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Tensile Properties of Cast Titanium Alloys

Titanium-6Al-4V *ELI and Titanium*-5Al-2.5Sn *ELI*

E. E. Billinghurst, Jr.
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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TECHNICAL PAPER

TENSILE PROPERTIES OF CAST TITANIUM ALLOYS (TITANIUM-6AL-4V ELI AND TITANIUM-5AL-2.5SN ELI)

INTRODUCTION/BACKGROUND

The liquid hydrogen turbopump for the space transportation main engine (STME) is under development. The turbopump impeller is proposed to be cast from titanium alloys in order to lower the cost and improve reliability. To help with the alloy selection, it was necessary to obtain reliable mechanical property data for the two candidate titanium alloys—Ti-6Al-4V ELI and Ti-5Al-2.5Sn ELI. Because available data for these alloys were from different sources, a fair comparison of properties could not be made. It is important to keep the process variables—such as casting source, casting size, hot isostatic pressing (HIP'ing), annealing, etc.—constant. Therefore, Marshall Space Flight Center (MSFC) Materials and Processes Laboratory conducted a test program to determine the tensile properties of cast Ti-6Al-4V and Ti-5Al-2.5Sn alloys in-house. Process variables were kept constant to minimize variability. This report describes the test procedure, then presents and discusses the results.

MATERIALS/PROCESSING

Ti-6Al-4V ELI and Ti-5Al-2.5Sn ELI alloys were cast—in 4-in diameter by 20-in long ingots in 1-in thick machined carbon molds—by the Duriron Company, Inc., Dayton, OH. The material was heated to 200 °F above the melting temperature and held for 15 min after all visible solids had melted. The cast ingots were HIP'ed at 1,650 °F, 15 ksi pressure, for 2 h; then annealed at 1,350 °F for 2 h. Photographs of the ingots are shown in figure 1. The microstructures were obtained from samples taken from several places—from the center to the outside of the ingot. These pictures of the structure are included as figures 2, 3, 4, and 5. The grain size was determined to be ASTM No. 1. The chemical compositions of the extra low interstitial grade titanium alloys were certified by the supplier and verified on the material adjacent to the tensile test specimens. Duriron's certification and MSFC's analytic results are summarized in table 1.

TEST PROCEDURE

Eight bars (0.505-in diameter by 5.0-in long) were electrical discharge machined (EDM'ed) from each ingot. The drawing of the EDM cutting template is shown in figure 6. The bars were machined into tensile specimens (fig. 7). The surface finish of the specimens was examined and visually compared to a standard, and was determined to be acceptable. Three samples from each ingot were tensile tested in air at ambient temperature (70 °F). Five samples from each ingot were tensile tested in liquid hydrogen at –423 °F. The tensile test data are reported in table 2 and summarized in table 3.

RESULTS/DISCUSSION

As expected, the Ti-6Al-4V ELI alloy has higher strength, but lower ductility, than the Ti-5Al-2.5Sn ELI alloy (table 3). The Ti-6Al-4V is 19.0-percent stronger at 70 °F and 19.7-percent stronger at –423 °F. Percentage of elongation was not used in the analysis because the samples frequently broke at or outside the gauge marks; hence, the numbers were not reliable. For this reason, the reduction of area was used as a measure of ductility, and the results are summarized in table 4. As expected, the Ti-5Al-2.5Sn has higher ductility than the Ti-6Al-4V at both test temperatures (61.8 percent at 70 °F and 34.5 percent at –423 °F). The present work does not support the reported extremely low ductility of Ti-6Al-4V ELI in the literature. As expected, both alloys are stronger and their ductilities are lower at cryogenic temperature (–423 °F) than at room temperature (70 °F).

It appears that either alloy could be used as an investment cast impeller for the STME fuel turbopump. The lower ductility of Ti-6Al-4V reported here is considered acceptable for the intended application. Because of its higher strength, Ti-6Al-4V alloy should be a preferred material choice for the impeller. This recommendation, however, does not take into account the possible differences in castability of the two alloys. Furthermore, minimum web thickness requirements of the investment casting process might render the strength difference of no consequence. It is suggested that castability of both alloys be investigated before the final selection is made.

