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EVALUATION OF LARGE TITANIUM ALLOY FORGINGS

SECOND QUARTERLY REPORT

REPORTING PERIOD 1 JULY 1965 THROUGH 30 SEPTEMBER 1965

CONTRACT NUMBER AF33(615)-2690

Air Force Materials Laboratory
Research and Technology Division
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LOCKHEED-CALIFORNIA COMPANY - BURBANK

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(6) EVALUATION OF LARGE TITANIUM ALLOY FORGINGS.

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~~Prepared by~~ Rod F. Simenz,
(10) Rod F. Simenz.
~~Project Leader~~

Approved by H. B. Sipple
H. B. Sipple
R&D Engineer, Materials and Processes

J. C. Duffendack
Chief Administrative Engineer

LOCKHEED-CALIFORNIA COMPANY, BURBANK, CALIFORNIA

(207 970)

FOREWORD

This report was prepared by the Lockheed-California Company, Burbank, California, under Contract No. AF 33(615)-2690. The program is administered under the direction of the Air Force Materials Laboratory, Research and Technology Division by Lt. D. C. LaGrone.

This work is conducted under the direction of Mr. H. B. Sipple, R & D Engineer, Materials and Processes, Mr. R. F. Simenz is Project Leader, assisted by Mr. W. L. Macoritto. Technical consultation is being provided by Mr. V. E. Dress and Mr. G. G. Wald, Research Specialist and Design Specialist, respectively.

Static testing is under the direction of Mr. R. L. Adamson, Materials Evaluation, assisted by Mr. S. L. Pendleberry. Fatigue testing is under the direction of Mr. R. H. Wells, Structures Test, assisted by Mr. C. S. Oswell.

Wyman-Gordon Company personnel who are actively participating in the program include:

Mr. J. J. Zecco, Jr., Research Project Engineer
Mr. R. E. Sparks, Senior Research Metallurgist

The period covered by this report is 1 July 1965 through 30 September 1965.

ABSTRACT

The purpose of this program is to evaluate large titanium forgings for reliable use in advanced weapon systems. Four forgings of Ti-6Al-4V and four forgings of IMI679 will be used in the evaluation. Two forgings of each alloy will be machined into test coupons for material property tests, one forging will be full scale fatigue tested and the other forging will be full scale static tested.

~~This report summarizes the work accomplished during the second quarterly period.~~ All forgings have been produced and heat treated. Machining of two forgings each of Ti-6Al-4V and IMI679 to a modified F-10[illegible] aft fuselage ring fitting is nearly completed.

Preparation of material property test coupons removed from forgings of IMI679 was started and some testing cor[illegible]ted. Preliminary smooth tension, notched tension, compression and fatigue data on IMI679 are presented.

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INTRODUCTION

Substantially increased usage of titanium alloy forgings is anticipated in future weapon systems because of the structural advantages offered by these materials. The purpose of this program is to provide data which will form a basis for the reliable use of titanium alloy forgings. Two titanium alloys will be evaluated in this program, Ti-6Al-4V and IMI679.

A total of four forgings will be produced in each alloy. Two forgings of each alloy will be machined into test coupons for material property tests, one forging will be full scale static tested and the other will be full scale fatigue tested. Mechanical property data to be obtained will include tensile, compression, bearing, shear, fracture toughness, and axial fatigue at temperatures of -110° to 550°F.

In a previous Air Force program AF 33(615)-1635, a similar evaluation was conducted on two other titanium alloy forgings Ti-6Al-6V-2Sn and Ti-13V-11Cr-3Al. Data obtained in the AF 33(615)-1635 program will be compared with data obtained in this program to illustrate the relative merits of four of the leading candidate titanium forging alloys.

PROCEDURE AND RESULTS

RAW MATERIAL DATA

Billet stock chemical analysis and test properties reported by TMCA are given in the Appendix.

FORGINGS

Four forgings of Ti-6Al-4V and four forgings of IMI679 have been received from Wyman-Gordon. Details on the forging operations used to produce these parts are presented in the Appendix.

HEAT TREATMENT

The IMI679 forgings were heat treated in full section size at Wyman-Gordon. The heat treatment recommended by the supplier for this alloy was used. This treatment consisted of heating at 1650°F for one hour, followed by fan cooling and then aging at 930°F for twenty-four hours.

The Ti-6Al-4V forgings were rough machined to a maximum thickness of 2-1/2 inches prior to heat treatment. The standard solution treatment and age was used for this alloy (i.e., 1750°F - 1 hour, water quench; age 4 hours at 1000°F.)

MATERIAL PROPERTY TESTS

Tensile tests on Ti-6Al-4V and IMI679 were conducted in all three grain directions on the billet stock from which the forgings were produced. The heat treatment procedures used on the billet stock were the same as those used on the forgings. The data obtained are given in the Appendix.

Two forgings of each alloy are being machined into test coupons for material property tests. The tests to be conducted include smooth and notched tension, compression, fatigue, shear, bearing and fracture

toughness. The location and orientation of test coupons in each forging are presented in Figures 1 through 6 .

Preliminary data have been obtained on IMI679. Smooth tension, notched tension, compression and fatigue data are presented in Tables 1 through 6. Additional tensile data were obtained by Wyman-Gordon on forgings of Ti-6Al-4V and IMI-679. These tests were conducted on test material forged integral with the parts. Specimen location for these tests are shown in Figure 7 . Test data are given in Tables 7 and 8.

FULL SCALE TESTING

Full scale static and fatigue testing will be conducted in the same test set-up as that used in Contract AF33(615)-1635. Final machining of two forgings of each alloy for full scale testing is nearing completion.

FUTURE WORK

During the next quarterly period, 1 October through 31 December, it is anticipated that the following work will be accomplished:

1. Machining of all parts and test coupons will be completed.
2. Material property testing will continue and additional metallographic work will be accomplished.
3. Test fixtures will be set up and full scale static testing will be initiated.

