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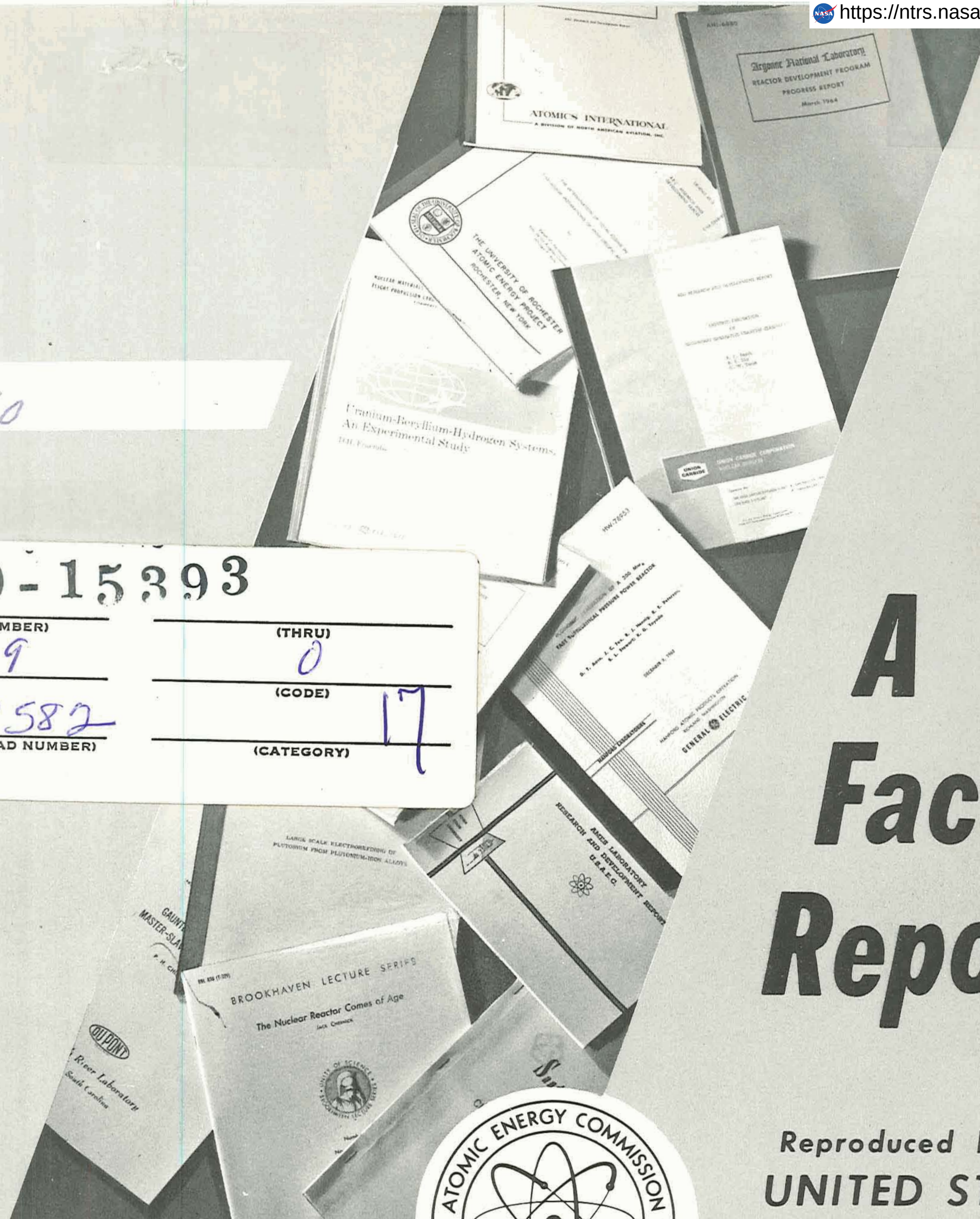

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Astronuclear Laboratory

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TENSILE PROPERTIES OF IRRADIATED Ti-5% Al-2.5%Sn ELI AT CRYOGENIC TEMPERATURES

UNCLASSIFIED NERVA RESEARCH AND DEVELOPMENT REPORT.

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I. ABSTRACT

Tensile specimens of Titanium-5% Aluminum-2.5% Tin ELI (Extra Low Interstitial) alloy were irradiated at the Ground Test Reactor in test GTR-19 to fluences of 5.6 to 11×10^{17} n/cm^2 (E > 1 Mev). The irradiation temperature was 140°R. Ultimate and yield strengths increased slightly while the notched strength was unaffected. At 140°R the percent elongation of specimens from a forging was significantly, though not seriously, reduced. Sheet specimens showed slight reductions in elongation, while that of the welded sheet specimens increased. About 60% of the radiation damage effect is "annealed out" at room temperature. Most of this recovery occurs within one hour. Complete annealing occurred after one hour at 1000°R.

II. INTRODUCTION

Ti-5% Al-2.5% Sn ELI is a medium strength alpha titanium alloy. The ELI grade shows good toughness and strength at cryogenic temperatures. In the NERVA reactor designs, the alloy is used as a major structural component in the core and reactor support rings, tie bolts and control drum ganged drive mechanism. These applications involve the use of bar, sheet and forged material. Maximum expected fluences range to 5×10^{18} n/cm^2 (E > 1 Mev) at temperatures from 100°R to room temperature.

Previous testing (GTR-16, WANL-TME-1281, "Cryogenic Radiation Effects in NERVA Structural Materials) had shown that bar material specimens had been significantly affected by radiation. At 140°R and 6×10^{17} n/cm^2 (E > 1 Mev) average tensile elongation values were reduced from 16.3% to 4.6%. The purpose of this experiment was to obtain mechanical property data on forging and sheet specimens to higher neutron fluences. It was expected that these forms of the alloy would show similar responses to radiation.

This test was part of WANL materials irradiation test No. 37/W405. The test specification was WANL-TME-1530 ("Final Test Specification Structural Materials Test No. 37/W405"). Data was reported to WANL by the testing agency (General Dynamics/Fort Worth Division) in FZK-342 (Vol. 1 and 2).

III CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this irradiation and previous testing in GTR-16 (WANL-TME-1281) the following conclusions and recommendations can be made:

(1) Plain and notched tensile strength properties of forged and sheet Ti-5% Al-2.5% Sn ELI were only slightly increased or unaffected by neutron fluences up to 10^{18} n/cm^2 temperatures between 140°R and 540°R.

(2) The effects of irradiation on the ductility of the alloy appears to depend on the form tested.

