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PH14-8Mo STAINLESS STEEL HONEYCOMB CORE SHEAR STRENGTH AT ELEVATED TEMPERATURES

by G. H. Arvin, D. A. Pantone,
and T. E. DeWitt

Los Angeles Division
North American Rockwell Corporation
El Segundo, Calif.

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FOREWORD

This report describes the activities performed by the Los Angeles Division of North American Rockwell Corporation on NASA Contract No. NAS 9-8327, "Testing of PH14-8Mo Stainless Steel Honeycomb Sandwich Core Shear Strength at Elevated Temperatures," dated 27 June 1968, including Modification of Contract No. 1S dated 17 June 1969.

This contract was sponsored by the Structures Branch of NASA Manned Spacecraft Center, Houston, Texas, and was under the technical direction of Dr. F. V. Stebbins. Mr. G. H. Arvin of North American Rockwell was the Program Manager, and Mr. D. A. Pantone was the Project Engineer for this program. The work covered by this contract was performed during the period from 1 July 1968 to 1 July 1969, and covers all phases of the program.

Publication of this report does not necessarily constitute NASA/MSC endorsement of North American Rockwell findings or conclusions. This report is published to disseminate information obtained under the contract.

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HONEYCOMB CORE SHEAR STRENGTH

AT ELEVATED TEMPERATURES

By G. H. Arvin, D. A. Pantone,
and T. E. DeWitt

Los Angeles Division
North American Rockwell Corporation
El Segundo, Calif.

SUMMARY

This report describes the fabrication and testing of PH14-8Mo stainless steel honeycomb sandwich specimens to develop shear strength data at elevated temperatures for 3-15, 3-20, 3-30, and 2-30 honeycomb core. The brazing fabrication of four stainless steel honeycomb panels in accordance with the pertinent Apollo specifications is discussed. The equipment used to conduct the shear tests along with test setups and procedures are described. Pictures of the heat shield from the Apollo Spacecraft 011 after orbiting and reentry are included, showing the specific locations of the heat shield specimens which were also tested and reported. A tabular listing of specimen sizes and test results along with photographs of typical longitudinal and transverse ribbon direction failures at each test temperature for each honeycomb core configuration tested are included. Also presented is an evaluation of the test data and curves for the core shear strength versus temperature (to 900° F) for each of the four core densities. The test data points are shown on these curves.

INTRODUCTION

Current spacecraft design uses of PH14-8Mo brazed stainless-steel honeycomb panels are generally limited to those applications where the structure temperature is 600° F or less. The design allowable core shear strength data currently available for this type of sandwich material are similarly limited to this temperature range. To extend the design use of PH14-8Mo honeycomb panels, this program was initiated to determine honeycomb core shear strength data for four honeycomb core configurations at higher temperatures. The basic program was intended to extend current design allowable core shear data to 800° F, and a contract modification (see Abstract) permitted a minimal development of core shear data to 900° F.

SCOPE OF THE PROGRAM

The purpose of this contractual effort was to define the allowable shear stress of four stainless steel (PH14-8Mo BCHT 1050) honeycomb sandwich core configurations in the 600° to 800°F temperature range. To accomplish this end, four honeycomb sandwich panels were brazed per Apollo specifications for testing. The honeycomb core configurations for these panels consisted of a 2-inch core depth and 2-30, 3-30, 3-20, and 3-15 core cell sizes. A minimum of three tests were to be conducted for each of the core configurations, for each core ribbon direction (longitudinal and transverse), and at each of a number of specified temperatures. The longitudinal specimens were tested at room temperature, 600°, 650°, 700°, 750°, and 800° F; and the transverse specimens were tested at 650°, 700°, 750°, and 800° F. In addition to these tests, a maximum of three specimens were to be provided by NASA/MSC as GFP for testing. These specimens were obtained from the heat shield of Apollo Spacecraft 011. Two specimens were tested at room temperature and the remaining one was tested at 800° F. These testing results were compared to the main body of data generated by the program.

As an addition to the basic program, Contract Modification No. 1S, dated 17 June 1969, included the testing of one longitudinal specimen from each core configuration at 900° F.

TEST METHOD SELECTION AND SPECIMEN DESIGN

Test Method Selection

Two procedures are conventionally used to develop core shear data. These methods are beam shear testing per MIL-STD-401A and ASTM C393-62, and flatwise shear testing per ASTM C 273-61. The beam shear test method was selected on the basis of experience gained by North American Rockwell during the XB-70 program and development of our Brazed Steel Honeycomb Structures Manual. Actually, we used both the beam shear test and the flatwise shear test to establish the core shear design allowables for the XB-70 program and the manual. We concluded that the beam shear test method yielded more consistent and realistic core shear modulus values, eliminating the need for excessive specimen replication to establish design allowables for a given point. Additionally, the beam shear test method is more desirable than the flatwise shear test method for elevated temperature testing. The flatwise shear test method requires thick loading plates, which are normally adhesive-bonded to either the sandwich specimen or to the test hoenycomb core sample alone. Conventional adhesive systems are generally limited to 600° F; consequently, the 800° F requirement of this program virtually precluded the use of the flatwise shear test method.

Test Specimen Design

Rectangular beam shear test specimens were used for all of the tests in this investigation. A sketch of this specimen with the nominal dimensions is shown in figure 1.

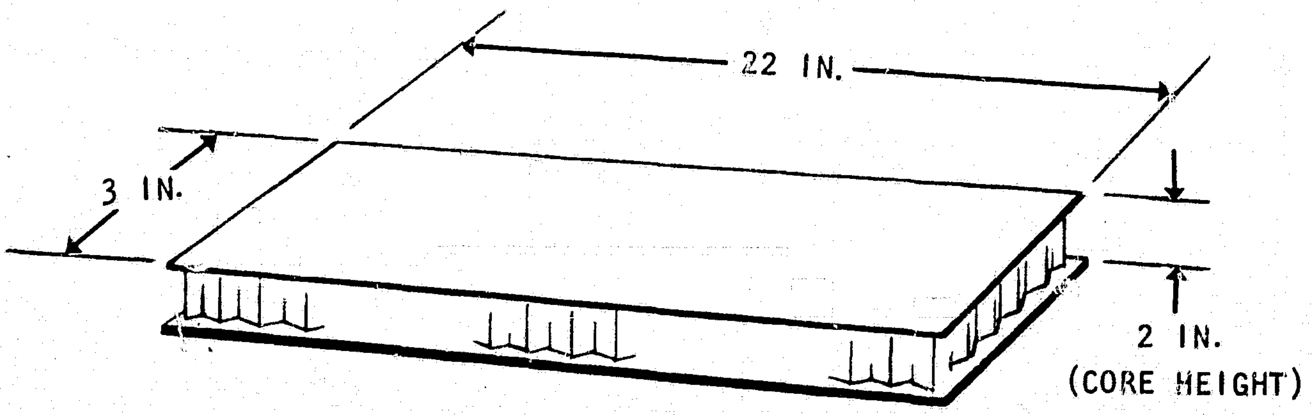

Figure 1.- Beam shear test specimen.

This test specimen agrees with the test specimen requirements specified in MIL-STD-401A and ASTM C393-62, except for the reduced specimen width. This specimen is identical to the test specimen configurations used in the development of the honeycomb core design allowable data developed by North American Rockwell and reflected in the company's Brazed Steel Honeycomb Structures Manual, and therefore, is known to be adequate for the required testing. In addition, the use of the same specimen design as the XB-70 program avoids the introduction of a potential source of incompatibility between the new and existing data.

The described specimens were cut from honeycomb panels specifically fabricated for this series of tests. Four honeycomb panels were fabricated, one panel for each of the honeycomb core densities required by the Statement of Work for the subject program. North American Rockwell Drawing No. L9000002, entitled "PH14-8Mo Stainless Steel Honeycomb Panel, Assy of (Layout)" (figure 2) was prepared to control the fabrication of honeycomb panels and test specimens. It was required that all of the materials and processing procedures used be in accordance with the Apollo specification for the fabrication of stainless steel sandwich. The face sheet gages, as represented in figure 2, were determined on the basis of avoiding the possibility of premature face sheet failure. Accordingly, a 1.5 scatter factor was applied to the predicted core shear strengths, and a 25-percent margin of safety was applied to the face sheet gage. The face sheet gages calculated from the preceding assumptions were modified slightly in some cases to agree with the availability of vacuum melt PH14-8Mo stainless steel sheet. The face sheet gage modifications were within acceptable tolerance limits.

The honeycomb panel was designed to provide the required number of longitudinal and transverse specimens plus some spares for each condition. In addition, special splice locations were designed into the honeycomb panel to allow for simplicity of material procurement and controlled specimen locations.

The three specimens from an Apollo heat shield having a reentry service history (Government-furnished property) also had the configuration shown in figure 1 excepting for minor curvatures resulting from the airfoil shape of the heat shield design. These heat shield specimens had (1) longitudinal core ribbon direction, (2) a core density of 8.3 lb/cu ft, and (3) 0.030 inch-face sheets. The specific area of the heat shield from which these specimens were removed is shown as location b in figure 16. This structure area is defined by North American Rockwell Drawing V16-327509-21.

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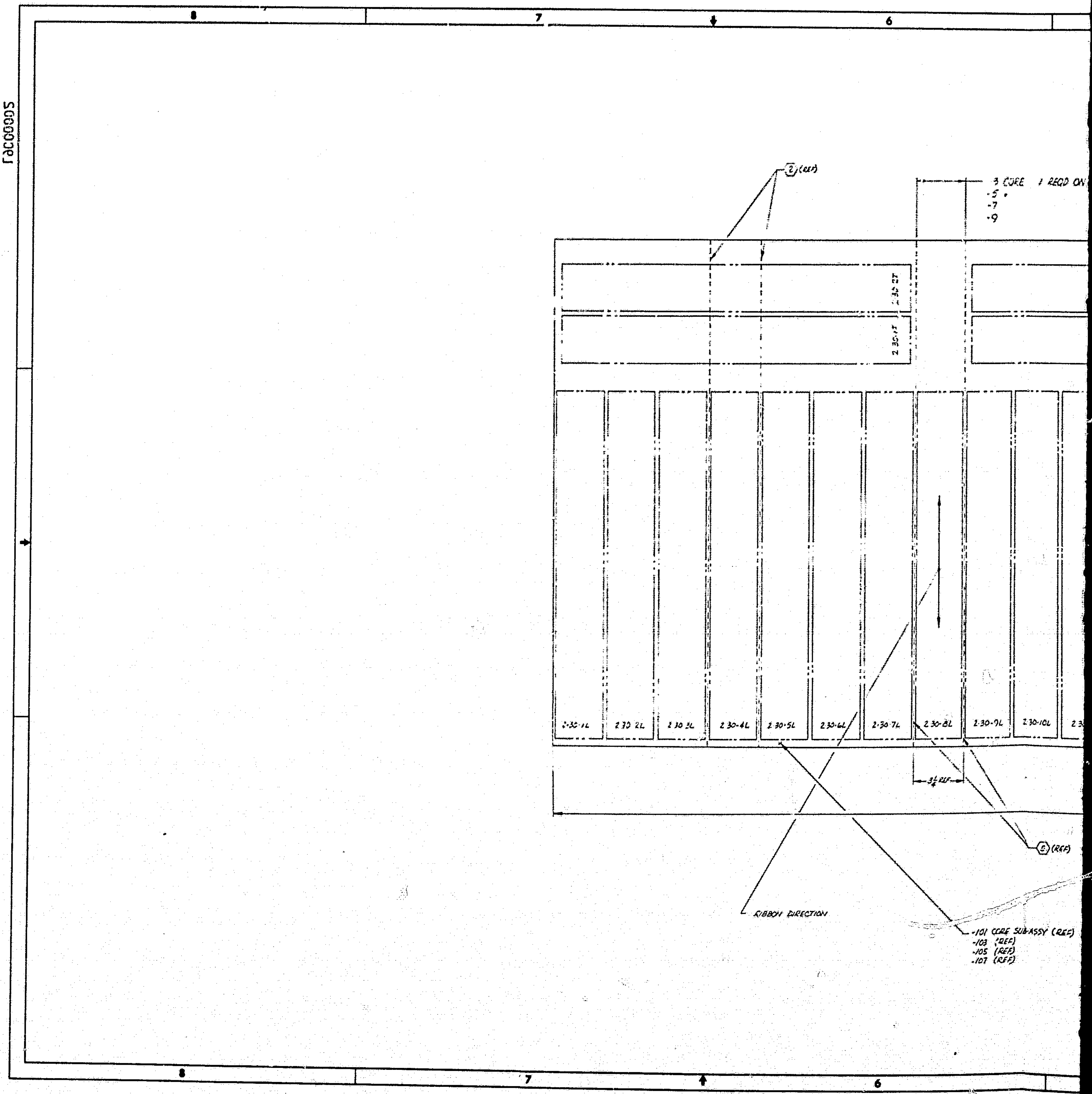

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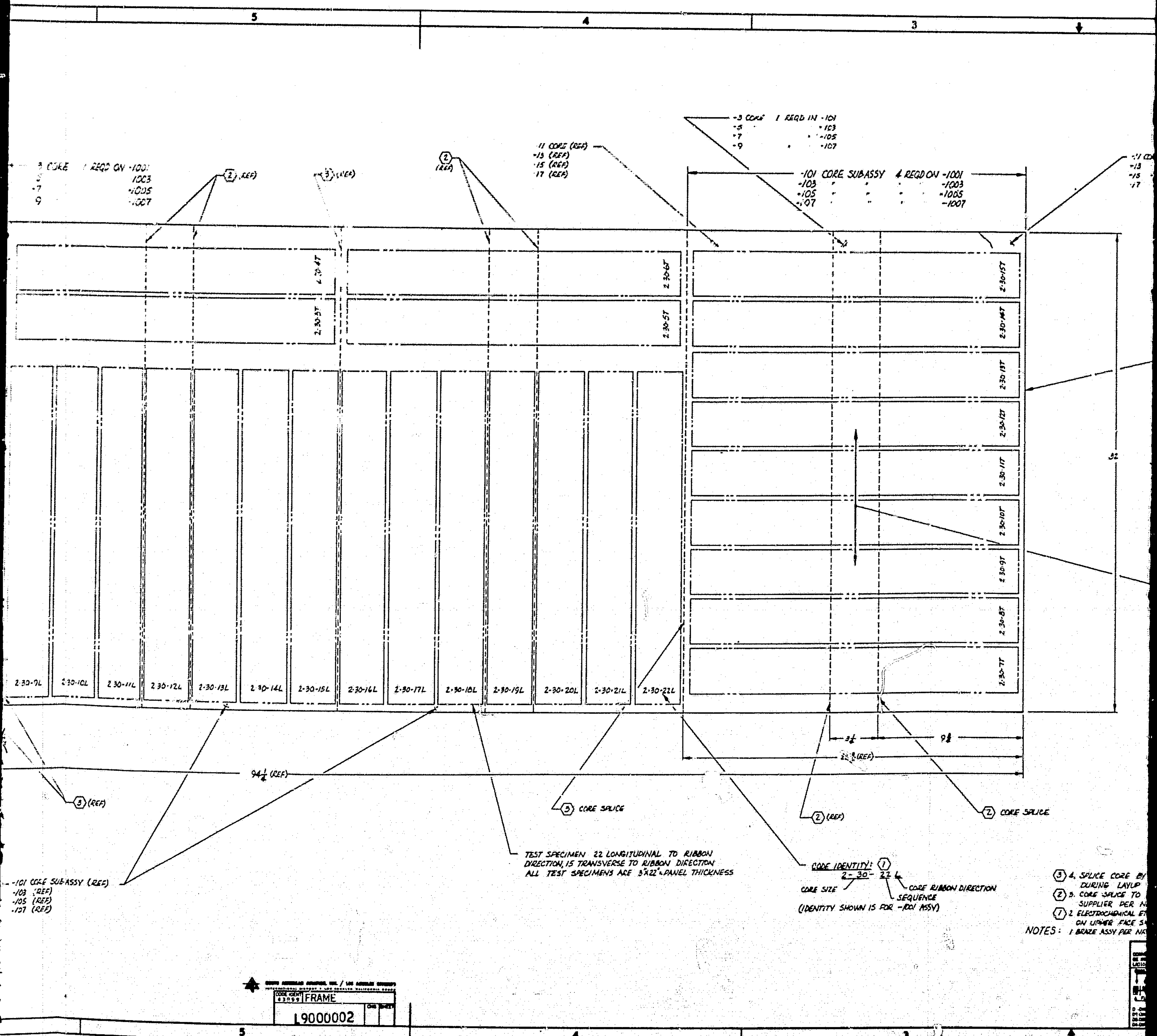

Figure 2. Assembly

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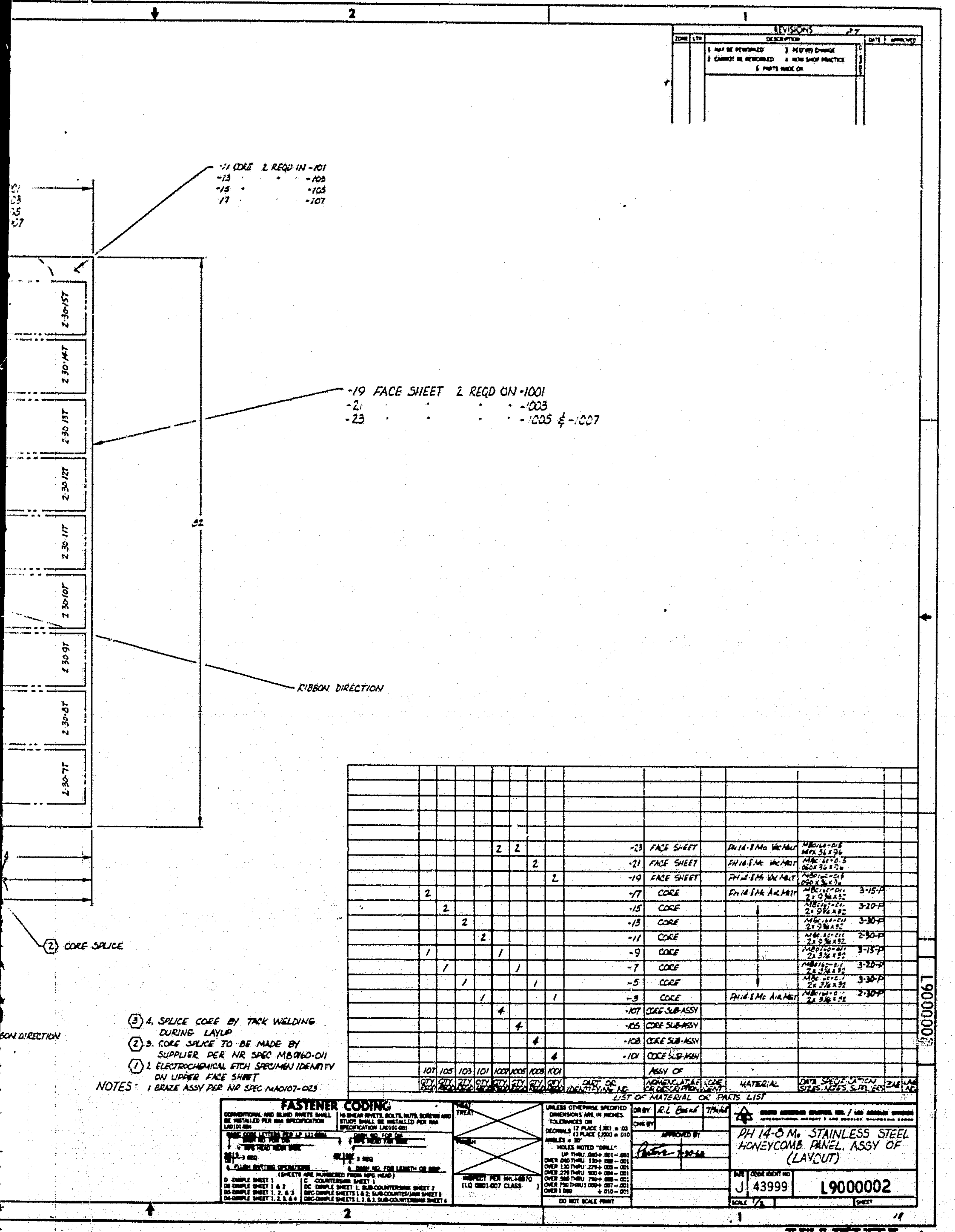

NOTES:
1. BRAZE ASSY PER NR SPEC MA0107-023
① 2. ELECTROCHEMICAL ETCH SPECIMEN IDENTITY ON UPPER FACE SHEET
② 3. CORE SPLICE TO BE MADE BY SUPPLIER PER NR SPEC MB0160-011
③ 4. SPLICE CORE BY TACK WELDING DURING LAYUP

QTY REQD	QTY REQD	QTY REQD	QTY REQD	QTY REQD	QTY REQD	QTY REQD	QTY REQD	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	DATA SPECIFICATION SIZES, NOTES, SUPPLIES
107	105	103	101	1007	1005	1003	1001		ASSY OF		
				2	2			-23	FACE SHEET	PH14-8Mo VacMelt	MB0160-015 .040x36x96
						2		-21	FACE SHEET	PH14-8Mo VacMelt	MB0160-015 .060x36x96
							2	-19	FACE SHEET	PH14-8Mo VacMelt	MB0160-015 .090x36x96
2								-17	CORE	PH14-8Mo AirMelt	MB0160-011 2x9⅝x52 3-15-P
	2							-15	CORE		MB0160-011 2x9⅝x52 3-20-P
		2						-13	CORE		MB0160-011 2x9⅝x52 3-30-P
			2					-11	CORE		MB0160-011 2x9⅝x52 2-30-P
1				1				-9	CORE		MB0160-011 2x3⅛x52 3-15-P
	1				1			-7	CORE		MB0160-011 2x3⅛x52 3-20-P
		1				1		-5	CORE		MB0160-011 2x3⅛x52 3-30-P
			1				1	-3	CORE	PH14-8Mo AirMelt	MB0160-011 2x3⅛x52 2-30-P
				4				-107	CORE SUB-ASSY		
					4			-105	CORE SUB-ASSY		
						4		-103	CORE SUB-ASSY		
							4	-101	CORE SUB-ASSY		

LIST OF MATERIAL OR PARTS LIST

DR BY R.L. Brand
APPROVED BY

PH 14-8 Mo STAINLESS STEEL HONEYCOMB PANEL, ASSY OF (LAYOUT)

Figure 2. Assembly of PH14-8Mo Stainless Steel Honeycomb Panel (layout).

FOLDOUT FRAME

C

PANEL FABRICATION

Material Procurement

The basic materials required for panel fabrication were vacuum melt PH14-8Mo stainless steel sheets, air-melt PH14-8Mo stainless steel honeycomb core, and 80/20 LTCM brazing alloy. These materials were procured from the Armco Steel Corporation, Stresskin Products Company, and Handy and Harmom Company, respectively. The aft heat shield from which the three Apollo heat shield specimens were cut was obtained through NASA/MSC and was made available by the Space Division of North American Rockwell. This heat shield had been installed on Apollo Spacecraft 011 and after orbiting and reentry maneuvers, it was used for various NASA and Space Division tests. Figures 3 and 4 show the condition of this heat shield after these tests.

Fabrication of Honeycomb Panels

A total of four honeycomb panels were fabricated to provide the test specimens of the required core densitites. These panels were brazed and heat treated by the Los Angeles Division of North American Rockwell in accordance with Apollo panel fabrication specifications. A description of the honeycomb core included in these panels is given in the following table.

TABLE I.- BRAZED PANEL HONEYCOMB CORE CONFIGURATIONS

Dwg L9000002 dash No.	Core thickness, inches	Core size designation	Core density, lb/cu ft
-1001	2	2-30	24.9
-1003	2	3-30	16.6
-1005	2	3-20	11.2
-1007	2	3-15	8.3

Basically, the fabrication and heat-treatment of the panels consisted of sealing the cleaned details (i.e., honeycomb core, braze alloy, and face sheets) in a steel retort and, with a combination argon/vacuum atmosphere, heating to the brazing temperature of 1,685° (±25°) F for 20 minutes, then cooling to 150° to 200° F. The panels were then rapidly and continuously cooled to the subzero condition of -145° (±25°) F and held for 8 hours. Aging was accomplished by heating to 1,065° (±10°) F for a period of 60 to 75 minutes then cooling to room temperature.

