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**401 386**

Report No. 8926-136

Material - Adhesives - Structural

Effect of Bond Voids on Fatigue Strength

C. Conaway, G. D. Lindeneau, W. E. Wise

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ANALYSIS  
PREPARED BY C. Conaway  
CHECKED BY W. E. Wise  
REVISED BY

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A DIVISION OF GENERAL ELECTRIC CORPORATION  
SAN DIEGO

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REPORT NO. 57-510  
MODEL F-102A  
DATE 8 April 1958

OBJECT:

This series of tests was conducted to determine the fatigue resistance of:

1. Bonds that contained voids.
2. Bonds that had been repaired by injecting adhesive into the unbonded area.

SPECIMENS:

The specimens were fabricated in accordance with Drawing 8-01672 (Reference Figures 1A - 1D). Specimens No. 1 through 16 were revisions (Reference Figure 1C) of the original type and were given the designation -40, except for No. 3 and 4 which were modified -19 assemblies.

Specimens No. 17 through 26 were -31 to -35 assemblies (Reference Figure 1B). Specimens No. 27 through 29 were -21 assemblies (Reference Figure 1D).

Specimens No. 30 - 63 were -1 through -19 assemblies (Reference Figure 1C).

Information regarding their fabrication beyond that given in Figures 1A - 1D is available in the files of the Materials and Processes Laboratories.

PROCEDURE:

The specimens were mounted in Sonntag Fatigue Testing Machines and cycled to failure except in a few instances where the number of cycles exceeded two million. Some of these specimens were dissected to see the nature of the void or the repair. Other specimens were carried on to failure at several million cycles.

Specimens of each of the three types of loading were tested as follows:

- (1) Tension Nos. 1 through 16 were tested in a 1-UA Sonntag Fatigue Testing Machine (Reference Figure 2).
- (2) Bending 17-26 (Reference Figure 3) and diagonal 27-29 (Reference Figure 4) in a 10-U Sonntag Fatigue Testing Machine.
- (3) Specimens No. 30-63, tension type (Reference Figure 2) were tested in a 20-U Sonntag Fatigue Testing Machine.

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PREPARED BY G. Conaway  
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PROCEDURE (Continued)

The diagonally loaded specimens were "stub-metered" to survey the voided areas. They were cycled and "stub-metered" at convenient intervals to observe any change or growth of the voids.

Void detection by this method was only approximate as foaming and partial adhesion confused the pattern.

The bond allowable used in the beginning was 2,000 psi. This was increased to 4,000 psi for the later specimens. The fatigue load applied was 4/9 of the above values.

All the specimens were loaded 100% maximum to 0 + 2% minimum except the diagonal specimens (Reference Figure 4) which were fully reversed + 100% maximum to -100% minimum.

The rate of cycling was 1,800 cycles per minute.

RESULTS:

The results are listed in the accompanying tables:

Summary of Table I

The cycles at failure for 1.0 in<sup>2</sup> area of adhesive metal bond loaded in shear to 4/9 of 8,000 pounds (3,555) was 53,000 ± 50% average (Reference Specimens No. 1-4).

The cycles at failure of bonds with 1.0 in<sup>2</sup> net area but with voids which increased the perimeters of the bonds varied from 166,000 cycles to 2,694,000 cycles (Reference Specimens No. 4 - 8 and 12 - 14).

Summary of Table II

The bending and diagonally loaded specimens produced no void propagation or growth.

Summary of Table III

These tests are listed to indicate that none of the bond and void combinations or injection repairs significantly influenced the fatigue life of this group.

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PREPARED BY  
CHECKED BY  
REVISED BY

C. Conaway  
W. E. Wise

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Summary of Table III (Continued)

The bond to metal ratio used in the early stages of these tests net area of bond in shear  $9.60 \text{ in}^2$ /net area of metal in tension  $.375 \text{ in}^2 = 25.6/1$  was too great as the metal failed. When the ratio was reduced to  $19.5/1$  the failures appeared in both metal and bond. A safe limit and with stress concentrations minimized to assure bond failures would be somewhat less than the latter figure.

