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TITANIUM - 6% ALUMINUM - 4% VANADIUM ALLOY: EFFECTS OF SPONGE PURITY, ALUMINUM CONTENT AND HEAT TREATMENT

TECHNICAL REPORT NO. WAL TR 405.21/1

BY

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SEPTEMBER 1959

O.O. PROJECT: TA2-8055, SPECIAL AMMUNITION T-317
D/A PROJECT: 5A12-15-003

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Titanium alloys, properties, mechanical

Titanium - 6% aluminum - 4% vanadium

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TITLE

TITANIUM - 6% ALUMINUM - 4% VANADIUM ALLOY: EFFECTS OF SPONGE PURITY, ALUMINUM CONTENT AND HEAT TREATMENT

ABSTRACT

An investigation was undertaken to determine the heat treating characteristics of the 6%Al-4%V titanium alloy; the solution and aging temperatures for optimum strength properties; and the effect of varying the aluminum and the interstitial contents on the heat treatment for optimum strength. The study involved the 6%Al-4%V titanium alloy made with three hardness levels of sponge (140, 160, 180 BHN) and three levels of aluminum (6%, 7%, 8%) made with the 140 BHN sponge. A fourth alloy of interest, 5%Al-3%FeCr-3%FeMo (140 BHN sponge) was included in the study.

The data show that the heat treatment for optimum strength-ductility-toughness should consist of a solution temperature, high in the alpha-plus-beta range, followed by short-time aging at a temperature which will give the maximum strength values desired. For the alloys involved in this study, an aging temperature of 1050°F appears to be appropriate. Increases in aluminum or interstitial contents result in increased strength values but with a significant lowering of the toughness values.

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INTRODUCTION

The titanium alloy containing 6% aluminum and 4% vanadium is one which, during its development, was found to have medium strength with good ductility and toughness. This alloy was developed by Armour Research Foundation under contract to Watertown Arsenal with technical supervision by Watertown Arsenal Laboratories.

On 24 May 1954, Mallory-Sharon Corporation produced and tested the first production-size ingot (1500 lb) of this alloy produced for Watertown Arsenal. During 1954, production of the alloy was initiated by Titanium Metals Corporation of America.

In October 1955, at a meeting of the American Society for Metals in Philadelphia, data on the heat-treating characteristics of this production alloy were presented by the Titanium Metals Corporation of America.[1] These data were very interesting and informative but their applicability for Ordnance use was regarded as limited for the following reasons:

(1) only two solution temperatures were involved,

(2) no data were included on the effect of alloy purity on mechanical properties after heat treatment,

(3) no data were given on aging at temperatures above 1000°F, and

(4) no data were given on aging for periods of less than 24 hours.

At that time it was thought by Watertown Arsenal personnel that shorter aging times could be used effectively with higher aging temperatures (1050° - 1150°F) without danger of omega embrittlement. Also, for purposes of saving time and processing cost, a shorter aging time was desirable. Ordnance materiel requirements and the need for suitable materials specifications suggested the desirability of obtaining data on the effect of sponge purity and heat treatment on properties of the alloy. The ultimate aim was to determine conditions which would produce the optimum strength-ductility-toughness combination for Ordnance use at ambient temperatures.

This study was undertaken to determine the optimum strength-ductility-toughness combination of the aluminum-vanadium-titanium base alloy obtainable by: varying sponge purity, varying aluminum content, varying solution temperature and short-time aging temperature.

The short-time elevated temperature strength after optimum heat treatment was also determined. Included in the study was an evaluation of a 5%Al-3%FeCr-3%FeMo titanium base alloy, of interest because of its potential as a high-strength alloy.

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[1] *SHERMAN, R. G. and KESSLER, H. D., Investigation of the Heat Treatability of the 6% Aluminum - 4% Vanadium Titanium-Base Alloy, ASM Transaction, vol. 48, 1956, p. 657-676.*

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MATERIALS AND PROCEDURE

The materials used in this investigation were received from the producer as forged 4½"-diameter round bars with chemistries as shown by Table I. Sponge hardnesses are also shown.

TABLE I

Chemical Analyses of Titanium Alloys (% by Wt.)

Heat No.	Al	V	Fe	Mn	Sn	O	H	N	Si	S	C	Mo	Cr	Sponge BHN
L1121R	5.99	4.06	0.14	0.02	.01*	0.161	0.0056	0.028	.01*	0.008	0.04	--	--	140
L1122R	6.12	4.11	0.19	.01*	.01*	0.162	0.0063	0.032	.01*	0.008	0.06	--	--	160
L1123R	6.15	4.29	0.24	0.05	.01*	0.208	0.0089	0.032	.01*	0.008	0.04	--	--	180
L1124R	6.87	4.02	0.23	0.05	.01*	0.179	0.0078	0.028	.01*	0.008	0.05	--	--	140
L1125R	7.93	4.06	0.24	0.03	.01*	0.165	0.0067	0.024	.01*	0.009	0.03	--	--	140
M1685R	4.10	.01*	160	.01*	--	0.207	0.0048	0.020	.01*	--	0.03	1.09	1.35	140

*Less than

Specimens for determining the effect of solution temperatures and aging temperatures on grain size and mechanical properties were taken from the 4½"-diameter bars as shown in Figure 1. Similar tests were made of drop-forged 3/4"-thick plate as shown in Figure 2. For determining the short-time elevated temperature strength characteristics, test specimens were taken from upset-forged plate as shown in Figure 3. In all instances forging was performed with the alloy in the alpha-beta range of temperature. No protective atmosphere was used in the heat treatment. Standard 0.357"-diameter tensile specimens and standard Charpy V notch specimens were used in these tests. In the tension testing, the rate of loading was 30,000 psi/minute to the yield strength at 0.2% offset and 60,000 psi/minute above that.

DATA AND DISCUSSION

The results of the tests to determine the effect of sponge purity, solution temperature and aging temperature on the mechanical properties of the 6%Al-4%V titanium base alloy are shown in Figure 4 (4½" barstock) and Figure 5 (drop-forged 3/4" plate). The short-time elevated temperature properties of this alloy in the press-forged 3/4" plate thickness are shown in Figure 6. It may be noted that the latter data are for material which has been heat treated to give optimum strength and toughness as indicated in Figures 4 and 5.

Table I shows that the interstitial chemistry of the 140 BHN and 160 BHN melts is essentially the same. It may be noted from Figures 4 and 5 that yield and tensile strength of the 180 BHN material shows an increase over the 140 BHN and 160 BHN alloys but that ductility shows no appreciable change. Toughness is reduced by approximately 4 ft-lb. As the aging temperature increases above 1050°F, the tensile properties are lowered with no appreciable effect on toughness. The optimum strength-ductility-toughness combination occurs with a solution temperature of about 1750°F and an aging temperature of about 1050°F. The short-time elevated temperature tensile properties are increased by an increase of interstitials within the limits tested (Figure 6, using a reference temperature of 800°F).

In Figure 7, data are shown on the mechanical properties of Heat 1121R (140 BHN sponge) of the 6%Al-4%V titanium alloy as affected by varying the solution temperature while holding the aging temperature constant at 1050°F. The solution temperature of 1750°F shows best tensile properties as previously mentioned. It will be noted that increasing the solution temperature from 1600° to 1750°F results in a substantial increase in both the ultimate tensile and yield strengths with no significant change in ductility or impact value. It is of interest to note also that solution temperatures in the neighborhood of the beta transus (1800° - 1850°F) result in a sharp drop in strength and ductility with some recovery at higher temperatures. Hardness remained constant over the entire range of heat treatments despite changes in tensile strength of approximately 15,000 psi indicating a lack of correlation between hardness and tensile strength in this titanium alloy.

The effect of increasing aluminum content on the strength characteristics of this alloy is indicated in Figure 8 (7%Al) and Figure 9 (8%Al). These data are from heats made with 140 BHN sponge, and the curves are put together for an easier comparison in Figures 11 and 12. In the 4½"-diameter barstock an increase of aluminum content shows a slight increase of tensile strength and yield strength with no appreciable change in ductility. In the forged 3/4" plate there is no appreciable change of tensile and yield strength until 8%Al is reached. The ductility shows a slight decrease with increasing aluminum. Optimum tensile properties appear to be obtained with a solution temperature of about 1750°F and an aging temperature of about 1050°F. The short-time elevated temperature tensile strength (Figure 13) appears to increase slightly with increasing aluminum content without appreciable change in ductility. As the aluminum content increases, the toughness appears to be slightly reduced.

Data on the Al-FeCr-FeMo titanium alloy made with 140 BHN sponge (Figure 10) indicates optimum tensile properties with a solution temperature of about 1700°F and an aging temperature of 900°F. Although the tensile strength is slightly higher than that of the 6%Al-4%V titanium alloy, the ductility is about the same and the toughness is slightly lower.

The data from which these curves were plotted are given by the tables in the Appendix.

The effect of solution temperature on microstructure of the 6%Al-4%V titanium alloy (140 BHN sponge) in the drop-forged 3/4"-thick plate is shown at 100X by Figures 14 through 19. By Figure 17 it is indicated that:

(1) the dynamic beta transus occurs between 1800° and 1850°F (1825° ± 20°F)

(2) grain boundaries do not appear at 1800°F but do appear at 1850°F.

From Figures 14 through 16, no grain boundaries are evident but the directional fiber of forging has nearly disappeared at 1750°F. Raising the solution temperature from 1850° to 2200°F (Figures 18 and 19) results in a ten-fold increase in grain size (0.14 diam. to 1.4 diam.). Following a solution treatment at 1850°F, the microstructure was fully martensitic and, except for grain growth, there was no significant change of structure up to 2200°F. This indicates that the decrease in mechanical properties resulting from solution treatments above the beta transus (Figure 7) is due to grain growth in the single phase field.

Figure 20 shows microstructures at 1000X of the "as-forged" plate and plate solution-treated at 1750°, 1800°, and 1850°F respectively. These show the progressive stages of dissolution and globularization of the alpha platelets and their final disappearance at the dynamic beta transus temperature.

The data of Figure 20 suggest that heat treatment for optimum strength properties should consist of a solution treatment 75° to 100°F below the dynamic beta transus followed by an aging treatment at a temperature which will produce yield strength and ductility levels consistent with the desired values.

Figures 21 through 24 show the microstructures of the four alloys, (140 BHN sponge) included in this study, after heat treatment for optimum strength properties. The details of working and heat-treatment of the 4½" barstock as-received are not available. It will be noted that the treatments for the Al-V titanium alloys are identical whereas the solution temperature for the Al-FeCr-FeMo titanium alloy is lower by 50° to 100°F. All of these solution temperatures were selected to be approximately 75° to 100°F below the dynamic beta transus of the alloy.

The etching solution used for these specimens consisted of HF + HNO_3 + glycerine (25% + 25% + 50% by volume).

CONCLUSIONS

From the results of this study the following conclusions are suggested:

1. Within the limits of interstitial content investigated (BHN 140-180), an increase in BHN of the 6%Al-4%V titanium alloy sponge resulted in an increase of the ultimate tensile and yield strengths of the alloy with no appreciable change in the ductility. However, the toughness (Charpy V notch

value) decreased by approximately 4 ft-lb from an original level of about 12 to 15 ft-lb.

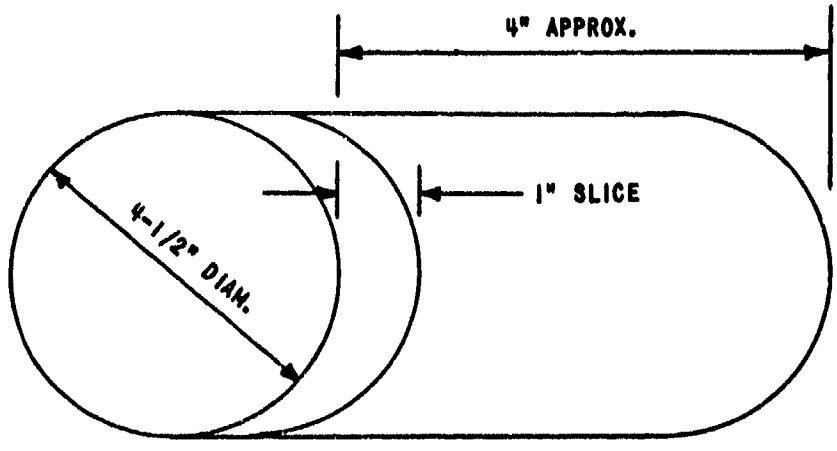
2. At the 140 BHN sponge hardness level, an increase of aluminum content from 6% to 8% resulted in an increase in strength at the sacrifice of some ductility and a reduction in impact resistance.

3. The Al-FeCr-FeMo titanium alloy does not compare favorably in impact resistance with the Al-V titanium alloys at similar strength levels and offers no advantages at elevated temperatures.

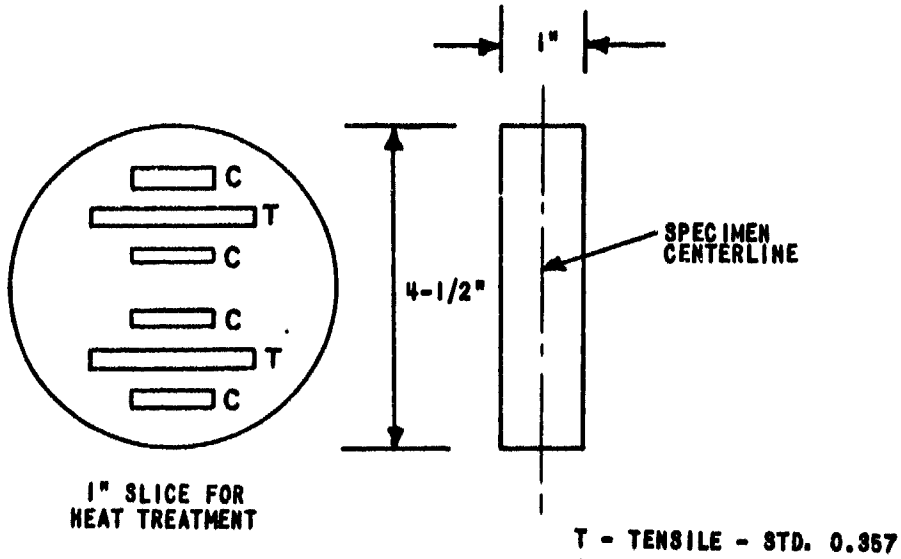
4. Heat treatment for optimum mechanical properties consists of a solution treatment 75° to 100°F below the beta transus temperature followed by short-time aging at approximately 1050°F.

5. Solution treatment of the 6%Al-4%V titanium alloy at temperatures in the vicinity of the beta transus result in a sharp drop in tensile properties with a slight recovery at higher solution temperatures.

6. Raising the solution temperature from 1850° to 2200°F results in a ten-fold increase in grain size and a decrease in mechanical properties.



