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NASA Contractor Report 165955

Design, Fabrication and Test of Graphite/Polyimide Composite Joints and Attachments

Data Report

J. B. Cushman, S. F. McCleskey and S. H. Ward

BOEING AEROSPACE COMPANY
SEATTLE, WASHINGTON

CONTRACT NAS1-15644
JULY 1982

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FOREWORD

This document was prepared by the Boeing Aerospace Company for the National Aeronautics and Space Administration, Langley Research Center in compliance with Contract NAS1-15644, "Design, Fabrication and Test of Graphite/Polyimide Composite Joints and Attachments for Advanced Aerospace Vehicles."

This report is one of five volumes that fully document contract results. It is the Data Report for Task 1.0 "Design, Fabrication and Test of Graphite/Polyimide Joints."

Dr. Paul A. Cooper was the contracting officer's technical representative for the full contract and Gregory Wichorek was the technical representative for design allowables testing of Celion 6000/PMR-15. Boeing performance was under the management of Mr. J. E. Harrison. Mr. D. E. Skoumal was the technical leader. Major participants in this program were James B. Cushman, Stephen F. McCleskey, and Stephen H. Ward from the Structural Development organization and Sylvester G. Hill of Materials and Processes.

The use of commercial products or names of manufacturers in this report does not constitute official endorsement of such products or manufacturers either expressed or implied by the National Aeronautics and Space Administration.

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1.0 SUMMARY

This report details the design, analysis and test activities performed under TASK 1.0 of NASA Contract NAS1-15644 to develop four types of graphite/polyimide (Gr/PI) bonded and bolted composite joints. Design data were established for building Gr/PI lightly loaded control surface structures for advanced space transportation systems that operate at temperatures up to 561K (550°F).

A detailed screening of joint design was conducted to select the most promising joint concepts. Material properties and "Small Specimen" tests were conducted to establish design data and to evaluate specific design details. "Static Discriminator" tests were conducted on preliminary designs to verify structural adequacy. These tests led to improvements which were incorporated into the final designs. Scaled-up specimens of the final designs, representative of production size requirements, were subjected to a series of static and fatigue tests to evaluate joint strength. Effects of environmental conditioning were determined by testing aged (125 hours @ 589K (600°F)) and thermal cycled (116K to 589K (-250°F to 600°F) 125 times) specimens.

Analyses and tests have demonstrated that bonded and bolted Gr/PI joints can be designed and fabricated to carry loads up to 560 kN/m (3200 lb/in), and moments up to 3.0 kN-m/m (684 in-lb/in) at temperatures up to 561K (550°F). Tests also demonstrated that bolted Gr/PI to titanium joints can be designed to carry loads up to 2100 kN/m (12000 lb/in). Bonded Gr/PI to titanium joints designed to carry this load level require further development with respect to co-cured bond processing. However, a load carrying capability of 875 kN/m (5000 lb/in) was demonstrated for a "3-step" Gr/PI to titanium symmetric step lap joint under Task 2.0 of this contract. Test results also indicated a loss of resin and degradation of laminates and adhesive bonds after exposure to 589K (600°F) for 125 hrs as evidenced by a decrease in laminate strengths. This has been attributed to resin chemistry and adhesive processing problems which were identified by post-test analysis.

2.0 INTRODUCTION

Advanced designs for high-speed aircraft and space transportation systems require more efficient structures for operation in the 116K (-250^{o}F) to 589K (600^{o}F) temperature range. Design data are needed for bonded and bolted composite joints to support advanced design of structural concepts.

The program discussed herein was designed to extend the current epoxy matrix composite technology in joint and attachment design to include high temperature polyimide matrix composites. It provides an initial data base for designing and fabricating graphite/polyimide (Gr/PI) flight components for advanced space transportation systems and high speed aircraft. The objectives of this program were twofold. The first objective was to develop and evaluate bonded and bolted design concepts for joints applicable to specific rib to skin, spar to skin and panel to panel configurations subjected to loads typical of those expected in lifting surfaces of high-speed aircraft and space transportation systems during reentry. The second objective was to explore advanced design concepts for bonded composite to composite and composite to metal joints. These objectives were pursued concurrently—TASK 1 was focused on the first objective and TASK 2 on the second. The overall program flow for the two tasks is shown in Figure 2-1. The technical activities and results of the TASK 1 investigation, shown enclosed in a dashed box in the figure, are reported in this document.

The generic joint concepts developed under TASK 1 are shown in Figure 2-2. In TASK 1.1, several concepts were designed and analyzed for each bonded and each bolted attachment type. Concurrent with this a series of material properties and "Small Specimen" tests were conducted under TASK 1.2 to support the concept designs. The analytical results of TASK 1.1 and the design data from TASK 1.2 were used to select the most promising bonded and bolted joint concepts.

In TASK 1.3, the most promising concepts for each joint type were fabricated, tested, and evaluated. Test results were used to define any design changes that would improve the joint performance.

Under TASK 1.4 any design changes from TASK 1.3 were incorporated and the final joint concepts were fabricated on a scaled-up basis (1.5m (5 ft) minimum length) to assure that the attachments could be fabricated for full-scale components. A series of static tests were performed on specimens cut from the scaled-up attachments to verify the validity of the scaled-up manufacturing process and the final designs. Other specimens were environmentally conditioned and subjected to a series of static and fatigue tests to evaluate joint strength. Test results were compared with the analytical predictions to verify design and analysis procedures.

This is one in a series of five reports that fully document the results of design, analysis and test activities performed under NASA contract NAS1-15644. The other reports are:

1. "Design Allowables Test Program, Celion 3000/PMR-15 and Celion 6000/PMR-15 Graphite/Polyimide Composites", NASA CR-165840

2. "Design, Fabrication and Test of Graphite/Polyimide Composite Joints and Attachments" - Summary, NASA CR-3601

3. "Test and Analysis of Celion 3000/PMR-15, Graphite/Polyimide Bonded Composite Joints" - Summary, NASA CR-3602

4. "Test and Analysis of Celion 3000/PMR-15, Graphite/Polyimide Bonded Composite Joints" - Data Report, NASA CR-165956

Measurement Units

All measurement values in this report are expressed in the International System of Units and in U.S. Customary Units. Actual measurements and calibrations were made in U.S. Customary Units.

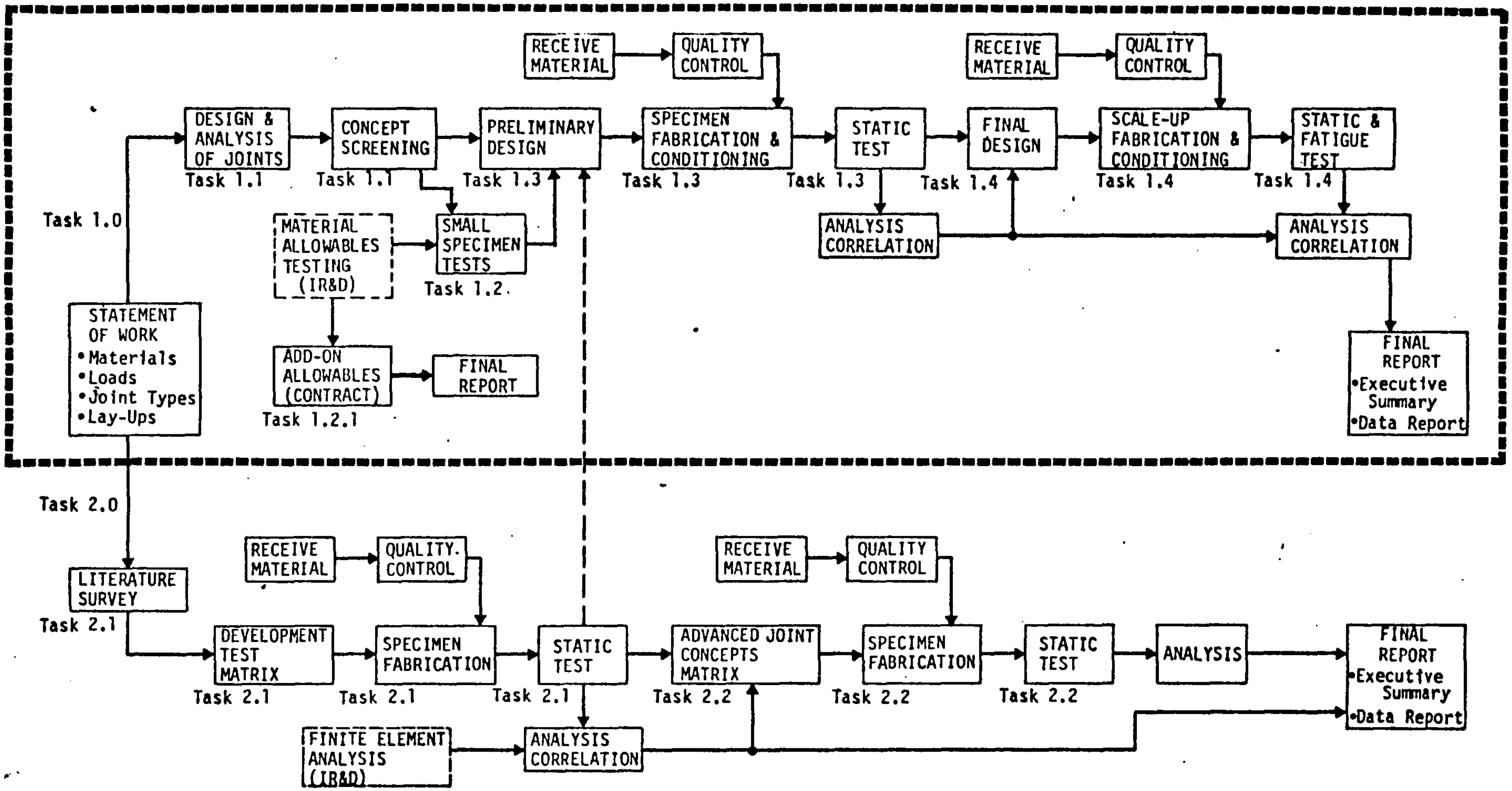


Figure 2-1: TASK 1 and TASK 2 PROGRAM FLOW

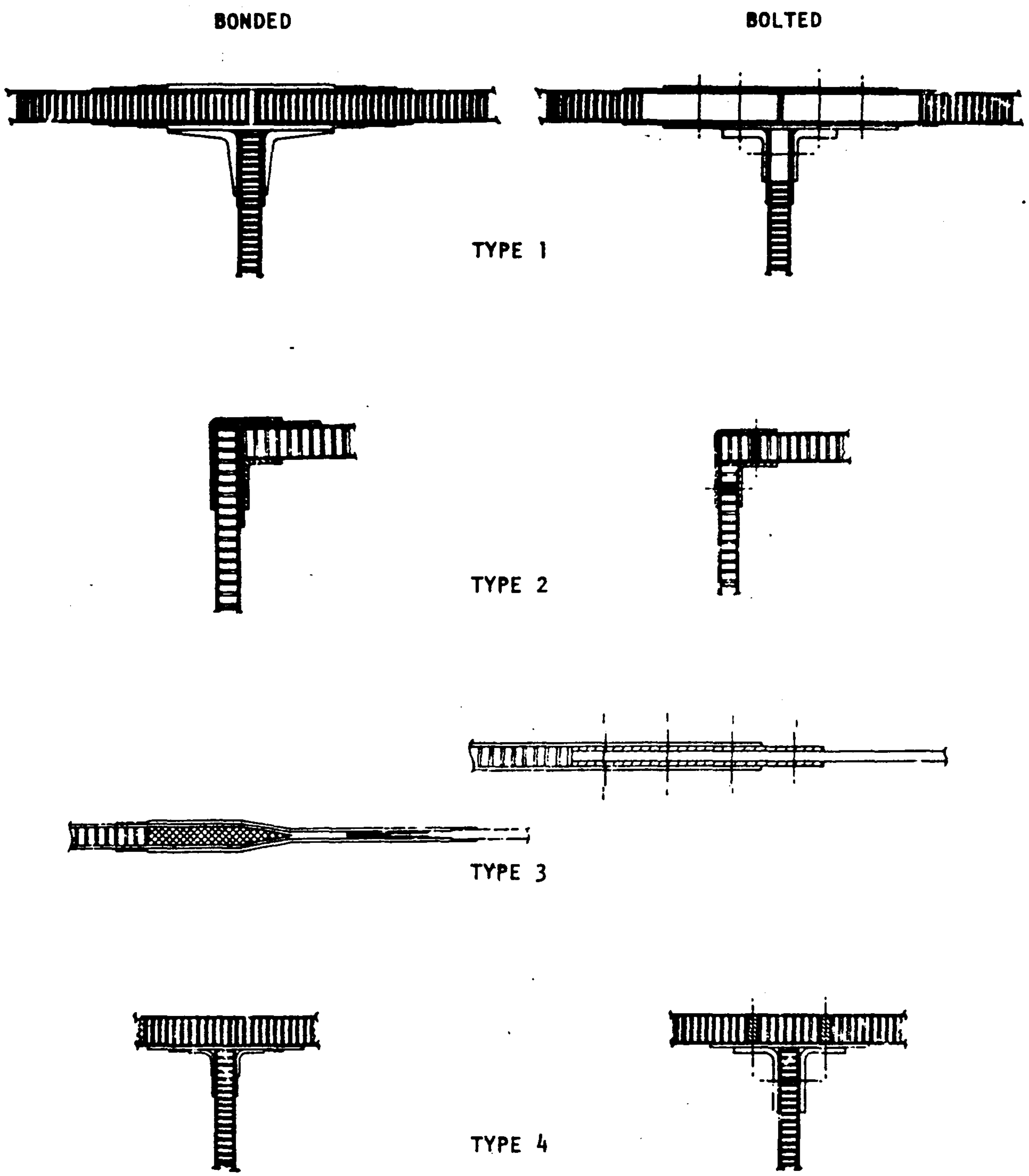


Figure 2-2: Generic Joint Concepts for 4 Attachment Types

3.0 JOINT CONCEPT DESIGN AND ANALYSIS

TASK 1 of this program was dedicated to design, analysis and testing of specific attachment concepts for each of the generic joint types shown in Figure 2-2. This section presents the design and analysis procedures used to establish the basic joint designs for each of the four joint types. The literature survey, failure modes, joint configurations, environmental conditioning, joint design loads, analysis procedures and concept screening and selection are discussed.