(3) Tensile elongation of sheet material was only slightly reduced by 8×10^{17} n/cm^2 (E > 1 Mev) at temperatures as low as 140°R. Above 100°R, the ductility of sheet should not be significantly degraded by neutron fluences at levels possible outside the core in NERVA reactors.

(4) Ductility of unannealed welds at cryogenic temperatures should be increased by irradiation at expected fluences.

(5) Tensile elongation of forged material was significantly, though not seriously, reduced at 140°R after fluences of 1.1×10^{18} n/cm^2 (E > 1 Mev). Applications of this form of the alloy above 100°R outside of the core should not be affected by expected fluence levels.

(6) Specimens of bar material irradiated to 6×10^{17} n/cm^2 (E > 1 Mev) in GTR-16 showed an average elongation of 4.6% at 140°R. Based on these data, brittle design criteria would be required below 230°R for this fluence level.

(7) Additional irradiations of Ti-5% Al-2.5% Sn bar material are recommended to fluences of at least those expected in future NERVA reactors to more accurately determine the temperature limitation for brittle design. Irradiation of additional forging and sheet material is also recommended to verify the variation in radiation effects with form of the material.

IV EXPERIMENTAL PROCEDURES

Material

Two forms of the material were tested. Round bar specimens were machined from forged core support ring test sections supplied by the Ladish Company. These rings were approximately 1" thick, 2.5" wide and 42" in diameter. Sheet and welded sheet specimens were machined from 0.125" sheet bought from Titanium Metals Corporation (heat number D-4203). Both materials were annealed at 1500°F for one hour by the suppliers. Welded specimens were taken from 5" by 6" blanks of the same sheet which had been TIG welded from two butted 2.5" by 6" pieces without filler metal. A weld pass was made along both sides of the blanks. The weld zone was at the center of the specimen gage section. The welded blanks were radiographically inspected. Welded specimens were not annealed.

Table 1 shows the chemical compositions of the materials. The forging was bought to and complied with all of the requirements of WANL PDS-30028-1-D and the sheet to WANL PDS-30067. Both specifications have the same chemistry requirements.

The long axis of the sheet specimens was in the longitudinal or rolling direction. The axis of the round bar specimens was tangential to the ring circumference. Unirradiated (control) specimens were taken from the same stock as those irradiated. Typical micrographs of the forging, sheet and weld zone material are shown in Figure 1. Average grain size of the forging was ASTM No. 7 and of the sheet ASTM No. 8.

Test Specimens

Test specimen designs are shown in Figures 2 and 3. Sheet specimen thickness was 0.080" with the specimen taken from the center of the sheet thickness. Pin-loaded sheet specimens were used to permit easier loading into the tensile grips. This procedure had to be performed under liquid nitrogen for the irradiated samples.

The round bar specimen was not a standard ASTM design. Because of material available, reactor dewar space and previous test specimen design, a long, thin specimen was chosen. Table 2 shows a comparison between ASTM standard 4D specimen data on this material and the control values from GTR-19. These results indicate that the specimen design had no effect on the results of the experiment.

Radiation Environment

Specimens were irradiated at the Ground Test Reactor at Fort Worth, Texas, by General Dynamics in accordance with WANL specifications. Specimens were immersed in liquid nitrogen (LN_2) during the irradiation. Calculations indicate that the material temperature was that of the bath (140°R) during the irradiation.

Specimen dosimetry was determined by a mapping run prior to the full irradiation. Dosimetry included bare and cadmium-covered copper foil, indium foil, sulfur pellets and aluminum foil. Further details can be found in FZK-342, Vol. 1.

Neutron fluences ranged from 3.1×10^{16} to 2.8×10^{17} n/cm^2, $E < 0.48$ ev and 5.6×10^{17} to 1.1×10^{18} n/cm^2, $E > 1$ Mev. Average gamma dose was 8×10^{11} ergs/gm(C). The reactor operated for 3380 Mw-hr. at a maximum power of 10 MW.

Equipment and Test Procedures

Figure 4 shows an overall view of the testing equipment and instrumentation. A Model TT-D split-console-type Instron machine was used for the tensile testing. Inconel 718 was used for the grips and pull rods for testing both specimen types. The round bar specimens were shoulder loaded. A small insert was placed in the specimen loading opening in each grip before seating of the specimen to give full circumferential loading.

High-temperature-annealed specimens for each data group were annealed together in argon after irradiation. Thermocouples were included in each specimen bundle to regulate annealing temperatures.

A lightweight polystyrene foam cryostat (Figure 5) attached to the bottom pull rod was used for the cryogenic tests. It was approximately 12" wide, 18" long and 12" deep. For the 140 R tests, a specimen was transferred from the irradiation dewar in a jar of liquid nitrogen (LN_2) to the LN_2 filled cryostat. It was then loaded into the grips and the test completed entirely under LN_2. For the 340°R tests the specimen was loaded in the same manner, then the cryostat was drained of LN_2. When the specimen reached approximately

340°R, as determined by a calibrated thermocouple on the grip, its temperature was controlled with regulated blasts of LN_2 from a perforated, double-walled manifold. A similar procedure was followed for the 340°R annealed specimens except the cryostat was refilled with LN_2 before testing. Test and anneal temperatures were controlled within ±5°R using this method. Further details can be found in AEC-NASA Tech Brief 67-10617. For the room temperature tests, specimens were heated from 140°R to room temperature (~540°R) in acetone for several minutes. Both the 340°R and 540°R test specimens were held at temperatures for 10 minutes before testing began.

Tests were run with a constant 0.1 in./min. Instron crosshead speed throughout for all types of specimens. This corresponds to an initial strain rate of 0.067 $min.^{-1}$ for the sheet specimens and 0.057 $min.^{-1}$ for the bar specimens.

Ultimate tensile strength, 0.2% offset yield strength and notched tensile strength were obtained from the Instron charts. Elongation data reported is total elongation obtained from bench measurements between scribe marks on the gage sections of the specimens. Original distance between the gage marks was nominally 1.56 inches and 1.42 inches for the sheet and round bar specimens, respectively. Percent reduction of area was determined from micrometer measurements.

V. RESULTS

The 0.2% offset yield strength results are summarized in Table 3 and plotted in Figures 6 and 7. Unirradiated strengths of the forging, sheet and welded sheet were essentially the same. As expected, the irradiation increased the yield strength, though not significantly. The effect was greater in the forging than in the sheet and increased at lower test temperatures. Figure 7 shows the effect of annealing time on the 140°R yield strength for various annealing temperatures. Only slight recovery had occurred at 340°R for a 60-minute anneal. At 540°R, about 60% of the damage disappears in 60 minutes. Little change occurs for longer times. After one hour at 1000°R or 1500°R, the irradiated specimens had recovered to less than the unirradiated value. Control specimens given a 1500°R anneal showed a slight increase in strength.