4-1/2"-DIAM. BARSTOCK

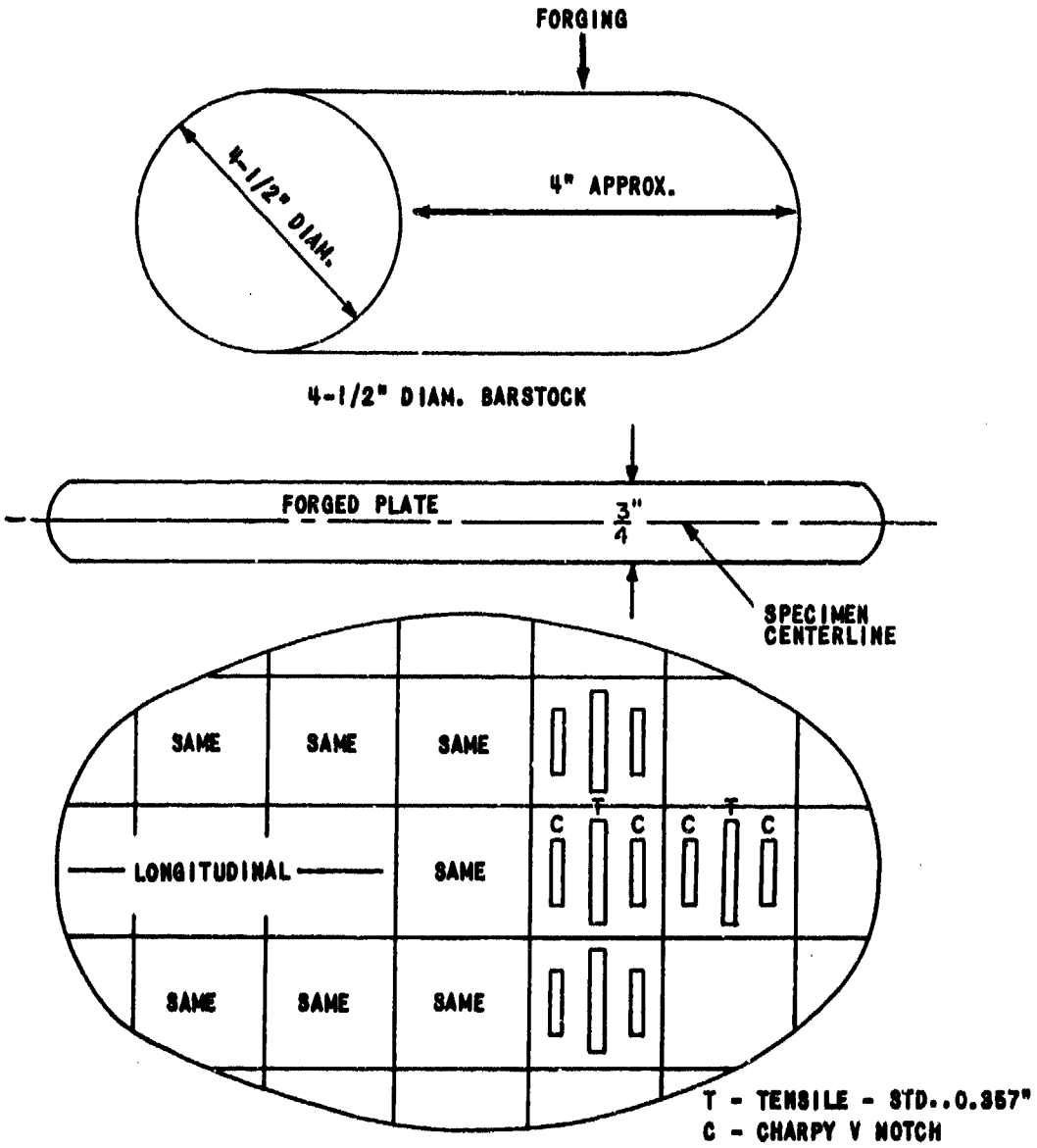


1" SLICE FOR HEAT TREATMENT

T - TENSILE - STD. 0.357
C - CHARPY V NOTCH

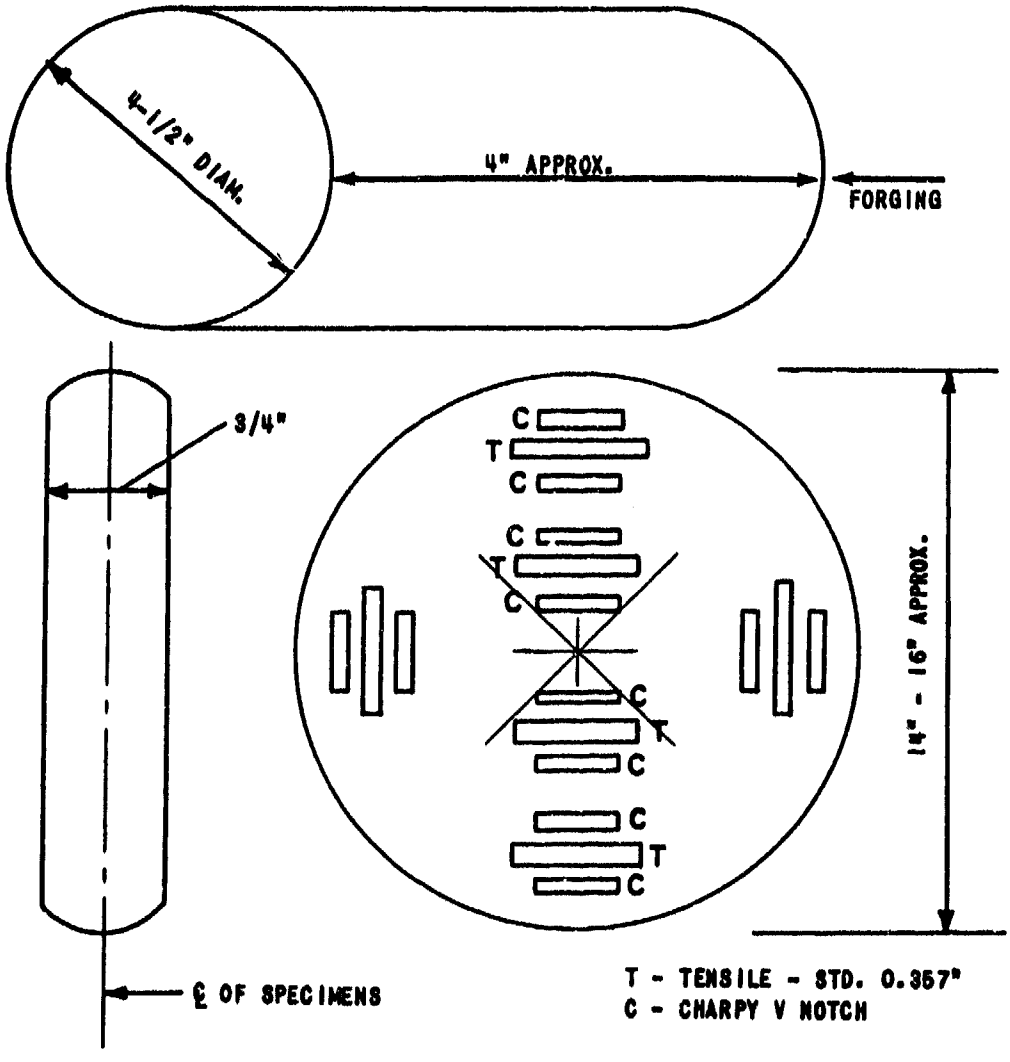
APPROX. SPECIMEN LAYOUT
4-1/2" DIAMETER BARSTOCK

FIGURE 1



APPROX. SPECIMEN LAYOUT
DROP-FORGED 3/4" PLATE

FIGURE 2



APPROX. SPECIMEN LAYOUT
PRESS-FORGED 3/4" PLATE

FIGURE 3

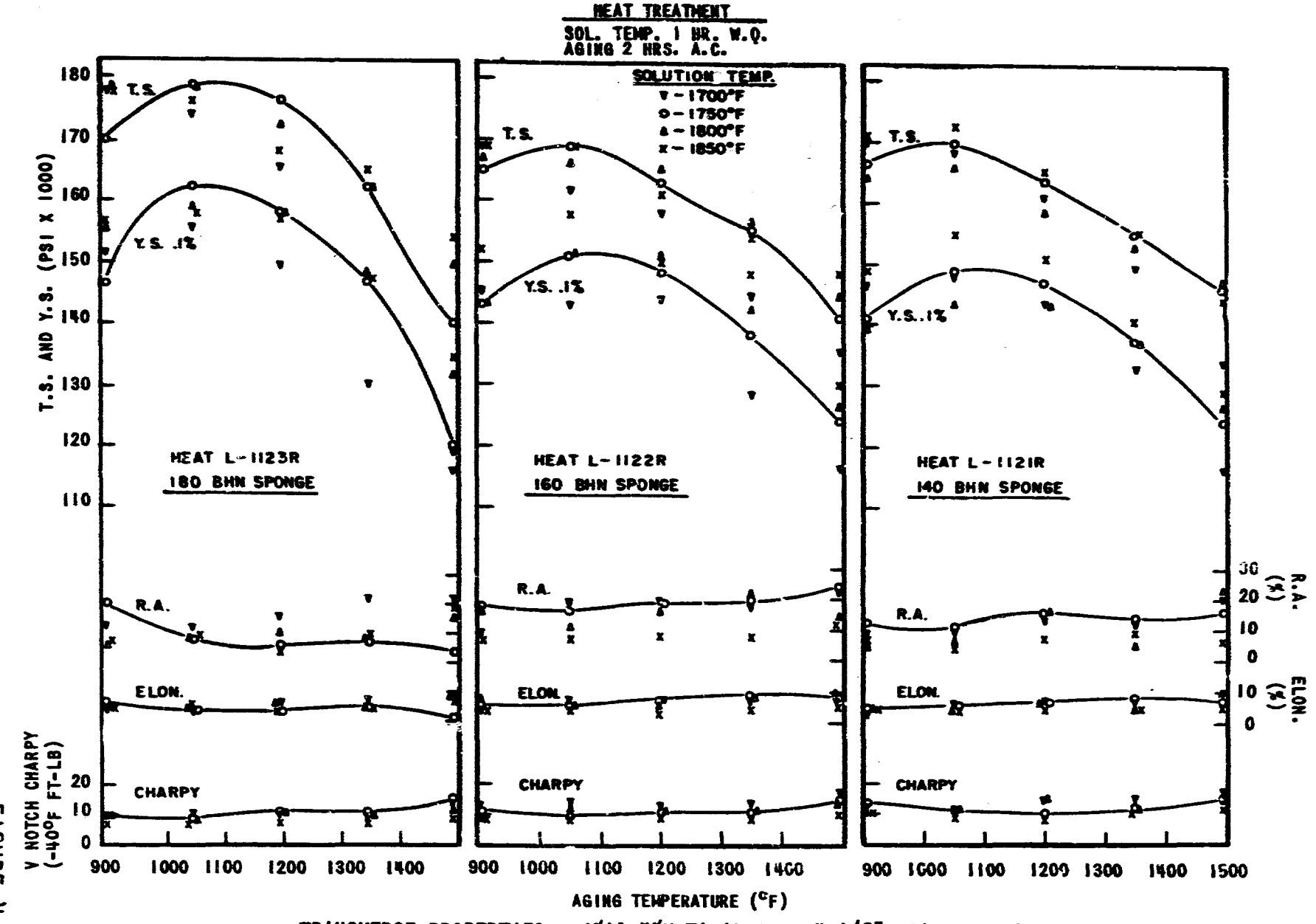


FIGURE 4

TRANSVERSE PROPERTIES - 6%Al-4%V Ti ALLOY - 4-1/2"-DIAMETER BARSTOCK
(TABLE I)

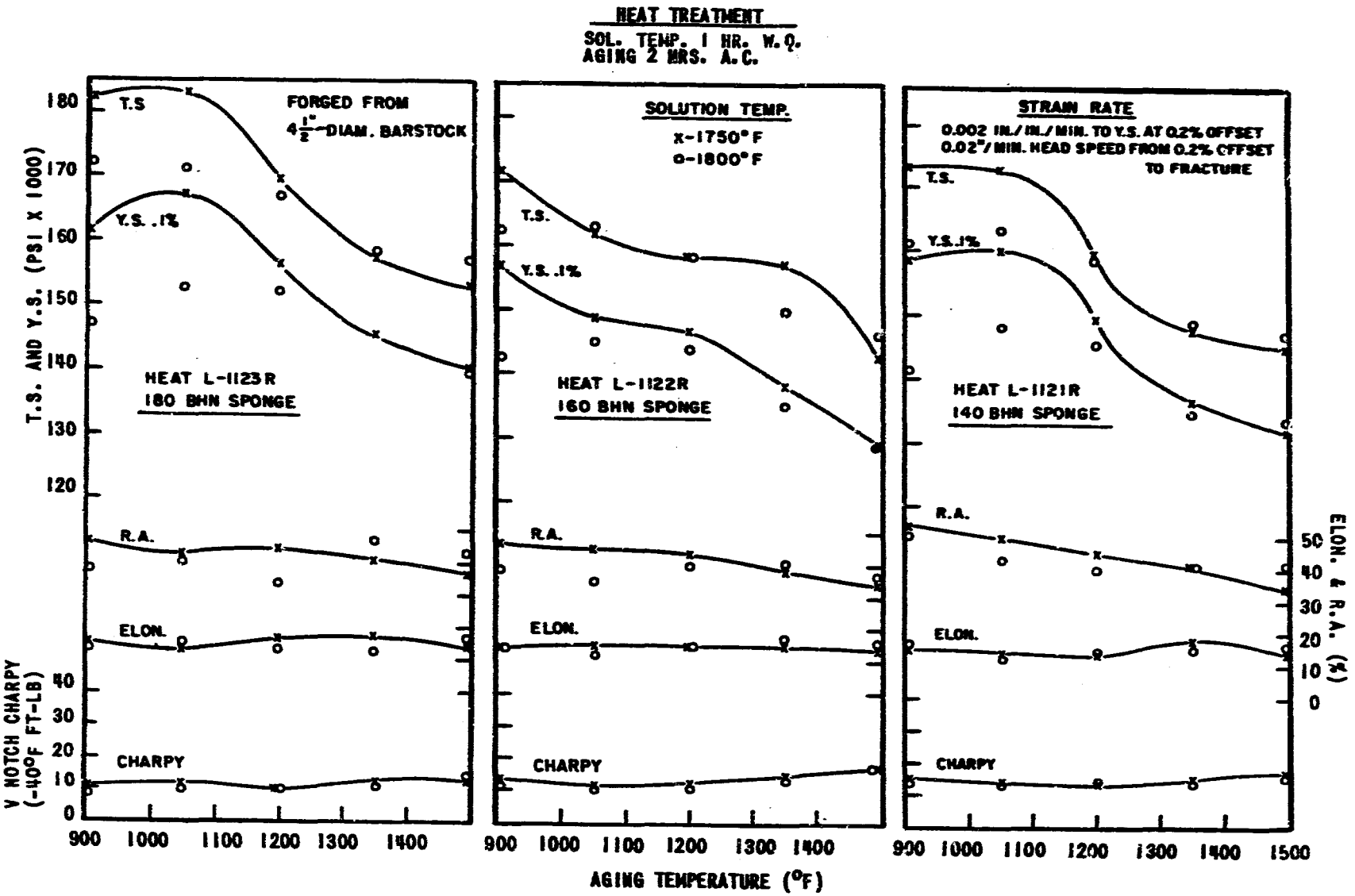


FIGURE 6

TRANSVERSE PROPERTIES - 6%Al-4%V Ti ALLOY - DROP-FORGED 3/4" PLATE
(TABLE II)

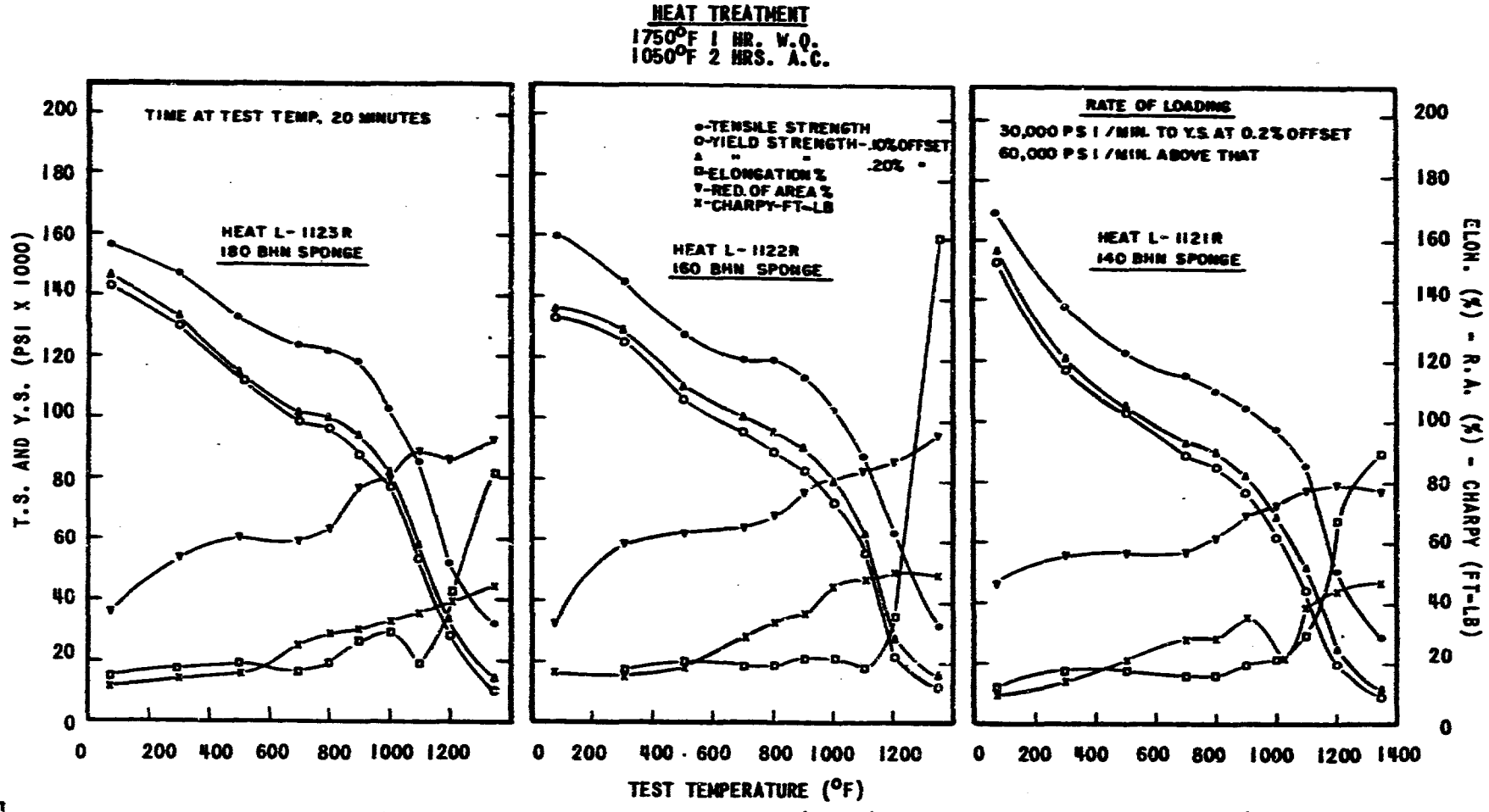
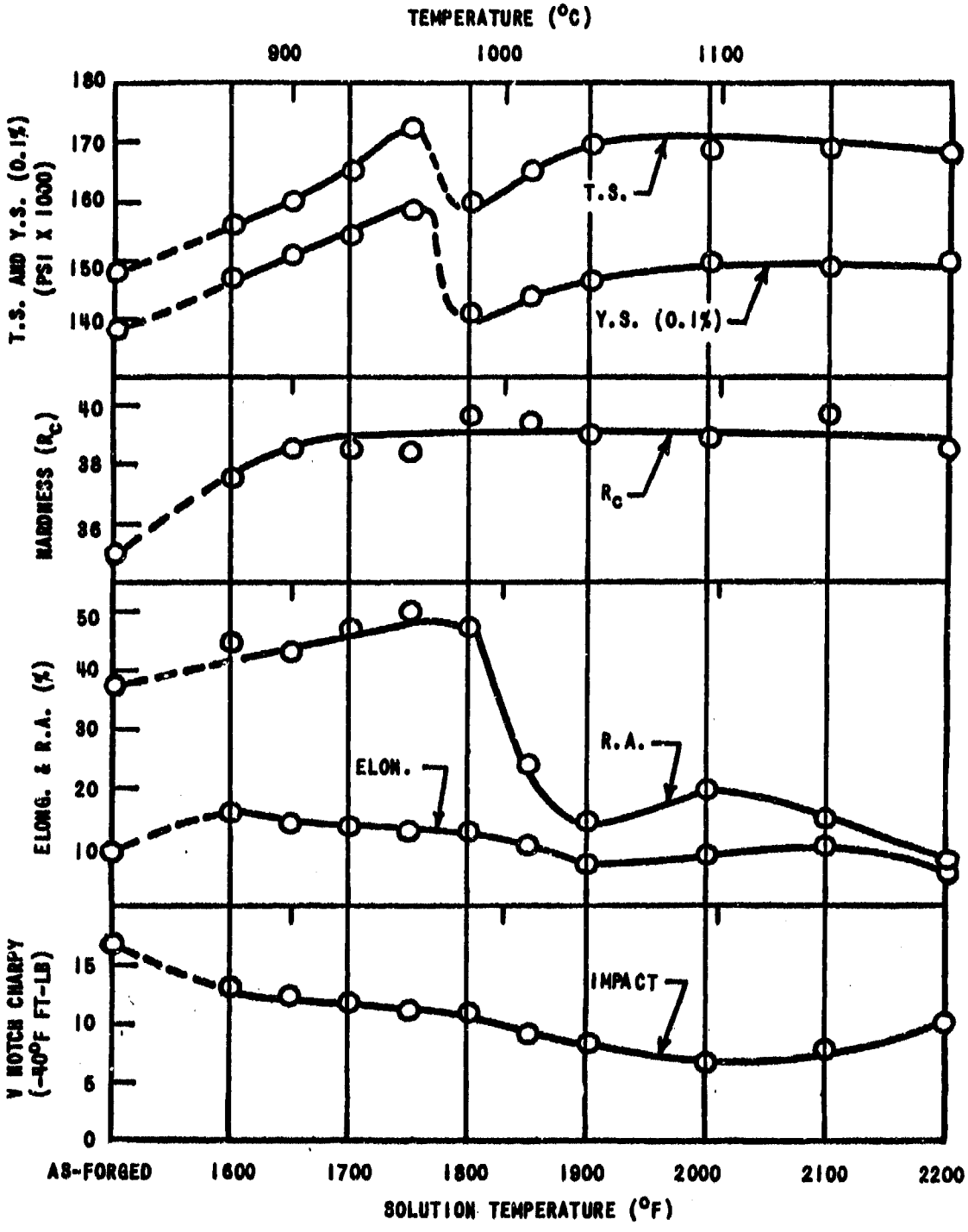