CONCLUSIONS:

While the results of these tests are not conclusive they are informative in the following regards:

1. Bond endurance depends on bond perimeter as well as area; longer perimeters with a given area produce longer life within certain limits.
2. Study voids did not expand or propagate under repeated load.
3. Repairable contamination voids are extremely difficult to produce as the contaminating substance is hard to extract when repair is to be made.
4. "Stub-meter" survey of voids is only an approximation of type and size.
5. Many possible refinements of adhesive metal bonding became evident during this testing: favorable orientation of bond edges, control of elasticity of adhesives, uniformity of pressures during curing and reduction of stress concentrations that induce either bond or metal fatigue.
6. Injection repair of voids is effective where the injected adhesive spreads throughout the voided area.
7. The ratio of bond area in shear to metal cross-sectional area in tension should not exceed 18 to 1 for fatigue tests.

NOTE:

The test data from which this report was prepared are recorded in Structures Test Laboratory Data Book No. 4056, pages 10 and 11.

REV. NO.	INCORP.	DATE	DESCRIPTION
40			CHANGE IN BONDING AREA
PAGE A			REPORT NO. 27-530
			DATE 8 APR 1958

TEST PROGRAM

ASSY. DASH NO.	QTY	TEST
-1, -19, -21, -31	2 EA.	STATIC TO DESIRE LOADS BY METHOD SHOWN
-1, -3, -5, -7		
-9, -11, -13, -15		
-17, -19, -21, -23	4 EA.	FATIGUE WITH LOADS SHOWN
-25, -27, -29, -31		
-33, -35, -37, -39		

8-01672

9. Δ CONK. PART-MINNESOTA MINING MFG. CO. ST. PAUL, MINN.
8. -19 ASSY TO BE MADE WITH .015-.025 ADHESIVE THICKNESS AT EACH BOND, OVER ENTIRE BOND AREA. CHECK WITH ADHESIVE LAB. ENGINEERING TEST LABORATORIES FOR METHOD FOLLOWING PROCEDURE:
  - (1) DETERMINE OUTLINE OF HOLE BY STUB METER.
  - (2) DRILL TO INJECTION BLEED HOLES THREE UNBONDED METAL ONLY, MAINTAIN A MINIMUM OF .25 EDGE DISTANCE AND PLACE HOLES SO AS NOT TO INTERFERE WITH ANY SUBSEQUENT GINETING IN THE AREA.
  - (3) INJECT ACRES UNDER PRESSURE UNTIL IT FLOWS FROM BLEED HOLES.
  - (4) CLAMP UP ENTIRE AREA OR USE WEIGHTS FOR BONDING PRESSURE USE PADS TO DAMAGE TO PART & PROVIDE MEANS FOR EXCESS BOND TO BE REMOVED FROM BLEED HOLES.
  - (5) CURE REPAIR AT 300°F FOR 15 MINUTES.
  - (6) REINSPECT, REMOVE FOR REMAINING Voids.
7. -5, -9, -13, -17, -21, -25, -29, -33 ASSYS TO BE MADE WITH ADHESIVE LAB. ENGINEERING TEST LABORATORIES FOR METHOD FOLLOWING PROCEDURE:
  - (1) REINSPECT, REMOVE FOR REMAINING Voids.
  - (2) DRILL TO INJECTION BLEED HOLES THREE UNBONDED METAL ONLY, MAINTAIN A MINIMUM OF .25 EDGE DISTANCE AND PLACE HOLES SO AS NOT TO INTERFERE WITH ANY SUBSEQUENT GINETING IN THE AREA.
  - (3) INJECT ACRES UNDER PRESSURE UNTIL IT FLOWS FROM BLEED HOLES.
  - (4) CLAMP UP ENTIRE AREA OR USE WEIGHTS FOR BONDING PRESSURE USE PADS TO DAMAGE TO PART & PROVIDE MEANS FOR EXCESS BOND TO BE REMOVED FROM BLEED HOLES.
  - (5) CURE REPAIR AT 300°F FOR 15 MINUTES.
  - (6) REINSPECT, REMOVE FOR REMAINING Voids.
6. -3, -7, -11, -15, -19, -23 ASSYS TO BE MADE WITH ADHESIVE LAB. ENGINEERING TEST LABORATORIES FOR METHOD FOLLOWING PROCEDURE:
  - (1) DETERMINE OUTLINE OF HOLE BY STUB METER.
  - (2) DRILL TO INJECTION BLEED HOLES THREE UNBONDED METAL ONLY, MAINTAIN A MINIMUM OF .25 EDGE DISTANCE AND PLACE HOLES SO AS NOT TO INTERFERE WITH ANY SUBSEQUENT GINETING IN THE AREA.
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  - (1) DETERMINE OUTLINE OF HOLE BY STUB METER.
  - (2) DRILL TO INJECTION BLEED HOLES THREE UNBONDED METAL ONLY, MAINTAIN A MINIMUM OF .25 EDGE DISTANCE AND PLACE HOLES SO AS NOT TO INTERFERE WITH ANY SUBSEQUENT GINETING IN THE AREA.
  - (3) INJECT ACRES UNDER PRESSURE UNTIL IT FLOWS FROM BLEED HOLES.
  - (4) CLAMP UP ENTIRE AREA OR USE WEIGHTS FOR BONDING PRESSURE USE PADS TO DAMAGE TO PART & PROVIDE MEANS FOR EXCESS BOND TO BE REMOVED FROM BLEED HOLES.
  - (5) CURE REPAIR AT 300°F FOR 15 MINUTES.
  - (6) REINSPECT, REMOVE FOR REMAINING Voids.
3. BOND BARE SHEET 00-A-355 HEAT TREATED TO T86 CLAD VALUES PER AN-148.
2. PREPARED DIMENSIONS CORE 16' MERCURY .0015 FOR SPEC. MIL-C-7858B TYPE 1C.
1. FABRICATE PER CONTINUING SPEC. 8-01672.