3.1 Literature Survey

The initial phase of the design activities was to conduct a literature survey to obtain information on graphite/polyimide (Gr/PI) composites pertinent to this program. The search was not limited to Gr/PI composites since the available literature on this specific subject is limited and design methods and parameters for other composites may also be applicable to Gr/PI joint designs. The following sources were searched using a wide range of key words:

SOURCE	TIME FRAME
o NASA	1978-1979
o NTIS	1964-1979
o CHEM ABSTRACTS	1972-1978
o ISMEC-MECH. ENGR.	1973-1977
o ENGINEERING INDEX	1970-1978
o SCISEARCH	1974-1978
o BOEING COMPANY DOCUMENTS	1974-1979
o BOEING TECHNICAL LIBRARY	1974-1979

A Defense Documentation Center (DDC) literature search was also conducted to obtain other references. This search used a narrow range of key words to avoid encountering a large quantity of miscellaneous references.

Approximately 1500 articles and reports were identified as relevant and based on the abstracts about 200 were selected for further study. Brief summaries of each report reviewed are reported in NASA Contract Reports Numbers CR159108 through CR159115.

3.2 Failure Modes

Results of the literature survey along with discussions with composite designers, analysts and processing personnel were used to identify possible failure modes for bonded and bolted joints of the four generic attachment types. Consideration was given to static and fatigue strength evaluation at ambient and 561K (550^{o}F). Tables 3-1 through 3-8 list the potential failure modes for each joint type. A fatigue failure mode is not listed separately because it will occur as one or more of the failure modes listed.

3.3 Joint Configurations

Basic joint configurations along with laminate lay-ups and honeycomb core thicknesses to be used for each of the joint types are presented in Table 3-9. Joint types are described below.

Type 1 Attachment

The Type 1 attachment is typical of an attachment in the sandwich shell, at a rib or spar interface or an aerodynamic surface such as a wing or control surface.

Type 2 Attachment

The Type 2 attachment is typical of the attachment occurring at an unloaded edge of a wing or aerodynamic surface.

Type 3 Attachment

The Type 3 attachment is typical of a localized attachment of a metallic plate to a composite sandwich structure. The attachment is subjected to relatively large inplane forces which must be distributed to the sandwich face sheets.

Type 4 Attachment

The Type 4 attachment is similar to the Type 1 attachment in that it connects members that are perpendicular. However, the cover panels are not spliced in the Type 4 attachment. This is intended to represent an attachment of minimum gage construction where the web provides normal support for the cover panels. Load levels are well below those required for the Type 1 attachment.

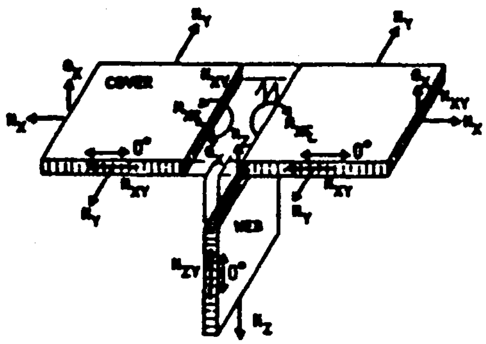
3.4 Environmental Conditioning

The effects of the following environmental conditionings were evaluated for each joint type.

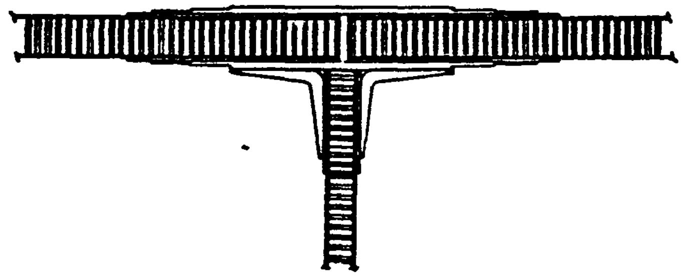
(1) As cured/post-cured

(2) Thermally aged 125 hours at 589K ($600^{\circ}F$) in a one atmosphere environment

(3) Thermally cycled 125 times from 116K ($-250^{\circ}F$) to 589K ($600^{\circ}F$) in a one atmosphere environment (see Figure 3-1).



NASA GUIDELINE CONCEPT



GENERIC JOINT

TABLE 3-1: POSSIBLE FAILURE MODES FOR BONDED ATTACHMENT TYPE NO. 1

At Cover Splice Plate

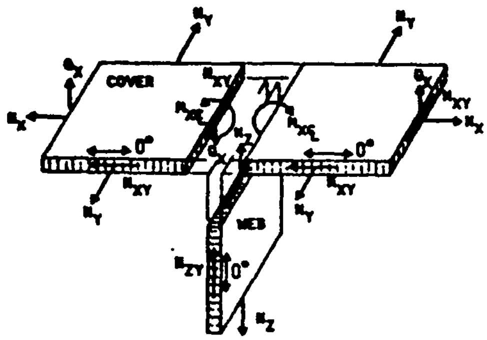
- o Face skin interlaminar tension
- o Face skin to core adhesive tension
- o Splice plate to face skin adhesive peel/shear
- o Splice plate to face skin adhesive shear
- o Splice plate - tension

At Attachment Angles to Cover

- o Face skin to core adhesive tension
- o Face skin interlaminar tension
- o Splice plate to face skin adhesive tension
- o Splice plate interlaminar tension
- o Angle to splice plate adhesive peel
- o Angle bending

At Attachment Angles to Web

- o Face skin interlaminar tension
- o Angle to face skin adhesive peel/shear



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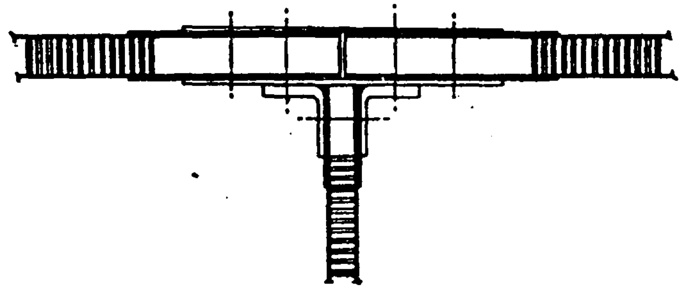


GENERIC JOINT

TABLE 3-2: POSSIBLE FAILURE MODES FOR BOLTED ATTACHMENT TYPE NO. 1

At Cover Doubler

- o Face skin interlaminar tension
- o Face skin to core adhesive tension
- o Doubler to face skin adhesive peel/shear

At Web Doubler

- o Face skin interlaminar tension
- o Face skin to core adhesive tension
- o Doubler to face skin adhesive peel/shear

At Cover Splice Plate

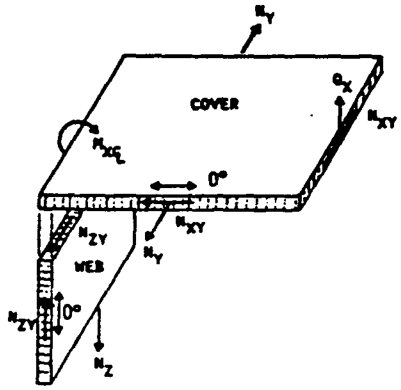
- o Splice plate/doubler/face skin - bearing/net tension/shearout

At Attachment Angles to Cover

- o Core crushing
- o Splice plate/doubler/face skin - bearing/net tension/shearout
- o Angle bending
- o Bolt pull through

At Attachment Angles to Web

- o Core crushing
- o Angle/doubler/face skin - bending/net tension/shearout
- o Bolt pull through



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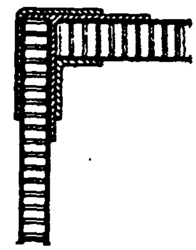


GENERIC JOINT

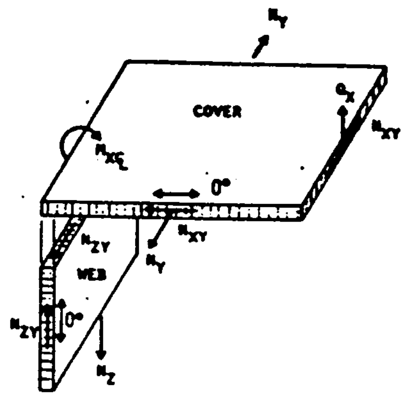
TABLE 3-3: POSSIBLE FAILURE MODES FOR BONDED ATTACHMENT TYPE NO. 2

At Corner Angles to Cover

- Core tension
- Face skin to core adhesive peel
- Face skin interlaminar tension
- Angle to face skin adhesive peel
- Angle bending

At Corner Angles to Web

- Core tension
- Face skin to core adhesive peel
- Face skin interlaminar tension
- Angle to face skin adhesive peel



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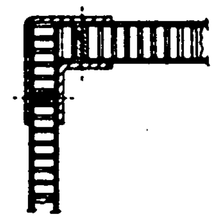


GENERIC JOINT

TABLE 3-4: POSSIBLE FAILURE MODES FOR BOLTED ATTACHMENT TYPE NO. 2

At Cover Doubler

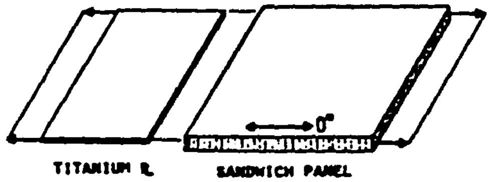
- o Face skin interlaminar tension
- o Face skin to cure adhesive tension
- o Doubler to face skin adhesive peel/shear

At Web Doubler

- o Face skin interlaminar tension
- o Face skin to core adhesive tension
- o Doubler to face skin adhesive peel/shear

At Attachment Angles to Cover/Web

- o Core crushing
- o Angle/doubler/face skin - bearing/net tension/shearout
- o Angle bending
- o Bolt pull through



NASA GUIDELINE CONCEPT

GENERIC JOINT

TABLE 3-5: POSSIBLE FAILURE MODES FOR BONDED ATTACHMENT TYPE NO. 3

At Doubler termination on panel

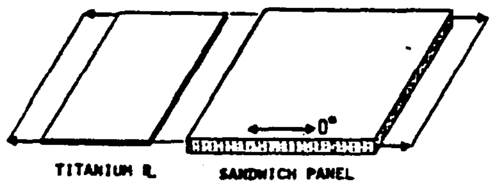
- o Face skin interlaminar tension
- o Doubler to face skin adhesive peel/shear

At Core Taper

- o Core crushing
- o Core/adhesive tension

At Titanium Steps

- o Face skin/doubler interlaminar tension
- o Face skin/doubler to titanium adhesive peel
- o Tension failure of titanium steps



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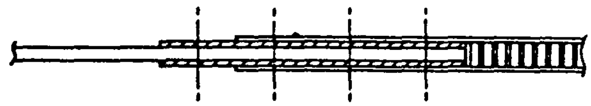


GENERIC JOINT

TABLE 3-6: POSSIBLE FAILURE MODES FOR BOLTED ATTACHMENT TYPE NO. 3

At Doubler Termination on Panel

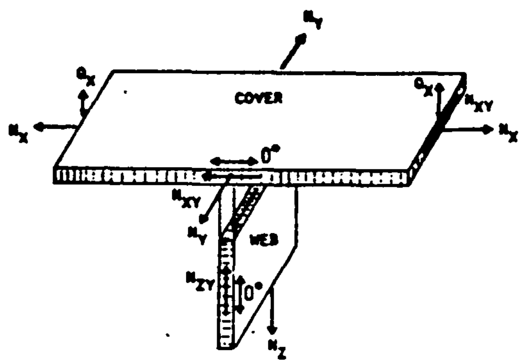
- o Face skin interlaminar tension
- o Doubler to face skin adhesive peel/shear

At Core Taper

- o Core crushing
- o Core/adhesive tension

At Titanium Steps

- o Face skins/doublers/titanium - bearing/net tension/shearout
- o Fastener shear



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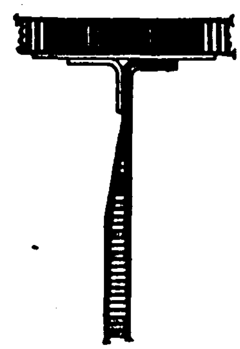


GENERIC JOINT

TABLE 3-7: POSSIBLE FAILURE MODES FOR BONDED ATTACHMENT TYPE NO. 4

At Cover Doubler

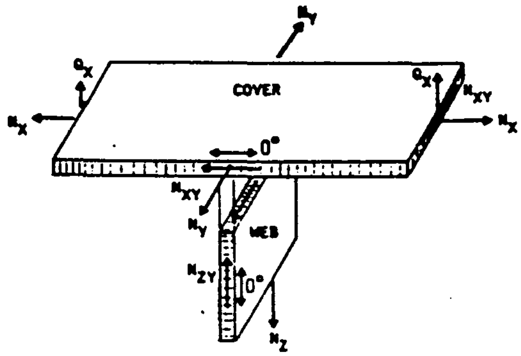
- o Face skin interlaminar tension
- o Face skin to core adhesive tension
- o Doubler to face skin adhesive peel/shear

At Attachment Angles to Cover

- o Face skin to core adhesive tension
- o Face skin interlaminar tension
- o Doubler to face skin adhesive tension
- o Doubler interlaminar tension
- o Angle to doubler adhesive peel
- o Angle bending

At Attachment Angles to Web

- o Face skin interlaminar tension
- o Angle to face skin adhesive peel/shear



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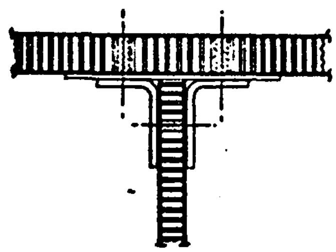


GENERIC JOINT

TABLE 3-8: POSSIBLE FAILURE MODES FOR BOLTED ATTACHMENT TYPE NO. 4

At Cover Doubler

- o Face skin interlaminar tension
- o Face skin to core adhesive tension
- o Doubler to face skin adhesive peel/shear

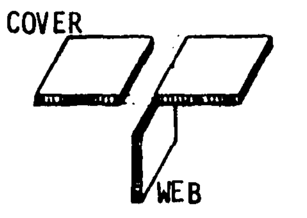
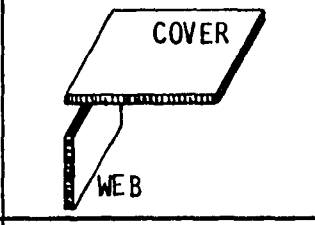
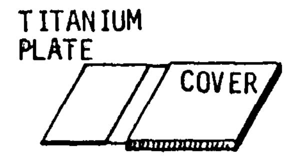
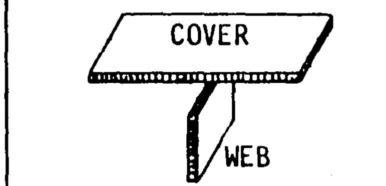
At Attachment Angles to Cover

