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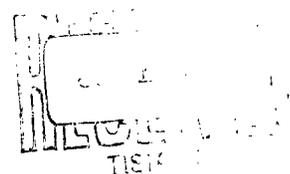
GENERAL DYNAMICS | CONVAIR

Report No. 8926-170

Material - Titanium - Commercially Pure, Ti 6Al-4V, Ti 5Al-2½ Sn  
Static and Fatigue Strength of Dissimilar Alloy Spotwelds

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18 April 1957



Published and Distributed  
under  
Contract AF33(657)-8926



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Static and Fatigue Strength of Dissimilar Alloy Spotwelds

Abstract:

Three spotwelded, lap seam combinations comprised of (1) 0.025" thick Ti 6Al-4V and 0.025" thick commercially pure titanium; (2) 0.025" thick Ti 5Al-2 $\frac{1}{2}$  Sn and 0.025" thick commercially pure titanium; and, (3) 0.025" thick Ti 6Al-4V and 0.025" thick Ti 5Al-2 $\frac{1}{2}$  Sn titanium were tension-shear, cross-tension and fatigue tested. The average tension - shear strengths of combinations (1), (2) and (3) were 903, 955 and 959 pounds per spot, respectively, and the average cross-tension strengths were 302, 236 and 275 pounds per spot, respectively. The respective tension-shear cross-tension ratios were 0.33, 0.25, and 0.29. The fatigue strengths for  $10^7$  cycles life were 53, 86 and 97 pounds per spot, respectively.

Reference: Winslow, E. K., Haney, R. J., Wise, W. E., "Spot-welded Titanium - Alpha and Alpha-Beta Alloy .025" Gage Sheet Combination - Shear, Tension and Fatigue Properties," General Dynamics/Convair Report SL 56-287, San Diego, California, 18 April 1957. (Reference attached).



ANALYSIS  
PREPARED BY E. K. Winslow  
CHECKED BY W. E. Wise  
REVISED BY

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SAN DIEGO

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MODEL F-102A  
DATE 18 April 1957

REPORT NO. 56-827  
SPOTWELDED TITANIUM  
ALPHA AND ALPHA-BETA ALLOY  
.025" GAGE SHEET COMBINATION  
SHEAR, TENSION, AND FATIGUE PROPERTIES  
MODEL F-102A

REFERENCES:

- (a) Convair Specification O-05003. "Welding - Spot and Seam. Commercially Pure and All Alpha Titanium Alloy."
- (b) TML Report No. 31. "Welding of Titanium and Titanium Alloys." Battelle Memorial Institute, Titanium Metallurgical Laboratory. 7 February 1956.
- (c) Convair Report No. 9748. "Spotwelding of 6AL4V Titanium Alloy". Shear, Tension, and Fatigue Characteristics. 6 October 1955.

OBJECT:

To determine and evaluate the tension, shear, and fatigue properties of alpha and alpha-beta titanium alloys, spotwelded in the following .025" gage sheet material combinations:

- a. Commercially Pure (alpha) to 6AL4V (alpha-beta).
- b. Commercially Pure (alpha) to 5 AL 2½ SN (alpha).
- c. 5 AL 2½ SN (alpha) to 6 AL4V (alpha-beta).

CONCLUSIONS:

1. Shear strength and weld nugget quality for each required sheet combination met Convair Specification O-05003.
2. Tension-shear ratio, an indicator of weld ductility, was .25 or above for all sheet combinations and comparable to commercially pure and all alpha titanium.
3. Fatigue strengths (pounds/spot) of 5 AL 2½ SN - Commercially Pure and 6AL4V - Commercially Pure lap joints were 88% and 55%, respectively, the fatigue strength of 5 AL 2½ SN - 6AL4V lap joints at the endurance limit. (Based on SN - Curve Comparison).

RECOMMENDATIONS:

It is recommended that spotwelded .025" - .025" commercially pure titanium lap joints be tested in fatigue for the purpose of comparison with fatigue test results reported here.

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TEST SPECIMENS AND PROCEDURE:

The following titanium sheet materials, .025" gage, were used for test specimen manufacture.

1. Commercially Pure (alpha) - MST III from Mallary Sharon. Heat number HT-25268 (AMS4901).
2. 6AL4V (alpha-beta) - titanium alloy sheet from Titanium Metals Corp. Heat number M-4274.
3. 5 AL 2½ SN (alpha) - titanium alloy sheet from Titanium Metals Corp. Heat number M-4384.

The chemical composition and physical properties of 6AL4V, according to the manufacturer, were as follows:

Aluminum	6.07%
Vanadium	4.05%
Carbon	.019%
Iron	.118%
Nitrogen	.011%
Hydrogen	.012%
Titanium	Balance

Tensile yield strength	Longitudinal grain	128,330 psi
Tensile yield strength	Transverse grain	130,000 psi
Ultimate Tensile strength	Longitudinal grain	142,900 psi
Ultimate Tensile strength	Transverse grain	147,730 psi
Elongation	Longitudinal grain	7%
Elongation	Transverse grain	9.0%

The chemical composition and physical properties of MST III (AMS 4901) and 5 AL 2½ SN were not available.