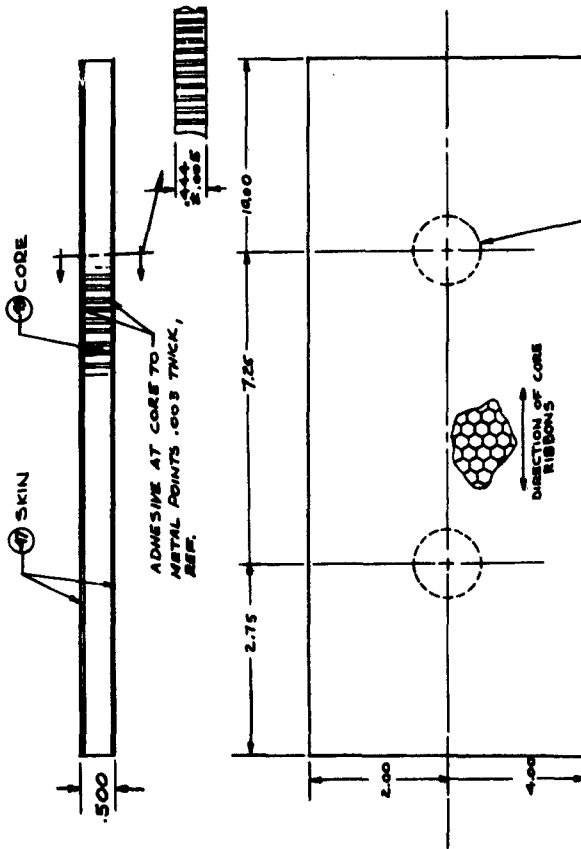
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38	11/11	PLATE		
39	11/11	PLATE		
40	11/11	PLATE		

TEST SPECIMEN BONDING VOID FATIGUE

8-01672

FIG-1A

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CREATES A 1.00 DIA. BONDING VOID BETWEEN CORE AND SKIN UPPER AND LOWER SURFACES 2 PLYS FOR .93 PER NOISE 5 AND .18 PER NOISE 6. SEE NOTE 7 FOR 374-89