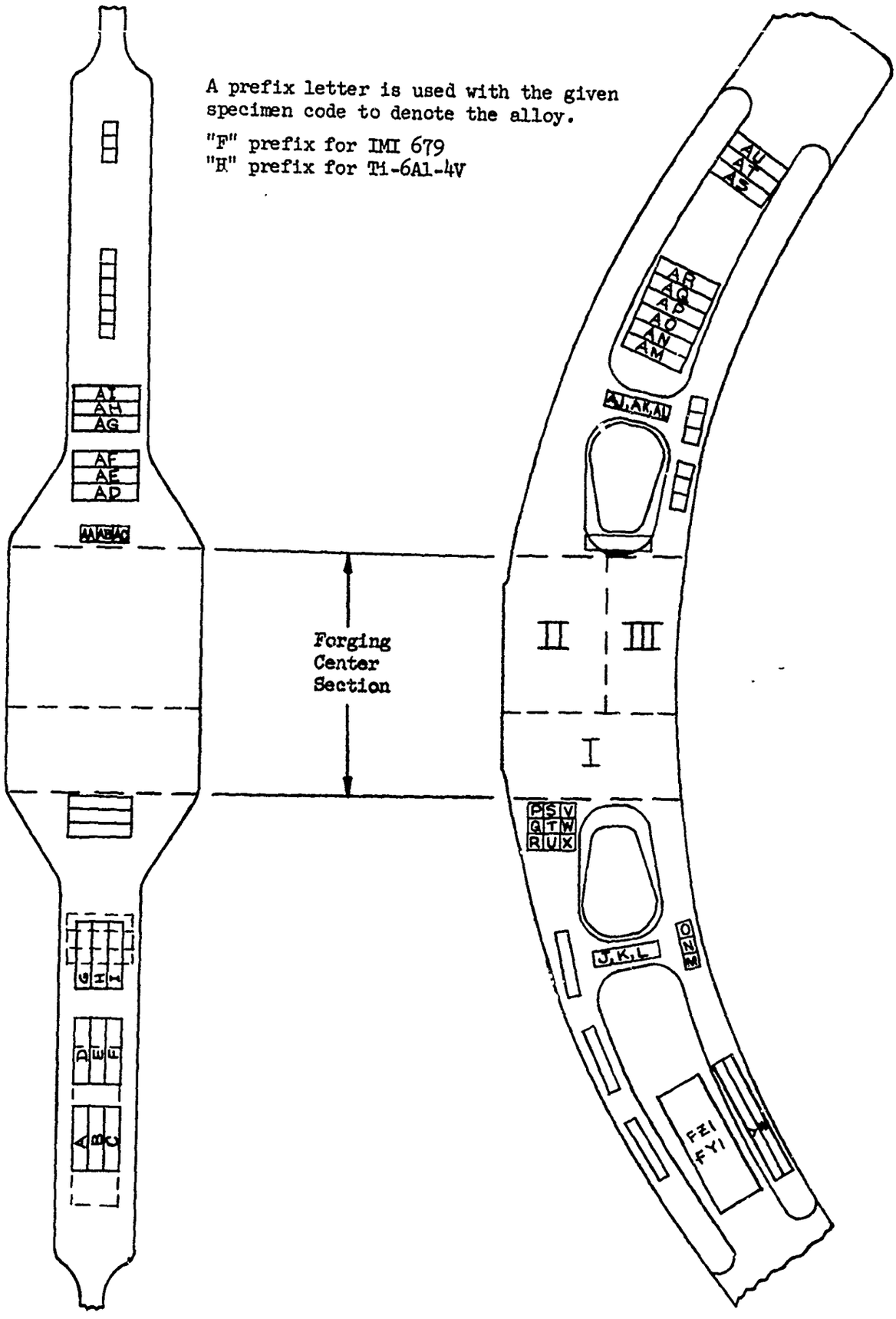


Figure 1. Specimen Layout First Forging IMI 679 and Ti-6Al-4V

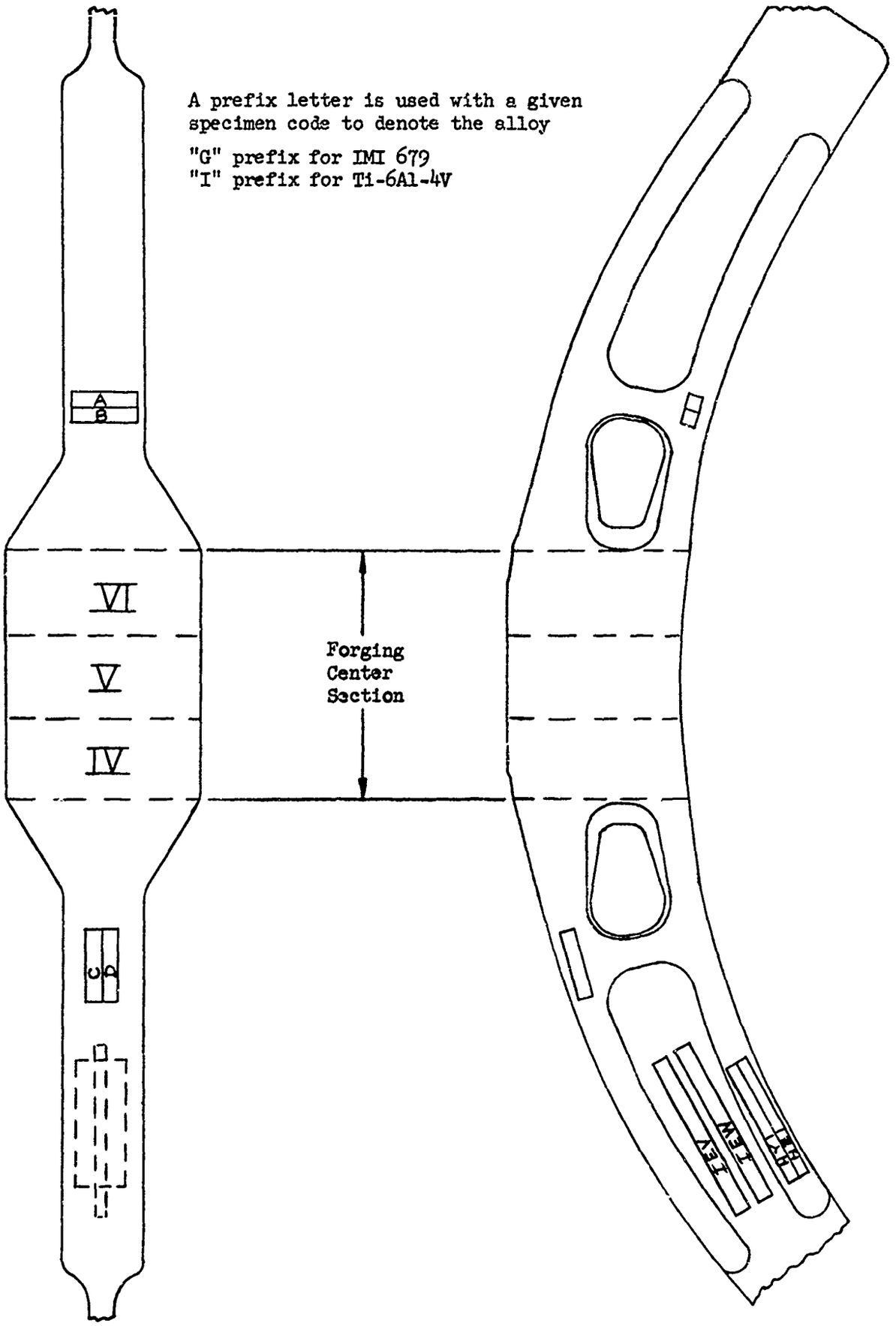


Figure 2. Specimen Layout Second Forging IMI 679 and Ti-6Al-4V

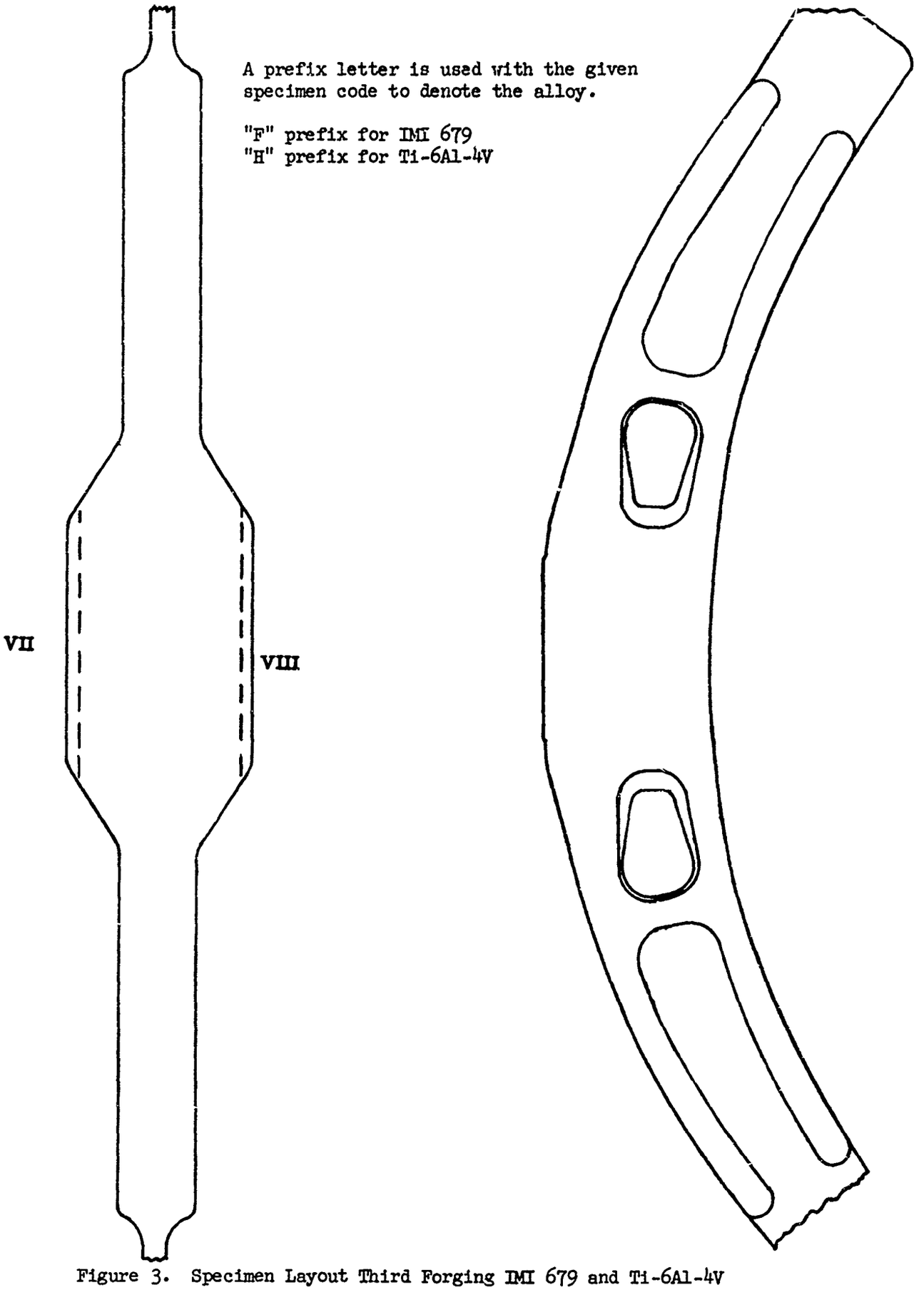
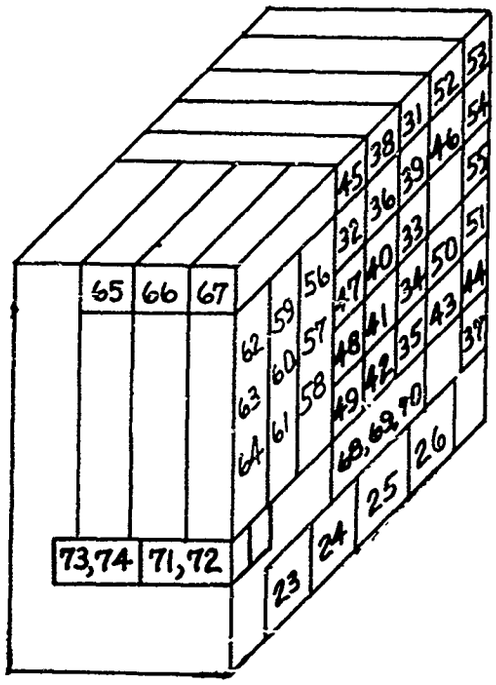
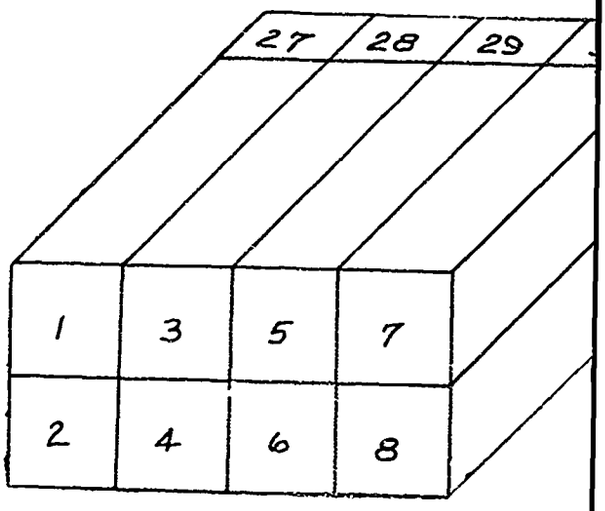


