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BELL AEROSYSTEMS COMPANY

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INVESTIGATION OF ALUMINUM ALLOY 6061 T4-T6
WELDED AND UNWELDED

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BELL AEROSYSTEMS COMPANY
DIVISION OF BELL AEROSPACE CORPORATION

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DIVISION OF BELL AEROSPACE CORPORATION

Engineering Laboratories

Bell Laboratory Report

BLR 61-40 (M)

Revision A

INVESTIGATION OF ALUMINUM ALLOY 6061 T4-T6 WELDED AND UNWELDED

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I. INTRODUCTION

The fusion welding of the aluminum alloy 6061 has been a part of fabrication development at Bell Aerosystems since the construction of the Rascal missile. New designs involving performance in or with new environments have necessitated the generation of design data not required previously such as mechanical property data at various cryogenic temperatures. For the most part, data available in the literature due to differences in welding techniques is not applicable. Bell Aerosystems' welding techniques have developed to a stage that allows Bell designers to use higher values than those found in the literature and published by other companies.

Aluminum alloy 6061 was studied from practical welding considerations. Every effort was made throughout the program to duplicate in-shop welding and heat treatment conditions. Areas of concern to the design and metallurgical engineering departments in regard to tank fabrication, including mismatch due to improper line up of various degrees (25, 50 and 100%), effect of weld repairs, hand versus machine, effect of aging, and the effect of low temperatures on the mechanical properties of welded and unwelded, notched and unnotched, solution treated and solution treated and aged material, were studied.

For clarity of presentation, each phase of the program will be reported on separately. However, the interaction of the various parameters reported on must be considered in any end item to be constructed.

Mismatch is encountered in hardware fabrication as the result of poor line up or warpage of one piece of material in respect to another prior to welding. The designer is in need of this information to arrive at sound engineering safety factors.

Weld repairs are a part of the daily routine of any airframe welding shop. However, the variety of conditions encountered make it difficult to assess the depreciation of weld joint strength. Hand repairs of welded parts fabricated with machine welds in which a precise degree of control over speed is exercised are detrimental.

Cryogenic temperatures are to be encountered in the storage of missile propellant fuels. Liquid gases for the above application result in temperatures from -150 F to -423 F. Specialists in this cryogenic field maintain that face-centered cubic metals are superior to the body-centered metals. Aluminum and it's alloys are face-centered cubic but performance within this group varies. Ductility of the aluminum alloys suffers as temperatures approach absolute zero (-460 F). Welded structures of aluminum are more subject to fatigue failure at the low temperatures despite the increase in yield and tensile strength that results from such an environment. It has been the purpose in this program to determine (1) the strength of the material (6061T6) unwelded and welded at -150 F and -320 F, (2) the effect of a "V" notch on welded and unwelded material, (3) the total elongation occurring at temperature, (4) the strain magnitude encountered at the apex of the "V" notch so that a relationship might be arrived at for elongation as reported in a standard two inch uniform cross sectional area specimen and a two inch "V" notch elongation where the cross sectional area is non-uniform due to the presence of the notch.

Heat treatment of aluminum alloys has been and will continue to be a shop practice requiring rigid controls on the equipment used and personnel performing the operations. Heat treatable aluminum alloys such as 6061 develop their properties by solution heat treatment and quenching, which suspends a precipitate (the result of alloying) in the aluminum matrix, followed by either natural or artificial aging, which promotes the growth of the precipitate resulting in a strengthened atomic lattice.

The physical properties of interest of the 6061 aluminum alloy studied herein are given in Table I.

TABLE I

Physical Properties of 6061 Aluminum Alloy

Density	.098 lb/in^3
Melting range (F)	1080-1200
Coeff. of Thermal Expansion (in/in/F x 10^{-6}) 68-212 F	13.1
Thermal Conductivity BTU/in/ft^2/F/hr at 77 F	1070 (T6)

The guarantee minimums for 6061T4 and T6 set forth in Military Handbook 5 are given in Table II.

TABLE II

Guarantee Minimums for Aluminum Alloy 6061

	T4 Condition	T6 Condition
Tensile Ultimate	30,000	42,000
Yield Strength (0.2% offset)	16,000	35,000
% Elongation in 2 inches	16	10

II. TEST PROCEDURE

A. Mismatch

In this phase a group of tensile specimens was deliberately misaligned to obtain 25, 50 and 100% mismatch with 0.125 inch thick material and 50 and 100% mismatch with 0.064 inch material. The 25% mismatch was not run on the 0.064 inch material. On the thinner material this degree of mismatch was very small, approximately 0.016 of an inch. The mismatch is expressed as percentage of total sheet thickness. Butt joints were made in 4 inch by 12 inch plates. These plates yielded nine tensile specimens per plate. The bars were tested at room temperature under uniaxial load conditions (shims were used to maintain alignment).

Figure 1 shows a typical grouping of the samples. Samples marked A are representative of 100% mismatch, B samples 50% and the C sample 25%. The excess weld metal shown in the pictures of the 0.125 inch samples A and B was not ground off for it has no effect on the mechanical properties.

The mechanical properties of the specimens tested are summarized in Tables III and IV. All specimens were welded in the T4 condition and aged to the T6 temper after welding.

TABLE III

Room Temperature Mechanical Properties of 6061 T6 Heliarc Butt Welds

(.124" Thick Material)

After various percentages of mismatch, material welded in T4 condition 20 ipm and aged to T6.

Specimen Number	Spec. Thick inches	% Mismatch	Tensile Str. (psi)	Yield Str (psi)	Elong. % in 2"	Fracture Area
1.	.125	25	37,300	36,400	4	Base Metal
2.	.125	25	36,900	35,000	4	Base Metal
3.	.125	25	39,700	34,600	4	Base Metal
Avg.			37,966	35,333	4	
1.	.125	50	42,100	32,900	2	Edge Weld
2.	.125	50	39,800	33,000	2	Edge Weld
3.	.125	50	40,200	33,400	2	Edge Weld
Avg.			40,700	32,966	2	
1.	.125	100	33,800	26,400	2	Edge Weld
2.	.125	100	33,700	25,200	1	Edge Weld
3.	.125	100	36,600	26,600	2	Edge Weld
Avg.			34,700	26,066	1.67	

TABLE IV

Room Temperature Mechanical Properties of 6061T6 Heliarc Butt Welds

(.064" Thick Material)

After various percentages of mismatch, material welded in T4 condition 20 ipm and aged to T6.

Specimen Number	Spec. Thick. inches	% Mismatch	Tensile Str. (psi)	Yield Str. (psi)	Elong. % in 2"	Fracture Area
1.	.064	50	42,000	-	2	Edge Weld
2.	.064	50	42,100	32,700	2	Edge Weld
3.	.064	50	40,600	30,800	2	Edge Weld
Avg.			4.566	31,700	2	
1.	.064	100	32,300	31,600	.5	Edge Weld
2.	.064	100	34,700	33,800	.5	Edge Weld
3.	.064	100	32,700	32,600	.5	Edge Weld
Avg.			33,233	32,666	0.5	

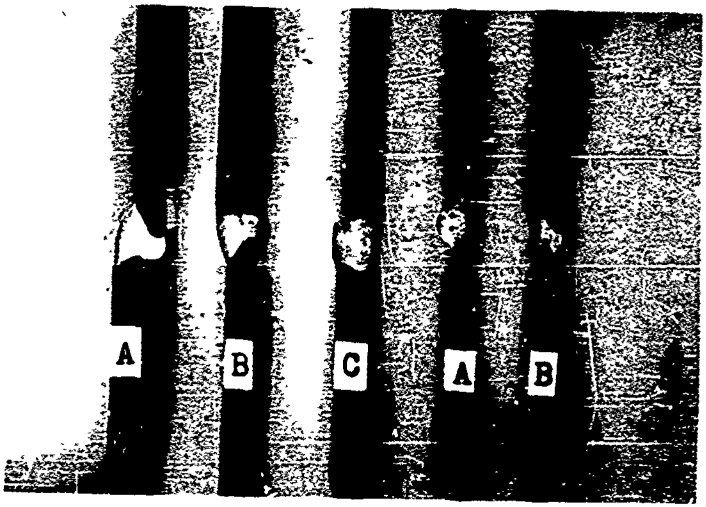

Figure 1. Photomacrograph showing various percentages of mismatch. Specimens marked

A = 100%
B = 50%
C = 25%

B. Weld Repair

This portion of the program deals with the effort made to ascertain strength depreciation following weld repairs. It is standard practice in the fabrication of parts to grind out defects found by radiographic techniques and re-weld the joint. The size and depth of the weld repair determines the area of depreciation.

Three plates were heliarc welded with the direction of rolling and three transverse to the direction of rolling. Fifty per cent of the weld metal was ground out of, 2 plates manually heliarc welded with the direction of rolling, two plates manually heliarc welded transverse to the direction of rolling, two plates automatic heliarc welded with the rolling direction and two plates automatically heliarc welded in the transverse rolling direction. The plates were then rewelded using the same welding method used on the original weld. One of two plates from each group was ground out for the second time and re-welded. After welding the plates were artificially aged to the T6 condition. Tensile specimens blanks were then cut from the welded plates and subsequently machined to the standard tensile specimen configuration. Tables V through XI present the data obtained. The control samples were taken at the beginning and end of each weld repair. They are representative of the welded sheet unrepaired.

TABLE V

6061T4 Manual weld and Aged to T6

Thickness		.050"				.125"			
	Specimen Number	Tensile Str.	Yield Str.	Elong.	Fracture	Tensile Str.	Yield Str.	Elong.	Fracture
Transverse	1.	27,400	22,800	2	OW	30,000	22,500	4	OW
	2.	27,000	21,400	2	OW	29,800	22,800	4	OW
	3.	26,700	21,700	2	OW	29,500	20,800	5	CW
	4.	26,500	21,100	3	OW	27,900	17,200	5	OW
	5.	27,000	20,400	2	OW	27,100	18,100	1	IW
	6.	26,800	21,800	2	OW	30,000	20,300	4	OW
	Avg.	26,900	21,500	2.2		29,050	20,300	3.8	
Longitudinal	1.	27,700	21,500	3	OW	28,500	20,300	5.5	OW
	2.	27,400	20,900	2	OW	28,400	20,500	5.5	OW
	3.	27,100	22,400	3	OW	27,200	17,600	7	OW
	4.	26,600	20,200	3	OW	27,600	20,600	5	OW
	5.	27,500	22,500	3	OW	28,200	21,400	5	OW
	6.	27,600	24,400	3	OW	28,700	21,300	5.5	OW
	Avg.	27,300	22,000	2.8		28,100	20,300	5.6	

Form 9948 Rev. 1949

TABLE VI

6061T4 - Automatic Weld(1) and Aged to T6

Thickness	Specimen Number	.050" Tensile Str.	.050" Yield Str.	.050" Elong.	.050" Fracture	.125" Tensile Str.	.125" Yield Str.	.125" Elong.	.125" Fracture
Transverse	1.	42,600	37,400	7	OW	50,200	45,400	10	OW
	2.	42,400	37,200	7	OW	50,200	45,400	9	OW
	3.	42,400	37,100	7	OW	50,200	45,400	10	OW
	4.	42,200	37,400	7	OW	50,300	45,400	10	OW
	5.	42,000	37,100	7	OW	50,300	45,200	10	OW
	6.	42,400	37,000	7	OW	50,200	45,400	10	OW
	Avg.	42,300	37,200	7		50,200	45,400	9.8	
Longitudinal	1.	42,700	38,700	7	OW	50,200	46,500	5	IW
	2.	43,400	39,000	7	OW	51,000	46,800	9	OW
	3.	43,200	38,800	7	OW	51,100	46,800	8	OW
	4.	43,300	38,800	7	OW	50,500	46,500	10	OW
	5.	42,700	38,400	6	OW	50,500	46,700	9	OW
	6.	42,700	38,400	6	OW	50,500	46,700	9	OW
	Avg.	43,100	38,800	6.7		50,100	46,800	8.3	

(1) Welded at 20 ipm.

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TABLE VII

6061T4 - Automatic Weld (1) and (one) Repair -- Aged to T6

Thickness		.050"				.125"			
	Specimen Number	Tensile Str.	Yield Str.	Elong.	Fracture	Tensile Str.	Yield Str.	Elong.	Fracture
Transverse Control Specimens	1.	42,400	-	6	OW	43,800	38,200	5	OW
	2.	42,400	38,000	6	OW	42,600	36,300	5	OW
	Avg.	42,400	38,000	6		43,200	37,250	5	
Repair Area	3.	-	-	-	-	33,600	28,400	4	OW
	4.	40,200	36,500	4	OW	34,000	28,700	3	OW
	5.	39,400	36,100	4	OW	32,700	25,700	3	OW
	6.	38,200	35,900	3	OW	32,600	27,200	3	OW
	7.	37,000	36,000	3	OW	32,600	27,000	3	OW
	8.	33,900	36,200	3	OW	32,600	27,000	3	OW
	Avg.	39,100	36,100	3.4		33,200	27,500	3.2	
Longitudinal Control Specimens	1.	42,800	38,400	6	OW	41,900	-	2	TW
	2.	42,000	38,400	6	OW	43,900	38,600	5	OW
	Avg.	42,400	38,400	6		42,900	38,800	3.5	
Repair Area	3.	38,400	36,100	3	OW	37,400	34,000	3	OW
	4.	38,200	35,100	3	OW	37,000	33,400	3	OW
	5.	40,000	36,600	4	OW	35,500	3[illegible],000	3	OW
	6.	39,300	36,600	3.5	OW	35,900	34,400	3	OW
	7.	40,800	37,100	4	OW	39,500	35,600	3	OW
	8.	39,[illegible]	36,100	[illegible]	OW	37,500	33,200	3	OW
	. . .	39,400	36,300	3.4		37,100	33,900	3	

(1) Welded at 20 ipm.

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TABLE VIII

6061T4 - Automatic Weld (1) and (two) Repairs - Aged to T6

Thickness		.050"				.125"			
	Specimen Number	Tensile Str.	Yield Str.	Elong.	Fracture	Tensile Str.	Yield Str.	Elong.	Fracture
Transverse Control Specimens	1.	43,800	36,200	7	OW	44,100	38,300	4	OW
	2.	42,400	36,400	6	OW	43,000	39,200	5	OW
	Avg.	43,100	36,300	6.5		43,550	38,750	4.5	
Repair Area	3.	36,400	35,900	2	OW	32,500	26,800	4	OW
	4.	36,100	-	2	OW	32,400	26,600	4	OW
	5.	34,000	31,200	2	OW	31,800	26,400	4	OW
	6.	35,700	30,600	2	OW	33,200	27,800	4	OW
	7.	35,200	32,600	2	OW	33,800	28,800	4	OW
	8.	35,500	32,900	2	OW	32,500	26,100	4	OW
	Avg.	35,500	32,700	2		32,700	27,100	4	
Longitudinal Control Specimens	1.	42,800	36,900	6	OW	43,700	40,000	5	OW
	2.	43,900	39,400	7	OW	43,700	38,300	5	OW
	Avg.	43,350	38,150	6.5		43,700	39,150	5	
Repair Area	3.	37,400	35,700	3	OW	33,300	26,400	4	OW
	4.	38,000	36,900	2	OW	33,100	26,600	4	OW
	5.	38,400	35,400	2	OW	33,000	27,200	4	OW
	6.	37,300	34,000	2	OW	33,400	27,400	4	OW
	7.	39,500	37,200	2	OW	34,900	29,200	4	OW
	8.	37,000	32,700	2	OW	33,200	28,200	4	OW
	Avg.	38,000	35,300	2.2		33,500	27,500	4	

(1) Welded at 20 ipm.