Specimen material was prepared for spotwelding as follows:

1. Vapor degrease
2. Alkaline cleaner
3. Hot H<sub>2</sub>O rinse
4. Titanium etch
5. Cold H<sub>2</sub>O rinse
6. Oakite #34 etch
7. Hot H<sub>2</sub>O rinse
8. Vapor degrease

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Hydrogen analysis of test materials was made in the as received and as etched conditions by Process Control Laboratory, Dept 27, Plant 2.

Shear and tension specimen drawings and specifications are shown in Figure 1 and fatigue specimen drawings are shown in Figure 2.

Specimens were spotwelded to give the following:

1. 60% to 80% penetration.
2. Sound nuggets.
3. .003 inches or less electrode indentation.
4. Free of surface burns and electrode pick up.
5. Sheet separation less than .005 inches.

Spotwelding machine settings are shown in Table I.

Tension and shear specimens were tested in a 12,000 pound Tinius Olsen Electromatic testing machine.

Fatigue specimens were tested in a Sonntag SF-1U fatigue machine at load levels (pounds/spot) and load ratios shown in Tables III, IV, and V. The fatigue test set-up is shown in Figure 3.

RESULTS AND DISCUSSION:

The results of tension and shear tests are given in Table II together with tension-shear ratio values.

Fatigue test results are shown in Tables III, IV and V. S-N curves of the three specimen types tested are shown in Figures 4, 5, and 6.

The results of the hydrogen analysis of specimen material was as follows:

<u>Material</u>	<u>Hydrogen %</u>	<u>Condition</u>
MST III	.0063	As received
MST III	.0061	As etched
5A1 2 $\frac{1}{2}$ SN	.0081	As received
5A1 2 $\frac{1}{2}$ SN	.0089	As etched
6 AL 4V	.0091	As received
6 AL 4V	.0085	As etched

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The shear loads and weld nugget quality of test specimens in all cases met Convair Specification O-05003. This specification requires a minimum allowable single spot shear strength of 595 pounds and lowest average single spot shear of 745 pounds.

The tension-shear ratio, an indicator of weld ductility, was .25 or better for all specimen types based on average values. Reference (b) indicates tension-shear ratios of .25 to .40 to be satisfactory for commercially pure titanium in most service applications. Reference (c) indicates tension-shear ratios of .25 or better to be satisfactory for commercially pure and all alpha titanium alloys.

Figure 7 shows comparative S-N curves of specimen groups.

The fatigue strength (pounds/spot) of 6AL4V - commercially pure and 5 Al 2 $\frac{1}{2}$  SN - commercially pure lap joints were 55% and 88%, respectively, the fatigue strength (pounds/spot) of 5 Al 2 $\frac{1}{2}$  SN - 6AL4V lap joints at the endurance limit.

Fatigue failures of all specimen groups tested were of types found in previous tests. Description of these failures are given in the remarks section of Tables III, IV and V. Photographs, representative of spot-weld failure usually encountered in fatigue work, may be found in Reference (c) Figure 8. This figure is shown in Figure 8 for convenient reference.

NOTE:

The data from which this report was prepared are recorded in Engineering Test Laboratories Data Book Nos. 874, page 2, and 4025 page 5.



TABLE II

MECHANICAL PROPERTIES OF SPOTWELDED TITANIUM ALLOYS - Ti-6AL-4V, Ti-5AL-2.55Ni & MST-III

SPEC. NO.	SHEET COMBINATION		SHEAR TEST		SHEAR STR. LBS.	AVG. SHEAR LBS.	NUGGET NOTES	SPEC. NO.	TENSION TEST		AVG. TENSILE STR. LBS.	NUGGET NOTES	TENSION-SHEAR RATIO		TENSILE STR. LBS.	SHEAR STR. LBS.	RATIO	
	SHEET COMBINATION	GAGE	SHEET COMBINATION	GAGE					TENSION COMBINATION	MAT'L			TENSION COMBINATION	MAT'L				TENSILE STR. LBS.
1	.025	6AL-4V	890					1	.025	6AL-4V	313							
2	.025	MST-III	986				2	.025	MST-III	418								
3							3			312								
4							4			288								
5							5			290	302							
6							6			252								
7							7			330								
8							8			265								
9							9			289								
10							10			259								
1	.025	5AL-2.55Ni	1095				1	.025	5AL-2.55Ni	249								
2	.025	MST-III	1040				2	.025	MST-III	260								
3							3			242								
4							4			218								
5							5			252	238							
6							6			216								
7							7			217								
8							8			231								
9							9			260								
10							10			210								
1	.025	6AL-4V	1005				1	.025	6AL-4V	312								
2	.025	5AL-2.55Ni	995				2	.025	5AL-2.55Ni	262								
3							3			273								
4							4			280								
5							5			290	275							
6							6			264								
7							7			270								
8							8			244								
9							9			283								
10							10			276								
* NUGGET NOTES:																		
1 "PULLED" INDICATES NUGGET PULLED FREE OF BASE METAL.																		
2 "N.G." INDICATES SPECIMEN WAS IMPROPERLY MANUFACTURED - THEREFORE WAS DISCARDED.																		