Figure 3. Specimen Layout Third Forging IMI 679 and Ti-6Al-4V



SUB-BLOCK I

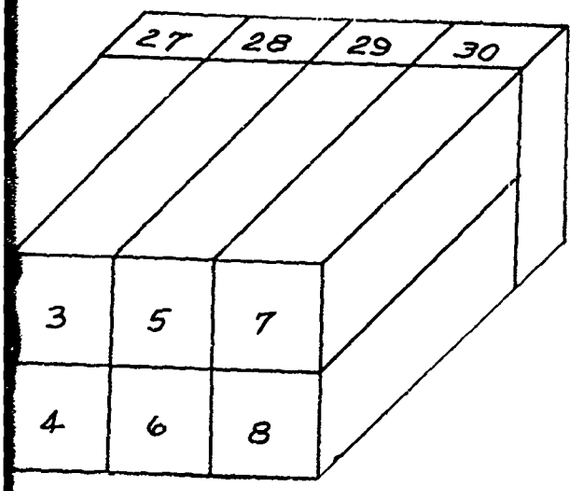


SUB-BLOCK II

Type	Specimen Number
23 through 26	Compression
39, 43, 46, 50, 52, 53	Notched Tensile
71 through 74	Shear
All Others	Tensile

Specimen Number	Type
1 through 8	Fracture Toughness
27 through 30	Compressio

Figure 4. Specimen Layout for IMI 679 and Ti-6Al-4V First Forging Center Section



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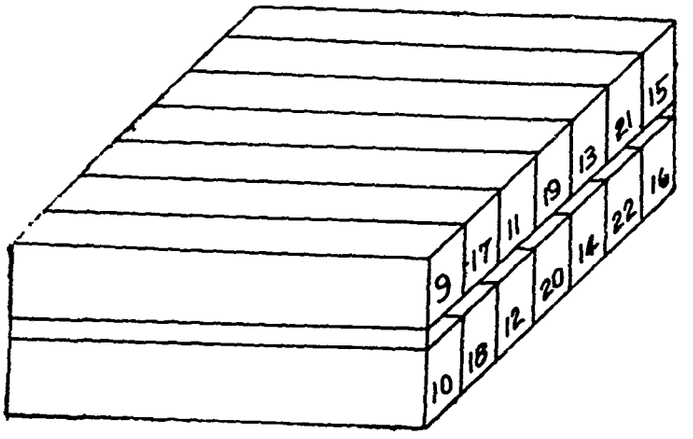
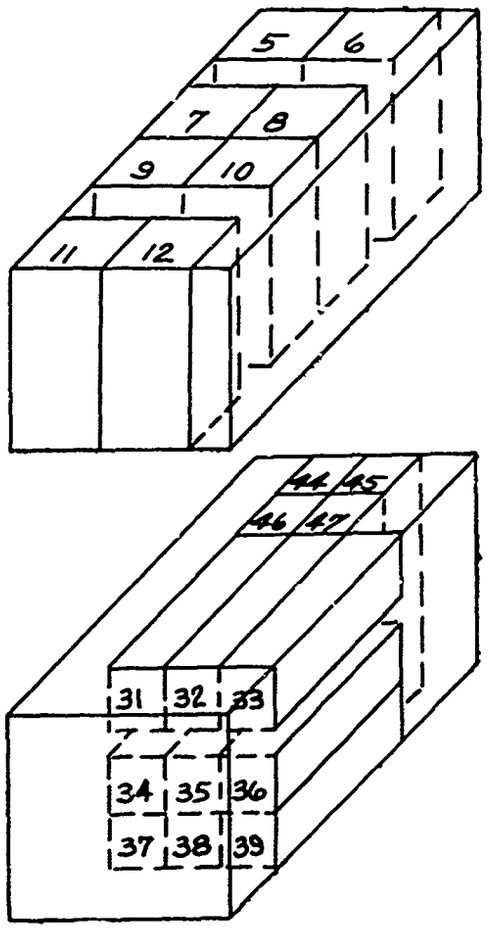


SUB-BLOCK III

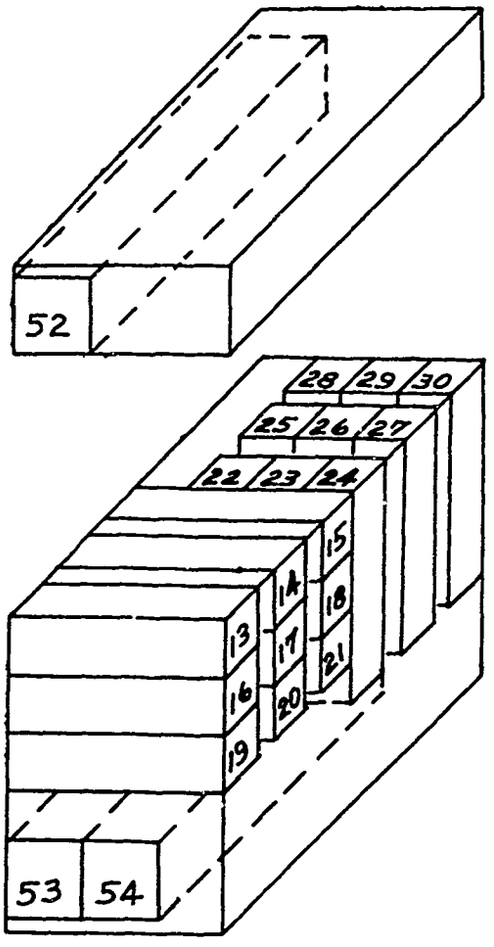
nen Number	Type
ough 8	Fracture Toughness
rough 30	Compression