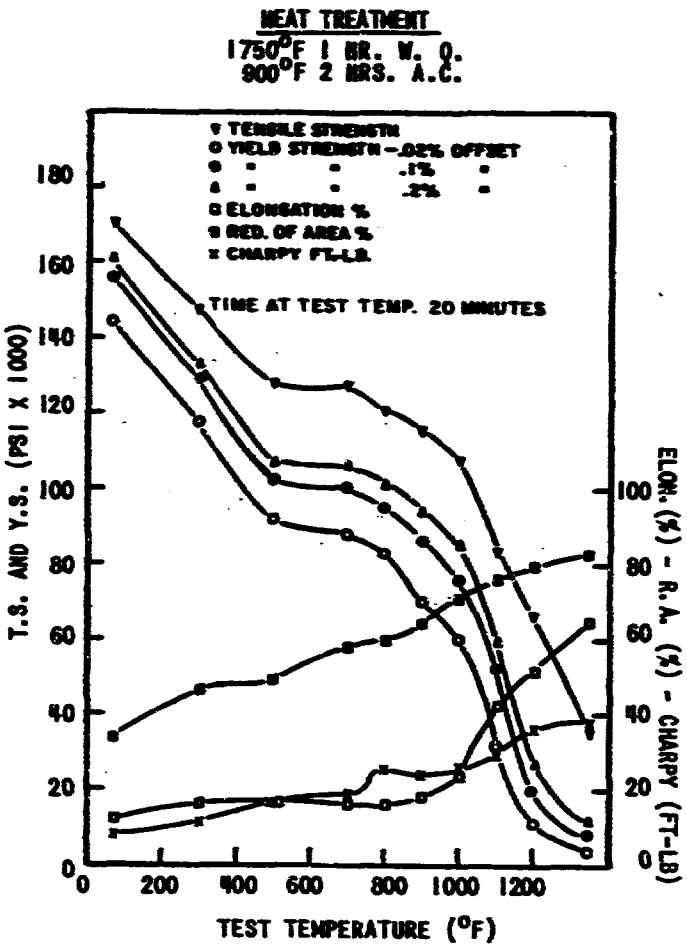
FIGURE 6

SHORT-TIME ELEVATED TEMPERATURE PROPERTIES - 6%Al-4%V Ti ALLOY - PRESS FORGED 3/4" PLATE
(TABLE III)

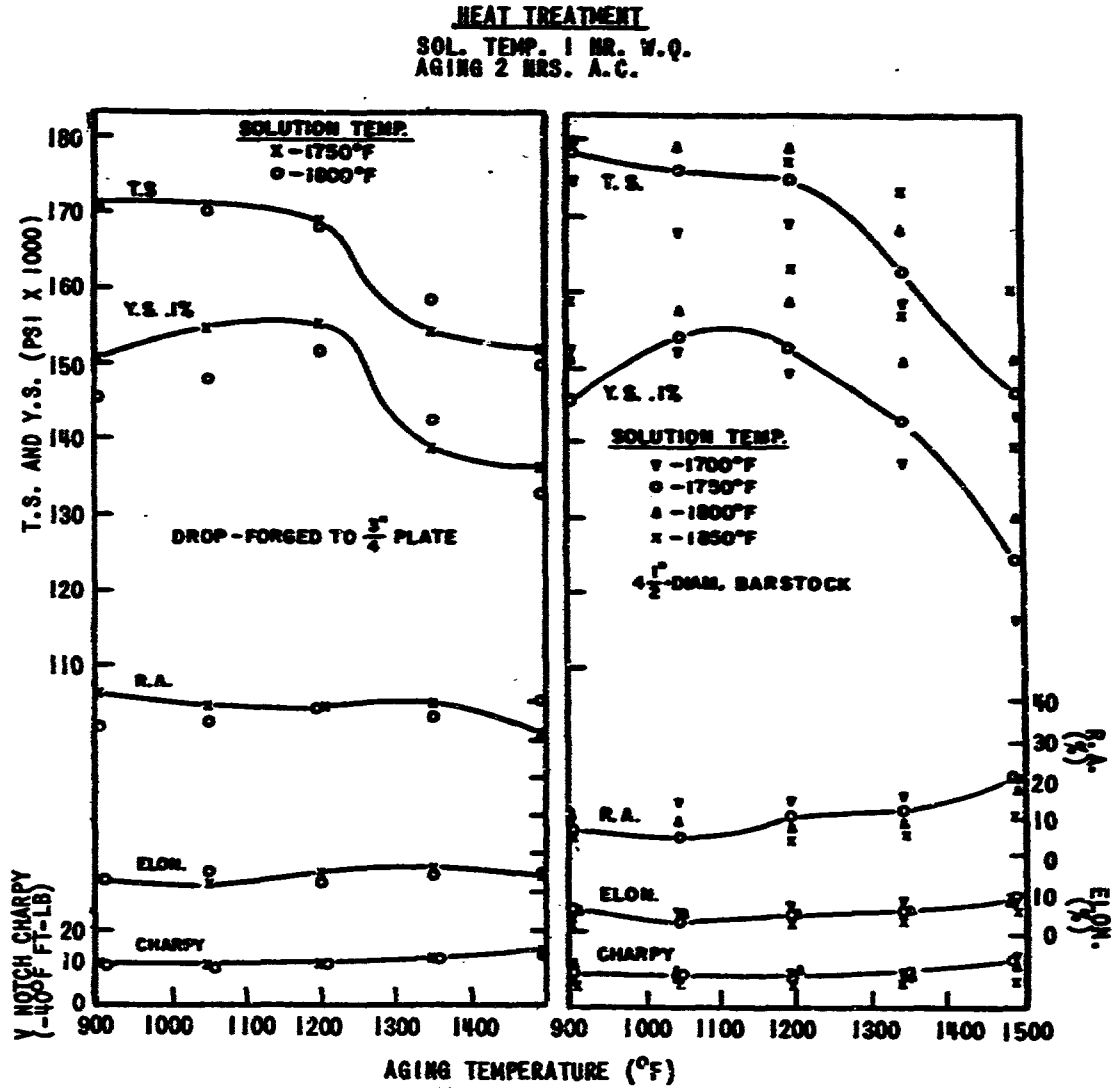


PHYSICAL PROPERTIES VERSUS SOLUTION TEMPERATURE 6A1-4V TI ALLOY - HEAT NO. 1121R - ALL SAMPLES AGED AT 1050°F (TABLE IV)

FIGURE 7

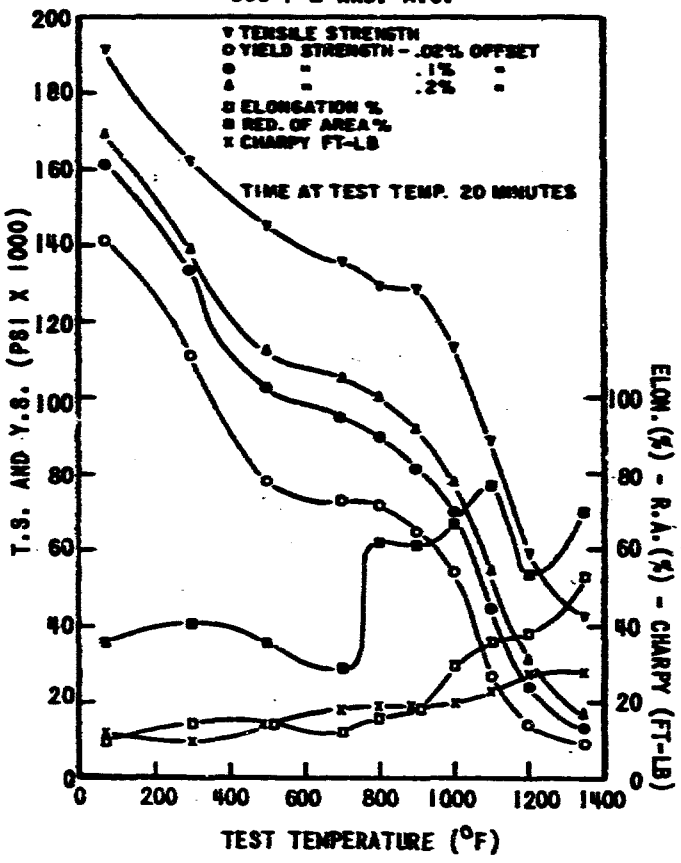


SHORT-TIME ELEVATED TEMPERATURE PROPERTIES
PRESS-FORGED 3/4" PLATE
HEAT L-1124R - 140 BHN SPONGE

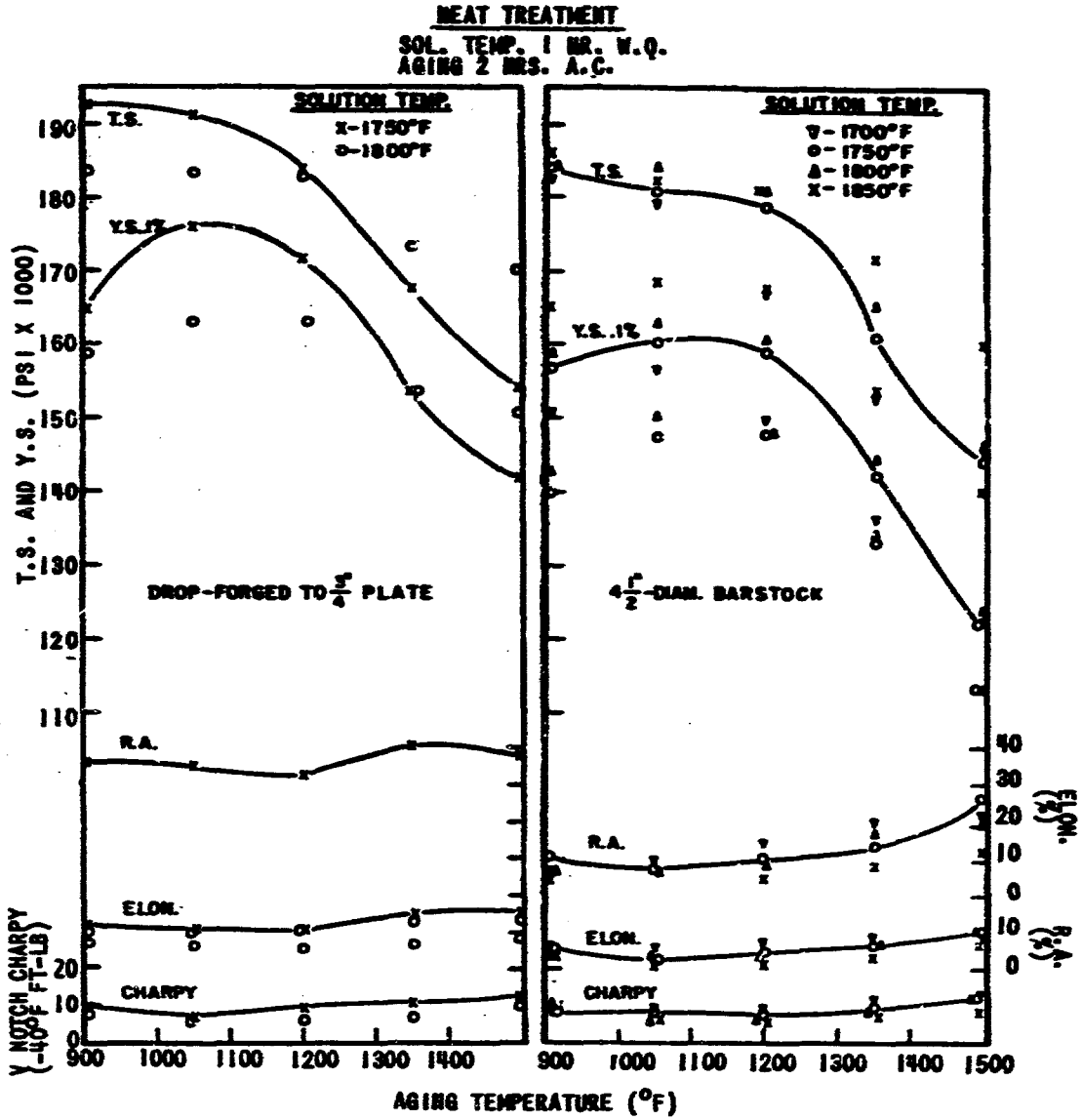


TRANSVERSE PROPERTIES - 7%Al-4%V Ti ALLOY
HEAT L-1124R - 140 BHN SPONGE
(TABLE V)