-31 THRU 39 ASSYS

FATIGUE LOADING

8-01672  
 2 4

SEE SHT 1 FOR B/M

APPLICATION CONT ON SHEET 3  
 FOR TEST

-27  
 -25  
 -21  
 -19  
 -17  
 -16

TEST SPECIMEN  
 BONDING VOID,  
 FATIGUE

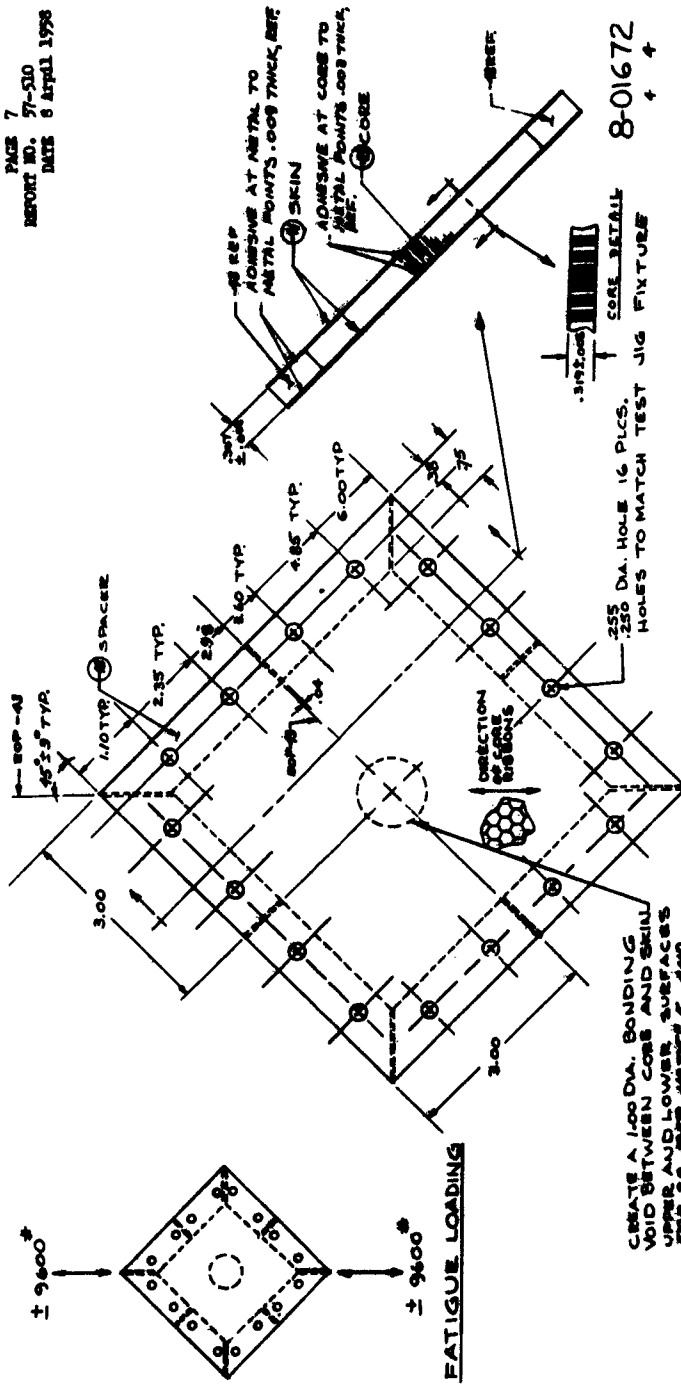
4/17  
 6-20  
 J. WILSON 6-20

8-01672  
 2 4

FIG.-1B



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CREATE A .100 DIA. BONDING VOID BETWEEN CORE AND SKIN UPPER AND LOWER SURFACES FOR 29 SEE NOTE 7 AND FOR 29 SEE NOTE 8 SEE NOTE 7 FOR 29 & 29