Specimen Number	Type
9 through 22	Fatigue

Center Section



SUB-BLOCK IV

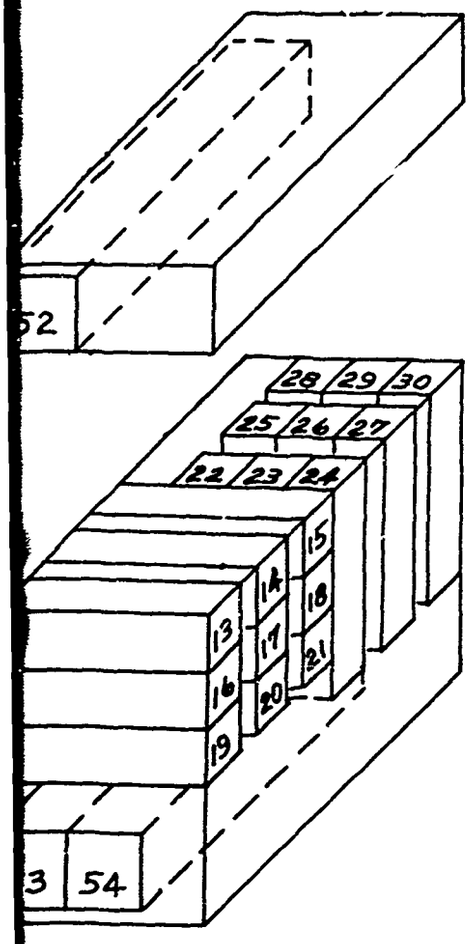


SUB-BLOCK V

Specimen Number	Type
5 through 12	Compression
44, 45, 46, 47	Notch Tensile
All Others	Tensile

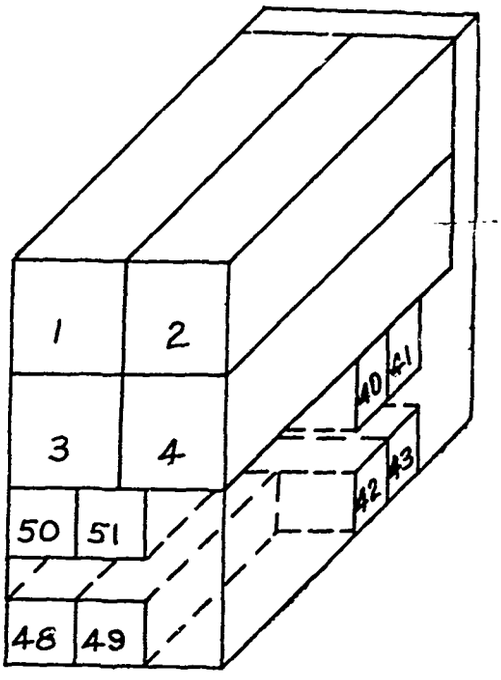
Specimen Number	Type
52, 53, 54	Fatigue
All Others	Tensile

Figure 5. Specimen Layout For IMI 679 and Ti-6Al-4V Second Forging Center Section



SUB-BLOCK V

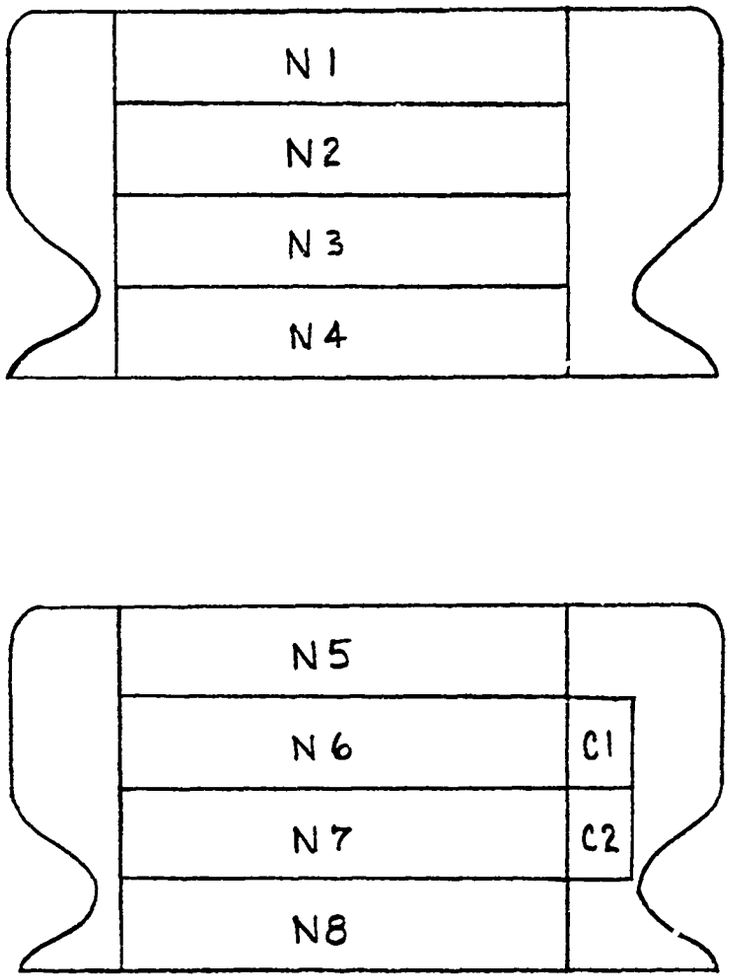
n Number	Type
3, 54	Fatigue
thers	Tensile