Figure 3.- Apollo heat shield (spacecraft 011) before specimen removal (outside view)

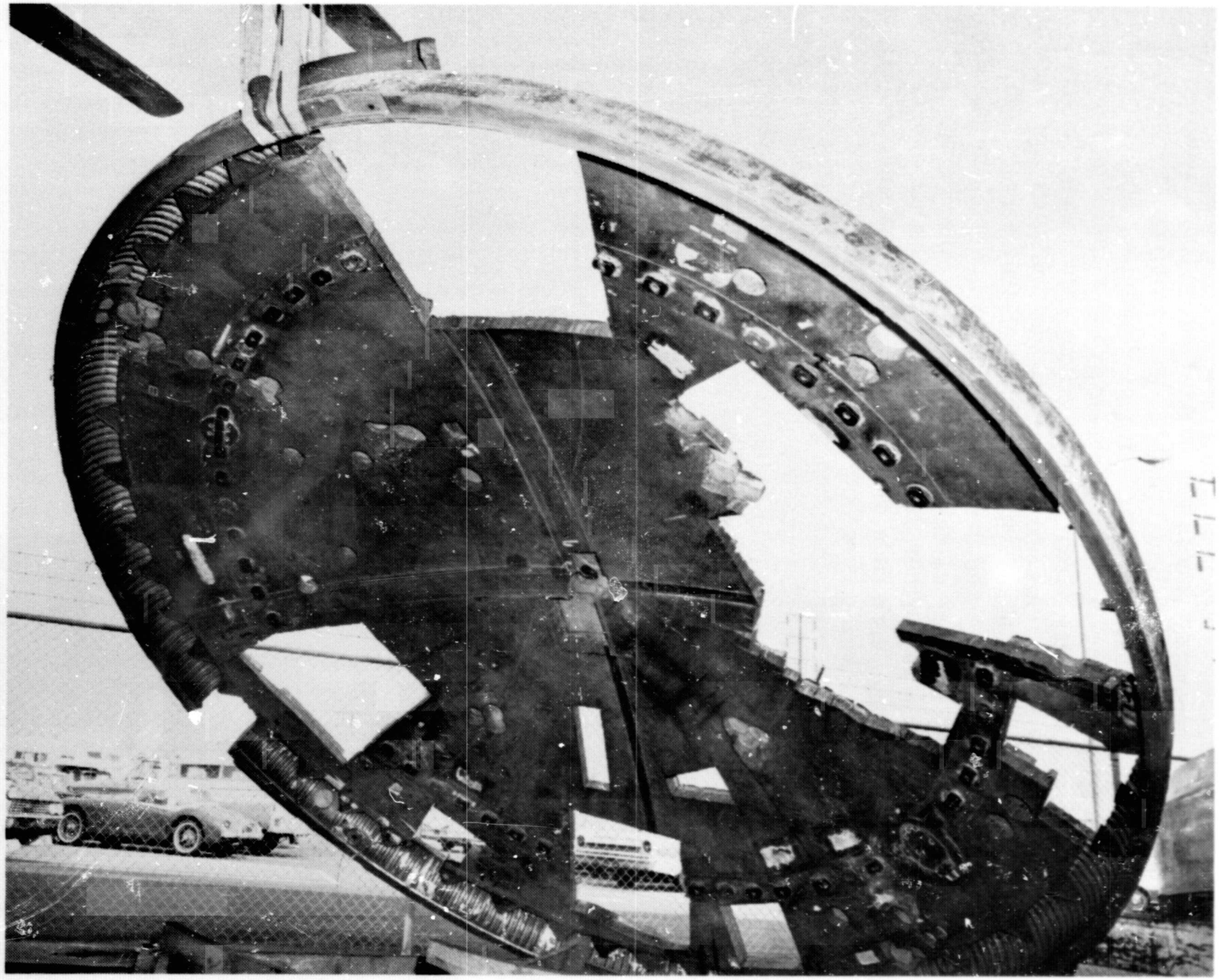

Figure 4.- Apollo heat shield (spacecraft 011) before specimen removal - inside view.

Inspection of Panels

Inspection of the honeycomb panels was controlled by Specification MQ0402-002. Following the normal visual inspection operations, the panels were radiographically inspected to evaluate fillet formation, node flow, and general structural integrity. One of the panels being x-rayed is shown in figure 5, and typical X-ray film views resulting from this inspection are shown in figures 6 through 13. Acceptable quality was indicated for each of the honeycomb panels inspected except for the L9000002-1001 panel (2-30, 24.9 lb/cu fit honeycomb core). The x-ray film for this particular panel did not completely define the quality of the panel because of the increased face sheet thickness. In order to further define the quality of this panel, ultrasonic C-scan recordings were made of both top and bottom surface (figures 14 and 15). Some line voids were detected by the ultrasonic recordings and examples are indicated by the arrow heads in figure 15. The potential problems that could result from the presence of line voids were negated by special orientation of specimens. This orientation consisted of locating the specimen so that the line voids were either missed entirely, or were parallel to the direction of load.

The heat-treat response for each of the honeycomb panels was determined by conducting tensile tests on material taken from each panel face sheet. The results of these tests are presented in table II, and, as shown, all values exceeded the minimum specification requirements.

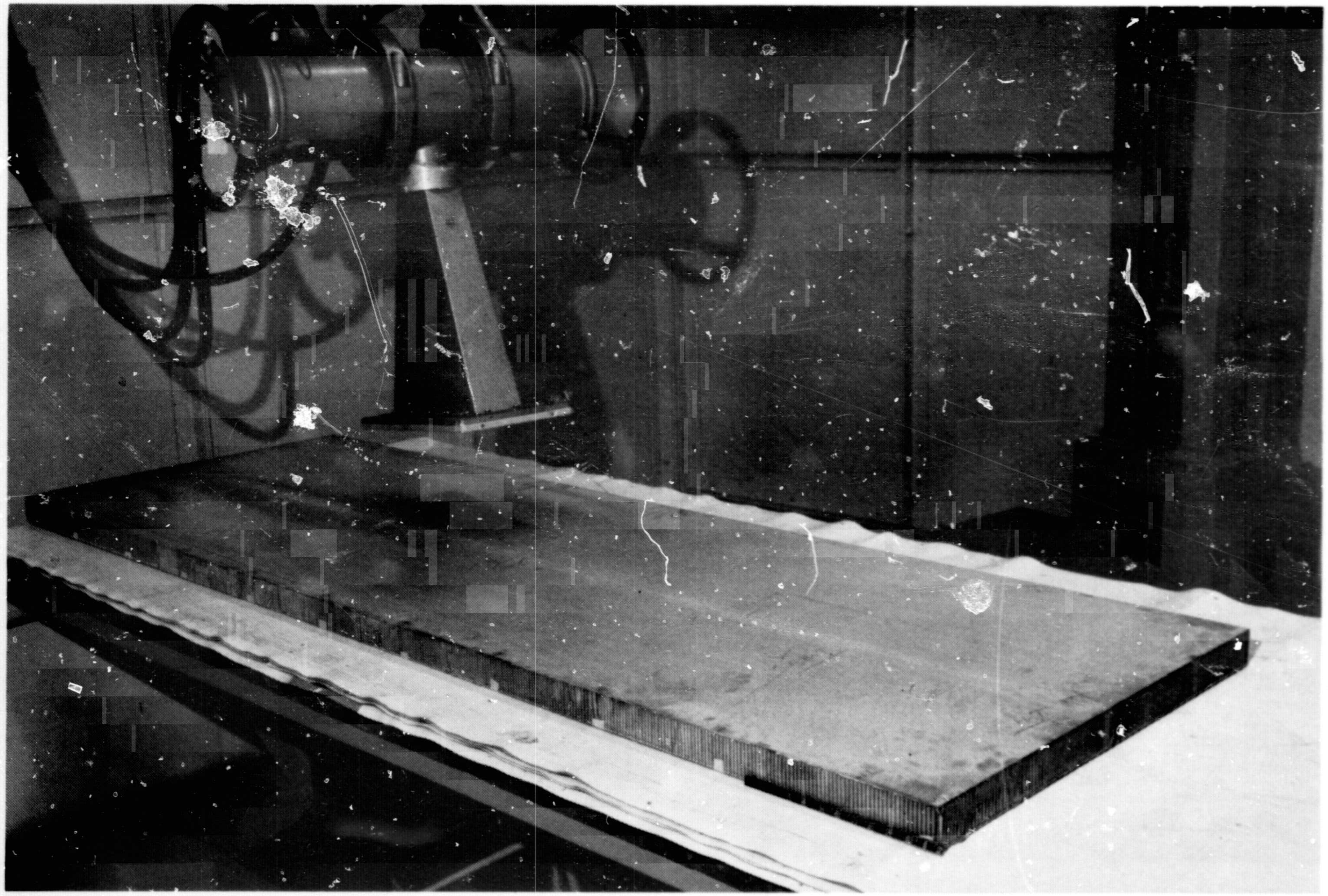

Figure 5.- Typical panel being x-ray inspected.

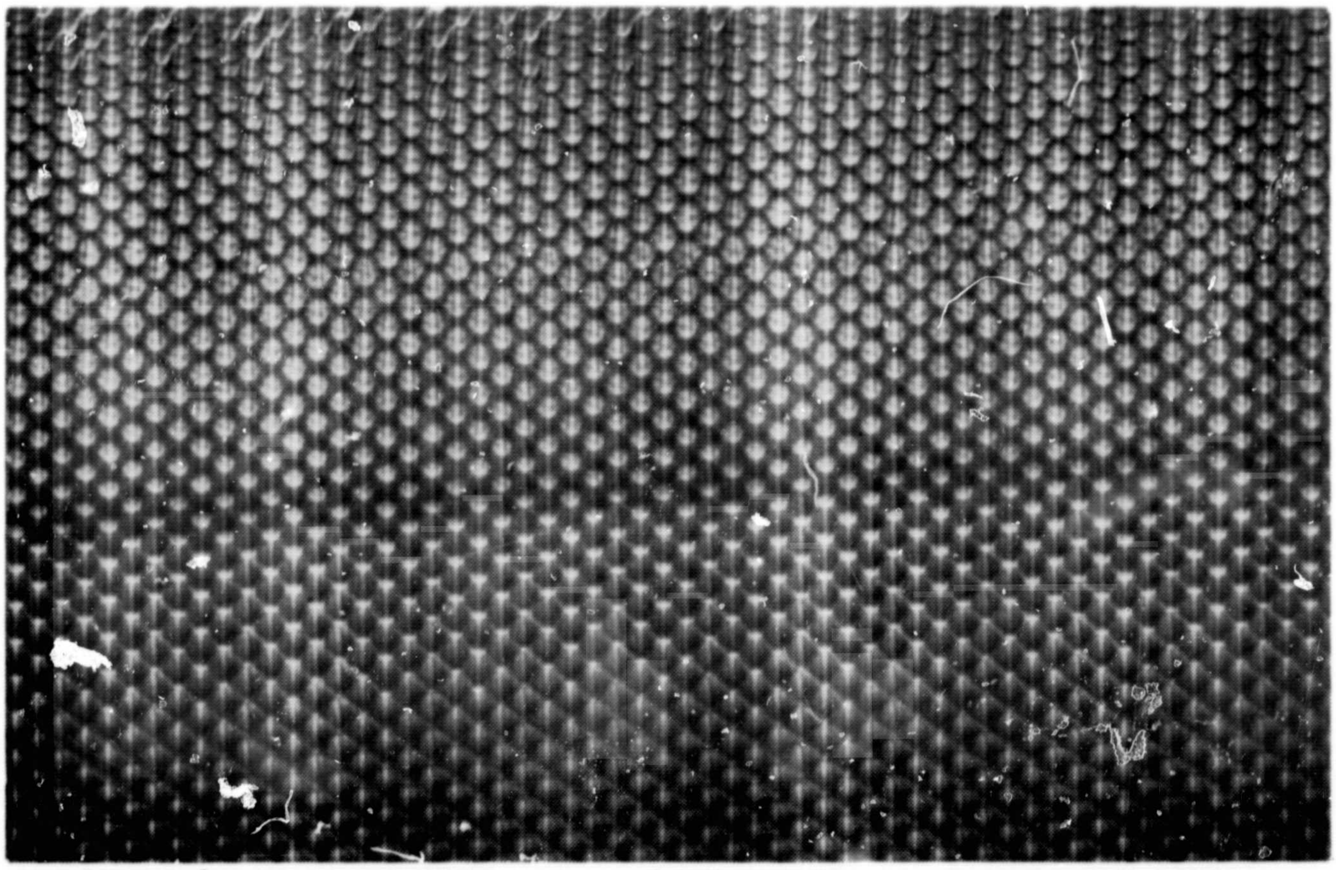

Figure 6.- Typical x-ray view of honeycomb panel L9000002-1001 - top surface.

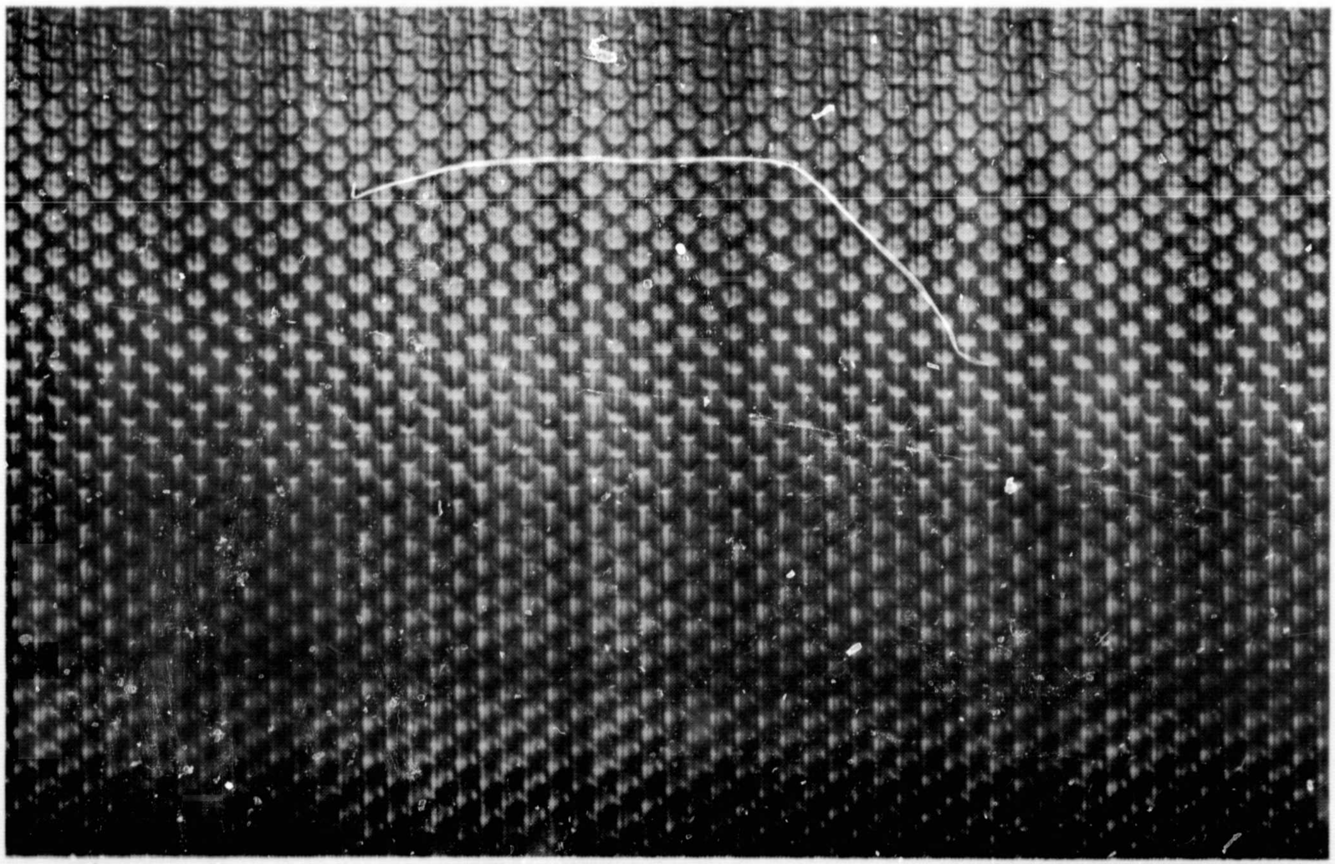

Figure 7.- Typical x-ray view of honeycomb panel L9000002-1001 - bottom surface.

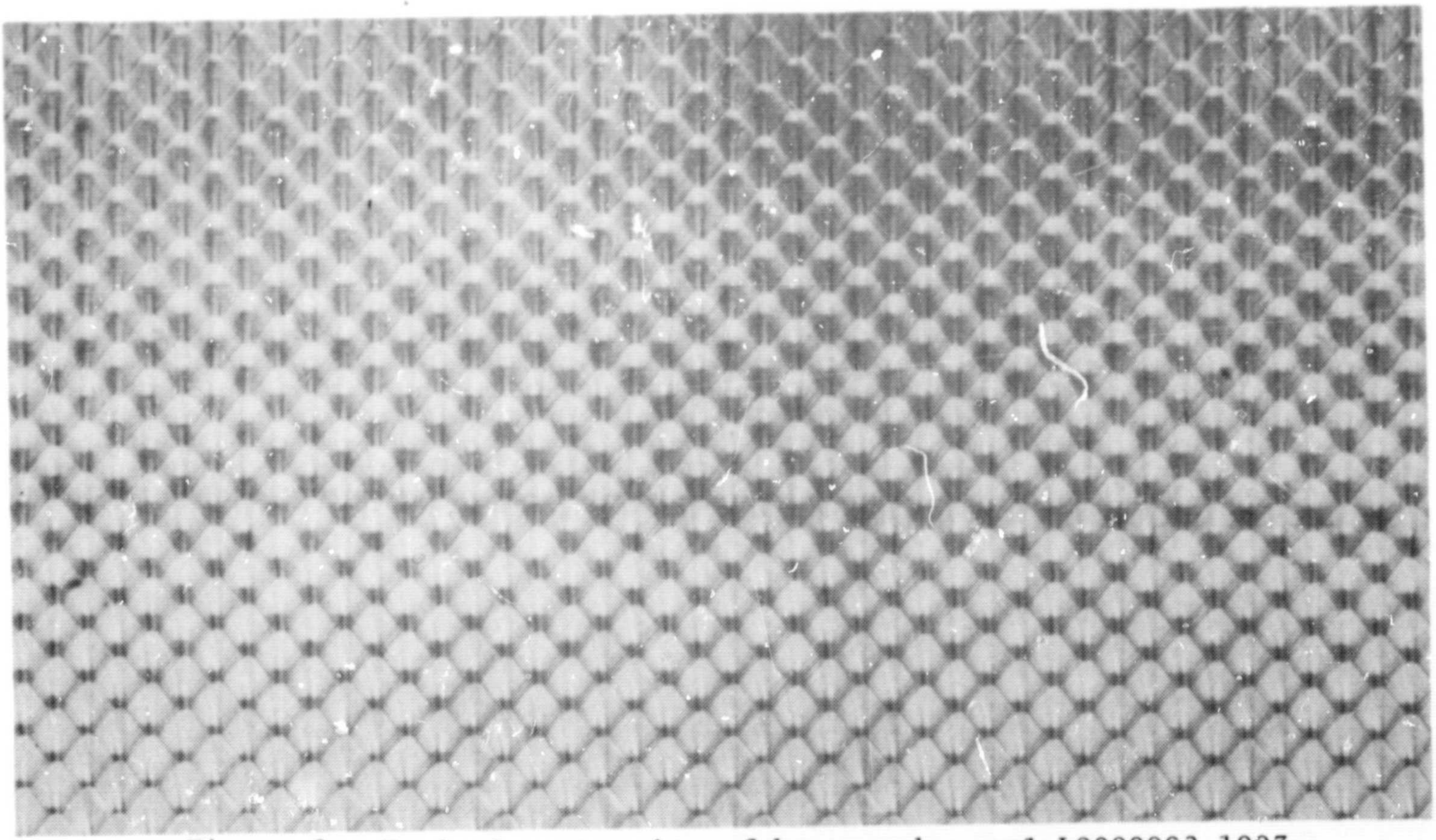

Figure 8.- Typical x-ray view of honeycomb panel L9000002-1003 - top surface.

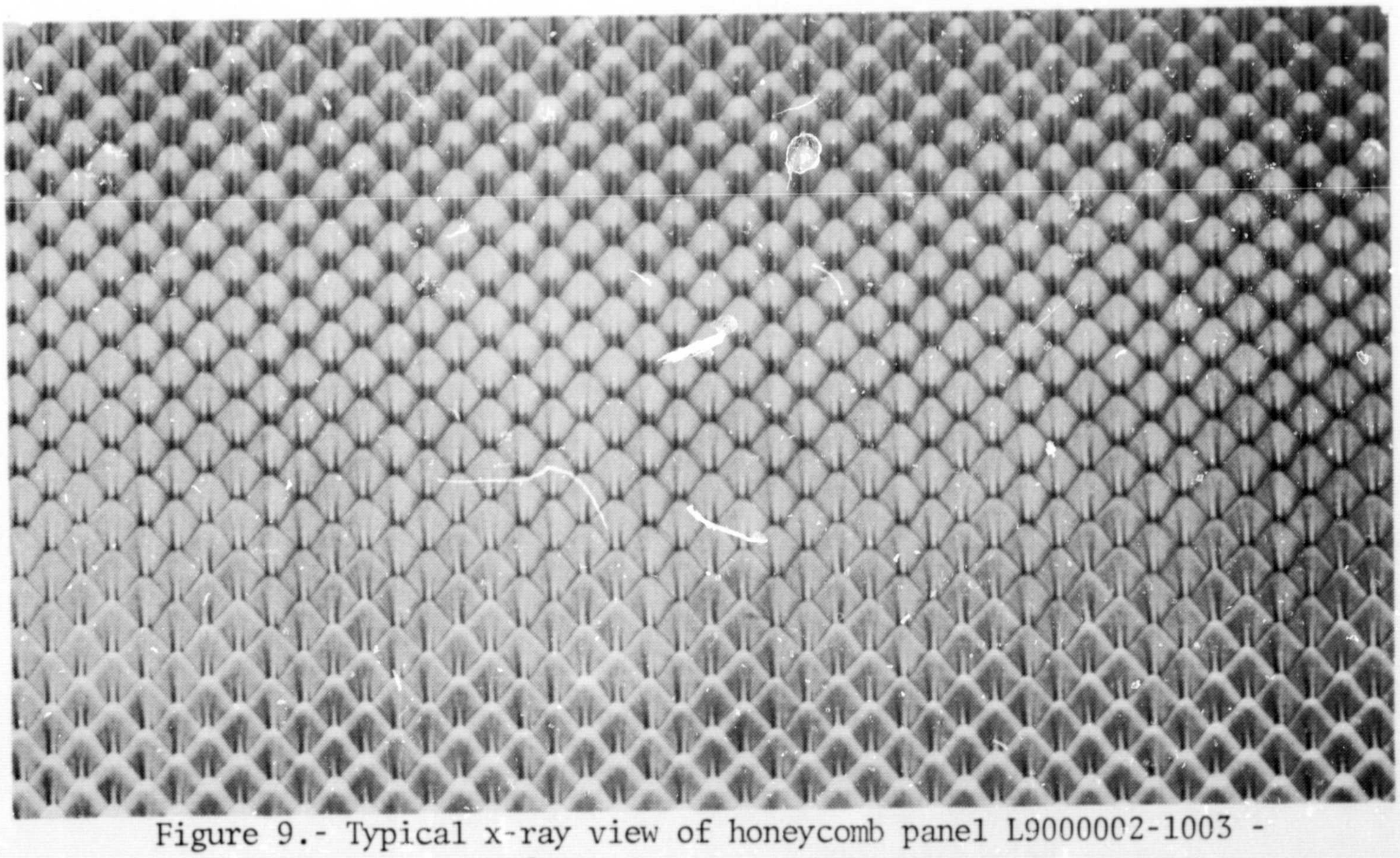

Figure 9.- Typical x-ray view of honeycomb panel L9000002-1003 - bottom surface.