FIGURE 8

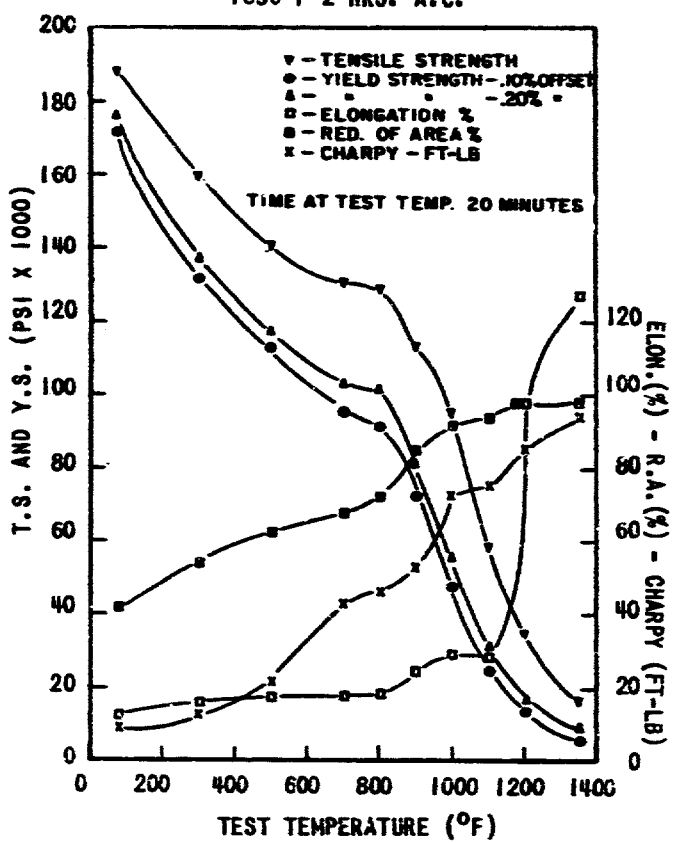


SHORT-TIME ELEVATED TEMPERATURE PROPERTIES
PRESS-FORGED 3/4" PLATE
HEAT L-1125R - 140 BHN SPONGE

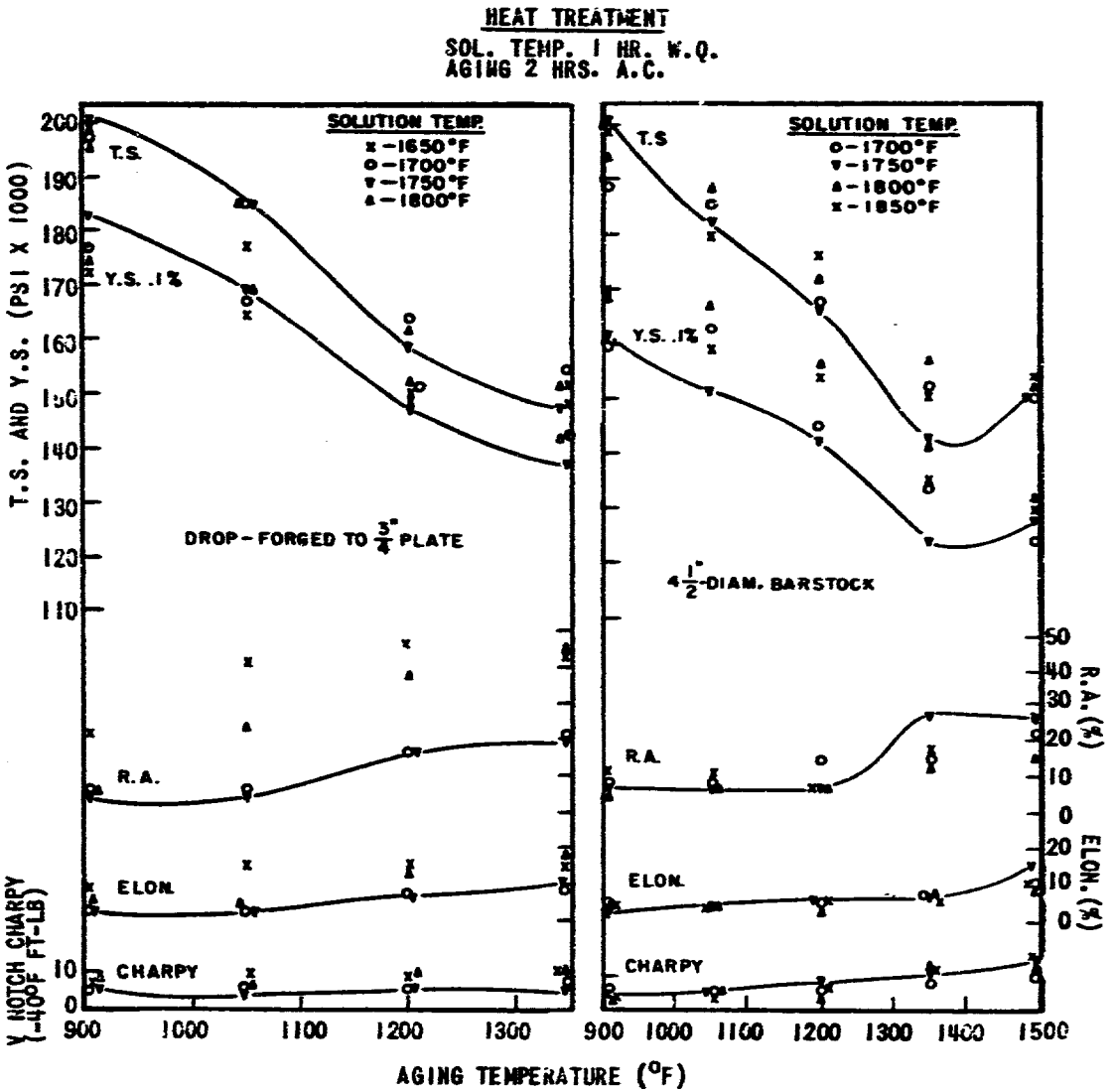


TRANSVERSE PROPERTIES - 8%Al-4%V Ti ALLOY
HEAT L-1125R - 140 BHN SPONGE
(TABLE VI)

FIGURE 9



SHORT-TIME ELEVATED TEMPERATURE PROPERTIES
PRESS-FORGED 3/4" PLATE
HEAT N-1685R - 140 BHN SPONGE



TRANSVERSE PROPERTIES - 5%Al-3%FeCr-3%FeMo Ti ALLOY
HEAT N-1685R - 140 BHN SPONGE
(TABLE VII)

FIGURE 10

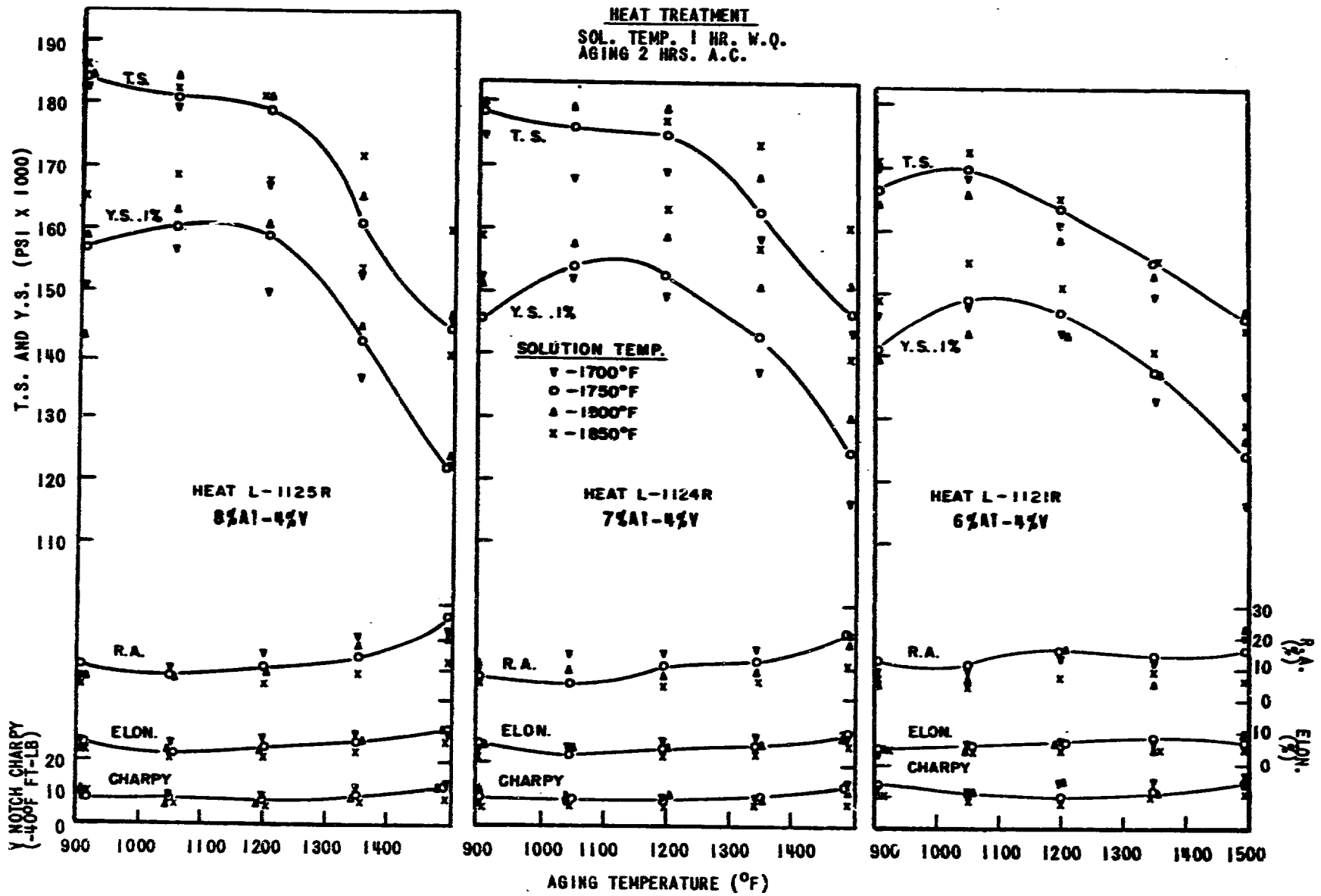


FIGURE 11

EFFECT OF ALUMINUM ON TRANSVERSE PROPERTIES - 4-1/2" DIAM. BARSTOCK - 140 BHN SPONGE
(From Figures 4, 8, & 9)

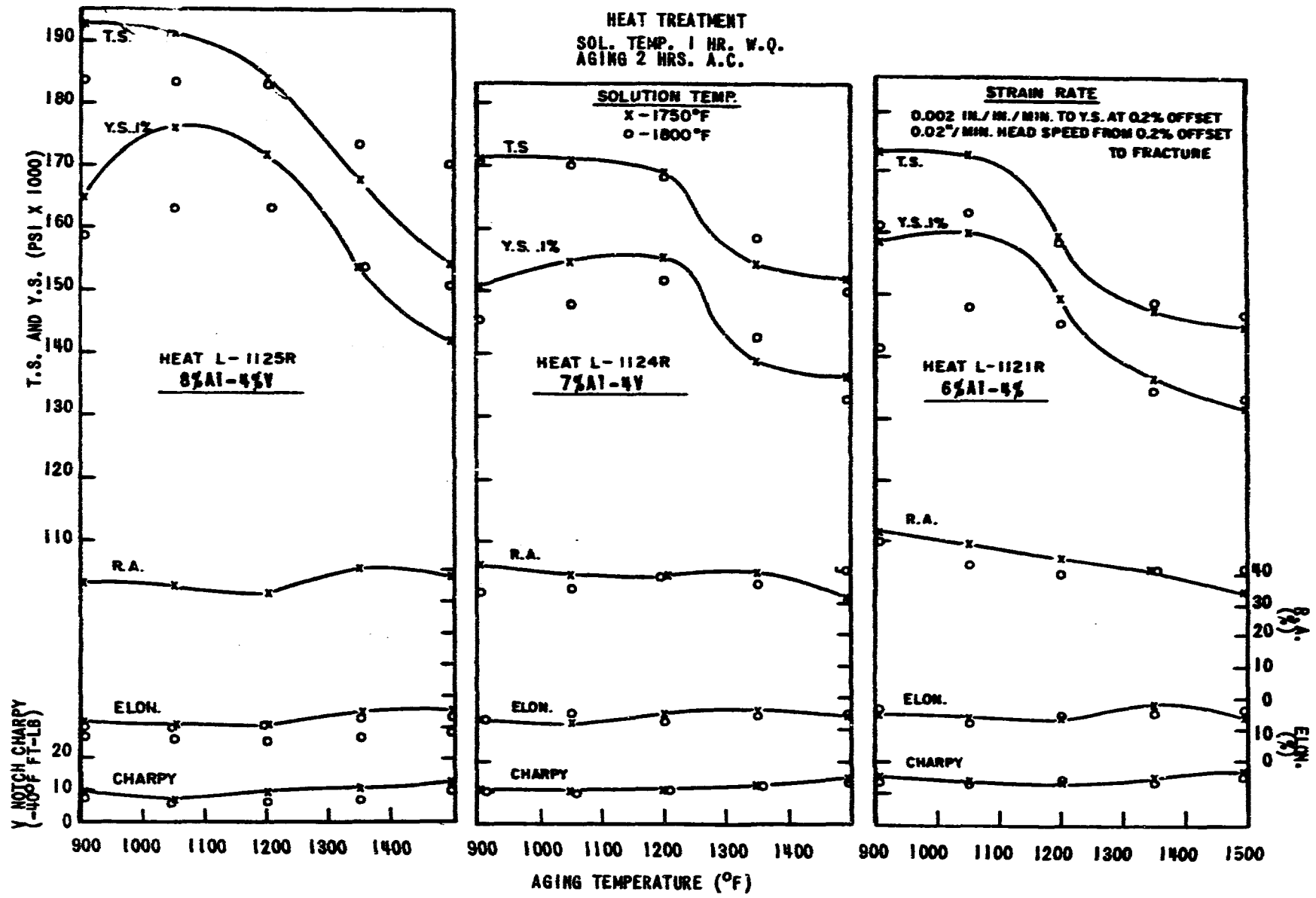


FIGURE 12

EFFECT OF ALUMINUM ON TRANSVERSE PROPERTIES - DROP-FORGED TO 3/4" PLATE - 140 BHN SPONGE
(From Figures 5, 8, & 9)

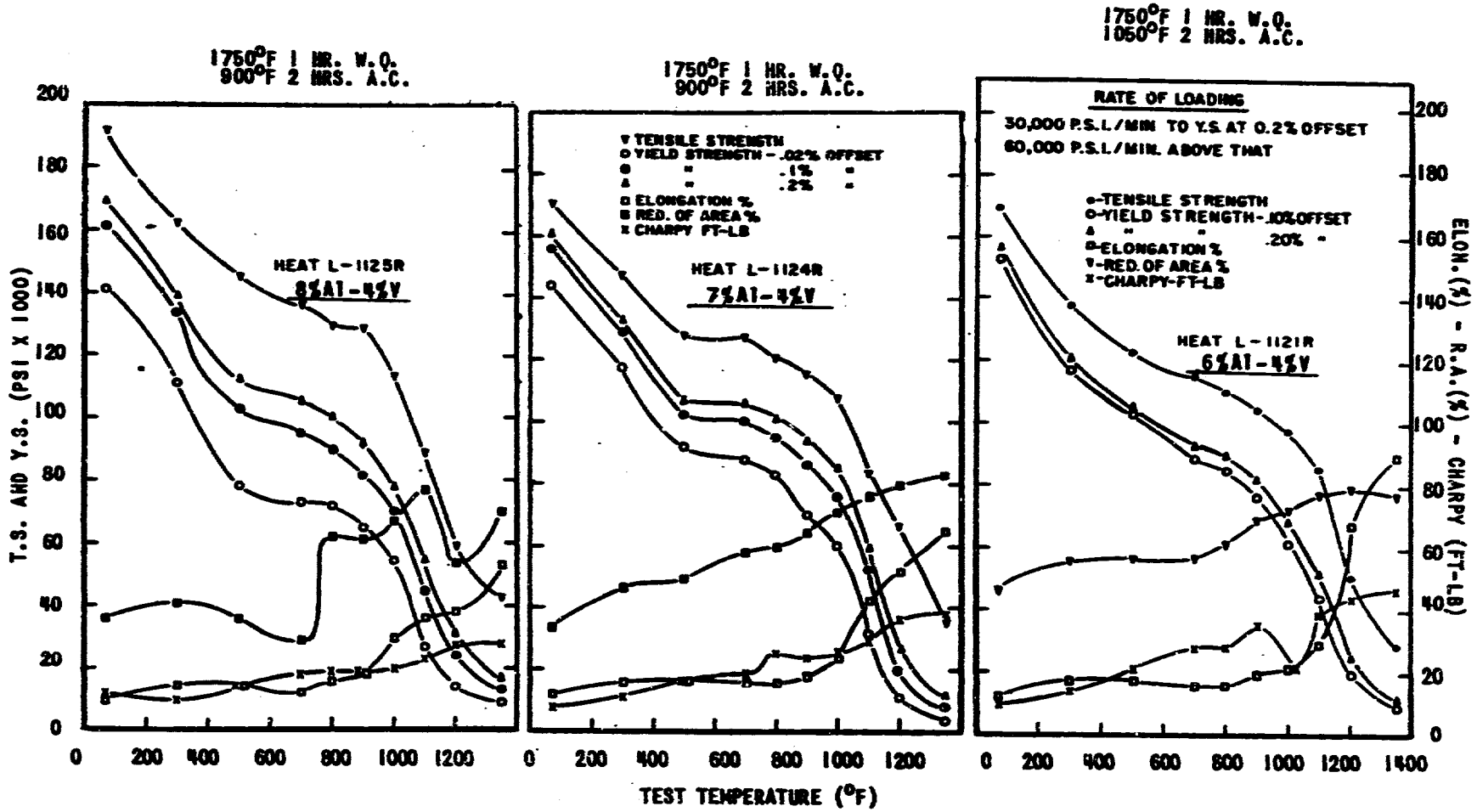
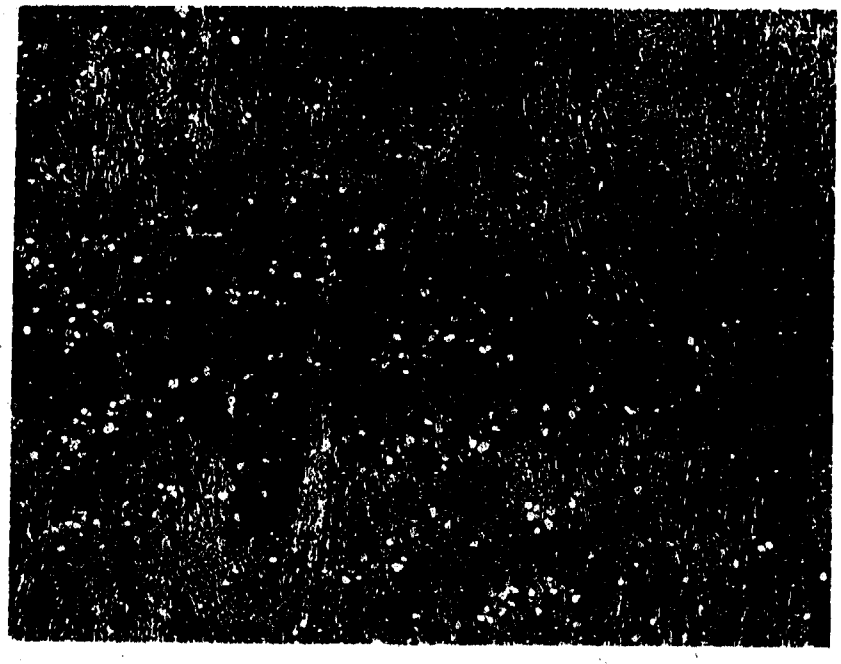


FIGURE 13

EFFECT OF ALUMINUM ON SHORT-TIME ELEVATED TEMPERATURE PROPERTIES
PRESS-FORGED 3/4" PLATE - 140 BHN SPONGE
(Time at test temperature 20 min.)
(From Figures 6, 8, & 9)