The ultimate tensile strength is shown in Table 4 and Figure 8. Irradiated strengths of all three material types were similar. They were increased only slightly by the irradiation even at the lowest test temperatures.

The percent reduction of area was not affected by the radiation except for the welded specimens at 140°R. In this condition it increased from 13% to 34%. The reason for this effect is not presently understood. The data is summarized in Table 5.

The effects of the radiation on the elongation is shown in Table 6 and Figure 9. The elongation was significantly though not seriously decreased by the irradiation except for the welded specimens at 140°R whose elongation increased. The forging showed decreases of 44% at 140°R and 13% at 540°R. The sheet elongation decreased only 14% at 140°R.

Notched tensile strength of the alloy was not affected by the radiation. See Table 7. The one exception was for the unwelded sheet at 140°R where the N.T.S. increased 16%. The notched to unnotched strength ratio (Figure 10) decreased at the lowest temperatures for the forging, but increased for the sheet.

VI. DISCUSSION OF RESULTS

Previous testing (GTR-16) of this alloy after irradiation to 6×10^{17} n/cm^2 (E > 1 Mev) had been reported in WANL-TME-1281. A summary of these results is shown in Table 8. Bar material was used in a similar specimen design. Except for the cryogenic elongation and notched tensile strengths after irradiation, results were comparable to those in GTR-19, although the fluence was lower by a factor of two. In GTR-16, the elongation at 140°R was reduced by 72%. A reduction was also found in the notched tensile strength. Other investigators have irradiated this alloy at cryogenic temperatures. Below 10^{17} n/cm^2 (E > 1 Mev) no reductions in elongation have been found.[(1)] At 10^{18} n/cm^2 (E > 1 Mev) Lockheed Nuclear Products report a reduction in elongation from 11% to 6% at 30°R.[(2)] They used a miniature round bar specimen. Aerojet-General Corporation found absolute reductions from 11% to 8% and from 17% to 12% for ring and pressure vessel forgings, respectively, at 140°R and 10^{18} n/cm^2 (E > 1 Mev).[(3)] The pressure vessel forging had properties near those of our forging material.

The results to date indicate that bar stock is affected to a greater extent than forged material while sheet is damaged only slightly at the available fluence levels. The reason for this effect is not clear since grain size, grain structure and degree of cold work are apparently similar. Additional testing is recommended to verify the effect. The irradiation caused an increase in ductility of the weld material at 140°R, probably due to a shift in the balance of properties between the weld and parent metal.

Since radiation increases the strength of most materials, unirradiated values are used for design purposes. Radiation generally reduces the ductility, however, and material design criteria should be determined from irradiated data. At the present time, the use of brittle material design criteria are required when basic materials elongation is less than 5% in standard tensile tests. Using an 80% factor, 6.3% typical elongation is required for ductile design. The data limit the use of ductile design criteria for bar application to temperatures above 230°R where the fluence reaches 6×10^{17} n/cm^2. This assumes that the elongation curve between 140°R and 540°R is approximately linear (as indicated by the GTR-19 data). It is likely that this temperature limit will be raised by fluences as high as those expected in the R-1 reactor. Present data does not permit these effects to be estimated.

The forging data from GTR-19 is applicable to the titanium support rings. Elongation values are adequate over the entire test temperature range. Predicted R-1 doses are not expected to further reduce these values significantly.

Possible sheet and welded sheet applications of the alloy, e.g. the ganged drive mechanism, are not expected to be affected seriously by irradiation.

VII. REFERENCES

(1) "The Effects of Nuclear Radiation on Structural Materials," REIC Report No. 45.

(2) "Effects of Nuclear Radiation on Materials at Cryogenic Temperatures," Lockheed Nuclear Products, NASA CR-72332, LAC ER-9757, 1967.

(3) "NERVA Materials Developments - First Quarter - Contract Year 1968, (1 October - 31 December)" Aerojet-General Corporation, Nuclear Division, Report No. RN-S-0451.

VIII. ACKNOWLEDGMENTS

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TABLE 1

CHEMICAL COMPOSITION OF Ti-5Al-2.5 Sn ELI MATERIALS

ELEMENT	SHEET SPECIMENS	FORGING SPECIMENS	WANL SPECIFICATION
C	0.022	0.013	0.05 Max.
Fe	0.14	0.08	0.25 Max.
Al	5.0	5.05	4.75 - 5.75
Ti	Bal.	Bal.	Bal.
N	0.011	0.01	0.04 Max.
H	0.012	0.008	0.015 Max.
Sn	2.4	2.6	2.2 - 2.8
O	0.07	0.05	0.12 Max.

TABLE 2

COMPARISON OF GTR-19 RESULTS WITH STANDARD 4-D SPECIMEN RESULTS

	NUMBER OF TESTS	UTS (ksi)	0.2% Y. S. (ksi)	ELONG. (%)
At 540°R				
GTR-19	3	119	115	15.1
4-D	8	120	108	15.5
At 140°R				
GTR-19	3	190	180	17.9
4-D	4	192	178	15.5

TABLE 3

GTR-19 Ti-5Al-2.5 Sn ELI
0.2% OFFSET YIELD STRENGTH

TYPE	FLUENCE E<.48 ev (n/cm²)	FLUENCE E>1 Mev (n/cm²)	TEST TEMP. (°R)	ANNEAL TEMP. (°R)	ANNEAL TIME (min)	No. OF SPECIMENS	0.2% OFF Y. S. (ksi)	SCATTER MIN / MAX (ksi)
Forging	0	0	140	---	---	3	180	178 / 182
	2.8(17)	1.1(18)	140	---	---	3	194	191 / 196
	2.8(17)	1.1(18)	140	340	60	3	193	190 / 198
	1.9(17)	9.7(17)	140	540	15	3	191	187 / 194
	9.6(17)	5.6(17)	140	540	60	1	186	----
	9.6(17)	5.6(17)	140	540	1440	1	185	----
	1.7(17)	8.1(17)	140	1000	60	3	178	176 / 179
	0	0	140	1500	60	3	182	181 / 183
	2.0(17)	9.3(17)	140	1500	60	3	176	175 / 177
	0	0	340	---	---	3	140	137 / 142
	1.6(17)	8.5(17)	340	---	---	3	145	143 / 146
	0	0	540	---	---	3	115	113 / 115
	1.6(17)	8.5(17)	540	---	---	3	117	114 / 121
Sheet	0	0	140	---	---	3	180	177 / 185
	3.1(16)	8.0(17)	140	---	---	3	188	187 / 189
	3.1(16)	8.0(17)	140	540	15	3	186	186 / 186
	3.1(16)	8.0(17)	140	540	1440	3	186	184 / 188
	3.1(16)	8.0(17)	140	1000	60	3	184	183 / 185
	0	0	140	1500	60	3	180	179 / 181
	3.1(16)	8.0(17)	140	1500	60	3	180	179 / 181
	0	0	540	---	---	3	110	108 / 110
	3.1(16)	8.0(17)	540	---	---	3	111	111 / 112
Sheet	0	0	140	---	---	3	179	178 / 180
Welded	3.1(16)	8.0(17)	140	---	---	3	186	180 / 190
	3.1(16)	8.0(17)	140	540	15	3	188	188 / 189
	3.1(16)	8.0(17)	140	1000	60	1	179	----
	0	0	540	---	---	3	111	110 / 111
	3.1(16)	8.0(17)	540	---	---	3	115	113 / 117