CONCLUSION

Either Ti-6Al-4V ELI or Ti-5Al-2.5Sn ELI alloy has adequate strength/ductility for use for the STME fuel turbopump impeller application; however, Ti-6Al-4V ELI does have an edge over Ti-5Al-2.5Sn ELI in tensile strength.

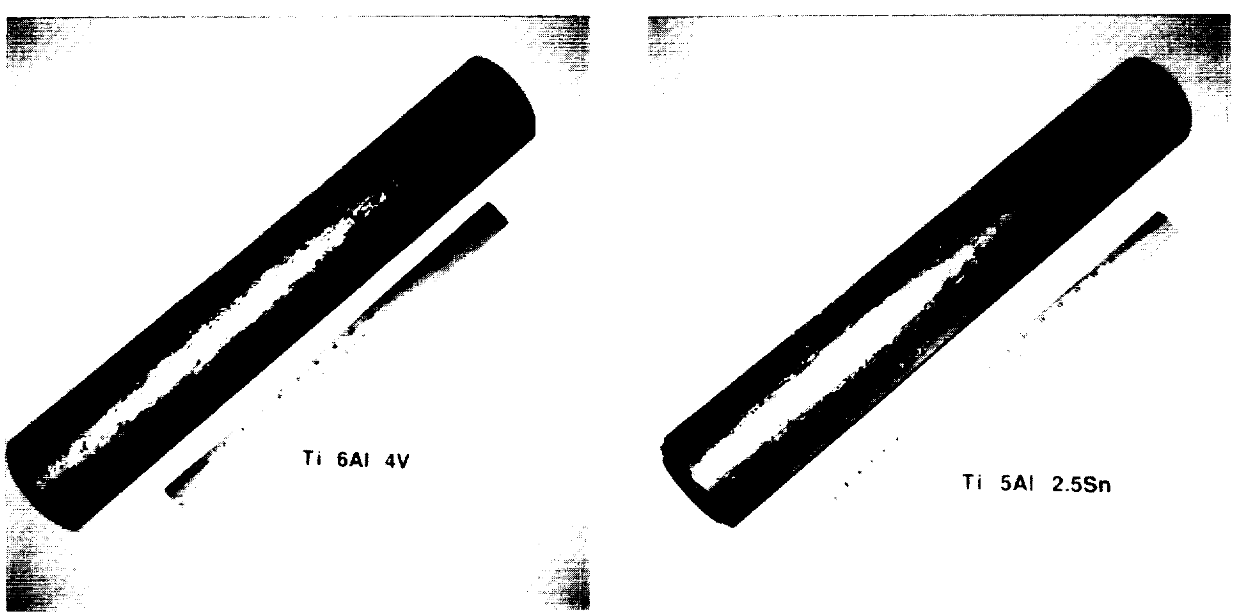

Figure 1. Cast, hot isostatic pressed (HIP'ed), annealed ingots.

