228	277	2	110	
	Trans.	245	280	0	149	
	Ave	237	279	1	130	0.47

TABLE XVII

Mechanical Properties of Titanium 6Al-4V Alloy

1/2" to 3/4" Wall Thickness, Hemispherical Forgings, Heat Treated

TEST TEMP.	DIRECTION WITH RESPECT TO GRAIN FLOW	YIELD STRENGTH psi	TENSILE STRENGTH psi	% ELONG.	% R.A.	V-NOTCH CHARPY (5 ft. lbs.
+70°F	Long.	127,700 (1)	146,200	27.0	53.5	14.0
+70°F	Long.	132,300 (1)	147,800	27.5	53.1	14.8
+70°F	Trans.	133,200 (1)	156,400	26.5	34.8	10.0
+70°F	Trans.	133,000 (1)	154,000	25.5	38.0	10.2
-320°F	Long.	225,300 (1)	232,800	11.1	30.0	9.5
-320°F	Long.	229,200 (1)	234,200	13.3	38.8	9.8
-320°F	Trans.	236,800 (1)	244,300	13.3	23.6	8.0
-320°F	Trans.	236,100 (1)	245,100	11.1	22.0	8.4
+70°F	Long.	137,000 (2)	156,100	16.2	52.6	17.7
+70°F	Long.	138,100 (2)	153,300	16.2	45.1	15.0
-320°F	Long.	228,700 (2)	236,400	11.1	36.4	10.0
-320°F	Long.	237,800 (2)	244,100	11.8	27.5	9.0
+70°F	Trans, base metal	140,800 (3)	153,500	10	27.9	-
-320°F	Trans, base metal	220,700 (3)	228,600	8	26.2	-
+70°F	Trans,	140,100 (4)	153,100	8	22.0	-
-320°F	Thru pressure weld	232,800 (4)	238,800	8	31.9	-

NOTES:

(1) Specimens from same forging, Fed. Std. 151, Specimen R4, 0.160" diam.

(2) Specimens from another forging, Fed. Std. 151, Specimen R4, 0.160" diam.

(3) Specimens from base metal of another forging, 0.113" diam., 0.625" gage length.

(4) Specimens with pressure weld transverse to middle of gage length. 0.113" diam., 0.625" gage length. Specimens machined after pressure welding and heat treating.

(5) Double width, half thickness of standard 0.394" square specimens, with half standard depth.

All forgings were heat treated. 1725° - 1750°F for 2-4 hours, water quenched, aged 1025° - 1050°F for 4-8 hours, air cooled.

TABLE XVIII

Mechanical Properties of Titanium 6Al-4V Alloy

0.75" Thick Forging - TMCA, Heat No. and Chemistry Unknown

FORGING AND HEAT TREATMENT	TEST TEMP.	YIELD STRENGTH psi	TENSILE (1) STRENGTH psi	% ELONG.	% R.A.	NOTCHED (2) TENSILE STRENGTH psi	NOTCHED UNNOTCHED TENSILE RATIO
Low finish forging temperature, air cooled,	+78°F	176,800	187,800	10.9	37.3	-	-
heated to 1725°F, 1 hr., water quenched, 1050°F, 3 hrs., air cooled.	-320°F	238,000	253,400	8.7	33.9	254,000	1.00
Forged at 1850°F, cooled, heated to 1725°F, 1 hr., water quenched, 1050°F, 3 hrs.	+78°F	143,300	172,500	10.0	15.0	-	-
air cooled.	-320°F	239,700	253,600	3.8	7.4	236,500	0.93

(1) Standard 0.252" diameter tensile test specimen, 1.0" gage length.

(2) Notched tensile specimen, 0.283" diameter away from notch, circumferentially notched to diameter under notch of 0.200", 60° angle notch, root radius .0025", Stress Concentration, K_t=6.3.

TABLE XIX

Mechanical Properties of Welded Joints in Titanium 6Al-4V Alloy

Plate, Heli-arc Butt Welds, "V" Joints, Welds Completed with 4 Passes of Filler Wire.

TEST	STRESS RELIEVED			HEAT TREATED		
	6Al-4V Filler Wire	3.5Al-2.5V Filler Wire	Ti75A Filler Wire	6Al-4V Filler Wire	3.5Al-2.5V Filler Wire	Ti75A Filler Wire
Tensile Strength, +70°F, weld machined	139,400 139,500	127,600 128,400	101,800 98,280	171,200 168,300	147,200 139,400	115,700 119,800
Tensile Strength, +70°F, weld not machined	141,700 140,700	136,800 137,500	129,200 125,800	173,900 173,500	170,600 166,000	132,700 139,900
Tensile Strength -320°F, weld machined flush	217,600	198,400 203,800	168,700 173,300	248,000 246,300	209,500 180,600	134,200 117,100
Tensile Strength, -320°F, weld not machined	220,200 221,800	219,300 219,400	185,000 195,700	249,500 251,000	232,500 228,600	157,800 157,200
% Elong., +70°F, weld machined flush	11.0 11.0	4.0 3.0	3.0 3.0	4.0 4.5	3.5 2.5	2.0 1.5
% Elong., +70°F, weld not machined	13.5 12.5	14.5 8.5	5.0 4.5	12.0 12.0	5.0 4.0	3.0 4.0
% Elong., -320°F, weld mahcined flush	11.5	3.5 2.5	3.0 2.5	2.0 2.0	1.5 2.0	1.0 1.0
% Elong., -320°F weld not machined	17.0	28.5	4.0 4.5	3.0 7.0	4.5 3.5	2.0 3.0
V-Notch Charpy, +70°F, ft. lbs.	17.0 10.0	21.5 22.0	25.9 27.4	10.0 8.0	23.0 20.8	6.0 7.0
V-Notch Charpy, -320°F, ft. lbs.	7.4 6.2	10.5 10.8	16.7 13.5	4.0 5.1	10.5 13.5	5.0 4.0