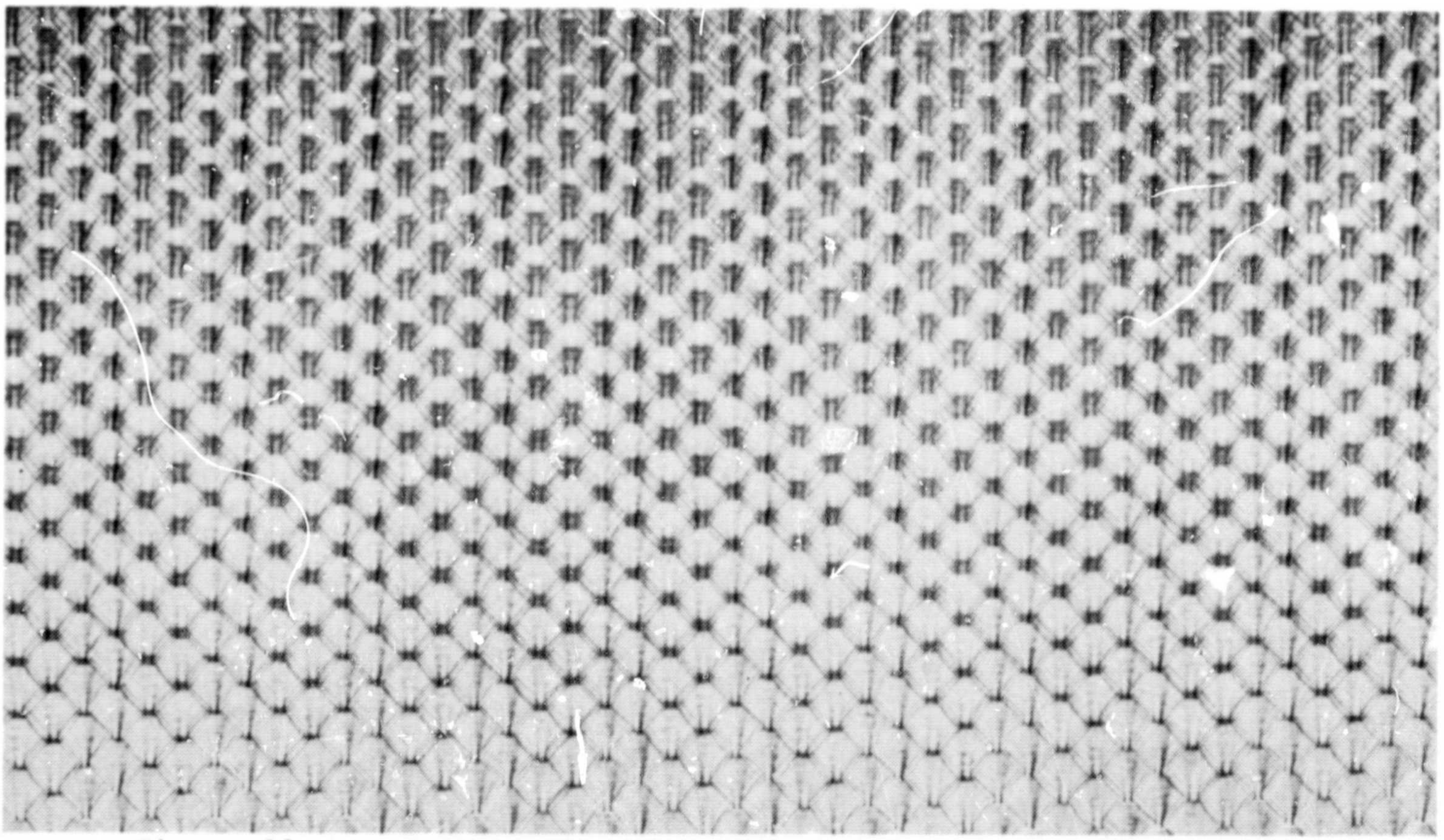

Figure 10.- Typical x-ray view of honeycomb panel L9000002-1005 - top surface.

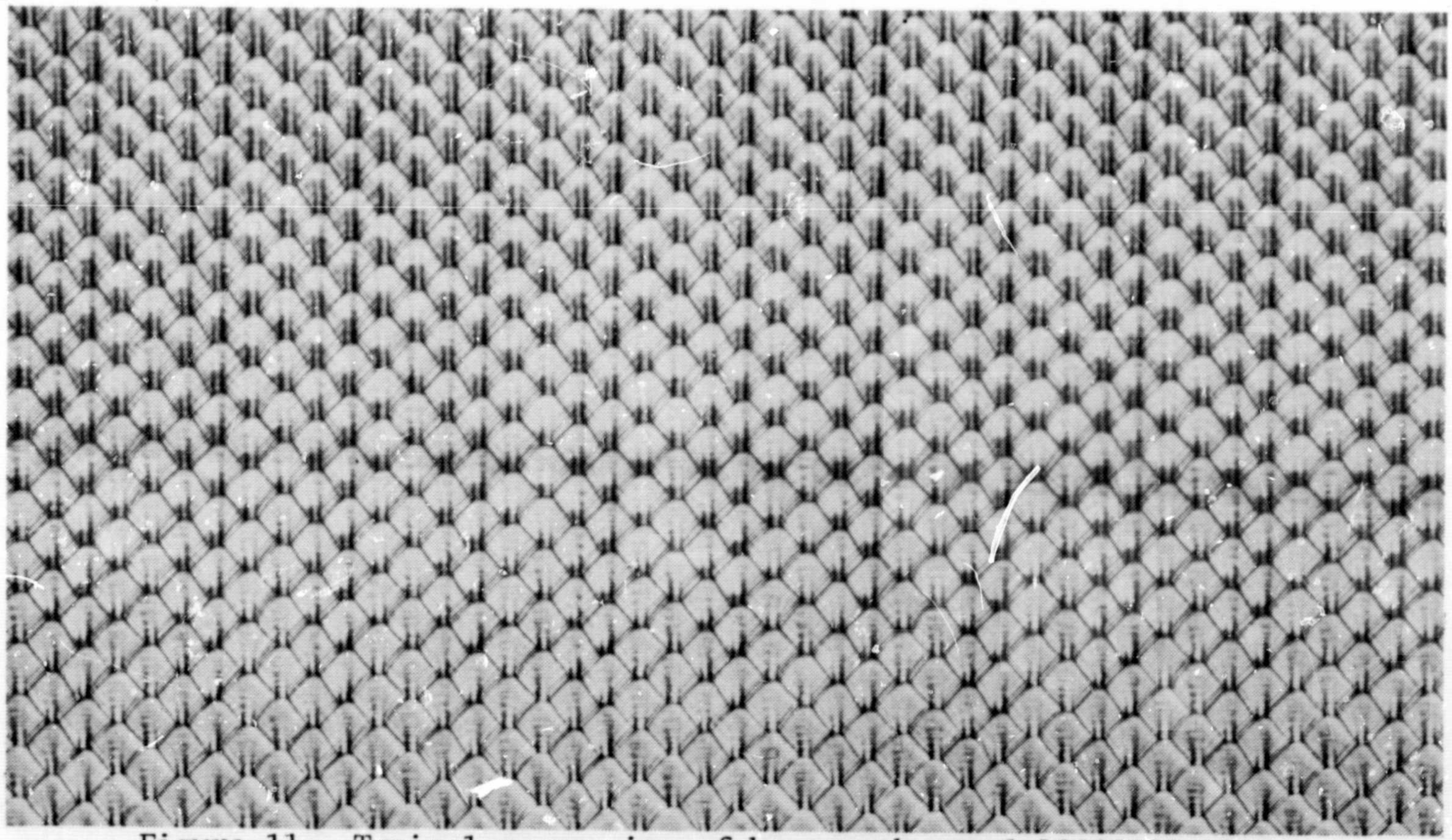

Figure 11.- Typical x-ray view of honeycomb panel L9000002-1005 - bottom surface.

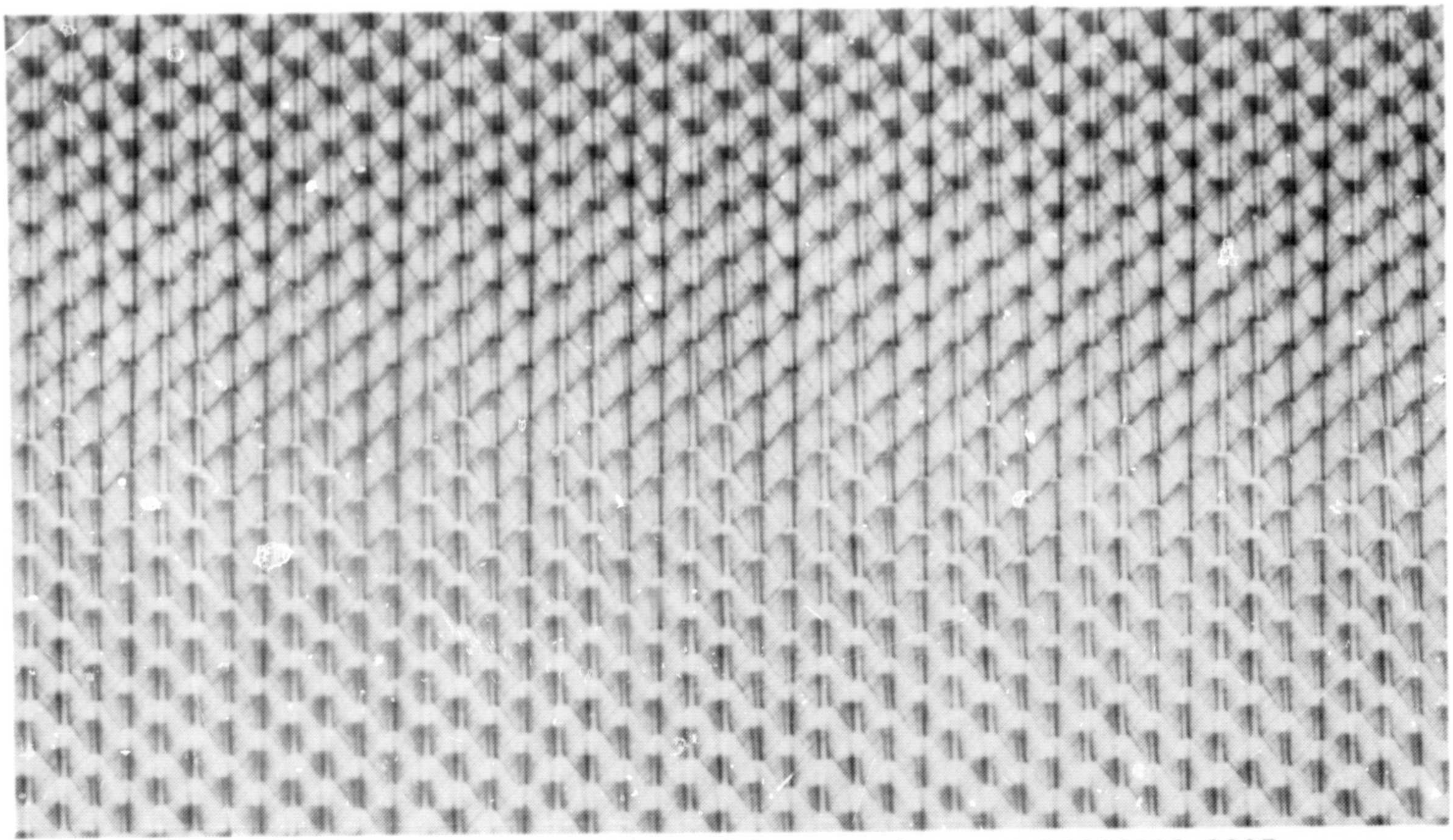

Figure 12.- Typical x-ray view of honeycomb panel L9000002-1007 - top surface.

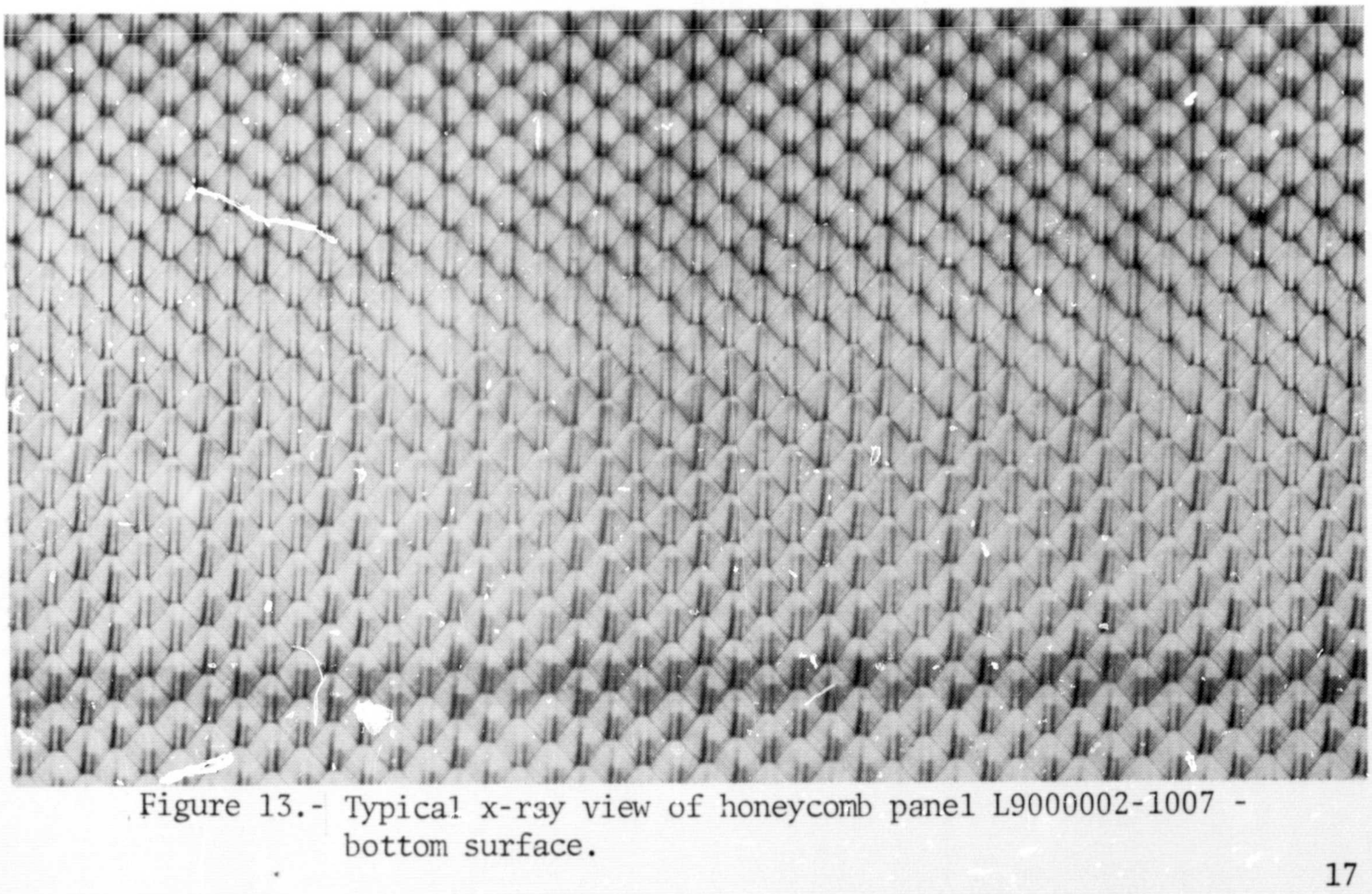

Figure 13.- Typical x-ray view of honeycomb panel L9000002-1007 - bottom surface.

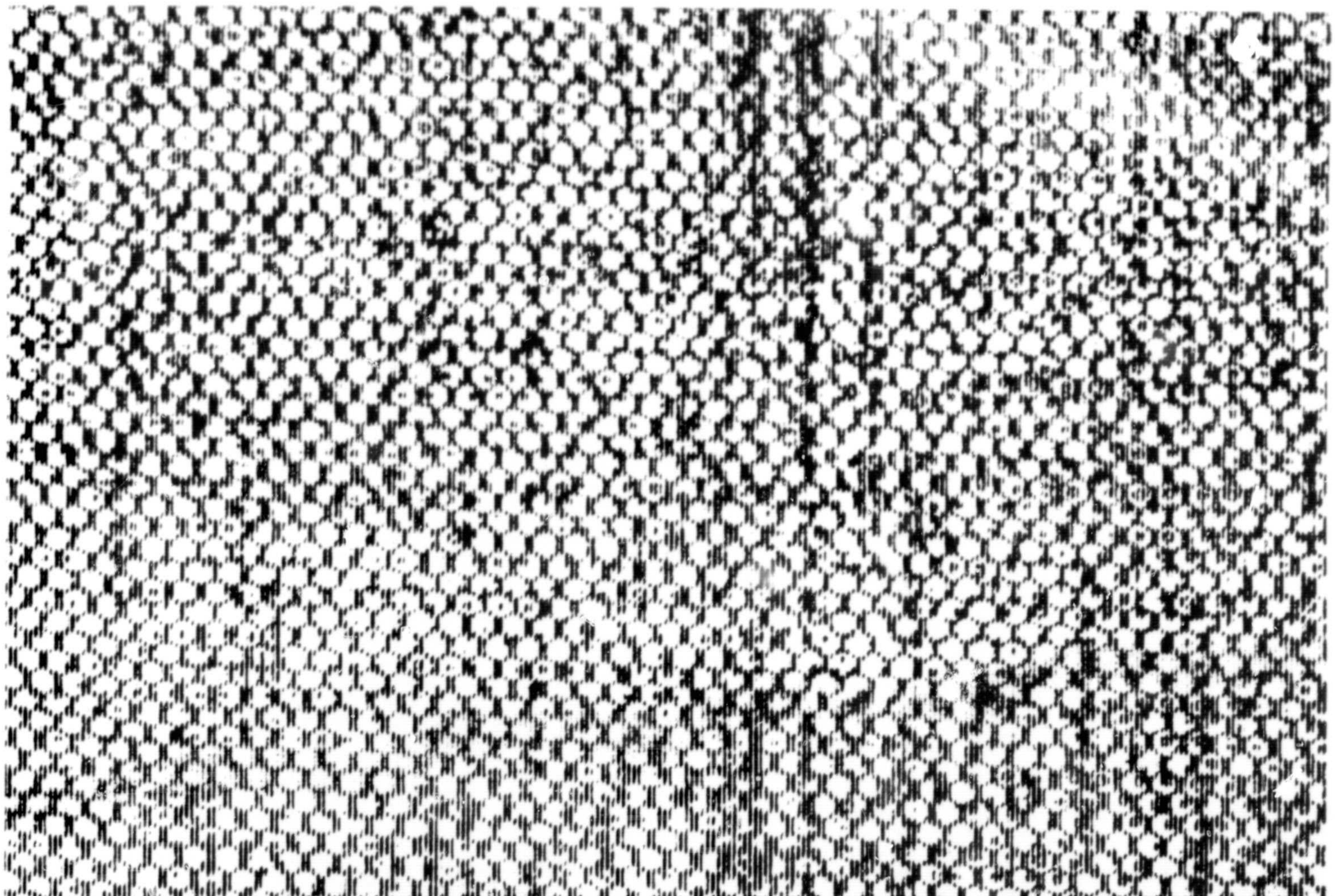

Figure 14.- Typical ultrasonic c-scan of honeycomb panel L9000002-1001 - bottom surface.

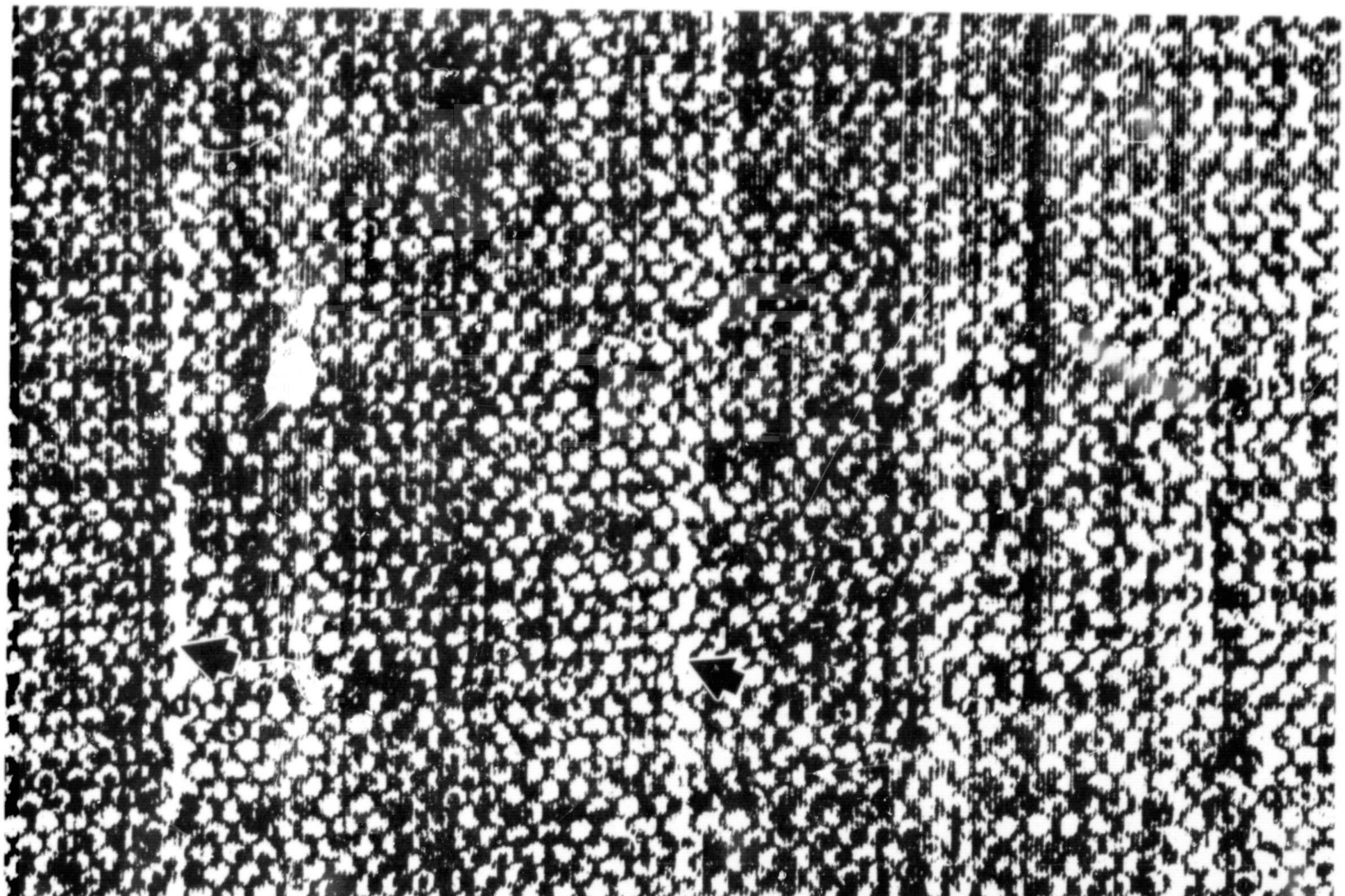

Figure 15.- Typical ultrasonic c-scan of honeycomb panel L9000002-1001 - top surface.