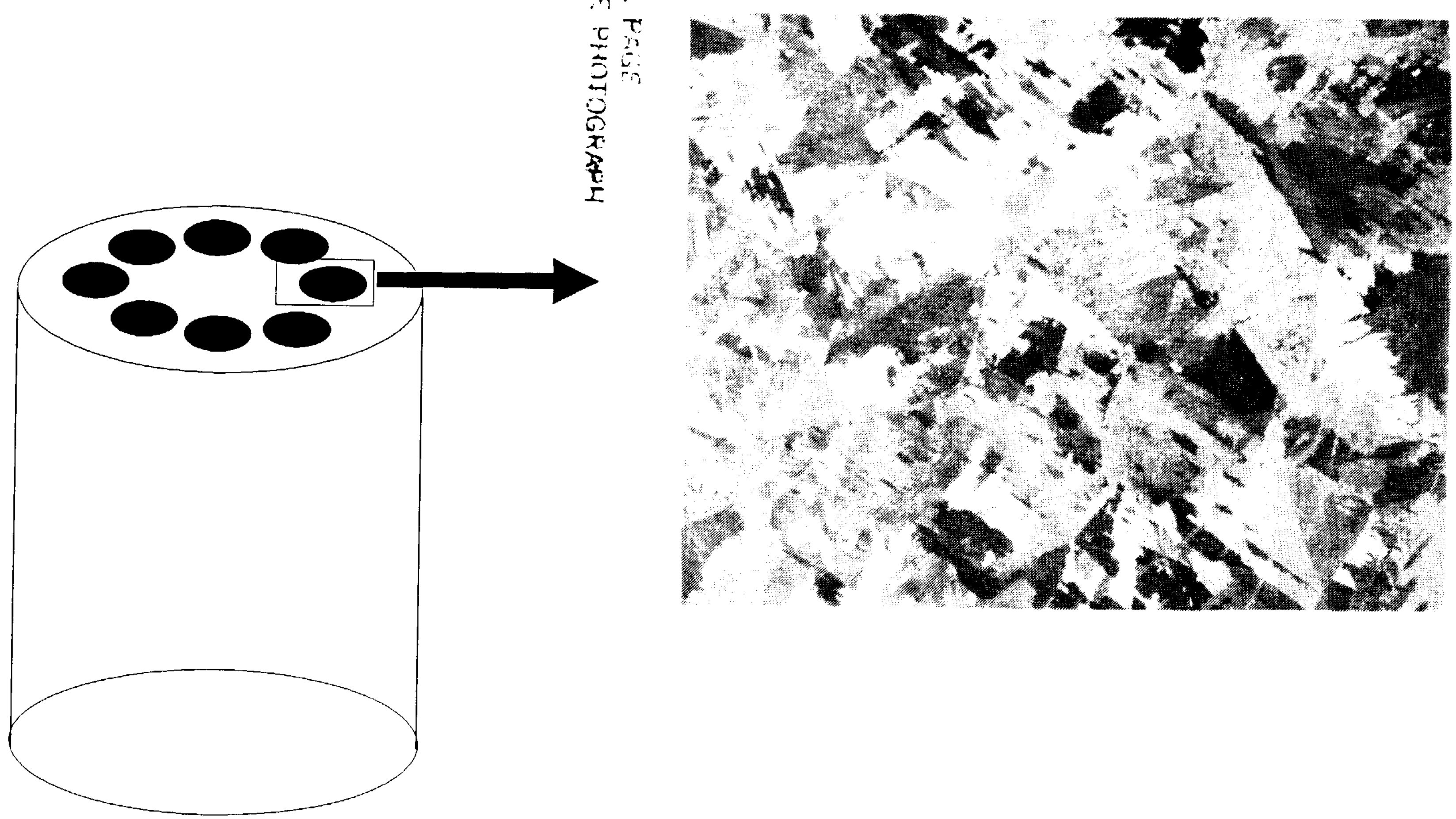

Figure 2. Photomacrograph of as-cast Ti-6Al-4V ELI taken from areas of the casting where tensile samples were removed (× 10, Kallings etch)

