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Report No. 8926-143

Material - Aluminum - 2020-T6, 2024-T3 and 7075-T6

Crack Propagation and Fatigue Characteristics

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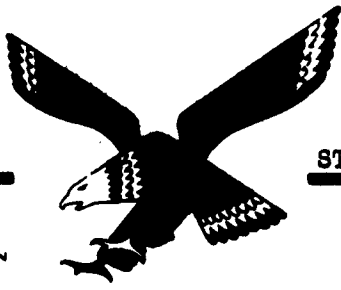
Abstract:

Crack propagation tests were made with 20" wide by 40" long specimens of .079" thick 2020-T6, .0795" thick clad 2024-T3, .091" thick clad 2024-T3, .081" thick bare 7075-T6 and .091" thick clad 7075-T6 aluminum alloys. Initial 5 inch long cracks were introduced into each specimen and crack growth was observed as it related to incremental load increases. The fracture work rate for crack propagation was calculated according to the formula $dW/dA = \sigma^2 \pi x / 2E$ where σ = max. gross stress, x = crack length at max. load and E = modulus of elasticity. The several crack propagation test results were as follows.

<u>Material</u>	<u>dW/dA, in lb./sq.in.</u>
.079" thick clad 2026-T6	144, 181
.0795" thick clad 2024-T3	1000, 990
.091" thick clad 2024-T3	1040
.081" thick bare 7075-T6	400
.091" thick clad 7075-T6	384

Axial fatigue curves were developed with the .079" thick 2020-T6 alloy in both the notched and un-notched conditions, and these are shown.

Reference: Lindeneau, G. D., Schiff, E., Wise, W. E., "Aluminum Alloy Sheet Evaluation, Crack Propagation and Fatigue Tests of Clad 2026-T6 Sheet," General Dynamics/Convair Report SL 58-283, San Diego, California, 23 February 1959. (Reference attached).



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STRUCTURES & MATERIALS LABORATORIES

REPORT SL58-283

DATE 23 February 1959

MODEL R & D 7038

REVISED 26 March 1959

TITLE

REPORT NO. SL58-283
ALUMINUM ALLOY SHEET EVALUATION
CRACK PROPAGATION AND FATIGUE TESTS OF
CLAD 2020-T6 SHEET
MODEL R & D
(7038)

PREPARED BY G. D. Lindeneau
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REFERENCE _____

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APPROVED BY E. F. Strong
E. F. Strong

Chief of Structures and
Materials Laboratories.

WITNESS:
R. A. Miller - Mat'ls Group NO. OF PAGES 15
NO. OF DIAGRAMS 10

REVISIONS

NO.	DATE	BY	CHANGE	PAGES AFFECTED
1	3/26/59	GDL	Changed Title, Figure No., and Table I	Title Page, 4 & 12

ACCESS NO.

Title: MATERIAL - ALUMINUM - 2020-T6, 2024-T3 and 7075-T6. CRACK PROPAGATION AND FATIGUE CHARACTERISTICS.

Authors: Lindeneau, G. D., Schiff, E., Wise, W. E.

Report No.: 8926-143

Date: 23 February 1959

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ABSTRACT: Crack propagation tests were made with 20" wide by 40" long specimens of .079" thick 2020-T6, .0795" thick clad 2024-T3, .091" thick clad 2024-T3, .081" thick bare 7075-T6 and .091" thick clad 7075-T6 aluminum alloys. Initial 5 inch long cracks were introduced into each specimen and crack growth was observed as it related to incremental load increases. The fracture work rate for crack propagation was calculated according to the formula $dW/dA = \sigma^2 \pi x / 2E$ where σ = max gross stress, x = crack length at max. load and E = modulus of elasticity. The several crack propagation test results were as follows.

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(CONTINUED)

ACCESS NO.

Title: MATERIAL - ALUMINUM - 2020-T6, 2024-T3 and 7075-T6. CRACK PROPAGATION
AND FATIGUE CHARACTERISTICS..... (Continued)

Axial fatigue curves were developed with the .079" thick 2020-T6 alloy in
both the notched and un-notched conditions, and these are shown.

15 pages, 3 tables, 7 figures, 3 references.

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INTRODUCTION:

The crack propagation characteristics of several materials have been reported. A proposal to use 2020-T6 aluminum alloy in the near future was being considered. This test was initiated in order to evaluate the crack propagation, mechanical, and fatigue properties of this material.