TABLE II.- FACE SHEET MECHANICAL PROPERTIES AFTER HEAT TREATING

Specimen No. *	Width, in.	Thickness in.	Area, sq.in.	Yield load, lb	Ultimate load, lb	Yield stress, psi	Ultimate stress, psi	Percent elong, 2 in. gage length
Requirements per MA0107-023	-	-	-	-	-	175,000	185,000	5
3-30-1T	0.4970	0.0624	0.03101	6,130	6,250	197,678	201,547	8
3-30-2T	0.5002	0.0623	0.03116	6,120	6,320	196,405	202,824	7.5
3-30-1B	0.4997	0.6598	0.02988	6,020	6,240	201,472	208,835	7
3-30-2B	0.5002	0.0602	0.03011	6,090	6,300	202,258	209,232	7.5
3-20-T1	0.5021	0.0420	0.02109	3,860	3,940	183,025	186,818	6.5
3-20-T2	0.5016	0.0421	0.02112	3,850	3,930	182,292	186,080	6.5
3-20-B1	0.5024	0.0471	0.02366	4,400	4,530	185,968	191,462	6.5
3-20-B2	0.5021	0.0470	0.02359	4,400	4,525	186,520	191,819	5.5
3-15-1T	0.4961	0.0419	0.02079	3,790	3,890	182,299	187,109	7
3-15-2T	0.4956	0.0420	0.02082	3,760	3,870	180,596	185,879	8
3-15-1B	0.4965	0.0421	0.02090	3,900	3,985	186,603	190,670	7
3-15-2B	0.4961	0.0422	0.02094	3,860	3,970	184,336	189,584	6.5
2-30-1T	0.5000	0.0833	0.04165	8,700	8,880	208,884	213,205	7.5
2-30-2T	0.5007	0.0833	0.04171	8,690	8,840	208,343	211,940	7
2-30-1B	0.5012	0.0833	0.04175	8,620	8,800	206,467	210,718	8
2-30-2B	0.5007	0.0831	0.04161	8,580	8,800	206,200	211,488	8

*"T" and "B" designations denote top and bottom face sheets, respectively.

PREPARATION OF TEST SPECIMENS

A layout of specimens was made on the honeycomb panel to agree with the locations indicated in figure 2. A special orientation of specimens for the 2-30 (24.9 lb/cu ft) honeycomb panel was made as discussed in paragraph 4.3 to negate the effects of the line voids discovered during the ultrasonic inspection. A permanent identification of each specimen was made in an unstressed specimen area using a mechanical vibration pencil.

Originally, the panel was divided into five sections by sawing along the layup splices shown in figure 2. All sawing was accomplished dry on a friction saw to preclude the possibility of fluid entrapment within any of the honeycomb cells. Such entrapment was considered a potential pressure rupture hazard during the high-temperature testing. Each specimen was rough-sawed then had the edges ground parallel on a Thompson surface grinder.

The heat shield specimens were rough-cut using a radiac blade in a power hand saw. Figure 16 shows the area of the heat shield from which these specimens were cut. The final configuration for these specimens was obtained as for the other honeycomb specimens, i.e., friction sawing and surface grinding. The ablative material was removed by carefully cutting to the epoxy adhesive scrim layer, thus preventing any possibility of face sheet damage.

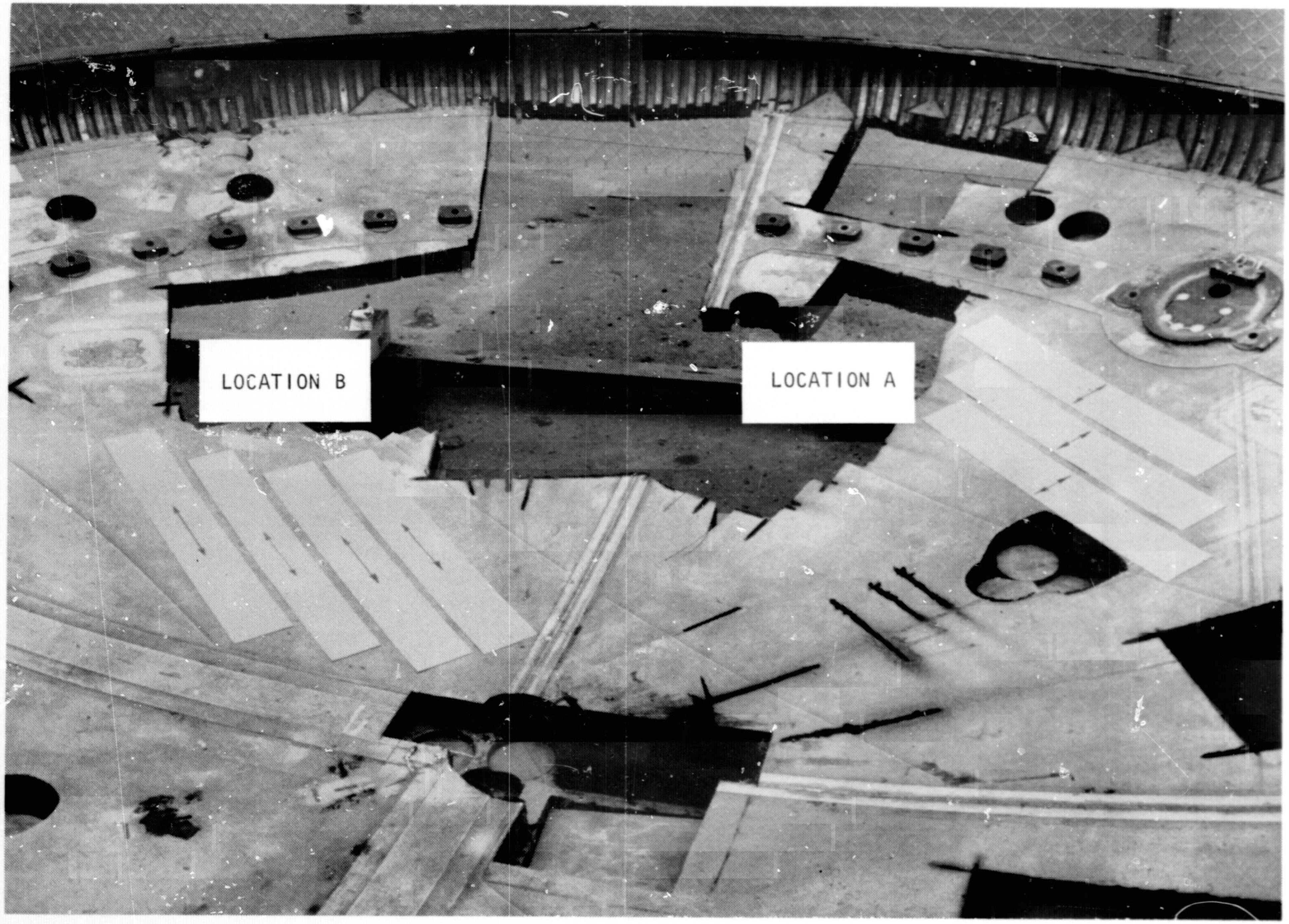

Figure 16.- Apollo heat shield (spacecraft 011) specific specimen locations.

DESCRIPTION OF TEST SETUP

Panel Specimens

The test procedures, as well as appropriate fixturing, were as described in MIL-STD-401A and ASTM C393-62. The test specimens were tested as a simple shear beam using four-point loading. Beam span load placement was determined to prevent excessive bending and optimize the core shear modes. Loading pads were used to distribute the load at each loading point over sufficient specimen surface area to avoid local core crushing. Loading of the beams was accomplished through the use of an electromechanical universal test machine, and elevated test temperatures were obtained by a circulating forced-air furnace capable of maintaining +10° F. This test setup is shown in figure 17; and figures 18 and 19 show an example of a beam specimen before and after testing. (Note that the specimen shown in these figures was not one of the specimens tested in this program. This figure is included because the size and placement of the actual honeycomb specimen within the furnace made photographing impractical). Individual test specimens were thermocoupled using 20 AWG chromel-alumel thermocouple wire. Temperature measurements were made with a calibrated potentiometer, and a Baldwin-Lima-Hamilton deflectometer was employed to measure deflection during testing. Autographic recordings of load versus deflection were made for each specimen tested.

Heat Shield Specimens

The test setup for the heat shield specimens was identical to that used for the panel specimens. The curved beam configuration of the heat shield specimens was accommodated by the self-aligning design of the test fixture. The component of spherical curvature transverse to the beam was considered to be negligible. For all of the heat shield specimens, the convex surface was oriented as the top specimen so that beam deflection curvature would relieve rather than augment the initial curvature.

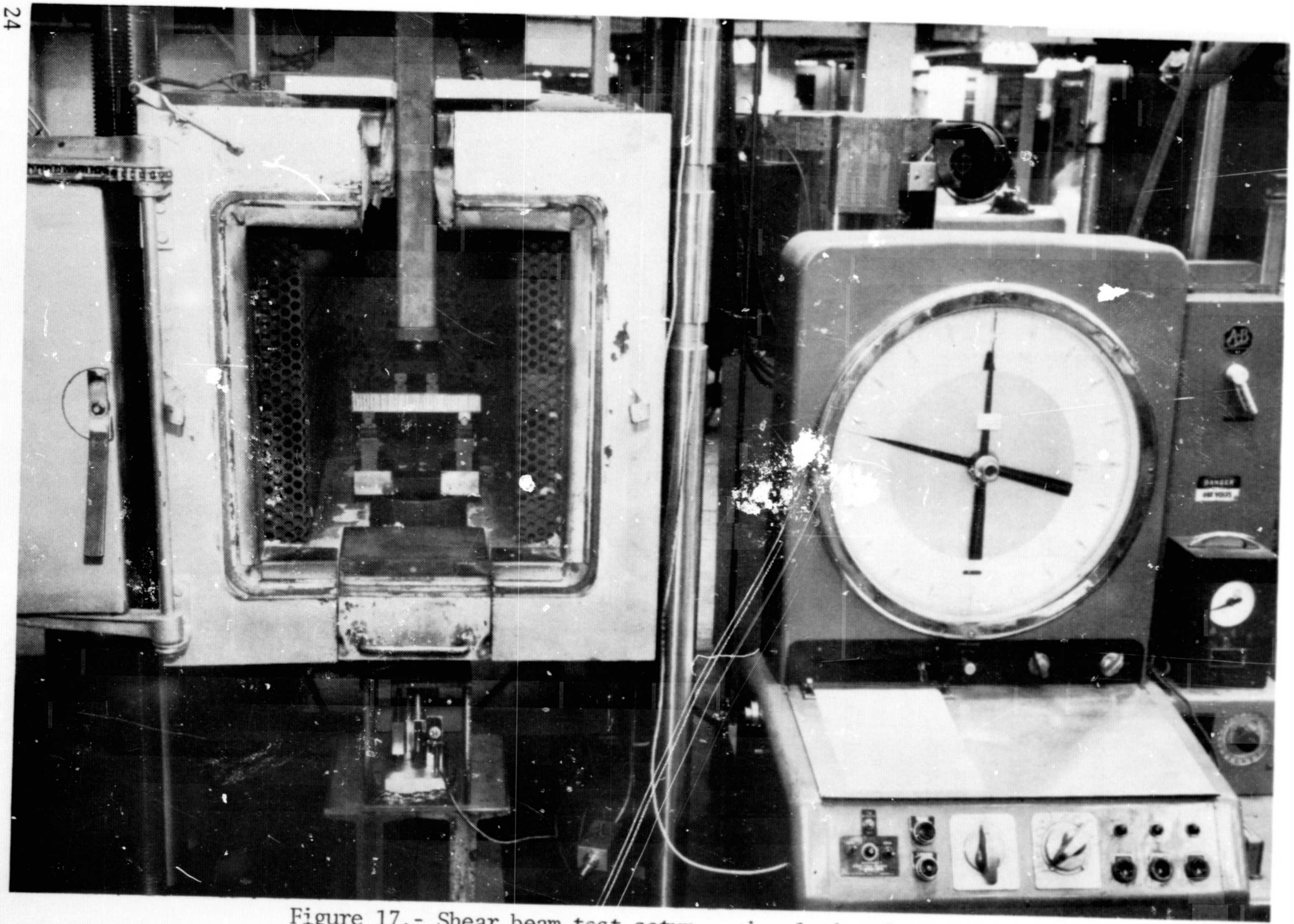

Figure 17.- Shear beam test setup - circulating forced air furnance and electromechanical universal testing machine.

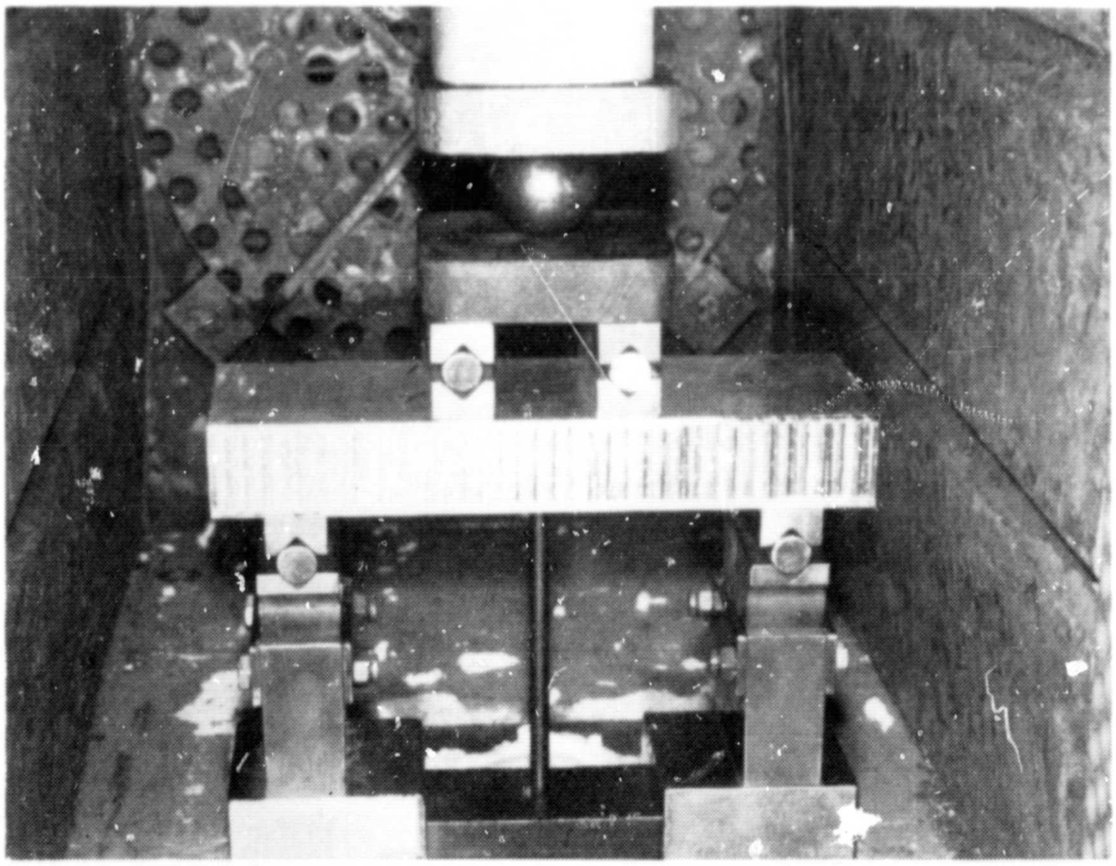

Figure 18.- Shear beam test setup - closeup before failure.

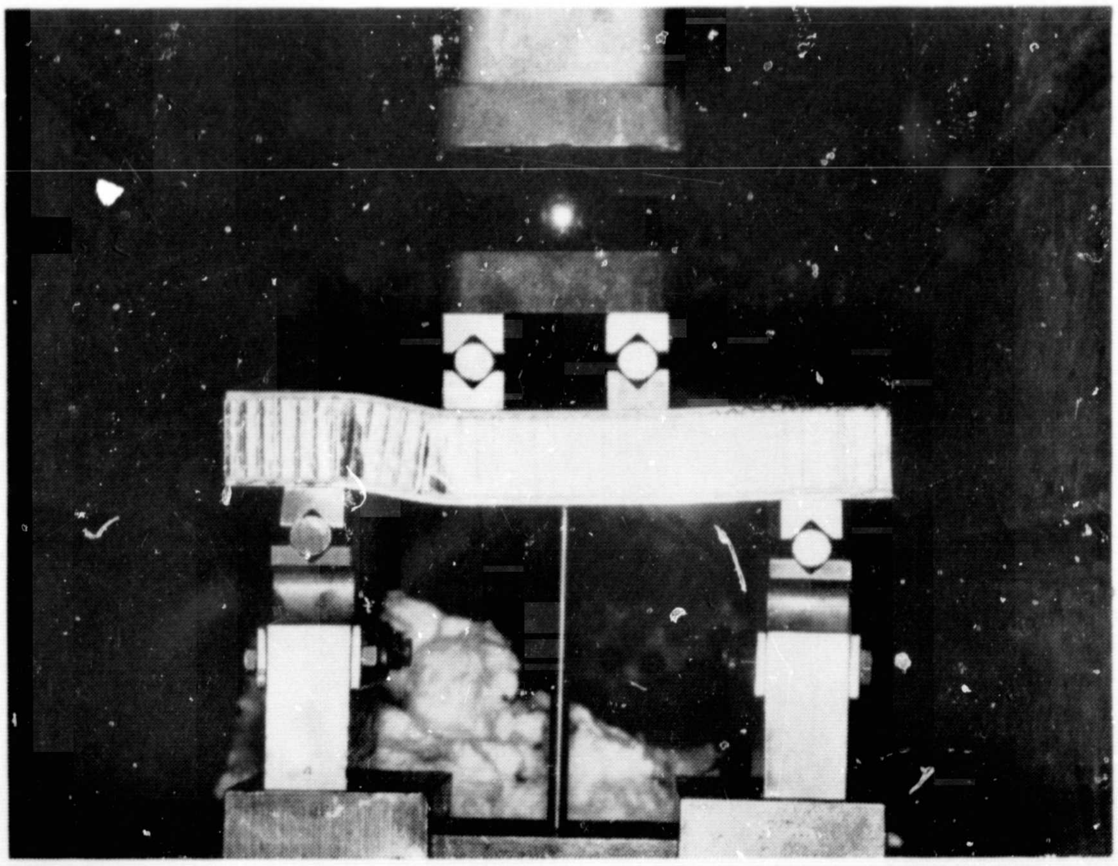

Figure 19.- Shear beam test setup - closeup after typical shear failure.

TEST PROGRAM

A minimum of three tests with longitudinal core direction specimens and three tests with transverse core direction specimens were conducted for each of the four honeycomb core configurations, at each of the following specified temperatures. The longitudinal specimens were tested at room temperature, 600°, 650°, 700°, 750°, and 800° F; and the transverse specimens were tested at 650°, 700°, and 800° F. As required by Contract Modification No. 1S, dated 11 June 1969, 900° F tests were added to the program to the extent of one longitudinal test specimen from each core configuration. Data resulting from these tests are presented in tables III through VI. Included in these tables is a description of the specimens, the failing loads, and a listing of the type of failure. Typical specimen failures for each test condition (honeycomb core configuration, temperature, and ribbon direction) are shown in figures 20 through 29.

Two of the three Apollo heat shield specimens were tested at room temperature to ascertain that no degradation of the honeycomb structure resulted from the reentry temperatures experienced by Apollo Spacecraft 011. The final heat shield specimen was tested at 800° F. These Apollo heat shield specimens after testing are shown in figure 30. Figure 31 shows the after -800° F condition of the Bloomingdale HT-424 epoxy adhesive film used to attach the ablative material to the stainless steel honeycomb sandwich. All that remains of the epoxy adhesive system is the flap of material shown in figure 31, which is the scrim into which the Bloomingdale HT-424 epoxy was impregnated. The test data for the Apollo heat shield specimens are shown in Table VII.

TABLE III.- CORE SHEAR TEST RESULTS - 2-30 HONEYCOMB CORE (24.9 LB/CU FT)

Specimen No. *	Test temp, °F	Height, in. **	Width, in.	Failing load, lb	Type of failure ***	Remarks
2-30-16L	RT	2.187	3.025	28,850	3	4 in. span
2-30-22L	RT	2.190	2.980	29,020	3	4 in. span
2-30-18L	RT	2.188	3.050	36,500	3	4 in. span
2-30-20L	600	2.190	2.980	21,700	3	4 in. span
2-30-17L	600	2.190	3.043	16,400	3	4 in. span
2-30-21L	600	2.190	3.054	15,850	3	4 in. span
2-30-19L	650	2.188	2.952	18,850	3	4 in. span
2-30-8L	650	2.185	3.010	20,650	3	4 in. span
2-30-13L	650	2.186	3.061	20,300	3	4 in. span
2-30-14L	700	2.185	3.049	20,750	3	4 in. span
2-30-9L	700	2.186	3.102	20,050	3	4 in. span
2-30-10L	700	2.188	3.090	20,700	3	4 in. span
2-30-11L	750	2.184	3.076	21,800	3	4 in. span
2-30-12L	750	2.186	3.135	25,600	3	4 in. span
2-30-3L	750	2.192	3.084	17,250	3	4 in. span
2-30-15L	800	2.188	2.985	20,150	3 severe	4 in. span
2-30-2L	800	2.190	3.022	14,650	3	4 in. span
2-30-4L	800	2.191	3.056	16,800	3	4 in. span
2-30-5L	900	2.186	3.030	19,500	5 slight	4 in. span
2-30-15T	RT	2.187	2.972	29,000	3	4 in. span
2-30-14T	650	2.190	3.060	16,050	3	4 in. span
2-30-13T	650	2.185	3.143	19,245	3	4 in. span
2-30-12T	650	2.186	3.071	24,100	3	4 in. span
2-30-5T	700	2.190	3.110	18,600	3	4 in. span
2-30-8T	700	2.188	3.060	19,600	3	4 in. span
2-30-9T	700	2.186	3.075	17,500	3	4 in. span
2-30-4T	750	2.192	3.125	29,300	3	4 in. span
2-30-7T	750	2.191	3.088	26,000	3	4 in. span
2-30-11T	750	2.190	3.082	28,850	3	4 in. span
2-30-3T	800	2.186	3.124	20,700	3	4 in. span
2-30-6T	800	2.189	3.025	23,700	3	4 in. span
2-30-10T	800	2.190	3.101	27,650	3	4 in. span

*"L" and "T" designations denote longitudinal and transverse ribbon directions, respectively.

**Height includes both face sheets.

***Code (type of shear failure)

1. Core shear rupture
2. Core shear creasing
3. Core-to-face braze separation
4. Face sheet buckling
5. Core crushing

TABLE IV.- CORE SHEAR TEST RESULTS - 3-30 HONEYCOMB CORE (16.6 LB/CU FT)

Specimen No. *	Test temp, °F	Height, in. **	Width, in.	Failing load, lb	Type of failure ***	Remarks
3-30-1L	RT	2.120	2.970	21,600	1, 2, 3	5 in. span
3-30-2L	RT	2.121	3.008	23,100	1, 2, 3	5 in. span
3-30-3L	RT	2.124	3.013	22,650	1, 2, 3	5 in. span
3-30-4L	600	2.120	3.022	17,100	3	5 in. span
3-30-5L	600	2.120	3.025	17,800	3, 1, 2	5 in. span
3-30-6L	600	2.122	3.017	16,250	3, 2	5 in. span
3-30-8L	650	2.118	2.956	11,125	3, 2	5 in. span
3-30-9L	650	2.132	2.985	16,100	3, 1	5 in. span
3-30-10L	650	2.127	3.001	12,850	3	5 in. span
3-30-11L	700	2.120	2.969	16,300	3, 1, 2	5 in. span
3-30-12L	700	2.120	3.030	15,700	3, 1	5 in. span
3-30-13L	700	2.120	3.000	15,900	3, 1, 2	5 in. span
3-30-14L	750	2.120	2.973	14,800	3, 2, 1	5 in. span
3-30-15L	750	2.121	2.870	14,600	1, 3	5 in. span
3-30-16L	750	2.123	3.033	15,650	1, 3	5 in. span
3-30-17L	800	2.172	3.075	13,850	3	5 in. span
3-30-18L	800	2.121	3.090	13,950	3, 1	5 in. span
3-30-19L	800	2.121	3.052	13,400	3, 2	5 in. span
3-30-20L	900	2.125	3.043	13,300	2, 4	4 in. span
3-30-3T	650	2.130	2.983	13,450	3, 2	5 in. span
3-30-4T	650	2.142	3.033	15,250	3, 2	5 in. span
3-30-5T	650	2.115	3.081	13,900	3, 2, 1	5 in. span
3-30-6T	700	2.116	3.140	15,900	3, 2	5 in. span
3-30-7T	700	2.130	3.042	14,225	3, 2	5 in. span
3-30-8T	700	2.120	3.041	14,800	3, 2, 1 slight	5 in. span.
3-30-9T	750	2.124	3.010	12,750	3, 2 slight	5 in. span
3-30-10T	750	2.122	3.034	13,800	3, 1	5 in. span
3-30-11T	750	2.124	3.006	13,650	3, 1	5 in. span
3-30-12T	800	2.120	3.023	13,750	3, 1	5 in. span
3-30-13T	800	2.124	3.039	12,950	3, 2 slight	5 in. span
3-30-14T	800	2.122	3.055	12,750	3, 2 slight	5 in. span

*"L" and "T" designations denote longitudinal and transverse ribbon directions, respectively.