50X

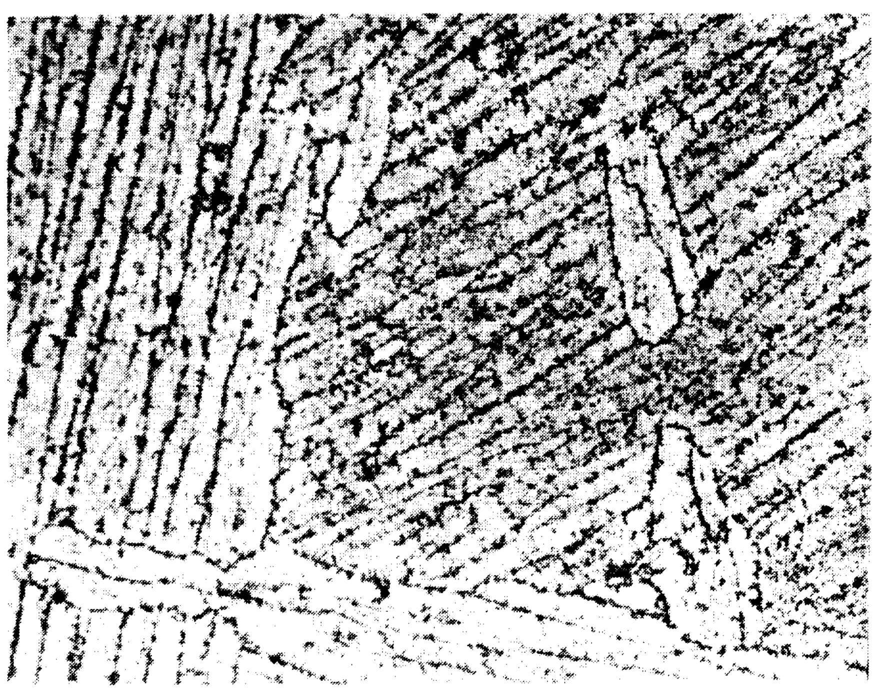

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Figure 3. Photomicrographs of as-cast Ti-5Al-2.5Sn ELI ($\times$ 50 and $\times$ 400, Kallings etch).

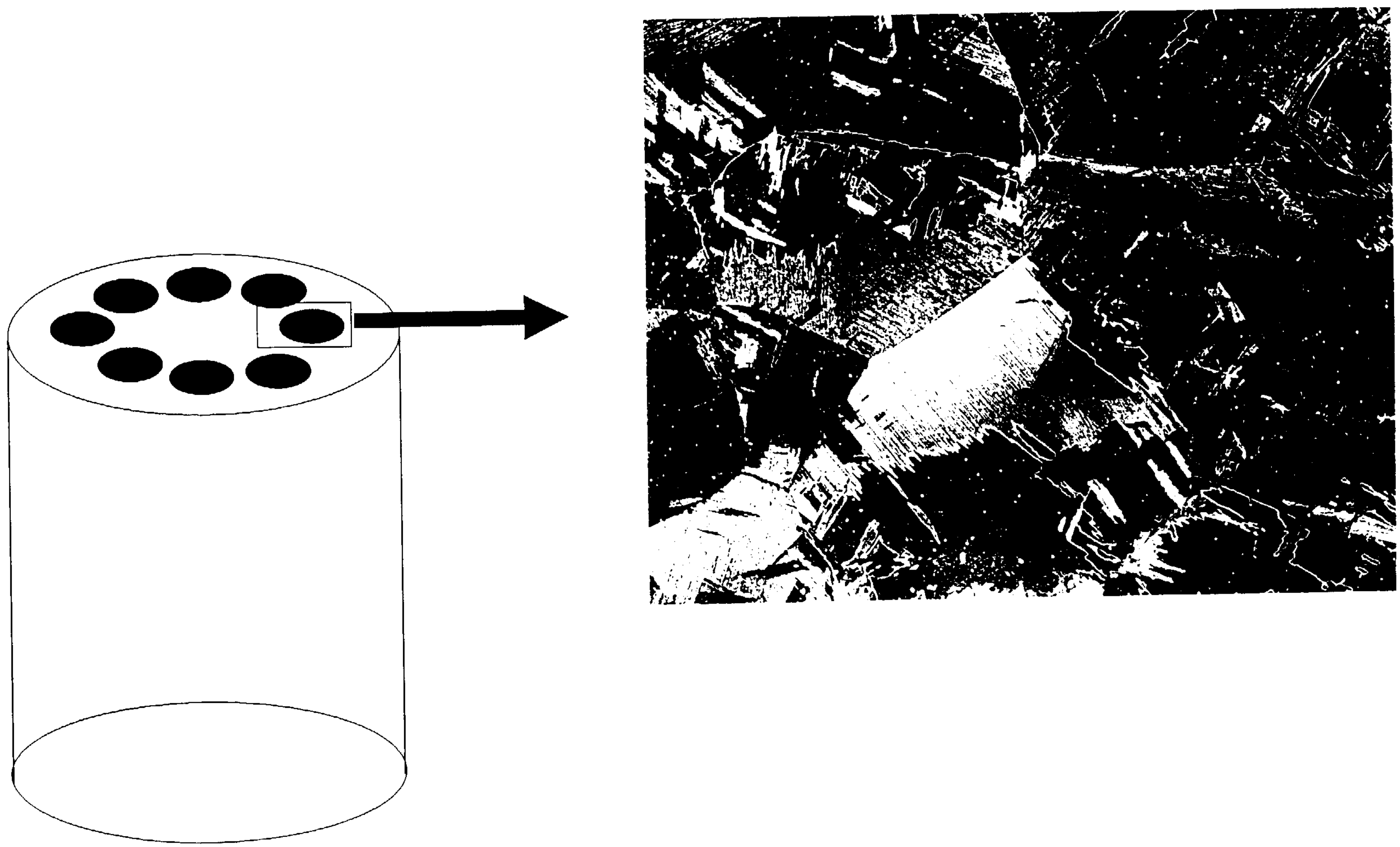
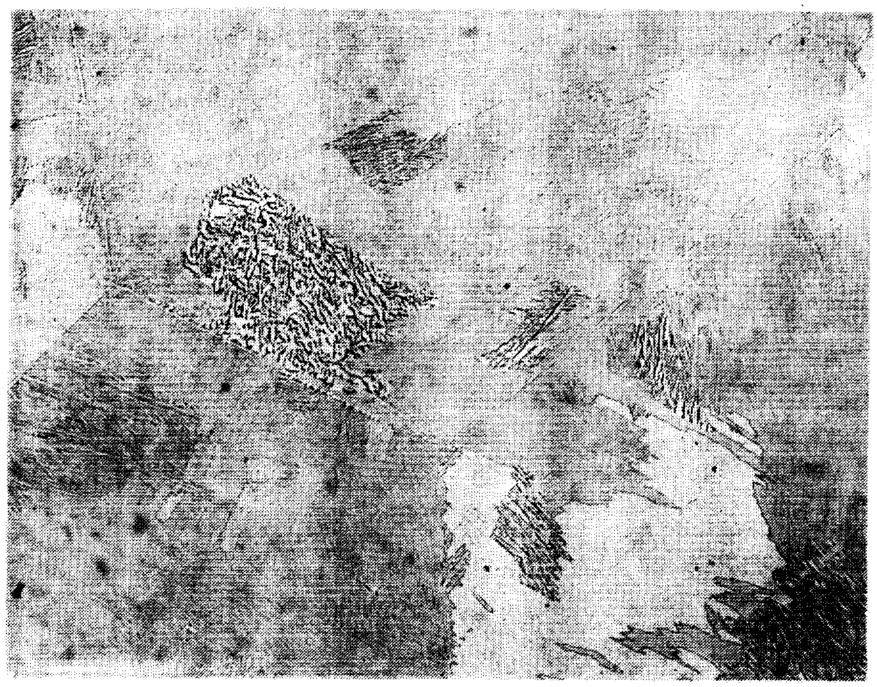