TABLE III  
 FATIGUE TEST RESULTS - SPOTWELDED TITANIUM LAP JOINT - .025 COMMERCIALY PURE  
 TITANIUM TO .025 GALVAN SHEET COMBINATION - TWO SPOTWELDS PER JOINT

SPEC. NO.	MAXIMUM LOAD		R	CYCLES TO FAILURE		REMARKS
	LB/SPOT	LB.		MIN.	LB.	
1-20	250	500	.05	25	16,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
1-22	220	440	.05	22	39,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-2	200	400	.05	20	33,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
1-1	200	400	.05	20	34,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-4	200	400	.05	20	37,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
1-3	200	400	.05	20	41,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
1-5	180	360	.05	18	47,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
1-14	160	320	.05	16	88,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
1-7	160	320	.05	16	95,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-16	140	280	.05	14	105,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-6	140	280	.05	14	238,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-8	120	240	.05	12	178,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-9	120	240	.05	12	451,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-11	100	200	.05	10	384,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-10	100	200	.05	10	463,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-13	80	160	.05	8	1,120,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-12	80	160	.05	8	1,139,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-17	60	120	.05	6	2,911,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-18	60	120	.05	6	4,097,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
1-19	55	110	.05	5.5	10,174,000	SPECIMEN DID NOT FAIL
1-21	55	110	.05	5.5	10,190,000	SPECIMEN DID NOT FAIL

\* C.P. DESIGNATES COMMERCIALY PURE TITANIUM.

TABLE IV  
 FATIGUE TEST RESULTS - SPOTWELDED TITANIUM LAP JOINT - .025 5AL-2.5SN TO .025  
 COMMERCIAL PURE TITANIUM SHEET COMBINATION - TWO SPOTWELDS PER JOINT

SPEC. NO.	MAXIMUM LOAD		R	CYCLES TO FAILURE		REMARKS
	LB/SPOT	MAX. LB.		MIN. LB.		
2-4	399.9	618.7	48.6	.079*	11,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
2-12	275	550	27.5	.05	19,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
2-7	275	550	27.5	.05	21,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
2-9	250	500	25	.05	29,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
2-3	257.5	514.9	39.9	.078*	30,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
2-8	225	450	22.5	.05	36,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
2-11	225	450	22.5	.05	46,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
2-10	200	400	20	.05	61,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
2-2	205	410	20	.049*	65,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
2-13	175	350	17.5	.05	89,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
2-5	179.6	359.3	26.7	.071*	103,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
2-6	150	300	15	.05	166,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
2-14	140	280	14	.05	265,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
2-20	140	280	14	.05	178,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
2-15	120	240	12	.05	371,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
2-16	90	180	9	.05	461,000	FAILED AT EDGE OF SPOT THRU C.P. TI SHEET
2-18	90	180	9	.05	10,081,000	SPECIMEN DID NOT FAIL
2-19	90	180	9	.05	10,218,000	SPECIMEN DID NOT FAIL
2-17	70	140	7	.05	10,009,000	SPECIMEN DID NOT FAIL

\* THESE SPECIMENS WERE RUN AT WRONG R VALUES.

\*\* C.P. DESIGNATES COMMERCIAL PURE TITANIUM.

TABLE V  
 FATIGUE TEST RESULTS - SPOTWELDED TITANIUM LAP JOINT -.025 6AL4V TO .025 5AL-2.5SN  
 SHEET COMBINATION - TWO SPOTWELDS PER JOINT

SPEC. NO.	MAXIMUM LOAD LB/SPOT	LOAD		R	CYCLES TO FAILURE	REMARKS
		MAX. LB.	MIN. LB.			
3-18	350	700	35	.05	9,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
3-17	350	700	35	.05	10,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
3-2	300	600	30	.05	12,000	FAILED BY NUGGET TEAT-OUT IN BOTH SHEETS
3-9	300	600	30	.05	28,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
3-3	250	500	25	.05	41,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
3-10	250	500	25	.05	43,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
3-14	225	450	22.5	.05	53,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
3-7	225	450	22.5	.05	77,000	FAILED BY NUGGET TEAR-OUT IN BOTH SHEETS
3-4	200	400	20	.05	91,000	FAILED AT EDGE OF SPOT THRU 6AL4V SHEET
3-11	200	400	20	.05	107,000	FAILED AT EDGE OF SPOT THRU 6AL4V SHEET
3-13	175	350	17.5	.05	120,000	FAILED AT EDGE OF SPOT THRU 6AL4V SHEET
3-8	175	350	17.5	.05	209,000	FAILED AT EDGE OF SPOT THRU 6AL4V SHEET
3-5	150	300	15	.05	276,000	FAILED AT EDGE OF SPOT THRU 6AL4V SHEET
3-12	150	300	15	.05	394,000	FAILED AT EDGE OF SPOT THRU 6AL4V SHEET
3-16	125	250	12.5	.05	714,000	FAILED AT EDGE OF SPOT THRU 6AL4V SHEET
3-6	125	250	12.5	.05	843,000	FAILED AT EDGE OF SPOT THRU 6AL4V SHEET
3-15	100	200	10	.05	3,508,000	FAILED AT EDGE OF SPOT THRU 6AL4V SHEET
3-19	100	200	10	.05	10,000,000	SPECIMEN DID NOT FAIL
3-1	90	180	9	.05	10,017,000	SPECIMEN DID NOT FAIL