- o Core crushing
- o Face skin net tension at bolt holes
- o Doubler/face skin/attachment angle - shearout
- o Angle bending
- o Bolt pull through

At Attachment Angles to Web

- o Core crushing
- o Angle/doubler/face skin -bearing/net tension/shearout

Table 3-9: STATEMENT-OF-WORK REQUIREMENTS FOR LAMINATE LAYUPS AND HONEYCOMB CORE THICKNESSES

	TYPE 1	TYPE 2	TYPE 3	TYPE 4
				
COVER PANEL FACE SHEETS	8 plies in 0^o,$+45^o$, -45^o,90^o directions, symmetric laminate.	8 plies in 0^o,$+45^o$, -45^o,90^o directions, symmetric laminate.	Symmetric, quasi-isotropic laminate.	Minimum gage, plies in 0^o,$+45^o$,-45^o,90^o directions, unsymmetric laminate, symmetric panel.
COVER PANEL HONEYCOMB CORE	Glass/polyimide, 19.1 mm (.75 in) thick.	Glass/polyimide, 19.1 mm (.75 in) thick.	Glass/polyimide, 12.7 mm (.50 in) thick	Glass/polyimide, 12.7 mm (.50 in) thick.
WEB PANEL FACE SHEETS	6 plies in 0^o,$+45^o$, -45^o directions, symmetric laminate.	6 plies in 0^o,$+45^o$, -45^o directions, symmetric laminate.	—	Minimum thickness, plies in 0^o,$+45^o$,-45^o directions, symmetric sandwich panel
WEB PANEL HONEYCOMB CORE	Glass/polyimide 12.7 mm (.50 in) thick.	Glass/polyimide 12.7 mm (.50 in) thick.	—	Glass/polyimide 12.7 mm (.50 in) thick.
METAL PLATE	—	—	Ti-6Al-4V, 6.35 mm (.25 in.) thick.	—

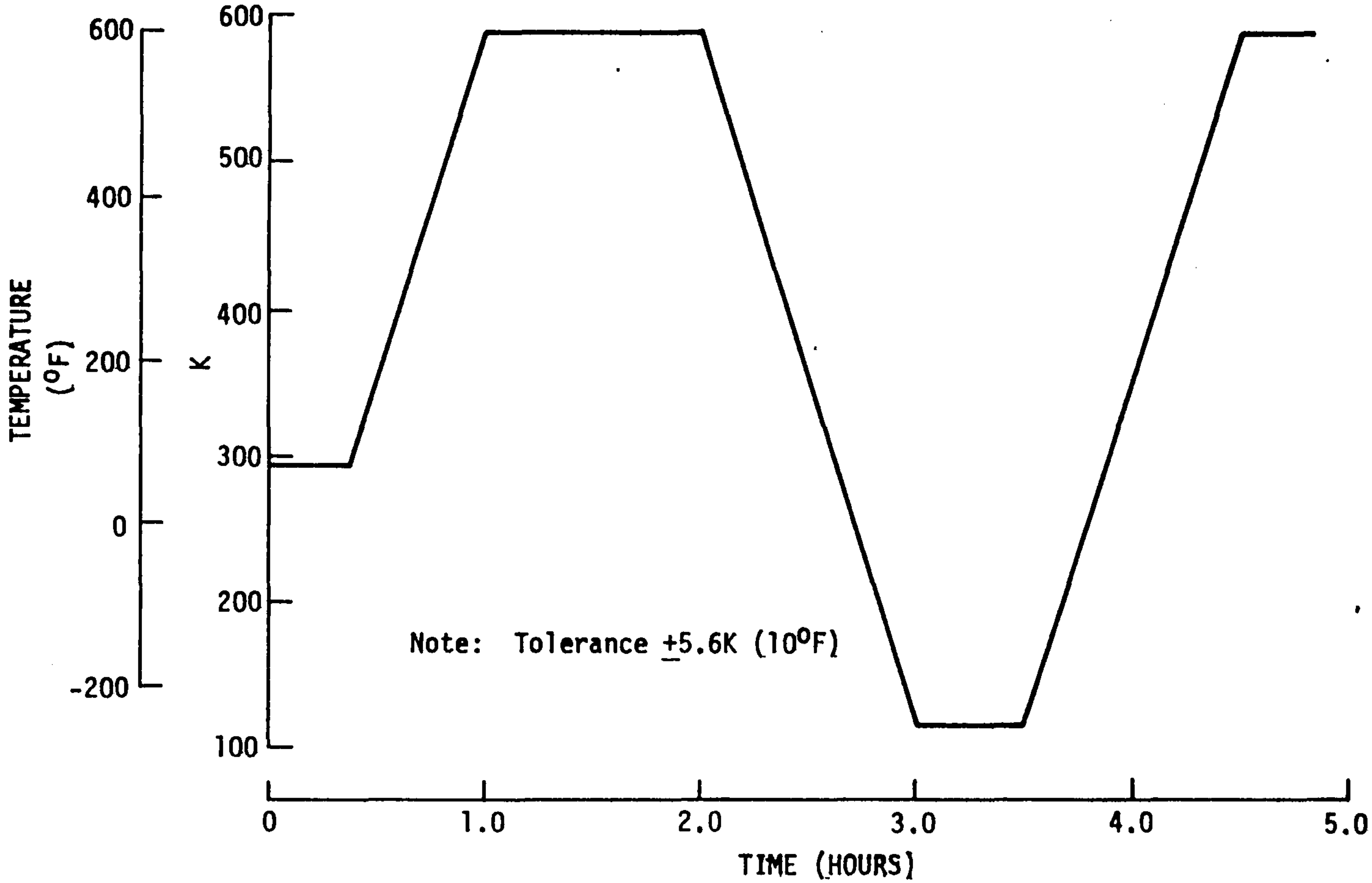


Figure 3-1: THERMAL CONDITIONING CYCLE

3.5 Joint Design Loads

Loading conditions and load ratios specified for each attachment type represent internal loads from the Space Shuttle Orbiter aft body flap. The loads were scaled to produce the design allowable stress state in at least one lamina of the cover panel outside the joint area, except for the Type 2 joints.

As required by the contract, NASA specified the graphite fiber, polyimide matrix, and adhesive system to be used. Celion fiber in either 6000 or 3000 filaments/tow form was specified. PMR-15 resin was specified as the matrix resin, with processing specified as Boeing procedures developed under NASA Contract NAS1- 15009. The design loads were selected based on an ultimate tensile strength of 551.6 MPa (80,000 psi) for (0/±45/90)NS laminate of Celion 3000/PMR-15. A nominal ply thickness of .0635 mm (2.5 mil) for Celion 3000/PMR-15 prepreg was used for the design load calculations.

Loading conditions, load ratios and calculated design loads for Type 1, Type 2, Type 3 and Type 4 joints are given in Tables 3-10 through 3-13. Ultimate loads for Type 1 and 4 attachments were determined by net tension in the cover face sheets due to the axial load N_x and the moment M_{xc}. Type 2 attach-ment ultimate loads are determined by net tension in the cover face sheets due to the load N_y. Type 3 attachment ultimate loads were determined by net tension in the cover face sheets.

3.6 Analysis Procedures

Analysis procedures used to size the bonded and bolted joints are discussed below:

Bonded Joints

From the standpoint of a designer, analysis of bonded joints should be as simple as possible to enable rapid and easy sizing. For single and double lap joints this is most easily accomplished if there are specific design curves for the laminate, adhesive and joint configuration being considered. These curves should show apparent ultimate shear stress (F_a^{SU}) versus bonded lap length (La). The joint allowable load (N_{xcr}) is given by

$$N_{xcr} = F_a^{SU} \, La \quad \text{per mm (in) of width}$$

This is the approach used for preliminary sizing of the bonded joints. Existing design curves from the literature (see Figure 3-2) were used to determine preliminary lap lengths. Joints were derated to account for thermal and stiffness mismatch as required using the non-dimensionalized derating factors presented in Reference 1.

Actual bonded joint data were generated for the material and adhesive systems under TASK 2 of this program. This design data was used to verify the lap lengths required for the bonded double lap joints. Design data for the attachment angle tension loads were generated during the "Small Specimen" tests discussed in Section 4.3.

Analyses of the Type 3 joint showed that a simple double lap bonded joint was not adequate to carry the design load. A symmetric step-lap joint was required. Analyses were performed using the A4EG computer code (Ref. 2). This code analyzes symmetric step-lap bonded joints, using both elastic and elastic-plastic analyses to predict ultimate joint strength. The analyses account for effects of adherend stiffness and thermal mismatch. Input data are joint geometry, adherend stiffness and strength, coefficient of thermal expansion (CTE), and adhesive properties. The joint is assumed to fail when the adhesive elastic or elastic-plastic strains are exceeded or the adherend strengths are exceeded.

Properties of A7F adhesive were not available during preliminary analyses; therefore estimated properties were used. These analyses were aimed at identifying performance trends rather than quantitative joint strengths. Final joint analyses were performed using adhesive properties obtained from the ancillary test program under TASK 2 (Ref. 3).

Analysis procedures used for bonded joints are summarized in Figure 3-2.

Bolted Joints

Preliminary bolted joint sizing was based on three basic failure modes: bearing, shearout, and net tension. Since basic material properties for Gr/PI were not available, preliminary sizing was based on estimated properties from the literature. Final analyses were performed using the material properties determined from the "Small Specimen" tests presented in Section 4.3.

Equations used for analysis of the bolted joints are given below. Shearout was analyzed by using a design curve that gave equivalent bearing stress as a function of edge margin.

Allowable Bearing Load $P_{BRG} = Dt\ F_{BRU}$

Allowable Tension Load $P_{TENS} = 2(\frac{S}{D} - 0.5)\ Dt\ F_{TUnet}$

where:

D	=	Bolt Dia.
t	=	Material thickness
S	=	0.5 Bolt spacing
F_{BRU}	=	Allowable ultimate bearing stress
F_{TUnet}	=	Allowable net tension stress.

Minimum bolt spacing of 5D, row spacing of 4D, edge margin of 2.75D and diameter to thickness ratio (D/t) of greater than 1.0 were used as guidelines for the joint designs.

Analysis procedures for the bolted joints are summarized in Figure 3-2.

Table 3-10: PRELIMINARY LOADS FOR TYPE 1 JOINTS

CASE	LOAD CONDITION [1]	RATIO	VALUE kN/m (lb/in)
1	N_x	1	442.3 (2526)
	N_{xy}	0.03 N_x	13.3 (76)
	N_y	0.15 N_x	66.4 (379)
	N_{zy}	0.10 N_x	44.3 (253)
	N_z	0.02 N_x	8.9 (51)
	$M_{x\text{℄}}$	(0.10 in) N_x	1.1* (253*)
	Q_x	0.01 N_x	4.4 (25.3)
2	N_x	1	239.6 (1368)
	N_{xy}	0.03 N_x	3.2 (41)
	N_y	0.15 N_x	35.9 (205)
	N_{zy}	0.10 N_x	24.0 (137)
	N_z	0.12 N_x	28.7 (164)
	$M_{x\text{℄}}$	(0.50 in) N_x	3.0* (684*)
	Q_x	0.06 N_x	14.4 (82)

LAYUP: COVER $(0/\pm45/90)_S$ WEB $(0/\pm45)_S$

*kN-m/m (lb-in/in)

[1] See Table 3-1

Table 3-11: PRELIMINARY LOADS FOR TYPE 2 JOINTS

CASE	LOAD CONDITION [2]	RATIO	VALUE kN/m (lb/in)
1	N_x	0	
	N_y	1	560.4 (3200)
	N_{xy}	0.10 N_y	56.0 (320)
	N_{zy}	0.10 N_y	56.0 (320)
	N_z	0.02 N_y	11.2 (64)
	$M_{x\text{℄}}$	(0.01 in) N_y	0.1* (32*)
	Q_x	0.02 N_y	11.2 (64)
2	N_x	0	
	N_y	0.40 N_{y1}	224.1 (1280)
	N_{xy}	0.10 N_y	22.4 (128)
	N_{zy}	0.10 N_y	22.4 (128)
	N_z	0.10 N_y	22.4 (128)
	$M_{x\text{℄}}$	(0.05 in) N_y	0.3* (64*)
	Q_x	0.10 N_y	22.4 (128)

LAYUP: COVER $(0/\pm45/90)_S$ WEB $(0/\pm45)_S$

*kN-m/m (lb-in/in)

[2] See Table 3-2

Table 3-12: PRELIMINARY LOAD FOR TYPE 3 JOINTS

CASE	LOAD CONDITION [1]	RATIO	VALUE kN/m (lb/in)
1	N_x	1	2100 (12,000)

LAYUP: Cover $(0/\pm45/90)_{2S}$

[1] See Table 3-3

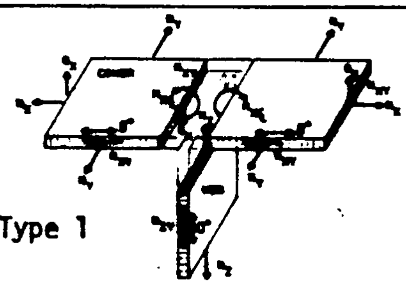
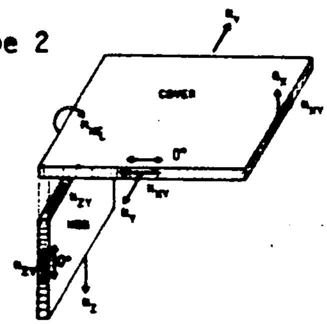
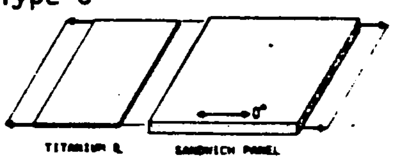
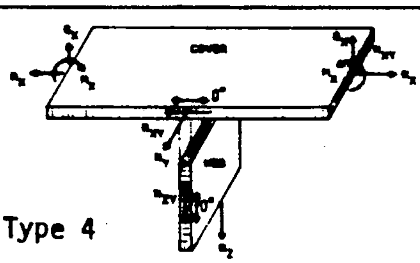
Table 3-13: PRELIMINARY LOADS FOR TYPE 4 JOINTS

CASE	LOAD CONDITION [2]	RATIO	VALUE kN/m (lb/in)
1	N_x	1	200.2 (1143)
	N_{xy}	0.03 N_x	6.0 (34)
	N_y	0.15 N_x	30.1 (172)
	N_{zy}	0.10 N_x	20.0 (114)
	N_z	0.02 N_x	5.0 (28)
	$M_{x℄}$	(0.10 in) N_x	0.5* (114*)
	Q_x	0.01 N_x	2.0 (11.4)
2	N_x	1	93.3 (533)
	N_{xy}	0.03 N_x	2.8 (16)
	N_y	0.15 N_x	14.0 (80)
	N_{zy}	0.10 N_x	9.3 (53.3)
	N_z	0.12 N_x	11.2 (64)
	$M_{x℄}$	(0.50 in) N_x	1.2* (266.5*)
	Q_x	0.06 N_x	5.6 (32)

LAYUP: COVER $(0/\pm45/90)$ WEB $(0/\pm45)$

*kN-m/m (lb-in/in)

[2] See Table 3-4

Joint Configuration	Bonded [1]	Bolted [1] [2]
 Type 1	Air Force Advanced Composite Design Guide Vol. 1, 3rd Ed. 2nd Rev. Sect. 1.3.1	Air Force Advanced Composites Design Guide Vol. 1, 3rd Ed. 2nd Rev. Sect. 1.3.2
Type 2 		
Type 3 	"Adhesive Bonded Scarf &Stepped Lap Joint" by L. J. Hart-Smith, Jan. 1973, NASA CR-112237 Computer Code A4EG (Ref. AFDDL-TR-75-26, Apr.75)	
 Type 4	Air Force Advanced Composite Design Guide Vol. 1, 3rd Ed. 2nd Rev. Sect. 1.3.1	

[1] Necessary material properties data were generated by test.