Parallel crack propagation and mechanical property tests were made on Clad 2024-T3 and Bare 7075-T6 materials.

OBJECT:

To determine:

- a) The crack propagation characteristics of clad 2020-T6, clad 2024-T3, and bare 7075-T6 aluminum alloys.
- b) The mechanical properties of the above three alloys.
- c) The fatigue stress - cycle curves of notched and unnotched clad 2020-T6 aluminum alloy.

CONCLUSIONS:

- a) The crack propagation tests show clad 2020-T6 to have the greatest tendency for crack propagation. This conclusion is based on the low $\frac{dw}{da}$ value (Reference Table I).
- b) The longitudinal and transverse mechanical properties of the three materials tested may be found in Table II.
- c) The clad 2020-T6 material has an unnotched million cycle life stress of 18,000 psi as compared to 26,000 psi for 2024-T3.

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TEST SPECIMENS AND PROCEDURE:

Part a) Crack Propagation Tests

The test specimens were 20" x 40" long with the grain direction parallel to the 40" dimension. Five inches at each end were gripped in the fixture leaving a test section 20" wide by 30" long. The final cut in the test section was made by an .008" diameter jewelers saw. These cuts extended approximately .38" beyond the end of the preliminary cut. A drawing of the test specimen is shown in Figure 1.

The specimens were loaded in increments in a 400,000 pound universal standard Baldwin-Southwark testing machine. Crack measurements and photographs were made at each increment. The load increments were small in order that the failure load could be correlated with the slowly propagated crack length.

Part b) Mechanical Property Tests

Standard 2" gage length tensile specimens were cut both with and cross grain from each sheet of material used in this test.

The tensile yield, ultimate strength and 2" gage elongation were determined in a 12,000 pound Tinius-Olsen electromatic testing machine.

Part c) Fatigue Tests

Six notched and six unnotched specimens as shown in Figure 2 were cut from the two sheets of clad 2020-T6 material. Half of each type were cut from each sheet.

The axial fatigue tests were run at the stress levels shown in Table III and a stress ratio (R) = .05 in a Sonntag SF-1U universal fatigue machine (Reference Figure 3).

RESULTS:

Part a) Crack Propagation Tests

The resistance of a material to crack propagation (or tear resistance) has been investigated by a number of laboratories. The two methods in use to measure this resistance are:

- 1) The energy balance between strain energy and the work necessary to cause fracture.
- 2) The use of a stress concentration factor based on an effective notch radius.

The factors obtained by these methods vary from 3.35 to 1 from (1), to 5.50 to 1 from (2). The variance is a result of the specimen size and initial crack length. Empirical formulas developed for a more reliable estimate of the tear resistance show a variance in results based on specimen size as well as material type.

A thorough discussion of the theory involved is beyond the scope of this report; however, the results of the test are calculated on the basis of these theories and compared to the results of tests by other laboratories. The results are presented in Table I. The discussion of the tear resistance theory may be found in Reference 1.

The clad 2020-T6 material shows the greatest tendency for crack propagation by the low value of $\frac{dw}{da}$.

The comparison of data from previous investigators shows a reasonable correlation.

Photographs of the cracks from initial to just before failure are shown in Figures 4 through 6.

Part b) Mechanical Property Tests

The complete results from these tests may be found in Table II. A summation of the test is shown below by three specimen averages.

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RESULTS: (Continued)

Part b) Mechanical Property Tests (Continued)

<u>Material</u>	<u>Grain Direction</u>	<u>Yield Strength</u> PSI	<u>Ultimate Strength</u> PSI	<u>% Elongation</u> <u>2" Gage</u>
Clad 2020-T6 Sheet #1	Long.	64,789	69,346	9.0
	Trans.	64,723	69,479	7.5
Clad 2020-T6 Sheet #2	Long.	63,366	69,071	8.66
	Trans.	63,268	69,301	8.0
Clad 2024-T3 (One Sheet)	Long.	52,110	70,064	19.83
	Trans.	45,966	67,414	19.83
Bare 7075-T6 (One Sheet)	Long.	76,173	83,097	14.5
	Trans.	73,594	82,648	13.66

Part c) Fatigue Tests

The fatigue test results on clad 2020-T6 are listed in Table III and shown as an S-N diagram in Figure 7. Data from Reference 2 on clad 7075-T6 and from Reference 3 on clad 2024-T3 material has been added to the curve for comparison purposes.