SUB-BLOCK VI

Specimen Number	Type
1, 2, 3, 4	Fracture Toughness
All Others	Notch Tensile

2



NOTE: N1 through N8 Fatigue
C1 and C2 Compression

Figure 6. Fatigue and Compression Specimen Layout Detail

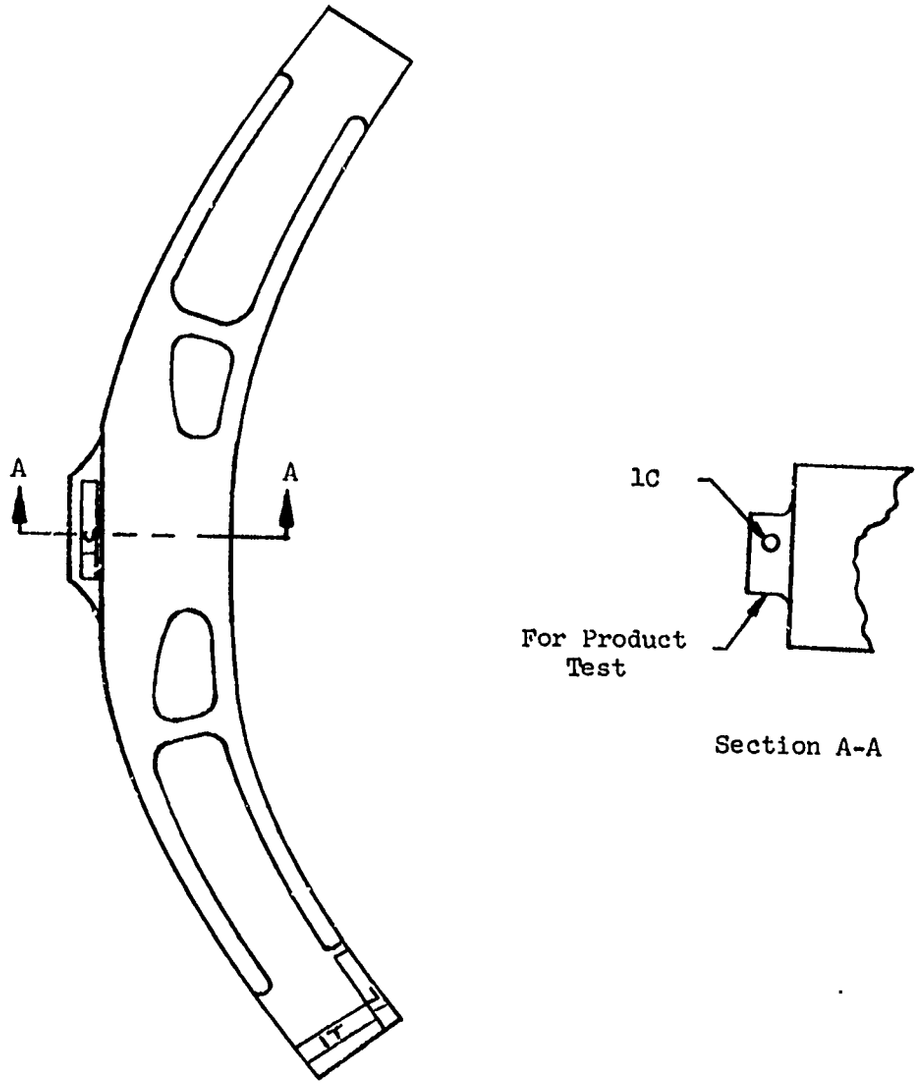


Figure 7. Capability Tests - Integrally Forged Coupons

TABLE 1 TENSILE RESULTS IMI 679 FORGING NUMBER HJU-1

Specimen Number	Specimen Location	Grain Direction	Test Temp. °F	Ultimate Tensile Strength ksi	Yield Strength 0.2% ksi	Elong. % 1 in.	R.A. %
FG	Flange	L	RT	150.8	133.0	15.0	43.7
FH				144.0	127.6	16.0	45.5
FI				147.0	130.2	14.5	45.0
Average				147.3	130.3	15.2	44.7
FJ	Complex	LT	RT	150.0	133.0	15.5	41.7
FK	Grain Flow			141.6	126.0	16.0	47.8
FL				149.6	132.2	14.5	42.5
Average				147.1	130.4	15.3	44.0
FM	Flange	ST	RT	147.6	131.8	12.0	44.4
FN				146.0	130.0	13.0	45.0
FO				146.0	130.4	10.5	31.9
Average				146.5	130.7	11.8	40.4
FD	Flange	L	550	120.6	93.0	17.0	43.7
FE				111.4	87.2	18.0	56.0
FF				118.4	89.8	19.0	50.0
Average				116.8	90.0	18.0	49.9
FAJ	Complex	LT	550	115.2	89.2	17.0	46.7
FAK	Grain Flow			110.6	85.8	19.0	53.4
FAL				114.0	88.0	15.5	49.0
Average				113.3	87.7	17.2	49.7
FAG	Flange	ST	550	114.0	88.0	15.5	50.0
FAH				114.0	87.2	16.0	50.0
FAI				115.0	88.8	16.5	49.0
Average				114.3	88.0	16.0	49.7

TABLE 2. IMI679 THICK SECTION TENSILE PROPERTIES FORGING HJU-1

Specimen Number	Specimen Location	Grain Dir.	Test Temp. °F	Ultimate Tensile Strength ksi	Yield Strength 0.2% ksi	Elong. % 1 inch	R.A. %
F34	Center	L	RT	141	127	15	40
F35				143	129	16	40
F38	Edge	L	RT	146	132	15	42
F45				148	134	13	33
F58	Center	LT	RT	136	121	15	44
F65	Edge	ST	RT	150	136	14	41
F66				151	136	16	40
F67				149	134	15	43
F70	Center	ST	RT	144	129	13	41

TABLE 3. IMI679 THICK SECTION TENSILE PROPERTIES FORGING HJU-2

Specimen Number	Specimen Location	Grain Dir.	Test Temp. °F	Ultimate Tensile Strength ksi	Yield Strength 0.2% ksi	Elong. % 1 inch.	R.A. %
G31	Center	ST	RT	137	121	11	30
G32				138	123	14	42
G33				140	127	14	43
Average				138.3	123.6	13.0	38.3
G34	Mid-radius	ST	RT	144	129	14	39
G35				144	130	15	42
G36				145	131	15	42
Average				144.3	130.0	14.6	41.0
G37	Edge	ST	RT	148	134	14	41
G38				150	135	13	38
G39				147	133	15	41
Average				148.5	134.0	14.0	40.0

TABLE 4. IMI679 NOTCHED TENSILE PROPERTIES

Forging Number	Specimen Number	Specimen Location	Grain Dir.	Test Temp. °F	Notched Tensile Strength ksi	$NTS/_{UTS}$ (K_t = 3.9)
HJU-2	GA	Flange	ST	RT	196	
	GB				207	
	Average				201.5	
	G40	Center	L	RT	206	
	G41				204	
	Average				205.0	
	G42	Edge	L	RT	210	
	G43				206	
	Average				208.0	
	G44	Edge	LT	RT	208	
	G45				206	
	Average				207.0	
	G46	Mid-radius	LT	RT	205	
	G47				201	
	Average				203.0	
	G48	Edge	ST	RT	204	
	G49				204	
	Average				204.0	
	G50	Mid-radius	ST	RT	202	
	G51				200	
	Average				201.0	

TABLE 5. IMI679 THICK SECTION COMPRESSION PROPERTIES

Forging Number	Specimen Number	Specimen Location	Grain Dir.	Test Temp. °F	Compression Yield Strength ksi
HJU-1	F23	Edge	L	RT	136
	F24				141
	Average				138.5
	F27	Edge	LT	RT	144
	F28				145
	Average				144.5
HJU-2	G5	Edge	LT	RT	149
	G6				148
	Average				148.5
	G7	Center	LT	RT	138
	G8				142
	Average				140

TABLE 6. IMI679 NOTCHED AXIAL TENSION FATIGUE PROPERTIES

Forging Number	Specimen Number	Grain Dir.	Test Temp.	Stress(1) max. - ksi	Cycles to Failure
GWN-13	FN 1	L	RT	80	8,640
	FN 2			60	28,440
	FN 6			50	562,500
	FN 3			40	1,583,460
	FN 4			38	3,845,160
	FN 7			35	781,200
	FN 8			30	7,380,000 (2)
	FN 5			LOST IN TEST	

(1) Stress Ratio R = 0.1; K_t = 3.0

(2) Test still in progress.

TABLE 7 PRODUCT TEST RESULTS - IMI-679 - TMCA HEAT 8427 (1)
ALL SAMPLES WERE INTEGRAL WITH FORGINGS AT TIME OF HEAT TREATMENT

Forging Number	Spec No.	Location	Ultimate Tensile Strength ksi	Yield Strength 0.2% ksi	Elong. % 1 in.	R.A. %
HJU-1	1L	End Pad Long.	152.4	134.0	15.0	46.7
	1T	End Pad Trans.	149.0	134.0	16.0	46.1
	1L	Center Pad Long.	146.4	131.2	15.0	37.6
HJU-2	1L	End Pad Long.	153.0	134.0	15.0	47.8
	1T	End Pad Trans.	146.2	131.6	16.0	43.1
	1L	Center Pad Long.	150.0	133.6	13.5	36.3
HJU-3	1L	End Pad Long.	153.8	134.6	15.0	43.7
	1T	End Pad Trans.	146.8	131.6	14.5	45.5
	1L	Center Pad Long.	150.0	131.6	14.5	42.5
HJU-4	1L	End Pad Long.	152.0	134.2	15.0	46.1
	1T	End Pad Trans.	150.0	132.0	15.0	39.5
	1L	Center Pad Long.	148.0	130.0	13.5	39.5

(1) Heat Treatment
Solution Treated 1650°F (1 hour) Fan Cool
Aged 930°F (24 hours) Air Cool

TABLE 8 PRODUCT TEST RESULTS Ti-6Al-4V TMCA HEAT D-7976
MATERIAL CUT FROM FORGING, HEAT TREATED AS COUPONS (1)

Forging Number	Spec. No.	Location	Ultimate Tensile Strength ksi	Yield Strength 0.2% ksi	Elong. % 1 in.	R.A. %
GWN-11	1L	End Pad Long.	178.0	164.0	10.0	29.9
	1T	End Pad Trans.	170.6	156.0	11.0	33.8
	1C	Center Pad Long.	168.0	154.0	10.5	31.8
GWN-12	1L	End Pad Long.	171.4	157.0	13.0	35.7
	1T	End Pad Trans.	173.6	158.0	11.0	35.7
	1C	Center Pad Long.	169.6	154.8	10.5	32.7
GWN-13	1L	End Pad Long.	181.6	169.2	10.5	35.7
	1T	End Pad Trans.	174.0	160.8	11.5	34.4
	1C	Center Pad Long.	168.4	155.8	10.5	34.4
GWN-14	1L	End Pad Long.	176.2	163.4	12.0	38.2
	1T	End Pad Trans.	168.0	153.8	13.5	45.0
	1C	Center Pad Long.	170.0	158.0	8.5	23.1

(1) Heat Treatment:
Solution Treated 1750°F (1 hour) W.Q.
Aged 1000°F (4 hours) A.C.

APPENDIX

TMCA chemical analysis for the Ti-6Al-4V and IMI679 billet stock are given in Table 9. Mechanical properties for both alloys reported by TMCA are presented in Table 10.

Wyman-Gordon data on tensile properties for all three grain directions on Ti-6Al-4V and IMI679 billet stock are given in Tables 11 and 12. The billet material was four inches thick at time of heat treatment.

Longitudinal and transverse macrosections of IMI679 billet are shown in Figures 8, 9, and 10. Microstructures of IMI679 and Ti-6Al-4V billet material are presented in Figures 11 and 12.