-21 THRU -29 ASSYS

TEST SPECIMEN  
 BONDING VOID  
 FATIGUE

4/4  
 6/20  
 J. WILSON 5/20

FULL

FIG-ID

8-01672

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CHECKED BY W. E. Wise  
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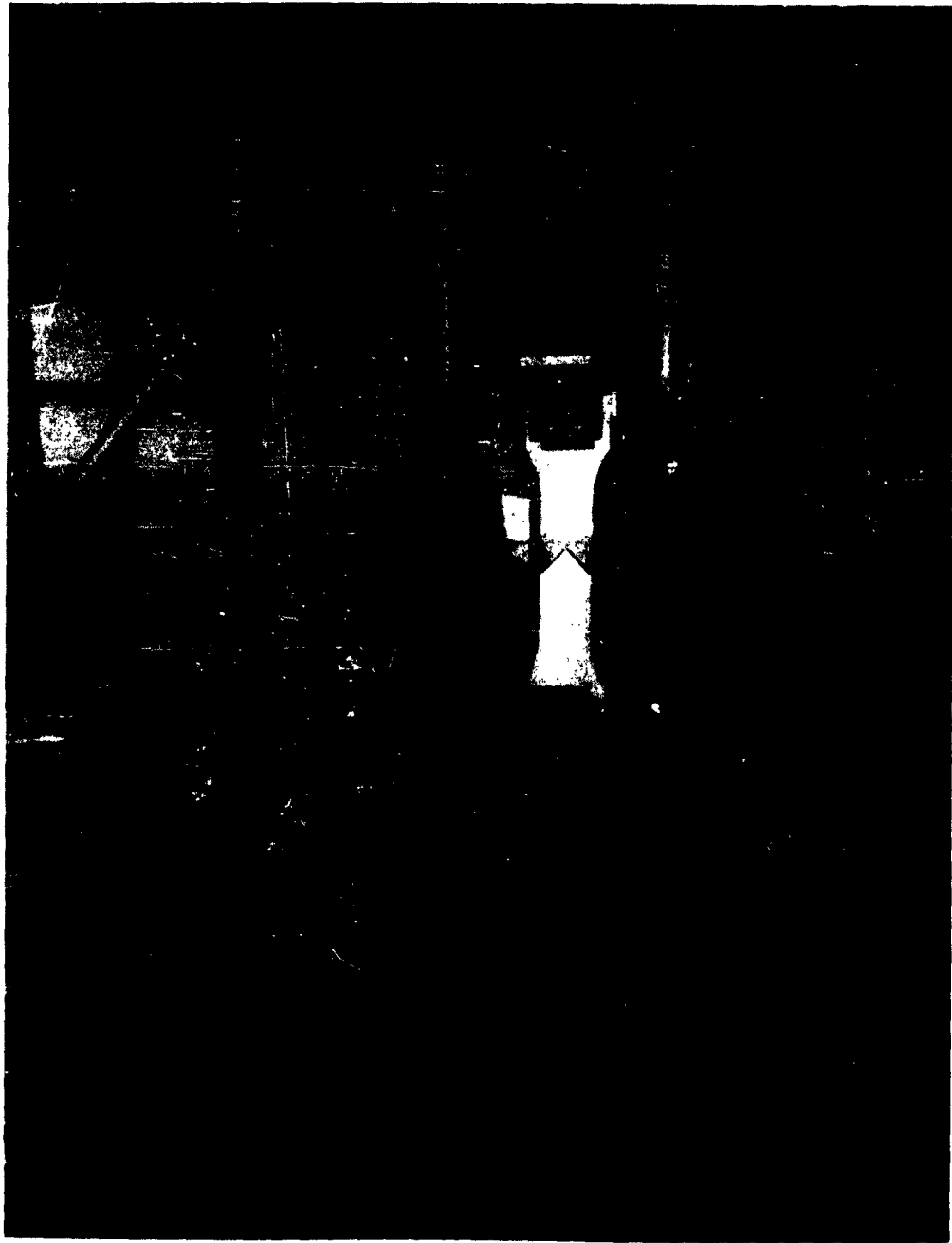