[2] Joint design data also from NASA ACEE development programs.

Figure 3-2: JOINT ANALYSIS PROCEDURE MATRIX (TASK 1)

3.7 Joint Concept Screening

In addition to the joint requirements specified in Section 3.3, joint designs were developed using the following design ground rules:

- A bonded joint was defined as one that is assembled primarily by means of a bonding process. Mechanical fasteners may be used in a bonded joint to reduce critical bond stresses. A bonded joint, however, cannot be separated into its major component parts by the removal of the mechanical fasteners.

- A bolted joint was defined as one that can be separated into its major component parts by removal of the mechanical fasteners.

- Joint Types 1, 2, 3 (bolted) and 4 were to be two-piece assemblies.

- Joint Type 3 (bonded) was to be an integral structure.

- Component assembly requirements:
  Laminate precure - 602K (625°F) at 1.379 MPa (200 psi), plus postcure.*
  Adhesive cure—589K (600°F) at 0.689 MPa (100 psi), plus postcure.*

- Joint operating environments:
  Loads as defined in Section 3.5

  Temperatures:
  116K (-250°F)
  Room Temperature
  561K (550°F)

*Postcure is the unbagged part exposed to 602K (625°F) for 6 hours at 1 atmosphere.

- Special design techniques associated with aerodynamic smoothness, e.g., flush head bolts, were not considered in this study. The reasons for this were:

    (1) An aerodynamic smoothness requirement was not specified in the work statement.
    (2) Many potential applications for Gr/PI components; e.g., Space Shuttle Orbiter aft body flap, will require a surface covering of insulation for thermal protection which makes bolt flushness for aerodynamic smoothness redundant.

- The corner joints (Type 2) were to be an "L" configuration as depicted in Table 3-3. "T" configurations were <u>not</u> considered.

- The joints were to be designed on the assumption that they would be accessible on all sides so that the required bonding temperature and pressure could be applied for the bonded joints and the required installation tools could be used for the bolted joints.

- The joints for Types 1, 2 and 4 were to be designed on the assumption that the shape of the surfaces range from flat to slightly contoured. Test specimens, however, were to be designed with flat surfaces.

- The joints for Type 3 were to be designed on the assumption that the surfaces would be flat.

- In actual practice, the designs of ribs and spars must account for the component assembly sequence and accessibility to the joint during assembly. Ribs and spars may have a bonded joint at the intersection of one skin panel surface, but may require a bolted joint at the other surface. However, in this study, because the intent was to determine the relative efficiencies of each pair of bonded and bolted attachment types, the above considerations associated with component assembly were ignored. Within the selection process, however, the comparative ease of assembly of the candidate joints for each type were to be considered.

Using the joint requirements and design ground rules presented above, approximately 10 concepts were defined for each of the bonded and bolted joint types. These concepts were then subjected to the screening flow process shown in Figure 3-3. During concept definition and screening the web attachment concepts were treated separately since they were applicable to both the Type 1 and Type 4 joints. The first cut screening was a gross evaluation based on the selection criteria and evaluation parameters shown in Figure 3-4. This screening resulted in deletion of some of the concepts and the addition of others. Concepts resulting from the first screening are shown in Figures 3-5 through 3-14.

The second cut screening was a more detailed evaluation of the concepts. Nineteen evaluation parameters, as listed in Figure 3-15, were considered. The rating assigned to the best concept in each joint category for each parameter was 1.0. The other concepts (within each joint category) were ratioed down according to how the concept ranked with the best. The ratings for each concept were averaged within each selection criteria. These averages were multiplied by 10 for convenience.

To obtain the final ranking of the concepts a weighting factor was applied to the rating score for each of the three selection criteria. Figure 3-16 describes how these weighting factors were determined. The seven design goals were first reviewed and a determination made as to their relative importance to the overall program goals. On this basis points were assigned for each design goal. It was assumed for the purposes of the second cut screening that each of the concepts being evaluated could be designed to carry the required load. For this reason goal number 5 was assigned zero weighting factor points. Fabrication practicality and economics of design were considered the dominant design goals; hence design goals 1 and 7 were assigned 10 points each. Points assigned to the other design goal items were proportioned accordingly. The design goals applicable to each selection criterion are shown in the weighting factor table in Figure 3-16. The table also shows how the points assigned to the design goals were used to determine the weighting factors for each selection criterion. Each joint concept was ranked according to its total weighted score (see Figure 3-15).

Results of the screening process led to the concepts shown in Figure 3.1-17 through 3-26. These were the baseline concepts that led to the preliminary joint designs that were subjected to the "Static Discriminator" tests discussed in Section 5.0. Two concepts were evaluated for the Type 3 bolted joint, one with Gr/PI splice plates and one with titanium splice plates. Detail sizing of the joints was accomplished using the analysis procedures in Section 3-6, the results of "Small Specimen" testing discussed in Section 4.3, material properties data presented in Reference 4, and ancillary adhesive and standard joint data presented in Reference 3. In addition, there was a continuous on-going dialogue with the materials and processes organization with regard to the manufacturability of the designs. This led to the conclusion that the Type 2 bonded concept shown in Figure 3-9 (Concept 2a), while acceptable for a small scale test laboratory processing, was not acceptable for a full scale joint fabrication. This was because the bonding operation would require applying pressure to the attach angles in two directions simultaneously, which could not be done in a manner satisfactory to assure a good bond. As a result the design was changed to the configuration shown in Figure 3-21. While the design is considerably more flexible than the original, analyses showed it would still carry the required design load.

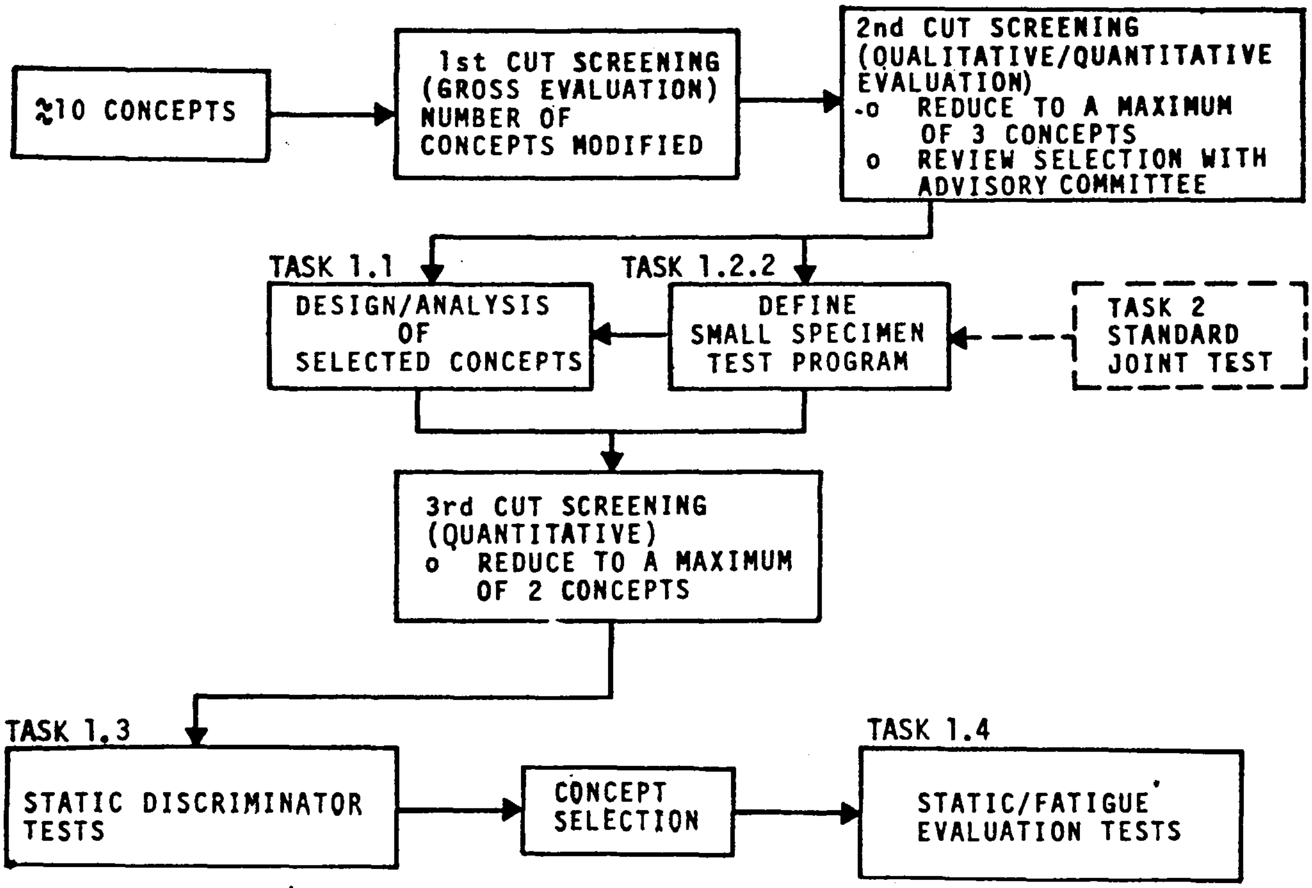


Figure 3-3: ATTACHMENT JOINT CONCEPTS SCREENING FLOW CHART

SELECTION CRITERIA	EVALUATION PARAMETER
LOAD TRANSFER ABILITY	DIRECTNESS OF LOAD PATH
FABRICATION COMPLEXITY	EASE OF FABRICATION
SERVICE LIFE	REDUNDANT LOAD PATHS