Figure 4. Photomacrograph of as-cast Ti-5Al-2.5Sn ELI taken from areas of the casting where tensile samples were removed (× 10, Kroll's etch).



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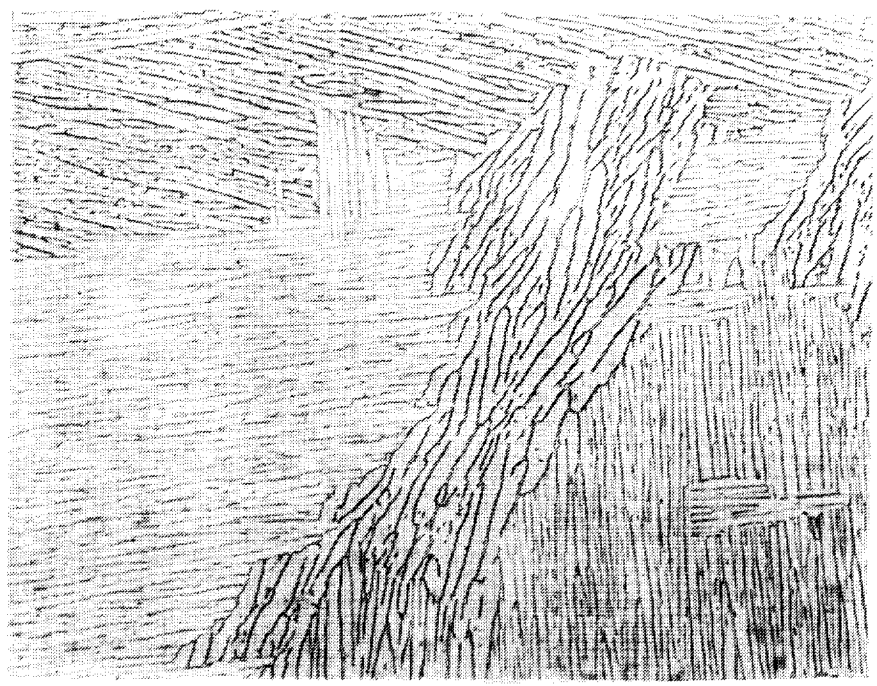