DATE 18 April 1957

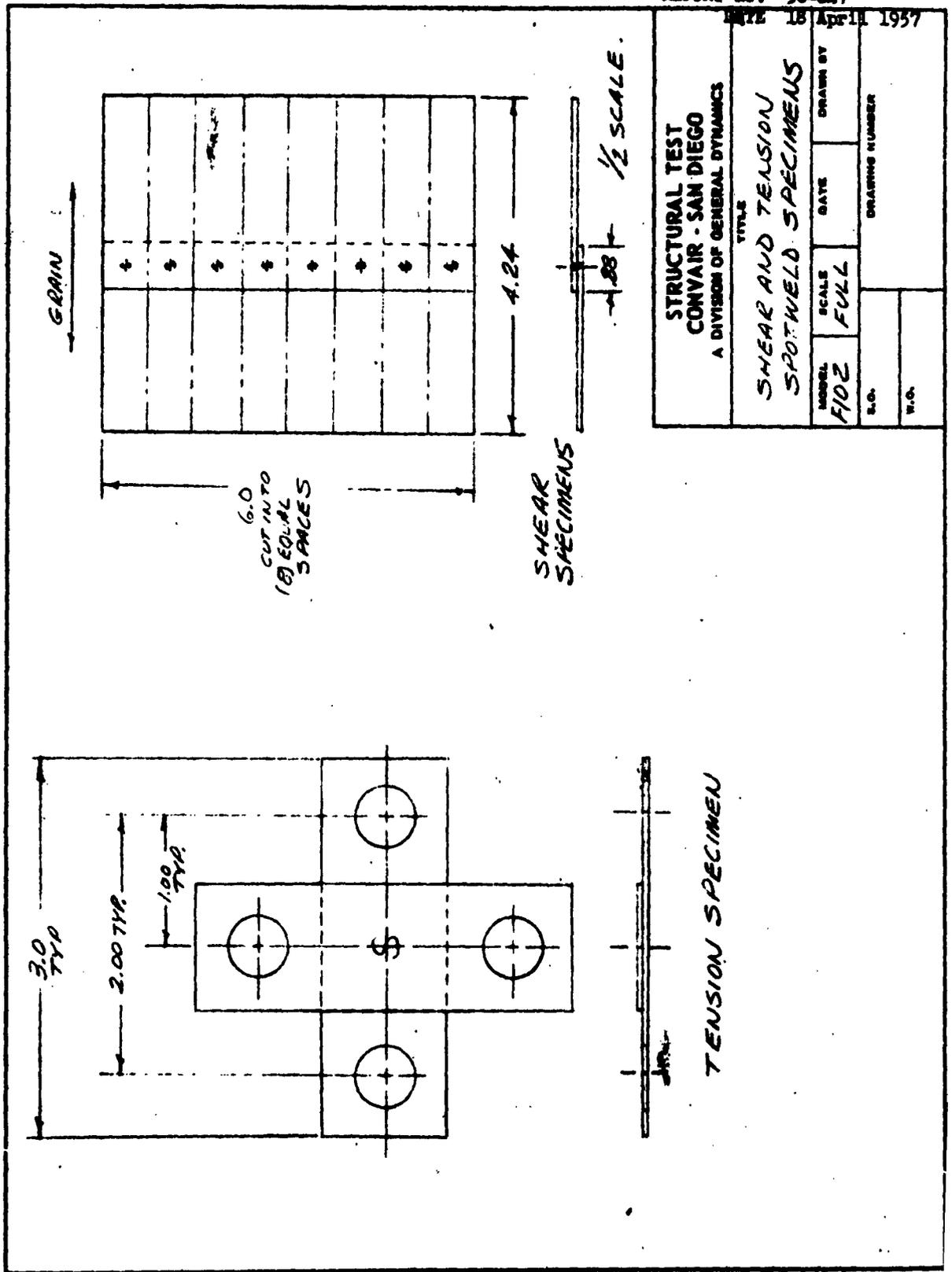


FIGURE 1.

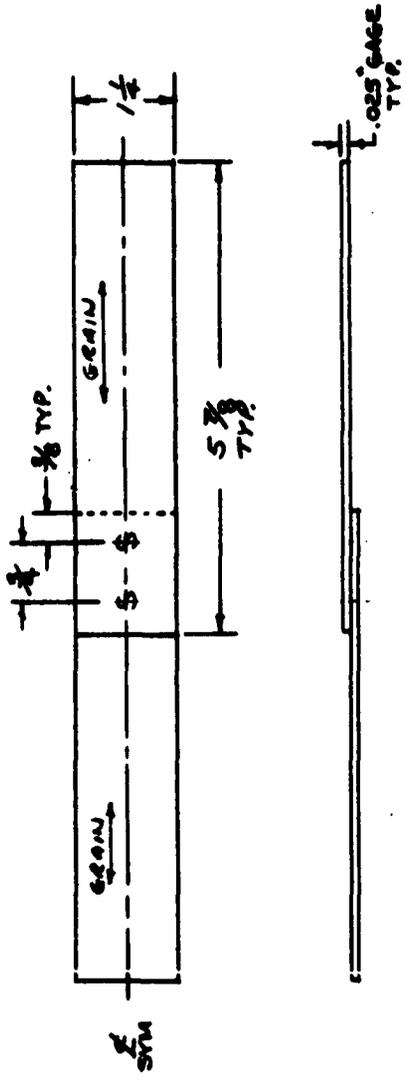
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STRUCTURAL TEST  
 CONVAIR - SAN DIEGO  
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TITLE  
 SPOTWELD FATIGUE  
 TEST SPECIMENS