Figure 2 TENSION TESTS

ANALYSIS

PREPARED BY

CHECKED BY

REVISED BY

C. Conaway

W. E. Wise

CONVAIR

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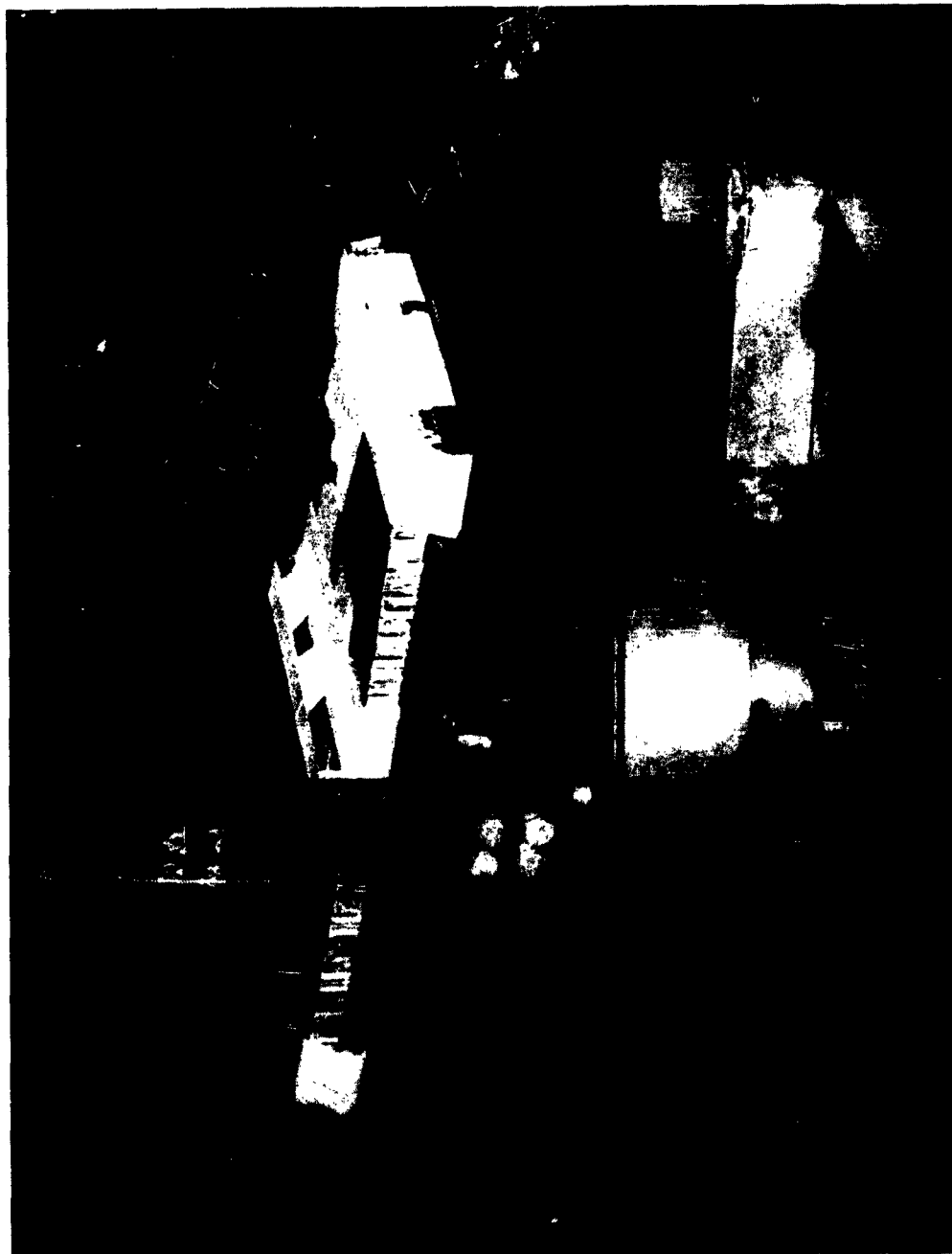


Figure 3 BENDING TESTS

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PREPARED BY  
CHECKED BY  
REVISED BY