TABLE IX

6061T4 - Sigmaweld and Aged to T6

Thickness .125"

	Transverse				Longitudinal			
Specimen Number	Tensile Str.	Yield Str.	Elong.	Fracture	Tensile Str.	Yield Str.	Elong.	Fracture
1.	41,000	37,200	4	OW	42,700	39,800	3.5	OW
2.	41,100	38,300	5	OW	41,500	39,200	4.5	OW
3.	41,200	38,400	4	OW	41,400	38,200	4	OW
4.	42,700	39,100	3	OW	41,400	38,500	4	OW
5.	43,200	39,300	4	OW	42,000	39,000	4	OW
6.	42,400	37,500	4	OW	43,100	40,300	3.5	OW
Avg.	41,900	38,300	4		42,000	39,200	3.9	

TABLE X

6061T4 - Sigma Weld and (one) Repair - Aged to T6

Thickness .125"		Transverse				Longitudinal			
	Specimen Number	Tensile Str.	Yield Str.	Elong.	Fracture	Tensile Str.	Yield Str.	Elong.	Fracture
Control Specimens	1.	44,500	39,800	5	OW	42,100	37,800	5	OW
	2.	42,800	38,100	5	OW	42,200	37,500	5	OW
	Avg.	43,650	38,950	5		42,150	37,650	5	
Repair Area	3.	36,400	33,200	3	OW	36,500	32,700	3	OW
	4.	36,600	33,000	3	OW	36,300	30,000	3	OW
	5.	36,600	33,000	3	OW	34,600	30,600	3	OW
	6.	36,000	33,100	3	OW	35,000	29,900	3	OW
	7.	36,600	31,400	3	OW	34,500	29,000	3	OW
	8.	35,500	30,500	3	OW	35,100	30,000	3	OW
	Avg.	36,300	32,400	3		35,200	30,400	3	

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TABLE XI

6061T4 - Sigma Weld and (two) Repairs - Aged to T6

Thickness .125"

		Transverse				Longitudinal			
	Specimen Number	Tensile Str.	Yield Str.	Elong.	Fracture	Tensile Str.	Yield Str.	Elong.	Fracture
Control Specimens	1.	44,600	38,600	5	OW	43,900	38,200	5	OW
	2.	38,100	32,800	4	OW	44,400	38,700	5	OW
	Avg.	41,350	35,700	4.5		44,150	38,450	5	
Repair Area	3.	33,100	28,700	4	OW	32,300	26,400	3	OW
	4.	32,700	27,200	4	OW	32,800	26,100	3	OW
	5.	32,200	25,700	4	OW	32,800	26,300	4	OW
	6.	32,100	26,800	4	OW	31,500	24,600	3	OW
	7.	32,900	26,700	4	OW	32,400	25,300	4	OW
	8.	33,300	25,800	3	OW	32,900	25,400	4	OW
	Avg.	32,700	26,850	3.8		32,450	25,700	3.5	

C. Mechanical Properties

This section presents the mechanical properties of the aluminum alloy 6061 in the welded and unwelded conditions. The alloy was studied in the solution heat treated condition (T4), and in the fully aged condition (T6), in both directions of rolling, transverse and longitudinal, as well as at various temperatures (-320 F, -65 F, R.T. and +150 F). "V" notches were also machined into welded and unwelded test bars, in both heat treat tempers, and tested at the various temperatures. The "V" notch used was representative of a stress concentration factor (K) of 3 on the 0.125 inch material.

The data obtained under the specified conditions is presented in Tables XII through XXVII. Figures 2 through 30 give representative curves of a single specimen under the various tempers, temperatures and welded conditions studied.

TABLE XII

Unwelded 6061 T4 Transverse Properties

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	45,240	25,550	20	41,240	22,705	28
	2	44,975	25,255	24	41,605	22,930	28
	3	45,660	25,390	26	41,360	23,715	26
	Avg.	45,530	25,400	23.3	41,400	23,115	27.3
R.T.	1	42,048	22,605	23	38,795	21,167	25
	2	42,300	23,923	23	38,640	21,725	25
	3	42,739	23,197	23	38,418	22,305	24
	Avg.	42,362	23,242	23	38,618	21,732	24.6
+150°F	1	40,670	-	23	37,890	23,820	25
	2	40,825	23,235	22	37,820	20,620	22
	3	40,915	22,620	22	37,865	20,670	24
	Avg.	40,800	22,925	22.3	37,860	21,700	23.6
-320°F	1	59,140	28,685	34	57,460	28,170	32
	2	58,395	28,905	34	58,610	28,465	37
	3	59,250	28,550	36	57,795	28,115	33
	Avg.	59,100	28,710	34.6	57,955	28,250	34

TABLE XIII

Unwelded 6061 T4 Longitudinal Properties

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	47,190	26,560	25	41,275	24,320	25
	2	46,790	26,295	20	41,115	22,800	24
	3	46,945	26,265	22	41,765	22,900	26
	Avg.	46,975	20,375	22.3	41,385	23,340	25
R.T.	1	44,185	25,250	17	38,545	21,195	22
	2	42,480	24,750	20	38,555	21,260	22
	3	43,435	24,220	24	38,445	21,419	23
	Avg.	43,365	24,740	20.3	38,515	21,290	22.3
+150°F	1	42,440	24,330	21	37,970	20,835	21
	2	42,030	24,595	23	38,130	21,140	22
	3	42,225	23,900	23	38,475	20,990	22
	Avg.	42,225	24,275	22.3	38,190	20,990	21.6
-320°F	1	64,235	32,700	33	57,130	28,130	37
	2	63,160	31,630	25	57,510	27,775	37
	3	64,635	33,290	34	57,745	28,445	37
	Avg.	64,010	32,540	31	57,460	28,115	37

TABLE XIV

As-welded 6061-T4 (Transverse Properties of Sheet)[1]

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	37,270	21,390	11	37,265	19,255	16
	2	36,225	21,360	11	37,010	20,040	18
	3	38,715	24,570	11	37,185	20,235	16
	Avg.	37,405	22,440	11	37,155	19,845	16.6
R.T.	1	32,610	20,320	8	34,790	19,385	14
	2	35,560	20,775	10	34,255	19,530	13
	3	33,675	19,570	10	34,360	18,710	14
	Avg.	33,945	20,220	9.3	34,465	19,210	13.6
-150°F	1	37,000	22,200	10	34,645	18,530	14
	2	34,440	20,630	9	34,290	19,270	14
	3	-	-	-	35,815	19,625	18
	Avg.	35,720	21,415	9.5	34,915	19,140	15.3
-320°F	1	53,570	29,900	13	53,870	26,550	21
	2		29,900	5	-	-	-
	3	56,475	30,130	17	53,905	26,235	24
	Avg.	55,020	29,975	11.5	53,890	26,395	22.5

(1) Welded at 20 ipm.

Table XV

As-Welded (1) 6061-T4 (Longitudinal Properties of Sheet)

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	37,915	22,565	11	37,420	20,720	16
	2	39,575	23,555	11	36,120	19,895	14
	3	35,865	20,950	11	36,610	20,480	14
	Avg.	37,785	22,355	11	36,715	20,365	14.6
R.T.	1	37,125	21,280	10	34,910	18,475	14
	2	35,450	20,655	10	34,760	18,820	14
	3	37,515	21,915	10	35,360	18,860	16
	Avg.	36,695	21,285	10	35,010	18,720	14.6
+150°F	1	37,220	22,845	10	35,540	19,380	14
	2	36,710	22,405	10	35,380	20,085	14
	3	37,250	22,160	10	36,490	19,950	17
	Avg.	37,060	22,470	10	35,805	19,800	15
-320°F	1	50,915	24,195	18	53,280	26,135	21
	2	52,755	27,450	18	-	-	-
	3	53,615	25,470	18	55,590	26,415	22
	Avg.	52,430	25,705	18	54,435	26,275	21.5

(1) Welded at 20 ipm.

TABLE XVI

Unwelded Notched 6061-T4 Transverse Properties *

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	45,310	34,220	3	42,570	30,065	4
	2	45,815	33,900	3	44,930	30,460	4
	3	45,550	34,110	2	43,600	30,545	4
	Avg.	45,560	34,075	2.6	43,700	30,355	4
R.T.	1	43,125	31,965	4	42,545	29,200	5
	2	43,735	31,575	3	41,935	29,840	6
	3	42,265	31,200	3	41,380	29,215	4.5
	Avg.	43,040	31,580	3.3	41,955	29,420	5.2
+150°F	1	43,290	31,760	3	40,100	29,625	4
	2	41,845	31,040	3	40,455	27,920	4
	3	42,110	31,780	3	40,085	29,085	4
	Avg.	42,415	31,525	3	40,215	20,075	4
-320°F	1	58,300	45,060	2	50,655	31,955	4
	2	59,205	43,540	2	57,410	39,445	4
	3	58,200	43,215	2	57,160	39,530	4
	Avg.	58,570	44,170	2	55,075	36,475	4

* Notch Factor = K3

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TABLE XVII

Unwelded Notched 6061-T4 Longitudinal Properties*

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	46,360	34,835	3	43,950	31,855	4
	2	46,620	34,630	3	44,045	30,395	4
	3	46,620	34,477	3	43,715	31,120	4
	Avg.	46,530	34,645	3	43,905	31,125	4
R.T.	1	43,545	-	3	41,665	28,630	4
	2	44,125	32,445	3	42,070	29,300	4
	3	44,125	32,290	3	43,055	29,525	4
	Avg.	43,930	32,365	3	42,265	29,150	4
+150°F	1	42,110	32,415	3	40,850	28,475	4
	2	42,635	32,095	3	41,345	28,595	4
	3	42,265	31,505	3	41,415	29,115	4
	Avg.	42,335	32,005	3	41,205	28,730	4
-320°F	1	61,355	44,675	3	59,650	39,045	4
	2	61,110	44,555	3	58,465	38,950	4
	3	60,845	44,370	3	58,600	38,925	4
	Avg.	61,105	44,535	3	58,905	38,973	4

* Notch Factor - K3

Form 9846 Rev. 1948

TABLE XVIII

As-welded (1) and notched 6061-T4 (Transverse Properties of Sheet)*

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	25,685	18,385	4	25,660	19,295	3
	2	25,020	20,175	3	31,520	21,660	3
	3	28,495	18,110	6	27,335	20,440	3
	Avg.	26,400	18,890	4.3	28,170	20,465	3
R.T.	1	26,000	21,065	2	27,625	18,205	3
	2	29,235	18,985	5	27,975	20,565	3
	3	27,300	19,220	4	26,515	19,675	2
	Avg.	27,511	19,755	3.6	27,370	19,480	2.6
+150°F	1	26,480	19,335	3	26,495	-	3
	2	27,680	18,260	4	30,230	20,280	3
	3	24,073	17,075	4	28,910	19,200	3
	Avg.	26,185	18,220	3.6	28,545	19,740	3
-320°F	1	32,440	25,550	2	33,750	-	3
	2	32,355	22,940	2	31,920	26,420	2
	3	30,935	23,895	3	32,475	26,530	2
	Avg.	32,075	24,130	2.3	32,715	26,475	2.3

* Notch Factor = K3

(1) Welded at 20 ipm.

TABLE XIX

As-welded (1) and Notched 6061-T4 (Longitudinal Properties of Sheet) *

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	28,160	17,610	6	30,465	20,805	4
	2	24,475	16,925	4	29,365	20,475	4
	3	28,620	18,785	5	31,390	22,165	3
	Avg.	27,085	17,775	5	30,405	21,150	3.6
R.T.	1	23,380	14,290	6	25,940	18,940	4
	2	26,820	18,750	5	-	-	-
	3	25,990	18,285	4	-	-	-
	Avg.	25,395	17,105	5			
+150°F	1	25,060	17,325	5	27,835	19,580	4
	2	24,790	16,520	4	29,685	20,725	4
	3	26,555	-	4	-	-	-
	Avg.	25,470	16,920	4.3	28,760	20,055	4
-320°F	1	31,430	24,745	2	-	-	-
	2	29,310	21,035	3	36,140	24,830	2
	3	31,305	22,890	3	34,055	26,110	3
	Avg.	30,680	22,890	2.0	35,095	25,470	2.5

* Notch Factor - K3

(1) Welded at 20 ipm.

TABLE XX

Unwelded 6061-T6 Transverse Properties

Thickness		.064"				.125"			
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Total Elong in 2"	Tensile Str.	Yield Str.	Elong	Total Elong in 2"
-320°F	1	65,505	47,850	22		62,620	49,485	21	
	2	65,430	48,130	22		62,901	49,935	21	
	3	65,905	48,320	22		60,856	-	20.5	19.68
	4	-	-	-		60,410	45,741	22	18.15
	5	-	-	-		60,970	46,343	21	
	Avg.	65,556	48,100	22		61,551	47,876	21.1	18.91
-65°F	1	54,345	44,170	16		50,970	43,765	15	
	2	54,345	44,075	16		50,935	43,825	15	
	3	54,430	44,035	16		50,650	41,940	15	
	4	-	-	-		49,600	41,920	14.5	
	5	-	-	-		49,440	41,499	14.5	13.75
	6	-	-	-		49,195	41,190	14.5	13.52
	Avg.	54,380	44,095	16		50,130	44,023	14.75	13.64
R.T.	1	50,140	41,285	14		47,185	41,560	13	
	2	49,390	40,765	14		47,085	41,290	12	
	3	49,970	41,695	14		47,410	41,625	12	
	4	49,070	40,683	14		46,385	40,393	14	
	5	49,215	40,440	14		45,555	-	13	
	6	48,895	41,325	16		46,505	40,032	12	12.53
	7	48,590	40,467	14.5	13.18	46.520	40,253	12.5	12.19
	8	48.935	40.547	14	13.44	56.565	40,527	12.5	11.06
	Avr.	49,275	40,900	14.3	13.31	46,650	40,811	12.6	11.93

TABLE XX (continued)

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield str.	Elong
+150°F	1	48,340	40,475	15	46,165	40,790	13.7
	2	48,025	39,970	14	46,350	41,450	13.7
	3	47,910	40,700	14	47,375	42,050	13
	Avg.	48,090	40,380	14.3	46,630	41,430	13.5

TABLE XXI

Unwelded 6061T6 - Longitudinal Properties

Thickness		.064"				.125"			
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Total Elong in 2"	Tensile Str.	Yield Str.	Elong	Total Elong in 2"
-320°F	1	67,460	50,505	22		63,385	50,705	-	
	2	67,175	52,315	22		63,490	50,985	-	
	3	67,460	51,680	22		63,785	51,090	-	
	4	-	-	-		62,664	48,694	20	
	5	-	-	-		62,171	49,147	20	
	6	-	-	-		61,687	48,715	14	
	Avg.	67,365	51,500	22		62,864	49,889	18	
-65°F	1	54,760	46,665	18		50,920	45,690	15	
	2	54,135	46,400	16		51,050	45,865	15	
	3	54,395	46,680	16		-	-	-	
	4	-	-	-		50,155	44,312	14.5	13.65
	5	-	-	-		49,845	44,197	14	13.30
	6	-	-	-		49,385	43,642	13.5	13.00
	Avg.	54,430	46,580	16.6		50,400	44,804	14.5	13.31
R.T.	1	51,250	44,360	16		47,200	43,200	13	
	2	50,140	43,935	15		46,940	42,935	13	
	3	50,205	43,870	15		47,055	43,310	13	
	4	49,685	43,270	13		46,285	41,718	14	
	5	48,285	42,025	14		46,925	42,215	12.5	
	6	49,695	43,222	14.5	14.06	46,835	42,114	12.5	12.03
	7	50,150	43,731	14	13.44	46,835	42,221	12	11.87
	8	49,050	42,595	14	13.56	46,565	42,075	13	12.50
	Avg.	49,810	43,378	14.4	13.69	46,830	42,473	12.9	12.10

TABLE XXI (continued)

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
+150°F	1	48,550	43,285	14	45,845	42,340	13
	2	48,550	42,875	14	46,200	42,590	13
	3	48,610	42,075	14	46,015	42,165	13
	Avg.	48,570	42,745	14	46,000	42,365	13

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TABLE XXII

6061-T4 Welded[(1)] and Aged (Transverse Properties of Sheet)

Thickness		.064"			.125"			
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong	Total Elong in 2"
-65°F	1	45,300	39,850	4	48,650	42,635	8	
	2	49,420	45,355	2	49,415	43,545	8.5	
	3	48,125	43,125	4	46,700	41,155	6	1.59
	4	-	-	-	45,116	39,784	3.5	3.31
	5	-	-	-	45,609	39,384	4.0	3.69
	6	-	-	-	40,923	40,023	4.0	
	Avg.	47,615	42,775	3.3	47,074	41,238	5.7	2.86
R.T.	1	44,520	40,035	4	44,290	40,325	6	
	2	-	-	-	-	-	-	
	3	46,045	41,860	3	43,715	39,530	6	
	4	-	-	-	40,958	36,692	3.5	2.34
	5	-	-	-	43,245	30,053	4.0	3.19
	6	-	-	-	42,178	37,577	4.0	3.00
	Avg.	45,285	40,950	3.5	42,877	36,835	4.6	2.84
+150°F	1	45,285	42,075	3	44,550	39,845	8	
	2	46,335	43,205	3	43,955	38,875	7	
	3	43,885	41,085	3	44,070	38,850	7	
	Avg.	45,165	42,190	3	44,190	39,190	7.3	
-320°F	1	62,800	-	6	56,290	48,385	4	
	2	55,360	50,495	1	60,855	47,955	12	
	3	62,155	50,515	8	60,610	48,295	12	
	4	-	-	-	[illegible]	45,937	1.5	1.77
	5	-	-	-	54,140	45,732	3	3.48
	Avg.	60,105	50,505	5	56,504	47,261	6.5	2.37

(1) Welded at 20 ipm.

