AFML-TR-65-304

PRECRACKED CHARPY IMPACT FRACTURE TOUGHNESS PROPERTIES OF BACKUP FLUX-WELDED Ti-5A1-2.5 Sn ALLOY PLATE FROM –320° TO 550°F

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RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This report was prepared by Sidney O. Davis of the Materials Information Branch, Materials Applications Division, Air Force Materials Laboratory, Research and Technology Division, Wright-Patterson Air Force Base, Ohio, and Roger M. Niemi of Monsanto Research Corporation, Dayton, Ohio. This program was conducted under Project No. 7381, "Materials Applications," Task 738106, "Design Information Development." The manuscript was released by the authors in August 1965 for publication as an RTD technical report.

This report covers work conducted from February to June 1964.

This technical report has been reviewed and is approved.

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Air Force Materials Laboratory

ABSTRACT

A program was conducted to evaluate the effects of a proprietary backup flux-welding technique on the impact fracture toughness properties of Ti-5Al-2.5 Sn alloy plate. The flux was the product of Mitron Research and Development Corporation. Precracked Charpy (often called subsize Charpy) specimens were tested under impact loads at -320°F, -100°F, room temperature, and 550°F. The weld and heat affected zone (HAZ) had greater fracture toughness resistance than the base metal. The fracture resistance, work per unit area (W/A) decreased with decreasing test temperature. At -320°F the weld and HAZ retained 1/3 of their fracture resistance at room temperature. However, the weld- and HAZ-converted W/A impact fracture resistance at -320°F had a $K_c \approx 125$ ksi$\sqrt{in.}$ which indicated good toughness for this temperature. The fracture resistance did not appear to be a function of the specimen's location through the thickness of the plate for a given specimen orientation. In general, the fracture resistance of the weld and HAZ compared to the base metal was excellent.

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SECTION I

INTRODUCTION

The highly reactive nature of titanium and the corresponding detrimental effect on mechanical properties caused by elements which dissolve interstitially (C, H, O, and N) has plagued fabricators for some time. This problem is acute when welding titanium since the weld and heat affected zones (HAZ) must be protected from contamination. Protection is usually afforded by using an inert cover gas or an inert gas-filled chamber (dry box). With either method, however, the procedure is a costly cumbersome task making on-site welding difficult and often impractical.

Mitron Research and Development Corporation has recently made advances in titanium-welding technology using a backup flux which eliminates reverse-side shielding. This flux can be applied as a paste, powder, or tape which fuses upon heating and subsequently volatilizes to seal the weld from the atmosphere.

The development described was sponsored by the Navy as a technique for welding Ti plate. Further development in applying the technique to sheet material was conducted by the Air Force under Contract AF 33 (615)-1384.

The initial report issued by Mitron Research and Development Corporation on the development of nonreactive fluxes for use when welding titanium has been released under Contract AF 33 (615)-1384 (References 1 and 2). Promising results have been obtained utilizing fluxes as a backup for gas tungsten arc-welding of 0.050-inch-thick Ti-6Al-4V. To date, paste fluxes appear better than powder fluxes because of residual moisture in the powder. This is partially shown in Table I by the lower as-welded hardness. Table II shows the conventional impact properties of the welds which were made (Reference 1). The flux compositions were not revealed. The fluxes were sufficiently coherent after one pass to permit multipass welding and could be removed with water and a wire brush (Reference 1).

This TR reports in-house work done to determine the fracture resistance characteristics of one of the titanium plates welded by Mitron. The fracture resistance measures the ability of a material to resist crack propagation when flaws are present in the material. This support work was done at the request of the Advanced Fabrication Techniques Branch, Manufacturing Technology Division, Air Force Materials Laboratory. In the ensuing report little emphasis is placed on welding procedures and the actual use of the flux. This type of information is beyond the scope of this report, but is available to interested readers by obtaining Mitron's report (Reference 3). The fracture resistance of the weld, HAZ, and base metal was evaluated using the precracked Charpy Test Method developed by Manlabs, Incorporated (References 4 and 5).

TABLE I

Microhardness Surveys of Cross Section of As-Welded Manual Tig Welds With Filler Metal and Automatic Tig Welds Without Filler Metal *

Welding Technique	Filler	Average Hardness, R_C			Flux Form
		Base	HAZ	Weld	
Manual TIG	Ti-6Al-4V	33.1	38.0	38.3	Powdered
	Ti-5Al-2.5 Sn	34.0	38.7	40.8	"
	Ti-5Al-2.5 Sn	32.5	37.0	38.0	"
	CP-Ti	35.0	37.0	38.0	"
Automatic TIG	None	34.6	36.9	41.0	Powdered
	None	33.1	36.0	37.0	Paste
	None	36.7	36.7	39.0	Paste
	None	35.8	36.6	36.2	None (gas backup)

* See Reference 1

TABLE II

Transverse As-Welded V-Notch Impact Strength at Room Temperature of 0.050-Inch Ti-6Al-4V Sheet Welds; Welds Ground Flat and Notched in Weld *

Material	Average Impact Strength, Inch-Pounds
Base material	22.8
Argon backup	20.1
Powder-flux backup	10.6
Paste-flux backup	20.2

* See Reference 1

SECTION II

PROCEDURE AND MATERIALS

WELDING PROCEDURE

The Ti-5A1-2.5 Sn plate was MIG welded using A-110-AT* filler wire with fore and aft argon shielding. The halide-chloride flux was applied to the reverse side of the plate and fused to form a "cocoon" as shown in Figure 1. The weld joint was a 60° Vee butt weld without a reverse-side weld pass. Four passes were required to fill the joint on a 9/16-inch-thick plate. Normal cleaning and MIG welding procedures were used.