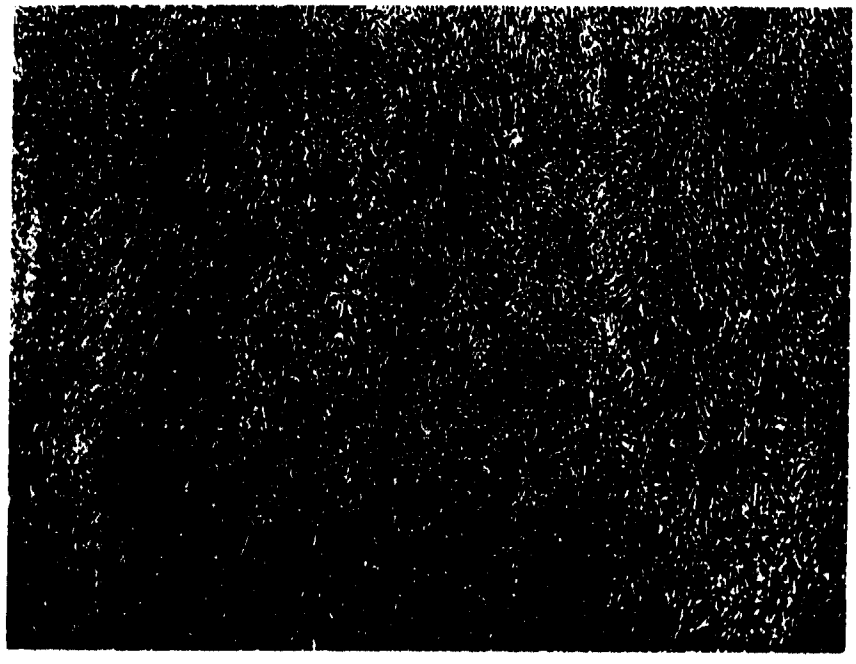


21 FGS-9, AS-FORGED, MAG. 100X

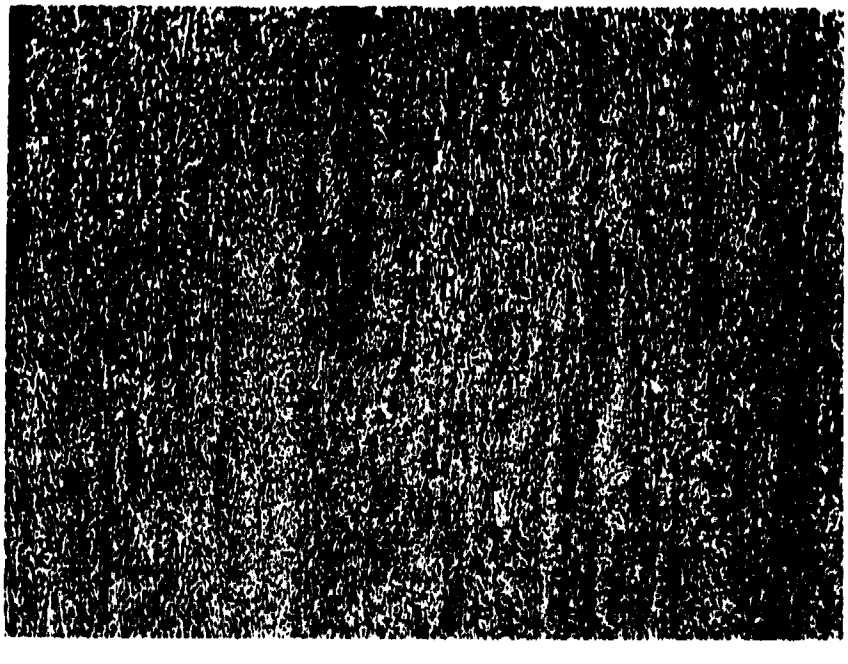
6%Al-4%V TI ALLOY - 140 BHN SPONGE

Wtn. 639-14,520

FIGURE 14



21 FGS-1T, 1600°F - 1-1/2 HRS. - W.Q., 1050°F - 2 HRS. - A.C., MAG. 100X

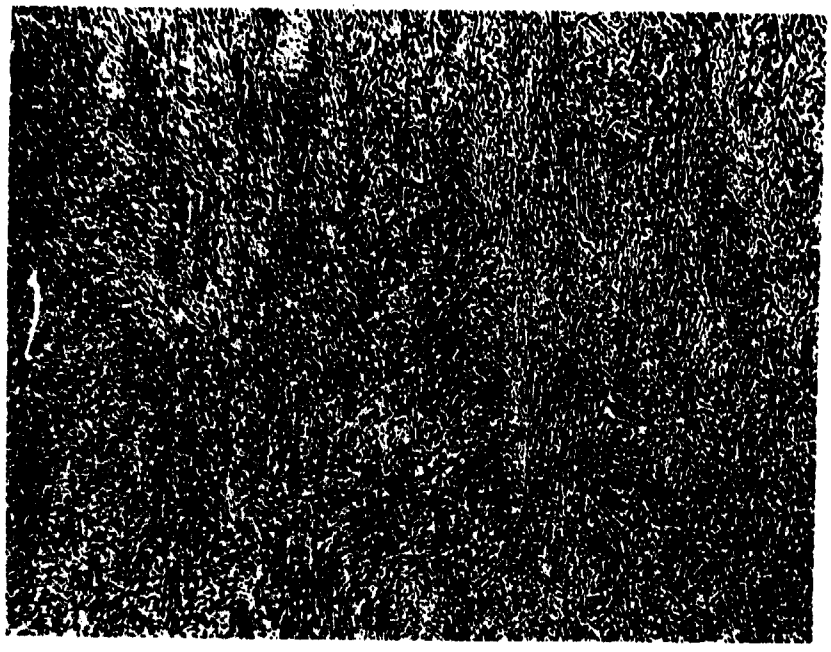


21 FGS-2T, 1650°F - 1-1/2 HRS. - W.Q., 1050°F - 2 HRS. - A.C., MAG. 100X

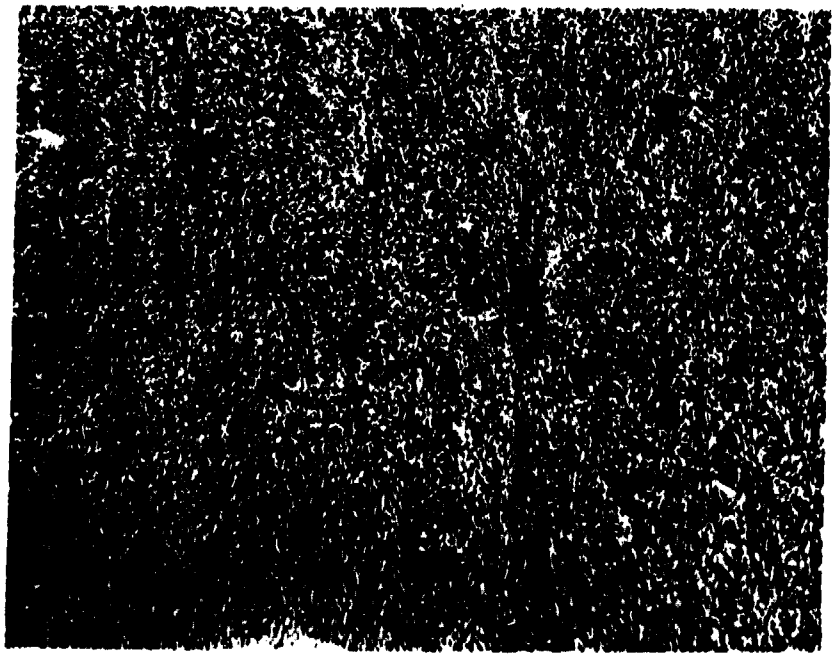
6%Al-4%V Ti ALLOY - 140 BHN SPONGE

Wtn. 639-14,521

FIGURE 15



21 FGS-3T, 1700°F - 1-1/2 HRS. - W. Q., 1050°F - 2 hrs. - A.C., MAG. 100X

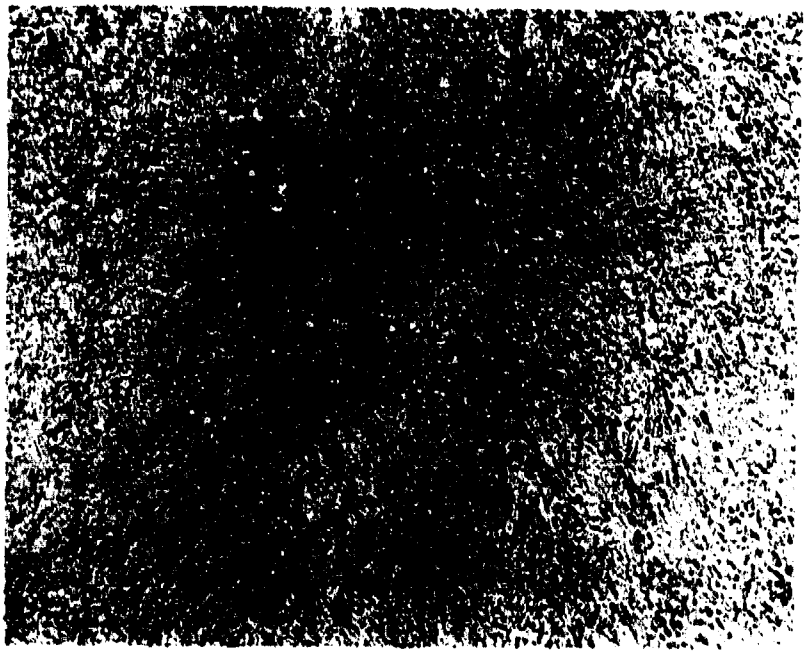


21 FGS-4T, 1750°F - 1-1/2 HRS. - W.Q., 1050°F - 2 HRS. - A.C., MAG. 100X

6%Al-4%V Ti ALLOY - 140 BHN SPONGE

Wtn. 638-14,522

FIGURE 16



21 FGS-5T, 1800°F - 1-1/2 HRS. - W.Q., 1050°F - 2 HRS. - A.C., MAG. 100X

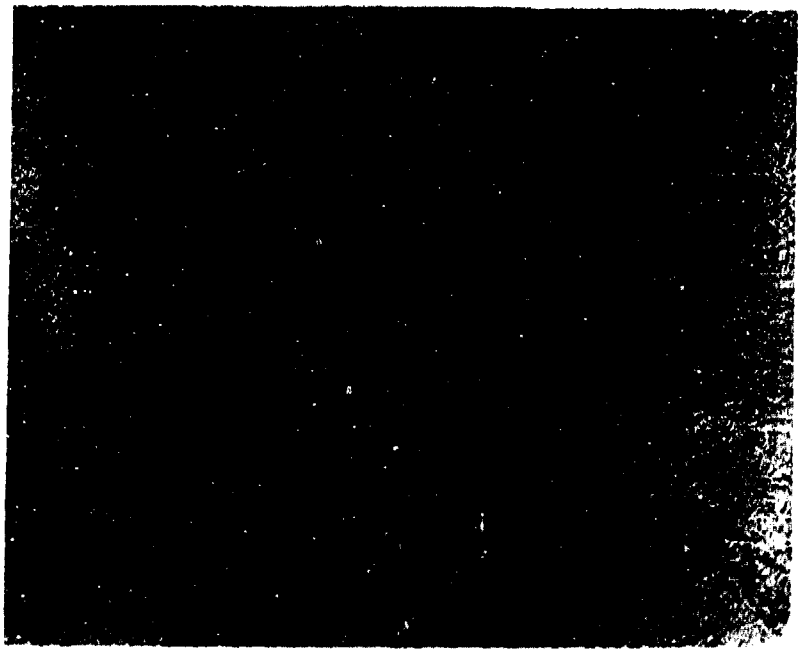
21 FGS-6T, 1850°F - 1-1/2 HRS. - W.Q., 1050°F - 2 HRS. - A.C., MAG. 100X

6%Al-4%V Ti ALLOY - 140 BHN SPONGE

Wtn. 639-14,617

FIGURE 17

21 FGS-7T, 1900°F - 1-1/2 HRS. - W.Q., 1050°F - 2 HRS. - A.C., MAG. 100X

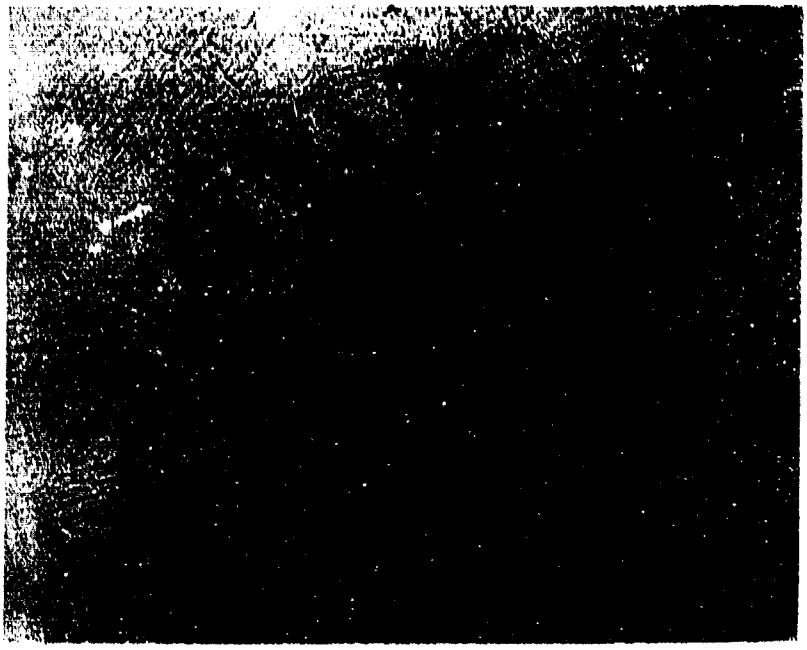


21 FGS-8T. 2000°F - 1-1/2 HRS. - W.Q., 1050°F - 2 HRS. A.C., MAG. 100X

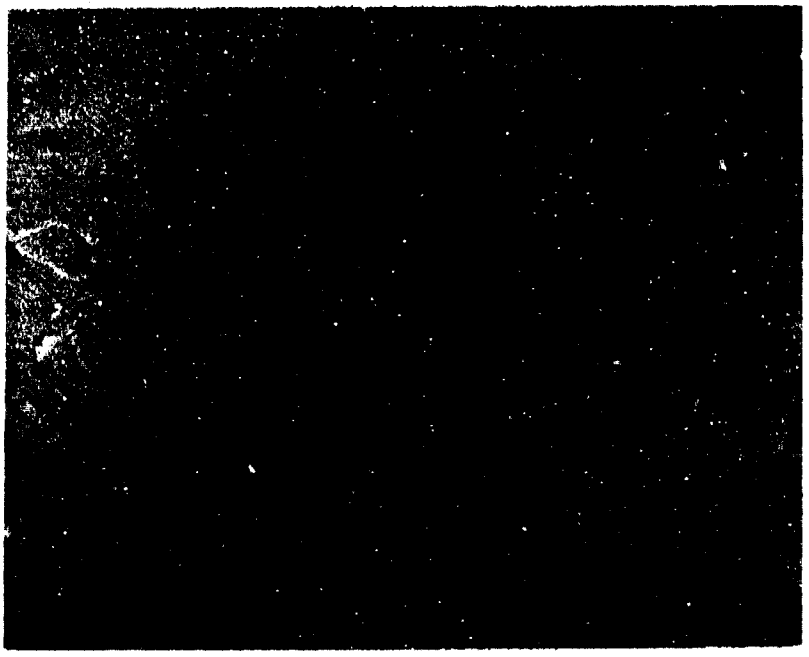
6%Al-4%V Ti ALLOY - 140 BHN SPONGE

Wtn. 699-14,518

FIGURE 18



21 FGS-9T, 2100°F - 1-1/2 HRS. - W.Q., 1050°F - 2 HRS. - A.C., MAG. 100X



21 FGS-10T, 2200°F - 1-1/2 HRS. W.Q., 1050°F - 2 HRS. - A.C., MAG. 100X

6%Al-4%V Ti ALLOY - 140 BHN SPONGE

Wtn. 638-14,519

FIGURE 18

A - AS-FORGED X1000

B - 1750°F SOL. TEMP.