Basic details related to production of the Ti-6Al-4V and IMI679 closed die forgings are presented in Tables 13 and 14.

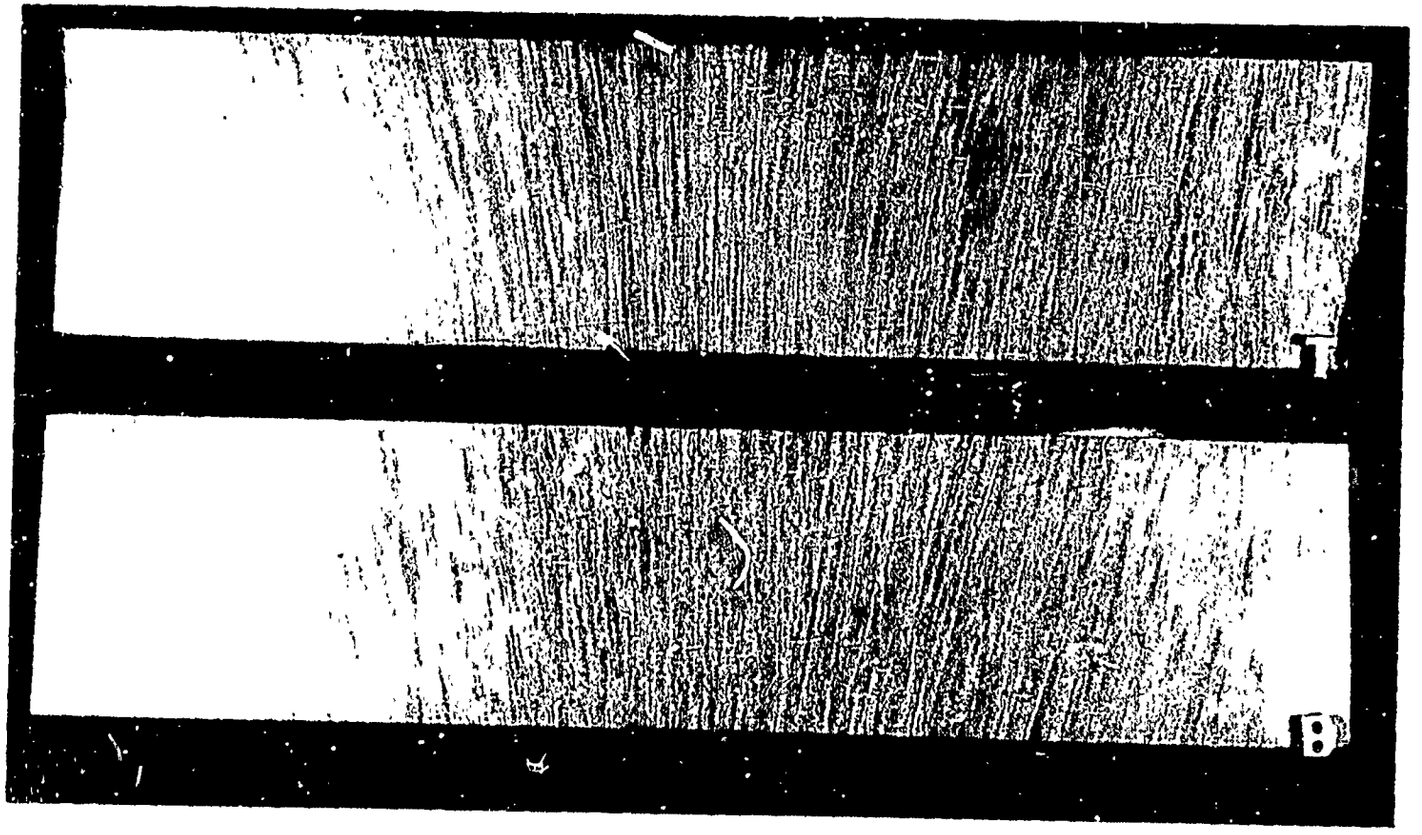


Figure 8. Macrosection of 7-Inch RCS Billet Stock IMI 679, Longitudinal Top (Upper) and Transverse Bottom (Lower)