MATERIAL

The comparative chemical composition of parent material and weld wire (Reference 3) is as follows:

ELEMENT	C	O	H (PPM)	N	Fe	Cl	Na	K	Al	Sn	Mn	Ti
PARENT MAT'L	0.030	0.096	76-83	0.01	0.14	0.024	0.006	0.001	5.50	2.50	0.030	BAL
WELD WIRE	0.034	0.07-0.092	37-61	0.012	0.21	—	—	—	5.56	2.49	0.014	BAL

The as-received welded Ti-5A1-2.5 Sn plate is shown in Figure 2. Nominal dimensions were 12 inch by 6 inch by 9/16 inch. This plate was received from the mill in the forged and vacuum-annealed condition. Typical mechanical properties are listed in Table III (Reference 3). Hardness measurements revealed little variation across the weld and HAZ. This consistency, shown in Figure 3, indicates a minimal amount of interstitial pickup in the weldment.

Metallographic examination of a companion plate welded in the same manner as the one tested revealed the sequenced macro and micro photographs shown in Figure 4 (Reference 3).

* A-110-AT is a crucible designation for Ti-5A1-2.5 Sn.

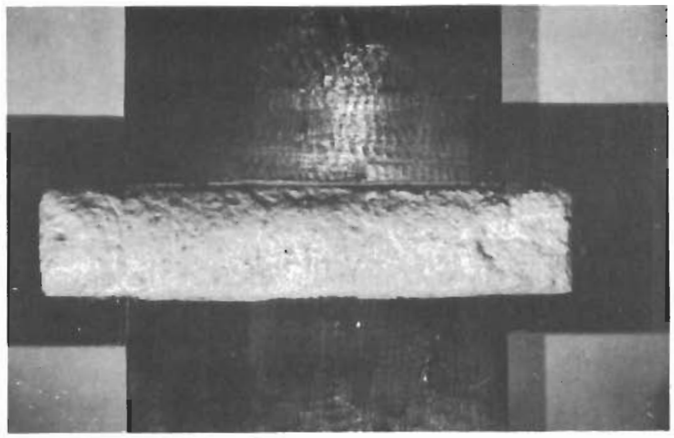
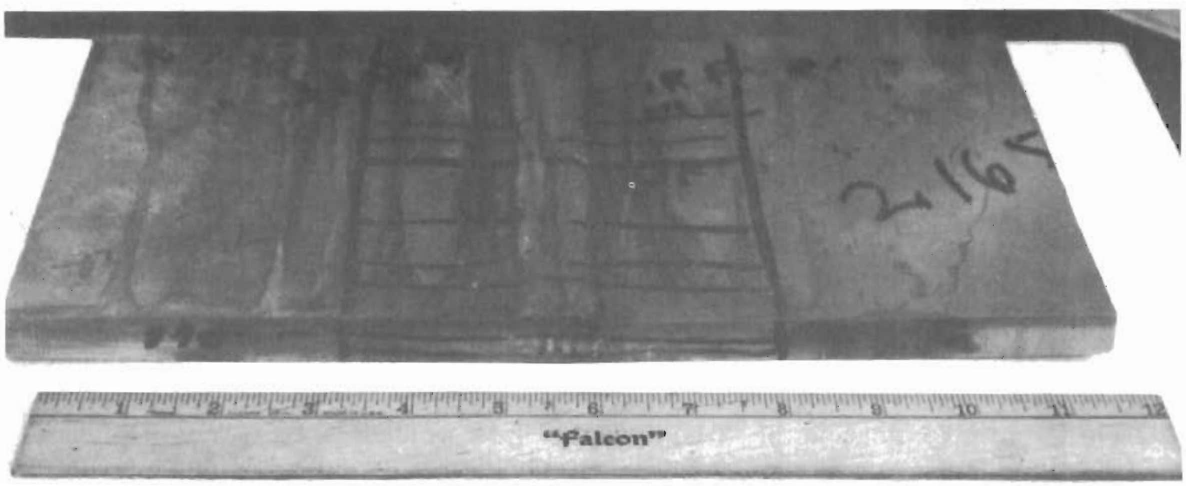


Figure 1. Photograph of MITRON Flux Adhering to Back Side of Welded Plates Forming a "Cocoon"



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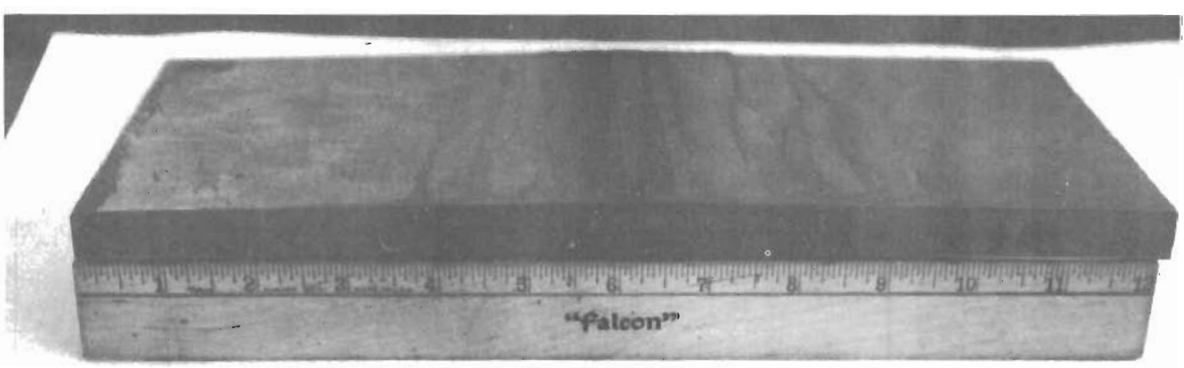