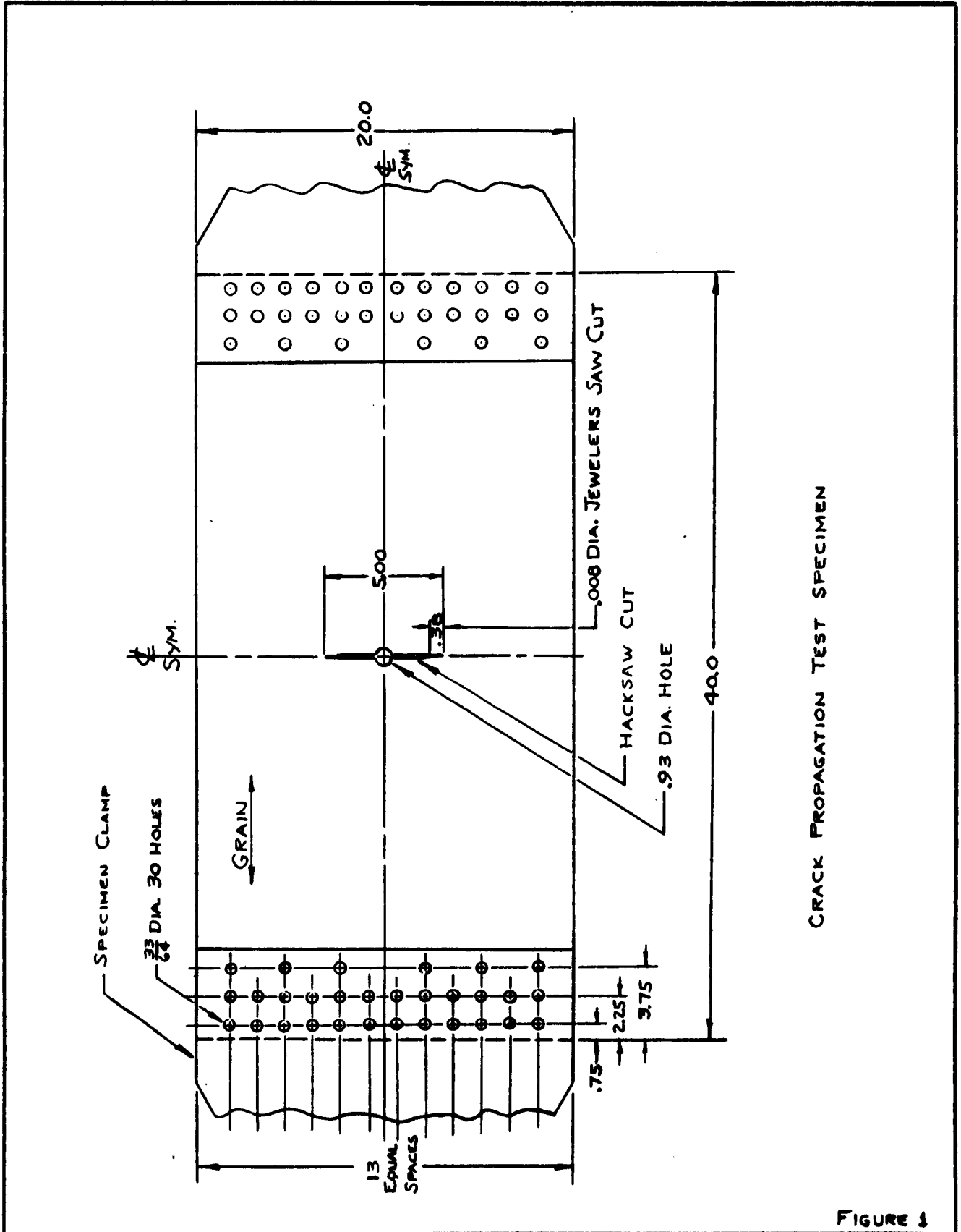
NOTE:

The test data from which this report was prepared are recorded in Structures Test Laboratory Data Book No. 4065, page 18.