Qualitative Assessment Only

Figure 3-4: 1st CUT SCREENING EVALUATION PARAMETERS

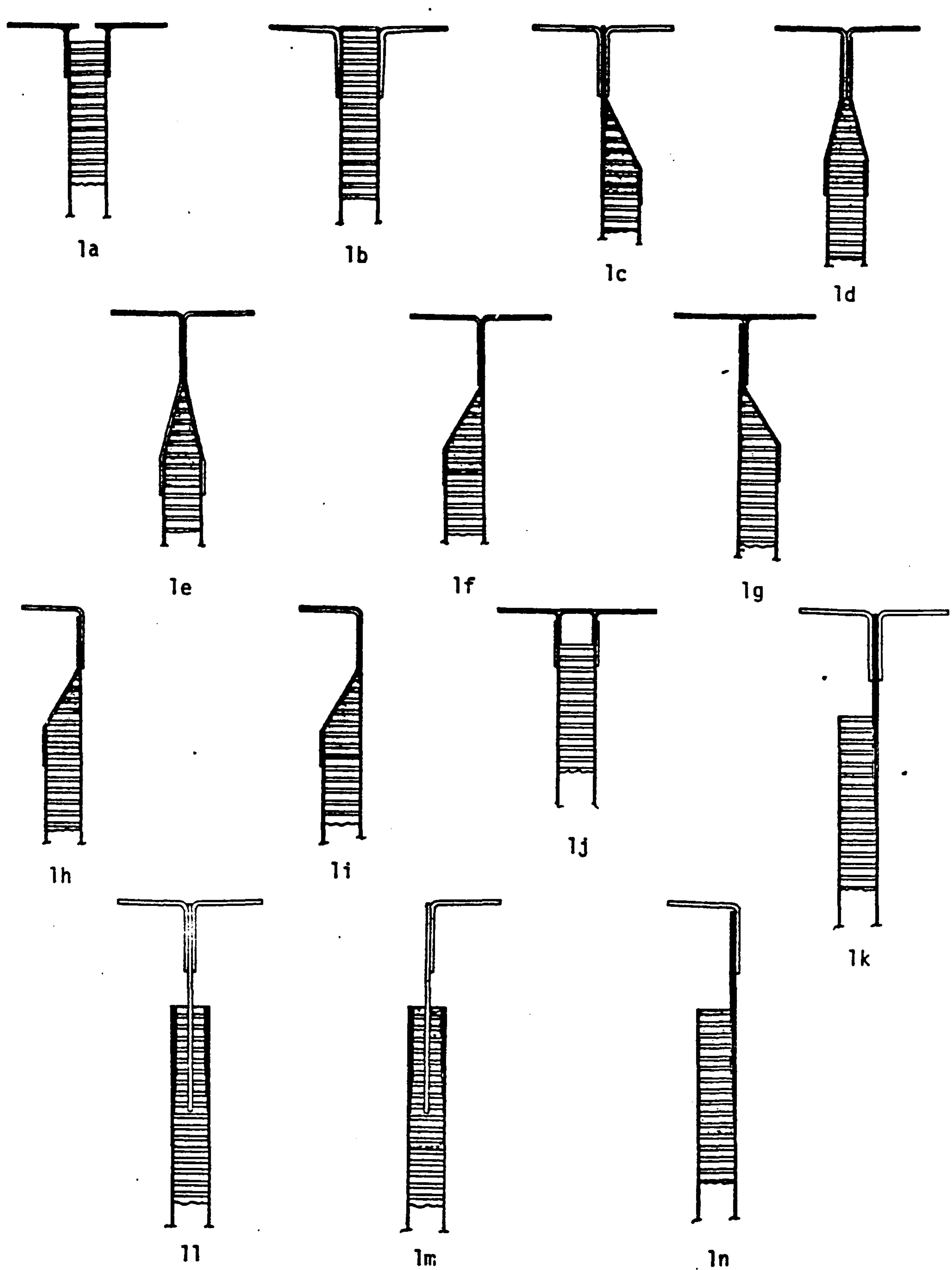


Figure 3-5: TYPES 1 & 4 BONDED JOINT CONCEPTS - WEB TO COVER ATTACHMENT

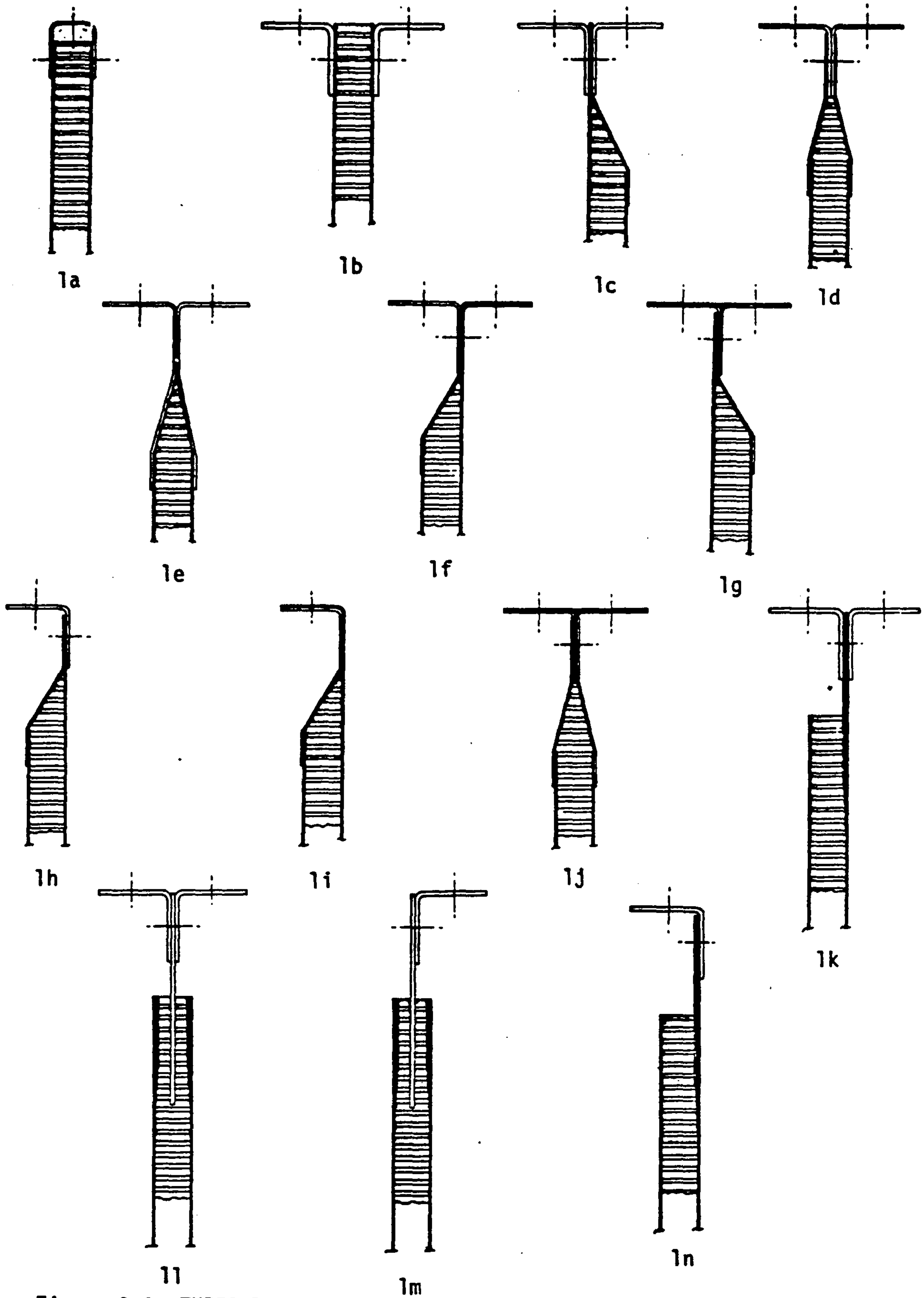


Figure 3-6: TYPES 1 & 4 BOLTED JOINT CONCEPTS - WEB TO COVER ATTACHMENT

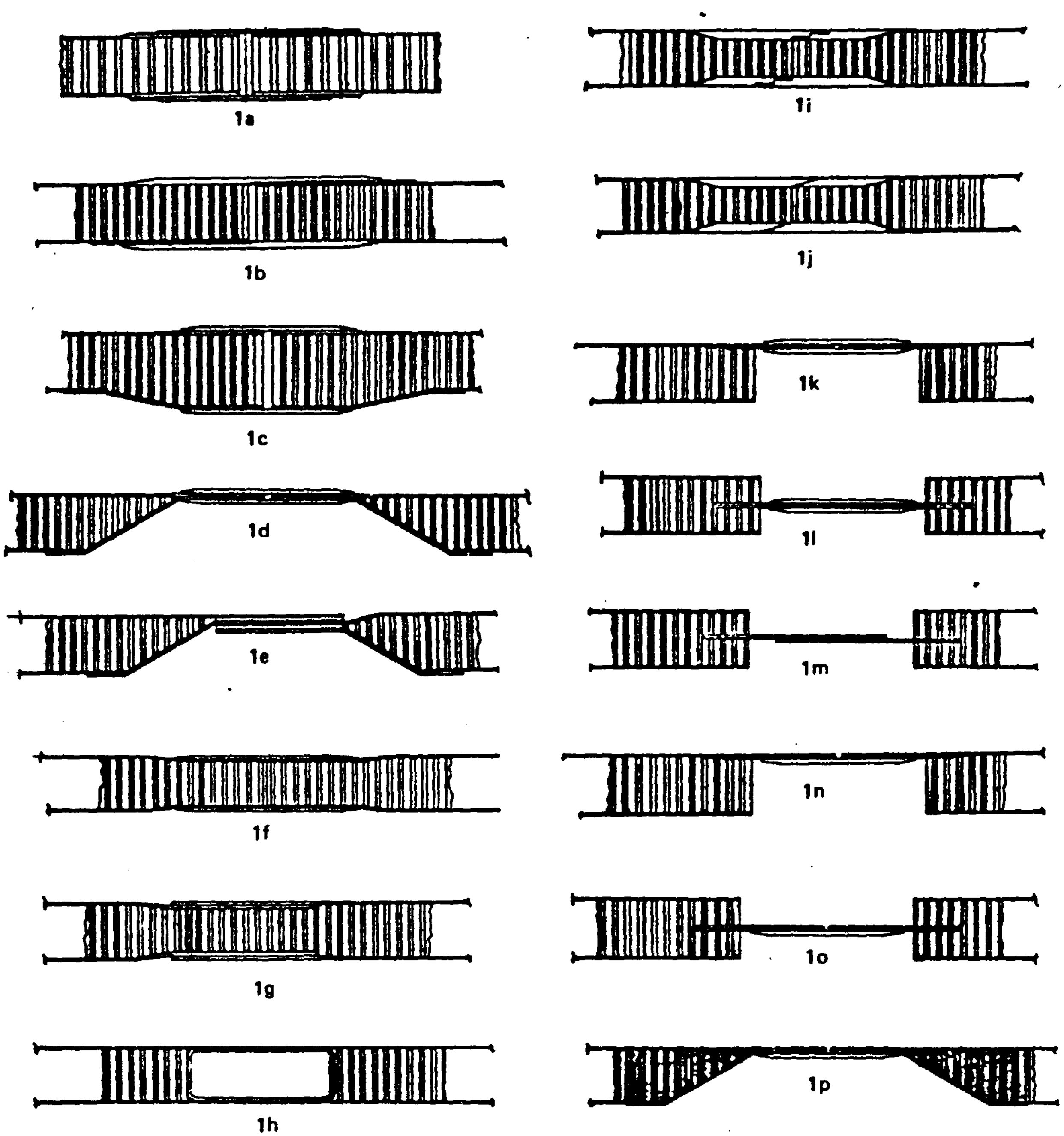


Figure 3-7: TYPE 1 BONDED JOINT CONCEPTS - COVER

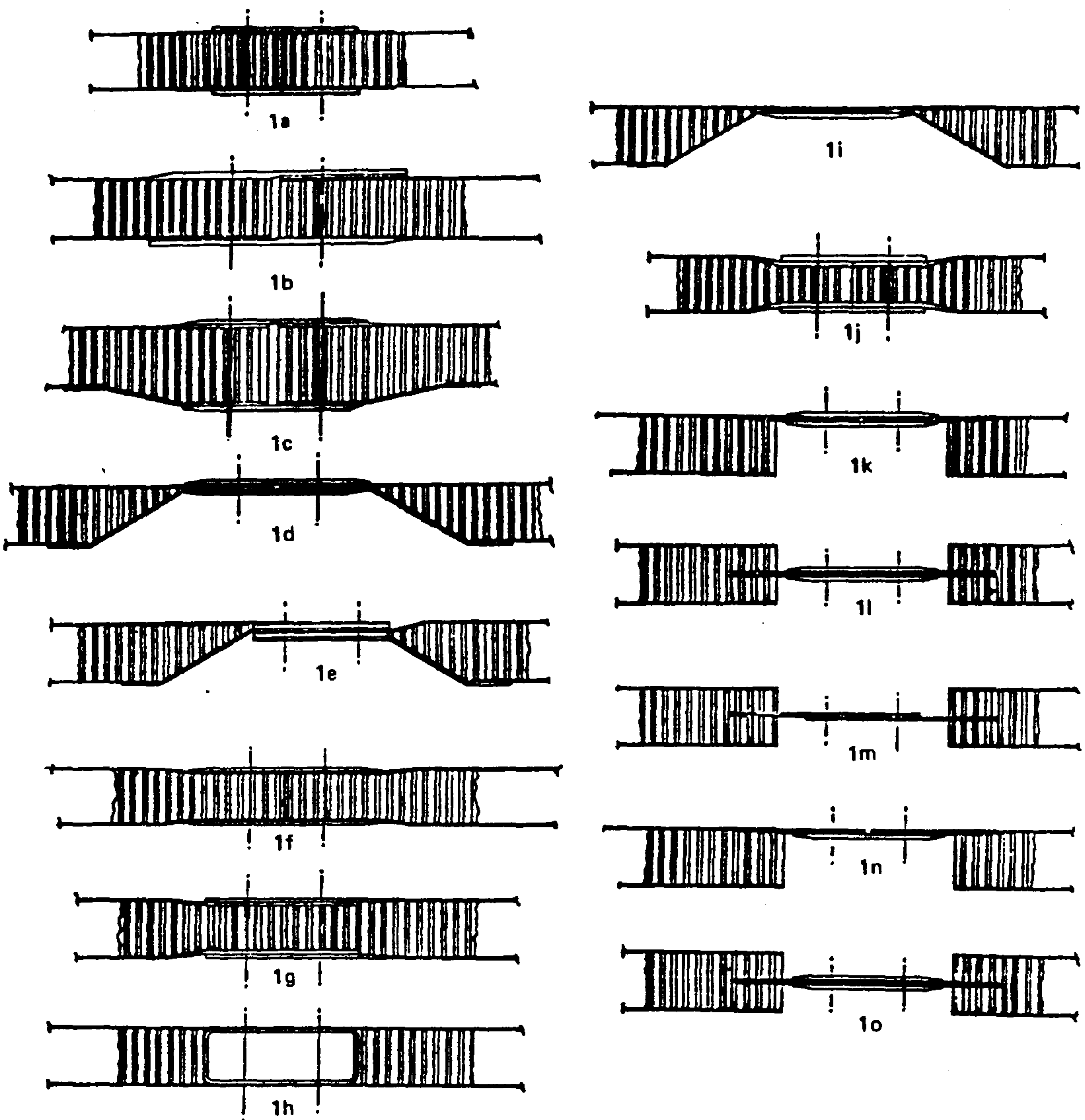


Figure 3-8: TYPE 1 BOLTED JOINT CONCEPTS - COVER

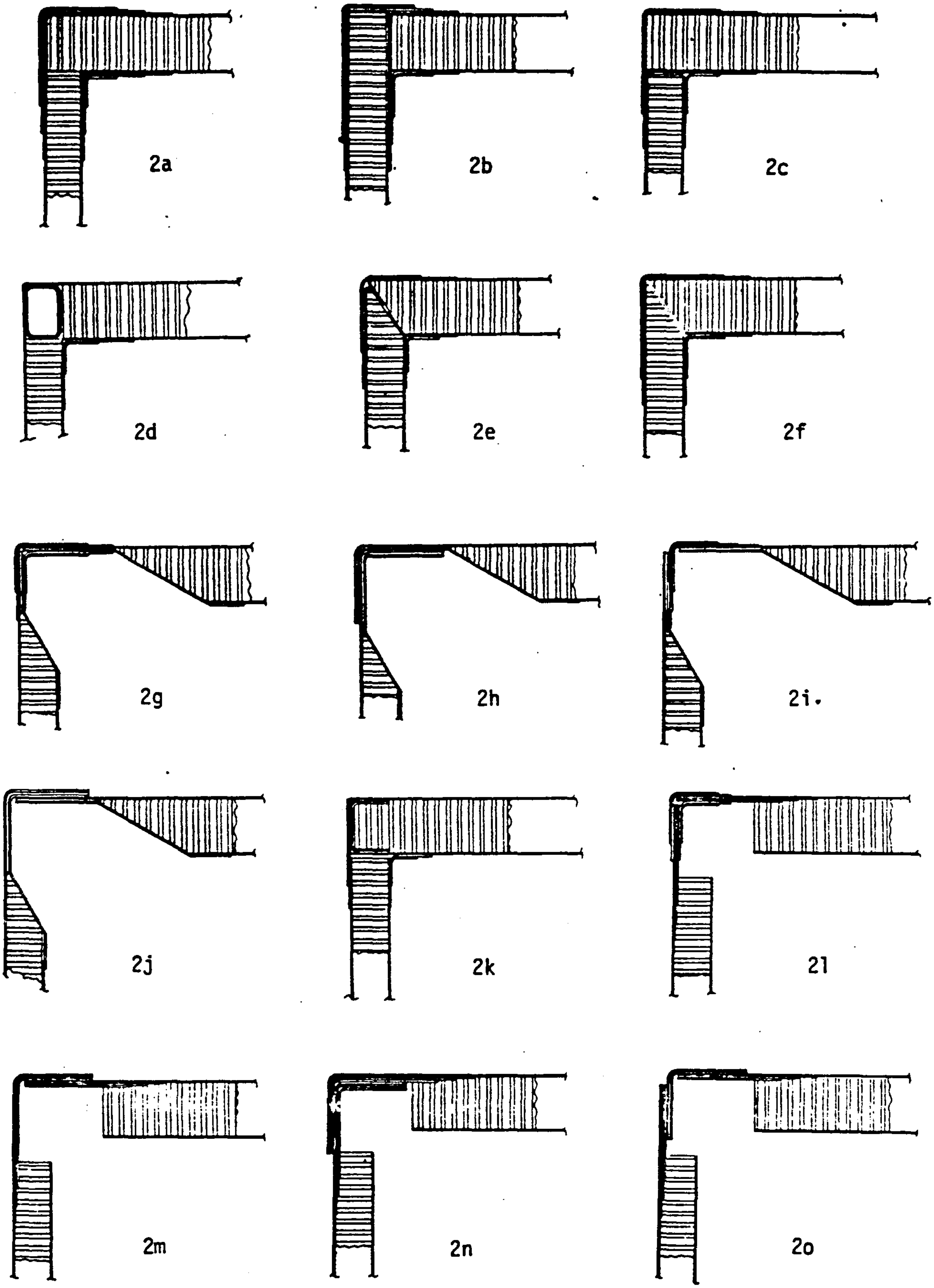


Figure 3-9: TYPE 2 BONDED JOINT CONCEPTS

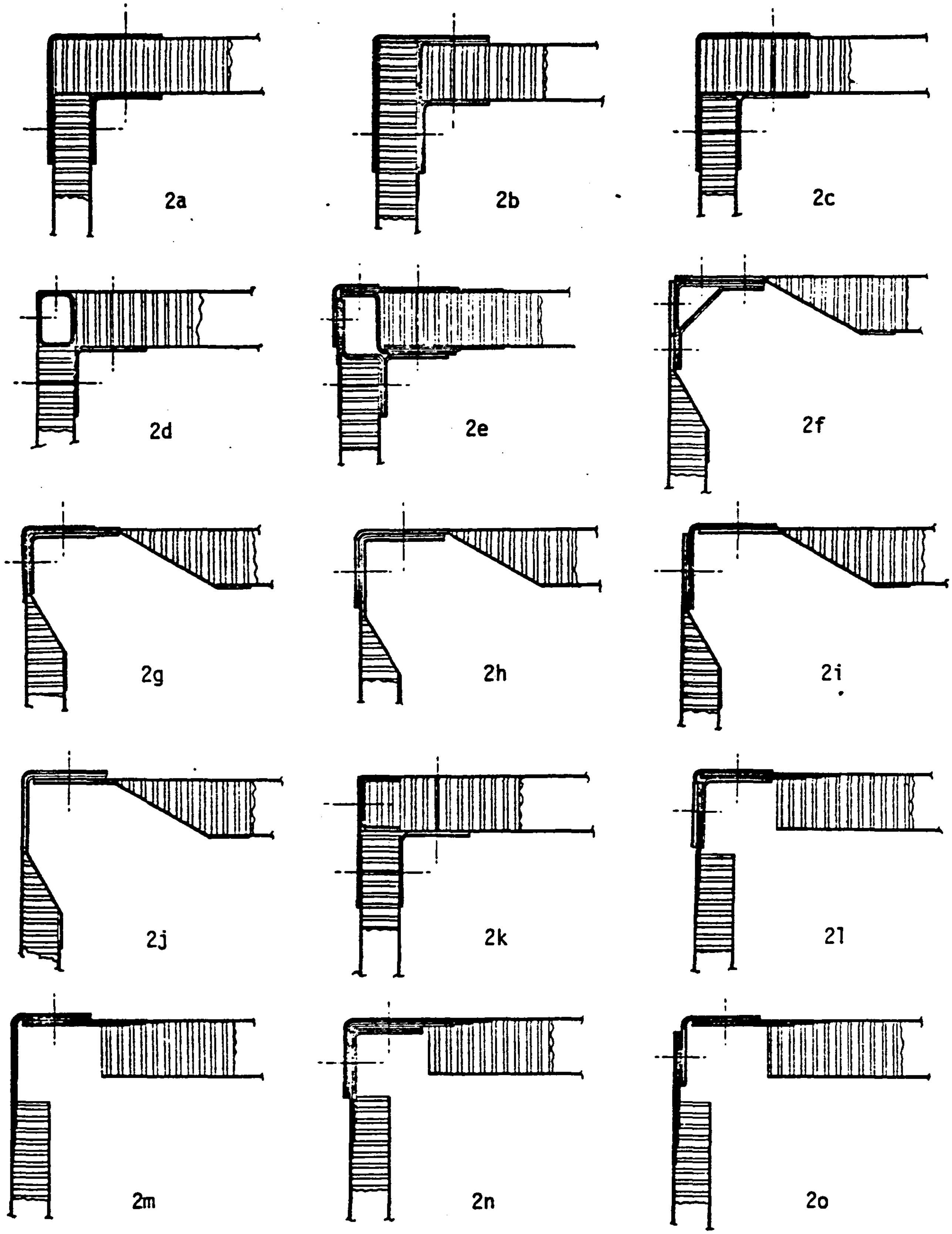


Figure 3-10: TYPE 2 BOLTED JOINT CONCEPTS

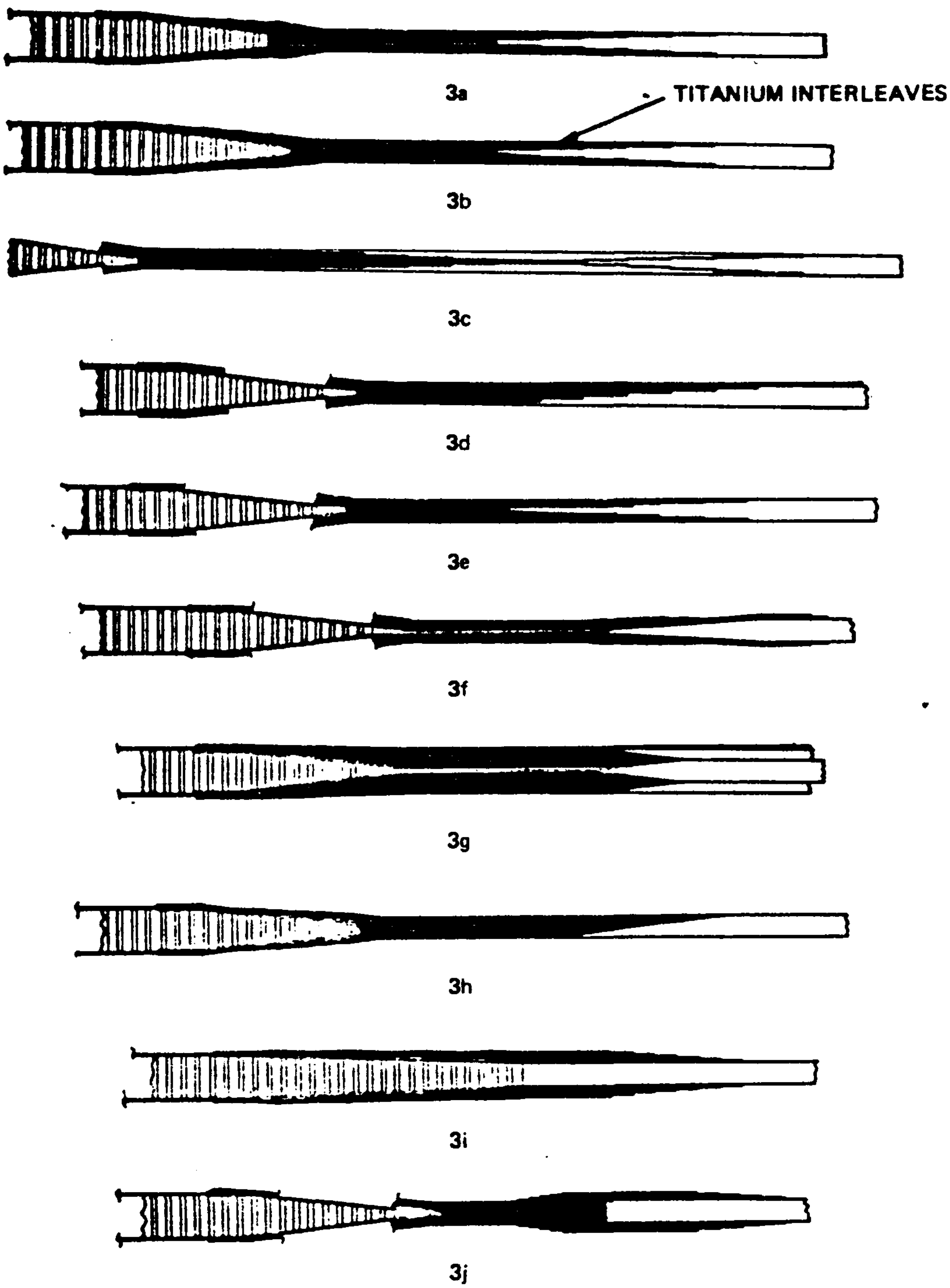


Figure 3-11: TYPE 3 BONDED JOINT CONCEPTS

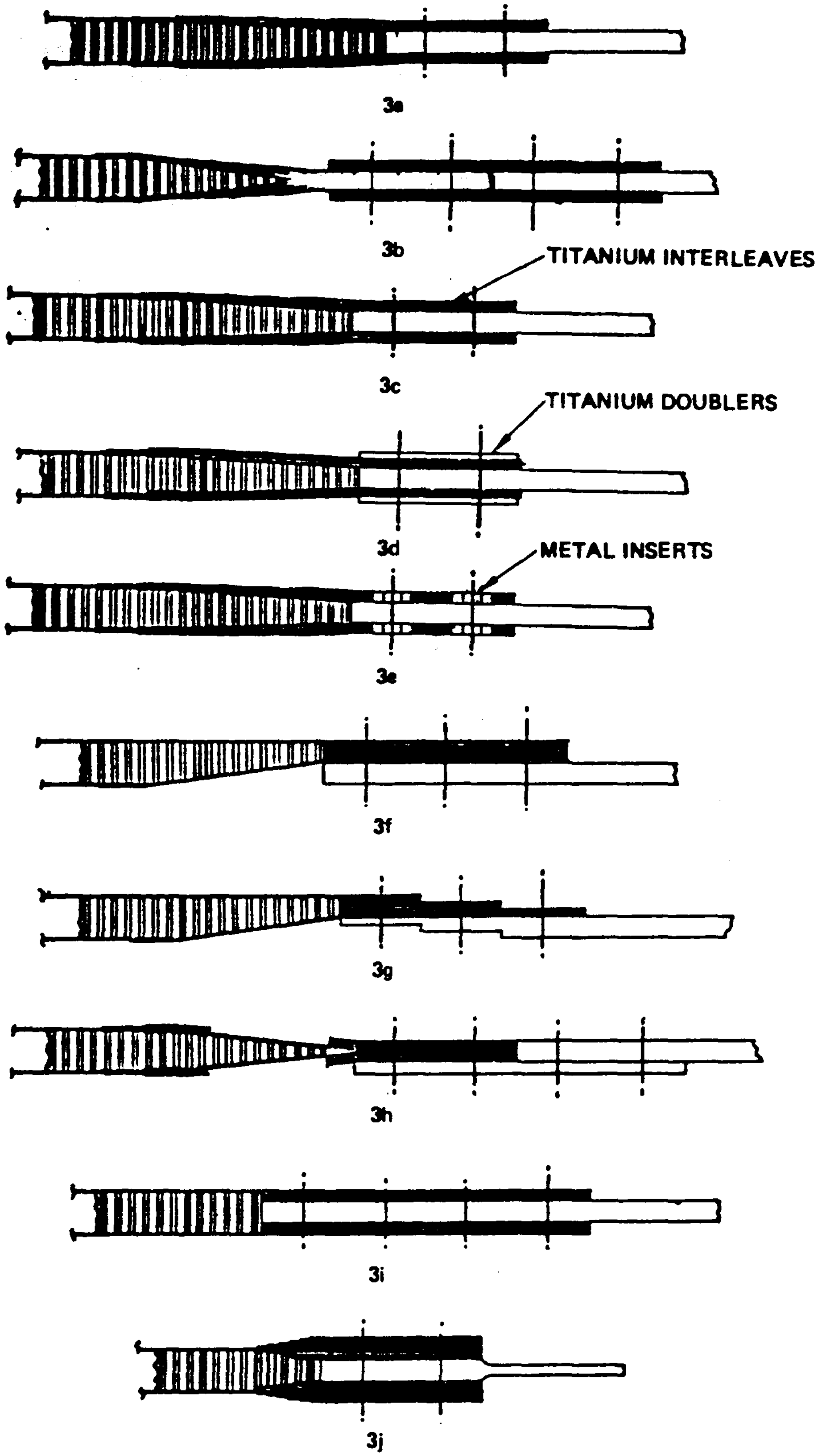


Figure 3-12: TYPE 3 BOLTED JOINT CONCEPTS

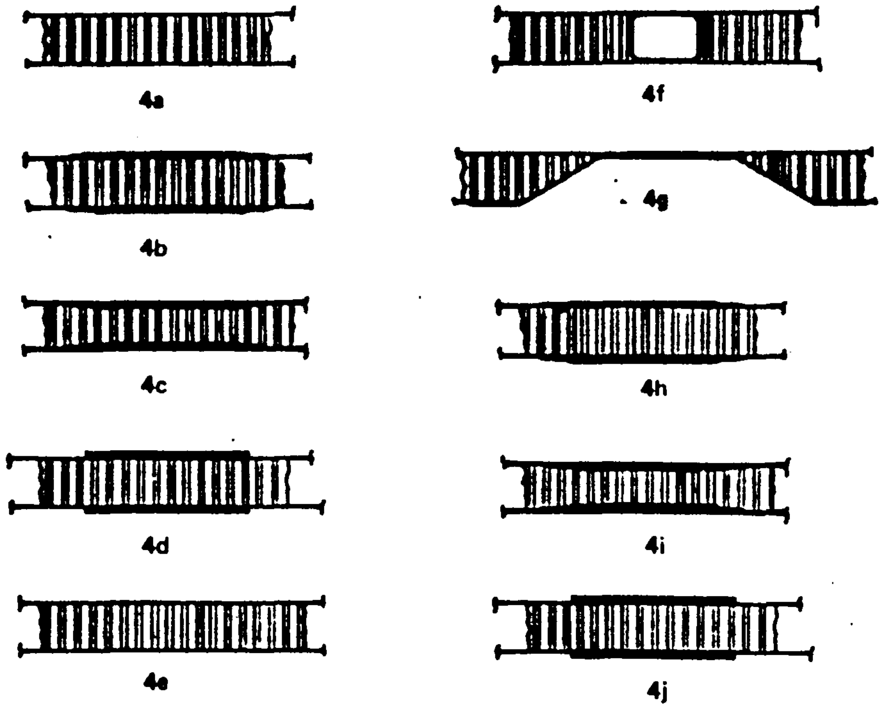


Figure 3-13: TYPE 4 BONDED JOINT CONCEPTS - COVER

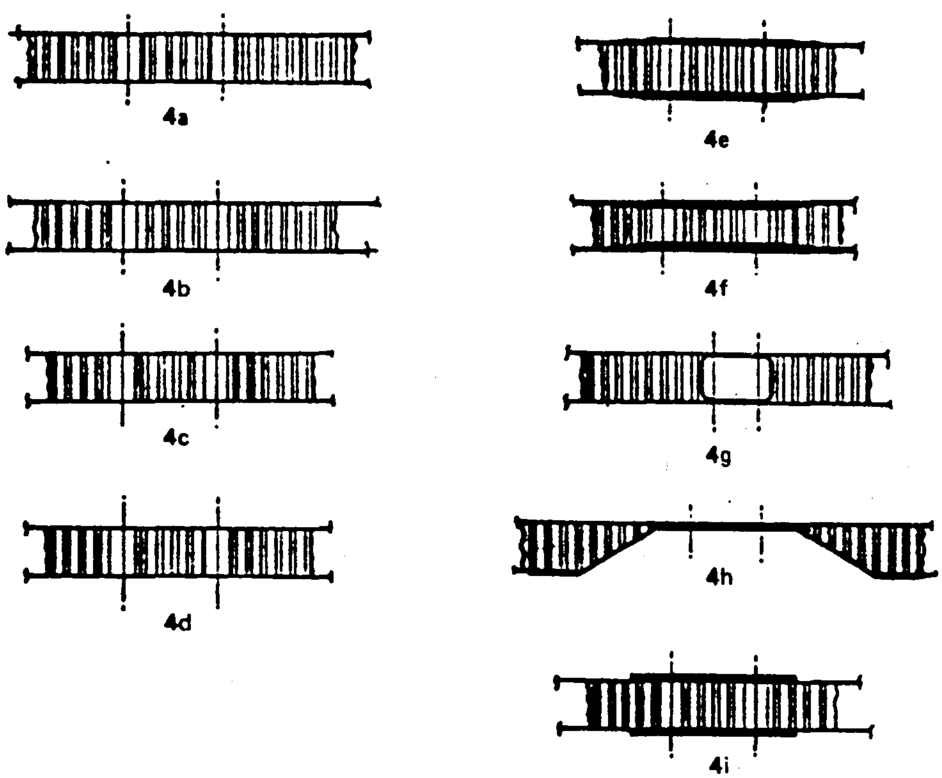


Figure 3-14: TYPE 4 BOLTED JOINT CONCEPTS - COVER

- o Best given rating of 1.0.
- o Others ratioed down.
- o Total rating for each selection criteria factored to baseline of 10 points.

SELECTION CRITERIA	WEIGHTING FACTOR	EVALUATION PARAMETER	RATING CONCEPT 1a	RATING CONCEPT 1b	CON
LOAD TRANSFER ABILITY	2	Directness of load path	1.00	1.00	
		Stress concentration areas	1.00	.66	
		Thermal balance	.50	.50	
		Stiffness balance	.75	.75	
		Abrupt change of section	1.00	1.00	
		AVERAGE X 10	8.50	7.82	
		AVERAGE x 10 x WEIGHTING FACTOR	17.00	15.64	
FABRICABILITY	5	Number of parts	1.00	1.00	
		Ease of detail fabrication	.80	1.00	
		Ease of component assembly	1.00	1.00	
		Ease of joint assembly	.50	.50	
		Inspectability	.50	.50	
		Special tooling	.90	.90	
		New development	.77	1.00	
		AVERAGE X 10	7.81	8.43	
		AVERAGE x 10 x WEIGHTING FACTOR	39.05	42.15	
SERVICE LIFE	3	Redundant load path	1.00	1.00	
		Crack propagation	.50	.50	
		Damage tolerance	1.00	1.00	
		Inspectability	.50	.75	
		Repairability	1.00	1.00	
		Length of bonded joint	1.00	1.00	
		Number of exposed edges	1.00	1.00	
		AVERAGE X 10	8.57	8.93	
		AVERAGE x 10 x WEIGHTING FACTOR	25.71	26.79	
		TOTAL RATING SCORE (Sum of averages x weighting factors)	81.76	84.58	

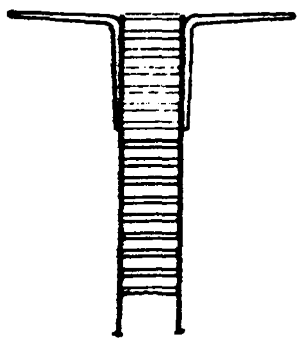
Figure 3-15: 2nd CUT SCREENING EVALUATION PARAMETERS

DESIGN GOALS	POINTS ASSIGNED
① Practicality of Full Scale Fabrication	10
② Minimum Mass	7
③ Reliability	9
④ Inspectability	7
⑤ Adequate Strength	0
⑥ Projected Fatigue Life	5
⑦ Economics of Design	10