BOTTOM

Figure 2. As-Received Welded Ti-5Al-2.5 Sn Plate

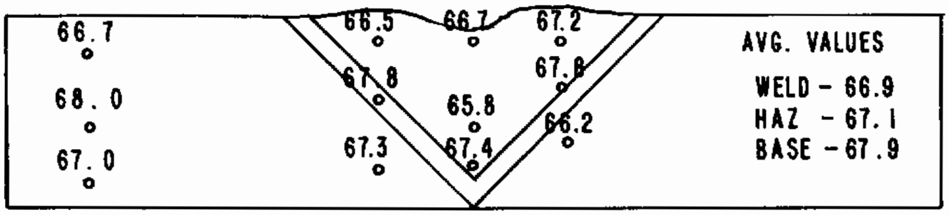
TABLE III

Transverse and Longitudinal Weld Tensile Properties of 9/16-Inch Ti-5A1-2.5 Sn Plate Welded With A-110 Wire*

Specimen Type Cut From Plate	Y.S.	T.S.	% Elong.** in 2 inches	% Elong. in 1 Inch	Fracture Location	Remarks
.357 Round (trans.)	113,500	126,000	11.5	----	weld	Good gas coverage and flux backup
Full Size "	111,000	125,000	7.0	14.0	weld	" " " " " "
Full Size "	112,000	126,000	8.5	17.0	weld	" " " " " "
Full Size "	108,000	122,000	9.9	19.8	weld	Good gas coverage and back pass
Full Size "	112,000	125,000	8.5	17.0	weld	" " " " " "
.357 Round "	113,500	120,500	8.0	----	weld	" " " " " "
.357 Round "	120,000	129,000	20.0	----	----	Parent material
.357 Round "	116,500	122,500	16.4	----	----	" "
Full Size "	111,000	127,500	7.5	15.0	----	Good gas coverage and flux backup
.357 Round (long.)	109,000	117,500	11.0	----	----	All-weld tensile specimen
.357 "	121,000	128,000	17.0	----	----	HAZ specimen
.357 Round "	126,000	132,000	17.0	----	----	Heat affected zone specimen

*See Reference 3

** The % elongation is presented for 2-inch and 1-inch gage lengths for the full-size tensile bars. This was done because the total amount of actual elongation occurring during testing was well within a 1-inch gage length, though a 2-inch gage length was used. Based on this fact it is felt that the % elongation for the 1-inch gage length is more realistic than the data presented for the 2-inch gage length.



Note: Ti-5Al-2.5 Sn welded with A-110-AT wire; no reverse weld pass. See, also. Reference 3.

Figure 3. Rockwell "A" Hardness Survey of Weld Metal, Heat Affected Zone, and Base Metal (Reference 3)

SPECIMENS

Fracture resistance of the weld, HAZ, and base metal was evaluated using the precracked Charpy specimen shown in Figure 5. Note that Charpy dimensions are standard except for a reduced thickness. A short crack (≈ 1/8 inch in length) was fatigued at the tip of the Vee notch into the specimens to simulate service cracks prior to precracked Charpy testing with the machine shown in Figure 6 manufactured by Manlabs, Incorporated.

The specimens were removed and prepared from the Ti plate using the following procedure:

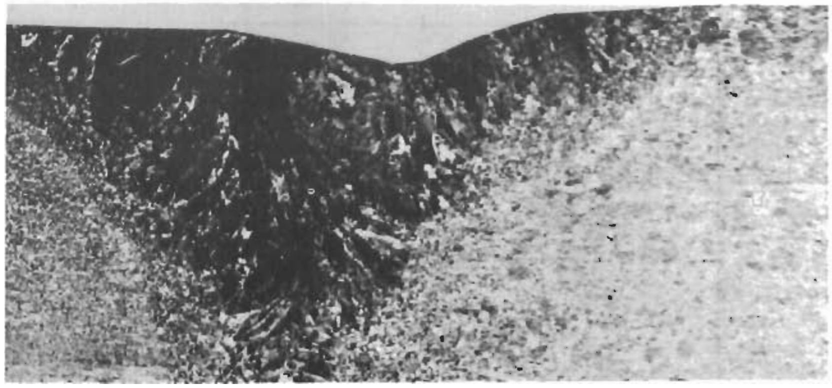
1. Cut into sections representing the weld, base metal, and HAZ using a Norton No. 32A-46-F12-VBP wheel.
2. Surface grind the thickness to 1/8 inch and the height to 0.394 inch.
3. Macro etch to locate weld and HAZ.
4. Notch and trim excess length (from 3.5 to 2.165 inch).
5. Surface grind the thickness to 0.100 inch.
6. Fatigue crack to a total depth of ≈0.125 inch.

The cutout pattern used was designed to yield the maximum number of specimens allowing tests in two crack-propagation directions (see Figure 7). A total of 59 specimens were prepared in this manner.