**Height includes both face sheets.

***Code (type of shear failure)

1. Core shear rupture
2. Core shear creasing
3. Core-to-face braze separation
4. Face sheet buckling
5. Core crushing

TABLE V.- CORE SHEAR TEST RESULTS - 3-20 HONEYCOMB CORE (11.2 LB/CU FT)

Specimen No. *	Test temp °F	Height in. **	Width in.	Failing load, lb	Type of failure ***	Remarks
3-20-12L	RT	2.070	3.008	10,100	1, 2, 4	5 in. span
3-20-13L	RT	2.052	2.992	9,700	1, 4, 5	5 in. span
3-20-14L	RT	2.059	3.095	9,900	1, 4, 5	5 in. span
3-20-15L	RT	2.060	3.074	9,700	4, 5	5 in. span
3-20-3L	600	2.072	3.032	7,660	4, 5	5 in. span
3-20-9L	600	2.055	3.052	9,120	2, 1 slight	4 in. span
3-20-2L	600	2.072	3.062	8,860	5	4 in. span
3-20-4L	600	2.069	3.015	8,660	2	4 in. span
3-20-6L	650	2.070	3.031	8,220	2 slight	4 in. span
3-20-10L	650	2.058	2.983	7,600	2 slight	4 in. span
3-20-11L	650	2.062	3.102	7,860	2 slight	4 in. span
3-20-20L	700	2.060	3.077	7,260	2 slight	4 in. span
3-20-21L	700	2.062	3.070	7,200	2 slight	4 in. span
3-20-22L	700	2.059	3.207	7,400	5	4 in. span
3-20-5L	750	2.079	3.080	7,400	2 slight	4 in. span
3-20-7L	750	2.072	3.108	7,100	2 slight	4 in. span
3-20-8L	750	2.065	3.142	6,780	2 slight	4 in. span
3-20-16L	800	2.057	3.086	6,840	2 slight	4 in. span
3-20-17L	800	2.059	3.038	6,860	2 slight	4 in. span
3-20-18L	800	2.060	3.044	6,400	2 slight	4 in. span
3-20-19L	900	2.060	3.097	6,580	2, 1 slight, 4 slight	4 in. span
3-20-3T	650	2.069	3.296	6,980	2, 1 slight	4 in. span
3-20-4T	650	2.067	3.240	6,580	2, 1 slight	4 in. span
3-20-7T	650	2.069	3.290	7,200	2, 1 slight	4 in. span
3-20-8T	700	2.060	3.272	7,120	2, 1 slight	4 in. span
3-20-9T	700	2.061	3.232	6,880	2, 1 slight	4 in. span
3-20-10T	700	2.070	3.245	7,060	2	4 in. span
3-20-11T	750	2.055	3.240	6,600	2	4 in. span
3-20-12T	750	2.067	3.272	6,620	2, 1 slight	4 in. span
3-20-13T	750	2.060	3.240	6,600	2, 1 slight	4 in. span
3-20-14T	800	2.063	3.255	6,420	2, 1 slight	4 in. span
3-20-6T	800	2.065	3.219	6,100	2	4 in. span
3-20-5T	800	2.068	3.264	6,320	2	4 in. span

*"L" and "T" designations denote longitudinal and transverse ribbon directions, respectively.

**Height includes both face sheets.

***Code (type of shear failure)

1. Core shear rupture
2. Core shear creasing
3. Core-to-face braze separation
4. Face sheet buckling
5. Core crushing

TABLE VI.- CORE SHEAR TEST RESULTS - 3-15 HONEYCOMB CORE (8.3 LB/CU FT)

Specimen No. *	Test temp, °F	Height, in. **	Width, in.	Failing load, lb	Type of failure ***	Remarks
3-15-2L	RT	2.083	3.029	5,940	2, 1	4 in. span
3-15-4L	RT	2.080	3.090	6,820	2, 1, 5	4 in. span
3-15-5L	RT	2.086	3.081	6,860	2, 5	4 in. span
3-15-6L	600	2.090	3.039	5,580	2, 5	4 in. span
3-15-7L	600	2.082	3.077	6,140	2, 5	4 in. span
3-15-8L	600	2.088	2.848	5,200	2, 5	4 in. span
3-15-9L	650	2.085	3.285	6,000	2, 5	4 in. span
3-15-10L	650	2.086	3.066	5,360	2, 5	4 in. span
3-15-11L	650	2.092	3.086	5,580	2, 5	4 in. span
3-15-14L	700	2.085	3.154	5,320	2, 5	4 in. span
3-15-15L	700	2.082	3.075	5,580	2, 1, 5	4 in. span
3-15-16L	700	2.082	3.072	5,440	2, 5, 1	4 in. span
3-15-17L	750	2.086	3.171	5,380	2, 5, 1	4 in. span
3-15-18L	750	2.086	3.164	5,140	2, 5, 1	4 in. span
3-15-20L	750	2.083	3.154	5.540	5	4 in. span
3-15-21L	800	2.085	3.160	5,300	2, 1, 5	4 in. span
3-15-3L	800	2.084	3.000	4,580	2, 5	4 in. span
3-15-12L	800	2.082	3.096	4,920	2, 5	4 in. span
3-15-13L	900	2.080	3.150	4,780	2, 1	4 in. span
3-15-3T	650	2.083	3.365	4,840	2	4 in. span
3-15-4T	650	2.081	3.250	4,560	2	4 in. span
3-15-6T	650	2.085	3.376	5,320	2, 5, 1	4 in. span
3-15-7T	700	2.085	3.112	4,520	2	4 in. span
3-15-8T	700	2.087	3.066	4,260	2	4 in. span
3-15-10T	700	2.085	3.100	4,340	2	4 in. span
3-15-11T	750	2.082	3.154	4,380	2, 1	4 in. span
3-15-12T	750	2.083	3.095	4,385	2	4 in. span
3-15-13T	750	2.086	3.090	4,080	2, 1, 3	4 in. span
3-15-5T	800	2.095	3.345	4,820	2, 5, 1	4 in. span
3-15-9T	800	2.088	3.140	4,200	2, 1, 3	4 in. span
3-15-14T	800	2.087	3.040	3,920	2, 1	4 in. span

*"L" and "T" designations denote longitudinal and transverse ribbon directions, respectively.

**Height includes both face sheets.

***Code (type of shear failure)

1. Core shear rupture
2. Core shear creasing
3. Core-to-face braze separation
4. Face sheet buckling
5. Core crushing

Figure 20.- Typical failures of 2-30 honeycomb core specimens (24.9 lb/cu ft) - longitudinal ribbon direction, each test temperature.

Figure 21.- Typical failures of 2-30 honeycomb core specimens (24.9 lb/cu ft) - transverse ribbon direction, each test temperature.

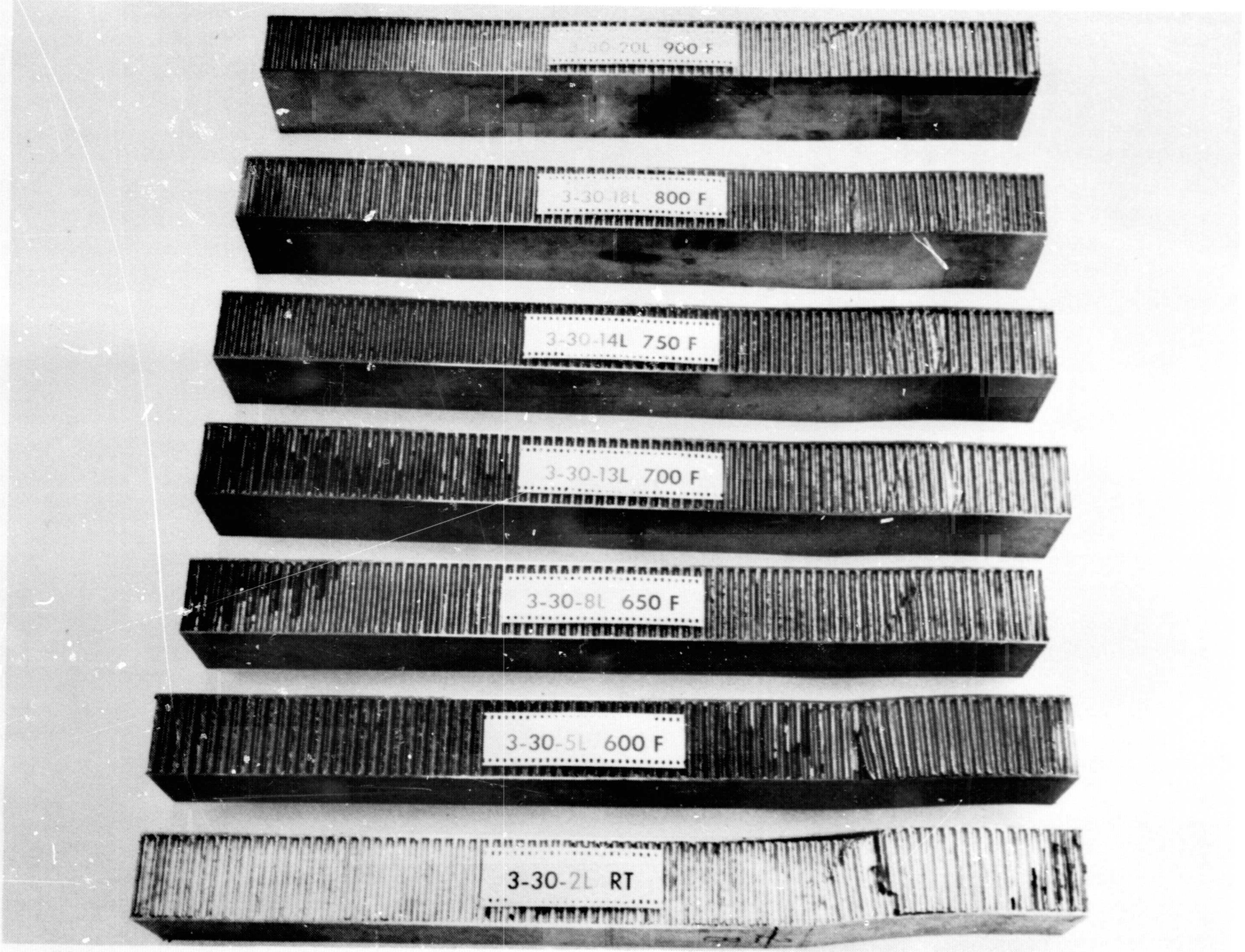

Figure 22.- Typical failures of 3-30 honeycomb core specimens (16.6 lb/cu ft) - longitudinal ribbon direction, each test temperature.

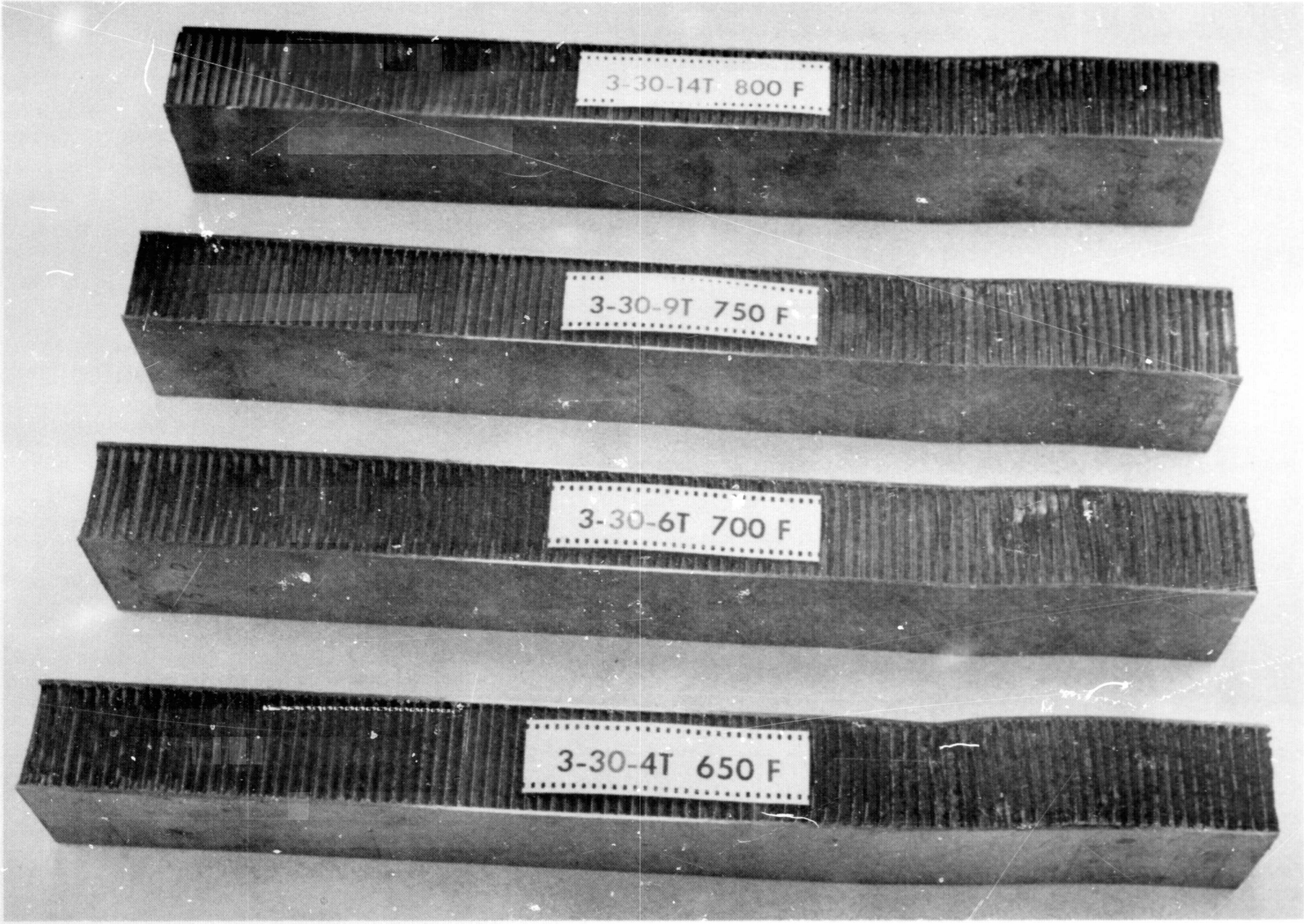

Figure 23.- Typical failures of 3-30 honeycomb core specimens (16.6 lb/cu ft) - transverse ribbon direction, each test temperature.

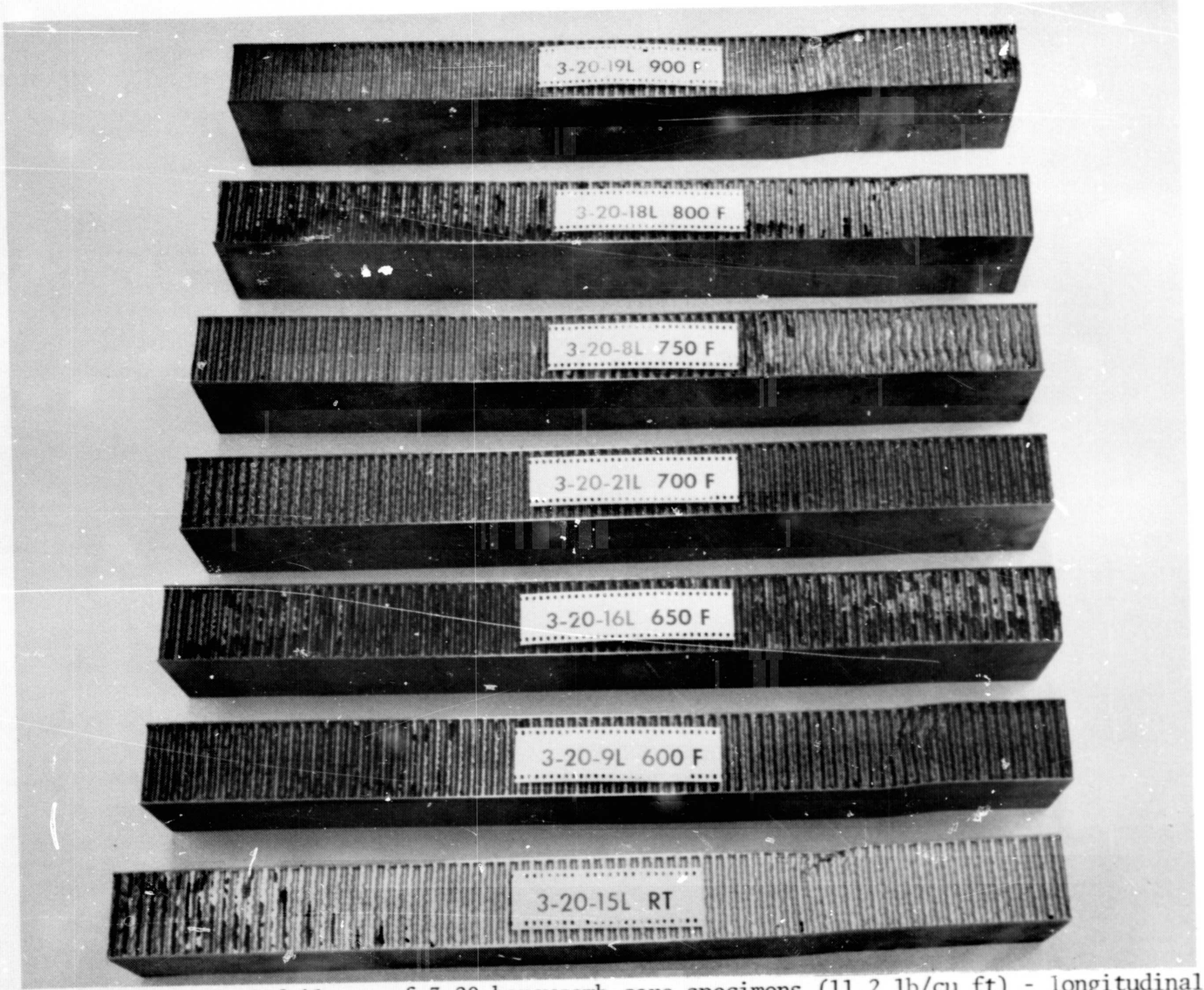

Figure 24.- Typical failures of 3-20 honeycomb core specimens (11.2 lb/cu ft) - longitudinal ribbon direction, each test temperature.

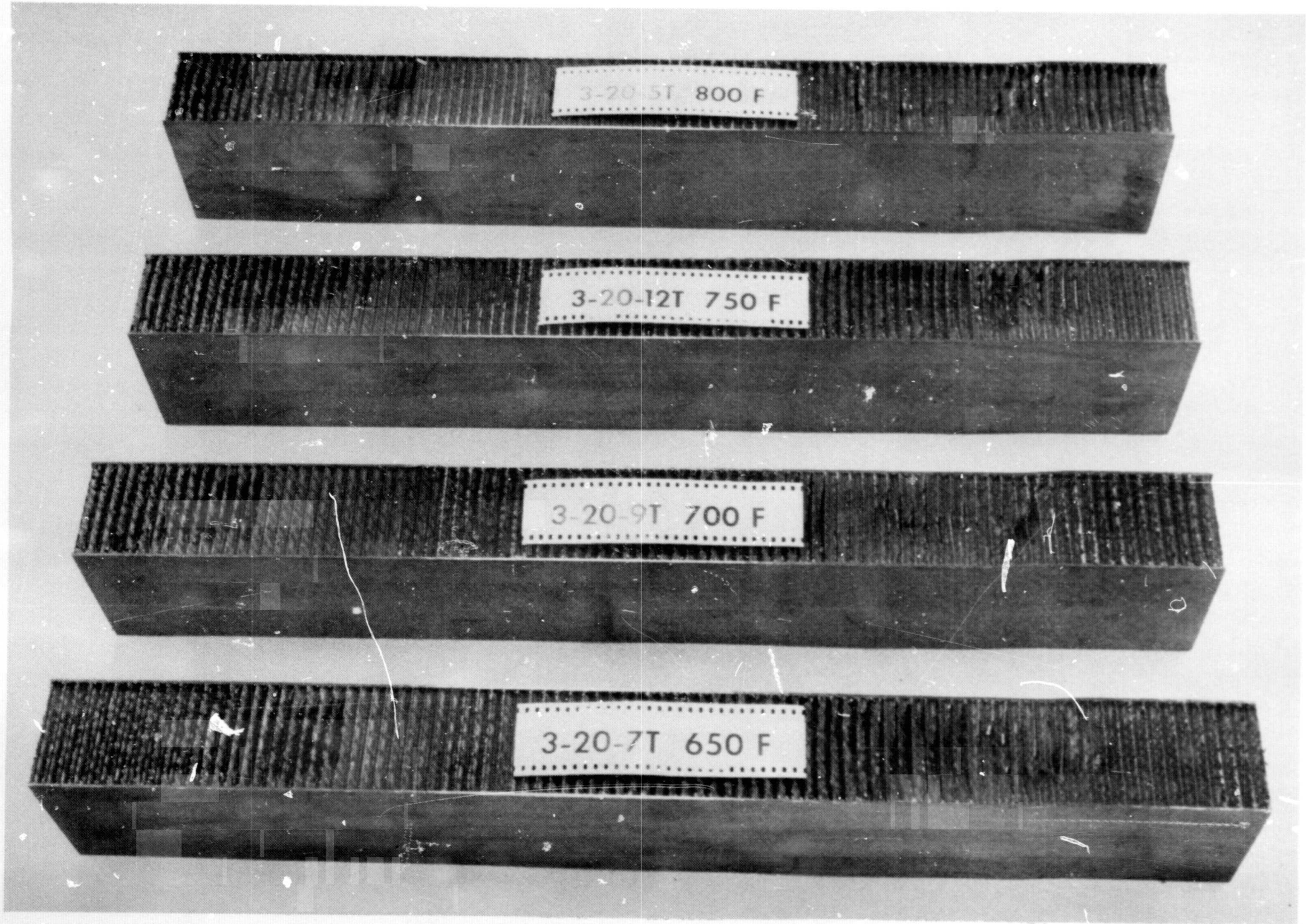

Figure 25.- Typical failures of 3-20 honeycomb core specimens (11.2 lb/cu/ft) - transverse ribbon direction, each test temperature.