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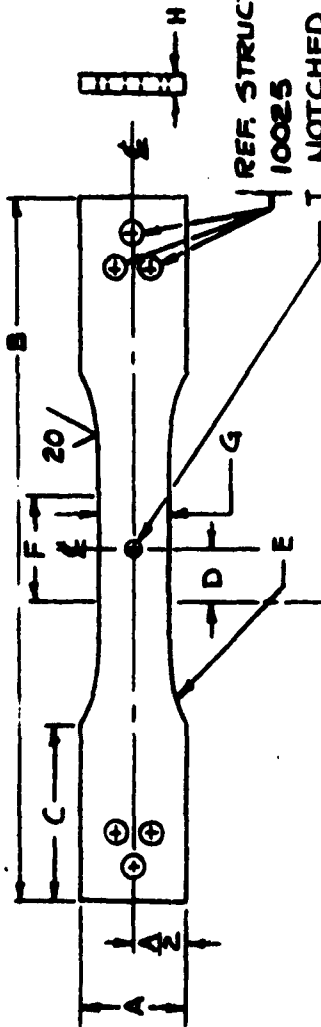
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CRACK PROPAGATION TEST SPECIMEN

FIGURE 1



- NOTES:
1. I DIMENSION USED TO SPECIFY NOTCHED SPECIMENS - TYPICAL NO. 10026-1 INCL.
 2. TYPICAL SPECIMEN NO. UNNOTCHED 10026-1.
 3. THERE ARE TO BE NO NICKS, SCRATCHES, OR UNDERCUTS IN THE TEST SECTION.
 4. UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE AS FOLLOWS: .XX - ±.03
 .XXX - ±.010; ANGULAR DIM. - 0.30
 5. HOLE PATTERN & TO BE SYMMETRICAL TO TEST SECTION WITHIN .003 T.I.R.
 6. MATERIAL TO BE AS SPECIFIED.
 7. GRAIN DIRECTION TO BE LONGITUDINAL UNLESS OTHERWISE SPECIFIED.
 8. FABRICATE IN ACCORDANCE WITH THE FOLLOWING PROCEDURE.
 - 8.1 SHEAR PATTERN TO A & B DIMENSIONS.
 - 8.2 DRILL HOLE PATTERN TO DRAWING 10025
 - 8.3 SAND SAW TEST SECTION TO $\frac{1}{8}$ - $\frac{1}{16}$ OVERSIZE.
 - 8.4 ROUT TEST SECTION TO .005 OVERSIZE (5000 R.R.M. ROUTER).
 - 8.5 DRAW FILE & LONGITUDINALLY POLISH CUT EDGES. USE 0 THRU 000 EMERY PAPER. BREAK CORNERS OF TEST SECTION .005 MAX.

B

STRUCTURAL TEST CONVAIR - SAN DIEGO A DIVISION OF GENERAL DYNAMICS		STANDARD FATIGUE SPECIMEN FLAT SHEET OR PLATE UNNOTCH & HOLE NOTCH.	
MODEL	SCALE NONE	DATE 3-11-58	DRAWN BY BRIGHT
S.O.		DRAWING NUMBER 10026	
W.O.			

	-1	-3	-5	-7	-9	
A	3.00	2.00	2.00	1.50	1.00	
B	13.72	10.98	9.80	9.36	4.87	
C	3.00	2.00	2.00	2.00	.75	
D	—	.50	—	—	—	
E	10.00 R	7.00 R	6.00 R	6.00 R	3.00 R	
F	—	1.0	—	—	—	
G	1.000 ± .002	.660 ± .002	.500 ± .002	.250 ± .002	.250	
H	.081 ± .005	1.008	1.005	1.005	1.005	
a	.250 ± .008	.125 ± .003	.095 ± .003			
b	.187 ± .003					
						Kt
						NET GROSS
						2.43 3.34
						2.54 3.39

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FIGURE 2

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Figure 3 TYPICAL AXIAL FATIGUE TEST SETUPS FOR SHEET SPECIMENS

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Figure 4 CRACK PROPAGATION PHOTO SHOWING TYPICAL INITIAL CRACK