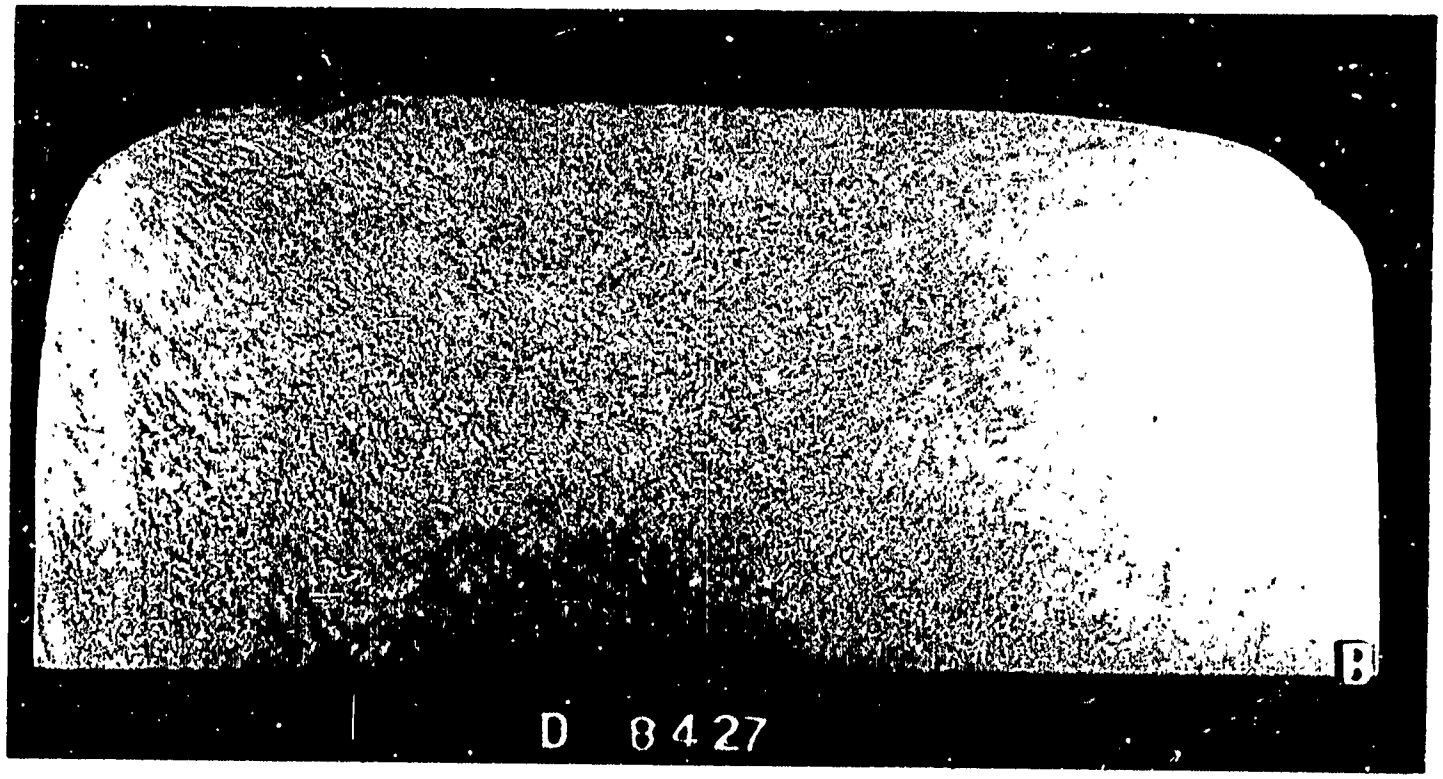


Figure 9. Macrosection of 7-Inch RCS Billet Stock IMI 679, Transverse - Bottom

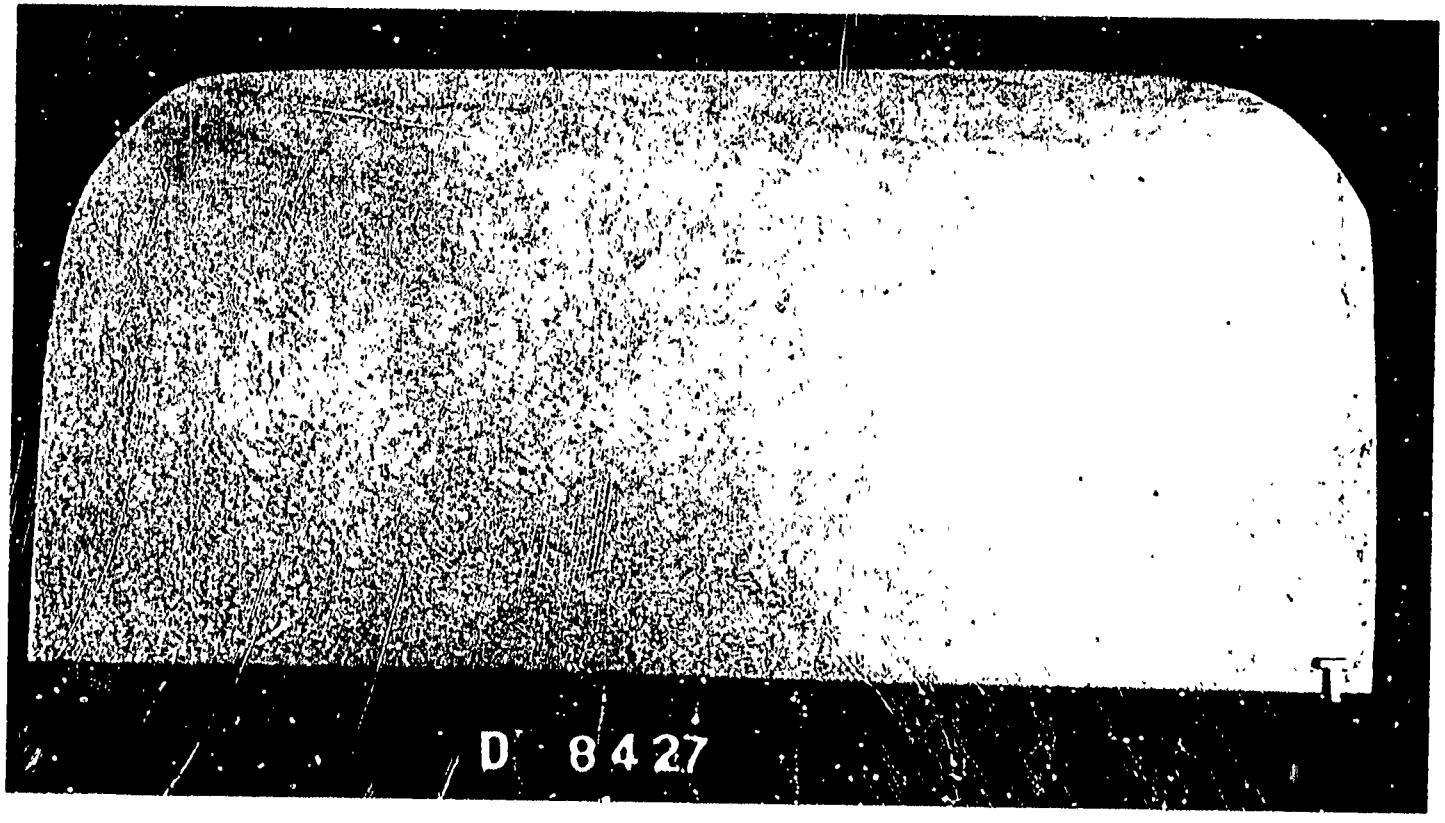


Figure 10. Macrosection of 7-Inch RCS Billet Stock IMI 679, Transverse - Top

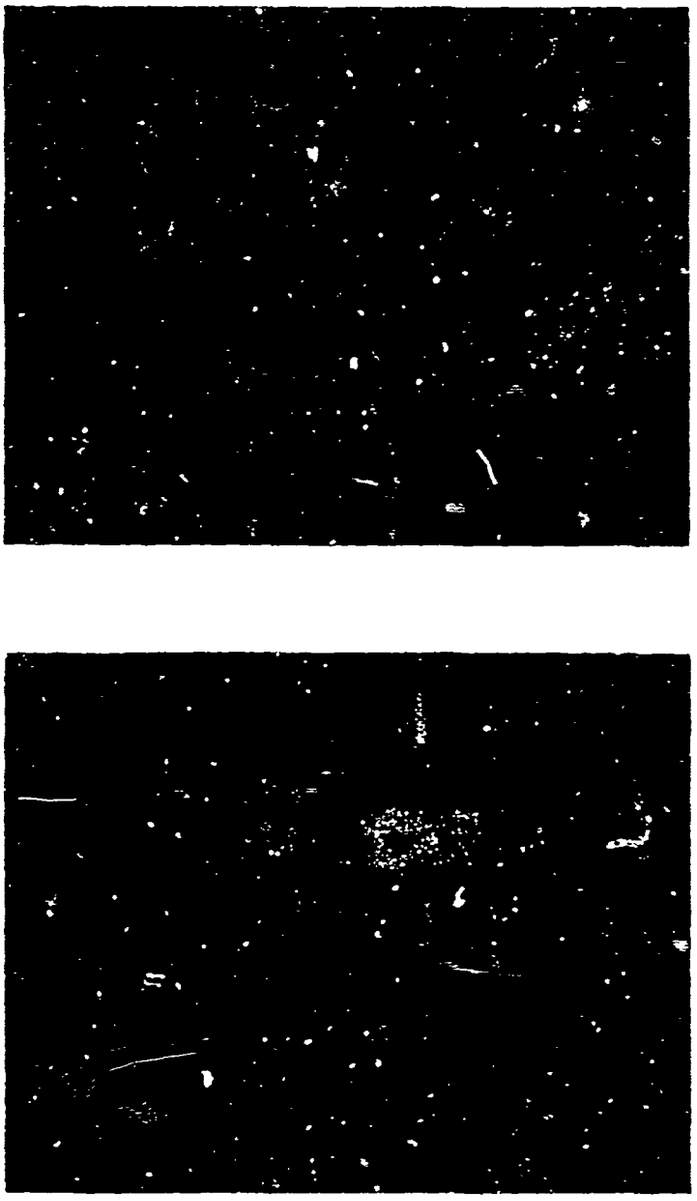


Figure 11. Microstructure of Heat Treated IMI-679 Billet Stock
(Longitudinal - Upper, Transverse - Lower)
Etchant: Benzal Stain 250X

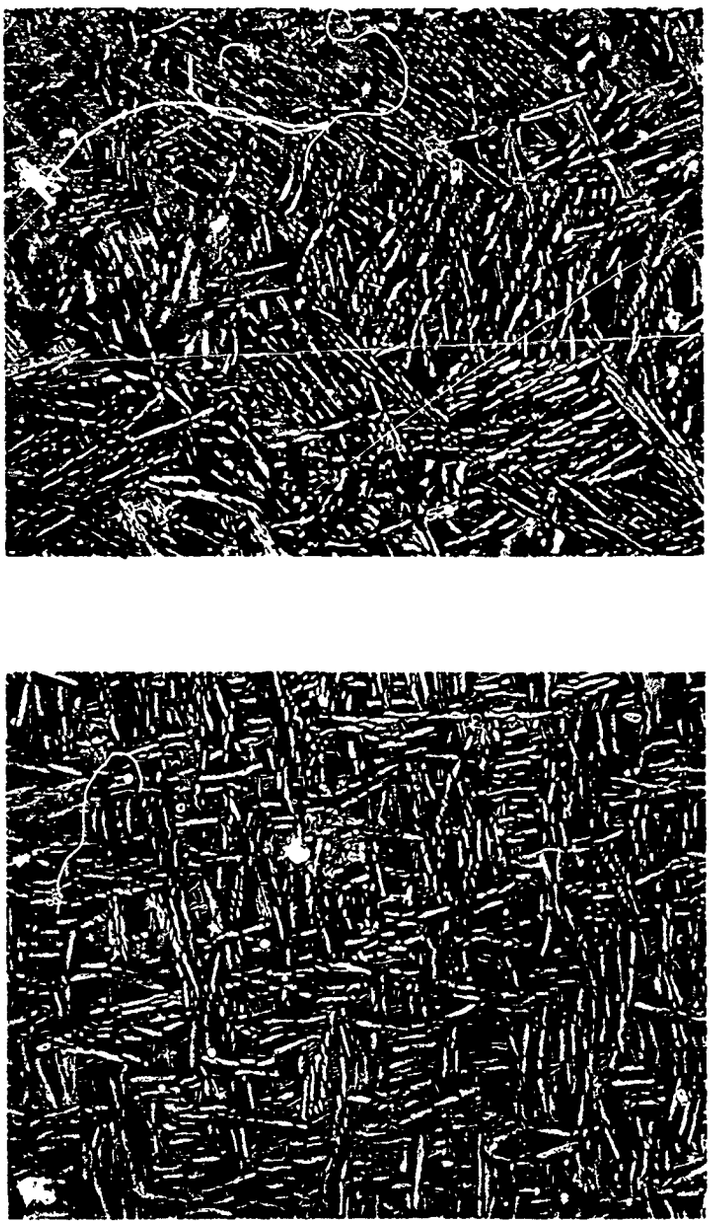


Figure 12. Microstructure of Heat Treated Ti-6Al-4V Billet Stock
(Longitudinal - Upper, Transverse - Lower)
Etchant: NAOH 100X