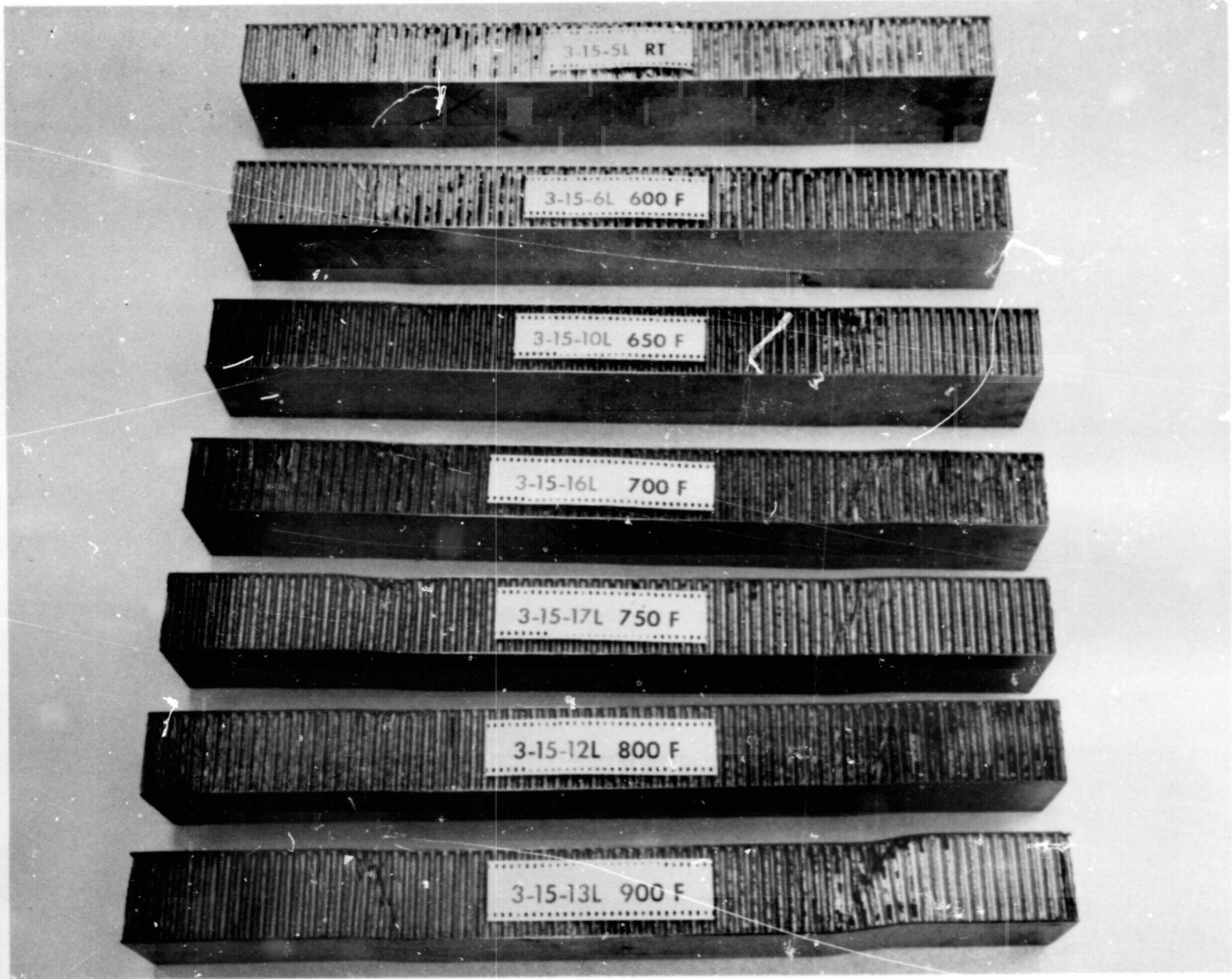

Figure 26.- Typical failures of 3-13 honeycomb core specimens (8.3 lb/cu ft) - longitudinal ribbon direction, each test temperature.

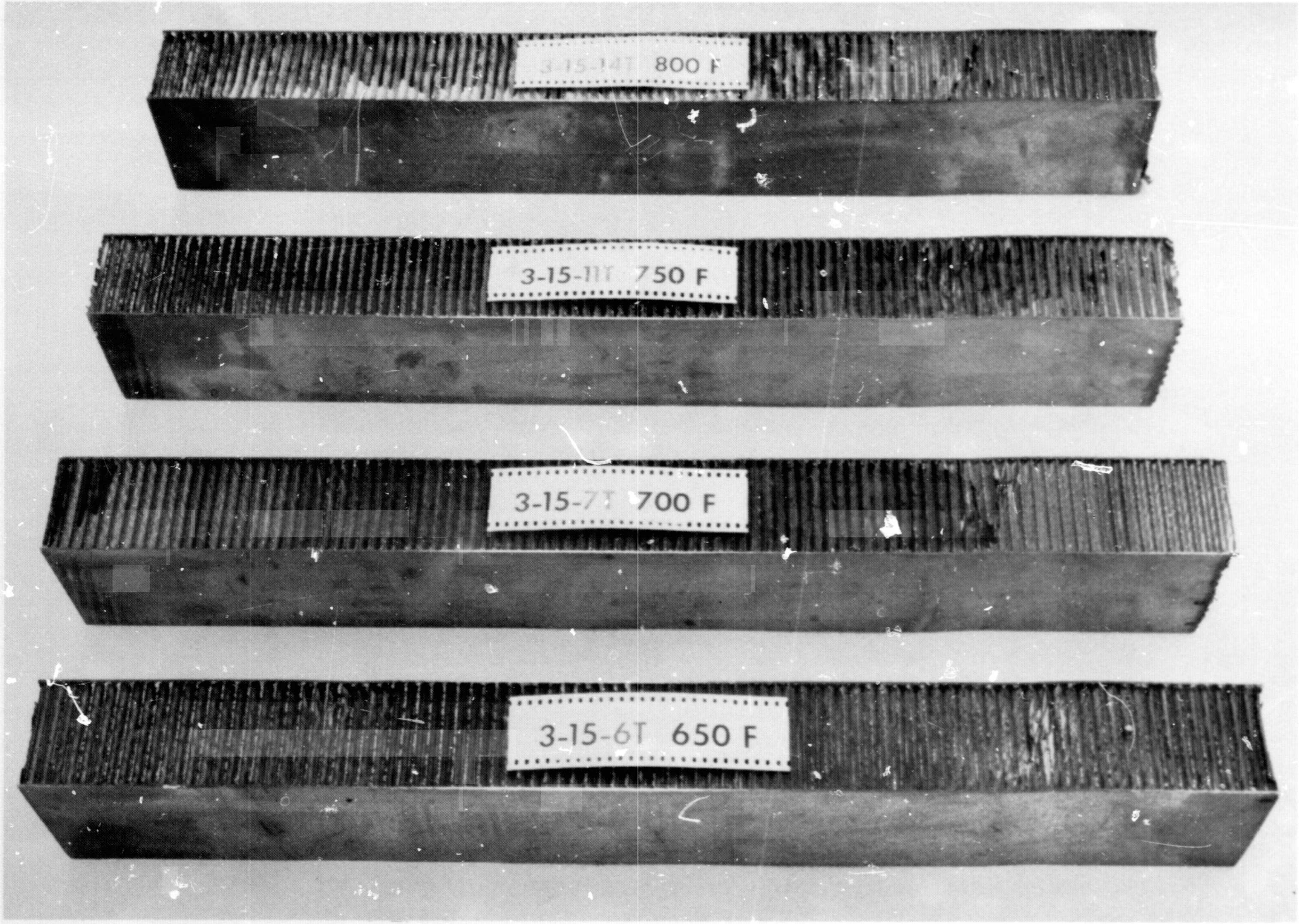

Figure 27.- Typical failures of 3-15 honeycomb core specimens (8.3 lb/cu ft) - transverse ribbon direction, each test temperature.

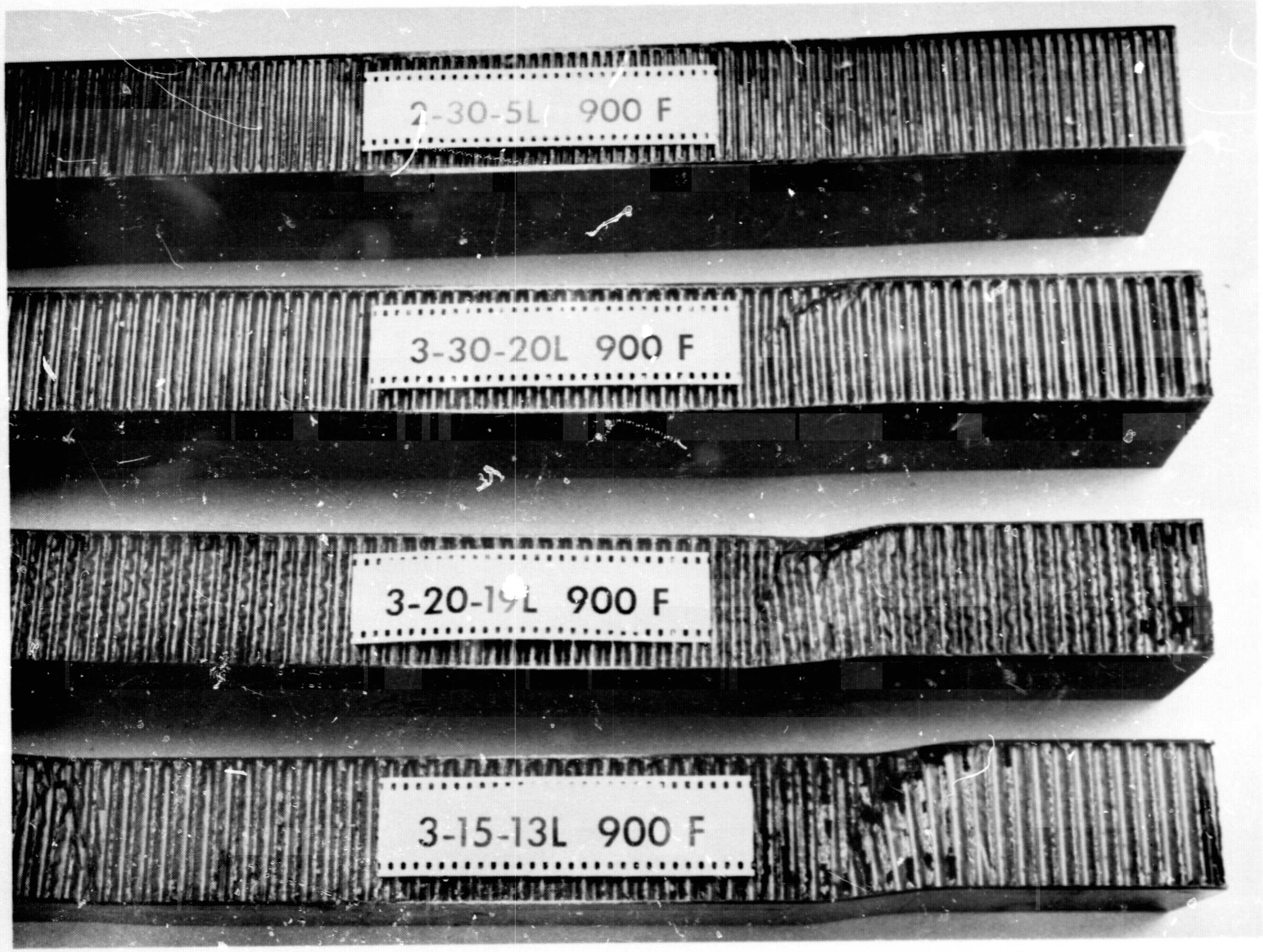

Figure 28.- Honeycomb core shear specimens after testing at 900° F.

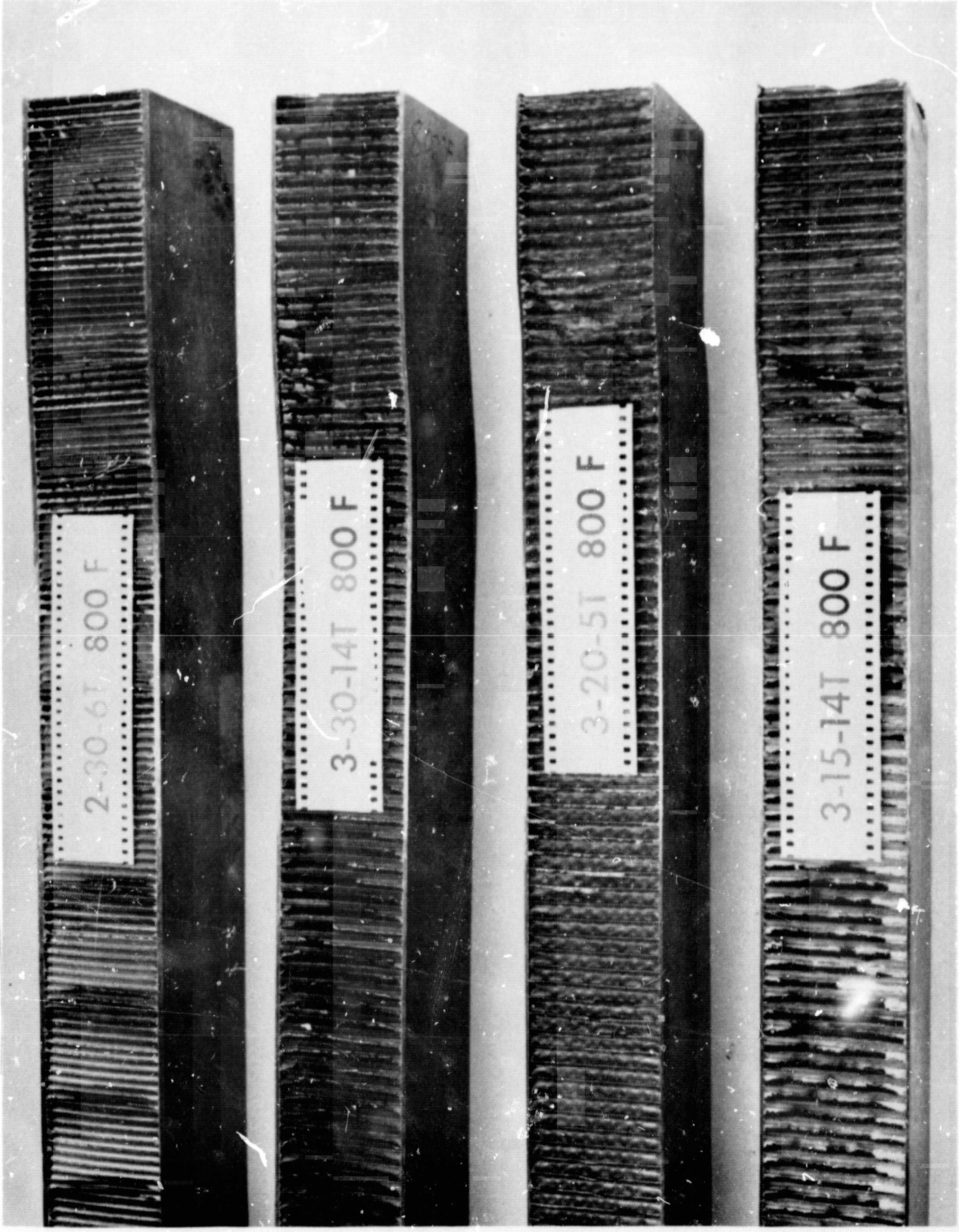

Figure 29.- Closeup of typical core shear failures.

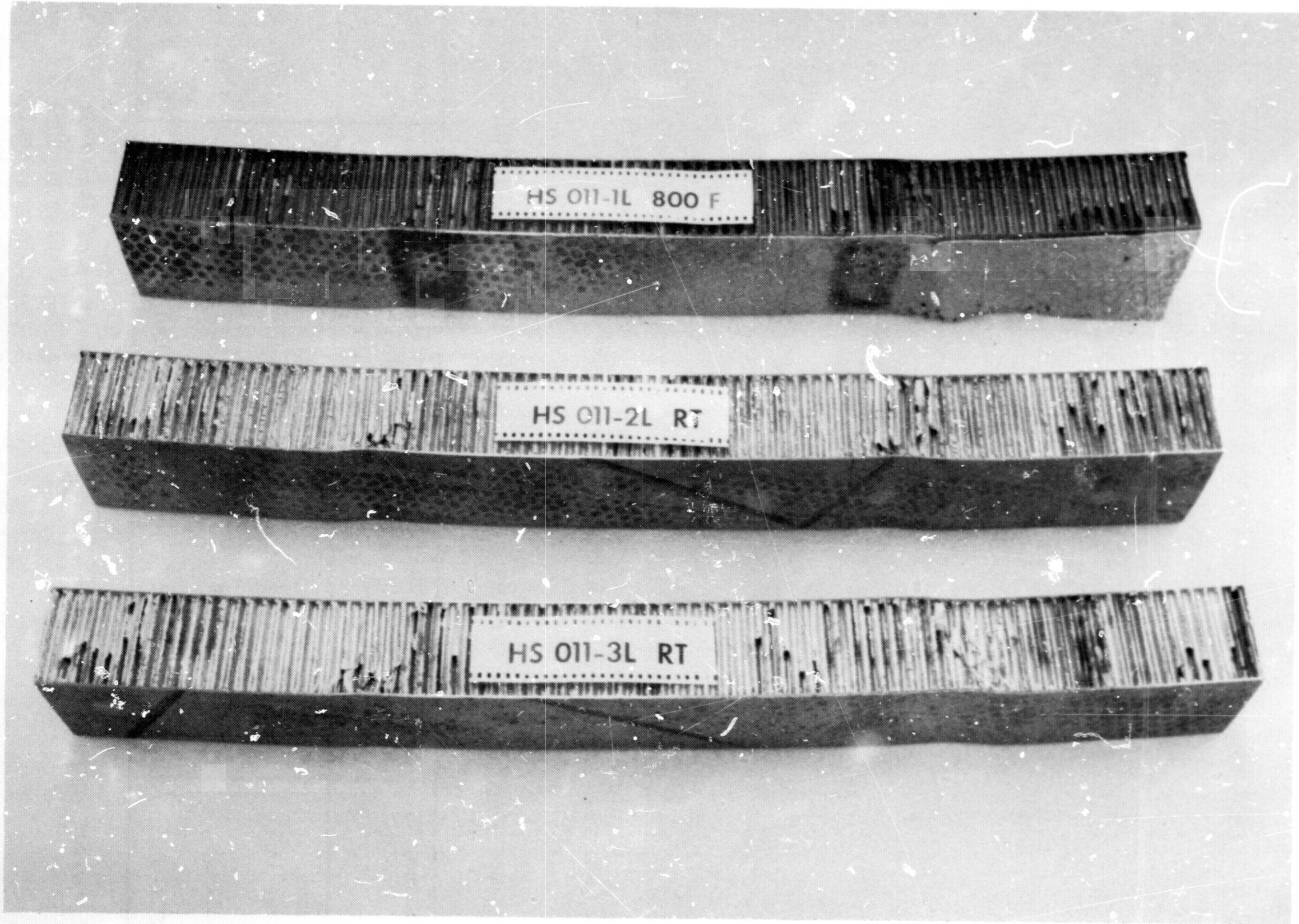

Figure 30.- Apollo heat shield (spacecraft 011) after testing.

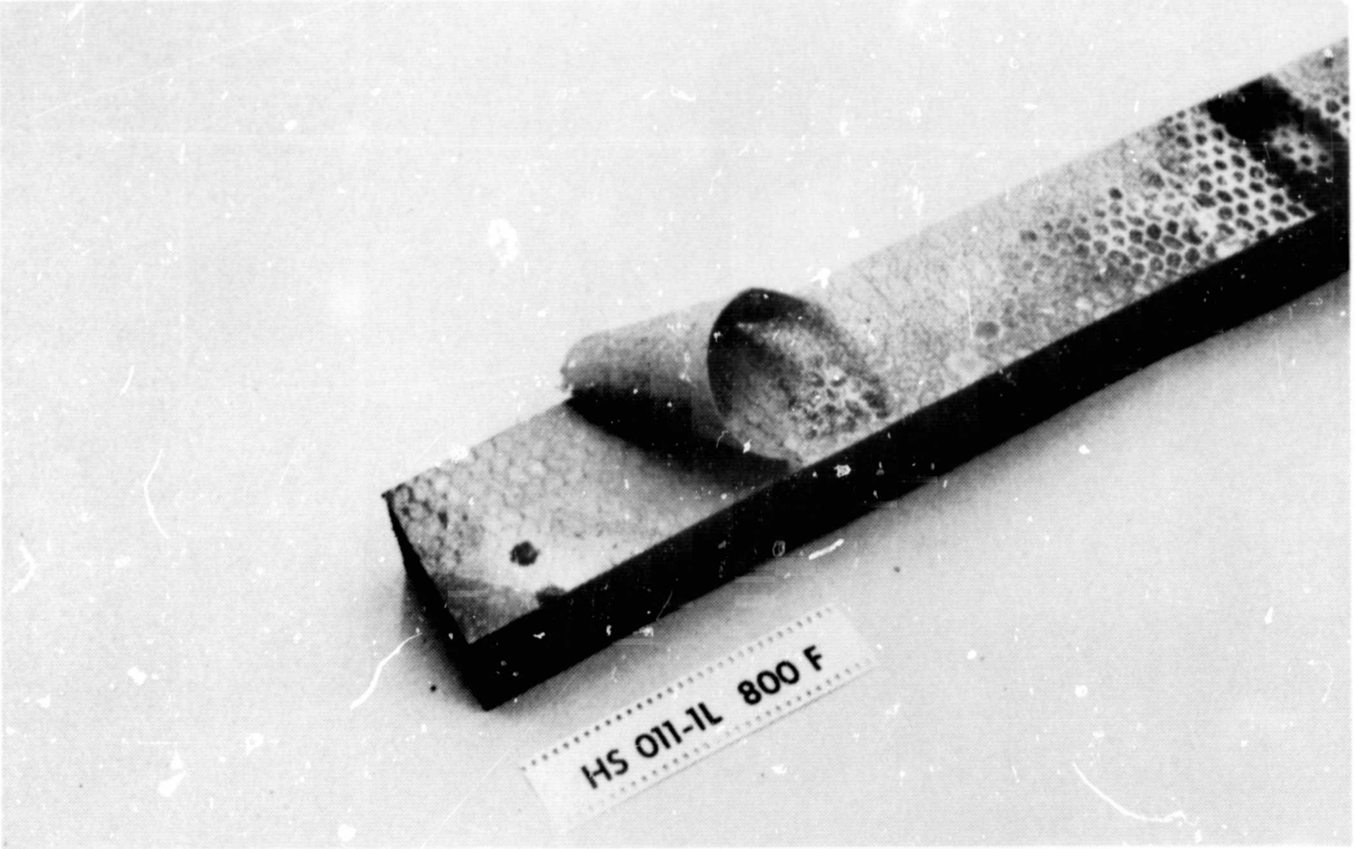

Figure 31.- Epoxy adhesive film residue on apollo heat shield specimen after testing at 800° F.

TABLE VII.- APOLLO HEAT SHIELD CORE SHEAR TEST RESULTS LONGITUDINAL RIBBON DIRECTION 3-15 HONEYCOMB CORE (8.3LB/CU FT)

Specimen No.	Test Temp, °F	Height, in. *	Width, in.	Failing load lb	Type of failure **	Remarks
HS011-1L	800	2.024	3.180	5,420	2, 5	4 in. span
HS011-2L	RT	2.024	3.167	7,140	2, 5	4 in. span
HS011-3L	RT	2.024	2.951	6,640	2, 5	4 in. span

* Height includes both face sheets

** Code (type of failure):

1. Core shear rupture
2. Core shear creasing
3. Core-to-face braze separation
4. Face sheet buckling
5. Core crushing

EVALUATION OF DATA

The first step in the evaluation of any test program is the normalization of the raw test data so that the individual data points can be compared and displayed on a rational basis. In this program, specifically the determination of brazed steel honeycomb core shear strength, the parameter to be normalized is the core ultimate shear stress, and the factors which must be individually considered are the test temperature, heat-treatment level of the steel, core height, core width, and core braze condition.

The specimen temperatures were automatically monitored during testing and were held to such a low excursion from nominal temperature that correction for this factor is not required.

Tensile coupon specimens obtained from the face sheets of the brazed panels were tested to determine actual heat-treatment response. The results are shown in table II. In the derivation of the normalizing factor for each panel, two assumptions are made. The first is that the core foil response is identical to the face sheet material; the second is that the ultimate shear stress of the core foil is proportional to the ultimate tensile stress. Both of these assumptions were proved valid during the XB-70 honeycomb development program. Consequently, all test shear stresses will be normalized by a factor equal to $200{,}000/\overline{F}_{tu}$, where $\overline{F}_{tu}$ for each panel is the average ultimate tensile stress of the four coupons from that panel, two from the top face sheet and two from the bottom. An ultimate tensile stress of 200,000 psi is the nominal design strength used as a basis for the existing allowable strength curves in the North American Rockwell Honeycomb Sandwich Structure Manual reproduced in the program work statement.

The measured core height (i.e., measured sandwich thickness minus the two face sheets) will be used directly in the calculation of test shear stress, rather than the nominal value of 2 inches. This value is individually determined for each specimen.

However, the strength of a core shear specimen is not, as with height, a direct function of the specimen width, but is a step function related to the number and arrangement of core ribbon elements. In a practical sense, of course, panel or specimen width is normally used as though it were a continuous parameter. The distinction is only made in such a situtation as this program, where basic allowable strengths are to be determined. A close approximation to this effect is obtained by using an effective width of specimen equal to the measured width reduced to the next lower multiple of the cell size. For simplicity, effective-width steps of 1/8 inch are used throughout in this program; this is conservative for the 3/16 cell cores.

In the category of core braze condition, the degree of node flow (of the braze alloy) is the only parameter normally accounted for with a standard correction factor. All other braze deviations are normally considered to be discrepancies subject to material review board disposition and are not considered acceptable in the determination of design allowable strength data. The panels brazed for this program were judged by X-ray inspection to be for the most part in the "full node flow" condition and, hence, the data may be said to be already in the normalized state for this parameter.