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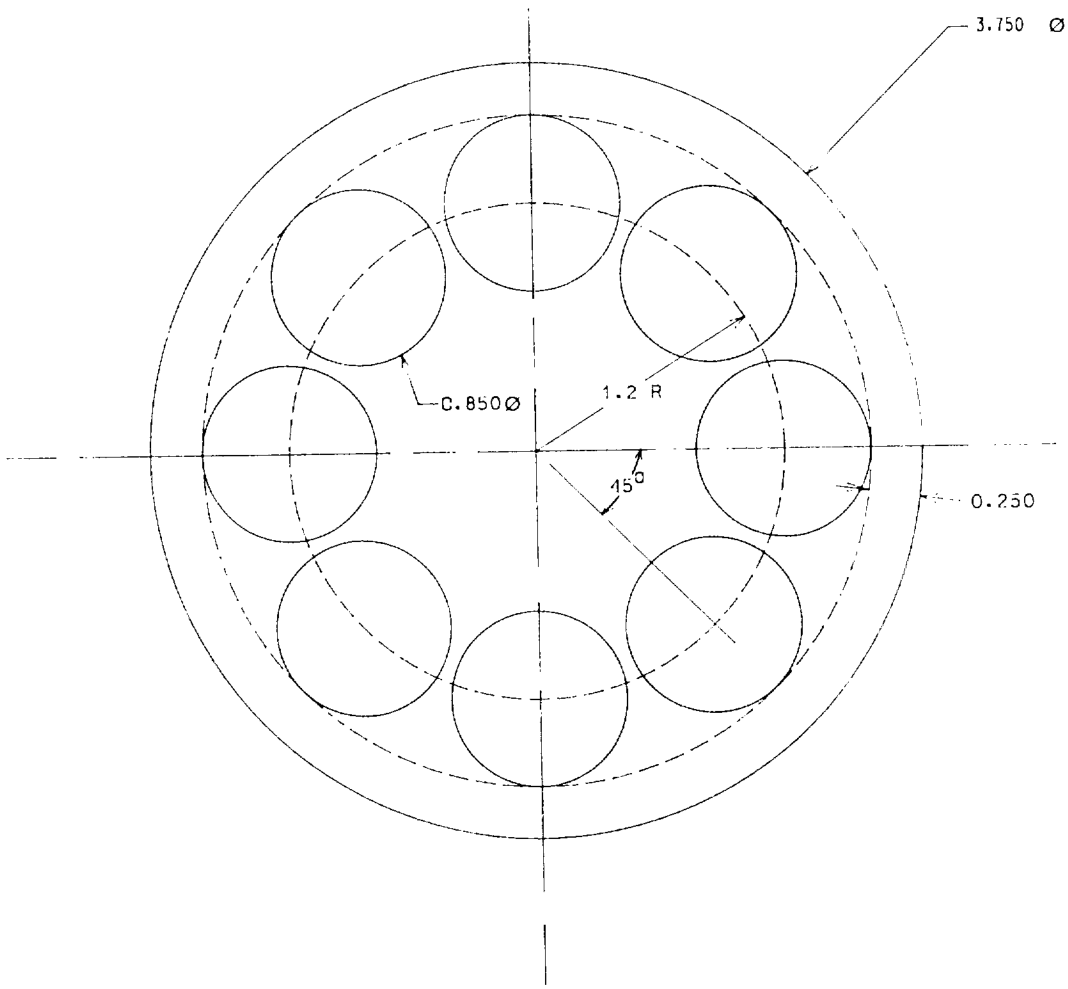
Figure 5. Photomicrographs of as-cast Ti-6Al-4V ELI (× 50 and × 400, Kallings etch).