TABLE 4

GTR-19 Ti-5Al-2.5 Sn ELI
ULTIMATE TENSILE STRENGTH

TYPE	FLUENCE E< 48 ev (n/cm²)	FLUENCE E>1 Mev (n/cm²)	TEST TEMP. (°R)	ANNEAL TEMP. (°R)	ANNEAL TIME (min)	No. OF SPECIMENS	U. T. S. (ksi)	SCATTER MIN / MAX (ksi)
Forging	0	0	140	---	---	3	190.0	188 / 192
	2.8(17)	1.1(18)	140	---	---	3	202.2	199 / 204
	2.8(17)	1.1(18)	140	340	60	3	201.6	198 / 204
	1.9(17)	9.7(17)	140	540	15	3	198.3	196 / 199
	9.6(16)	5.6(17)	140	540	60	1	193.5	----
	9.6(16)	5.6(17)	140	540	1440	1	194.7	----
	2.0(17)	9.3(17)	140	1000	60	3	188.3	185 / 190
	0	0	140	1500	60	3	191.9	191 / 194
	2.0(17)	9.3(17)	140	1500	60	3	184.4	183 / 186
	0	0	340	---	---	3	145.0	142 / 147
	1.6(17)	8.5(17)	340	---	---	3	140.9[1]	127 / 149
	0	0	540	---	---	3	119.2	119 / 119
	1.6(17)	8.5(17)	540	---	---	3	120.9	118 / 124
Sheet	0	0	140	---	---	3	190.7	187 / 193
	3.1(16)	8.0(17)	140	---	---	3	197.9	197 / 199
	3.1(16)	8.0(17)	140	540	15	3	196.1	195 / 197
	3.1(16)	8.0(17)	140	540	1440	3	196.2	196 / 197
	3.1(16)	8.0(17)	140	1000	60	3	192.6	192 / 193
	0	0	140	1500	60	3	189.4	188 / 191
	3.1(16)	8.0(17)	140	1500	60	3	189.5	189 / 190
	0	0	540	---	---	3	115.4	114 / 117
	3.1(16)	8.0(17)	540	---	---	3	115.6	115 / 116
Sheet	0	0	140	---	---	3	189.3	188 / 190
Welded	3.1(16)	8.0(17)	140	---	---	3	194.5	189 / 197
	3.1(16)	8.0(17)	140	540	15	3	194.3	194 / 195
	3.1(16)	8.0(17)	140	1000	60	1	189.6	----
	0	0	540	---	---	3	116.8	116 / 117
	3.1(16)	8.0(17)	540	---	---	3	117.8	117 / 119

[1] UTS = 147.5 Without one low value/used in graphs

TABLE 5

GTR-19 Ti-5Al-2.5 Sn ELI
REDUCTION OF AREA

TYPE	FLUENCE E<.48 ev (n/cm²)	FLUENCE E>1Mev (n/cm²)	TEST TEMP. (°R)	ANNEAL TEMP. (°R)	ANNEAL TIME (min)	No. OF SPECIMENS	R. A. (%)	SCATTER MIN / MAX (%) (%)
Forging	0	0	140	---	---	3	33	32 / 33
	2.8(17)	1.1(18)	140	---	---	2	30	29 / 32
	2.8(17)	1.1(18)	140	340	60	3	26	25 / 26
	1.9(17)	9.7(17)	140	540	15	3	27	23 / 31
	9.6(16)	5.6(17)	140	540	60	1	31	---
	9.6(16)	5.6(17)	140	540	1440	1	29	---
	2.0(17)	9.3(17)	140	1000	60	3	27	23 / 33
	0	0	140	1500	60	3	24	15 / 29
	2.0(17)	9.3(17)	140	1500	60	3	11	10 / 14
	0	0	340	---	---	3	34	31 / 36
	1.6(17)	8.5(17)	340	---	---	3	24	15 / 30
	0	0	540	---	---	3	41	40 / 43
	1.6(17)	8.5(17)	540	---	---	3	39	36 / 42
Sheet	0	0	140	---	---	2	36	36 / 36
	3.1(16)	8.0(17)	140	---	---	3	34	32 / 35
	3.1(16)	8.0(17)	140	540	15	3	33	32 / 33
	3.1(16)	8.0(17)	140	540	1440	3	41	29 / 48
	3.1(16)	8.0(17)	140	1000	60	3	39	29 / 52
	0	0	140	1500	60	3	32	28 / 35
	3.1(16)	8.0(17)	140	1500	60	3	35	34 / 36
	0	0	540	---	---	3	43	42 / 45
	3.1(16)	8.0(17)	540	---	---	3	45	43 / 48
Sheet Welded	0	0	140	---	---	3	13	13 / 14
	3.1(16)	8.0(17)	140	---	---	3	34	28 / 41
	3.1(16)	8.0(17)	140	540	15	3	34	32 / 35
	3.1(16)	8.0(17)	140	1000	60	1	13	---
	0	0	540	---	---	3	44	44 / 45
	3.1(16)	8.0(17)	540	---	---	3	43	42 / 44