C. Conway  
W. E. Wise

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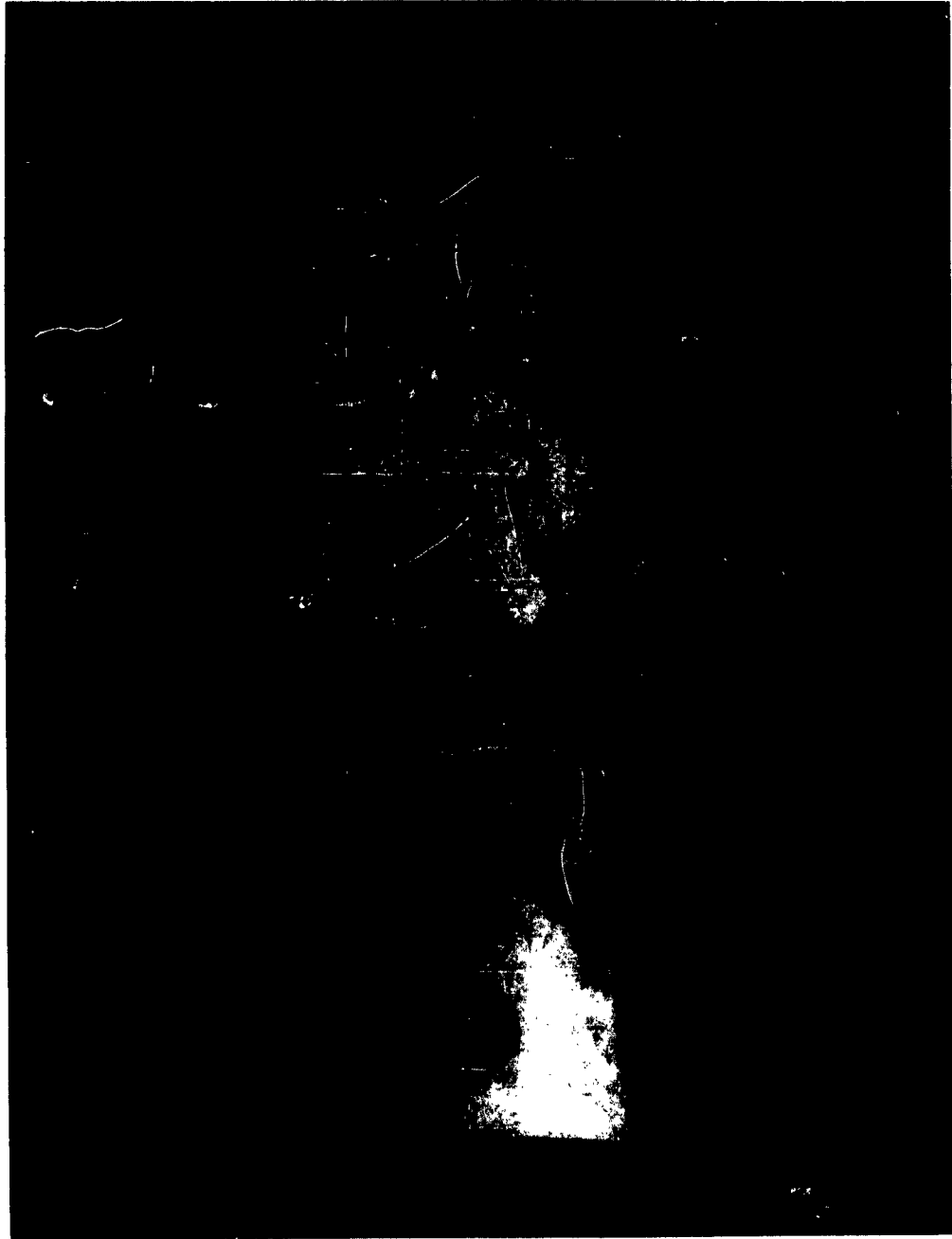


Figure 4 DIAGONAL TESTS

TABLE I

TENSION TEST RESULTS

SPECIMEN NO	TYPE	LOADING	BOND			TOTAL	LOAD PS.I	R	CYCLES TO FAILURE	REMARKS
			PERIMETER	AREA	%					
1	-40	TENSION	8	2	4	3555	1770	.02	THESE 4 SPECIMENS WERE WITHOUT VOIDS	
2	-40		"	"	"	"	"	77,000		
3	-19		8.68	7.35	1.18	13830	1880	79,000		
4	"		"	"	"	13,070	1770	62,000		
5	-40	TENSION	12.68	2	6.34	3555	"	166,000	THESE 4 SPECIMENS HAD VOIDS MANUFACTURED IN THE EDGE OF THE BONDS	
6	D1		"	"	"	"	"	2,694,000		
7	D2		"	"	"	"	"	2,570,000		
8	D3		"	"	"	"	"	1,845,000		
9	D4	TENSION	12	*	**	"	**	∞	THE VOIDS OF THESE 3 SPECIMENS INADVERTENTLY BONDED.	
10	P1		"	"	"	"	"	"		
11	P2		"	"	"	"	"	"		
12	P3		"	"	"	"	"	"		
13	PO1	TENSION	"	2	6.00	1770	1770	184,000	VOIDS OF THESE 3 SPECIMENS WERE MANUFACTURED WITHIN THE BONDS.	
14	PO2		"	"	"	"	"	1,499,000		
15	PO3		"	"	"	"	"	355,000		
16	PO4		"	"	"	"	"	∞		
16	PO5	TENSION	"	*	**	3555	**	1,682,000	VOID REPAIRED BY INJECTION INJECTION ONLY PARTIALLY SUCCESSFUL.	