WEIGHTING FACTORS:

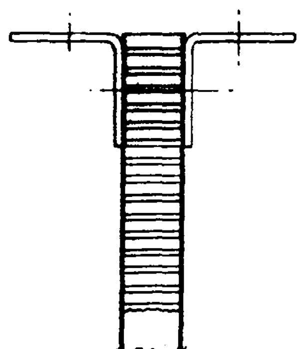
SELECTION CRITERIA	APPLICABLE DESIGN GOALS	POINTS ASSIGNED PER GOAL	POINTS ASSIGNED TOTAL	RATIO	WEIGHTING FACTOR
LOAD TRANSFERABILITY	②, ⑥	7+5	12	12/55	2
FABRICABILITY	①, ④, ⑦	10+7+10	27	27/55	5
SERVICE LIFE	③, ④	9+7	16	16/55	3
		TOTAL	55		

Figure 3-16: 2ND CUT SCREENING WEIGHTING FACTORS



1b

Figure 3-17: SELECTED TYPES 1 & 4 BONDED JOINT CONCEPT - WEB TO COVER ATTACHMENTS



1b

Figure 3-18: SELECTED TYPES 1 & 4 BOLTED JOINT CONCEPT - WEB TO COVER ATTACHMENTS

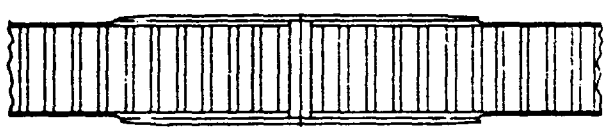
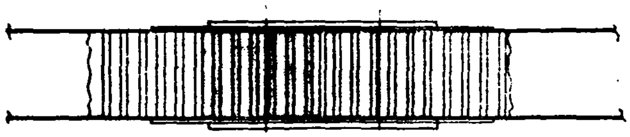


Figure 3-19: SELECTED TYPE 1 BONDED JOINT CONCEPT - COVER

1a



1a

Figure 3-20: SELECTED TYPE 1 BOLTED JOINT CONCEPT - COVER

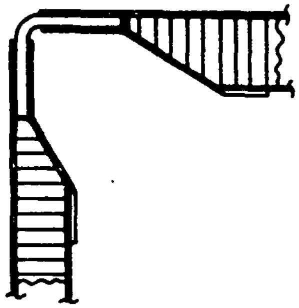


Figure 3-21: SELECTED TYPE 2 BONDED JOINT CONCEPT

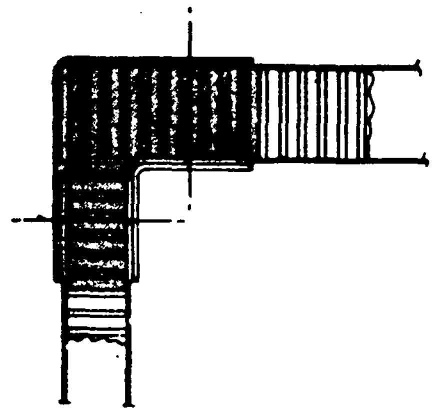
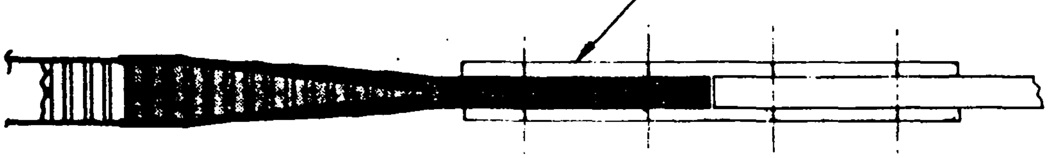


Figure 3-22 : SELECTED TYPE 2 BOLTED JOINT CONCEPT

3a

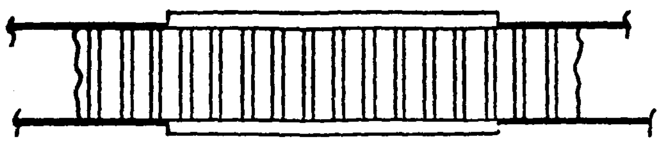
Figure 3-23: SELECTED TYPE 3 BONDED JOINT CONCEPT

3b



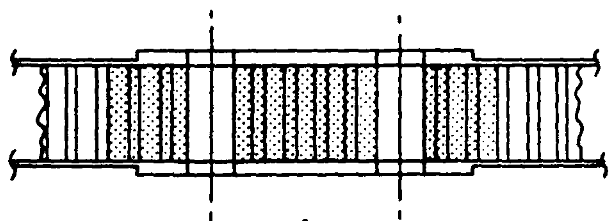
3b modified

Figure 3-24 : SELECTED TYPE 3 BOLTED JOINT CONCEPT



4b

Figure 3-25: SELECTED TYPE 4 BONDED JOINT CONCEPT--COVER



4e

Figure 3-26: SELECTED TYPE 4 BOLTED JOINT CONCEPT--COVER

4.0 MATERIAL AND SMALL COMPONENT CHARACTERIZATION

To finalize the detail design of each joint type, basic material properties and performance of specific joint details under load were required. This section presents results of material properties and "Small Specimen" testing conducted to obtain the required design data.

4.1 Materials

The graphite fibers, polyimide resin and adhesive system used for this program were contractually specified by NASA/Langley. Following are descriptions of the principal materials used.

Composites

The composite joints were made from laminates of graphite fibers preimpregnated with polyimide resin. The graphite fibers were Celanese Corp. Celion 3000 and Celion 6000 with NR-150B2G polyimide sizing. The polyimide resin was PMR-15, processed according to the procedures developed under contract NAS1-15009 (Ref. 5). PMR-15 is an addition-type, thermosetting polyimide system originated by NASA/Lewis and further studied by Boeing under NASA/LaRC sponsored CASTS* studies. Material was procured from U.S. Polymeric, Inc., Santa Ana, CA to the material specification in Reference 5. Quality control test results are given in the appropriate fabrication sections, Sections 4.3, 5.3 and 6.3. Chemical characterization tests of the resin system were also conducted using high pressure liquid chromatography, gas chromatography, mass spectrography, infrared spectroscopy, and thermal gravametric analysis.