The test data for all specimens were normalized in accordance with the foregoing paragraphs and are presented in tables VIII through XV. The data for the longitudinal ribbon direction are plotted on figures 32, 34, 36, and 38 for the four core densities, respectively, with the existing ultimate allowable shear stress curves from the North American Rockwell Manuals. In the cases of the two heavier cores, 2-30 and 3-30, figures 32 and 34 show a braze-cutoff curve governing at higher temperatures. On all four figures, the allowable strength curves are extended from 600° to 800° F by "engineering approximation" of a 90-percent probability curve based on the new data. Figures 33, 35, 37, and 39 are plots of the data from the transverse ribbon of direction tests, where the allowable strength curves are at a strength level of 80 percent of the corresponding longitudinal curve.

The longitudinal data for the 2-30 core, figure 32, show considerable scatter, but generally on the high side, so that the extrapolated curve required only a slight slope steepening. The two low points at 600° F are considered to be faulty data and are ignored. This conclusion is felt warranted on the basis of the general trend indicated by the other points, but, at this time, no attempt will be made to ascertain the reason for the low values. The transverse data, figure 33, also show a large scatter, but well above the extrapolated transverse design curve.

The longitudinal data for the 3-30 core, figure 34, show a very good grouping, except for two specimens at 650° F, but considerably above and generally parallel to a straight-line extension of the allowable curve. However, in view of both the two lower points and the well-established background of the existing curve, a straight-line extension is the most generous that is felt warranted. The transverse data on figure 35 also show a good grouping, also parallel to and well above the extrapolated design curve. An interesting point about these data is that although the points would seem at first to be more logically related to the core strength curve (extended), ignoring the braze cutoff curve, the failures nevertheless included a braze failure mode in almost every specimen.

In figure 36, the longitudinal data for the 3-20 core are very well grouped, but the indicated trend forces a noticeable "knee" in the extension to the design allowable curve. The trend appears to be a steady, steeper slope once the "knee" is passed, however, not a continuously increasing slope (i.e., the second derivative appears to drop to zero again). The transverse data on figure 37 are very tightly grouped and moderately above the extended allowable curve.

The 3-15 longitudinal data on figure 38 are very tightly grouped and indicate only a slight steepening of the allowable curve. The transverse data on figure 39 are also very tightly grouped and are close to the extended allowable curve. For the 3-15 core, as shown by these two figures, the validity of the standard 80-percent reduction for transverse ribbon direction is especially well demonstrated.

The three specimens from the heat shield of Apollo Spacecraft 011 are also shown by the square diamond code in figure 38, two points at room temperature and one at 800° F. These three points match well with the data from the virgin panels of this program, indicating that the heat shield suffered no material property degradation as a result of its reentry history. It should be noted, however, that the original and current heat-treatment levels of the PH14-8Mo steel in the heat shield are unknown, so that neither the actual degradation (if any) nor the normalized data values can be determined. The nominal data, however, indicate that both of these considerations may apparently be ignored.

Figure 40 illustrates a face sheet buckling failure. The occurrence of this type of failure in the first few specimens of the 3-20 core led to the redesign of the test fixture from a 5-inch end-couple span to a 4-inch couple. This reduced the bending stress in the face sheets to 80 percent of the original value, while leaving the shear stress in the core unaffected. This change, designed to force the failure to occur in the core, was used for all subsequent specimens regardless of core density.

TABLE VIII.- CORE SHEAR STRENGTH EVALUATION

2-30 CORE (24.9 LB/FT^3) - LONGITUDINAL RIBBON DIRECTION

$\bar{F}_{tu}$ = 211 800 KSI (REFERENCE TABLE II)

Specimen No.	Temp (°F)	F'_s ksi (1)	F'_s (n) Normalized ksi (2)	$\bar{F}'_s$ (n) Average ksi	(F'_s) Structures Manual ksi
-16L	RT	2380	2250	2480	2300
-22L	RT	2490	2350		
-18L	RT	3010	2840		
-20L	600	1870	1770	1770	1620 (3)
-17L	600	1350	1270		
-21L	600	1310	1240		
-19L	650	1620	1530	1580	
-8L	650	1710	1610		
-13L	650	1680	1590		
-14L	700	1710	1610	1600	
-9L	700	1660	1570		
-10L	700	1710	1610		
-11L	750	1800	1700	1650	
-12L	750	2030	1920		
-13L	750	1420	1340		
-15L	800	1730	1630	1360	
-2L	800	1210	1140		
-4L	800	1380	1300		
-5L	900	1610	1520		

(1) $F'_s = \dfrac{\text{Failing Load}}{2\ cw}$ (Ref table III)

(2) $F'_s\ (n) = F'_s\ \dfrac{200\ 000}{F_{tu}}$

(3) Braze cutoff

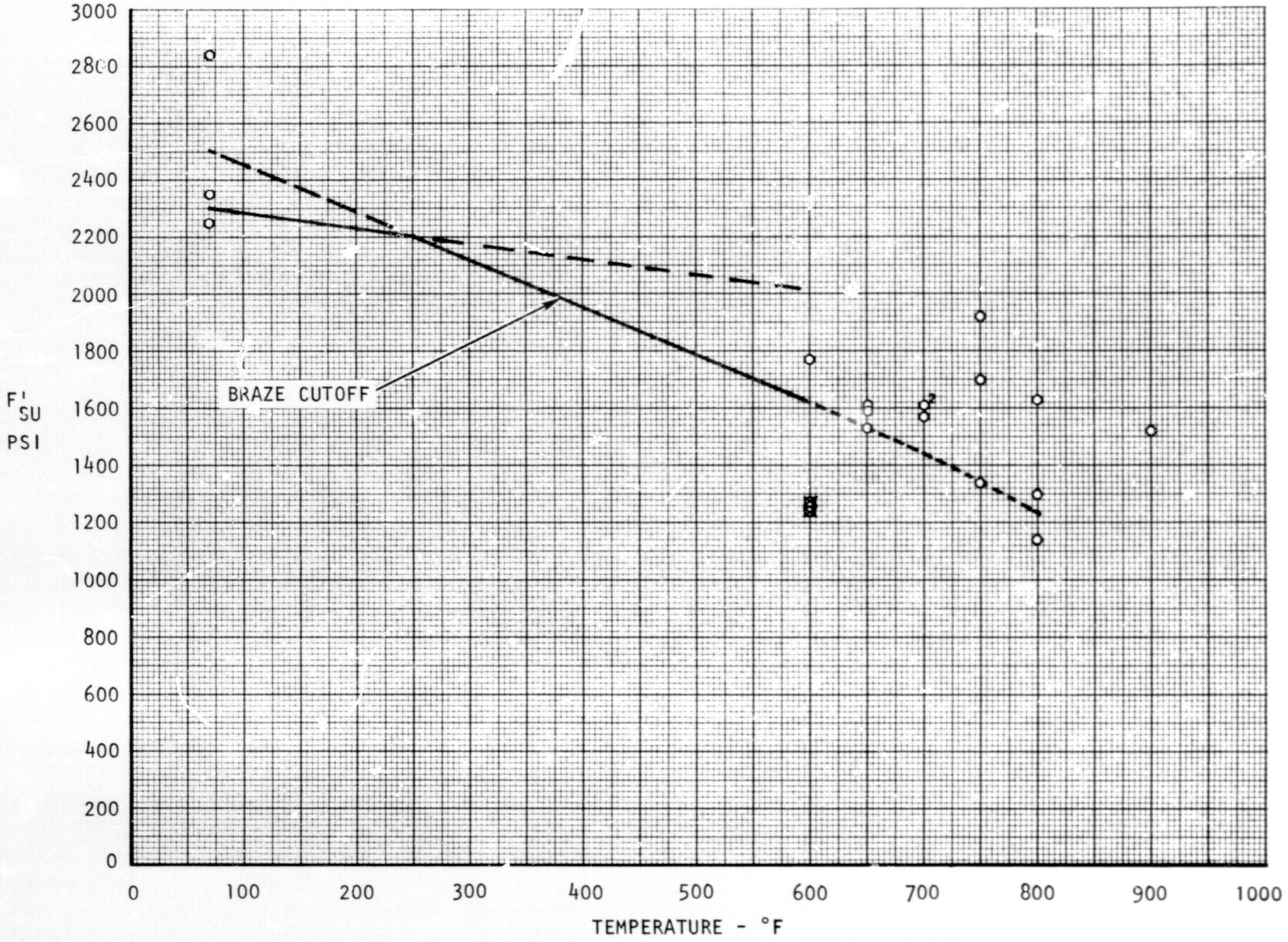

Figure 32.- Core shear strength versus temperature - 2-30 core - longitudinal ribbon direction.

TABLE IX.- CORE SHEAR STRENGTH EVALUATION

2-30 CORE (24.9 LB/FT^3) - TRANSVERSE RIBBON DIRECTION

$\overline{F}_{tu}$ = 211 800 KSI (REFERENCE TABLE II)

Specimen No.	Temp (°F)	F'_s ksi (1)	F'_s (n) Normalized ksi (2)	F'_s (n) Average ksi	(F'_s) Structures Manual ksi
-15T	RT	2500	2360		1840
-14T	650	1320	1250	1520	
-13T	650	1530	1440		
-12T	650	1990	1880		
-5T	700	1530	1440	1440	
-8T	700	1620	1530		
-9T	700	1440	1360		
-4T	750	2410	2280	2180	
-7T	750	2140	2020		
-11T	750	2380	2250		
-3T	800	1710	1610	1870	
-6T	800	1960	1850		
-10T	800	2280	2150		

(1) $F'_s = \dfrac{\text{Failing load}}{2\ cw}$ (Ref table III)

(2) $F'_s\ (n) = F'_s \ \dfrac{200\ 000}{F_{tu}}$

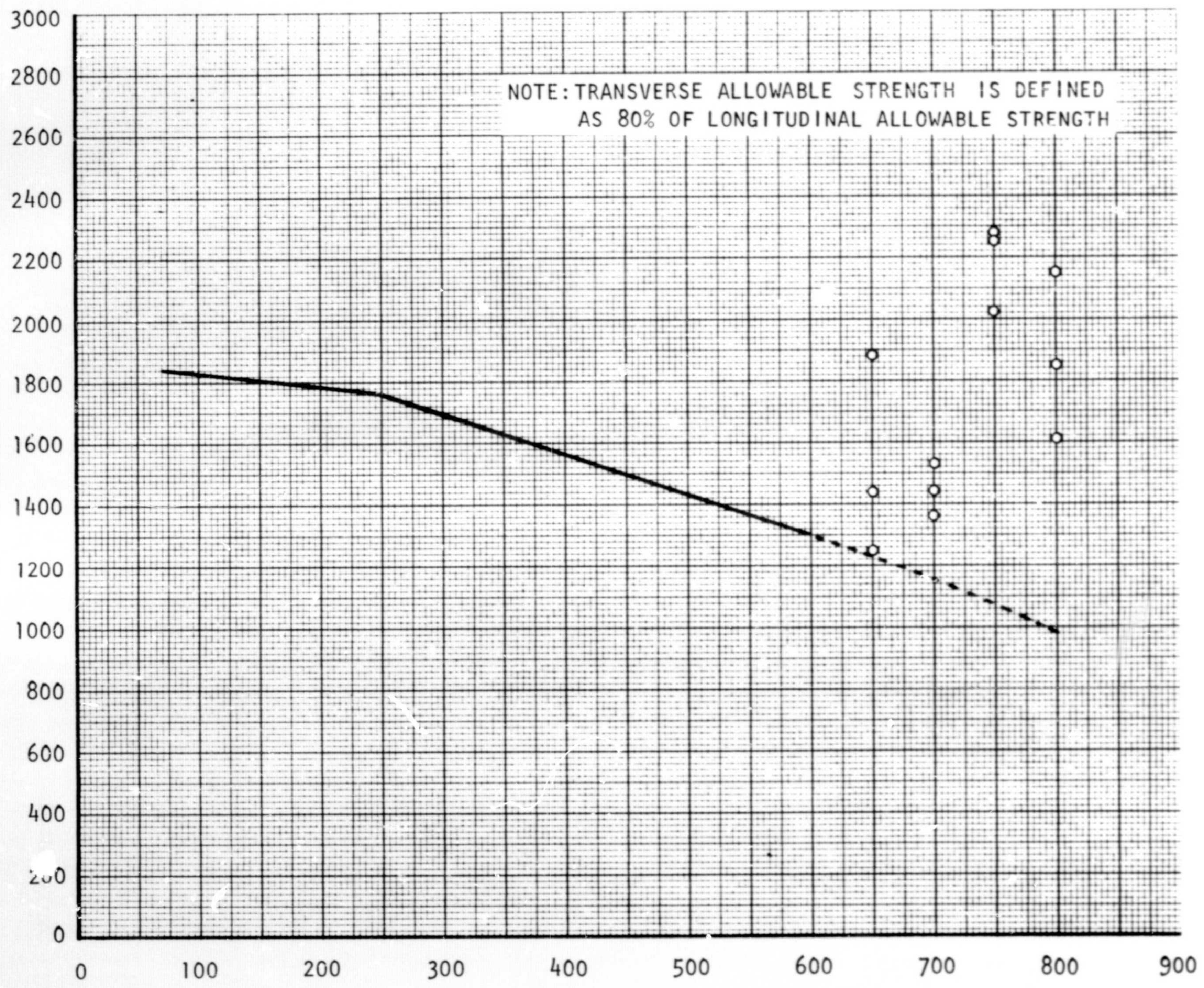

Figure 33.- Core shear strength versus temperature - 2-30 core - transverse ribbon direction.

TABLE X.- CORE SHEAR STRENGTH EVALUATION

3-30 CORE (16.6 LB/FT^3) - LONGITUDINAL RIBBON DIRECTION

$\overline{F}_{tu}$ = 205 600 KSI (REFERENCE TABLE II)

Specimen No.	Temp (°F)	F'_s ksi (1)	F'_s (n) Normalized ksi (2)	$\overline{F}'_s$ (n) Average ksi	(F'_s) Structures Manual ksi
-1L	RT	1880	1830	1850	1320
-2L	RT	1930	1880		
-3L	RT	1890	1840		
-4L	600	1430	1390	1380	1070 (3)
-5L	600	1480	1440		
-6L	600	1350	1310		
-8L	650	970	940	1110	
-9L	650	1390	1350		
-10L	650	1070	1040		
-11L	700	1420	1380	1310	
-12L	700	1310	1270		
-13L	700	1330	1290		
-14L	750	1290	1250	1270	
-15L	750	1330	1290		
-16L	750	1300	1260		
-17L	800	1150	1120	1110	
-18L	800	1160	1130		
-19L	800	1120	1090		
-20L	900	1110	1080		

(1) $F'_s = \frac{\text{Failing Load}}{2\ cw}$ (Ref Table IV)

(2) $F'_s\ (n) = F'_s \ \frac{200\ 000}{F_{tu}}$

(3) Braze Cutoff

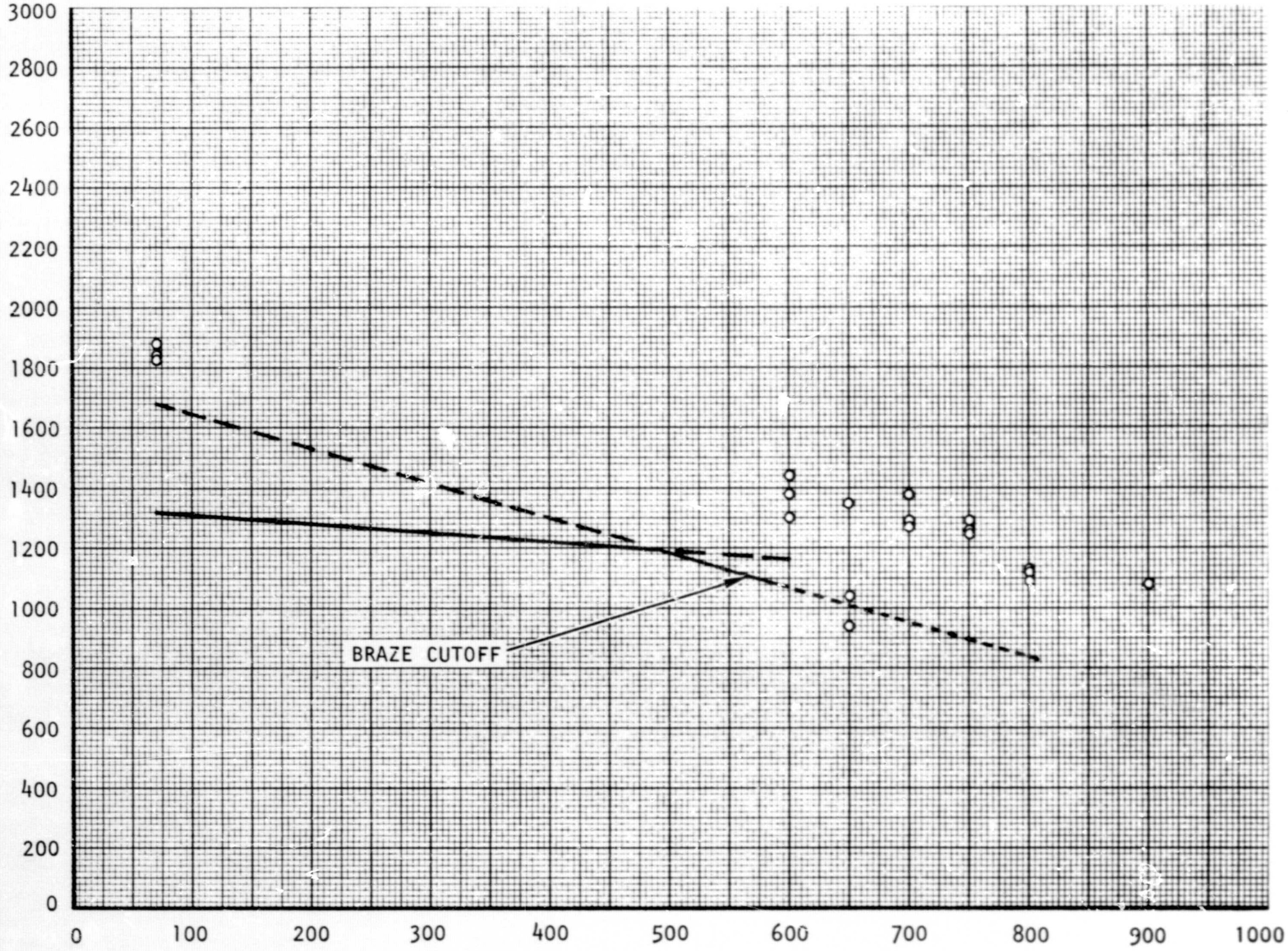

Figure 34.- Core shear strength versus temperature - 3-30 core - longitudinal ribbon direction.

TABLE XI.- CORE SHEAR STRENGTH EVALUATION

3-30 CORE (16.6 LB/FT3) - TRANSVERSE RIBBON DIRECTION

$\overline{F}_{tu}$ = 205 600 KSI (REFERENCE TABLE II)

Specimen No.	Temp (°F)	F'_s ksi (1)	F'_s (n) Normalized ksi (2)	$\overline{F}'_s$ (n) Average ksi	(F'_s) Structures Manual ksi
-3T	650	1160	1130	1160	
-4T	650	1260	1230		
-5T	650	1160	1130		
-6T .	700	1280	1250	1200	
-7T	700	1180	1150		
-8T	700	1230	1200		
-9T	750	1060	1030	1090	
-10T	750	1150	1120		
-11T	750	1140	1110		
-12T	800	1150	1120	1070	
-13T	800	1080	1050		
-14T	800	1060	1030		

(1) $F'_s = \dfrac{\text{Failing Load}}{2\ cw}$ (Ref Table IV)

(2) $F'_s\ (n) = F'_s\ \dfrac{200\ 000}{F_{tu}}$

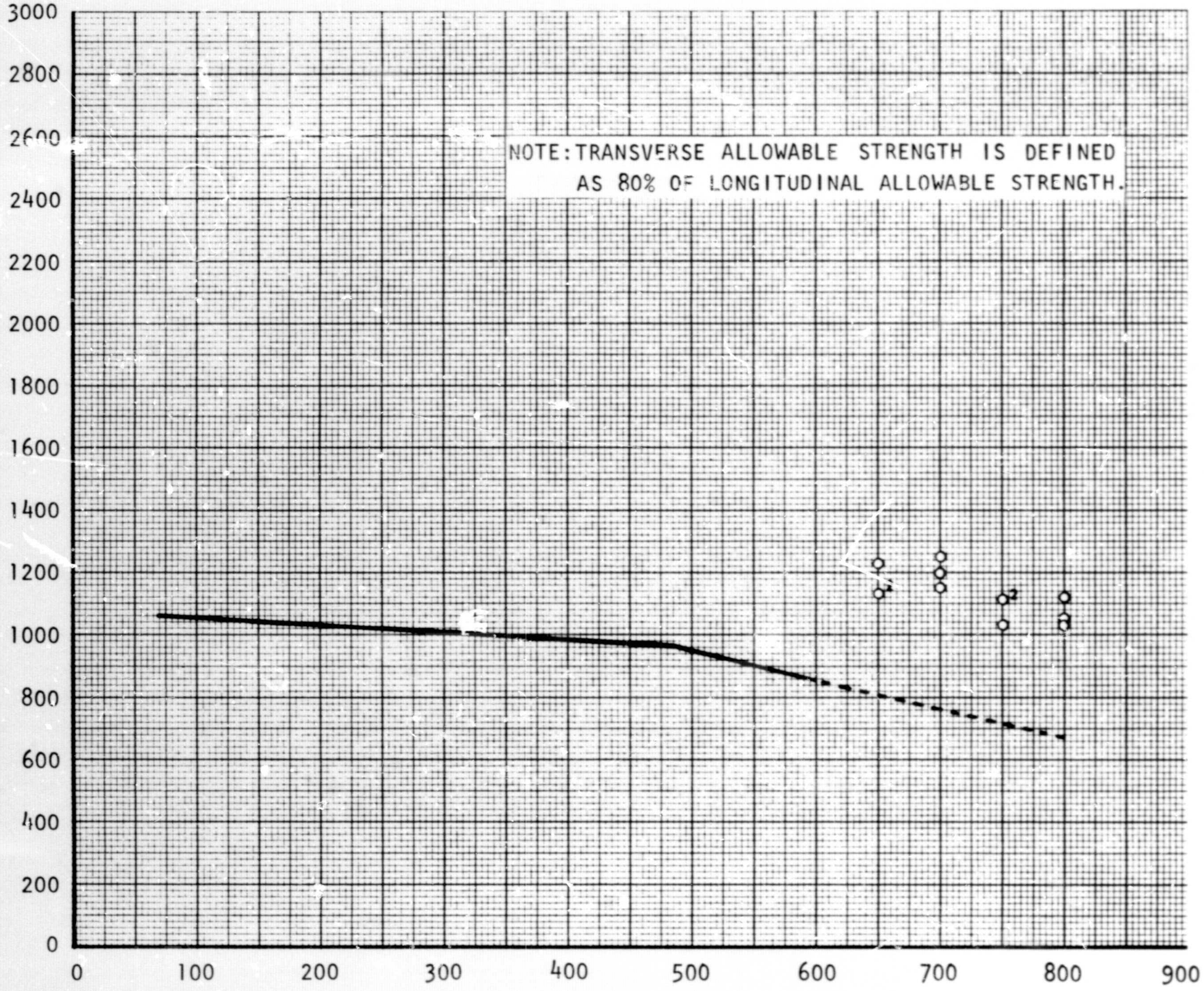

Figure 35.- Core shear strength versus temperature - 3-30 core - transverse ribbon direction.