\* THESE AREAS WERE NOMINALLY 2 IN<sup>2</sup> BUT BECAME INDEFINITE.  
 \*\* THESE RATIOS AND STRESSES WERE INDETERMINATE.

TABLE II  
BENDING & DIAGONAL LOADING RESULTS — VOID PROPAGATION

SPECIMEN		BENDING				CYCLES TO FAILURE	REMARKS
NO.	TYPE	LOADING	LOAD LBS.	STRESS P.S.I.	"R"		
17	-31	BENDING	592	26,620	.02	2,687,000	THE VOIDS IN THESE SPECIMENS DID NOT PROGRESS UNDER REPEATED LOAD.
18	-31					946,000	
19						650,000	
20						745,000	
21						2,973,000	
22	-35	BENDING	592	26,620	.02	795,000	
23	-35					805,000	
24						1,413,000	
25						5,299,000	
26						1,811,000	
DIAGONAL TENSION & COMPRESSION							
27	-23	DIAGONAL	±9600	±25650	±1.00	4,000	NO GROWTH OF VOIDS
28	**	DIAGONAL	±8000	±21400	±1.00	7,000	
29	**	DIAGONAL	±8000	±21400	±1.00	30,000	

\* STRESS IN SANDWICH SKIN.  
 \*\* THIS SPECIMEN HAD A VOID CREATED BY INSERTING A TOOL THROUGH A 1/8 IN. HOLE IN THE SKIN AND GOUGING OUT THE BOND.

TABLE III  
 TENSION TESTS -- METAL FAILURES

SPECIMEN NO.	SPECIMEN TYPE	AREA	LOAD LBS.	LOAD P.S.I.	CYCLES TO FAILURE	REMARKS
30	-1	9.60	9450	985	1000	FAULTY BOND
31	-1	9.60	9450	985	315,000	METAL FAILURE
32	-1	9.60	9450	985	175,000	
33	-1	9.60	9450	985	329,000	
34	-1	9.60	9450	985	216,000	
35	-3	8.03	9450	1175	148,000	
36	-3	8.03	9450	1175	214,000	
37	-3	8.03	9450	1175	185,000	
38	-3	8.03	9450	1175	221,000	
39	-5	8.03	9450	1175	245,000	
40	-5	8.03	9450	1175	218,000	
41	-5	8.03	9450	1175	250,000	
42	-5	8.03	9450	1175	228,000	
43	-7	9.60	9450	985	225,000	
44	-7	9.60	9450	985	162,000	
45	-7	9.60	9450	985	282,000	
46	-7	9.60	9450	985	162,000	
47	-7	9.60	9450	985	304,000	
48	-11	8.03	9450	1175	179,000	
49	-11	8.03	9450	1175	242,000	
50	-11	8.03	9450	1175	289,000	
51	-11	8.03	9450	1175	120,000	
52	-13	8.03	9450	1175	328,000	
53	-13	8.03	9450	1175	270,000	
54	-13	8.03	9450	1175	311,000	
55	-13	8.03	9450	1175	266,000	
56	-15	8.03	9450	1175	137,000	METAL FAILURE

TABLE III (CONT.)

SPECIMEN NO.	TYPE	AREA	LOAD		CYCLES TO FAILURE	REMARKS
			LBS.	PS.I.		
57	-15	8.03	9450	1175	132,000	METAL FAILURE METAL FAILURE
58	-15	8.03	9450	1175	219,000	
59	-19	9.60	9450	985	130,000	
60	-19	9.60	9450	985	186,000	
61	-19	9.60	9450	985	170,000	
62	-19	9.60	9450	985	337,000	
63	-19	9.60	9450	985	437,000	