*Composites for Advanced Space Transportation Systems (Contracts NAS1-15009 and NAS1-15644)

Adhesive

The high temperature adhesive system used for this program was designated A7F. This is a 50:50 resin solids copolymer blend of the NASA/LaRC supplied LaRC-13 adhesive (supplied by NASA, Langley) (Ref. 6) and AMOCO's AI-1130 L Amide-imide. Sixty percent by weight aluminum powder was added to improve high temperature performance. Five percent by weight Cab-o-sil was added as a thickening agent. The material was blended to a uniform consistency and spread on 6 mil 122 style E-glass cloth with A-1100 finish to make an adhesive film for bonding operations.

Titanium

Titanium used was 6Al-4V (standard) purchased to MIL-T-9406, Type III Comp. C.

Mechanical Fasteners

Fasteners used were NAS 1303, with NAS 679 self-locking nuts.

Potting Compound

Two types of potting compounds were used in the joint areas. They were BMS 8-126 (Boeing Materials Spec.) high temperature structural foam, and BR34 polyimide resin with 6% aluminum powder filler from American Cynamid.

Honeycomb Core

Honeycomb core used was a bias weave glass/polyimide purchased from Hexcel Corporation to Boeing specification XBMS 8-125. The Hexcel designation was HRH-327. Core used was 12.7 mm (0.50 inch) and 19mm (0.75 inch) thick, had a cell size of 4.76mm (3/16 inch) and densities of 64.1 kg/m^3 (4 lb/ft^3) and 128.2 kg/m^3 (8 lb/ft^3).

4.2 Design Allowables Testing

A design allowables test program was conducted under Boeing IR&D funds to establish material properties data for Celion 3000/PMR-15 composites. Tests were conducted on unidirectional laminates and on quasi-isotropic laminates used extensively in the various joint designs. A summary of the test results is given in Tables 4-1 through 4-5. Details of material processing, specimen fabrication, test procedures and environmental conditioning are given in Reference 4.

In addition, there was a contract modification to TASK 1.2.1 that provided funding for additional material properties testing of Celion 6000/PMR-15 composites. A summary of the Celion 6000/PMR-15 test results is given in Table 4-6. Detailed procedures and results for these tests are also reported in Reference 4.