TABLE 6

GTR-19 Ti-5Al-2.5 Sn ELI
PERCENT ELONGATION

TYPE	FLUENCE E<.48 ev (n/cm²)	FLUENCE E>1 Mev (n/cm²)	TEST TEMP. (°R)	ANNEAL TEMP. (°R)	ANNEAL TIME (min)	No. OF SPECIMENS	ELONG. (%)	SCATTER MIN / MAX (%) (%)
Forging	0	0	140	---	---	3	17.9	16.1 / 20.7
	2.8(17)	1.1(18)	140	---	---	3	10.0	8.6 / 10.9
	2.8(17)	1.1(18)	140	340	60	3	12.4	10.8 / 15.0
	1.9(17)	9.7(17)	140	540	15	3	12.2	8.8 / 14.7
	9.6(16)	5.6(17)	140	540	60	1	8.2	----
	9.6(16)	5.6(17)	140	540	1440	1	11.6	----
	2.0(17)	9.3(17)	140	1000	60	2	17.5	17.5 / 17.6
	0	0	140	1500	60	3	16.0	13.5 / 17.9
	2.0(17)	9.3(17)	140	1500	60	2	9.1	8.3 / 10.9
	0	0	340	---	---	3	12.9	12.2 / 13.9
	1.6(17)	8.5(17)	340	---	---	3	11.1	10.5 / 12.3
	0	0	540	---	---	3	15.1	13.3 / 16.5
	1.6(17)	8.5(17)	540	---	---	3	13.1	12.8 / 13.4
Sheet	0	0	140	---	---	3	17.4	17.3 / 17.5
	3.1(16)	8.0(17)	140	---	---	3	15.0	14.7 / 15.3
	3.1(16)	8.0(17)	140	540	15	3	15.0	14.7 / 15.6
	3.1(16)	8.0(17)	140	540	1440	3	15.6	15.5 / 15.7
	3.1(16)	8.0(17)	140	1000	60	3	16.0	13.3 / 17.5
	0	0	140	1500	60	3	17.8	17.6 / 18.2
	3.1(16)	8.0(17)	140	1500	60	3	18.8	17.9 / 20.0
	0	0	540	---	---	3	17.5	17.3 / 17.6
	3.1(16)	8.0(17)	540	---	---	3	17.7	17.2 / 18.0
Sheet Welded	0	0	140	---	---	3	5.2	2.6 / 6.6
	3.1(16)	8.0(17)	140	---	---	3	10.3	9.5 / 11.0
	3.1(16)	8.0(17)	140	540	15	3	13.1	12.2 / 14.5
	3.1(16)	8.0(17)	140	1000	60	1	8.4	----
	0	0	540	---	---	3	16.1	15.4 / 16.8
	3.1(16)	8.0(17)	540	---	---	3	13.3	12.7 / 13.6

TABLE 7

GTR-19 Ti-5Al-2.5 Sn ELI
NOTCHED TENSILE STRENGTH

TYPE	FLUENCE E<.48 ev (n/cm^2)	FLUENCE E>1 Mev (n/cm^2)	TEST TEMP. (°R)	ANNEAL TEMP. (°R)	ANNEAL TIME (min)	No. OF SPECIMENS	N. T. S. (ksi)	SCATTER MIN / MAX (ksi) (ksi)
Forging	0	0	140	---	---	3	255	231 / 267
	2.8(17)	1.1(18)	140	---	---	4	250	243 / 254[1]
	2.8(17)	1.1(18)	140	340	60	3	248	244 / 252
	1.9(17)	9.7(17)	140	540	15	3	257	252 / 261
	9.6(16)	5.6(17)	140	540	1440	2	263	263 / 264
	2.3(17)	8.5(17)	140	1000	60	3	262	258 / 265
	0	0	140	1500	60	3	247	237 / 261[2]
	2.3(17)	8.5(17)	140	1500	60	2	247	247 / 247
	0	0	340	---	---	3	224	220 / 228
	1.8(17)	7.8(17)	340	---	---	3	219	216 / 221
	0	0	540	---	---	3	192	189 / 194
	1.8(17)	7.8(17)	540	---	---	3	194	190 / 197
Sheet	0	0	140	---	---	3	172	170 / 173
	8.5(16)	7.8(17)	140	---	---	3	205	204 / 206
	8.5(16)	7.8(17)	140	540	15	3	205	205 / 206
	8.5(16)	7.8(17)	140	540	1440	3	206	205 / 206
	8.5(16)	7.8(17)	140	1000	60	3	172	172 / 172
	0	0	140	1500	60	3	201	201 / 201
	8.5(16)	7.8(17)	140	1500	60	3	198	198 / 199
	0	0	540	---	---	3	127	126 / 128
	8.5(16)	7.7(17)	540	---	---	3	128	128 / 128
Sheet	0	0	140	---	---	3	199	196 / 201
Welded	8.5(16)	7.8(17)	140	---	---	3	202	187 / 212
	8.5(16)	7.8(17)	140	540	15	3	197	190 / 208
	8.5(16)	7.8(17)	140	540	1440	2	196	193 / 199
	0	0	540	---	---	3	130	129 / 132
	8.5(16)	7.8(17)	540	---	---	3	132	130 / 134

1 Value of 194 ksi not included

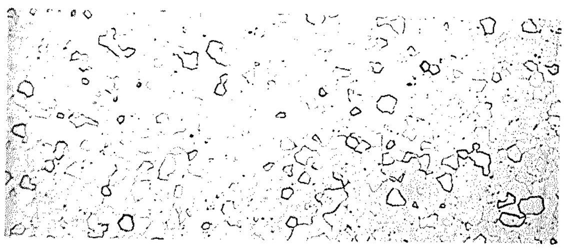
2 Value of 157 ksi not included

TABLE 8

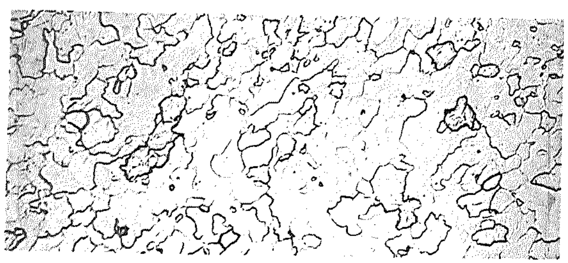
SUMMARY OF GTR-16 Ti-5Al-2.5 Sn ELI RESULTS

TESTED AT:		0.2% OFF. Y.S. (ksi)	U. T. S. (ksi)	ELONG (%)	N. T. S. (K_t = 6) (ksi)
140°R	Control	177.6	183.3	16.3	245.0
	Irradiated	195.0	197.5	4.6	227.1
540°R	Control	119.6	121.0	16.5	189.3
	Irradiated	128.6	129.0	12.8	193.2

Weld Zone



Sheet



Forging

FIGURE 1

100X Micrographs of GTR-19 Ti-5%Al-2.5%Sn ELI Material
Etchant: 17 Parts HNO_3, 3 Parts HF, 80 Parts H_2O