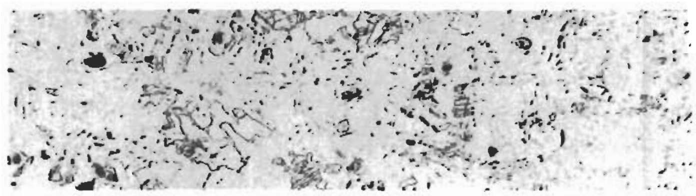
TEST PROCEDURE

The precracked Charpy (often called subsize Charpy) specimens were tested at -320°F, -100°F, room temperature, and 550°F. Subzero tests were accomplished by rapid transfer of the specimen from the environment to the impact tester anvil. Elevated temperatures were monitored with Cr-Al thermocouples located in the furnace shown in Figure 8. Testing was done on the 24 ft-lb capacity impact machine also shown in Figure 8. The machine was developed and designed for subsize Charpy testing by Manlab Incorporated. Test values are reported as work/area (W/A) and may be related to the fracture toughness K_c by the formula $K_c^2 \approx EG_c$ where W/A is substituted for G_c and E is the elastic modulus. The reader is cautioned that $W/A \doteq G_c$ is true only on a unit basis, (both $\frac{in.-lb}{in.^2}$). From a fundamental conceptual viewpoint, the parameters W/A and G_c are different.

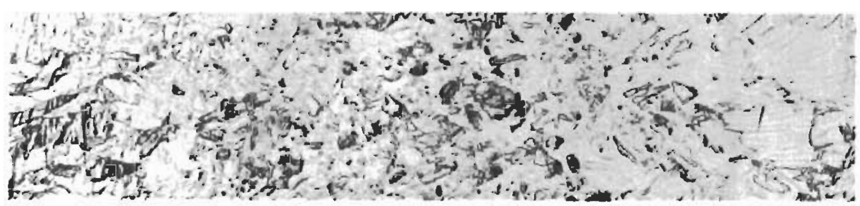
After testing, the fractured surface (not the fatigue-cracked surface) area A, was measured with a 50X toolmakers microscope to an accuracy of ±.001 inch^2 for the calculation of W/A impact toughness values of Ti-5Al-2.5 Sn Alloy.



4a. Macrophotograph of Welded Specimen Etchant: Modified Kroll's Etch. Magnification: 4X



4b. Microphotograph of Base Material Etchant: Modified Kroll's Etch. Magnification: 100X



4c. Microphotograph of Heat Affected Zone Etchant: Modified Kroll's Etch. Magnification: 100X

4d. Microphotograph of Fusion Zone Etchant: Modified Kroll's Etch. Magnification: 100X

Figure 4. Macrophotograph and Microphotographs of Ti-5Al-2.5 Sn Alloy Plate-Welded With Alloy Wire. No Reverse Pass. (See Reference 3.)