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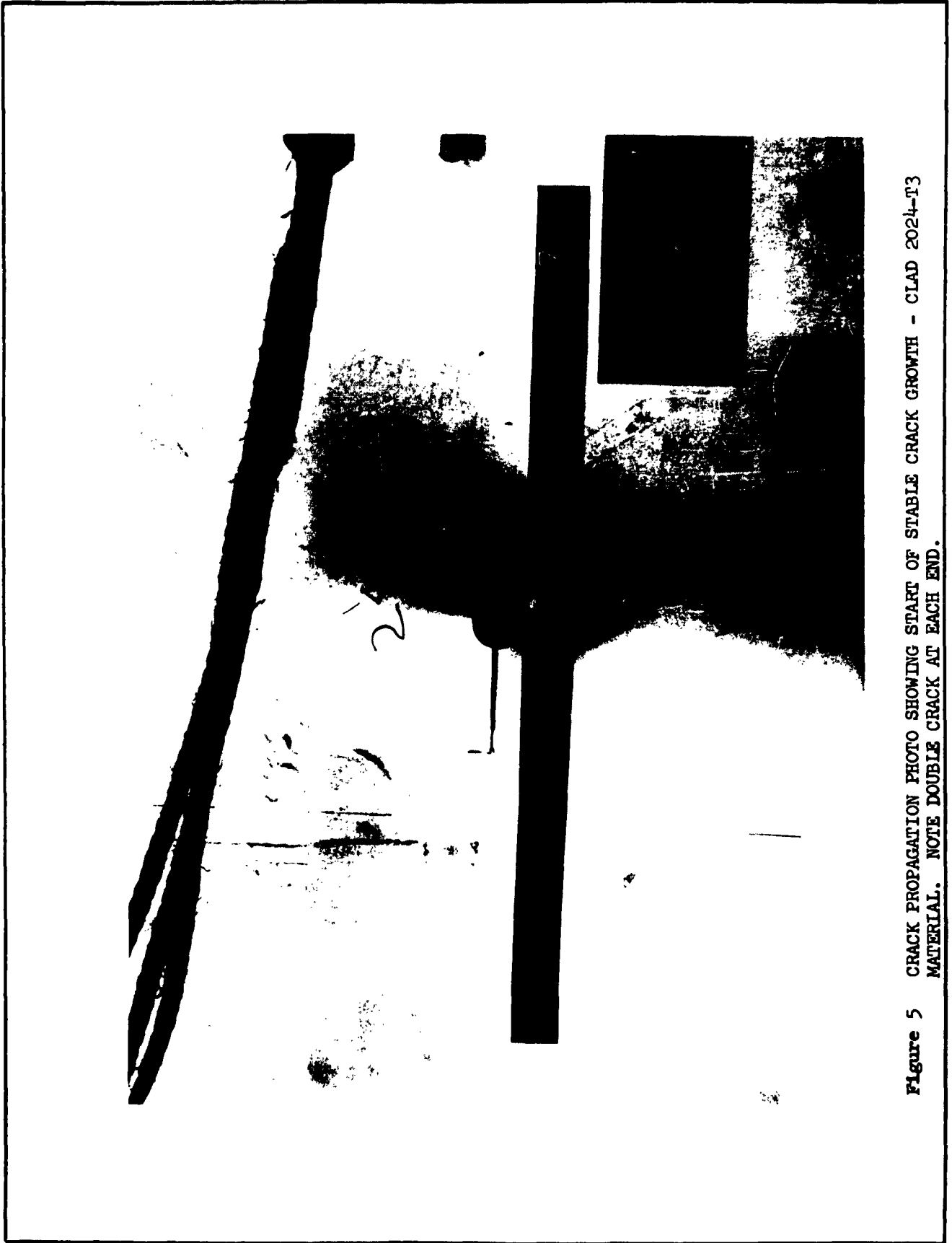


Figure 5 CRACK PROPAGATION PHOTO SHOWING START OF STABLE CRACK GROWTH - CLAD 2024-T3 MATERIAL. NOTE DOUBLE CRACK AT EACH END.