TABLE XXXIII

Welded and Aged 6061-T4 (Longitudinal Properties of Sheet) (1)

Thickness		.064"			.125"			
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong	Total Elong in 2"
-65°F	1	45,525	40,135	4	48,615	43,810	6	
	2	49,485	44,785	4	46,695	41,130	6	
	3	44,850	40,075	4	47,090	41,325	6	
	4	-	-	-	47,741	41,963	4	4.73
	5	-	-	-	41,963	39,366	1	.6
	6	-	-	-	44,444	39,187	3	2.63
	Avg.	46,620	41,665	4	46,091	41,130	4.3	2.65
R.T.	1	39,690	36,805	3	44,000	40,125	6	
	2	42,472	-	3	43,900	38,695	6	
	3	48,990	45,735	3	45,845	41,075	6	
	4	-	-	-	43,984	39,484	5	3.56
	5	-	-	-	43,818	39,687	4	4.00
	Avg.	43,715	40,270	3	44,309	39,813	5.4	3.78
+150°F	1	-	-	-	43,765	39,685	6	
	2	45,760	43,175	3	42,540	38,390	5	
	3	46,610	44,005	3	42,370	38,500	5	
	Avg.	46,185	43,590	3	42,890	38,860	5.3	
-320°F	1	59,415	-	6	-	-	-	
	2	55,995	49,985	2	58,275	46,295	10	
	3	55,520	45,910	2	60,365	48,005	10	
	4	-	-	-	57,287	46,059	4	5.38
	5	-	-	-	55,968	48,226	3.5	3.12
	6	-	-	-	57,729	46,845	4	5.24
	Avg.	56,975	47,935	3.3	57,905	47,061	6.3	4.58

(1) Welded at 20 ipm.

TABLE XXIV

Unwelded Notched 6061-T6 Transverse Properties*

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	55,965	53,305	2	56,705	53,980	2
	2	56,195	53,455	2	56,450	53,455	2
	3	56,745	54,275	2	56,710	54,370	2
	Avg.	56,300	53,680	2	56,620	53,935	2
R.T.	1	52,630	50,495	1	53,145	52,090	2
	2	53,570	51,225	1	53,280	51,425	2
	3	53,290	50,890	2	52,550	50,080	2
	4	52,820	-	1.5	52,175	50,054	2
	5	53,075	50,462	1.5	51,770	49,646	2
	Avg.	53,077	50,768	1.4	52,584	50,659	2
+ 150°F	1	50,645	48,490	2	51,480	49,815	2
	2	50,985	49,340	2	51,610	50,000	2
	3	50,710	48,905	2	51,665	49,865	2
	Avg.	50,780	48,912	2	51,585	49,890	2
-320°F	1	69,890	61,600	2	69,070	-	3
	2	68,450	60,565	2	69,540	61,605	2
	3	69,050	61,795	2	68,940	61,135	2
	Avg.	69,130	61,320	2	69,185	61,370	2.3

* Notch Factor = [illegible]

Form 9046 Rev. 1948

TABLE XXV

Unwelded Notched 6061-T6 Longitudinal Properties *

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	57,120	54,560	2	56,715	54,175	2
	2	56,350	53,790	2	56,585	53,885	2
	3	56,510	53,905	2	55,920	53,700	2
	Avg.	56,660	54,085	2	56,405	53,920	2
R.T.	1	53,455	50,820	2	52,090	50,235	3
	2	53,230	50,530	2	53,580	-	3
	3	53,610	49,245	2	52,485	50,985	3
	4	54,145	51,160	2	51,560	49,454	2
	5	54,120	51,154	2	51,910	49,771	2
	Avg.	53,712	50,582	2	52,325	50,111	2.6
+150°F	1	51,455	49,460	2	50,765	48,940	2
	2	50,915	48,655	2	50,900	49,235	2
	3	50,915	48,975	2	51,030	49,365	2
	Avg.	51,095	49,030	2	50,895	49,180	2
-320°F	1	72,700	60,335	2	69,805	61,870	2
	2	71,155	63,435	2	69,145	62,005	2
	3	70,370	62,275	2	68,940	60,355	2
	Avg.	71,408	62,015	2	69,297	61,410	2

* Notch Factor = K3

Form 9846 Rev. 1960

TABLE XXVI

6061-T4 Welded and Aged,(1) Notched (Transverse Properties of Sheet)*

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	35,675	33,255	4	38,815	-	1
	2	38,920	35,755	2	39,885	-	1
	3	-	-	-	35,670	-	1
	Avg.	37,300	34,505	3	38,125	-	1
R.T.	1	-	-	-	39,540	-	2
	2	35,335	32,960	1	35,630	-	2
	3	33,610	-	1	36,765	-	2
	Avg.	34,470	32,960	1	37,310	-	2
+150°F	1	37,460	36,190	1	39,615	-	2
	2	34,000	31,920	2	39,245	-	2
	3	31,390	28,480	2	36,935	-	1
	Avg.	34,285	32,195	1.6	38,600	-	1.6
-320°F	1	46,245	39,105	1	44,825	-	1
	2	39,680	36,745	1	-	-	1
	3	37,535	36,275	1	41,856	-	1
	Avg.	39,153	37,375	1	43,345	-	1

* Notch Factor = K3

(1) Welded at 20 ipm.

Form 9848 Rev. 1948

TABLE XXVII

6061-T4 Welded(1) and Aged, Notched (Longitudinal Properties of Sheet)

Thickness		.064"			.125"		
Test Temp	Specimen Number	Tensile Str.	Yield Str.	Elong	Tensile Str.	Yield Str.	Elong
-65°F	1	33,455	28,055	[illegible]	41,405	-	1
	2	35,910	33,635	[illegible]	43,760	-	1
	3	33,745	31,635	[illegible]	36,945	-	1
	Avg.	34,370	31,110	[illegible].6	40,700	-	1
R.T.	1	33,590	31,075	1	42,125	41,165	1
	2	33,410	29,440	2	38,580	-	1
	3	32,735	30,035	2	-	-	1
	Avg.	33,245	30,185	1.6	40,355	41,165	1
+150°F	1	20,465	26,315	2	42,080	41,145	2
	2	32,830	29,325	2	39,035	37,420	2
	3	34,720	33,250	2	40,540	39,405	2
	Avg.	32,340	29,630	2	40,550	39,325	2
-320°F	1	38,135	-	1	41,620	-	1
	2	39,410	38,710	1	40,565	-	2
	3	40,130	38,280	1	47,100	-	2
	Avg.	39,225	38,495	1	43,095	-	1.6

* Notch Factor = K3

(1) Welded at 20 ipm.

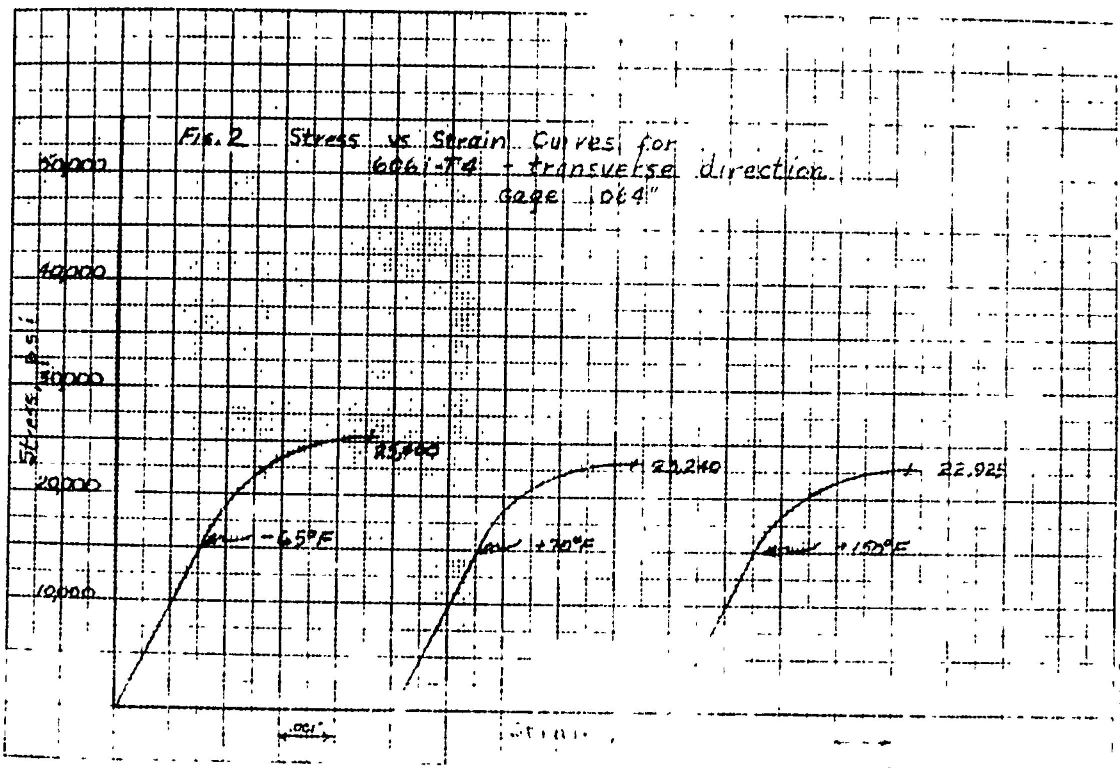


Fig. 2 Stress vs Strain Curves for 6061-T4 - transverse direction
Gage .064"

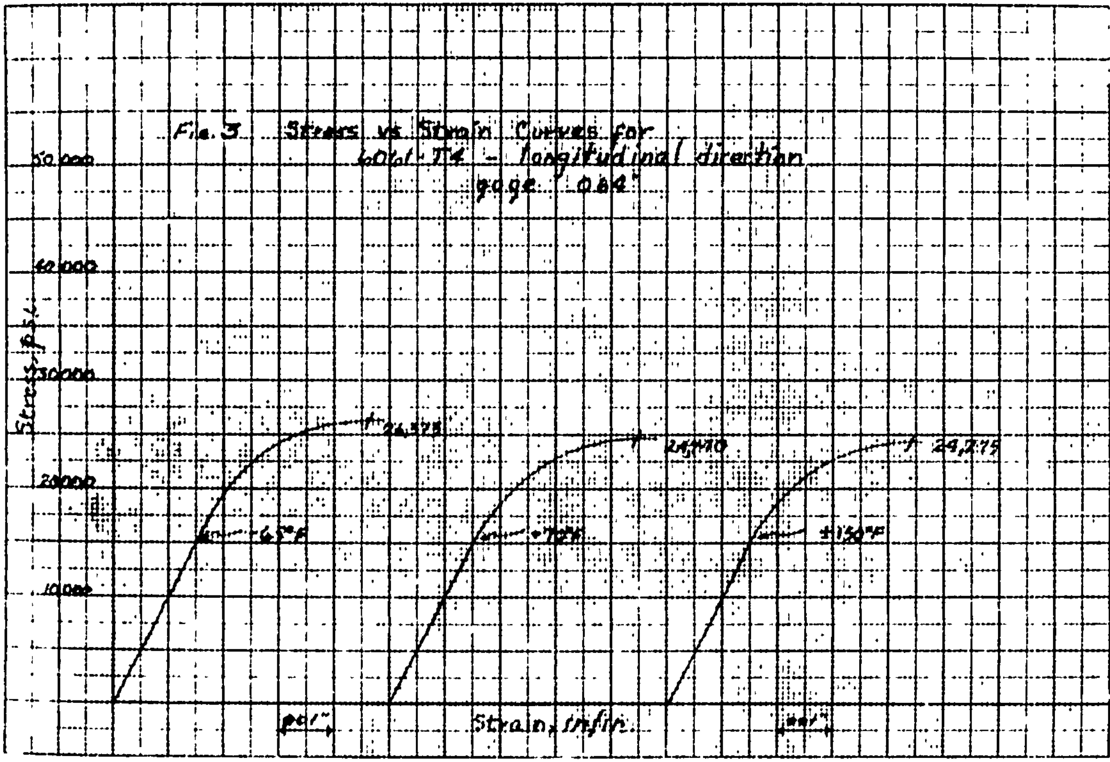
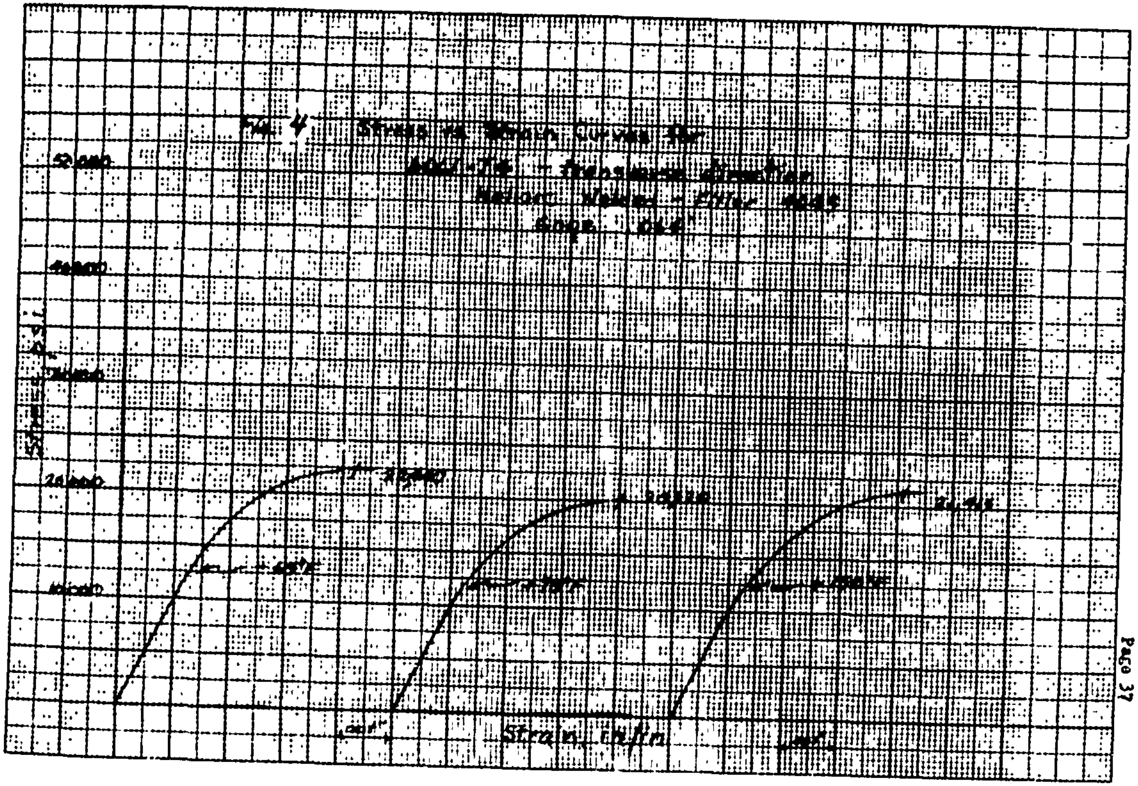


Fig. 3 Stress vs Strain Curves for
6061-T4 - longitudinal direction
gage 0.64"
Stress, psi
50,000
40,000
30,000
20,000
10,000
24,575
24,440
24,275
-65°F
+150°F
Strain, in/in.

K+E 10 X 10 TO THE ½ INCH 358T-11
KEUFFEL & ESSER CO.