MODEL F102  
 SCALE 3/4  
 DATE  
 DRAWN BY

S.O.  
 W.O.  
 DRAWING NUMBER



- NOTES:
1. THE FOLLOWING SPECIMENS REQUIRED:
    - (20) 6AL-4V - COMMERCIALY PURE - TITANIUM
    - (20) 5A1-2 1/2 SN. " " "
    - (20) 5A1-2 1/2 SN - 6A1-4V - TITANIUM.

FIGURE 2.

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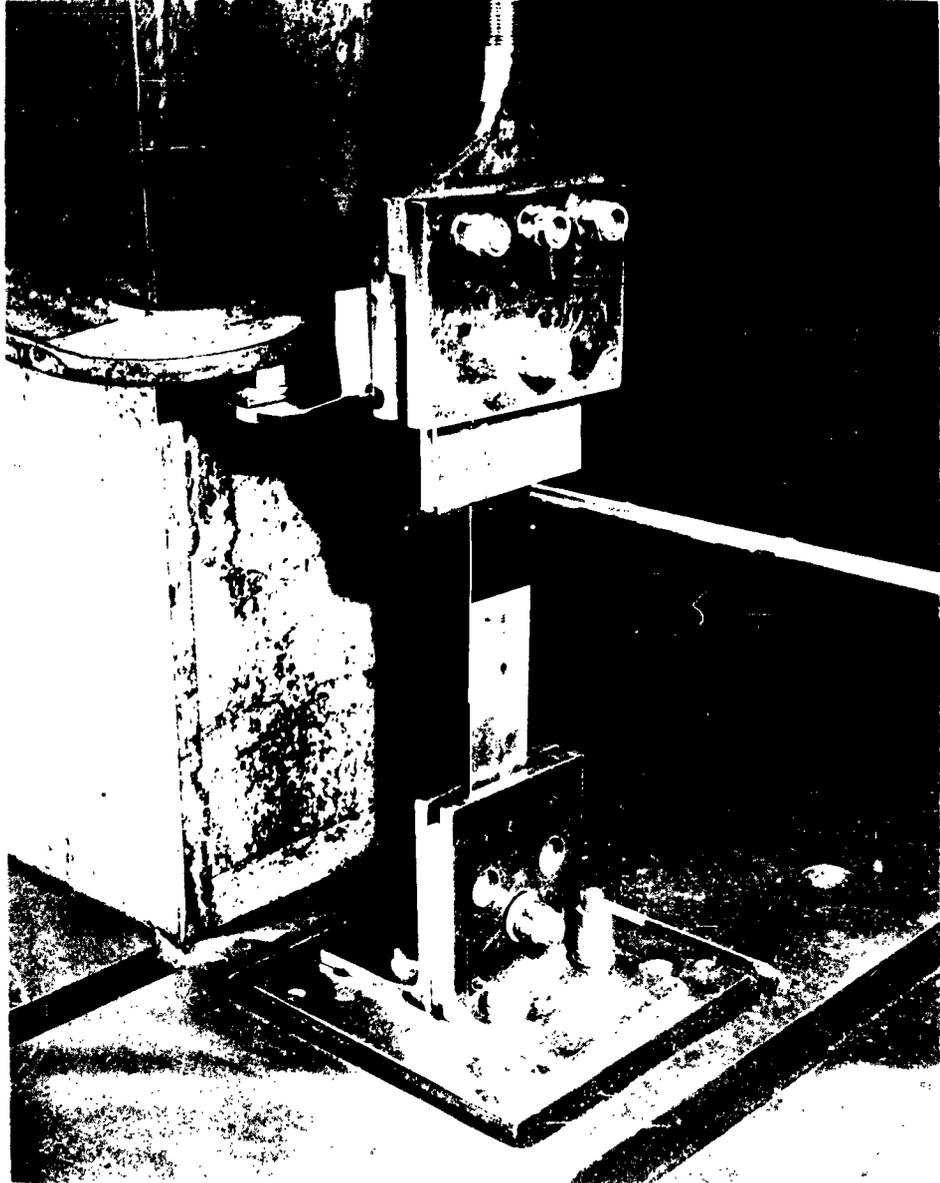
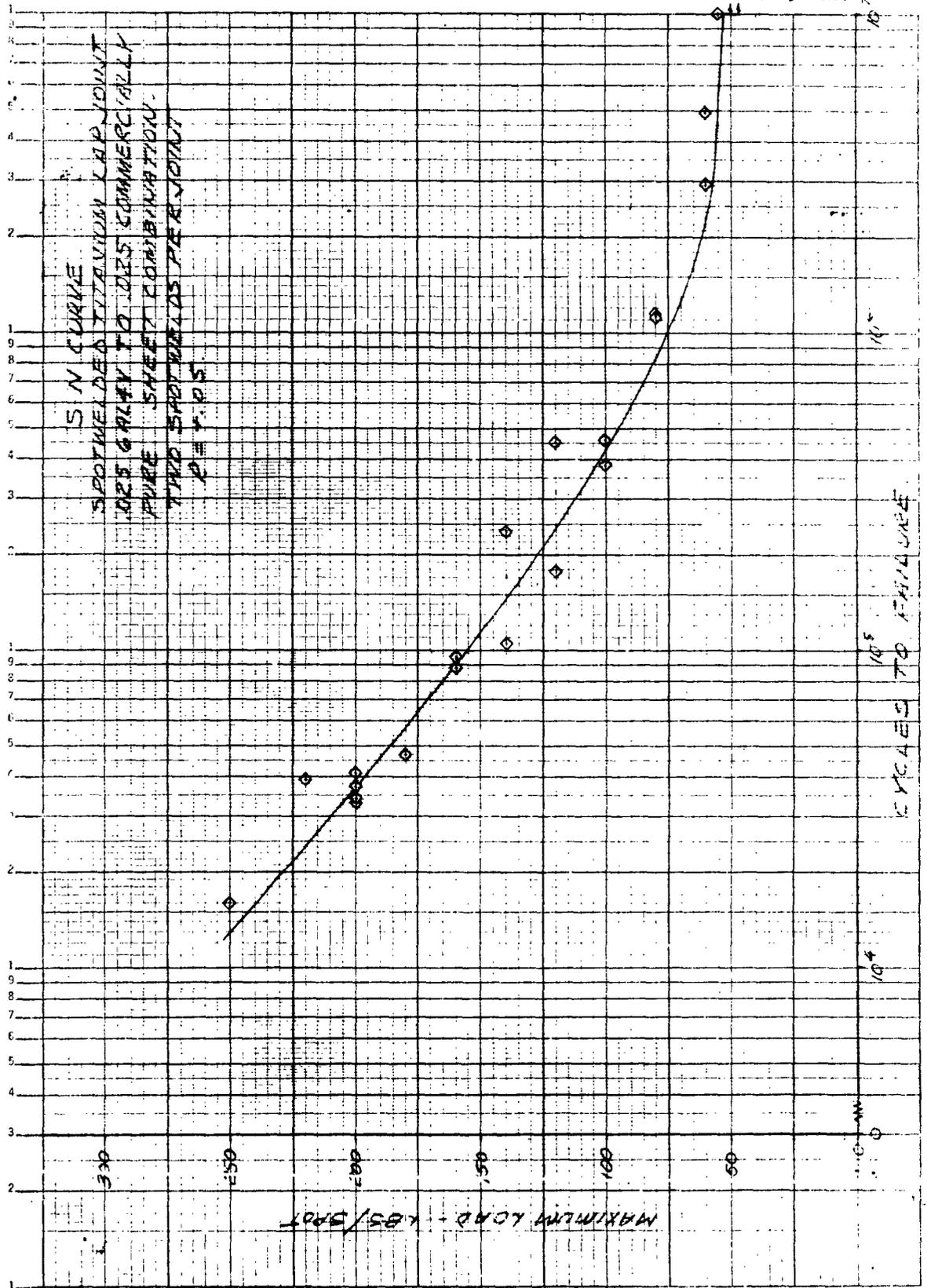