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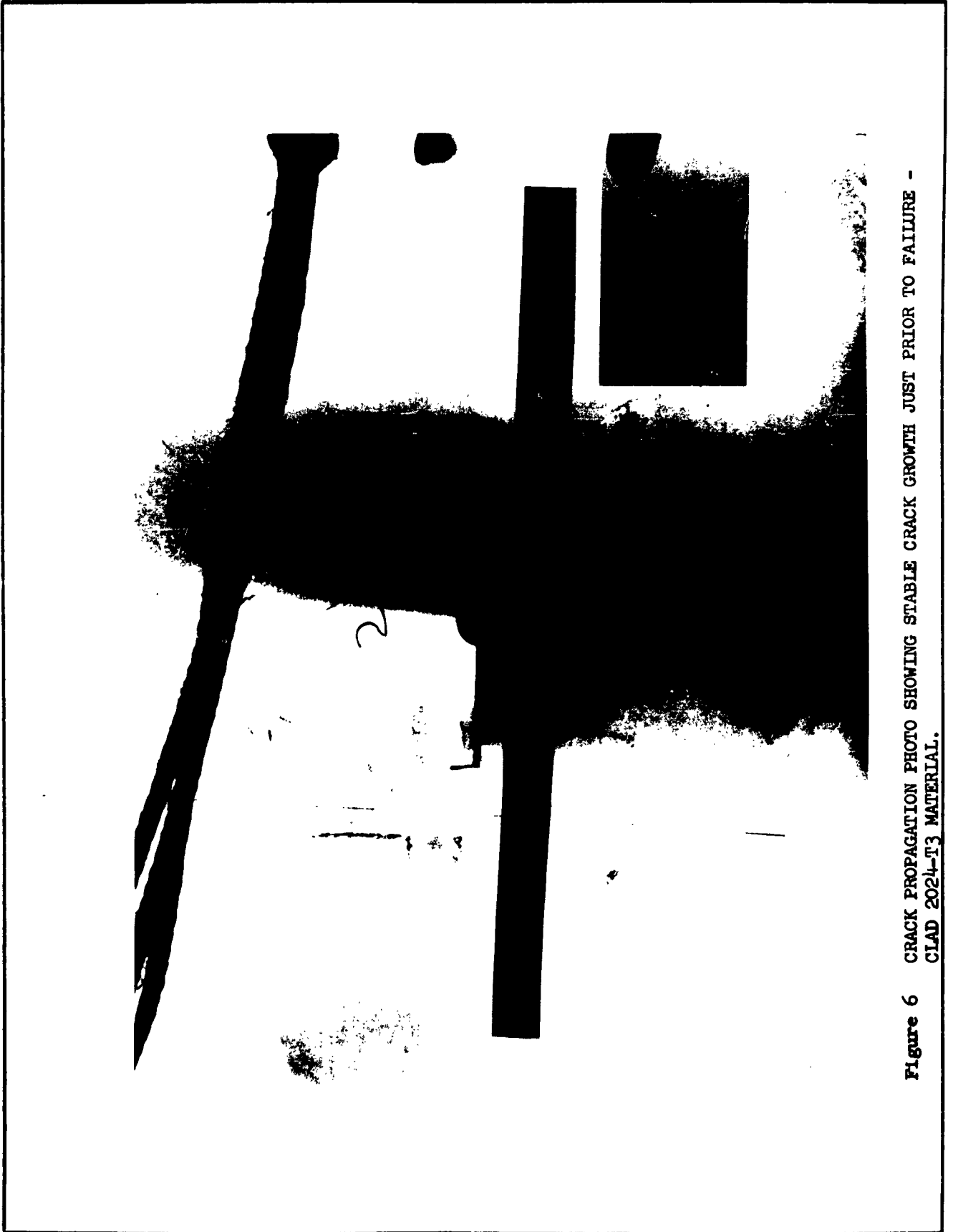


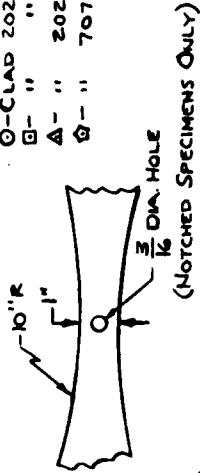
Figure 6 CRACK PROPAGATION PHOTO SHOWING STABLE CRACK GROWTH JUST PRIOR TO FAILURE -
CLAD 2024-T3 MATERIAL.

C O N V A I R
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MATERIAL: 2020T6 CLAD
Mfr _____ Ht. No. _____
F_{tu} = 69,000 PSI. F_{ty} = 64,000 PSI.
SPECIMEN (Sketch and Dimensions)

FORM: CLAD SHEET
CEL. = 90%
Surf. Fin. - L-111 Micro In
T-16 " "
Rockwell - " E " 95

- O-CLAD 2020-T6 - UNNOTCHED
- - " " - NOTCHED
- △ - " " 2024-T3 - UNNOTCHED (REF 3)
- ⊙ - " " 7075-T6 - UNNOTCHED (REF 2)



TEST CONDITIONS: Machine SONNITAG SF1U
R = .05 Mean Stress = —
Other — Temp R.T
Speed 1800 CPM Kt (Net Section) = 2.5
Date: 1-2