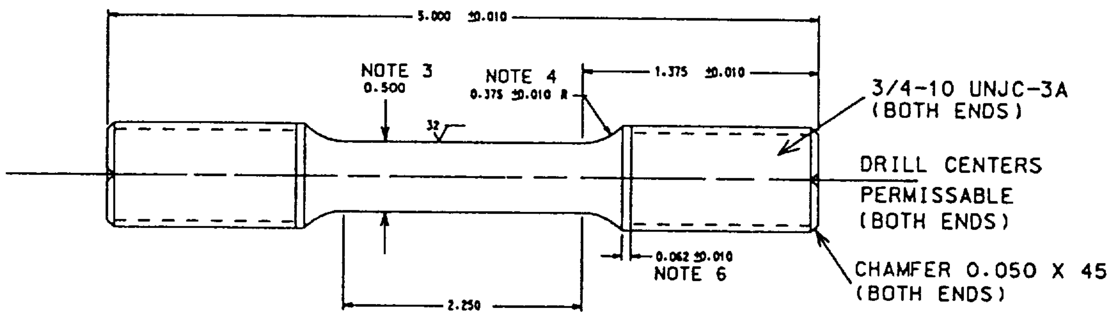


1. ALL DIMENSIONS IN INCHES
2. NOT TO SCALE, WORK TO DIMENSIONS GIVEN

REV. DATE: 10/30/90	DRAWN: RKJ	EDM CUTTING TEMPLATE FOR .505 BARS
REV. DATE:	INSPECTED: SJM	
REV. DATE:	APPROVED: EJV	DRAWING NO. MRF-126

Figure 6. Drawing No. MRF-126, EDM cutting template for 0.505 bars.

FROM ASTM E 8



1. NOT TO SCALE, WORK TO DIMENSIONS GIVEN
2. ALL DIMENSIONS IN INCHES
3. SLIGHT TAPER TO CENTER REQUIRED (0.005 MAX)
4. DO NOT UNDERCUT RADII
5. UNSPECIFIED TOLERANCES ± 0.005
6. THREADS ARE NOT TO EXTEND TO RADIUS

REV. DATE: 11/8/90	DRAWN: RKJ	STANDARD .505 SMOOTH TENSILE SPECIMEN
REV. DATE:	INSPECTED: SJM	
REV. DATE:	APPROVED: EJV	DRAWING NO. MRF-1030

Figure 7. Drawing No. MRF-1030, standard 0.505 smooth tensile specimen.

Table 1. Summary of cast ELI grade analytic results.

	Composition					
	Ti-6Al-4V ELI			Ti-5Al-2.5Sn ELI		
	Specification Percentage	Duriron Cert.	MSFC Anal.	Specification Percentage	Duriron Cert.	MSFC Anal.
Ti	REM	89.54	91.24	REM	92.00	93.27
Al	5.5–6.75	6.20	5.28	4.5–5.1	5.04	4.59
V	3.5–4.5	4.09	3.27	—	—	0.08
Sn	—	—	0.03	1.9–2.5	2.50	1.96
C	0.08 max.	0.013	0.015	0.05 max.	0.017	0.01221
	0.05 max.	0.0148	0.00073	0.05 max.	0.0122	0.00043
H	0.015 max.	0.0059	0.00593	0.015 max.	0.045	0.003586
O	0.13 max.	0.151	0.0093	0.10 max.	0.077	0.0161
Fe	0.25 max.	—	0.15	0.25 max.	—	0.01

Table 2. Tensile properties of cast ELI grade titanium alloys.