NOTES:

Stress relieved - 1300°F - 1 hr. at temp. air cooled, after welding.

Heat treated - 1725°F - 1 hr. at temp., water quenched, aged at 1050°F - 2 hrs., air cooled, after welding.

Tensile test specimens - Fed. Std. 151, Type F2, flat test specimen, weld transverse to axis.

V-Notch Charpy test specimens - Twice standard width, half standard thickness, 1/2 standard depth of notch; notched in weld metal.

TABLE XX

Mechanical Properties of Titanium 13V-11Cr-3Al Alloy

0.062" Sheet, Crucible, Solution Annealed (1400°F, 30 Min., AC)

TEST TEMP.	DIRECTION	F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/UNNOTCHED TENSILE RATIO
+78°F	Long.	-	135	22	161	
	Long.	-	135	22	162	
	Long.				160	
	Ave.	-	135	22	161	1.19
-320°F	Long.	-	288	-	149	
	Long.				180	
	Long.				87	
	Long.				220	
	Ave.		288	-	159	0.55
-423°F	Long.				133	
					131	
	Ave.				132	

TABLE XXI

Mechanical Properties of Titanium 13V-11Cr-3Al Alloy

0.062" Sheet, Crucible, S.T. And Aged (900°F, 20 Hr., A.C.)

TEST TEMP.	DIRECTION		F_{ty} ksi	F_{tu} ksi	el. %	NOTCHED T.S. (K_t=6.3) ksi	NOTCHED/UNNOTCHED TENSILE RATIO
+78	Long.		159	176	8	173	
	Long.		-	-	-	173	
		Ave.	159	176	8	173	0.98
-320°F	Long.					129	
	Long.		—	—	—	145	
		Ave.				137	
-423°F	Long.					99.7	
	Long.		—	—	—	83.1	
		Ave.				91.4	

0.062" Sheet, Crucible, S.T. And Aged (900°F, 72 Hr., A.C.)

+78°F	Long.		181	201	6	169	
	Long.		—	—	—	160	
		Ave.	181	201	6	165	0.82
-320°F	Long.					127	
	Long.		—	—	—	93	
		Ave.				110	
-423°F	Long.					97	
	Long.		—	—	—	119	
		Ave.				109	

TABLE XXII

Mechanical Properties of Titanium 13V-11Cr-3Al Alloy

0.250 Plate, Crucible, Heat R-98103

As Received - Mill Annealed

DIRECTION	TEST TEMP., °F	YIELD STRENGTH 0.2% OFFSET, psi	TENSILE (1) STRENGTH psi	% ELONG.	% R.S.	V-NOTCH CHARPY IMPACT ft. lbs.
Trans.	+70	140,600	150,400	18.8	54.0	6.0
Trans.	+70	140,400	148,200	17.2	53.0	-
Long.	+70	136,300	144,300	21.9	55.0	-
Long.	+70	137,700	145,800	18.8	54.0	-
Trans.	-320	-	251,700	1.5	1.5	1.4
Trans.	-320	-	239,800	1.5	0	1.5
Long.	-320	-	148,400	1.5	0.5	-
Long.	-320	-	197,000	1.5	1.0	-

Annealed at Convair-Astronautics, Heated to 1400°F, held 30 minutes, air cooled

Trans.	+70	139,200	144,100	21.9	54.0	10.0
Trans.	+70	137,600	144,900	17.2	52.0	9.9
Long.	+70	133,500	140,900	23.4	59.0	-
Long.	+70	134,200	141,500	21.9	56.0	-
Trans.	-320	-	214,900	1.5	0.5	1.3
Trans.	-320	-	246,300	4.6	1.5	1.5
Long.	-320	-	234,800	1.5	1.0	-
Long.	-320	-	265,800	1.5	0	-

NOTES:

(1) Tensile test specimens were 0.160" diameter round shank, with 0.64" gage length.

(2) V-Notch Charpy specimens were twice standard width (0.788"), 1/2 standard thickness (0.197"), and 1/2 standard notch depth (0.039"), but with standard notch contour.

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