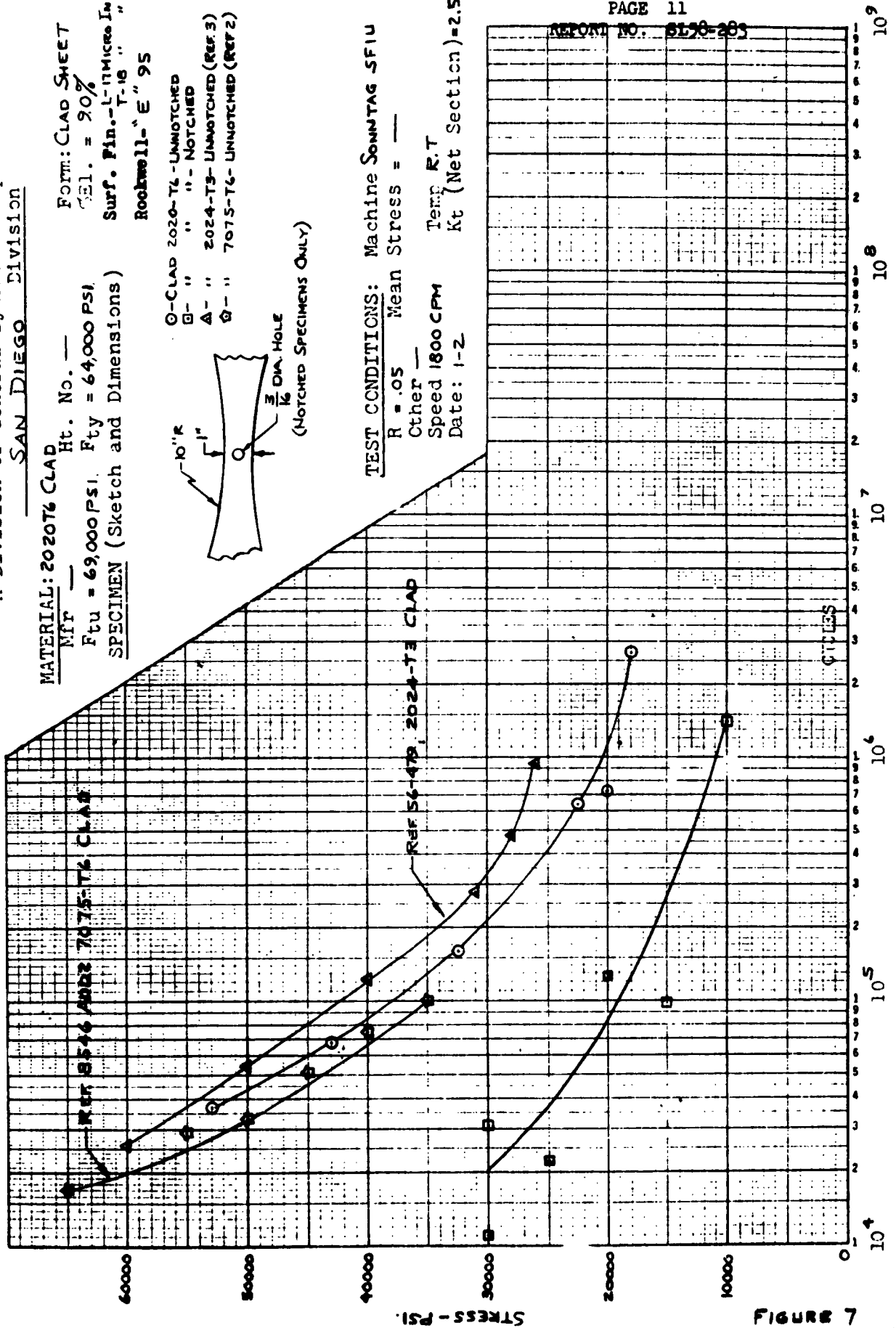


FIGURE 7

TABLE I - CRACK PROPAGATION TEST RESULTS

MATERIAL TYPE	SPECIMEN NUMBER	SHEET NUMBER	YIELD STRENGTH		AVERAGE STRESS		% ELONGATION		SPEC. DIM.		INITIAL CRACK LENGTH	CRACK LENGTH @ MAX. LOAD	MAX. LOAD	MAX. STRESS	MAX. NET STRESS	MAX. NET STRESS d/A
			LONG PSI	TRANS. PSI	LONG PSI	TRANS. PSI	LONG	TRANS.	WIDTH IN.	THICKNESS IN.						
CLAD 2020-T6	1	1	64,789	64,723	69,345	69,479	9.0	7.5	2.00	.079	5.00"	5.48"	22,400	14,150	19,500	14.4
			63,366	63,268	69,071	69,301	8.66	8.0	2.00	.079	4.99"	5.20"	24,900	14,450	21,200	18.1
CLAD 2024-T3	1	1	52,110	45,966	70,064	67,414	19.83	19.83	2.00	.0795	5.00"	6.15"	48,400	39,400	43,600	1000
			—	—	—	—	—	—	2.00	.0795	4.99"	6.06"	48,150	30,250	43,800	990
* CLAD 2024-T3	6	—	—	—	62,000	—	—	—	2.00	.091	5.40"	6.80"	48,400	28,500	40,200	1040
			—	—	—	—	—	—	2.00	.081	4.99"	6.15"	33,600	29,750	—	—
BARE 7075-T6	1	1	74,173	73,594	83,097	82,648	14.5	13.66	2.00	.081	4.99"	5.36"	35,000	21,600	29,500	4.00
			—	—	—	—	—	—	2.00	.081	4.97"	5.36"	35,000	21,600	29,500	4.00
* CLAD 7075-T6	11	—	—	—	72,000	—	—	—	2.00	.091	5.34"	6.07"	34,600	19,000	27,300	384
			—	—	—	—	—	—	2.00	.091	5.34"	6.07"	34,600	19,000	27,300	384

WHERE: σ_T = MAX. GROSS STRESS
 X = CRACK LENGTH AT MAX. LOAD
 E = MODULUS OF ELASTICITY

* DATA FROM REFERENCE 1 FOR COMPARISON PURPOSES.

** FIRST SPECIMEN TESTED - FINAL CRACK MEASUREMENT NOT POSITIVE.

*** $E = 10.3 \times 10^6$, USED FOR THESE CALCULATIONS $\frac{\delta W}{\delta A} = \sigma^2 \frac{IX}{ZE}$ = FRACTURE WORK RATE FOR CRACK PROPAGATION, IN. LB/IN.

TABLE II - STATIC TENSILE TEST RESULTS