Sample I.D.	Material	Media	Test Temp. (°F)	UTS (ksi)	YS (ksi)	Percent RA	Percent EL 1 in	Percent EL 2 in
2332	Ti-5Al-2.5Sn	Air	70	107.5	99.4	22.7	15.4	10.4
2333	Ti-5Al-2.5Sn	Air	70	108.0	100.0	24.4	5.5	9.1*
2334	Ti-5Al-2.5Sn	Air	70	108.9	101.3	26.7	6.7	7.5*
			Averages:	108.5	100.2	24.6	9.2	9.0
2335	Ti-5Al-2.5Sn	LH_2	–423	186.9	NA	13.6	10.0	6.3
2336	Ti-5Al-2.5Sn	LH_2	–423	187.7	NA	10.7	7.4	7.1*
2337	Ti-5Al-2.5Sn	LH_2	–423	188.5	NA	12.1	7.0	7.3*
2338	Ti-5Al-2.5Sn	LH_2	–423	174.8	NA	12.6	2.5	4.1*
2331	Ti-5Al-2.5Sn	LH_2	–423	187.1	156.9	9.5	10.9	7.0
			Averages:	185.0		11.7	7.6	6.4
2344	Ti-6Al-4V	Air	70	128.8	118.4	12.9	10.5	7.5
2345	Ti-6Al-4V	Air	70	130.0	119.6	14.3	9.4	7.4
2346	Ti-6Al-4V	Air	70	128.4	117.8	18.5	12.5	8.5
			Averages:	129.1	118.6	15.2	17.4	7.8
2339	Ti-6Al-4V	LH_2	–423	214.1	NA	10.7	2.8	2.8*
2340	Ti-6Al-4V	LH_2	–423	219.1	NA	8.2	4.4	3.4
2341	Ti-6Al-4V	LH_2	–423	211.3	NA	8.2	5.5	2.9
2342	Ti-6Al-4V	LH_2	–423	203.0	NA	11.6	7.3	4.0
2343	Ti-6Al-4V	LH_2	–423	213.4	199.0	4.9	8.1	3.3
			Averages:	212.2		8.7	5.6	3.3

*Sample broke outside of 1-in gauge marks.

Table 3. Summary of test results/average of tensile mechanical properties.

Material	Test Temp.	UTS (ksi)	YS (ksi)	Percent RA	Percent EL 1 in	Percent EL 2 in	No. of Samples
Ti-6Al-4V ELI	70 °F	129.1	118.6	15.2	17.4	7.8	3
Ti-5Al-2.5Sn ELI	70 °F	108.5	100.2	24.6	9.2	9.0*	3
Ti-6Al-4V ELI	–423 °F	212.2	199.0†	8.7	5.6	3.3	5
Ti-5Al-2.5Sn ELI	–423 °F	185.0	156.9†	11.7	7.6	6.4*	5

*Samples broke outside 1-in gauge marks.
†YS value for one sample only.

Table 4. Ultimate tensile strength (ksi)/percent reduction in area.

Alloy	Ultimate Tensile Strength (ksi) Tested in Air (70 °F)	Ultimate Tensile Strength (ksi) Tested in LH_2 (–423 °F)	Percent Reduction of Area Tested in Air (70 °F)	Percent Reduction of Area Tested in LH_2 (–423 °F)
Ti-5Al-2.5Sn ELI	108.4	185.0	24.6	11.7
Ti-6Al-4V ELI	129.1	212.2	15.2	8.7

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13. ABSTRACT *(Maximum 200 words)*

This work was performed to determine the tensile properties of cast, hot isostatic pressed (HIP'ed), and annealed titanium alloys, Ti-6A1-4V ELI and Ti-5A1-2.5Sn ELI, that are candidate materials for the space transportation main engine (STME) liquid hydrogen turbopump impeller. Samples of the cast alloys were HIP'ed, annealed, and machined into tensile specimens. The specimens were tested in air at ambient temperature (70 °F) and also at –423 °F in liquid hydrogen. The Ti-6A1-4V alloy had an average ultimate strength of 129.1 ksi at 70 °F and 212.2 ksi at –423 °F. The Ti-5A1-2.5Sn alloy had an average ultimate strength of 108.4 ksi at 70 °F and 185.0 ksi at –423 °F. The ductility, as measured by reduction of area, for the Ti-6A1-4V averaged 15.2 percent at 70 °F and 8.7 percent at –423 °F, whereas for the Ti-5A1-2.5Sn alloy average reduction of area was 24.6 percent at 70 °F and 11.7 percent at –423 °F.

14. SUBJECT TERMS
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