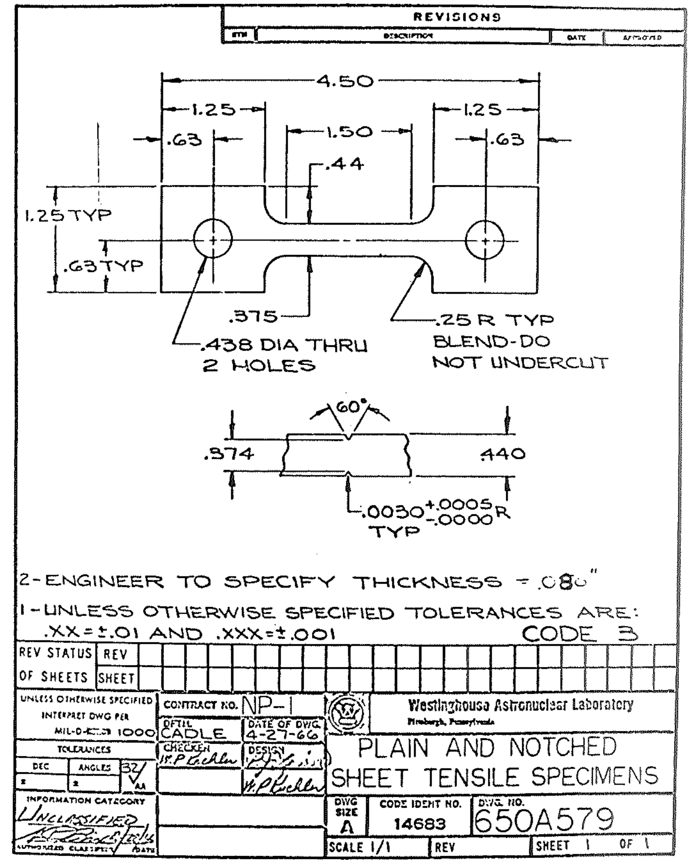
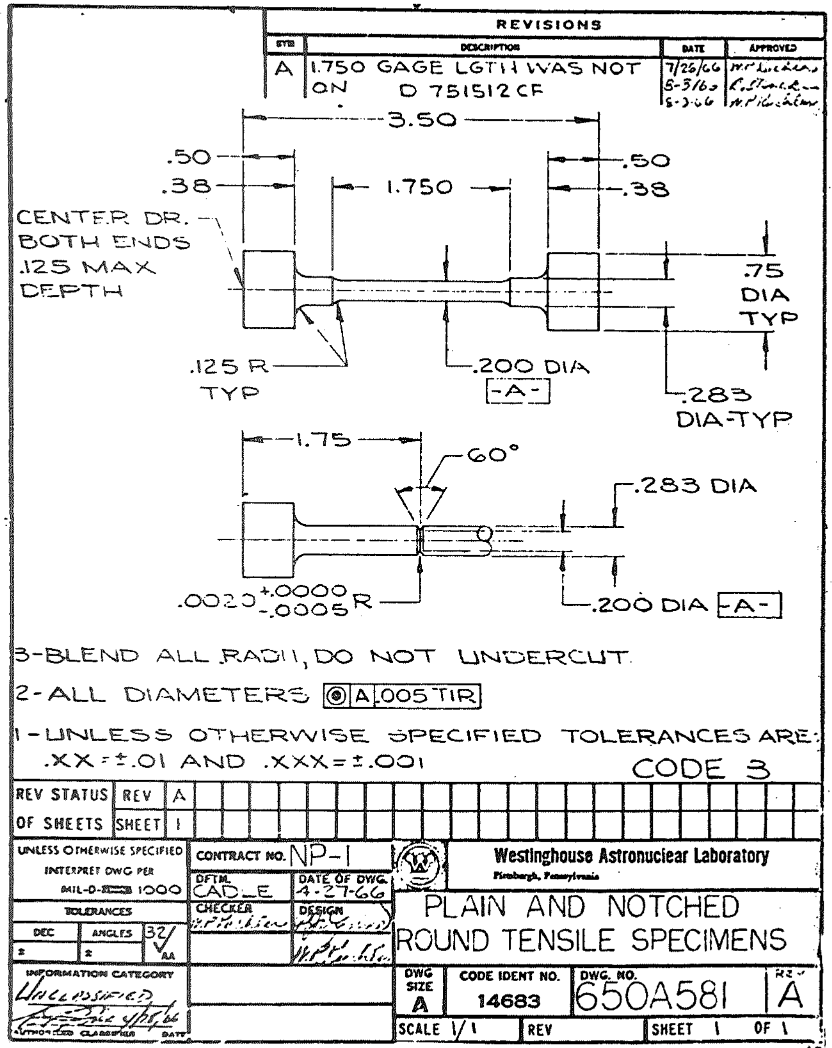