Figure 3 FATIGUE TEST SET UP



1000  
 100  
 10  
 1

FIGURE 4

SEMI-LOGARITHMIC 359.31  
 KELUFFE & ESSER CO. PAID IN U.S.A.  
 3 CYCLES X 70 DIVISIONS

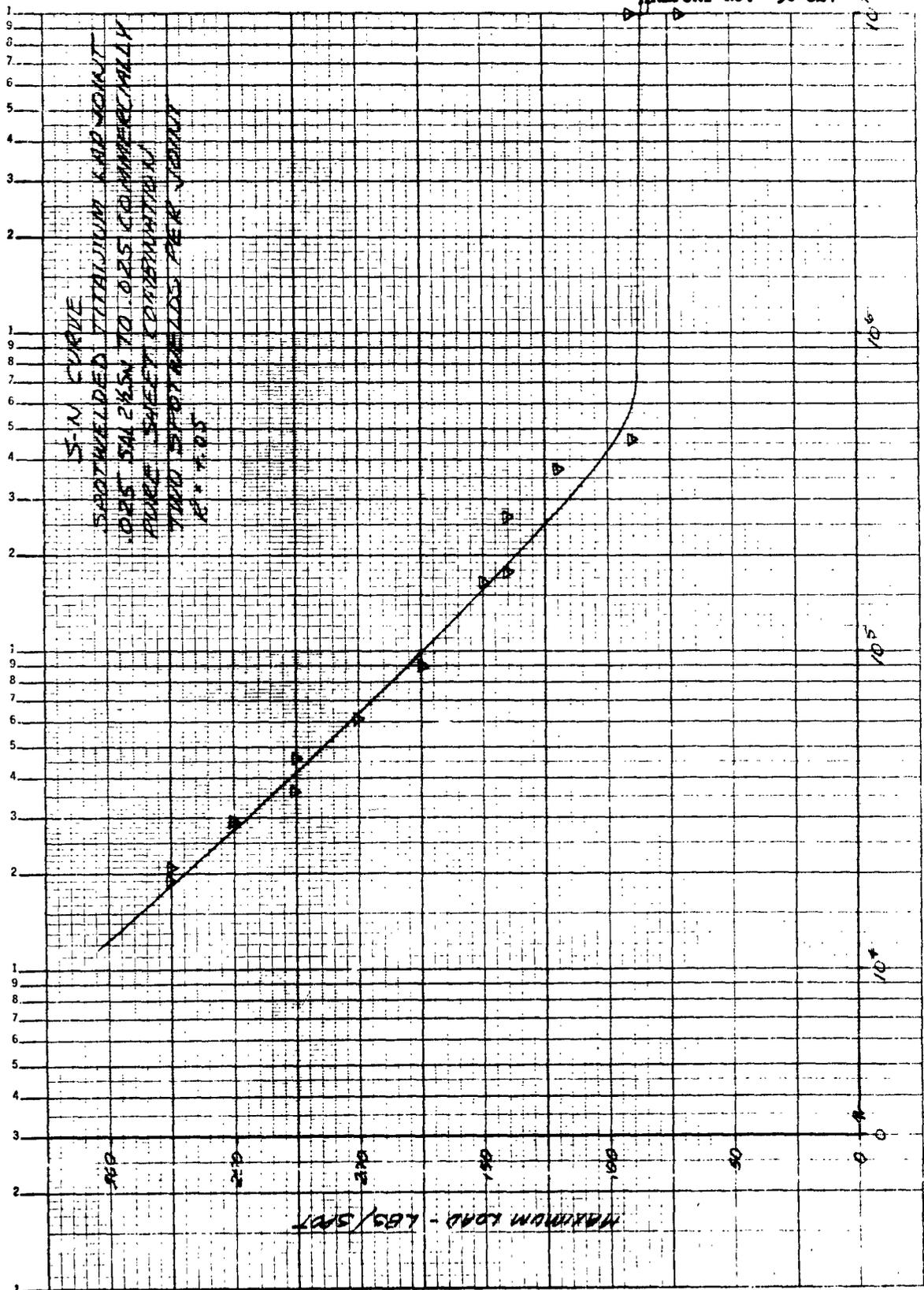


FIGURE 5

**KE** SEMI-LOGARITHMIC 359-81  
 KEUFFEL & ESSER CO. FAC. 'N. U. S. A.  