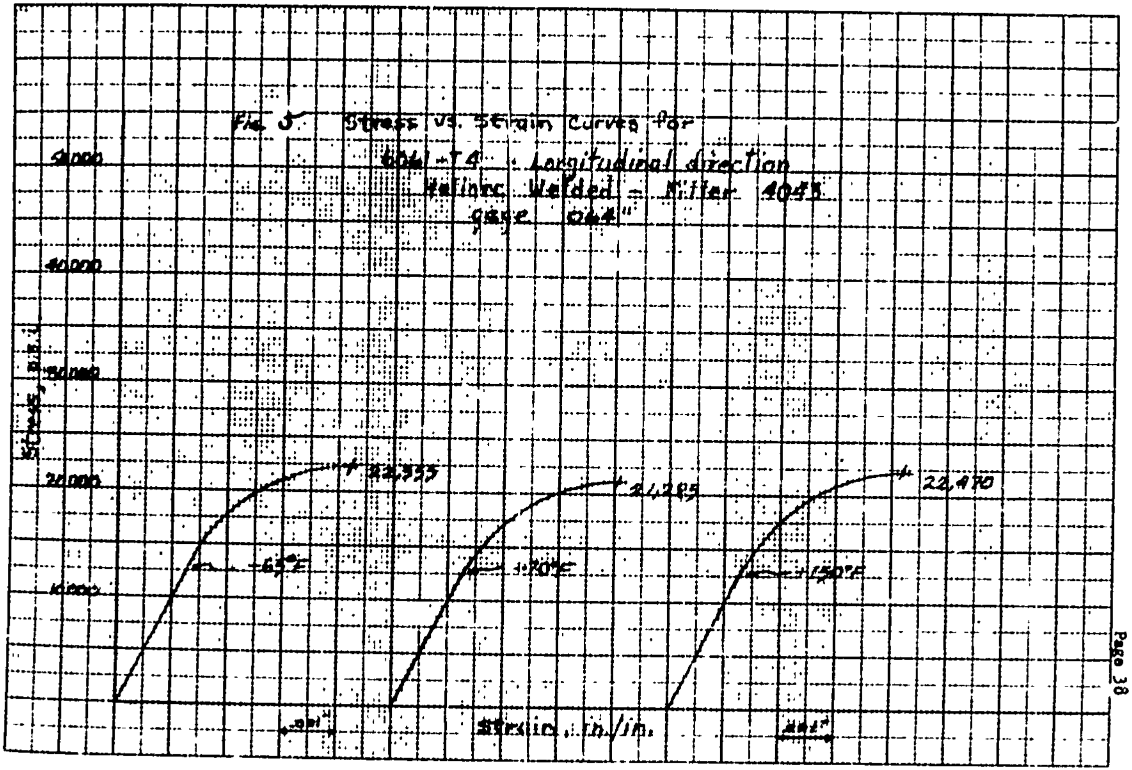


Fig. 5 Stress vs. Strain curves for
6061-T4 Longitudinal direction
Heliarc Welded – Filler 4043
gage .064"

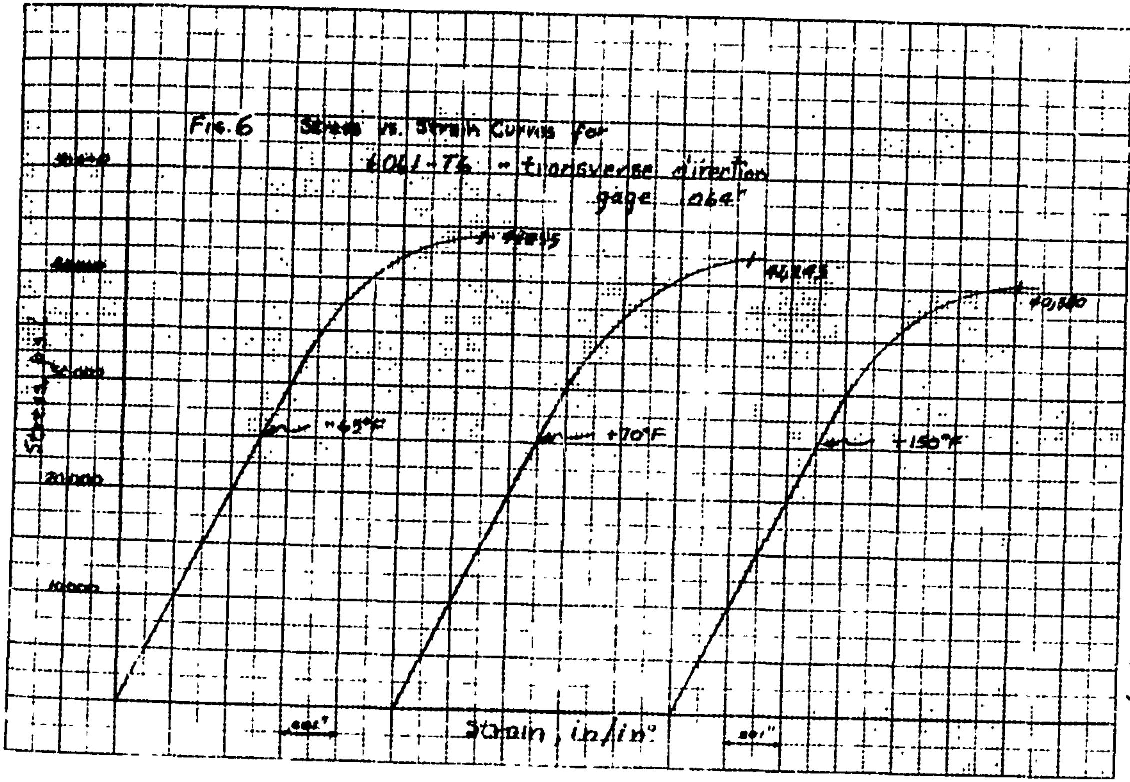


Fig. 6 Stress vs. Strain Curves for 6061-T6 - transverse direction gage .064"

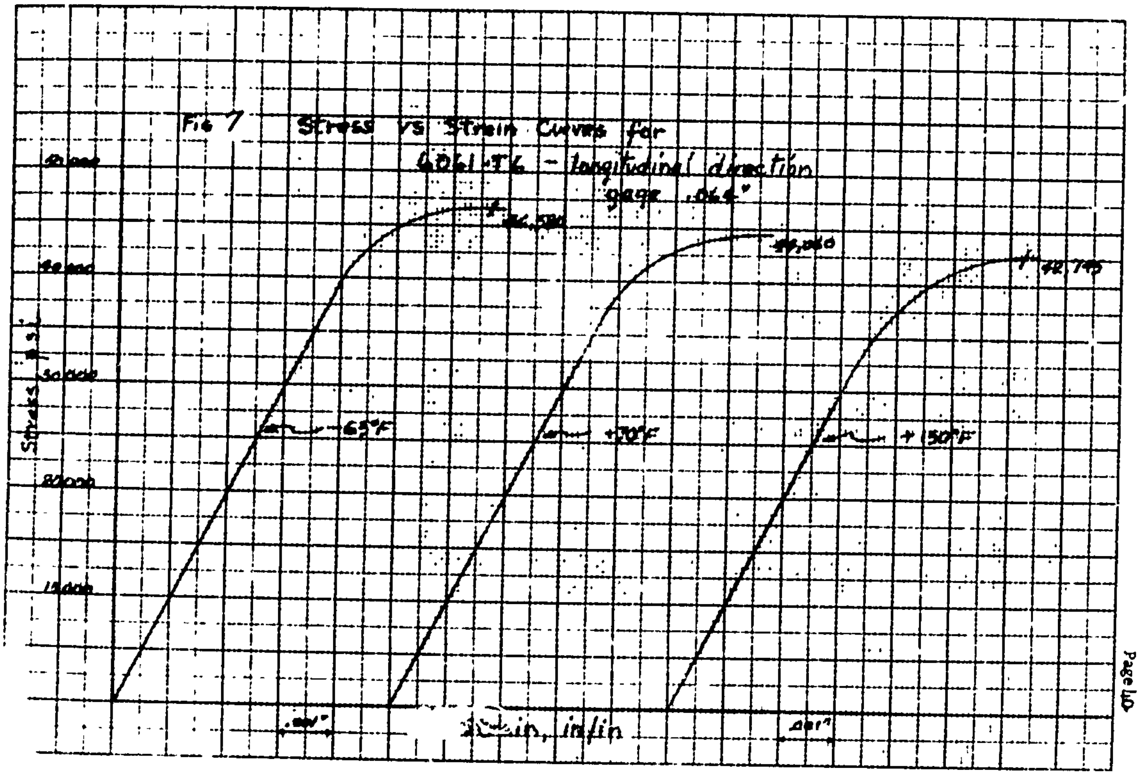


Fig 7 Stress vs Strain Curves for
6061-T6 - longitudinal direction
gage .064"
Stress, p.s.i.
-65°F
+70°F
+150°F
42,745
in/in

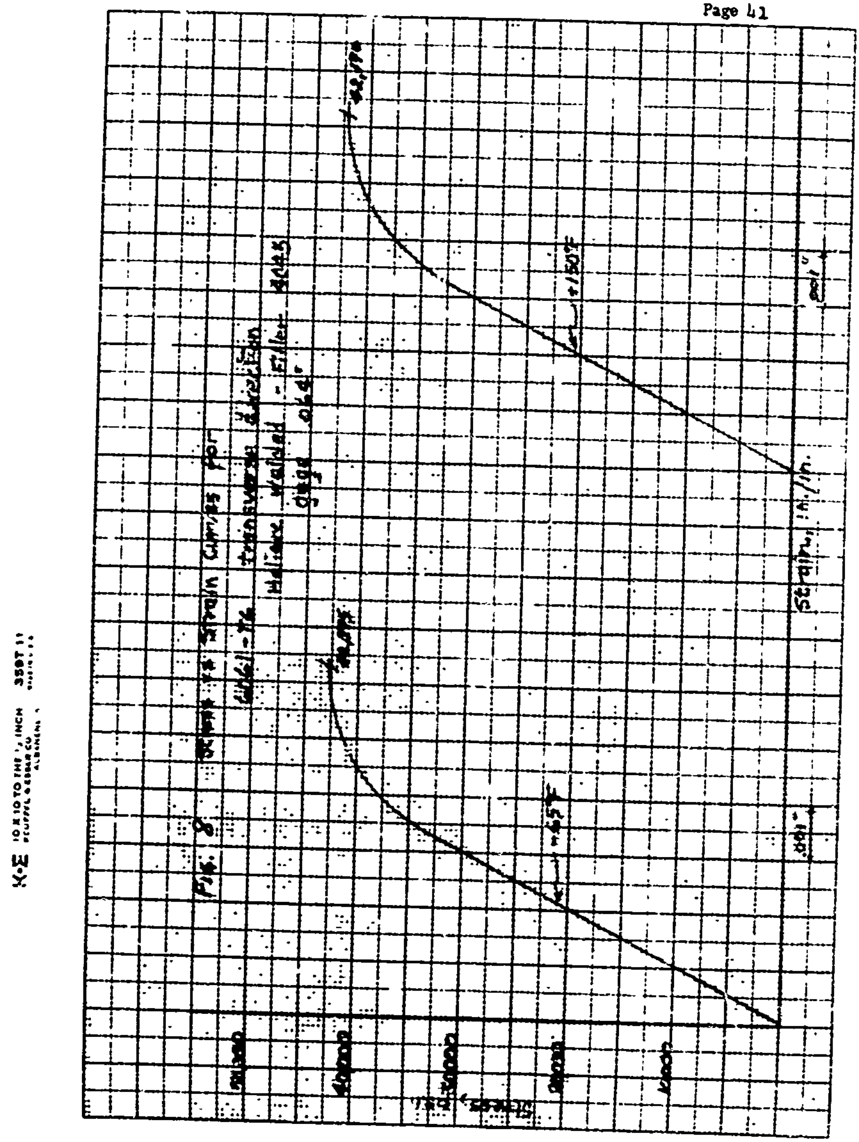


Fig. 8
Strain Curves for
6061-T6 transverse direction
Heliarc welded - Filler 4043
gage .064"
40000
30000
20000
+65°F
+150°F
Strain, in./in.
.001"
.001"
K·E 10 X 10 TO THE ½ INCH 359T 11
KEUFFEL & ESSER CO.

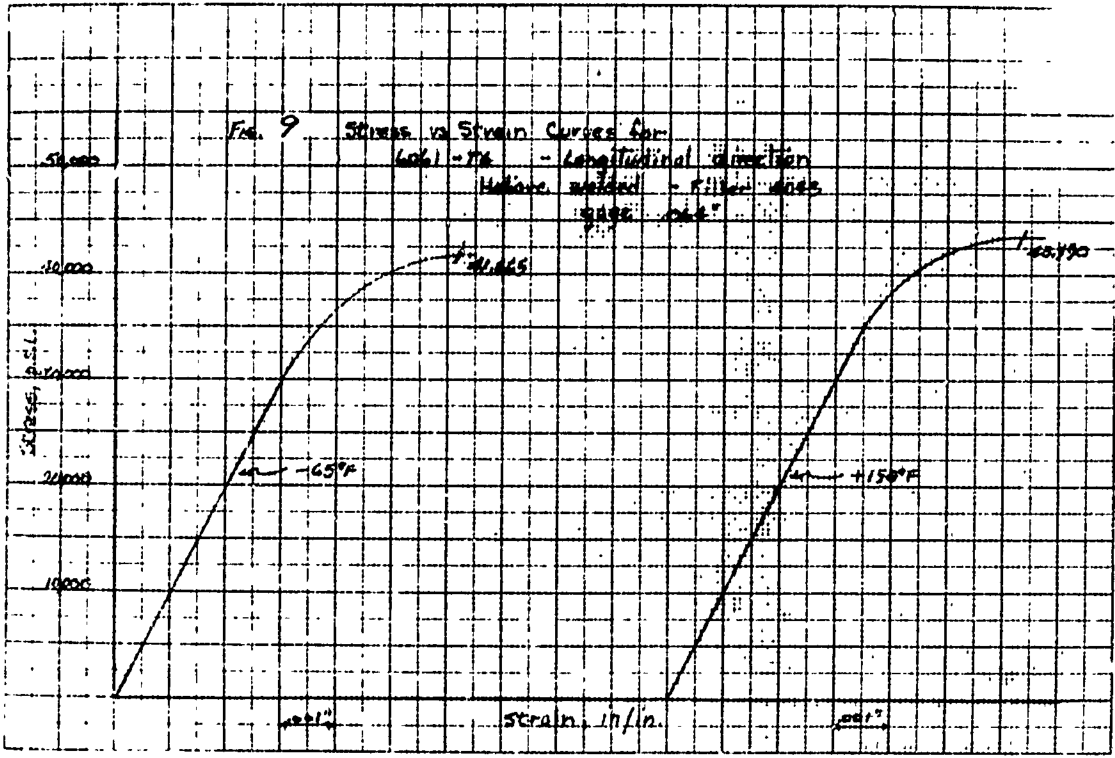


Fig. 9 Stress vs Strain Curves for 6061-T6 - Longitudinal direction Heliarc welded - Filler 4043 gage .064"

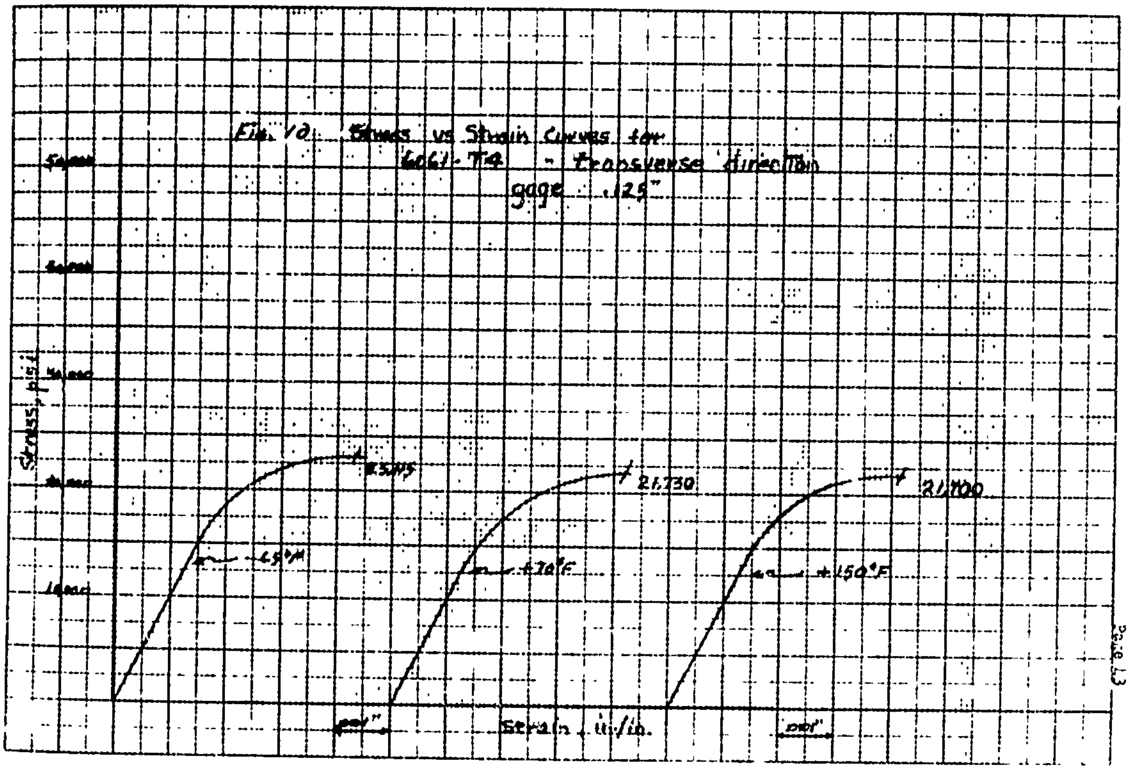


Fig. 12 Stress vs Strain Curves for
6061-T4 - transverse direction
gage .125"
50,000
40,000
30,000
20,000
10,000
Stress, psi
-65°F
+70°F
+150°F
21,730
21,700
.001"
Strain, in/in.
.001"