FIGURE 2

Sheet Specimen



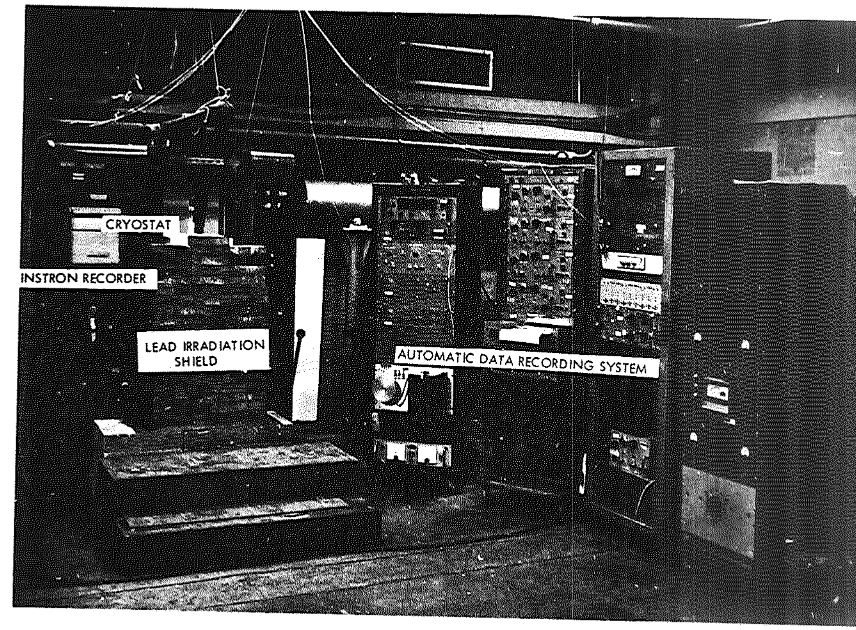


FIGURE 4

Test Set-Up at GD/FW

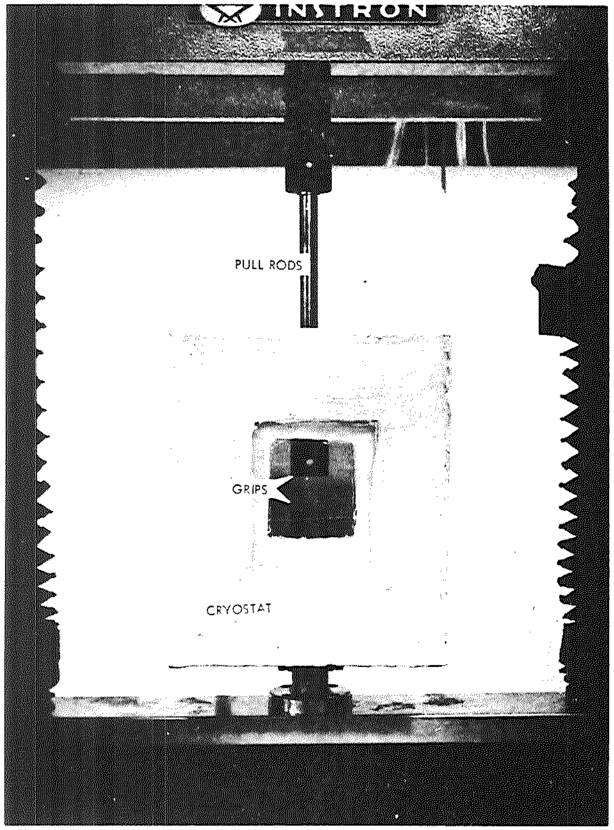


FIGURE 5

Specimen Pulling Equipment

Astronuclear Laboratory

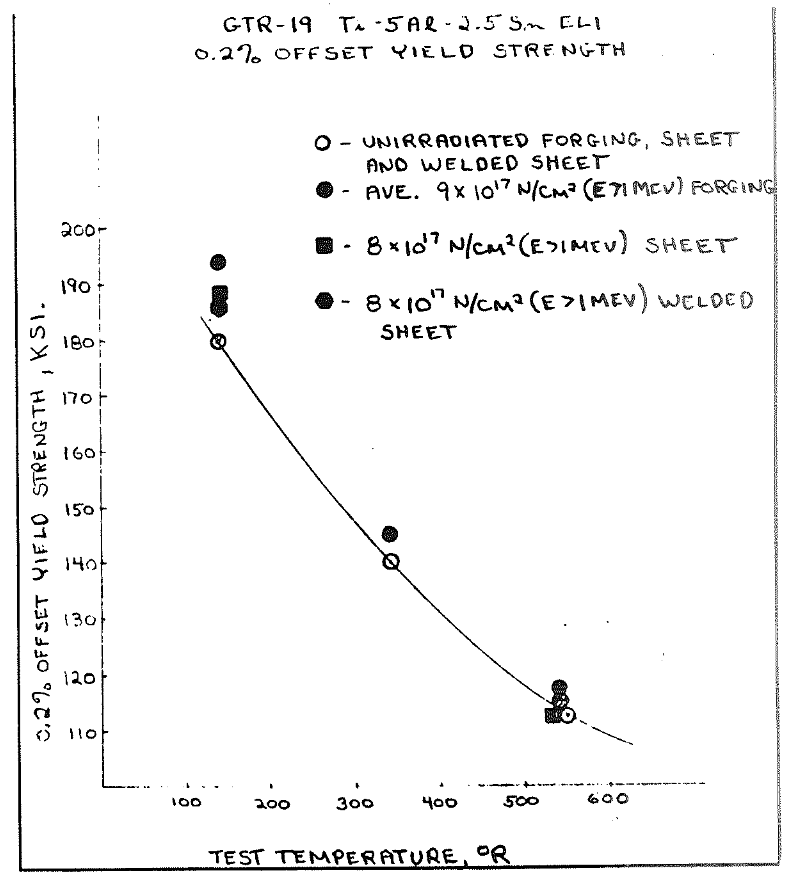


FIGURE 6

0.2% Offset Yield Strength

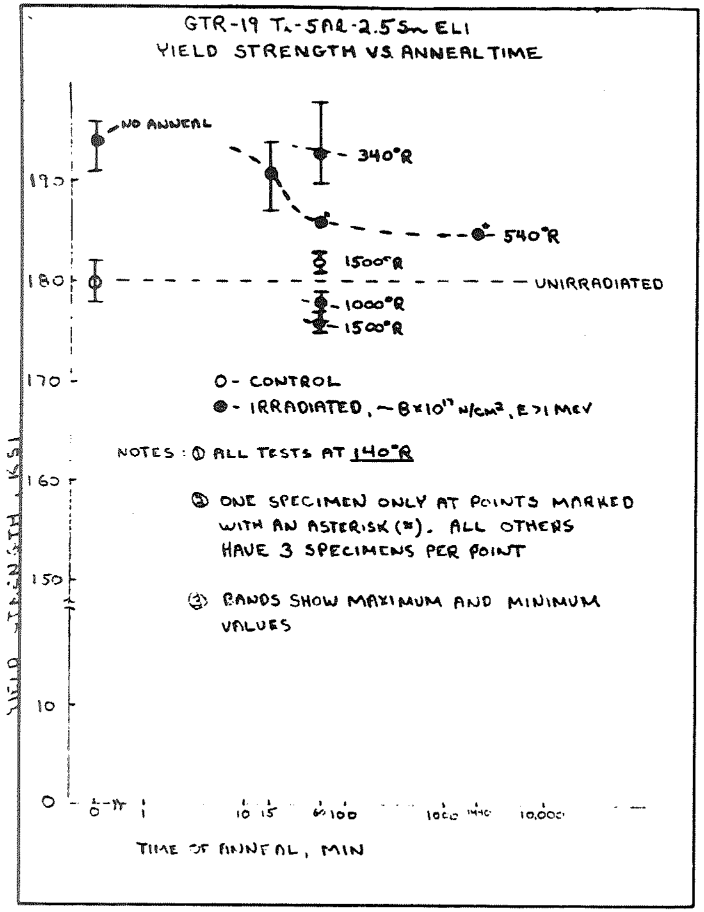