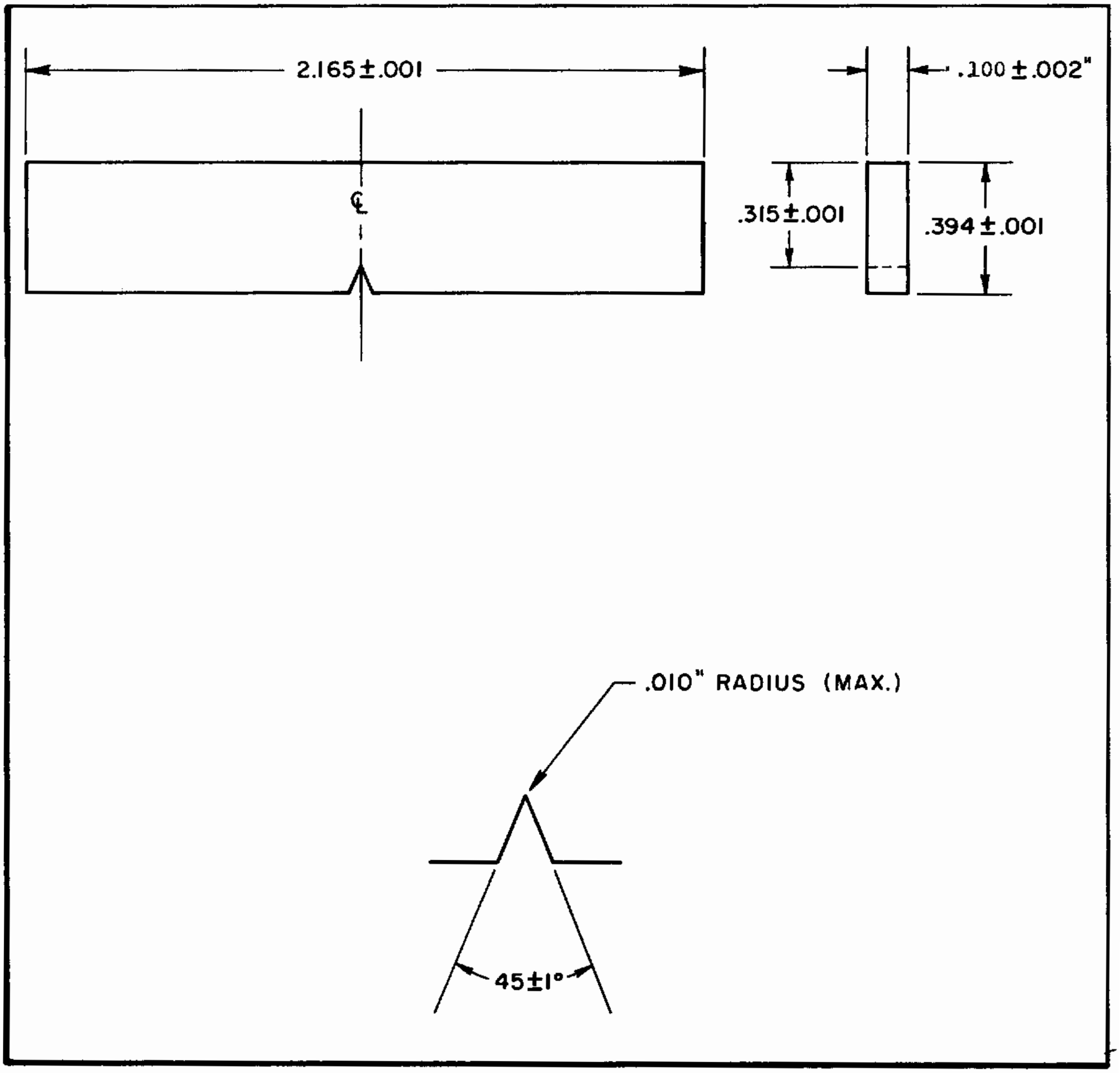


Figure 5. Subsize Precracked Charpy Test Specimen

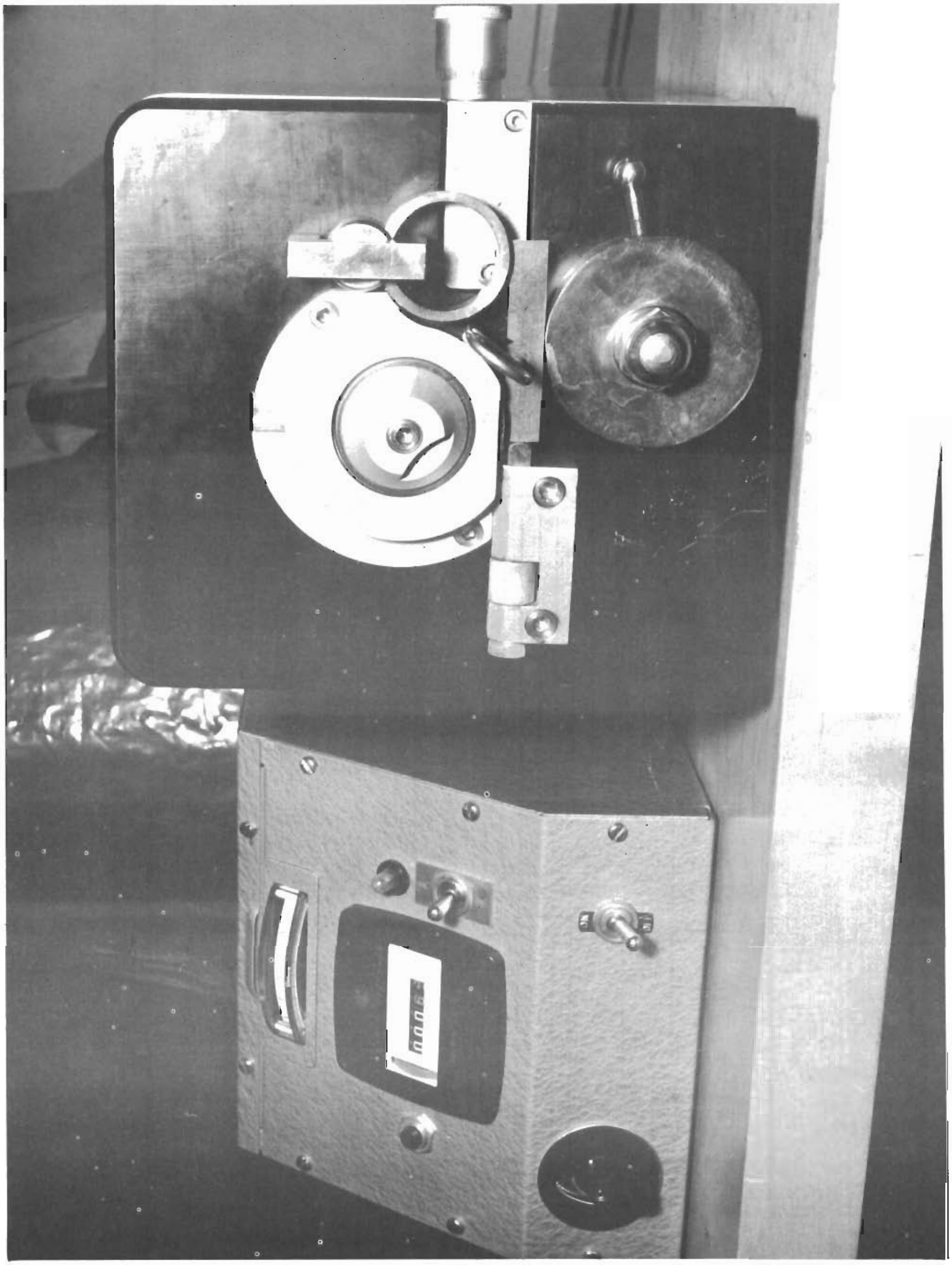


Figure 6. Precracked Charpy Specimens Fatigue Machine

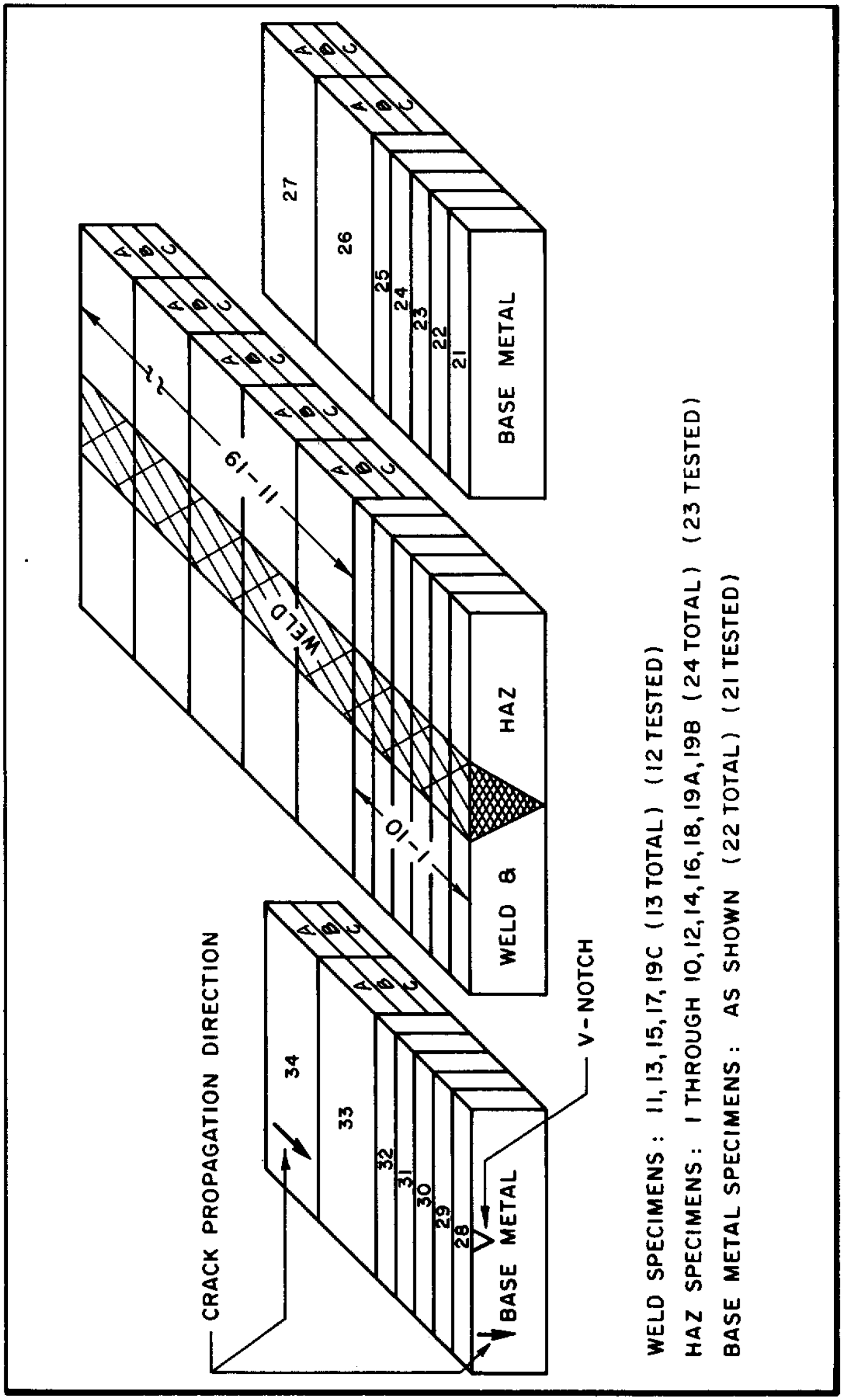


Figure 7. Schematic Specimen Cutout Pattern

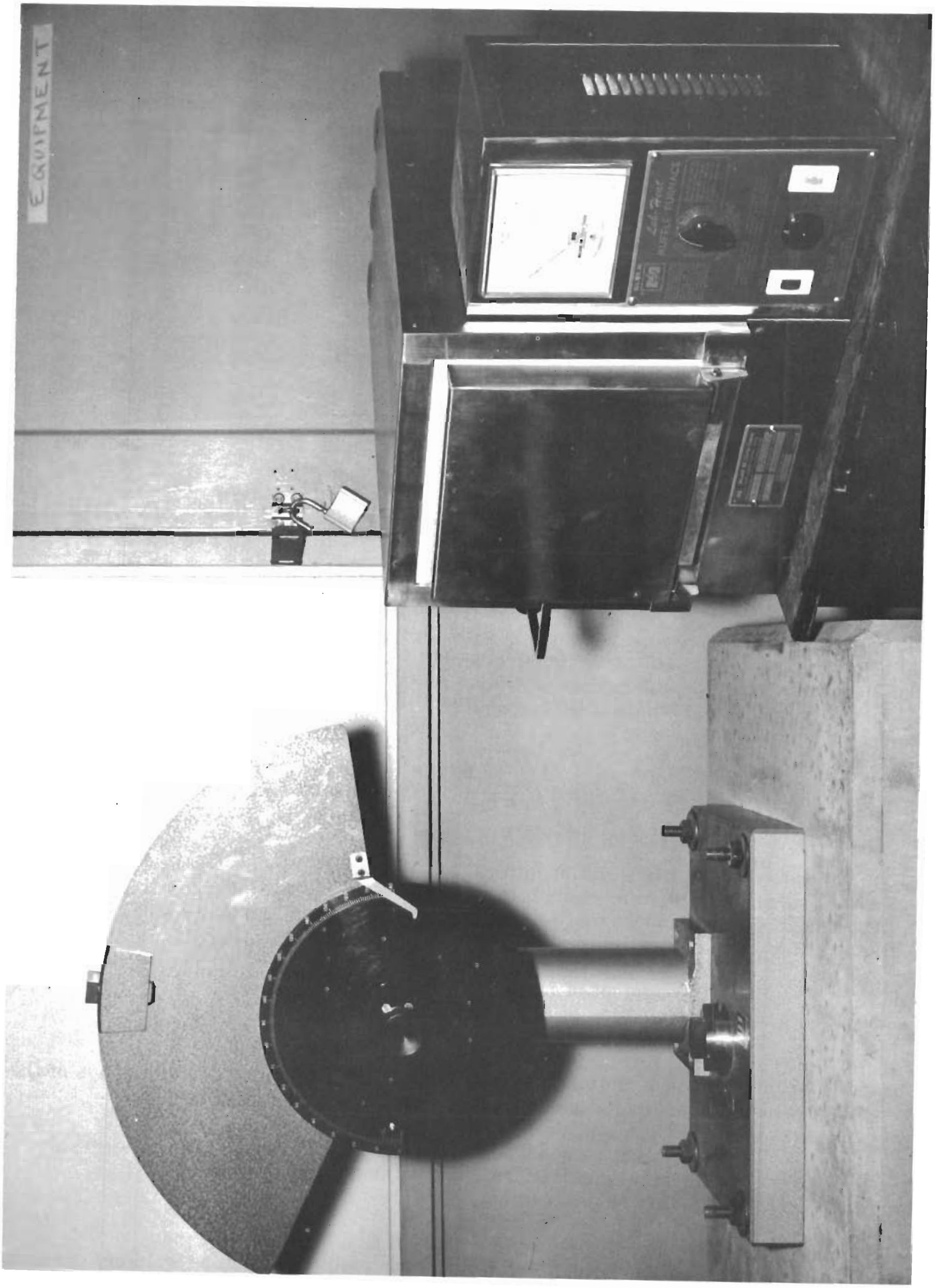


Figure 8. Charpy Impact Test Machine (24 Ft-Lb Capacity) and 2000°F Furnace.

SECTION III

DISCUSSION AND RESULTS

TESTING TECHNIQUE

Currently, there is a correlation between G_c and W/A (under slow bend loading only) based on the prediction of residual strength (σ) using the following modified Griffith-Orowan relationship used by Hartbower (References 4 and 5).

$$\sigma = \sqrt{\frac{\left(\frac{W}{A}\right) E}{\pi a_0}} \approx \sqrt{\frac{G_c E}{\pi a_0}}$$

where:

- E = Young's modulus
- a_0 = initial critical half-crack length
- W/A = work done on the specimen per unit area or energy absorbed by the material per unit area
- G_c = the energy release rate under plane stress conditions
- σ = the residual strength (crack strength). It is the impaired or reduced ultimate strength of a member containing a crack, notch, or some form of physical material damage.

Manlabs, Incorporated, has reported a relative good agreement (15%) between the G_c and W/A values in terms of the residual strength (σ) of four medium carbon steels (Reference 4). The measured values of residual strength were based on center-notched tensile tests. The predicted values were based on slow bend (W/A) test values and use of the modified Griffith-Orowan mathematical relation (Reference 4):