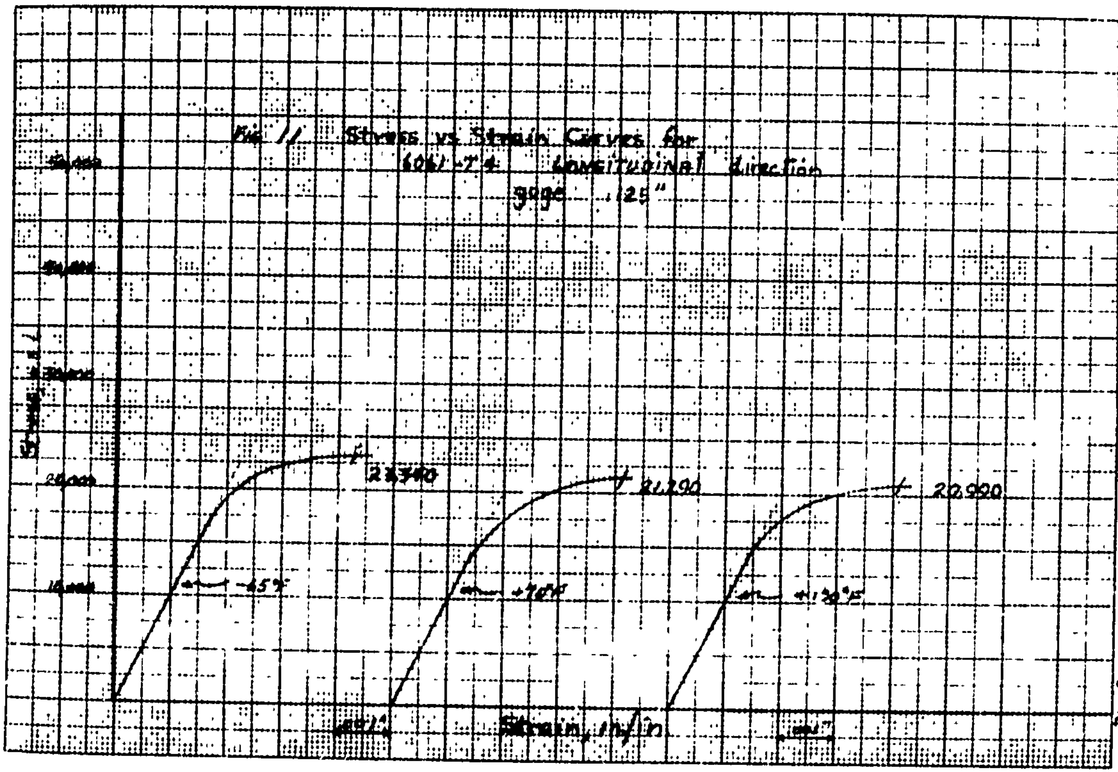


Fig 11 Stress vs Strain Curves for
6061-T4 Longitudinal direction
gage .125"
22,740
21,290
20,990
Strain, in/in

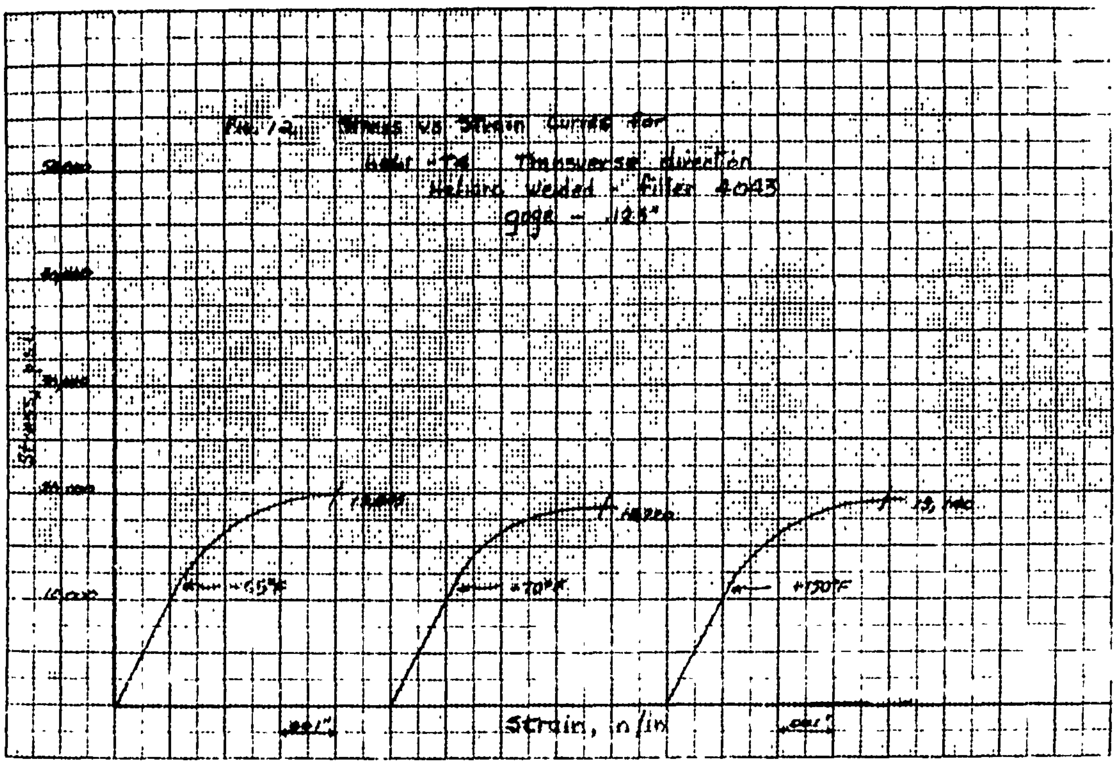


Fig. 12 Stress vs Strain curves for
6061-T6 Transverse direction
Heliarc welded - Filler 4043
gage - .125"
Stress, psi
10,000
+65°F
+70°F
+130°F
.001"
Strain, in/in
.001"

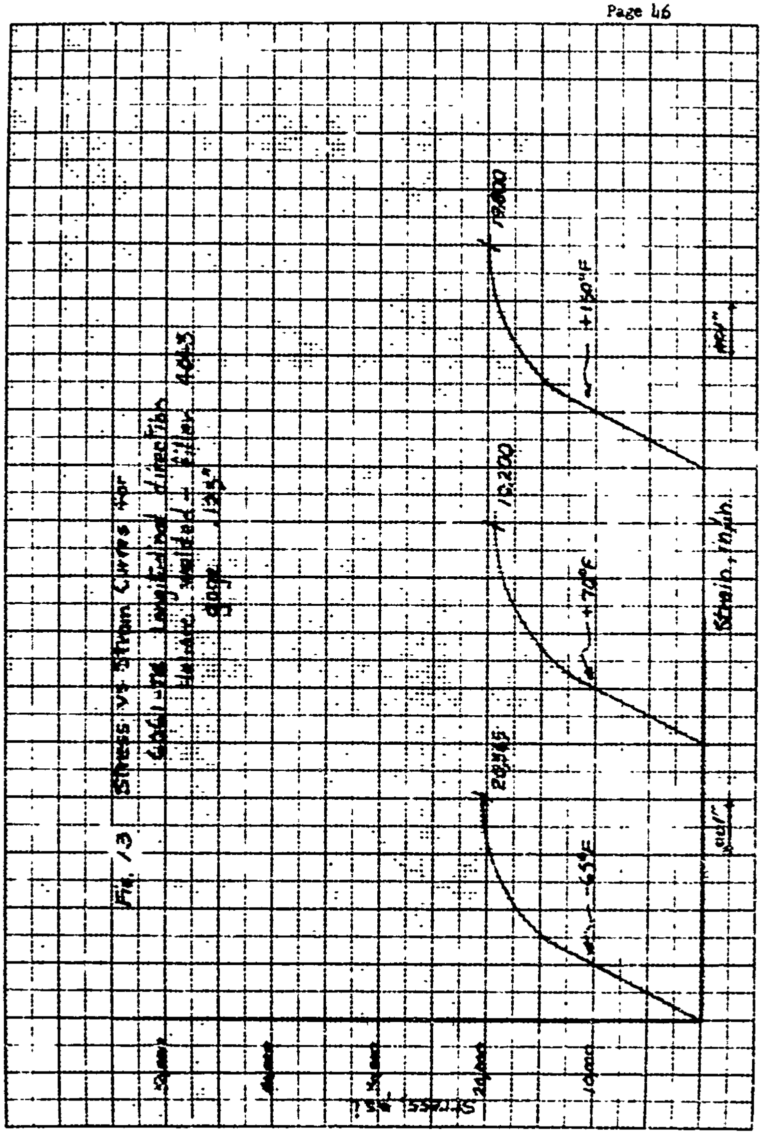


Fig. 13 Stress vs Strain Curves for
6061-T6 Longitudinal direction
Heliarc welded - filler 4043
gage .125"
Stress, psi
30,000
20,000
10,000
20,365
-65°F
+70°F
+150°F
Strain, in/in.
.001"

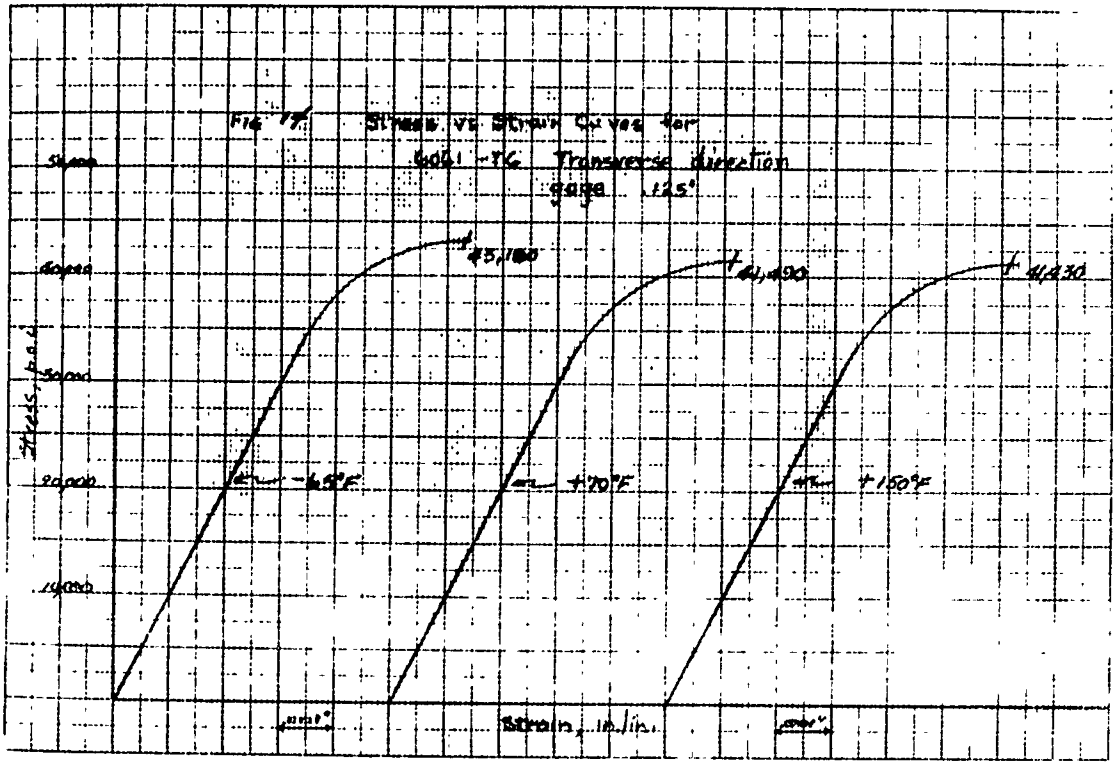


Fig 77 Stress vs Strain Curves for
6061-T6 Transverse direction
gage .125"
45,180
41,490
41,430
-65°F
+70°F
+150°F
50000
40000
30000
20000
10000
Stress, psi
Strain, in./in.

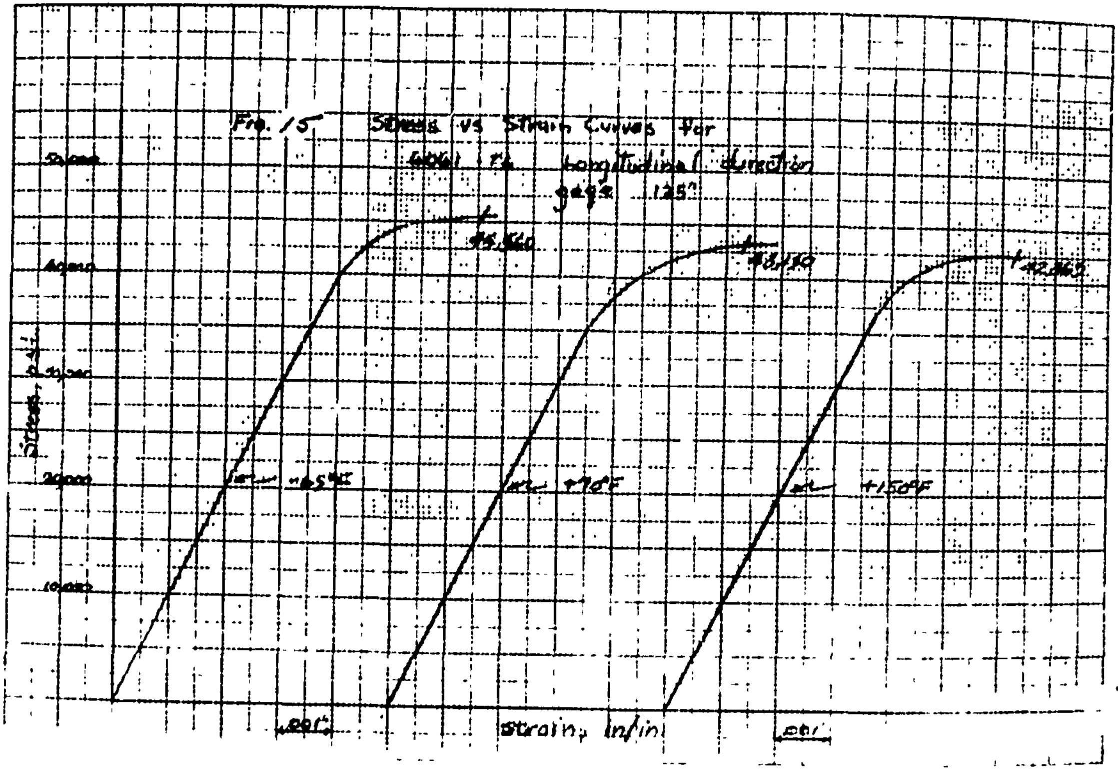


Fig. 15 Stress vs Strain Curves for
longitudinal direction
gage .125"
50,000
40,000
30,000
20,000
10,000
Stress, psi
+65°F
+150°F
.001
Strain, in/in
.001

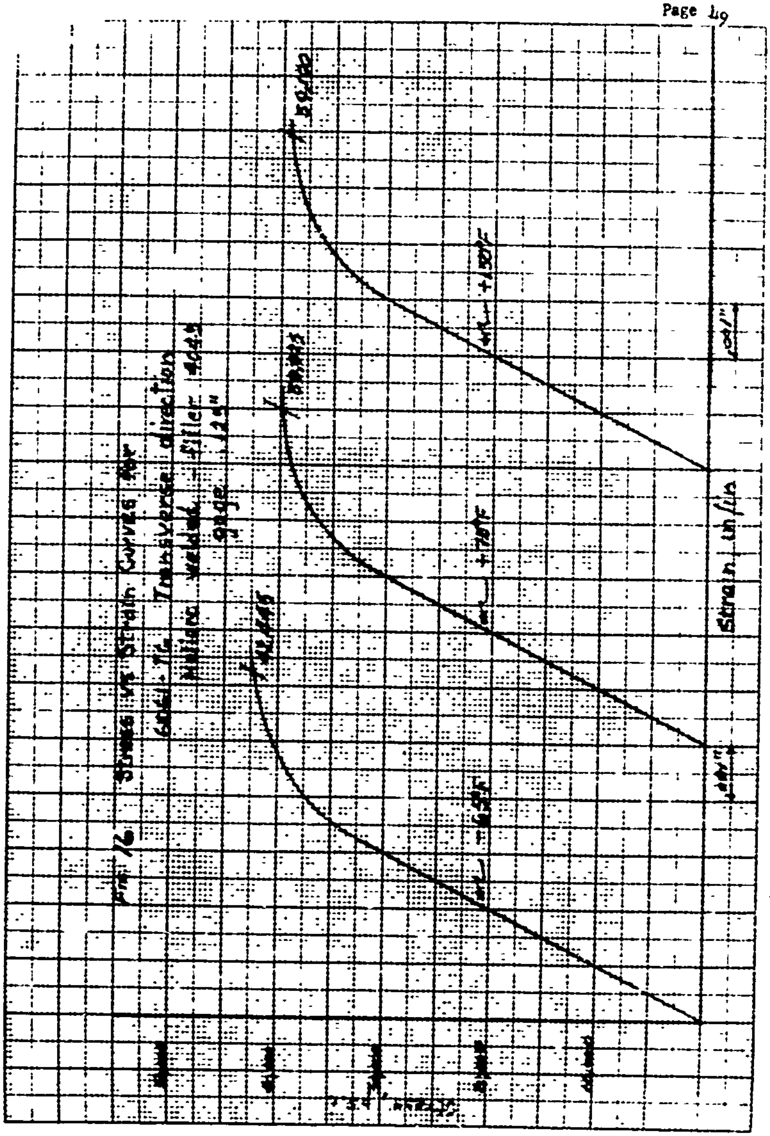


Fig 76 Stress vs Strain Curves for
6061-T6 Transverse direction
Heliarc welded - filler 4043
gage .125"
42,445
-65°F
+150°F
.001"
Strain in/in