TABLE XII.- CORE SHEAR STRENGTH EVALUATION

3-20 CORE (11.2 LB/FT^3) - LONGITUDINAL RIBBON DIRECTION

$\overline{F}_{tu}$ = 189 000 KSI (REFERENCE TABLE II)

Specimen No.	Temp (°F)	F'_s ksi (1)	F'_s (n) Normalized ksi (2)	F'_s (n) Average ksi	(F'_s) Structures Manual ksi
-12L	RT	850	900	900	780
-13L	RT	860	910		
-14L	RT	840	890		
-15L	RT	820	870		
-3L	600	640	680	760	680
-9L	600	770	810		
-2L	600	740	780		
-4L	600	730	770		
-6L	650	690	730	710	
-10L	650	670	710		
-11L	650	660	700		
-20L	700	610	650	640	
-21L	700	610	650		
-22L	700	600	630		
-5L	750	620	660	620	
-7L	750	600	630		
-8L	750	550	580		
-16L	800	580	610	600	
-17L	800	580	610		
-18L	800	540	570		
-19L	900	560	590		

(1) $F'_s = \dfrac{\text{Failing load}}{2\ cw}$ (Ref Table V)

(2) $F'_s\ (n) = F'_s\ \dfrac{200\ 000}{F_{tu}}$

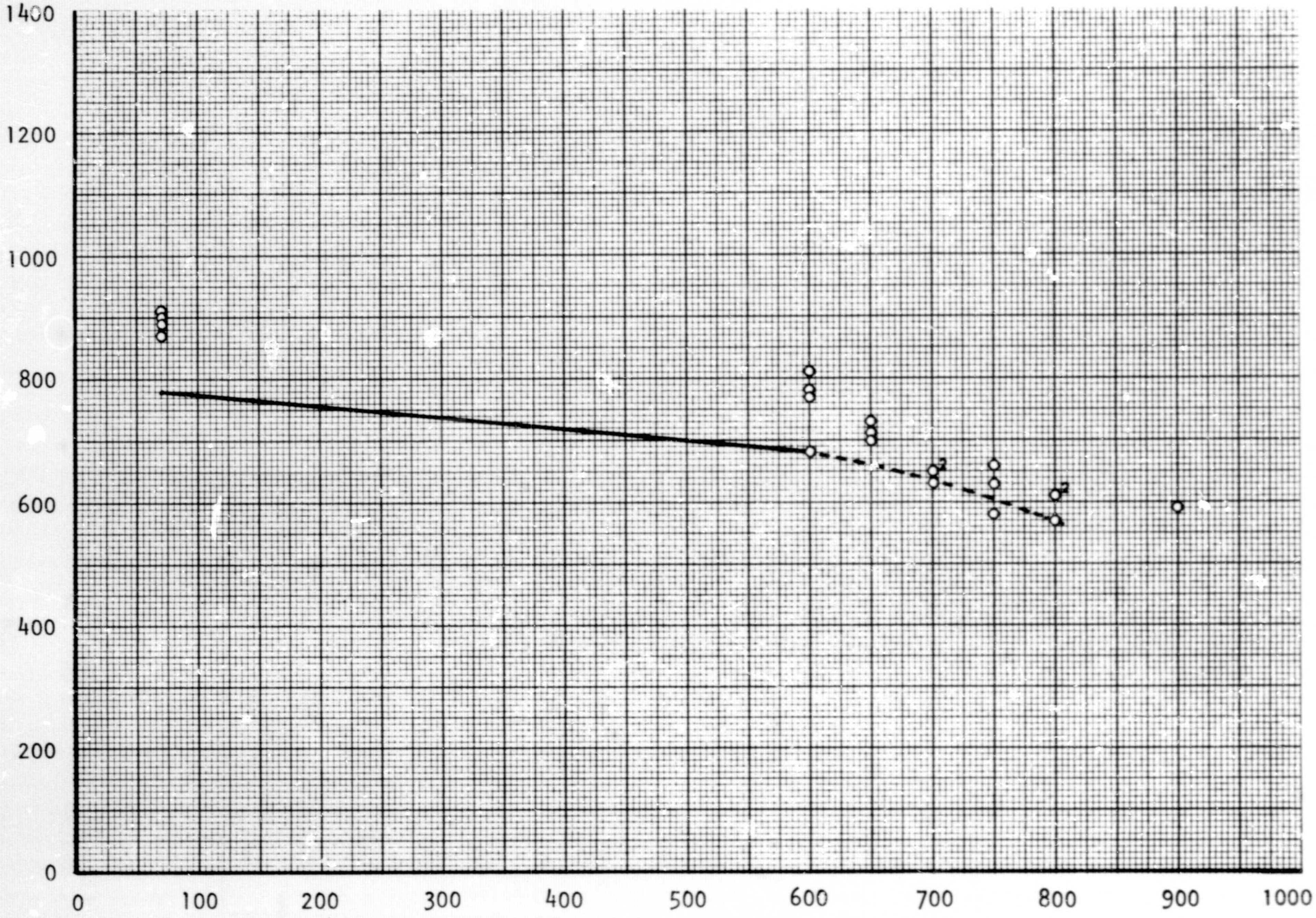

Figure 36.- Core shear strength versus temperature - 3-20 core - longitudinal ribbon direction.

TABLE XIII.- CORE SHEAR STRENGTH EVALUATION

3-20 CORE (11.2 LB/FT^3) - TRANSVERSE RIBBON DIRECTION

$\overline{F}_{tu}$ = 189 000 KSI (REFERENCE TABLE II)

Specimen No.	Temp (°F)	F'_s ksi (1)	F'_s (n) Normalized ksi (2)	$\overline{F}'_s$ (n) Average ksi	(F'_s) Structures Manual ksi
-3T	650	540	570	570	
-4T	650	530	560		
-7T	650	560	590		
-8T	700	560	590	590	
-9T	700	560	590		
-10T	700	570	600		
-11T	750	540	570	560	
-12T	750	510	540		
-13T	750	540	570		
-14T	800	500	530	520	
-15T	800	490	520		
-5T	800	490	520		

(1) $F'_s = \dfrac{\text{Failing Load}}{2\ cw}$ (Ref table V)

(2) $F'_s\ (n) = F'_s\ \dfrac{200\ 000}{F_{tu}}$

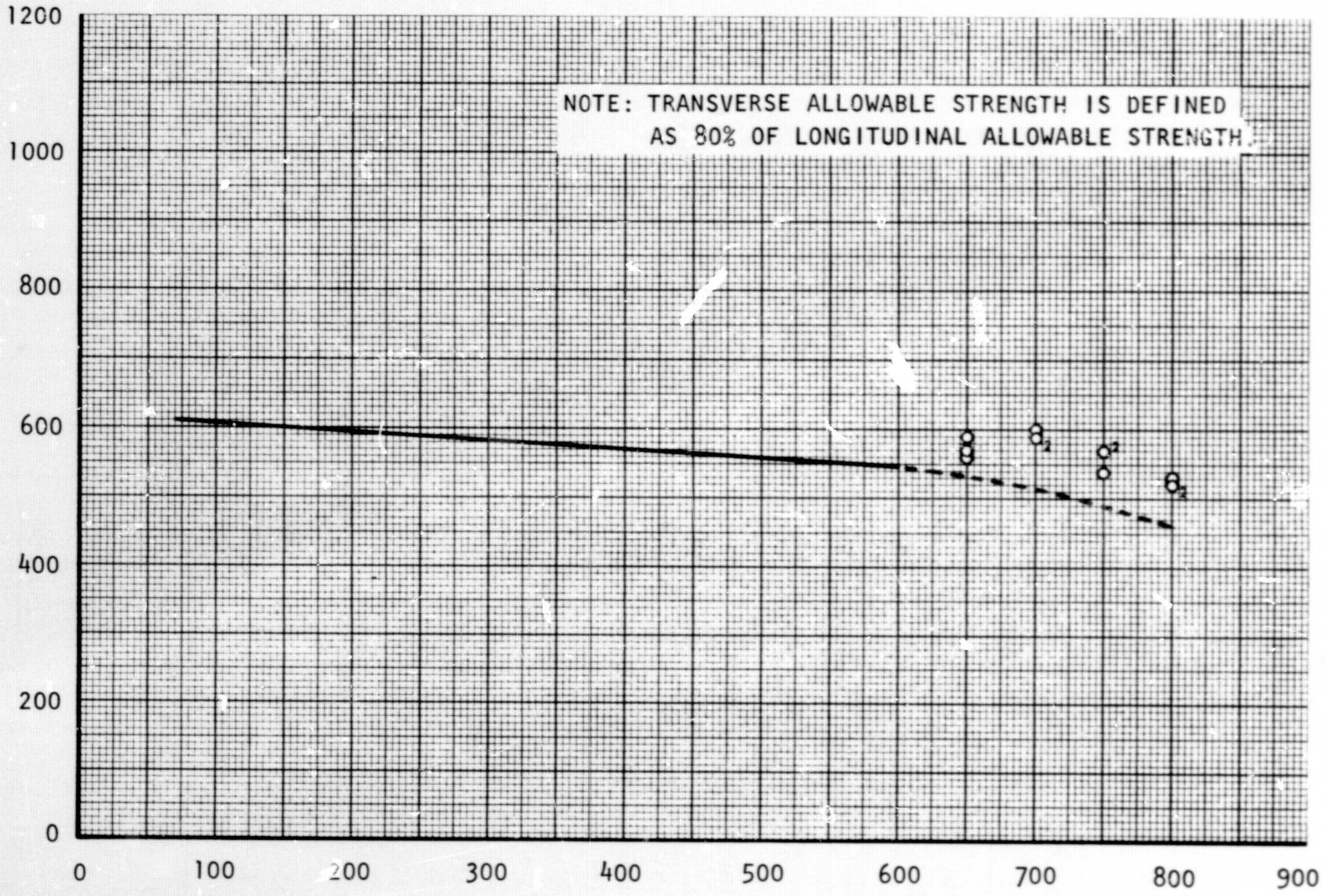

Figure 37.- Core shear strength versus temperature - 3-20 core - transverse ribbon direction.

TABLE XIV.- CORE SHEAR STRENGTH EVALUATION

3-15 CORE (8.3 LB/FT^3) - LONGITUDINAL RIBBON DIRECTION

$\overline{F}_{tu}$ = 188 200 KSI (REFERENCE TABLE II)

Specimen No.	Temp (°F)	F'_s ksi (1)	F'_s (n) Normalized ksi (2)	$\overline{F}'_s$ (n) Average ksi	(F'_s) Structures Manual ksi
-2L	RT	500	530	580	525
-4L	RT	570	610		
-5L	RT	570	610		
-6L	600	460	490	510	460
-7L	600	510	540		
-8L	600	470	500		
-9L	650	460	490	490	
-10L	650	450	480		
-11L	650	460	490		
-14L	700	430	460	480	
-15L	700	470	500		
-16L	700	450	480		
-17L	750	430	460	460	
-18L	750	410	440		
-20L	750	440	470		
-21L	800	420	450	430	
-3L	800	380	400		
-12L	800	410	440		
-13L	900	400	430		
HS011-1L	800	450	480		
HS011-2L	RT	590	630		
HS011-3L	RT	600	640		

(1) $F'_s = \dfrac{\text{Failing Load}}{2\ \text{cw}}$ (Ref table VI)

(2) $F'_s\ (n) = F'_s\ \dfrac{200\ 000}{F_{tu}}$

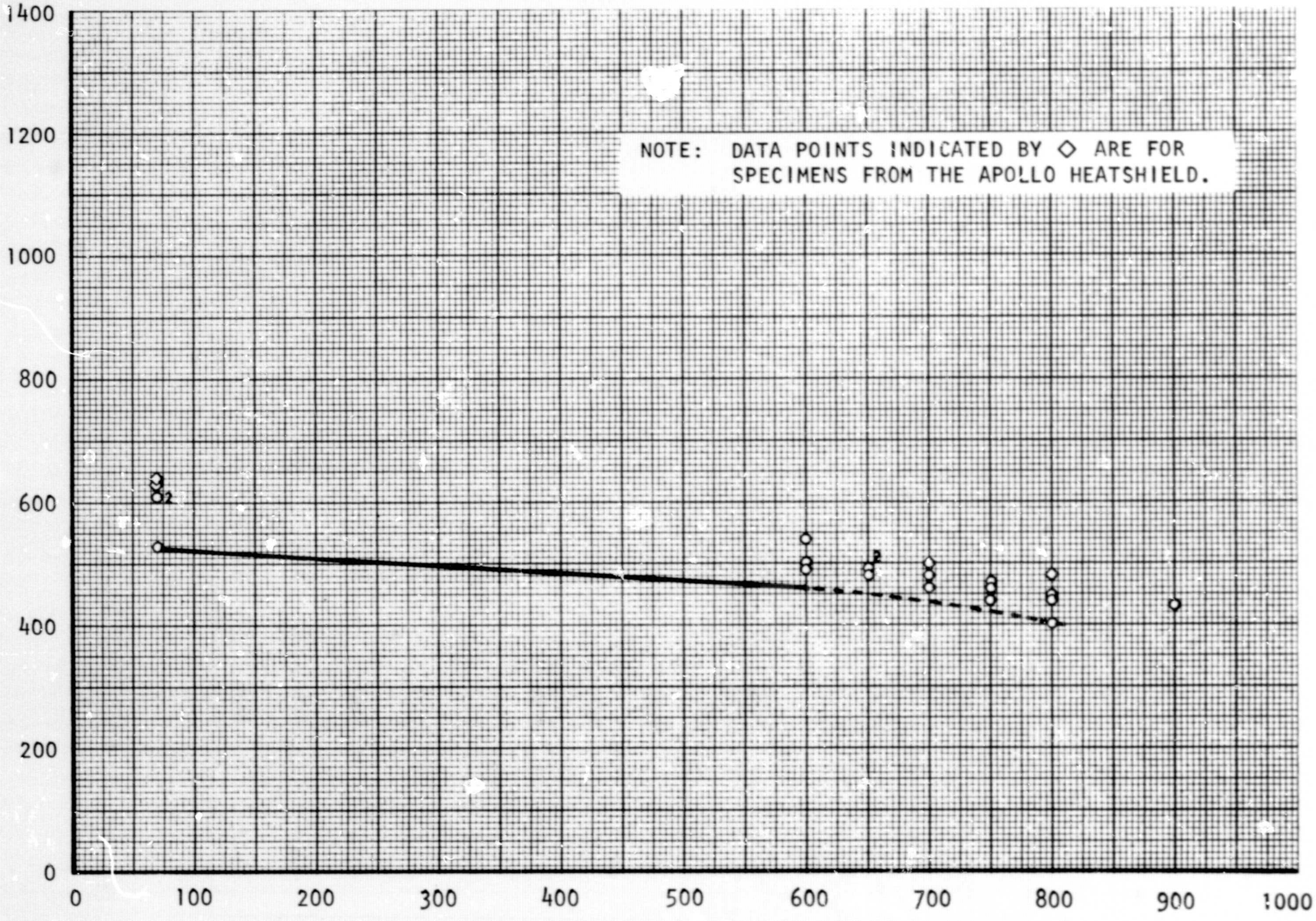

Figure 38.- Core shear strength versus temperature - 3-15 core - longitudinal ribbon direction.

TABLE XV.- CORE SHEAR STRENGTH EVALUATION

3-15 CORE (8.3 LB/FT^3) - TRANSVERSE RIBBON DIRECTION

$\overline{F}_{tu}$ = 188 200 KSI (REFERENCE TABLE II)

Specimen No.	Temp (°F)	F'_s ksi (1)	F'_s (n) Normalized ksi (2)	$\overline{F}'_s$ (n) Average ksi	(F'_s) Structures Manual ksi
-3T	650	370	390	400	
-4T	650	370	390		
-6T	650	390	410		
-7T .	700	380	400	380	
-8T	700	350	370		
-10T	700	360	380		
-11T	750	350	370	370	
-12T	750	370	390		
-13T	750	340	360		
-5T	800	370	390	370	
-9T	800	340	360		
-14T	800	330	350		

(1) $F'_s = \frac{\text{Failing Load}}{2\ cw}$ (Ref table VI)

(2) $F'_s\ (n) = F'_s\ \frac{200\ 000}{F_{tu}}$

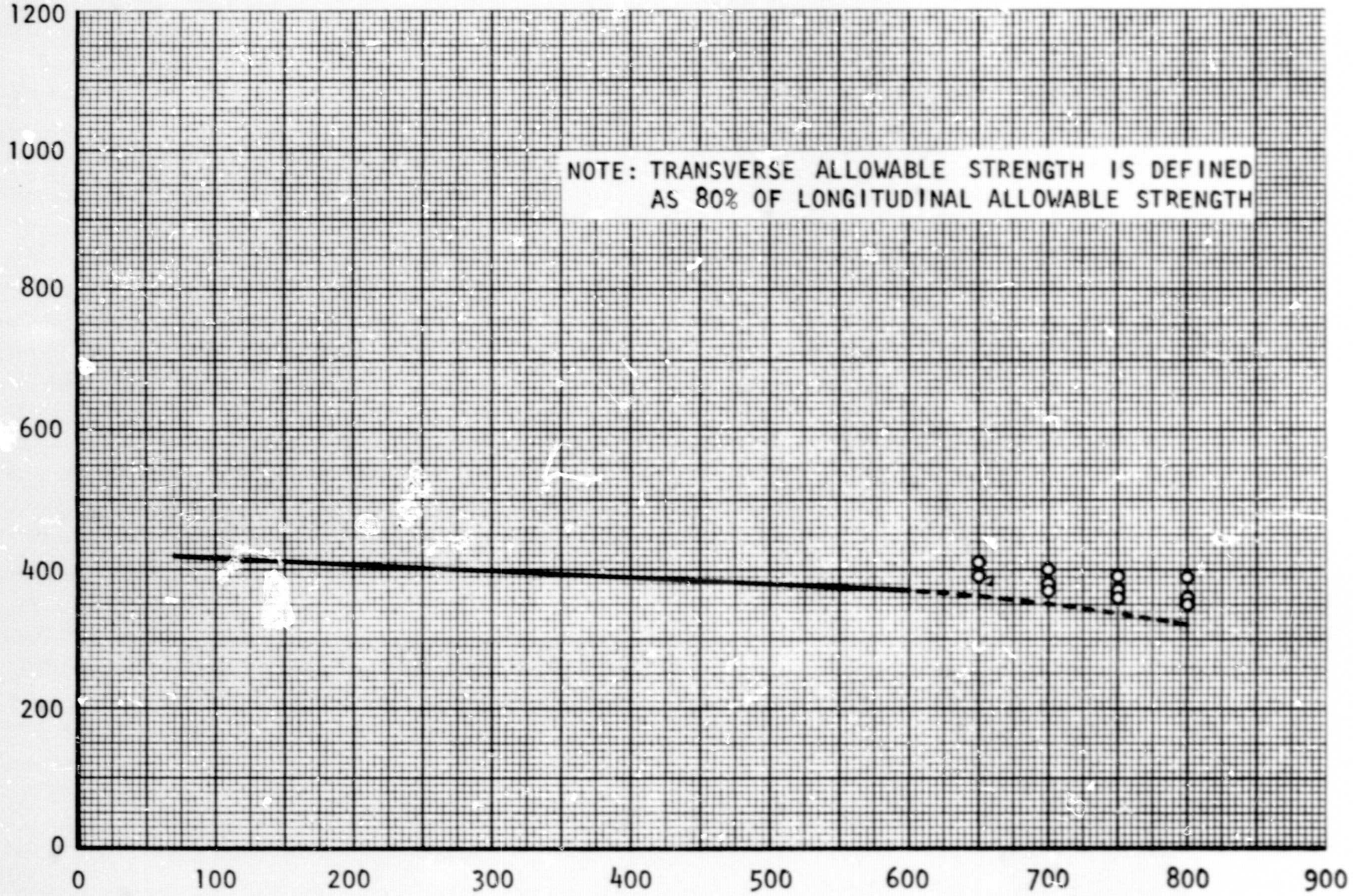

Figure 39.- Core shear strength versus temperature - 3-15 core - transverse ribbon direction.

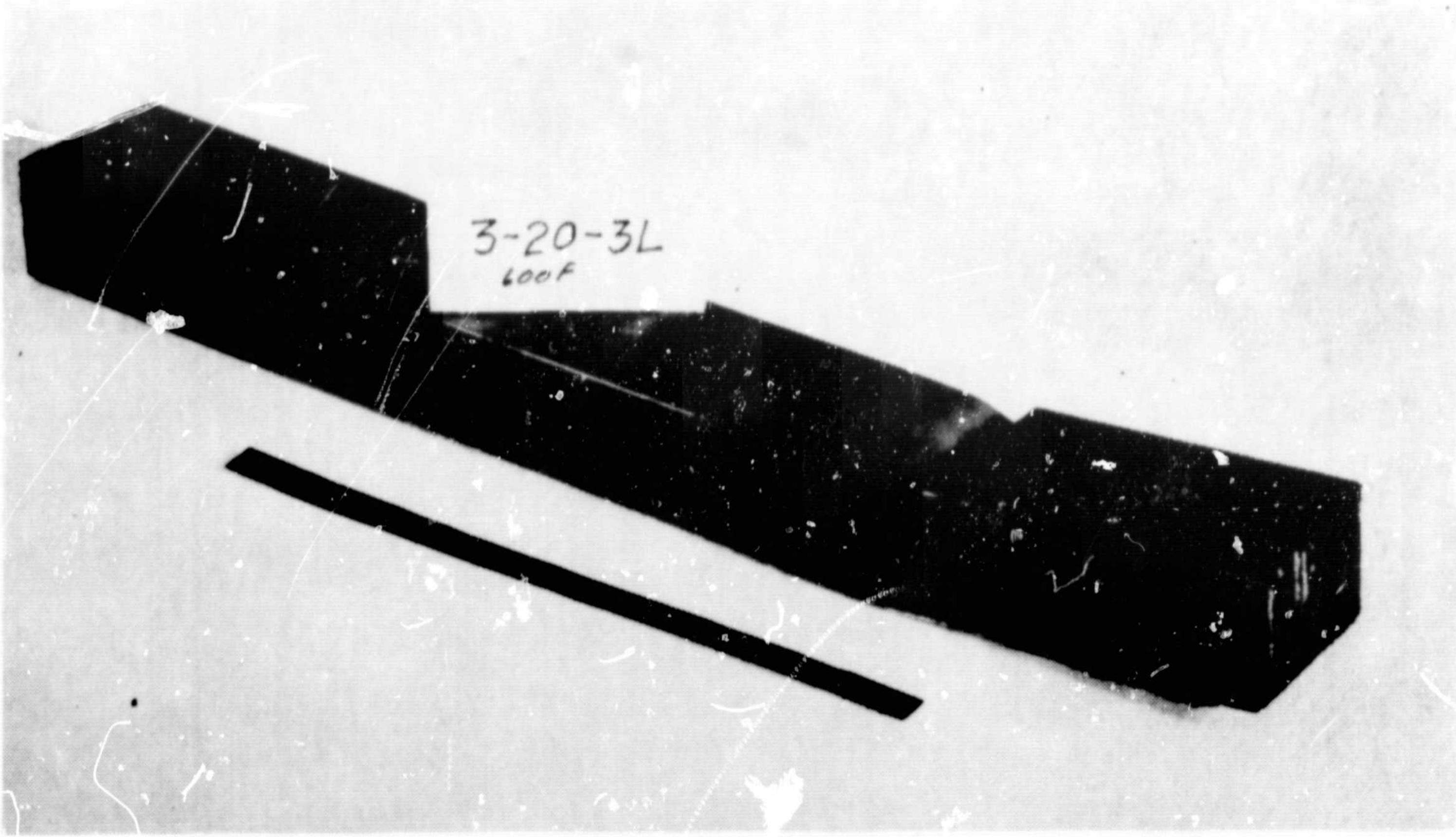

Figure 40.- Core crushing and face sheet compression failure before reducing couple arm.

CONCLUSIONS

This program has successfully extended the short-time ultimate shear strength curves for PH14-8Mo brazed stainless steel honeycomb sandwich core from 600° to 800° F. The resultant data indicate that the core shear strength does not degrade drastically in this range, but rather continues to diminish with increasing temperature along a slope equal to or only slightly greater than the slope of the existing curve at 600° F. One additional data point for each core at 900° F tends to indicate that the material behavior is still stable at that temperature. No statistical evaluation of the data was attempted because of the modest number of data points; "engineering accuracy" curves through the new points are considered satisfactorily reliable at this stage for use in preliminary design and sizing calculations. A more rigorous program with a larger number of specimens is recommended for final detail design and analysis stages of any hardware project.

This program also demonstrated that the PH14-Mo honeycomb sandwich structure in the Apollo heat shield suffers no permanent degradation of strength from the type of environment encountered by Spacecraft 011.