TABLE 9. TMCA CHEMICAL ANALYSIS

Alloy	Heat No.	C	Fe	N	Al	V	Mo	H	Zr	Sn	O_2	Si
Ti-6Al-4V	D-7976											
	T	.026	.12	.018	6.3	4.2		.007			.17	
	M	.022	.08	.018	6.3	4.1		.009			--	
	B	.022	.08	.022	6.3	4.0		.009			.20	
IMI-679	D-8427											
	T	.022	.08	.009	2.0		.9	.005	4.9	11.1	.11	.23
	M	.022	.05	.008	2.0		1.0		4.4	11.3		.24

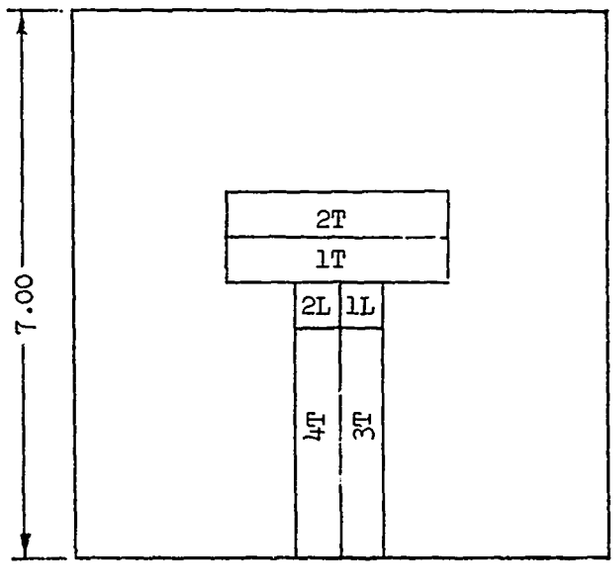
TABLE 10 TMCA MECHANICAL PROPERTIES

Alloy	Heat No.	Heat Treatment	Test No.	Tensile Strength ksi	Yield Strength ksi	Elong. % inch	R.A. %	Hardness Rc
Ti-6Al-4V	D-7976	Upset 2" to 3/4" at 1750°F Annealed 2 hrs. at 1300°F	(top)					
			Rad.	144.8	133.9	18.0	38.2	31.5
			Tang.	149.2	138.9	18.0	34.9	30.5
			(bottom)					
			Rad.	147.6	137.0	16.0	32.5	34.5
			Tang.	145.9	138.4	18.0	40.1	31.5
	D-7976	Solution Treated (1 hr. 1725°F W.Q.	(top)					
			Rad.	171.1	156.2	13.0	40.6	
			Tang.	168.3	158.1	14.0	39.3	
		Lab. Aged (3 hrs) 900°F	(bottom)					
			Rad.	167.5	157.0	13.0	31.7	
			Tang.	168.7	157.0	15.0	38.7	
IMI-679	D-8427	Upset 2" to 3/4" at 1650°F Solution Treated 1 hr. at 1650°F Aged 24 hours at 930°F	Rad.	152.6	133.9	19.0	44.9	
			Tang.	151.2	134.3	14.5	44.9	

TABLE 11. BILLET STOCK TENSILE TEST RESULTS
Ti-IMI 679 - TMCA HEAT D-8427(1)
(7 x 7 x 4 Billet)

Specimen Number	Ultimate Tensile Strength ksi	Yield Strength 0.2% ksi	Elong. % 1 in.	R.A. %
1L	144.0	125.6	13.5	35.7
1T	139.0	118.0	14.0	33.8
2L	140.0	121.8	15.0	38.2
2T	142.0	122.0	11.5	29.9
3T	152.0	134.0	15.0	31.1
4T	150.0	133.8	10.0	29.9

(1) Heat Treatment:
Solution Treated 1650°F (1 hour) Fan Cool
Aged 930°F (24 hours) Air Cool

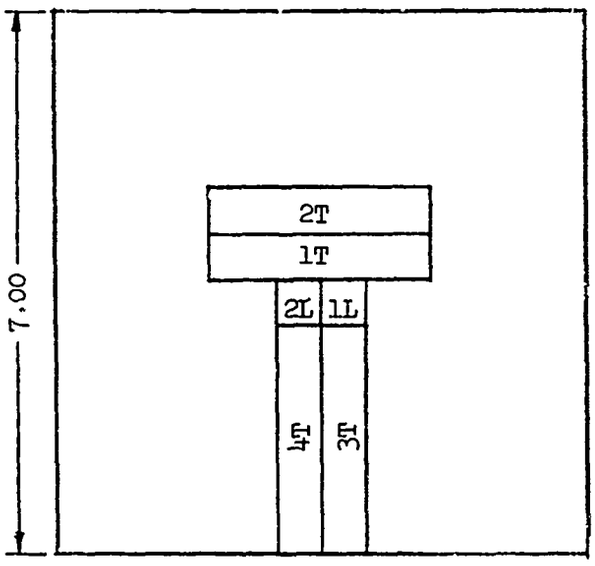


Test Locations

TABLE 12. BILLET STOCK TENSILE TEST RESULTS
Ti-6Al-4V TMCA HEAT D-7976 (1)
(7 x 7 x 4 Billet)

Specimen Number	Ultimate Tensile Strength ksi	Yield Strength 0.2% ksi	Elong. % 1 in.	R.A. %
1L	143.0	127.0	13.0	32.7
2L	137.6	114.0	14.5	33.8
1T	143.4	128.4	12.5	26.6
2T	140.0	128.8	15.0	28.3
3T	150.0	132.0	10.0	21.7
4T	148.0	129.2	10.0	25.1

(1) Heat Treatment:
Solution Treated 1750°F (1 hour) W.Q.
Aged 1000 F (4 hours) A.C.



Test Locations

TABLE 13. Ti-6Al-4V FORGING PROCESS DATA

Forging Number	Cut Weight lbs.	Forge Operations	Press Equipment tons	Heat Cycle hrs.	Furnace Temp. °F	Temperature of Forging, °F		
						Out Furnace	On Dies	Off Dies
GWN-11	106	Draw	1,500	6	1800	1725	1665	1450
GWN-12	106-1/2					1720	1650	1450
GWN-13	107					1725	1665	1450
GWN-14	108					1725	1660	1450
GWN-11	---	Bend	600	2-1/2	1800	1730	1670	1500
GWN-12	---					1725	1665	1540
GWN-13	---					1730	1670	1500
GWN-14	---					1740	1680	1500
GWN-11	---	1st Finish	18,000	2-1/2	1775	1735	1665	----
GWN-12	---					1725	1660	----
GWN-13	---					1720	1600	----
GWN-14	---					1725	1670	----
GWN-11	---	2nd Finish	18,000	1/2	1775	1725	1660	----
GWN-12	---					1730	1660	----
GWN-13	---					1725	1670	----
GWN-14	---					1720	1670	----

All cooling was in air

TABLE 14. Ti IMI 679 FORGING PROCESS DATA

Forging Number	Cut Weight lbs.	Forge Operation	Press Equipment tons	Heat Cycle hrs.	Furnace Temp. °F	Temperature of Forging, °F		
						Out Furnace	On Dies	Off Dies
HJU-1	108	Draw	1,500	5	1675	1600	1550	1450
HJU-2	109			5		1610	1540	
HJU-3	109			7-1/2		1600	1530	
HJU-4	111			7-1/2		1620	1550	
HJU-1	---	Bend	600	3	1675	1630	1555	1500
HJU-2	---					1620	1540	1485
HJU-3	---					1625	1535	1495
HJU-4	---					1630	1550	1500
HJU-1	---	1st Finish	18,000	2-1/2	1675	1560	1470	1400
HJU-2	---					1580	1490	
HJU-3	---					1580	1500	
HJU-4	---					1560	1470	
HJU-1	---	2nd Finish	35,000	2-1/2	1675	1610	1545	---
HJU-2	---					1620	1555	---
HJU-3	---					1610	1550	---
HJU-4						1615	1545	---

All cooling was in air