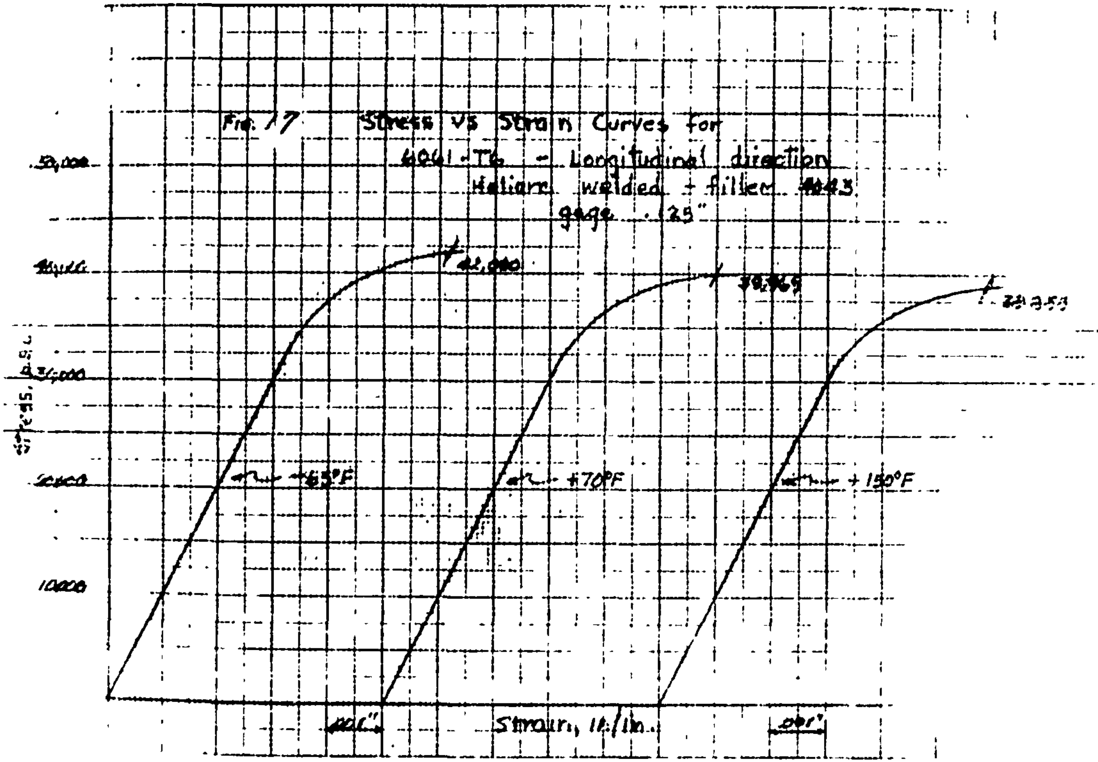
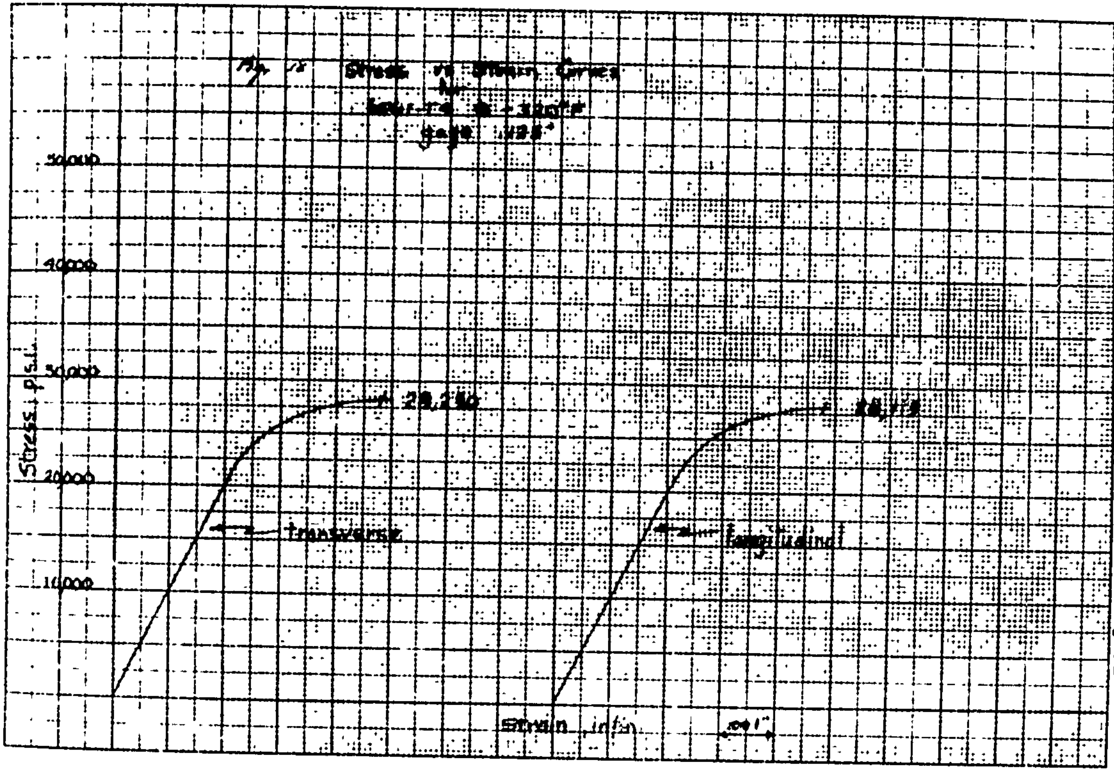
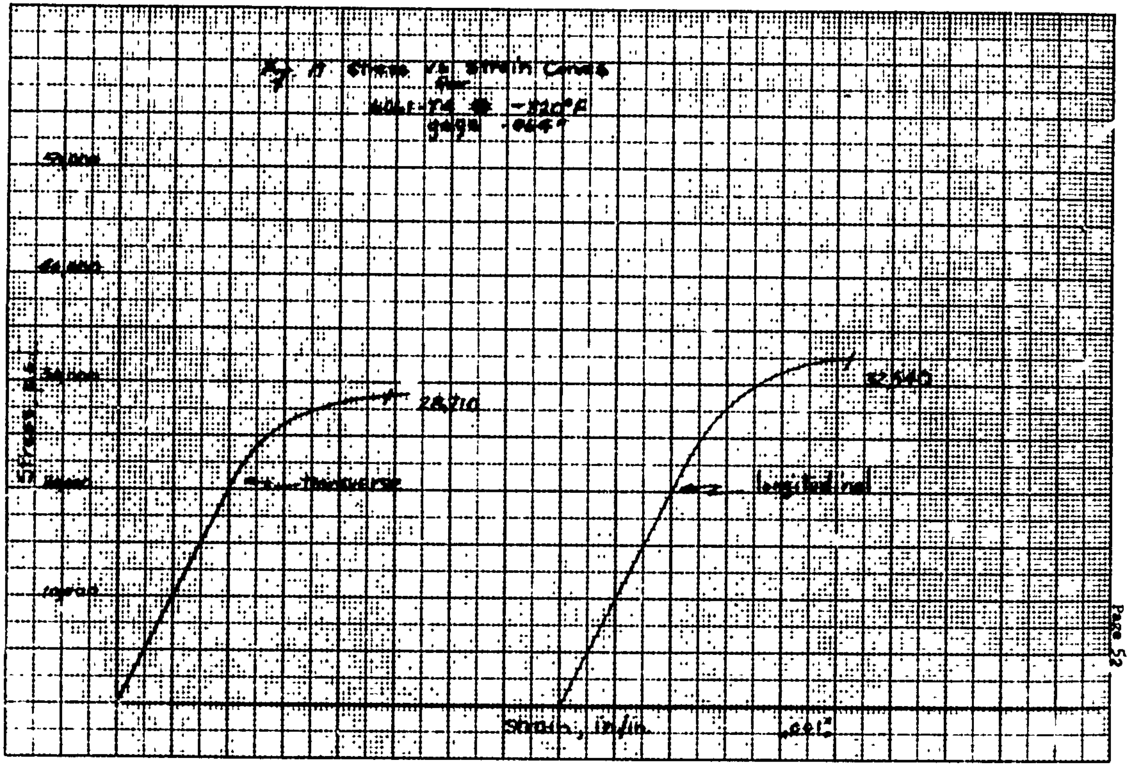
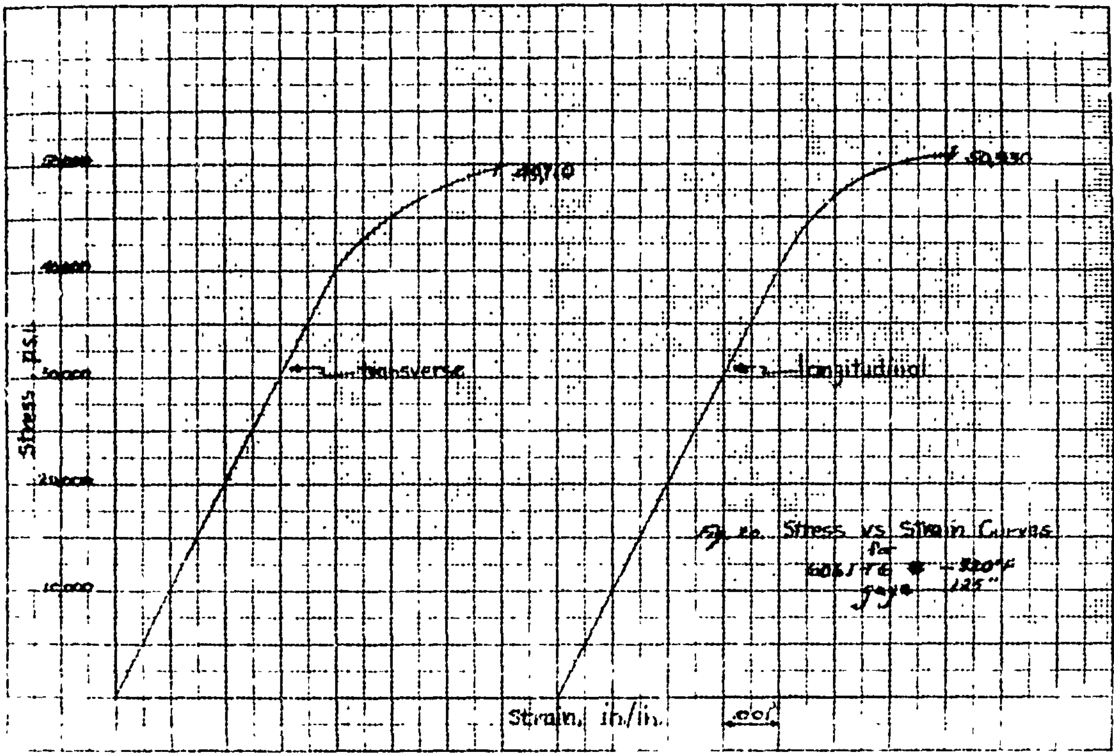


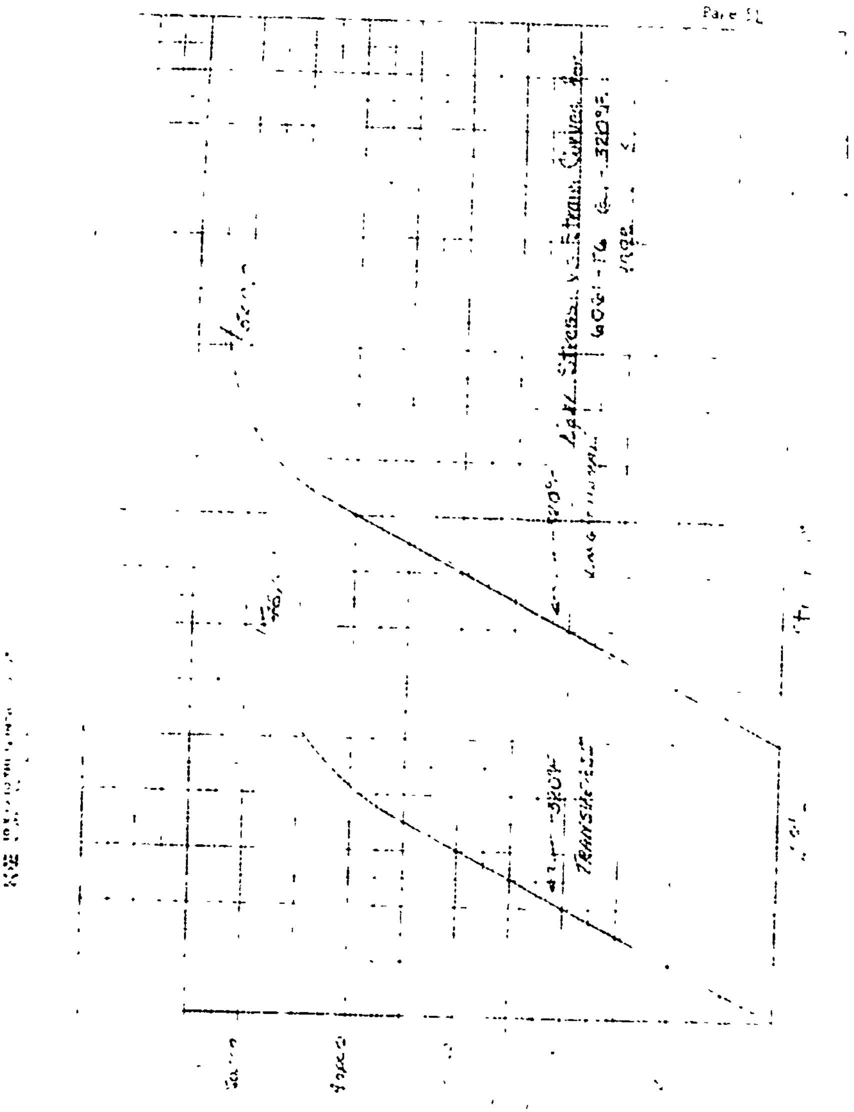
Fig. 17 Stress vs Strain Curves for 6061-T6 - Longitudinal direction Heliarc welded + filler 4043 gage .125"

K+E 10 X 10 TO THE ½ INCH 358T-11
KEUFFEL & ESSER CO.
ALBANENE




Stress vs Strain Curves
-320°F
gage
50,000
40,000
30,000
20,000
10,000
Stress, psi
28,710
32,540
Transverse
Longitudinal
Strain, in/in
.001"


Stress, psi
10,000
20,000
30,000
40,000
50,000
Strain, in/in.
.001
transverse
longitudinal
50,530
Stress vs Strain Curves


Long. Stress vs Strain Curves for
6061-T6 @ -320°F
Longitudinal
-320°F
TRANSVERSE