C - 1800°F SOL. TEMP. X1000

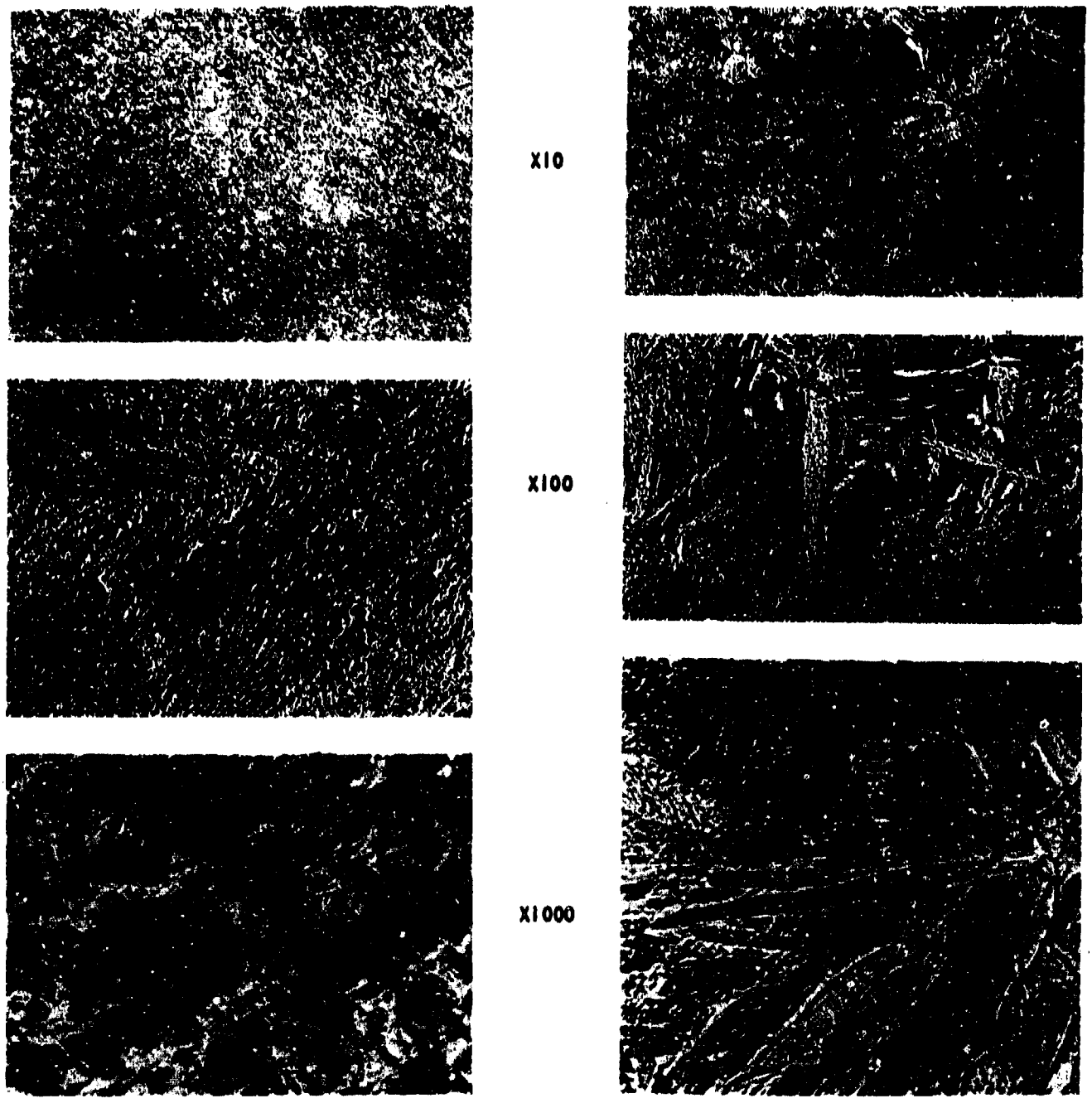
D - 1850°F SOL. TEMP.

6%Al-4%V Ti ALLOY - 140 BHN SPONGE

SOL. TEMP. 1HR. W.Q.
1750°F 2 HRS. A.C.

Wtn. 639-16,778

FIGURE 20



DROP-FORGED 3/4" PLATE

4-1/2"-DIAM. BAR

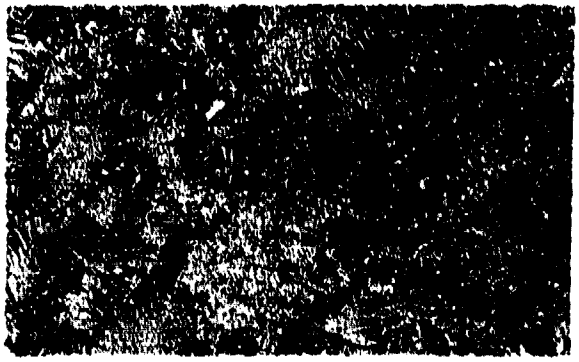
6%Al-4%V Ti ALLOY - 140 BHN SPONGE

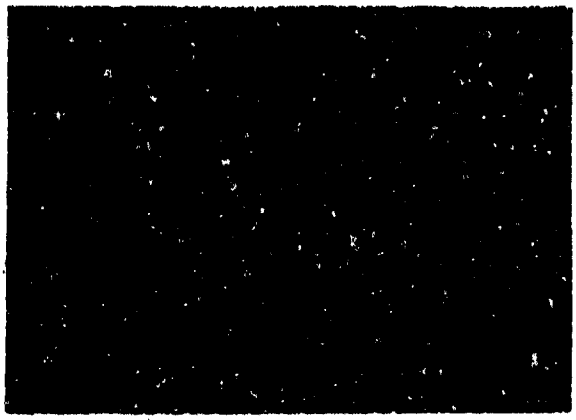
1750°F 1 HR. W.Q.
1050°F 2 HRS. A.C.

Wtn. 639-13,419-A

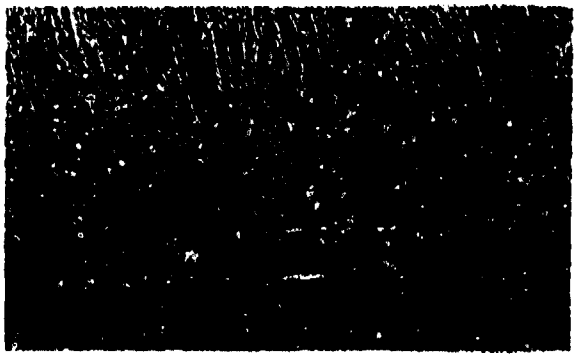
FIGURE 21

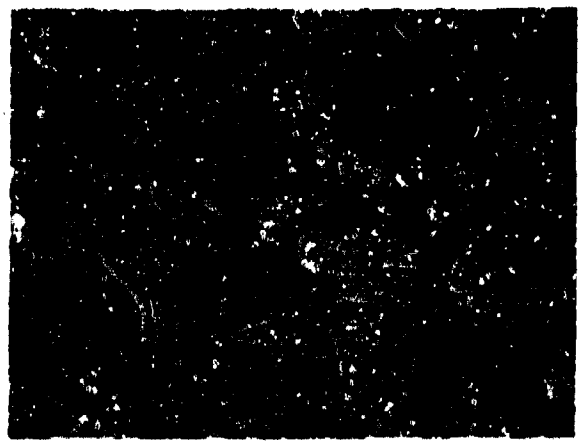
X10



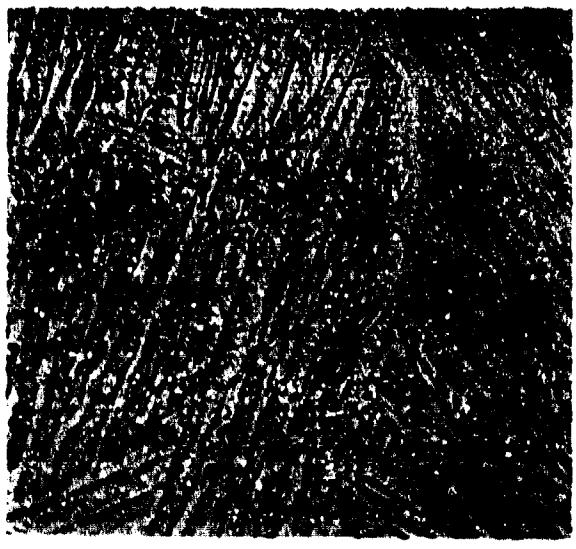


X100





X1000



DROP-FORGED 3/4" PLATE

4-1/2"-DIAM. BAR

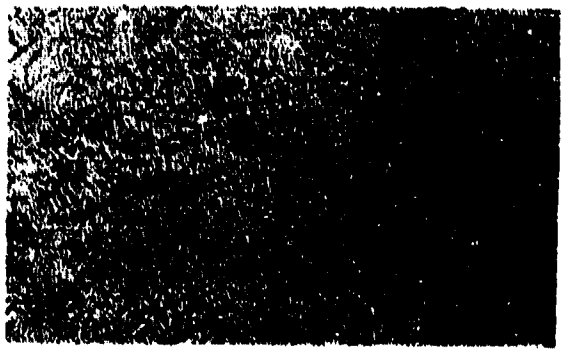
7%Al-4%V Ti ALLOY - 140 BHN SPONGE

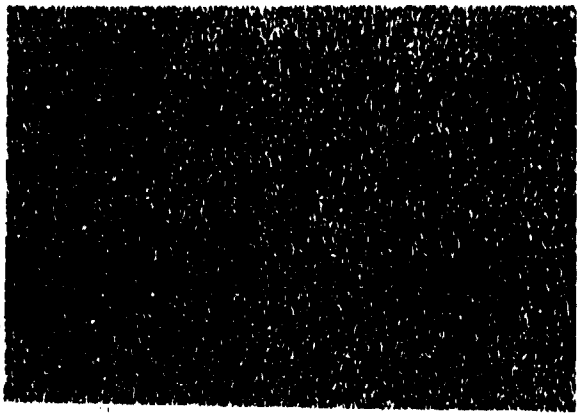
1750°F 1 HR. W.Q.
1050°F 2 HRS. A.C.

Wtn. 639-13,417-A

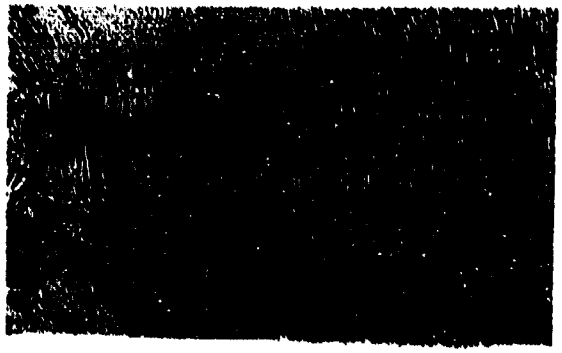
FIGURE 22

X10

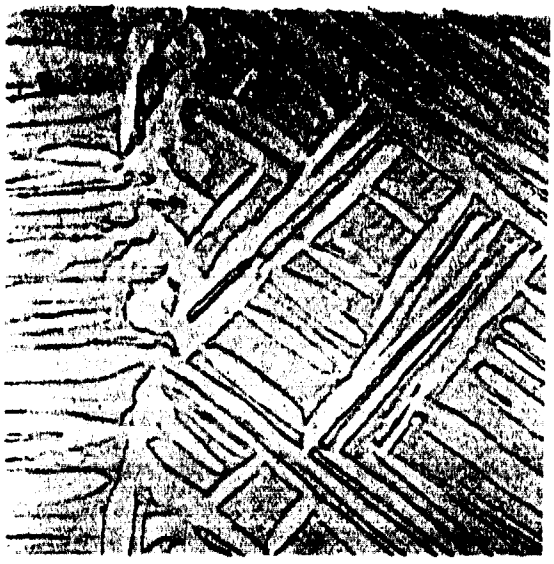




X100



X1000



DROP-FORGED 3/4" PLATE

4-1/2"-DIAM. BAR

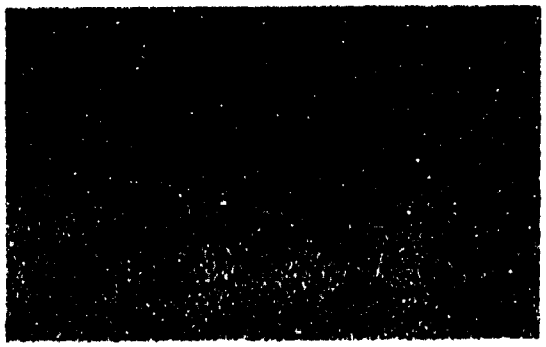
8%Al-4%V Ti ALLOY - 140 BHN SPONGE

1750°F 1 HR. W.Q.
1050°F 2 HRS. A.C.

Wtn. 639-13,424-A

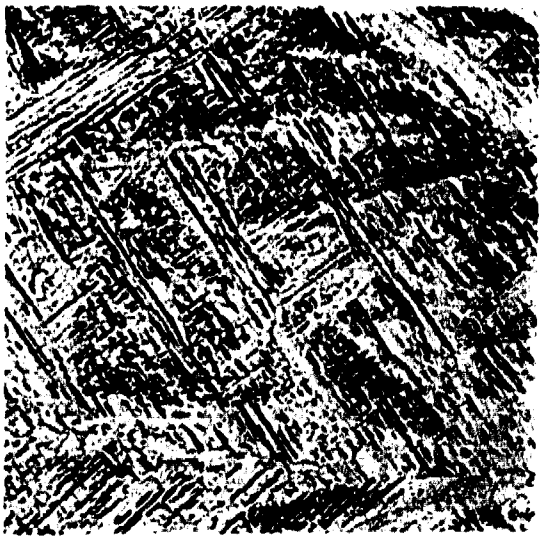
FIGURE 23

X10



X100

X1000



DROP-FORGED 3/4" PLATE

4-1/2"-DIAM. BAR

5%Al-3%FeCr-3%FeMo Ti ALLOY - 140 BHN SPONGE

1700°F 1 HR. W.Q.
900°F 2 HRS. A.C.

Wtn. 639-14,877-A

FIGURE 24

APPENDIX

TABLE I

HEAT TREATMENT SURVEY

Titanium Metals 6%Al-4%V Alloy (100-lb Ingot)
As-Received - 4½"-Diam. Barstock
Heat-Treated in 1"-Thick Discs

HT - L1121R (140 BHN Sponge)

Mark	Heat Treatment °F		Yield Strength psi		Tensile Strength psi	% Elon.	% R.A.	Impact -40°F Ft-Lb	Rockwell "C" Range
	Solution	Temper	0.1%	0.2%					
1X	1700-1-WQ	900-2-AC	146,500	152,000	170,000	4.3	8.7	11.5/13.0	37.5/40.0
2X	1700-1-WQ	1050-2-AC	148,000	152,500	168,000	5.7	9.3	10.0/12.0	38.0/39.0
3X	1700-1-WQ	1200-2-AC	143,500	147,500	161,000	7.1	13.5	15.0/16.5	37.0/38.5
4X	1700-1-WQ	1350-2-AC	132,500	136,500	149,500	5.7	12.4	15.0/	35.5/36.5
5X	1700-1-WQ	1500-2-AC	116,000	121,000	133,800	10.0	20.6	17.5/17.0	33.0/35.5
6X	1750-1-WQ	900-2-AC	141,000	148,500	166,500	5.0	13.0	14.5/13.0	38.5/40.0
7X	1750-1-WQ	1050-2-AC	149,000	154,500	170,000	5.7	11.4	13.0/11.5	38.5/40.0
8X	1750-1-WQ	1200-2-AC	147,000	152,000	163,800	7.1	16.6	11.0/10.0	38.5/40.0
9X	1750-1-WQ	1350-2-AC	137,500	141,500	155,000	8.6	14.5	11.0/12.9	37.0/38.0
10X	1750-1-WQ	1500-2-AC	124,000	128,500	146,000	7.1	16.1	15.5/16.9	34.0/35.5
11X	1800-1-WQ	900-2-AC	139,000	146,500	164,000	4.3	5.4	11.0/10.5	37.0/38.0
12X	1800-1-WQ	1050-2-AC	144,000	150,000	166,000	5.0	7.1	10.3/12.8	37.0/38.0
13X	1800-1-WQ	1200-2-AC	143,000	148,000	158,800	6.4	16.1	14.5/15.0	37.5/39.0
14X	1800-1-WQ	1350-2-AC	137,000	142,000	152,800	4.3	5.5	10.8/12.0	36.0/37.0
15X	1800-1-WQ	1500-2-AC	126,000	131,500	146,500	8.6	23.1	16.0/13.0	34.5/35.5
16X	1850-1-WQ	900-2-AC	149,000	156,000	171,000	4.3	7.1	10.0/9.9	38.5/40.0
17X	1850-1-WQ	1050-2-AC	155,000	160,500	173,000	4.3	5.5	9.5/10.0	39.0/40.0
18X	1850-1-WQ	1200-2-AC	151,000	156,000	165,000	4.3	7.6	8.0/9.0	38.5/39.5
19X	1850-1-WQ	1350-2-AC	140,500	145,000	155,000	4.3	10.9	11.0/10.0	37.0/38.5
20X	1850-1-WQ	1500-2-AC	129,000	133,500	148,500	6.4	6.6	10.3/12.0	35.5/36.5
As-Received Properties			120,000	125,000	139,000	11.4	22.1	13.2	33.0/34.0
			117,500	122,500	140,000	7.9	14.0	9.0	32.5/33.5

HT - L1122R (160 BHN Sponge)

1X	1700-1-WQ	900-2-AC	145,000	152,000	168,800	3.6	8.2	11.5/13.0	38.5/39.5
2X	1700-1-WQ	1050-2-AC	143,000	149,000	162,000	6.4	18.6	15.0/12.0	38.5/39.5
3X	1700-1-WQ	1200-2-AC	144,000	149,000	158,400	6.4	19.1	12.0/11.0	38.0/39.0
4X	1700-1-WQ	1350-2-AC	128,000	132,000	144,000	6.4	18.1	12.5/15.0	35.0/36.5
5X	1700-1-WQ	1500-2-AC	116,000	122,000	135,000	7.1	21.6	17.0/17.0	34.0/35.0
6X	1750-1-WQ	900-2-AC	143,000	151,000	165,000	5.7	17.6	13.5/10.0	39.5/41.0
7X	1750-1-WQ	1050-2-AC	151,000	158,000	169,200	5.0	16.6	10.0/10.3	39.0/40.0
8X	1750-1-WQ	1200-2-AC	148,000	154,000	163,000	6.4	19.1	11.0/10.0	39.5/40.5
9X	1750-1-WQ	1350-2-AC	138,000	144,000	155,000	8.6	19.6	11.0/10.0	37.0/38.0
10X	1750-1-WQ	1500-2-AC	124,000	128,000	141,000	7.9	24.1	15.9/15.0	34.5/36.0
11X	1800-1-WQ	900-2-AC	143,000	151,000	166,800	7.1	16.6	9.0/8.5	39.0/40.0
12X	1800-1-WQ	1050-2-AC	151,000	157,000	166,200	5.0	9.8	11.5/11.9	39.0/40.0
13X	1800-1-WQ	1200-2-AC	151,000	157,000	165,000	5.0	16.1	9.0/12.0	38.5/40.0
14X	1800-1-WQ	1350-2-AC	142,000	147,000	156,400	7.9	20.6	9.5/11.9	36.5/38.0
15X	1800-1-WQ	1500-2-AC	126,000	131,000	144,000	9.3	14.0	14.0/15.0	35.5/36.5
16X	1850-1-WQ	900-2-AC	152,000	158,000	168,400	3.6	7.1	8.8/8.0	39.0/41.0
17X	1850-1-WQ	1050-2-AC	158,000	163,000	169,000	4.3	7.1	8.1/10.0	40.0/41.0
18X	1850-1-WQ	1200-2-AC	150,000	155,000	160,800	2.9	7.6	8.8/9.0	39.0/40.0
19X	1850-1-WQ	1350-2-AC	148,000	152,000	158,000	3.6	7.1	8.0/8.9	38.0/39.0
20X	1850-1-WQ	1500-2-AC	130,000	135,000	148,000	6.4	11.9	10.0/9.9	36.0/37.0
As-Received Properties			113,500	120,500	140,000	5.7	11.9	13.5	32.5/33.5
			114,000	120,000	137,500	8.6	17.1	9.8	33.0/33.5