FIGURE 7

Irradiated Yield Strength vs. Anneal Time

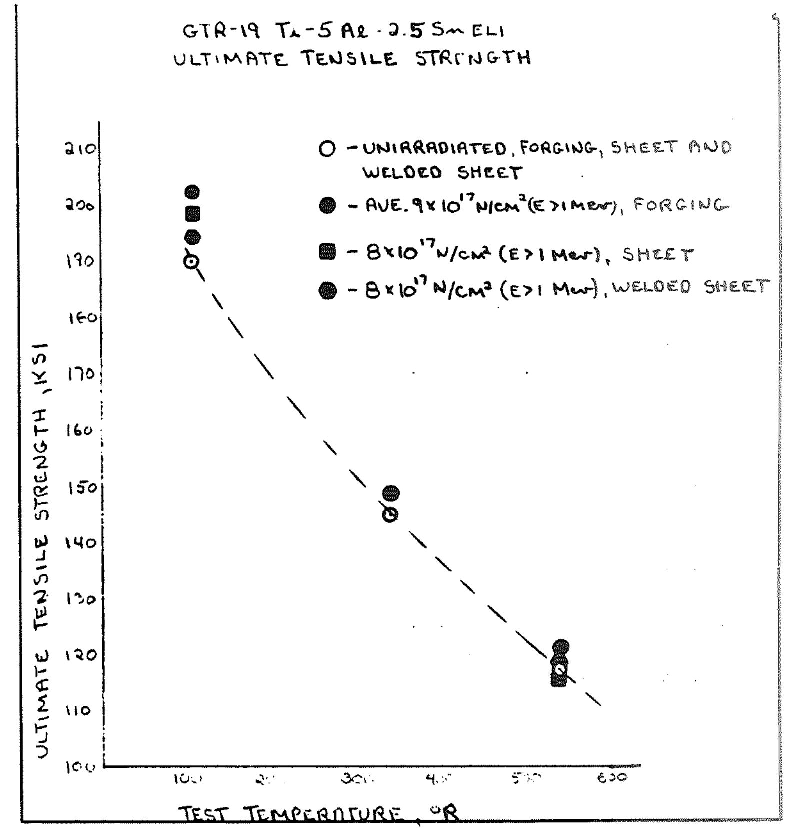


FIGURE 8

Ultimate Tensile Strength

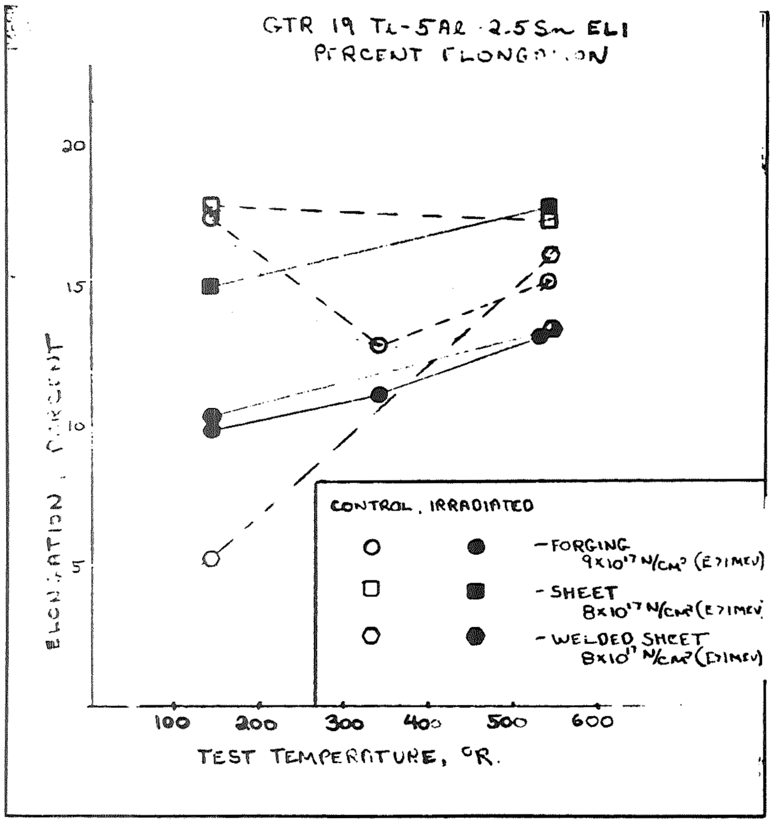


FIGURE 9

Tensile Elongation

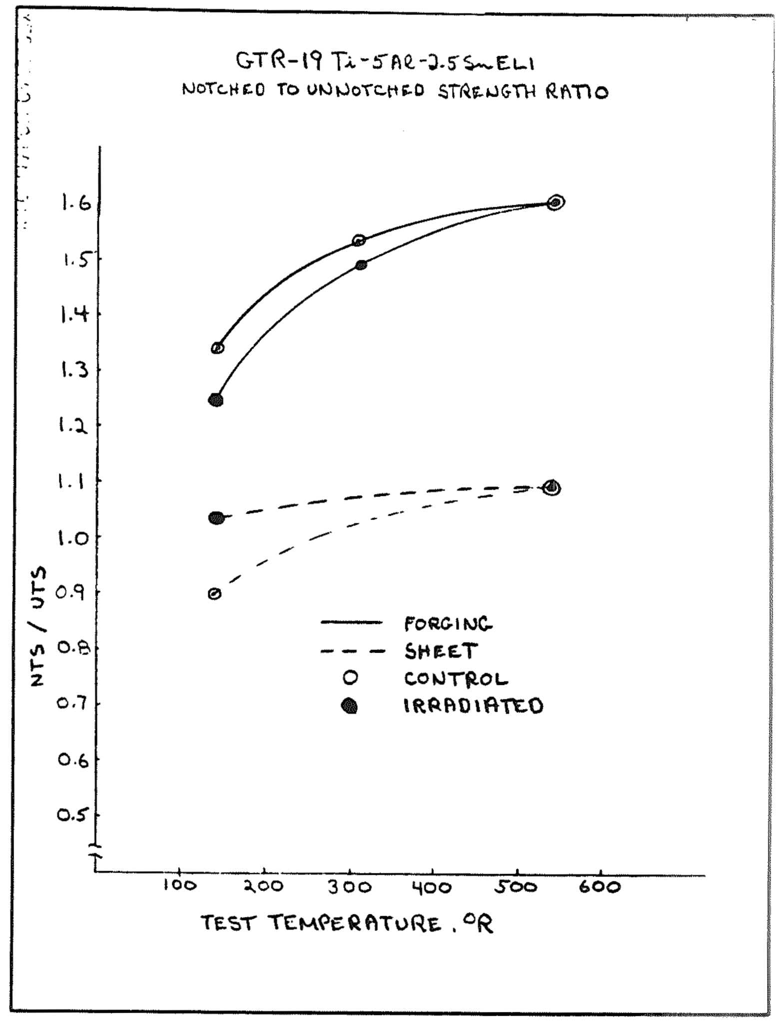


FIGURE 10

Notched to Unnotched Strength Ratio