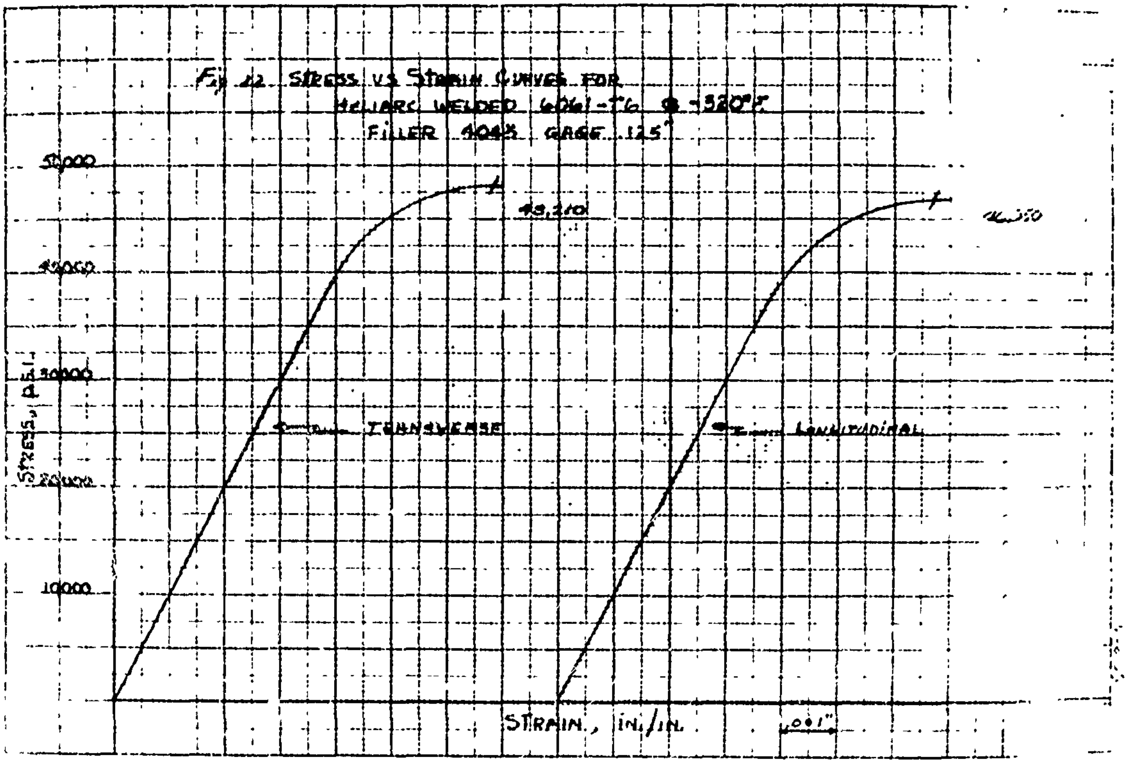
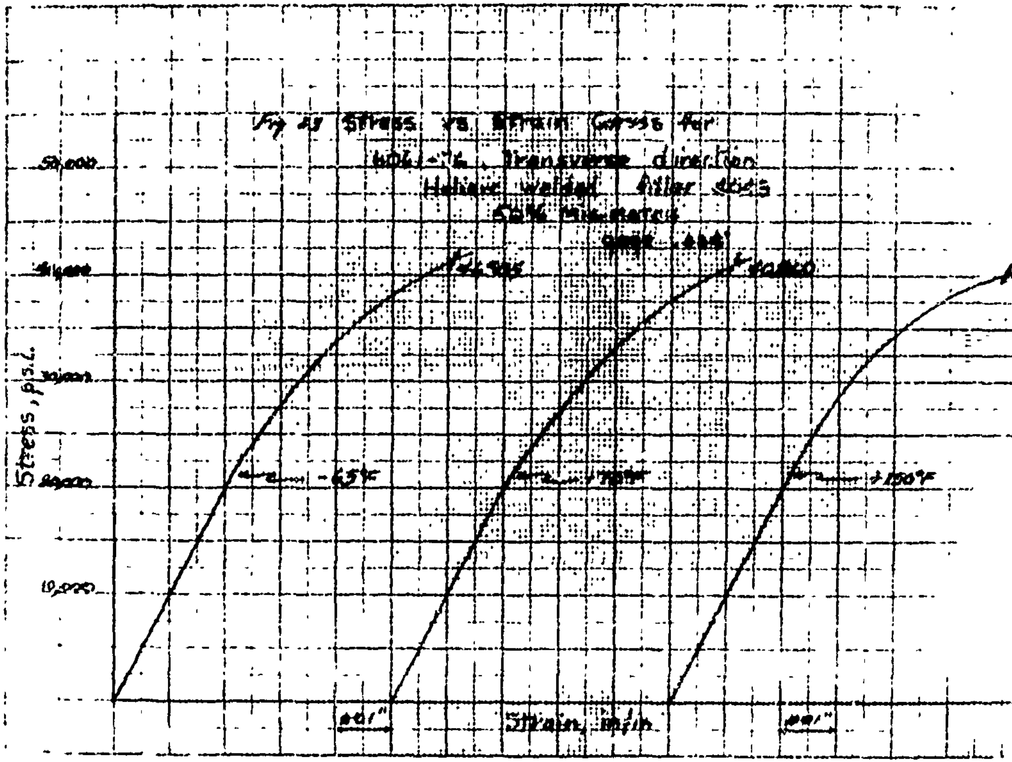


Fig. 12 STRESS VS STRAIN CURVES FOR HELIARC WELDED 6061-T6 @ -320°F
FILLER 4043 GAGE .125"


Stress vs Strain Curve for
Transverse direction
Heliarc welded filler
-65°F
+150°F
40,150
Stress, psi.
Strain, in/in
10,000
.001"
.001"

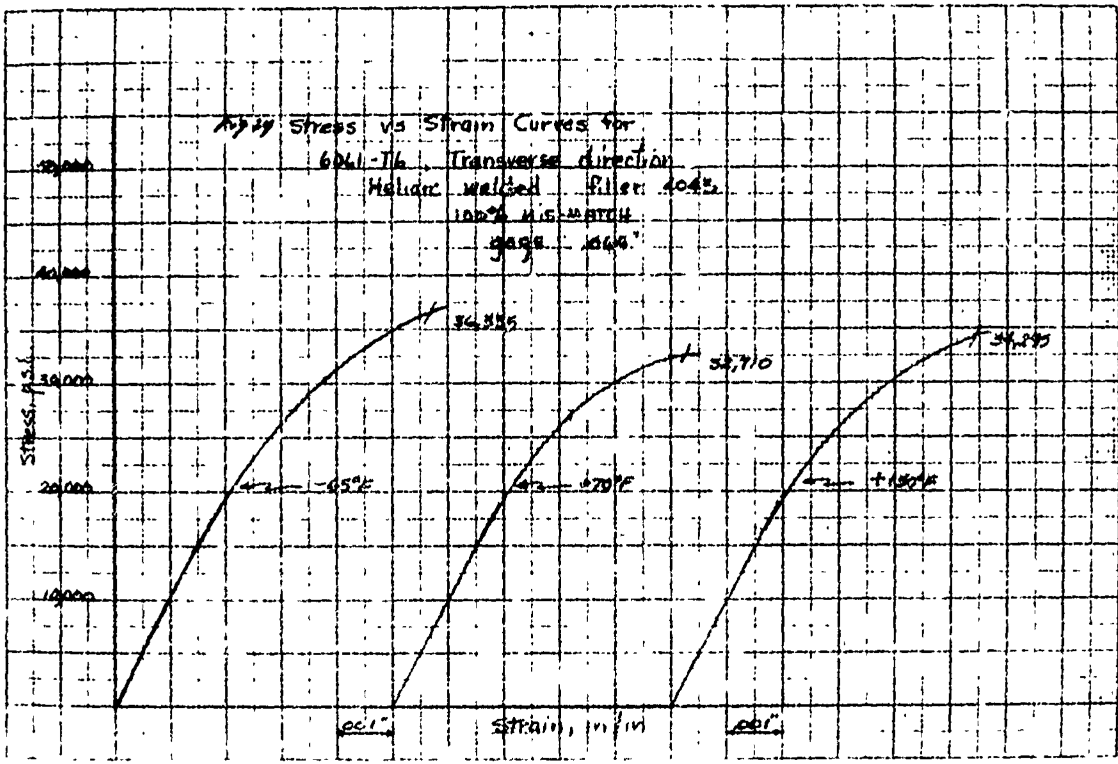
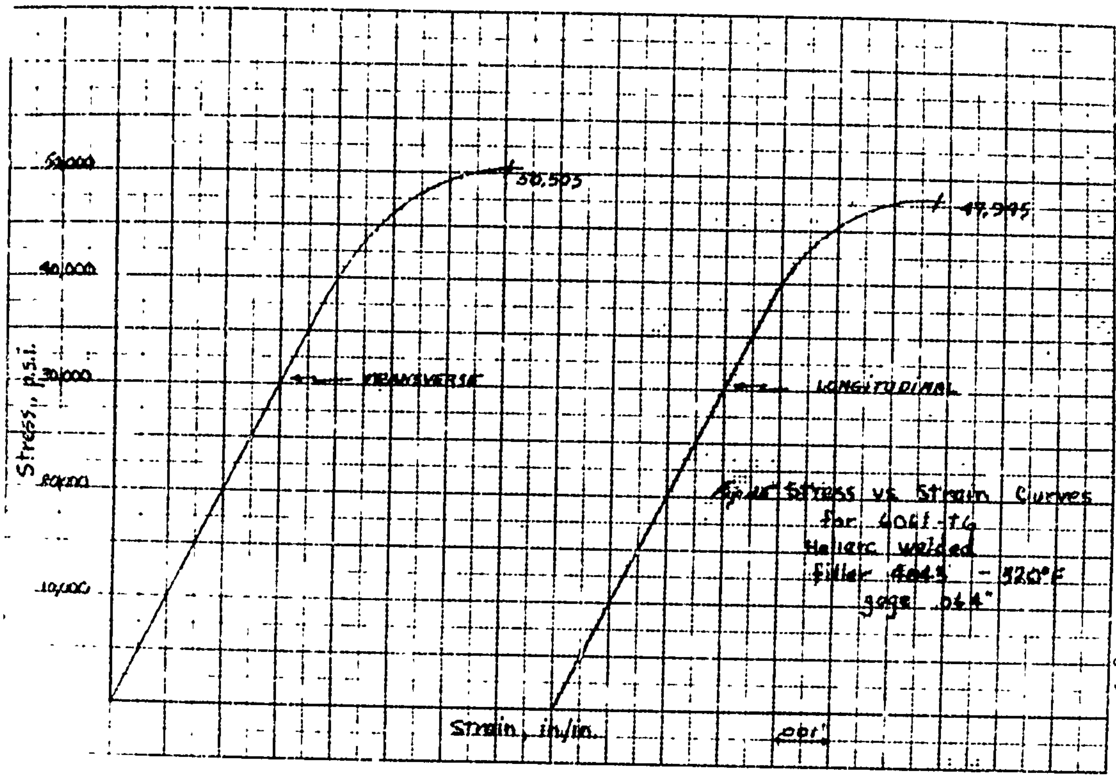


Fig 29 Stress vs Strain Curves for
6061-T6 Transverse direction
Heliarc welded filler 4043
100% mis-match
gage .064"
50,000
40,000
30,000
20,000
10,000
Stress, p.s.i.
34,555
33,710
34,295
-65°F
+70°F
+150°F
.001"
Strain, in/in
.001"

K+E 10 X 10 TO THE ½ INCH 359T-11
KEUFFEL & ESSER CO.



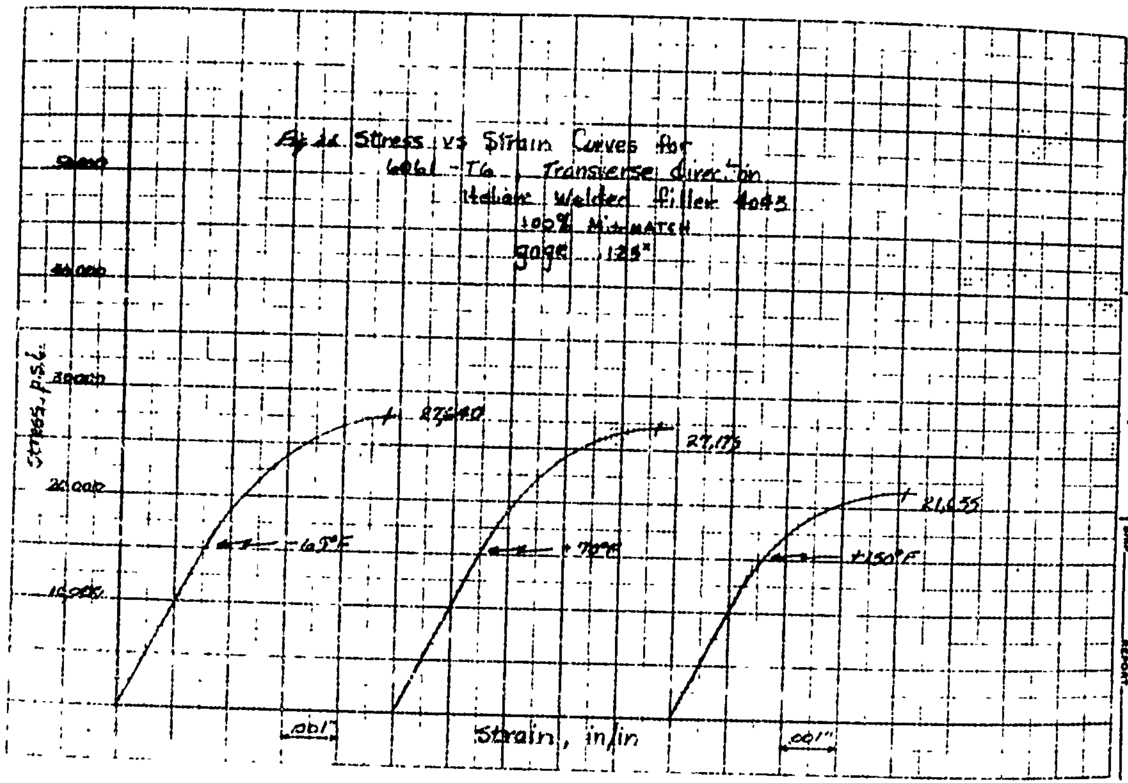
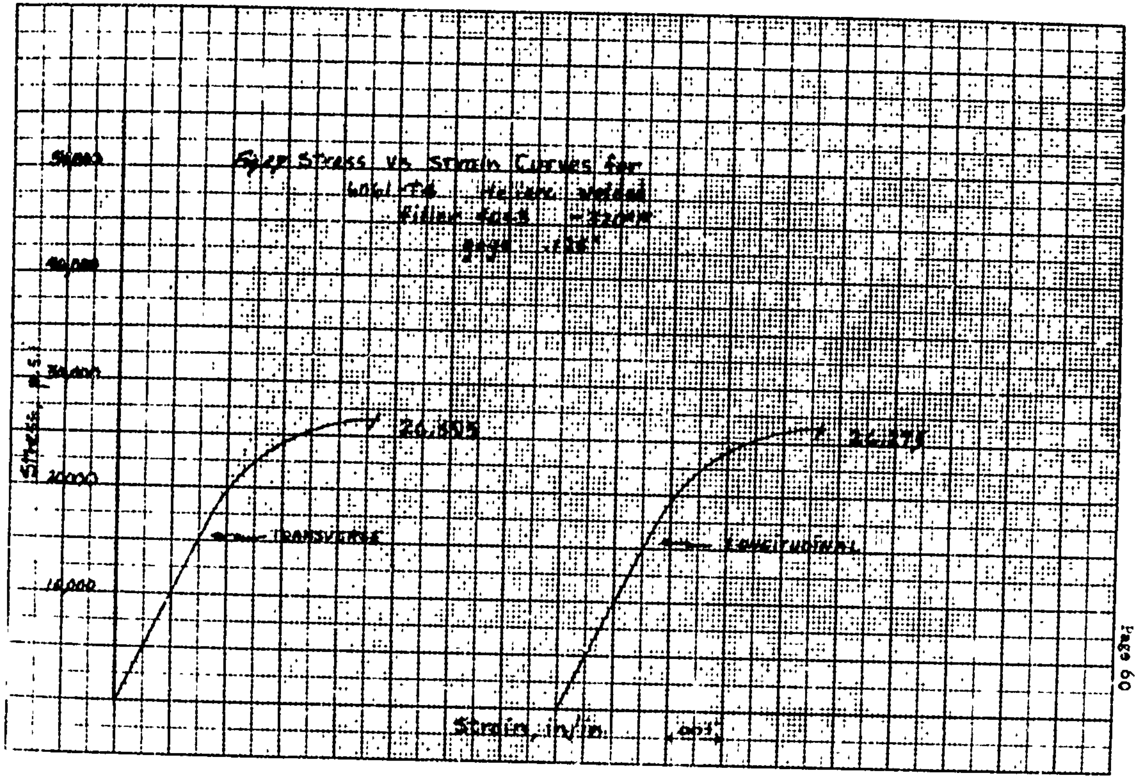
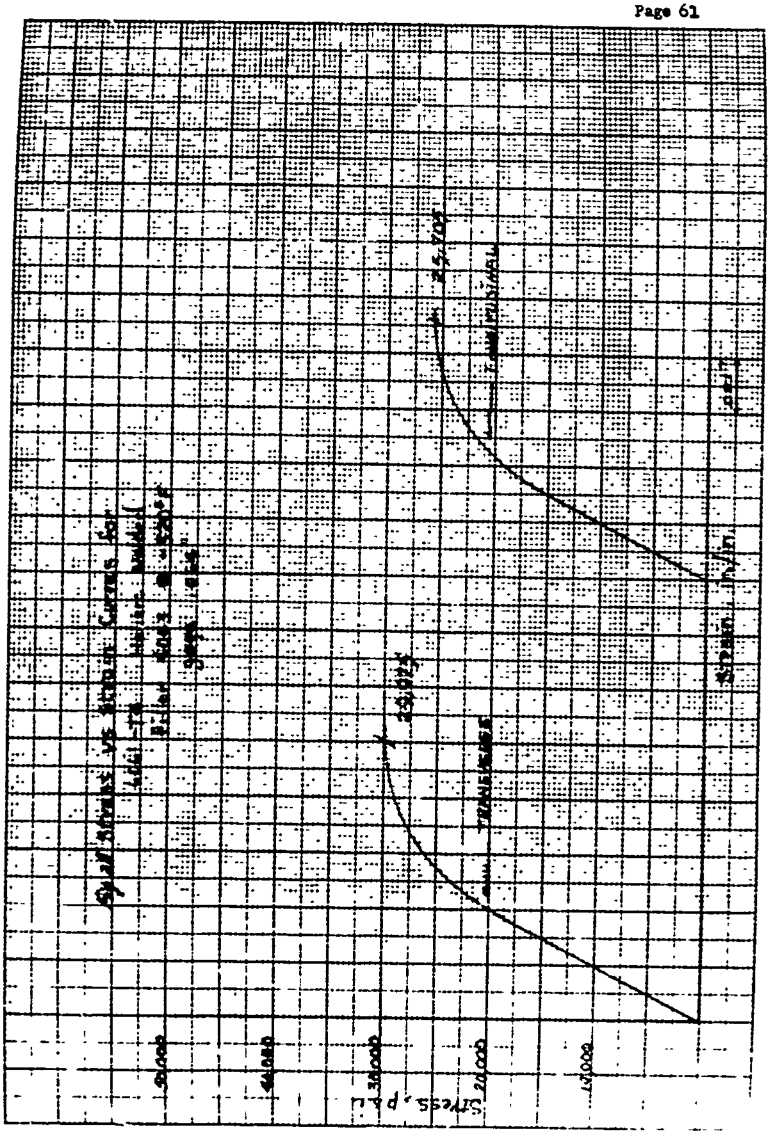


Fig 26 Stress vs Strain Curves for
6061 T6 Transverse direc. in
Heliarc Welded filler 4043
100% Mismatch
gage .125"
50000
40000
30000
20000
10000
Stress, p.s.i.
27,540
27,175
21,655
-65°F
+70°F
+150°F
.001"
.001"
Strain, in/in


Stress vs Strain Curves for
50,000
40,000
30,000
20000
10,000
26,805
TRANSVERSE
LONGITUDINAL
Strain, in/in.
.001


Stress, p.s.i.
50,000
40,000
30,000
20,000
10,000
25,025
25,705
TRANSVERSE
Strain, in/in.