$$\sigma = \sqrt{\frac{\left(\frac{W}{A}\right) E}{\pi a_0}}$$

It should be cautioned that this relationship is based upon tensile-testing strain rates and not impact strain rates as utilized to evaluate the Ti-5A1-2.5 Sn welded alloy in this program. However, precracked Charpy impact test for determining fracture resistance is advantageous from the standpoint of economy with respect to:

1. The amount of material used for testing
2. Preparation of test specimens
3. Testing time

Also, based upon a common specimen geometry and testing conditions the influence of the following can be evaluated expediently under Charpy impact fracture testing:

1. Chemical composition
2. Thermal and mechanical treatment
3. Quality of processing
4. Melting practice
5. Temperature effects
6. Quality control of processing methods, such as welding, casting, rolling, forging, and extruding

TEST RESULTS

The data obtained is presented in Table IV and is graphed in Figure 9. If the weld had absorbed interstitial elements, the fracture tests would have revealed a lower fracture resistance in the weld and HAZ compared to the base metal. In fact, 0.5% 0_2 will render Ti uselessly brittle. But, it is obvious from Figure 9 that the weld and HAZ had greater fracture resistance than the base metal. As expected, the fracture resistance (W/A) decreased with decreasing test temperature. But, compared to room temperature W/A values, at -320°F the weld and HAZ retained 1/3 of their fracture resistance with a converted $K_c \approx 125$ ksi $\sqrt{in.}$ indicating good toughness under this severe condition.

Fracture resistance did not appear to be a function of the specimen's location in the plate, i.e., in positions A, B, or C (Figure 7). Weld specimens were tested only in one direction since it was assumed there would be no directional effects in the weld metal.

Mitron has reported the following nominal transverse tensile weld properties for the material tested:

0.2 per cent Y. S.	- 112 ksi
T. S.	- 126 ksi
Elongation	- 7-11 per cent

TABLE IV

Tabulated Ti-5A1-2.5Sn Precracked Charpy Impact Fracture Toughness Test Data

	Room Temperatures			550°F		
	BM	Weld	HAZ	BM	Weld	HAZ
Normal	2050* 2375 1750	- - -	2900 2950 2175	3350 3575 3725	- - -	2600 3775 3700
Avg.	2060		2675	3550		3360
Parallel	1375 1775 1625	2900 3300 2475	2350 2500 2025	3200 2750 3250	3875 4200 3650	3500 3025 3400
Avg.	1600	3100 2900	2425 2290	3100	3900	3310
	-100°F			-320°F (Liquid N_2)		
	BM	Weld	HAZ	BM	Weld	HAZ
Normal	1275 1225 -	- - -	2075 1800 -	575 500 -	- - -	1050 .825 -
Avg.	1250		1940	540		940
Parallel	1200 1225 -	2300 2575 2400	1775 1975 1825	800 600 500	750 925 1075	700 750 750 650
Avg.	1210	2425	1860	630	920	710