 4 CYCLES X 70 DIVISIONS

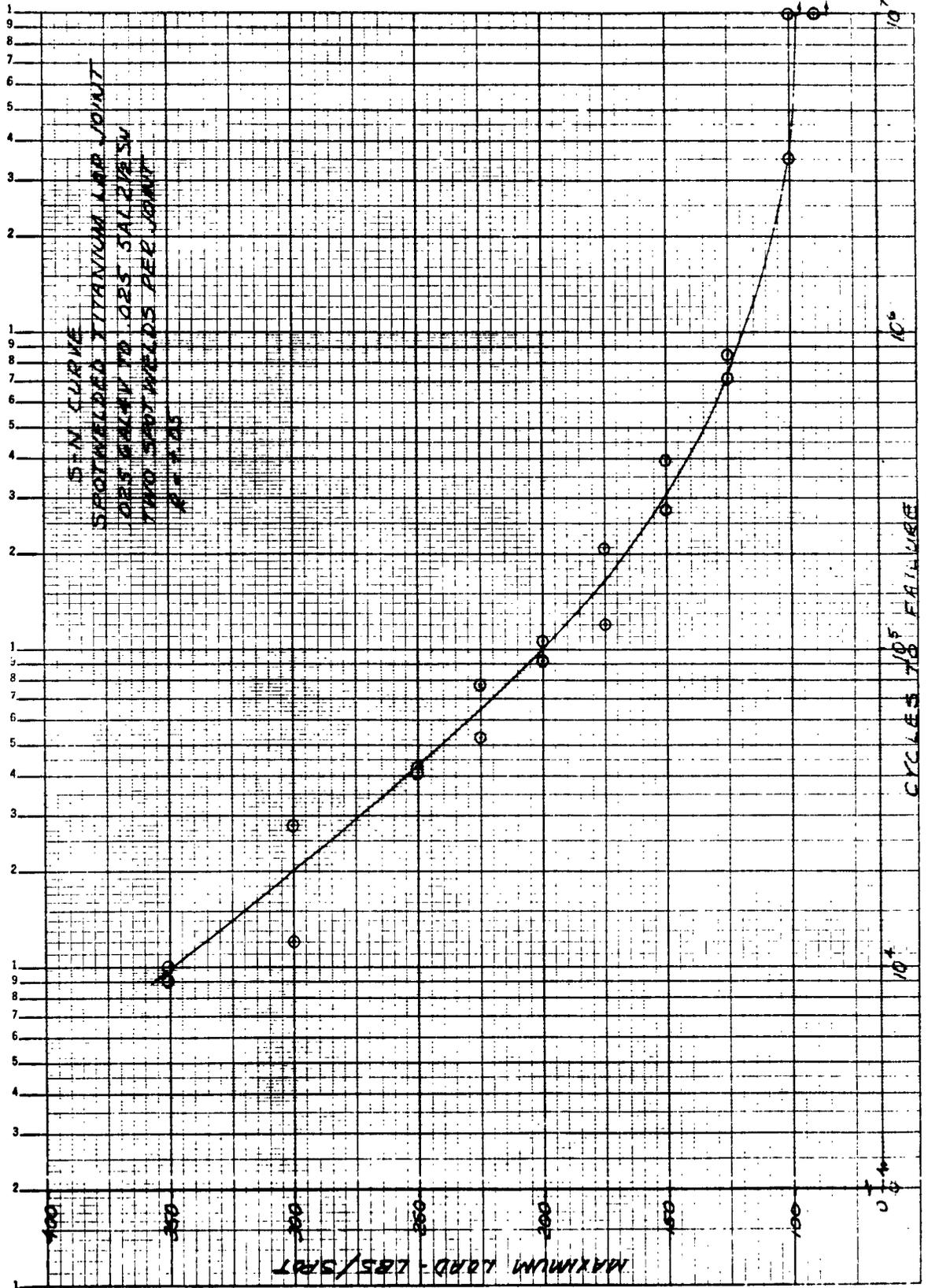


FIGURE 6

K&S SEMI-LOGARITHMIC 359-81  
 KEUFFEL & ESSER CO. NEW YORK, U.S.A.  
 1 CYCLES A TO DIVISIONS

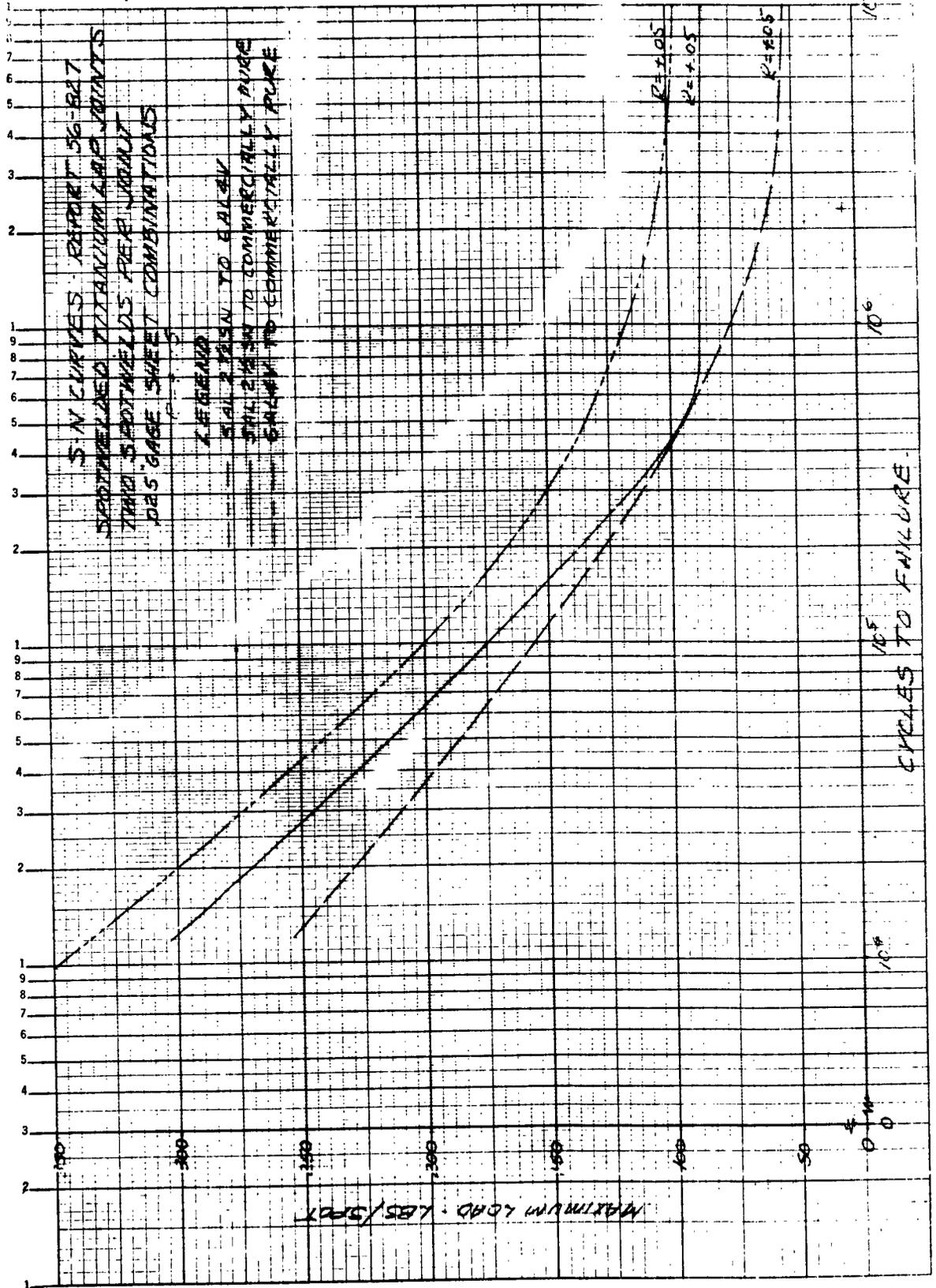


FIGURE 7

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