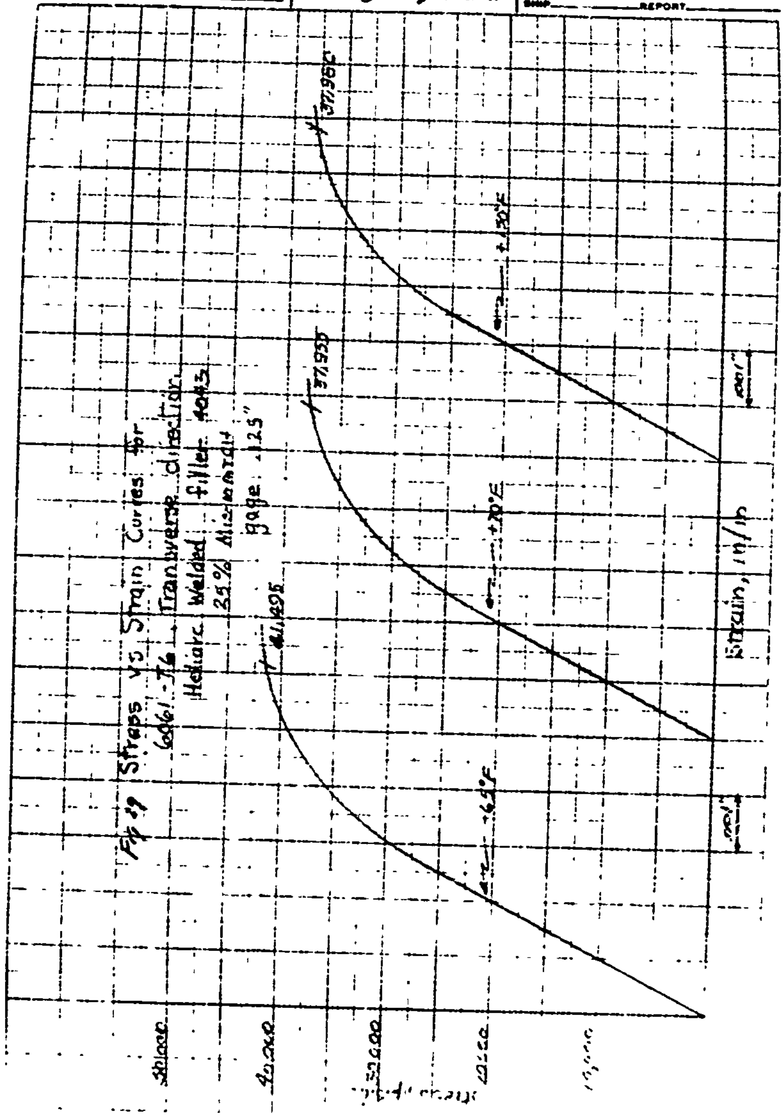
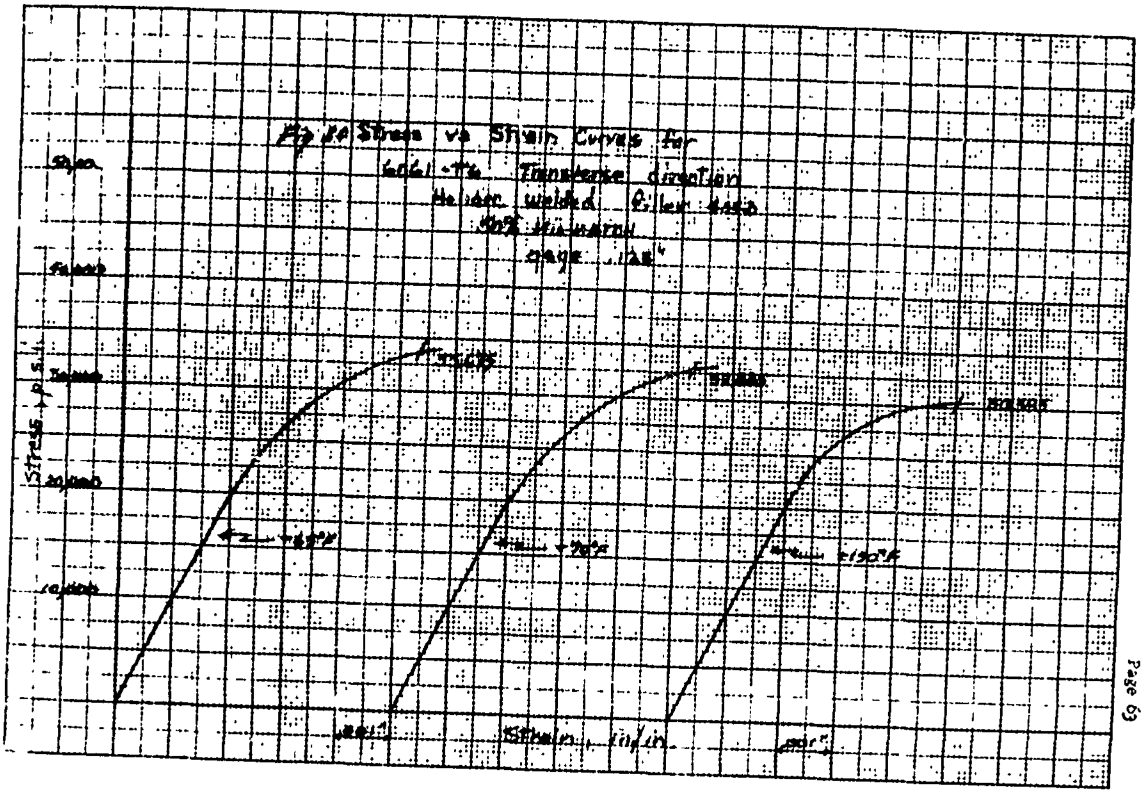


Fig 29 Stress vs Strain Curves for
6061-T6 Transverse direction
Heliarc Welded filler 4043
25% Mismatch
gage .125"
37,960
+130°F
37,955
+70°F
41,295
+65°F
.001"
Strain, in/in
50,000
40,000
30,000
20,000


Stress vs Strain Curves for
Transverse direction
Stress, p.s.i.
20,000
10,000
Strain, in/in

D. Bulge Test

Experience has shown that there is very little if any correlation between tensile tests of small cross- welded specimens and the performance of pressure vessels under service conditions. The bulge test or hydraulic burst test has replaced the tensile test since it predicts weld performance under biaxial stresses.

The fixture consisted of two heavy steel plates in which the specimen was bolted at intervals along its' outer circumference. The upper plate was machined to a semi-conical shape (Figure 31) to allow for deformation of the welded sheet.

Biaxial tensile stress of the welded plate is calculated from measurements of pressure and height of deformation. This stress can be calculated at any point during the test allowing data to be obtained for stress height and pressure height curves.

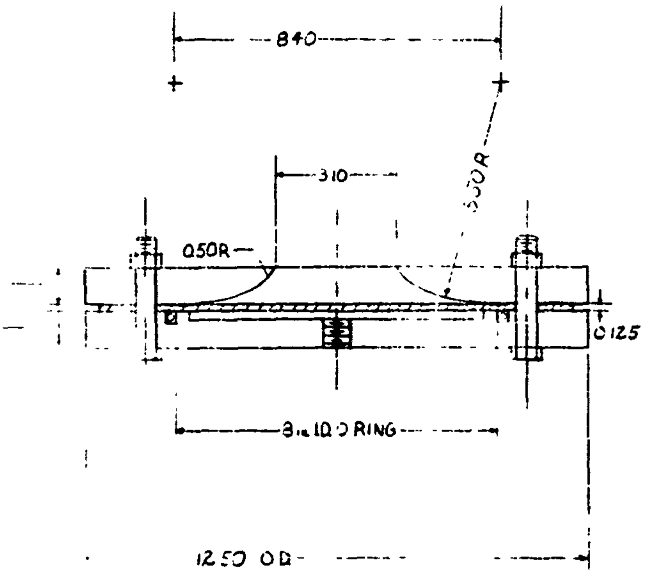
One of the major problems in this test is that no slippage of the plate can be allowed to occur during loading. Errors produced by bending stresses are greatest when the height of the bulge is low. The ratio of the diameter to sheet thickness of Bell's apparatus is 41 to 1. If the ratio were increased to 200 to 1 errors from bending stresses could be reduced.

Figures 32 and 33 show the Bell bulge test fixture with a specimen after test. The dial gage is used to measure the bulge height. The fixture and specimen after disassembly is shown in Figure 33.

Figure 34 is a diagramatic sketch of the fixture showing the mathematical parameters of interest in determining the radius of curvature. A sheet panel bulged through an open circular die generally decreases in radius as bulging progresses. Unless bending stresses around the clamped edge are significant, all points in the sheet are under or equal biaxial tensile stress, which can be calculated from the equation for membranes:

$$\sigma = \frac{pR}{2\,t_o}$$

where σ is the biaxial stress, p is the bulging pressure, R is the radius of curvature of the bulge, and t_o is the original sheet thickness. In using the height of the bulged the assumption is made that the deformation occuring is spherical.



gure 31 [illegible]IA[illegible]M TEST F[illegible]

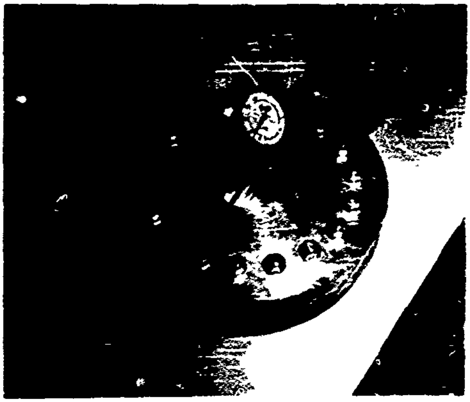


Figure 32. Bulge Test Fixture

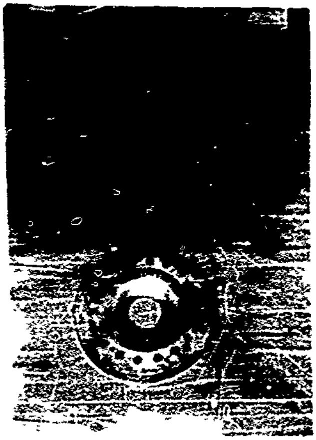


Figure 33. Bulge Test Fixture Disassembled

R = RADIUS OF CURVATURE
a = RADIUS OF DIE EDGE
r = RADIUS OF DIE OPENING
h = BULGE HEIGHT

① BASIC RELATIONSHIP: $(R+a)^2 = (r+a)^2 + (R-h+a)^2$

② SOLVE FOR R: $R = \frac{r^2+h^2+a^2+2ar-2ah}{2h}$

③ SUBSTITUTE DIE DIMENSIONS: $R = \frac{h^2-2h+25}{2h}$
$a = 1"$
$r = 4"$

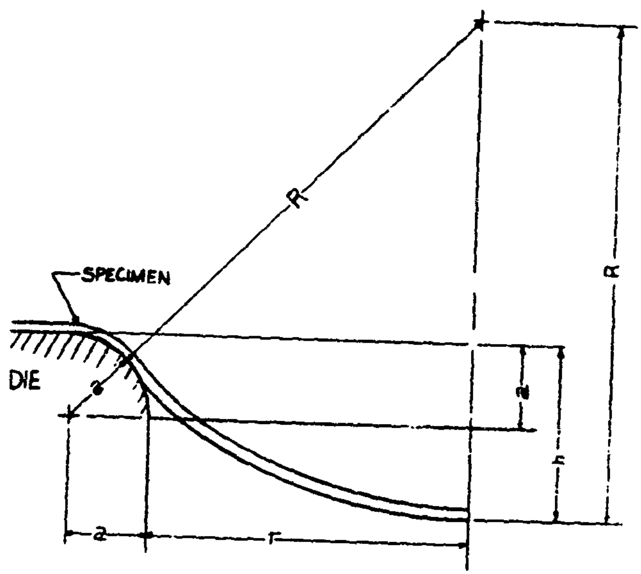


Figure 34. RADIUS OF CURVATURE CALCULATION

TABLE XXVIII

Bulge Test Data

Material	Heat Treatment	Thickness (inch)	Deflection (inch)	Pressure (psi)
6061T4	As welded	.125	.055	100
			.140	200
			.215	300
			.275	400
			.330	500
			.385	600
			.425	700
			.460	800
			.495	900
			.530	1000
			.560	1100
			.585	1200
			Burst	2350
6061T6	Aged after welding	.125	.074	100
			.140	200
			.200	300
			.250	400
			.290	500
			.330	600
			.360	700
			.390	800
			Burst	1350

III. METALLURGY AND HEAT TREATMENT OF ALUMINUM ALLOY 6061

Aluminum alloy 6061 is an aluminum magnesium, silicon alloy which is responsive to precipitation heat treatment. Magnesium silicide is dissolved into the aluminum matrix during solution heat treatment at 970-1010 F. Upon quenching, small microscopic particles of magnesium silicide are ejected from the solid solution. Aging at 340-355 F causes growth of the precipitate thus strengthening the atomic lattice.

This alloy offers good strength, formability, weldability and very good corrosion resistance. It is widely used by the aircraft industry in applications requiring the combination of properties this alloy possesses.

IV. DISCUSSION OF RESULTS

Mismatch

The tabulated results of this study presented in Table III and Table IV show that there is very little depreciation of properties up to 50% mismatch. At 100% mismatch there is an appreciable decrease in the strength of the welded material. These specimens all failed at the edge of the weld or in the annealed zone area which does not respond to aging. The specimens were shimmed during loading to eliminate bending stresses.

Weld Repair

The properties of the material were reduced to the annealed condition by manual welding. No further tests were conducted as to evaluating repairs, for the strength of the material was reduced to a minimum and the structure due to annealing would be unresponsive to aging. The automatic welded (heliarc and sigma) 0.064 inch thick material showed slight decreases in tensile and yield strengths as shown by the data given in Tables V to XI. There was, however, a marked decrease in elongation which, when considered with the strengths obtained, is due to the increase in size of the weld bead.

The 0.125 inch thick material, in comparison to the 0.064 inch material, welded in the same manner shows a much greater decline in tensile and yield strengths, due to the higher heat input during welding which caused more overaging of the heat affected zone than experienced with the 0.064 inch thick material.

Mechanical Properties

The increase in yield, tensile and elongation properties at low temperatures is brought out by both tempers (T4 and T6) studied. This increase is best explained by the application of dislocation theory. Upon subjection to low temperatures the atomic lattice undergoes a contraction, the thermal agitation of the atoms is reduced and the material will undergo a greater amount of uniform strain before dislocation pile ups become keyed. During this strain period the lattice becomes strengthened by the repeated generation of dislocations and a higher yield stress and tensile stress is obtained. The period of uniform elongation is of longer duration than at room or elevated temperatures resulting in a higher measured elongation.

The difference in the T4 yield strength and the T6 at -??? reflects the difference in the matrix strength the T4 being considerably weaker due to submicroscopic particles. In the T6 condition, the matrix has been strengthened by the growth of these particles.

The "V" notch data was obtained late in this program. Notched to unnotched ratios will be obtained in the next phase and stress concentrations factors (K) greater and less than 3 will be evaluated.

Bulge Test

The data presented herein is raw data and will be reduced during the coming year. Modification of the jig will be accomplished also to improve the accuracy of the test results.