* W/A values in $\frac{\text{in.-lbs}}{\text{in.}^2}$

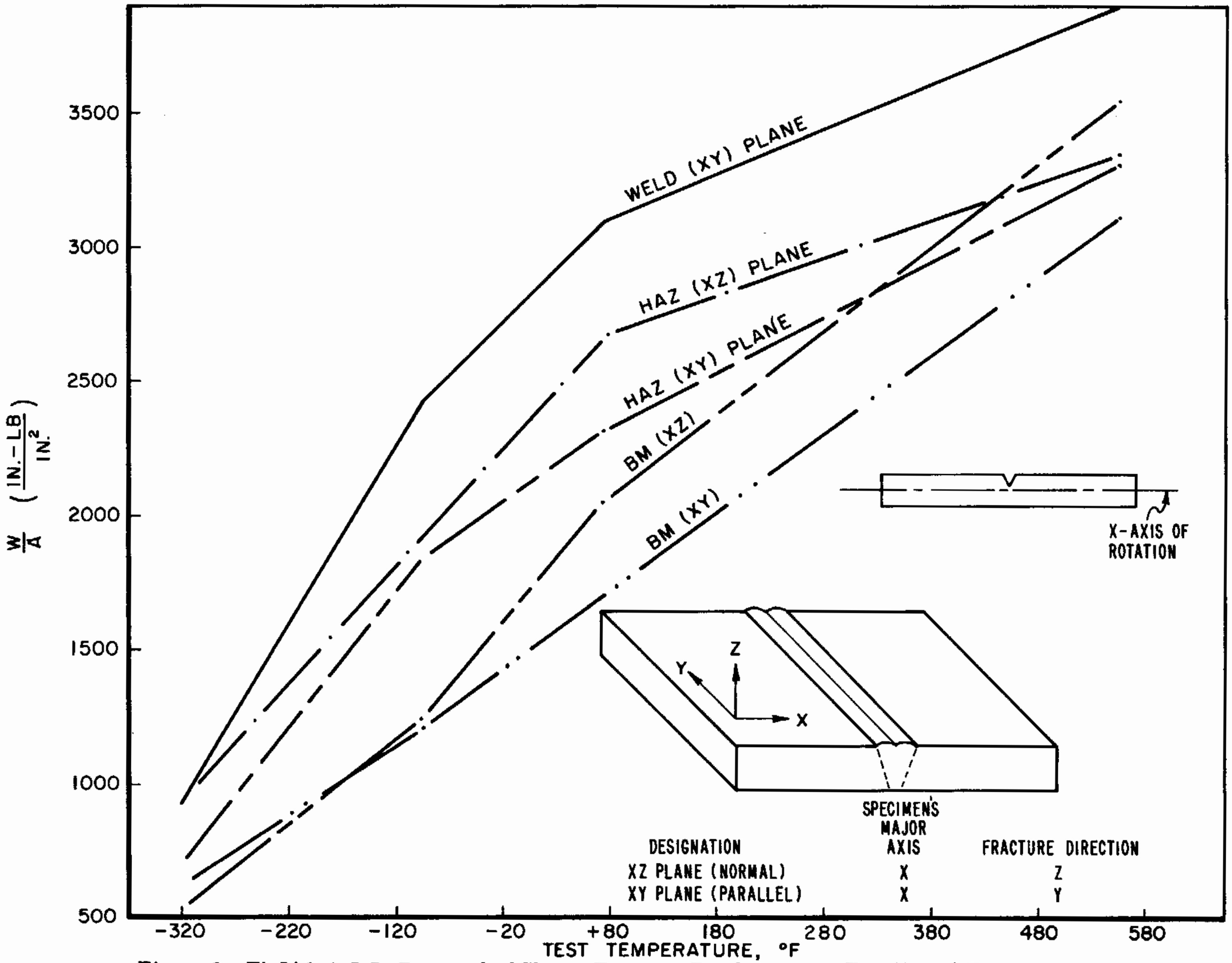


Figure 9. Ti-5Al-2.5 Sn Precracked Charpy Fracture Toughness as a Function of Temperature

CONCLUSIONS

On the basis of fracture resistance, Mitron's backup flux-welding technique is promising. In general, the fracture resistance of the weld and HAZ compared to the base metal was excellent.

The precracked Charpy impact testing technique demostrated that it is advantageous from the standpoint of accuracy, reproducibility, and economy with respect to: (1) the amount of material used for testing, (2) preparation of test specimens, and (3) testing time required to evaluate the welding technique. However, the technique cannot be used to obtain data to calculate accurate K_c's and critical flaw sizes of high strength materials under plane stress or plane strain conditions for design use.

The precracked Charpy testing technique does, however, have merit when evaluating the influence of chemistry, heat treatment, processing history, joining techniques, and quality control on the mechanical properties of metallic materials.

REFERENCES

1. R. M. Evans, Metal Joining, DMIC Review of Recent Developments, Battelle Memorial Institute, Columbus 1, Ohio, August 28, 1964.

2. Mitron Research and Development Corporation, Tungsten Inert Gas Arc Welding Titanium Using a Nonreactive Flux, Interim Engineering Progress Report, May 1964.

3. Mitron Research and Development Corporation, Application of Mitron's Nonreactive Flux in Welding MST-40 Titanium and Ti-5A1-2.5 Sn Plate, Final Report, June 1963.

4. C. E. Hartbower and G. M. Orner, Manlabs, Incorporated, Investigation of Fracture Toughness in High Strength Alloys, ASD-TDR-62-868, Part II, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, January 1964.

5. C. E. Hartbower and G. M. Orner, Manlabs, Incorporated, Metallurgical Variables Affecting Fracture Toughness In High Strength Sheet Alloys, ASD-TDR-62-868, Part I, October 1962.

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13. ABSTRACT

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14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

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