MATERIAL TYPE	SHEET NUMBER	THICKNESS	TENSILE YIELD STRENGTH		TENSILE ULTIMATE STRENGTH		2' ELONGATION - PERCENT		
			LONGITUDINAL	TRANSVERSE	LONGITUDINAL	TRANSVERSE	LONGITUDINAL	TRANSVERSE	
CLAD 2020-T6	1	.079	64516	63896	69479	69479	90	75	
			65050	64268	69403	69403	90	80	
			69901	66008	69154	69154	90	70	
			AVERAGE	64723	AVERAGE	69345	AVERAGE	90	75
			64229	63906	69905	69905	80	85	
CLAD 2024-T3	1	.0795	52208	45570	69951	67204	190	20.5	
			52221	47563	69969	67716	200	19.5	
			51901	44966	70272	67322	20.5	19.5	
AVERAGE	52110	45966	AVERAGE	70064	AVERAGE	19.83	19.83		
BARE 7075-T6	1	.081	76702	73288	82544	82217	140	130	
			75881	73694	83333	82812	14.5	140	
			75988	73801	83595	82917	150	140	
			AVERAGE	76173	73594	AVERAGE	83097	AVERAGE	14.5

TABLE III
 FATIGUE DATA - CLAD 2020-T6 ALUMINUM ALLOY

SPECIMEN NUMBER	MAXIMUM GROSS STRESS, PSI	R	CYCLES TO FAILURE	NOTCHED	REMARKS
1-6	53,000	.05	37,000	No	FAILED IN TEST SECTION ↓ FAILED IN TEST SECTION
1-5	43,000	↓	67,000	↓	
1-4	32,500		159,000		
2-4	22,500		633,000		
2-5	29,000	.05	721,000	No	
2-6	18,000		2,689,000		
1-3	39,000	.05	31,000	Yes	FAILED IN TEST SECTION ↓ FAILED IN TEST SECTION
2-2	39,000	↓	11,000	↓	
1-2	25,000		23,000		
1-1	29,000		126,000		
2-1	15,000	.05	98,000	Yes	
2-3	19,000		1,415,000		

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2. G. D. Lindeneau, "XA 78S-T6 and 75S-T6 Clad Aluminum Alloy Sheet - Static and Fatigue Tests", Convair Engineering Test Laboratory Report No. 85-5 Addendum 2, dated July 1955.
3. D. M. Forney, Jr., "The Effect of Artificial Aging on the Fatigue Behavior of Bare and Clad 2024 Aluminum Alloy", Convair Engineering Test Laboratory Report No. 56-479, dated October 20, 1956.