(Continued over)

TABLE I (Continued)

HT - L1123R (180 BHN Sponge)

Mark	Heat Treatment °F		Yield Strength psi		Tensile Strength psi	% Elon.	% R.A.	Impact -40°F Ft-Lb	Rockwell "C" Range
	Solution	Temper	0.1%	0.2%					
1X	1700-1-WQ	900-2-AC	151,500	156,500	179,000	5.0	13.5	9.8/8.0	40.5/42.0
2X	1700-1-WQ	1050-2-AC	156,000	161,000	175,000	4.3	12.4	10.0/10.3	39.0/42.0
3X	1700-1-WQ	1200-2-AC	149,000	153,500	166,000	6.4	16.6	10.0/10.0	38.5/40.5
4X	1700-1-WQ	1350-2-AC	130,000	134,000	147,000	7.9	22.1	12.0/10.3	37.0/38.0
5X	1700-1-WQ	1500-2-AC	115,000	121,000	140,000	8.6	21.6	15.5/13.0	35.0/36.0
6X	1750-1-WQ	900-2-AC	146,000	152,000	170,500	7.1	21.6	8.5/11.3	40.5/41.5
7X	1750-1-WQ	1050-2-AC	163,000	168,000	180,500	4.3	9.3	8.0/7.9	41.0/41.5
8X	1750-1-WQ	1200-2-AC	158,500	162,500	177,500	4.3	6.6	10.0/13.3	40.0/41.5
9X	1750-1-WQ	1350-2-AC	147,500	151,500	163,000	5.0	7.6	9.0/9.0	38.0/39.5
10X	1750-1-WQ	1500-2-AC	118,500		119,000	1.4	4.4	18.0/12.0	34.5/36.5
11X	1800-1-WQ	900-2-AC	155,500	161,500	179,500	5.0	7.1	8.0/11.0	40.0/41.5
12X	1800-1-WQ	1050-2-AC	159,000	164,000	179,500	4.3	8.2	9.2/6.3	40.0/41.5
13X	1800-1-WQ	1200-2-AC	158,000	162,000	173,200	6.4	10.3	7.9/12.0	41.0/41.5
14X	1800-1-WQ	1350-2-AC	148,000	152,000	162,600	4.3	8.2	8.8/8.3	38.0/39.5
15X	1800-1-WQ	1500-2-AC	131,000	135,000	149,400	9.3	15.0	9.0/9.5	36.0/37.5
16X	1850-1-WQ	900-2-AC	156,500	162,500	178,500	4.3	8.2	7.0/7.0	41.0/42.0
17X	1850-1-WQ	1050-2-AC	158,500	162,500	177,000	5.7	9.8	7.0/8.0	41.0/42.0
18X	1850-1-WQ	1200-2-AC	157,000	160,000	168,800	4.3	4.9	7.0/7.0	40.5/41.5
19X	1850-1-WQ	1350-2-AC	147,000	151,000	165,500	5.0	10.3	7.0/8.0	39.0/40.0
20X	1850-1-WQ	1500-2-AC	134,000	138,000	154,000	7.9	19.1	8.0/11.0	36.5/38.5
As-Received Properties			123,500	128,500	148,500	6.4	13.5	9.5	37.0/37.5
			124,500	128,500	150,000	7.9	18.1	8.4	34.5/36.0

NOTE: *WQ - Water Quenched*
AC - Air Cooled

See Figure 4

TABLE II

HEAT TREATMENT SURVEY

Titanium Metals 6%Al-4%V Alloy (100-lb Ingot)
4½"-Diam. Barstock Drop-Forged to ¾" Plate

HT - L1121R (140 BHN Sponge)

Mark	Heat Treatment °F Solution	Temper	Yield Strength psi 0.1%	0.2%	Tensile Strength psi	% Elon.	% R.A.	Impact -40°F Ft-Lb	Rockwell "C" Range
FX1	1750-1-WQ	900-2-AC	158,000	162,000	173,000	15.0	54.1	15.2/15.5	38.0/39.5
FX2	1750-1-WQ	1050-2-AC	160,000	163,000	172,500	14.3	50.2	15.8/14.2	37.5/39.5
FX3	1750-1-WQ	1200-2-AC	149,000	151,000	159,500	13.6	45.3	13.6/13.6	37.5/38.5
FX4	1750-1-WQ	1350-2-AC	136,000	137,000	147,000	17.1	40.7	15.2/14.9	34.5/35.5
FX6	1750-1-WQ	1500-2-AC	131,000	133,500	144,000	14.3	34.0	16.8/18.4	33.5/34.5
FX7	1800-1-WQ	900-2-AC	141,000	145,500	161,000	16.4	49.8	14.9/14.2	38.5/39.5
FX9	1800-1-WQ	1050-2-AC	148,000	151,500	163,500	13.6	42.8	13.0/15.5	39.0/40.0
FX10	1800-1-WQ	1200-2-AC	145,000	148,000	158,000	14.3	40.2	14.2/14.2	37.5/38.5
FX11	1800-1-WQ	1350-2-AC	134,000	136,000	148,000	15.0	41.0	15.5/14.9	34.5/36.0
FX13	1800-1-WQ	1500-2-AC	132,500	134,500	146,000	15.7	41.5	15.5/16.5	34.5/35.5
As-Forged Properties			131,500	134,000	146,000	12.9	36.7	19.0	34.0/35.0

HT - L1122R (160 BHN Sponge)

FX2	1750-1-WQ	900-2-AC	157,000	161,000	171,800	14.3	47.0	13.0/14.5	39.5/41.5
FX3	1750-1-WQ	1050-2-AC	149,000	152,000	161,600	15.0	44.9	11.8/11.5	39.5/40.5
FX4	1750-1-WQ	1200-2-AC	147,000	150,000	158,200	15.0	43.6	12.4/12.4	38.5/39.5
FX5	1750-1-WQ	1350-2-AC	138,000	140,000	157,000	15.0	38.5	14.9/13.9	36.0/37.5
FX6	1750-1-WQ	1500-2-AC	129,000	132,000	142,200	14.3	34.0	16.5/17.8	34.5/35.5
FX7	1800-1-WQ	900-2-AC	143,000	148,000	162,800	14.3	38.9	11.5/11.8	39.5/40.5
FX8	1800-1-WQ	1050-2-AC	145,000	150,000	163,200	12.1	34.9	10.9/10.6	38.5/40.0
FX9	1800-1-WQ	1200-2-AC	144,000	148,000	158,400	15.0	40.2	11.2/10.3	38.5/40.5
FX10	1800-1-WQ	1350-2-AC	135,000	138,000	150,000	16.4	41.1	14.2/13.0	35.5/37.5
FX13	1800-1-WQ	1500-2-AC	129,000	133,000	146,000	15.7	37.1	17.8/16.2	34.5/35.5
As-Forged Properties			135,000	137,500	150,000	12.9	34.5	18.0	35.5/36.5

HT - L1123R (180 BHN Sponge)

FX1	1750-1-WQ	900-2-AC	161,000	167,000	182,000	12.9	46.5	11.5/11.3	40.0/41.5
FX2	1750-1-WQ	1050-2-AC	167,000	172,000	183,000	12.9	42.4	11.0/12.2	40.0/41.5
FX3	1750-1-WQ	1200-2-AC	156,500	160,000	169,000	15.7	43.6	10.2/9.9	39.0/40.5
FX4	1750-1-WQ	1350-2-AC	145,500	147,500	157,500	16.4	40.7	12.0/11.2	37.0/38.0
FX6	1750-1-WQ	1500-2-AC	140,500	143,000	153,000	14.3	35.8	13.9/13.9	36.0/37.5
FX7	1800-1-WQ	900-2-AC	147,000	153,000	172,000	14.3	37.6	7.9/10.0	40.0/41.5
FX9	1800-1-WQ	1050-2-AC	152,000	157,000	171,000	15.0	39.8	9.9/9.9	40.5/41.0
FX10	1800-1-WQ	1200-2-AC	152,000	156,000	167,000	13.6	33.5	10.0/11.0	39.5/41.0
FX11	1800-1-WQ	1350-2-AC	139,600	142,400	158,000	13.0	47.0	11.3/11.6	37.0/38.0
FX13	1800-1-WQ	1500-2-AC	140,000	143,000	157,000	16.4	42.8	12.3/13.0	37.0/38.0
As-Forged Properties			145,000	147,500	159,500	14.3	49.4	16.0	36.0/37.0

NOTE: *WQ - Water Quenched*
AC - Air Cooled

See Figure 5

TABLE III

SHORT-TIME ELEVATED TEMPERATURE TEST

Titanium Metals 6%Al-4%V Alloy (100-lb Ingot)
4½"-Diam. Barstock Press-Forged to ¼" Plate

HT - L1121R (140 BHN Sponge)

Mark	Temperature °F	Yield Strength psi 0.1%	Yield Strength psi 0.2%	Tensile Strength psi	% Elon.	% R.A.	V Notch Charpy Impact Ft-Lb	Rockwell "C" Range	Modulus X 10^6
21FET- 8	Room	153,000	156,000	168,600	12.1	46.1	11.6	38.0/39.0	
2	300	117,500	121,000	138,800	17.1	56.3	14.2	38.0/38.5	15.8
3	500	103,000	105,000	122,500	17.1	56.3	21.1	38.0/38.5	15.4
4	700	89,000	93,000	116,000	16.4	56.7	27.7	37.5/38.5	13.8
5	800	85,000	90,200	110,500	16.4	60.3	28.3	37.5/38.5	13.1
6	900	76,500	82,200	105,000	19.3	69.2	36.1	37.5/38.5	13.2
9	1000	61,800	68,500	98,000	21.4	72.0	21.1	37.5/38.0	11.1
10	1100	44,500	51,750	86,000	28.6	77.4	39.4	37.5/38.5	9.3
11	1200	19,500	25,000	50,800	67.1	78.6	44.4	38.0/39.0	10.3
12	1350	8,850	11,450	29,500	89.3	76.5	47.4	37.5/38.5	4.8

HT - L1121R (160 BHN Sponge)

22FET-11	Room	133,000	136,000	147,500	12.9	32.2	16.8	35.0/36.0	
1	300	125,000	128,500	144,500	17.9	58.9	15.5/16.0	35.5/39.0	14.5
2	500	106,500	109,500	127,000	19.3	63.0	18.5/20.5	36.0/39.5	13.0
3	700	96,500	100,000	119,500	17.9	63.7	26.0/30.0	38.0/40.0	12.5
4	800	89,300	94,800	117,500	18.6	68.0	33.5	38.5/39.5	14.0
5	900	83,300	90,000	113,000	21.4	75.4	35.0	38.5/39.0	13.2
7	1000	71,700	78,500	102,000	21.4	80.6	44.0/43.0	38.5/40.0	12.5
8	1100	56,300	61,300	81,500	17.9	85.6	46.0/45.5	38.0/39.0	9.0
9	1200	21,100	26,800	60,000	35.0	85.7	50.0/51.0	37.5/39.0	
10	1350	13,250	16,100	31,400	160.7	94.9	50.5/46.0	38.0/38.5	

HT - L1123R (180 BHN Sponge)

23FET-11	Room	142,500	146,000	156,000	14.3	36.3	13.8	36.0/38.5	
1	300	129,500	132,500	147,000	17.1	53.7	14.0	40.0/42.0	15.9
2	500	112,500	115,000	133,000	18.6	61.3	17.5/14.5	40.0/41.0	16.2
3	700	99,000	103,000	124,000	16.4	59.9	23.5/25.5	38.5/42.0	12.5
4	800	95,700	100,300	121,400	18.6	63.4	27.5/28.0	40.0/41.0	11.2
5	900	87,600	94,500	117,000	26.4	77.3	29.5	40.5/41.5	12.5
7	1000	75,600	82,000	103,000	29.3	80.1	33.0/30.5	40.5/41.0	12.2
8	1100	52,700	58,500	85,000	17.8	85.4	34.5/35.0	40.5/41.0	9.5
9	1200	27,300	34,400	52,000	42.1	85.0	39.5/42.5	39.5/40.5	
10	1350	10,250	13,100	30,600	80.7	92.4	45.0	43.0/43.5	

Heat Treatment - *1750°F - 1 hr - WQ*
1050°F - 2 hrs - AC

Time at Testing Temperature - 20 min.

Rockwell "C" Readings Taken at Room Temperature Prior to Testing

See Figure 6

TABLE IV

EFFECT OF SOLUTION TEMPERATURE ON MECHANICAL PROPERTIES OF 6%Al-4%V TITANIUM ALLOY

140 Brinell Hardness Sponge HT 1121R (100-lb Ingot)
4¼"-Diam. Barstock Drop-Forged to 7/8" Plate

All Samples Held 1½ Hrs. at Sol. Temp., W.Q., Tempered at 1050°F, and A.C.

Mark	Sol. Temp. °F	Yield Strength psi 0.1%	Yield Strength psi 0.2%	Tensile Strength psi	% Elon.	% R.A.	V Notch Charpy Impact Ft-Lb	Rockwell "C" Range
21FGS-T1	1600	147,000	149,000	156,000	15.7	44.5	13.0	37.0/38.0
-T2	1650	151,000	152,500	160,000	14.3	43.2	12.3	38.0/39.0
-T3	1700	154,500	156,000	165,000	13.6	47.0	11.8	38.0/39.0
-T4	1750	158,500	161,000	172,300	12.9	50.6	11.0	38.0/39.0
-T5	1800	141,000	145,000	160,000	12.9	47.4	11.0	38.0/41.5
-T6	1850	144,000	147,500	165,000	10.7	24.1	9.0	38.5/40.5
-T7	1900	146,500	152,000	169,500	7.1	14.5	8.5	38.5/39.5
-T8	2000	149,500	152,500	168,500	8.6	20.1	6.8	38.5/39.5
-T9	2100	148,500	152,000	169,000	10.0	14.5	7.8	39.5/40.0
-T10	2200	150,000	155,000	168,000	5.7	7.6	10.0	38.0/39.0
Au-Forged -								
21FGS-1BF		135,000	137,500	147,000	10.9	38.0	17.1	34.5/35.5
-6BF		141,700	143,800	149,200	7.8	36.8	16.2	34.5/35.5

See Figure 7

TABLE V

HEAT TREATMENT SURVEY

7%Al-4%V Titanium Alloy (140 BHN Sponge)
Titanium Metals HT - L1124R (100-lb Ingot)
(As-Received - 4½"-Diam. Barstock)
(Heat-Treated in 1"-Thick Discs)

Mark	Heat Treatment °F		Yield Strength psi		Tensile Strength psi	% Elon.	% R.A.	Impact -40°F Ft-Lb	Rockwell "C" Range
	Solution	Temper	0.1%	0.2%					
1X	1700-1-WQ	900-2-AC	152,000	158,000	175,000	4.3	9.3	7.3/9.0	40.0/41.0
2X	1700-1-WQ	1050-2-AC	152,000	156,000	168,000	5.7	14.5	8.0/9.0	40.0/41.0
3X	1700-1-WQ	1200-2-AC	149,000	153,500	169,000	7.1	15.0	8.4/10.2	38.0/40.0
4X	1700-1-WQ	1350-2-AC	137,500	141,000	158,000	9.3	16.6	10.0/10.0	36.0/40.0
5X	1700-1-WQ	1500-2-AC	116,500	122,500	143,500	8.6	21.6	13.0/13.8	35.0/37.5
6X	1750-1-WQ	900-2-AC	145,500	148,000	179,000	5.7	8.2	8.0/9.8	34.0/41.0
7X	1750-1-WQ	1050-2-AC	154,500	158,000	176,500	3.6	6.0	9.0/8.8	41.0/42.0
8X	1750-1-WQ	1200-2-AC	153,000	156,500	175,000	5.7	10.9	9.0/8.2	39.5/41.5
9X	1750-1-WQ	1350-2-AC	142,500	146,000	162,500	6.4	13.0	10.0/11.0	37.0/38.5
10X	1750-1-WQ	1500-2-AC	124,500	129,000	146,500	10.0	22.1	12.2/14.5	34.0/36.0
11X	1800-1-WQ	900-2-AC	151,500	156,500	180,000	5.7	10.9	11.8/9.0	40.0/41.0
12X	1800-1-WQ	1050-2-AC	157,500	162,000	179,500	5.0	9.3	8.0/10.0	40.0/42.0
13X	1800-1-WQ	1200-2-AC	158,500	163,000	179,000	5.0	9.8	9.8/8.8	40.0/41.5
14X	1800-1-WQ	1350-2-AC	150,500	155,000	168,000	5.7	9.8	7.3/9.7	38.0/41.5
15X	1800-1-WQ	1500-2-AC	130,000	135,000	151,000	8.6	18.1	12.2/11.0	34.0/36.0
16X	1850-1-WQ	900-2-AC	159,000	165,500	181,000	2.9	5.5	6.7/6.5	40.0/41.5
17X	1850-1-WQ	1050-2-AC	160,000	165,000	186,500	2.9	7.1	6.8/6.9	40.5/41.5
18X	1850-1-WQ	1200-2-AC	163,000	167,500	177,500	2.9	4.9	7.3/7.8	40.0/41.5
19X	1850-1-WQ	1350-2-AC	157,000	161,000	173,500	3.6	6.6	6.7/7.5	38.5/40.5
20X	1850-1-WQ	1500-2-AC	139,500	143,500	160,000	5.7	10.9	7.3/7.0	37.5/38.5
As-Received Properties									
24-ARA			117,500	123,500	144,500	7.9	18.1	11.2	33.5/34.5
ARB			121,000	127,000	145,500	8.6	17.6	10.0	33.5/34.5
(Drop-Forged to ¾" Plate)									
FX2	1750-1-WQ	900-2-AC	150,500	155,000	171,000	13.6	42.8	9.8/11.5	40.5/42.0
FX3	1750-1-WQ	1050-2-AC	154,500	158,000	171,000	12.1	38.0	9.2/10.2	40.0/41.5
FX4	1750-1-WQ	1200-2-AC	155,000	157,500	169,000	15.0	38.9	10.8	40.0/41.0
FX5	1750-1-WQ	1350-2-AC	138,400	141,600	154,000	16.0	39.8	13.2/11.5	36.5/37.5
FX6	1750-1-WQ	1500-2-AC	136,000	138,500	152,000	13.6	31.7	14.2/14.5	38.0/37.0
FX7	1800-1-WQ	900-2-AC	145,500	151,000	170,500	13.6	34.0	11.0/10.3	41.0/41.0
FX8	1800-1-WQ	1050-2-AC	147,200	153,400	170,000	15.0	34.8	9.8/9.9	40.5/42.0
FX9	1800-1-WQ	1200-2-AC	151,500	156,000	168,000	12.9	38.9	9.9/11.9	40.0/41.0
FX10	1800-1-WQ	1350-2-AC	142,500	146,000	158,000	14.3	36.3	11.5/12.2	37.5/39.0
FX11	1800-1-WQ	1500-2-AC	132,400	136,000	150,000	14.0	41.0	13.9/13.8	36.0/37.0
As-Forged Properties			146,500	150,000	161,000	12.1	38.9	16.9	36.0/37.0

NOTE: *WQ - Water Quenched*
AC - Air Cooled

(Continued over)

TABLE V (Continued)

SHORT-TIME ELEVATED TEMPERATURE TEST
(4½"-Diam. Barstock Press-Forged to ¾" Plate)

Mark	Temperature °F	Yield Strength psi 0.1%	Yield Strength psi 0.2%	Tensile Strength psi	% Elon.	% R.A.	V Notch Charpy Impact Ft-Lb	Rockwell "C" Range	Modulus X 10^6
24FET- 2	Room	156,000	160,000	170,000	12.1	33.5	8.0	36.5/41.5	
3	300	129,000	132,000	147,000	16.4	46.1	11.4	42.5/43.5	17.3
4	500	102,500	106,500	127,500	16.4	49.0	16.0	42.5/43.0	16.4
5	700	100,500	105,700	127,000	15.7	58.1	18.2	44.5/45.5	14.6
6	800	95,000	100,200	121,000	16.4	59.9	25.5	43.0/46.0	14.6
7	900	86,700	93,300	116,000	17.9	63.7	23.7	43.0	14.0
8	1000	76,400	84,900	107,700	23.6	70.2	25.0	43.0/43.5	14.3
9	1100	52,500	59,200	83,000	42.9	75.9	29.7	41.5/42.0	11.8
10	1200	20,000	26,200	66,500	51.4	79.6	36.6	46.0/47.0	8.8
11	1350	8,675	11,600	35,500	64.3	82.9	36.9	42.5/43.5	4.5

Heat Treatment - 1750°F - 1 hr - WQ
1050°F - 8 hrs - AC

Time at Testing Temperatures - 20 min.

Rockwell "C" Readings Taken at Room Temperature Prior to Testing

See Figure 8

TABLE VI

HEAT TREATMENT SURVEY

8%Al-4%V Titanium Alloy (140 BHN Sponge)
Titanium Metals HT - L1125R (100-lb Ingot)
(As-Received - 4½"-Diam. Barstock)
(Heat-Treated in 1"-Thick Discs)

Mark	Heat Treatment °F		Yield Strength psi		Tensile Strength psi	% Elon.	% R.A.	Impact -40°F Ft-Lb	Rockwell "C" Range
	Solution	Temper	0.1%	0.2%					
1X	1700-1-WQ	900-2-AC	150,500	158,000	182,500	5.0	6.6	7.8/9.0	42.0/43.5
2X	1700-1-WQ	1050-2-AC	157,000	162,500	179,000	5.0	8.2	9.3/8.5	41.0/42.0
3X	1700-1-WQ	1200-2-AC	149,500	154,000	167,000	5.7	14.0	8.7/9.0	40.0/41.0
4X	1700-1-WQ	1350-2-AC	136,500	140,000	153,000	8.6	20.1	12.3/10.9	36.5/38.0
5X	1700-1-WQ	1500-2-AC	122,500	128,000	145,500	9.3	21.1	12.0/13.0	35.0/36.0
6X	1750-1-WQ	900-2-AC	157,000	164,000	184,000	5.7	10.3	9.0/8.5	41.5/42.5
7X	1750-1-WQ	1050-2-AC	160,000	165,000	181,000	2.9	7.1	9.0/6.5	41.0/42.5
8X	1750-1-WQ	1200-2-AC	159,000	164,000	179,000	5.0	9.3	7.5/7.0	41.0/42.5
9X	1750-1-WQ	1350-2-AC	142,500	147,000	161,000	6.4	13.5	9.3/9.0	39.0/41.0
10X	1750-1-WQ	1500-2-AC	122,500	127,000	144,500	10.0	26.5	13.0/12.0	35.0/37.0
11X	1800-1-WQ	900-2-AC	156,500	166,500	184,000	3.6	6.6	9.8	41.0/43.0
12X	1800-1-WQ	1050-2-AC	163,000	168,500	184,000	2.9	6.0	8.0/5.2	41.0/42.5
13X	1800-1-WQ	1200-2-AC	160,500	166,500	181,000	3.6	8.2	7.2/5.0	42.0/42.5
14X	1800-1-WQ	1350-2-AC	144,000	148,500	165,000	6.4	16.1	8.0/9.0	39.5/40.5
15X	1800-1-WQ	1500-2-AC	124,000	129,500	146,500	10.0	19.6	12.5/11.5	35.5/37.0
16X	1850-1-WQ	900-2-AC	165,000	172,500	186,000	2.9	5.5	11.0/7.0	42.0/43.0
17X	1850-1-WQ	1050-2-AC	168,500	175,000	182,000	1.4	3.8	7.5/5.8	43.5/44.5
18X	1850-1-WQ	1200-2-AC	167,500	172,500	181,000	1.4	4.4	5.2/6.0	43.0/46.0
19X	1850-1-WQ	1350-2-AC	153,500	157,500	171,500	2.9	7.6	7.0/7.0	41.0/42.0
20X	1850-1-WQ	1500-2-AC	140,000	144,500	160,000	6.4	11.9	9.0/8.0	38.0/40.0
As-Received Properties									
15-ARA			119,000	125,000	144,500	10.0	18.6	10.0	34.5/35.5
ARB			118,500	125,000	145,000	10.0	17.6	6.5	34.5/35.5
(Drop-Forged to ¾" Plate)									
FX1	1750-1-WQ	900-2-AC	165,000	169,000	192,500	11.4	36.3	10.0	41.5/42.0
FX3	1750-1-WQ	1050-2-AC	176,000	179,000	191,000	10.7	34.9	6.5	41.5/42.5
FX4	1750-1-WQ	1200-2-AC	171,500	174,000	184,000	10.7	33.1	9.2	41.5/42.0
FX6	1750-1-WQ	1350-2-AC	153,500	155,500	167,500	14.3	40.7	11.5	38.0/40.0
FX7	1750-1-WQ	1500-2-AC	141,500	144,000	154,000	15.0	38.5	13.0	37.0/39.0
FX9	1800-1-WQ	900-2-AC	158,500	163,500	184,000	6.4	9.3	7.5	42.5/43.5
FX10	1800-1-WQ	1050-2-AC	163,000	167,000	183,500	5.7	8.8	6.0	42.5/43.5
FX12	1800-1-WQ	1200-2-AC	163,000	167,000	183,000	5.0	10.3	6.5	42.5/43.5
FX13	1800-1-WQ	1350-2-AC	153,500	158,500	173,000	7.1	13.0	7.5	40.0/41.5
FX14	1800-1-WQ	1500-2-AC	150,500	153,500	170,000	8.6	13.5	10.0	39.5/40.5
As-Forged Properties			144,000	150,000	161,000	13.6	41.1	16.0	36.5/37.0

NOTE: WQ - Water Quenched
AC - Air Cooled

(Continued over)

TABLE VI (Continued)

SHORT-TIME ELEVATED TEMPERATURE TEST
(4½"-Diam. Barstock Press-Forged to ¾" Plate)

Mark	Temperature °F	Yield Strength psi 0.1%	Yield Strength psi 0.2%	Tensile Strength psi	% Elon.	% R.A.	V Notch Charpy Impact Ft-Lb	Rockwell "C" Range	Modulus X 10^6
25FET-14	Room	161,000	169,000	191,500	10.0	35.5	12.0	41.5/43.0	17.5
56	300	133,000	138,500	162,000	14.3	40.7	9.7	42.5/43.5	16.8
4	500	102,500	111,500	145,000	14.3	35.4	14.2	42.5/43.0	15.9
5	700	95,300	104,500	135,500	11.4	29.4	16.1	44.5/45.5	15.8
6	800	89,700	99,700	130,000	15.7	62.0	18.1	43.0/46.0	14.1
9	900	81,300	91,000	128,500	17.9	60.6	16.4	43.0	13.2
10	1000	69,800	77,500	113,500	30.0	67.3	20.5	43.0/43.5	12.5
11	1100	45,000	53,500	89,000	36.4	76.8	22.9	41.5/42.0	9.6
12	1200	24,000	30,600	58,750	37.9	53.7	28.3	46.0/47.0	6.6
57	1350	13,700	16,500	42,900	52.9	70.4	28.3	42.5/43.5	6.5

Heat Treatment - *1750°F - 1 hr - WQ*
900°F - 2 hrs - AC

Time at Testing Temperatures - *20 min.*

Rockwell "C" Readings Taken at Room Temperature Prior to Testing

See Figure 9

TABLE VII

HEAT TREATMENT SURVEY

5%Al-3%FeCr-3%FeMo Titanium Alloy (140 BHN Sponge)
Titanium Metals HT - M1685R (100-lb Ingot)
(As-Received - 4¼"-Diam. Barstock)
(Heat-Treated in 1"-Thick Discs)

Mark	Heat Treatment °F		Yield Strength psi		Tensile Strength psi	% Elon.	% R.A.	Impact -40°F Ft-Lb	Rockwell "C" Range
	Solution	Temper	0.1%	0.2%					
85RX1	1700-1-WQ	900-2-AC	160,000	167,000	188,600	4.3	7.6	6.3	42.0/43.5
85RX2	1700-1-WQ	1050-2-AC	163,000	169,000	186,000	5.0	8.2	6.0	41.5/42.5
85RX3	1700-1-WQ	1200-2-AC	145,000	151,000	188,200	5.7	14.5	6.6	38.5/39.5
85RX4	1700-1-WQ	1350-2-AC	134,000	138,000	152,400	7.1	14.5	10.1	35.5/37.5
85RX5	1700-1-WQ	1500-2-AC	124,000	130,000	151,000	10.7	22.1	10.3	35.0/36.0
85RX6	1750-1-WQ	900-2-AC	160,500	170,000	200,800	2.1	5.5	4.7	43.5/45.5
85RX7	1750-1-WQ	1050-2-AC	146,000	155,000	180,200	3.6	5.5	6.1	39.5/42.0
85RX8	1750-1-WQ	1200-2-AC	142,000	147,000	167,100	5.7	6.6	8.7	36.5/38.0
85RX9	1750-1-WQ	1350-2-AC	123,900	128,000	143,500	7.1	27.4	10.3	34.5/35.5
85RX10	1750-1-WQ	1500-2-AC	128,500	134,000	151,200	10.0	25.5	14.5	33.5/36.0
85RX11	1800-1-WQ	900-2-AC	168,500	175,000	193,800	2.9	3.3	4.0	43.0/44.0
85RX12	1800-1-WQ	1050-2-AC	167,000	173,000	188,000	2.9	5.5	6.0	42.0/43.0
85RX13	1800-1-WQ	1200-2-AC	156,000	161,000	172,200	2.1	6.0	4.7	40.5/41.0
85RX14	1800-1-WQ	1350-2-AC	142,000	146,000	157,000	7.9	12.4	8.2	36.5/37.5
85RX15	1800-1-WQ	1500-2-AC	132,500	136,000	152,600	9.3	14.0	7.7	36.5/37.5
85RX16	1850-1-WQ	900-2-AC	170,000	178,000	198,800	3.6	10.9	4.4	43.5/44.5
85RX17	1850-1-WQ	1050-2-AC	159,000	166,000	180,000	3.6	10.3	4.9	41.0/42.5
85RX18	1850-1-WQ	1200-2-AC	154,000	160,000	177,600	5.0	7.1	7.3	39.5/40.0
85RX19	1850-1-WQ	1350-2-AC	134,500	138,000	151,600	6.4	17.6	7.1	36.0/37.5
85RX20	1850-1-WQ	1500-2-AC	130,000	135,000	154,000	10.7	27.0	10.5	36.0/38.0
As-Received Properties			130,500	133,500	145,000	14.3	29.4	6.8	34.5/36.0
			121,500	125,000	136,500	5.7	15.6	7.1	33.0/35.0

(Drop-Forged to ⅜" Plate)

1X	1650-1-WQ	900-2-AC	173,000	179,000	199,000	7.9	20.8	7.3	43.5/44.0
2X	1650-1-WQ	1050-2-AC	165,000	168,000	177,000	15.0	41.5	10.0	40.5/41.0
3X	1650-1-WQ	1200-2-AC	149,000	149,000	150,000	15.7	46.5	10.0	34.5/35.5
4X	1650-1-WQ	1350-2-AC	147,000	148,000	151,500	15.0	43.2		37.0/37.5
5X	1700-1-WQ	900-2-AC	177,000	184,000	197,000	2.9	6.6	6.6	48.5/49.5
6X	1700-1-WQ	1050-2-AC	167,000	173,000	185,000	2.9	6.0	6.5	44.5/46.0
7X	1700-1-WQ	1200-2-AC	151,000	155,500	164,000	7.1	16.6	6.6	37.5/38.5
8X	1700-1-WQ	1350-2-AC	142,500	146,000	154,500	10.0	20.1	9.5	37.5/38.0
9X	1750-1-WQ	900-2-AC	183,000	190,000	200,200	2.1	3.3	5.9	43.0/44.0
10X	1750-1-WQ	1050-2-AC	169,000	175,000	185,200	2.9	4.4	4.7	42.5
11X	1750-1-WQ	1200-2-AC	147,000	152,000	158,200	6.4	16.4	8.2	38.5/39.0
12X	1750-1-WQ	1350-2-AC	136,000	140,000	148,400	10.7	19.1	6.5	37.5
13X	1800-1-WQ	900-2-AC	174,000	183,000	195,800	3.6	4.9	7.5	47.5/49.5
14X	1800-1-WQ	1050-2-AC	169,000	175,000	185,800	7.9	22.1	5.9	41.5/42.5
15X	1800-1-WQ	1200-2-AC	152,000	156,000	160,600	13.6	36.7	10.5	38.0/39.0
16X	1800-1-WQ	1350-2-AC	141,000	145,000	151,600	16.4	43.6	10.0	36.5/37.5

NOTE: *WQ - Water Quenched*
AC - Air Cooled

(Continued over)

TABLE VII (Continued)

SHORT-TIME ELEVATED TEMPERATURE TEST
(4½"-Diam. Barstock Press-Forged to ¾" Plate)

Mark		Temperature °F	Yield Strength psi 0.1%	Yield Strength psi 0.2%	Tensile Strength psi	% Elon.	% R.A.	V Notch Charpy Impact Ft-Lb	Rockwell "C" Range	Modulus X 10^6
85FET-	8	Room	172,600	176,000	188,000	12.2	42.0	9.5	39.5/40.5	17.6
	1	300	132,000	137,000	159,000	16.4	55.2	14.0	40.5/41.0	16.3
	2	500	113,000	117,000	140,500	17.1	63.4	21.0	42.0/42.5	16.1
	3	700	96,000	103,000	131,000	17.9	68.0	43.0	41.0/41.5	14.5
	4	800	91,300	100,700	129,000	18.6	73.1	45.5	41.5/42.0	13.8
	5	900	72,500	81,000	113,000	24.3	82.8	53.0	41.0/42.0	12.5
	6	1000	48,000	56,800	84,000	29.3	93.0	73.0	41.0/42.0	10.9
	7	1100	35,100	30,000	57,250	29.3	93.7	75.0	40.0/41.0	9.6
	9	1200	13,350	16,600	34,300	97.9	98.1	85.0	40.0/41.0	5.9
	10	1350	5,750	6,850	18,400	127.1	98.3	94.5	41.0/42.0	

Heat Treatment - *1750°F - 1 hr - WQ*
1050°F - 2 hrs - AC

Time at Testing Temperatures - 20 min.

Rockwell "C" Readings Taken at Room Temperature Prior to Testing

See Figure 10

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