The design allowables testing demonstrated that Celion 3000/PMR-15 and Celion 6000/PMR-15 are processable composites that have sufficient strength at 561K (550^{o}F) to make them acceptable as light weight structural materials for high temperature applications. Test results also show that there is little degradation of Celion 3000/PMR-15 due to aging and thermal cycling.

Table 4-1: Summary of Tension Tests-Celion 3000/PMR-15, Fiber Volume = 51.4%

TEST TYPE	LAYUP	COND. CODE	TEMPERATURE K	TEMPERATURE °F	NO. OF SPEC.	AVERAGE STRESS MPa	AVERAGE STRESS Ksi	AVERAGE STRESS [1]	FAILURE STRAIN	FAILURE STRAIN [1]	EXTENSOMETER MODULUS GPa	EXTENSOMETER MODULUS Msi	EXTENSOMETER MODULUS [1]	STRAIN GAGE MODULUS GPa	STRAIN GAGE MODULUS Msi	POISSON'S RATIO
TENSION	$(0)_{16}$	1	294	70	3	1278	185.3	.029	.0106	.065	122.9	17.82	.049			
		1	561	550	3	1302	188.8	.047	.0109	.093	125.5	18.20	.057			
		2	294	70	3	1287	186.6	.072	.0098	.054	129.5	18.79	.074			
		2	561	550	2	1129	163.7	.029	.0085	.116	133.1	19.30	.021			
		3	294	70	5	1238	179.5	.036	.0097	.054	126.5	18.35	.045	129.6*	18.80	.3272*
		3	561	550	5	1188	172.3	.039	.0097	.053	125.9	18.25	.048	150.7*	21.85	.4013*
TENSION	$(90)_{30}$	1	294	70	3	47.02	6.820	.022	.0060	.252	8.18	1.19	.049			
		1	561	550	3	19.99	2.900	.130	.0036	.200	5.72	.83	.042			
		2	294	70	3	45.37	6.580	.094	.0057	.113	8.37	1.21	.024			
		2	561	550	3	17.88	2.593	.093	.0034	.147	5.61	.81	.111			
		3	294	70	5	41.59	6.032	.094	.0055	.105	7.80	1.13	.035	8.62*	1.25	.0320*
		3	561	550	5	15.24	2.210	.047	.0034	.278	5.41	.78	.149	6.21*	.90	.0176*
		4	294	70	3	42.86	6.217	.064	.0053	.078	7.33	1.06	.005			
		4	561	550	3	7.65	1.109	.076	.0026	-	2.73	.40	.124			
TENSION	$(0/\pm45/90)_{4S}$	1	294	70	3	508.6	73.77	.293	.0108	.059	49.1	7.13	.041			
		1	561	550	3	481.7	69.87	.068	.0112	.006	44.4	6.45	.010			
		2	294	70	3	477.3	69.23	.022	.0097	.015	50.1	7.27	.021			
		2	561	550	3	452.1	65.57	.029	.0101	.054	45.8	6.64	.095			
		3	294	70	5	400.6	58.10	.041	.0098	.062	45.2	6.55	.045	46.4*	6.74	.3280*
		3	561	550	5	375.9	54.52	.058	.0090	.111	45.7	6.63	.103	47.7*	6.92	.3477*
		4	561	550	5	370.4	53.72	.046	.0094	.047	39.4	5.72	.010			
TENSION	$(\pm45)_{8S}$	1	294	70	3	202	29.4	.024	No Data		14.5	2.11	.031			
		1	561	550	2	106	15.4	.064	.0430	-	8.0	1.16	.202			
		2	294	70	4	206	29.8	.043	No Data		14.5	2.10	.022	16.5**	2.40	.8690**
		2	561	550	4	100	14.6	.103	No Data		9.3	1.35	.094	10.1**	1.46	.8139**
		3	294	70	5	151	21.8	.111	.0172	-	13.1	1.89	.040	14.6*	2.12	.7851*
		3	561	550	5	110	16.0	.057	No Data		9.3	1.35	.120			
		4	294	70	3	227	33.0	.109	No Data		16.6	2.41	.141	15.6*	2.26	.7951
		4	561	550	3	Tab Failure			No Data		8.1	1.17	.107			

* 2 Specimens
** 1 Specimen

[1] Coefficient of Variation

Table 4-2: Summary of Compression Tests-Celion 3000/PMR-15, Fiber Volume = 51.4%

TEST TYPE	LAYUP	COND. CODE	TEMPERATURE K	TEMPERATURE °F	NO. OF SPEC.	AVERAGE STRESS MPa	AVERAGE STRESS Ksi	AVERAGE STRESS ▷	FAILURE STRAIN	FAILURE STRAIN ▷	EXTENSOMETER MODULUS GPa	EXTENSOMETER MODULUS Msi	EXTENSOMETER MODULUS ▷	STRAIN GAGE MODULUS GPa	STRAIN GAGE MODULUS Msi
COMPRESSION	$(90/\pm45/0)_{4S}$	1	294	70	4	532	77.2	.065	.0141	.095	41.8	6.06	.024		
		1	561	550	4	470	68.1	.205	.0116	.144	44.2	6.40	.046		
		2	294	70	4	512	74.2	.080	.0146	.068	38.7	5.62	.054		
		2	561	550	3	413	59.9	.027	.0110	-	41.5	6.02	.026		
		3	294	70	4	534	77.4	.074	.0147	.175	42.7	6.20	.118		
		3	561	550	8	448	65.0	.121	.0117	.120	43.5	6.30	.078		
COMPRESSION SANDWICH BEAM	$(0/\pm45/90)_S^*$	2	294	70	6	452	65.6	.093						61.9**	8.98
		2	561	550	5	407	59.1	.124						59.9**	8.68

* Celion 6000/PMR-15 ** Only 2 Specimens

Table 4-3: Summary of Rail Shear Tests - Celion 3000/PMR-15, Fiber Volume = 51.4%

TEST TYPE	LAYUP	COND. CODE	TEMPERATURE K	TEMPERATURE °F	NO. OF SPEC.	AVERAGE STRESS MPa	AVERAGE STRESS Ksi	AVERAGE STRESS ▷	STRAIN GAGE MODULUS GPa	STRAIN GAGE MODULUS Msi
RAIL SHEAR	$(\pm45)_{3S}$	1	294	70	3	324	47.0	.504	39.5	5.74
		1	561	550	3	330	47.8	.128	40.6	5.88
		2	294	70	2	358	52.0	.007	40.5	5.88
		2	561	550	2	240	34.8	.104	33.3	4.84

▷ Coefficient of Variation

Table 4-4: Summary of Flatwise Tension Tests - CELION 3000/PMR-15, Fiber Volume = 51.4%

TEST TYPE	LAYUP	COND. CODE	TEMPERATURE K	TEMPERATURE °F	NO. OF SPEC.	AVERAGE STRESS MPa	AVERAGE STRESS Ksi	1
FLATWISE TENSION LAM. TO LAM.	$(0/\pm45/90)_{2S}$	1	116	-250	3	20.76	3.011	.347
		1	294	70	3	26.43	3.833	.013
		1	561	550	3	8.84	1.282	.170
		2	116	-250	3	11.05	1.603	.548
		2	294	70	3	13.32	1.932	.186
		2	561	550	3	9.97	1.447	.392
FLATWISE TENSION LAM. TO CORE	$(0/\pm45/90)_{2S}$ TO HONEYCOMB CORE	1	116	-250	2	1.79	.259	.551
		1	294	70	3	6.23	.904	.130
		1	561	550	4	2.49	.361	.232
		2	116	-250	0	*	*	*
		2	294	70	3	5.05	.733	.023
		2	561	550	4	3.95	.573	.048

* Failure Due to Thermal Stresses

1 Coefficient of variation

Table 4-5; CTE DATA: CELION 3000/PMR-15

Specimen No.	Laminate	Condition*	Test Axis	CTE, m/m-Kx10^{-6} (in/in°Fx10^{-6}) 116K to RT (-250F)	RT to 589K (600°F)	116K to 589K (-250°F) (600°F)
2W4582-15D1	$(0/\pm45/90)_{4S}$	2	X	2.13 (1.18)	2.65 (1.47)	2.45 (1.36)
2W4582-15D3	$(0/\pm45/90)_{4S}$	2	X	2.17 (1.2)	2.79 (1.55)	2.55 (1.42)
2W4582-15C2	$(0/\pm45/90)_{4S}$	1	X	2.14 (1.19)	2.55 (1.42)	2.39 (1.33)
2W4582-10B	$(\pm45)_{8S}$	2	Z		52.9 (29.4)	
2W4582-7C	$(0/\pm45/90)_{2S}$	3	Z		48.1 (26.7)	
2W4582-13B	$(\pm45/90/0)_{4S}$	3	Z		37.7 (20.9)	
2W4582-14B	$(0/\pm45/90)_{4S}$	2	Z		48.5 (26.9)	
2W4582-14	$(0/\pm45/90)_{4S}$	1	Z		54.7 (30.4)	
2W4582-10	$(\pm45)_{8S}$	1	Z		54.1 (30.1)	

* 1 = as cured/postcured; 2 = aged 125 hrs @589K (600°F), 3 = 125 thermal cycles

Table 4-6: Celion 6000/PMR-15 Design Allowables Summary
Baseline "Dry" 65.3% Fiber Volume

TEST TYPE	LAMINATE LAYUP	TEMPERATURE K (°F)	NUMBER OF SPECIMENS	AVERAGE FAILURE STRESS MPa (ksi)	▷	EXTENSOMETER DATA: AVERAGE MODULUS Ex GPa (10^6 psi)	▷	EXTENSOMETER DATA: AVERAGE FAILURE STRAIN ult	▷	STRAIN GAGE DATA: AVG. TANGENT MODULUS ε = .002 E_x* GPa (10^6 psi)	STRAIN GAGE DATA: AVERAGE POISSON'S RATIO ε = .002 ν_{xy}*	STRAIN GAGE DATA: AVERAGE LAMINA SHEAR MODULUS γ_{12} = .0036 G_{12}* GPa (10^6 psi)	STRAIN GAGE DATA: AVERAGE LAMINATE SHEAR MODULUS γ_{xy} = .0026 G_{xy}* GPa (10^6 psi)
TENSION	$[0]_8$	116 (-250)	10	1590 (231)	.052	135 (19.6)	.053	.0113•	.086	134++ (19.5)	.383++	—	—
		294 (70)	10	1510 (219)	.089	132 (19.1)	.037	.0112•	.076	136 (19.7)	.333	—	—
		589 (600)	10	1600 (232)	.030	136 (19.6)	.071	.0124•	.079	143 (20.8)	.316	—	—
TENSION	$[0/+45/90/-45]_S$	116 (-250)	10	529 (76.7)	.054	44.8 (6.5)	.044	.0119	.087	50.7++ (7.35)	.317++	—	19.2++ (2.79)
		294 (70)	10	525 (76.1)	.116	48.3 (7.0)	.047	.0118	.124	50.3 (7.29)	.340	—	18.8 (2.72)
		589 (600)	10	516 (74.8)	.045	46.2 (6.7)	.021	.0119	.054	49.7+ (7.21)	.349+	—	18.4+ (2.67)
TENSION	$[\pm 45]_{2S}$	116 (-250)	10	131 (19.0)	.023	20.0 (2.9)	.073	.0128•	.177	20.7 (3.00)	.739	5.94 (.862)	—
		294 (70)	10	123 (17.9)	.017	17.9 (2.6)	.065	.0129	.119	17.4 (2.52)	.873	4.65 (.674)	—
		589 (600)	11	108 (15.6)	.069	11.7 (1.7)	.093	.0795	.162	8.41 (1.22)	.826	2.31 (.335)	—
COMPRESSION	$[0]_{16}$	116 (-250)	10	1250 (182)	.098	—	–	–	–	132**+ (19.1)	.376**+	—	—
		294 (70)	10	972 (141)	.163	—	–	–	–	122** (17.7)	.331**	—	—
		589 (600)	10	549 (79.6)	.106	—	–	–	–	119***+++ (17.3)	.301***+++	—	—
COMPRESSION	$[0/+45/90/-45]_{2S}$	116 (-250)	10	614 (89.1)	.162	—	–	–	–	60.5 (8.78)	.354	—	22.4 (3.25)
		294 (70)	10	545 (79.0)	.060	—	–	–	–	41.9 (6.07)	.319	—	15.9 (2.30)
		589 (600)	10	380 (55.1)	.049	—	–	–	–	50.7** (7.35)	.381**	—	18.3** (2.66)
COMPRESSION	$[\pm 45]_{4S}$	116 (-250)	10	231 (33.5)	.266	—	–	—	–	24.3+++ (3.52)	.664+++	7.31+++ (1.06)	—
		294 (70)	10	168 (24.4)	.081	—	–	–	–	12.3+ (1.79)	.654+	3.70+ (.537)	—
		589 (600)	10	101 (14.6)	.165	—	–	–	–	8.14 (1.18)	.833	2.22 (.322)	—
INPLANE SHEAR	$[0/+45/90/-45]_S$	116 (-250)	10	364 (52.8)	.099	—	–	–	–	—	—	—	18.0 (2.61)
		294 (70)	10	357 (51.8)	.080	—	–	–	–	—	—	—	17.2 (2.50)
		589 (600)	10	307 (44.5)	.043	—	–	–	–	—	—	—	18.3++++ (2.66)
INTERLAMINAR SHEAR	$[0]_{20}$	116 (-250)	5	125 (18.1)	.040	—	–	–	–	—	—	—	—
		294 (70)	9	105 (15.2)	.044	—	–	–	–	—	—	—	—
		589 (600)	5	53.4 (7.7)	.024	—	–	–	–	—	—	—	—

▷ Coefficient of variation (standard deviation/average).
* 3 specimens unless noted.
** 2 specimens.
*** 1 specimen.
\+ 1 longitudinal strain gage faulty on 1 specimen.
++ 1 transverse strain gage faulty on 1 specimen.
+++ 1 longitudinal and 1 transverse strain gage faulty on 1 specimen.
++++ 1 strain gage faulty on 1 specimen
• 9 specimens

4.3 Small Specimen Tests

The "Small Specimen" test program was developed to provide design data to support detail design of the joint concepts defined by the screening process. Tests were conducted to measure bolted joint allowables (net tension, bearing, and shear-out) for quasi-isotropic layups used extensively in the joint designs. In addition, tests were conducted to determine 1) the strength of bonded versus co-cured doublers, 2) the impact of honeycomb sandwich inner adherends on double-lap bonded joint strength, and 3) tension "pull-off" tests of bonded attachment angles. Effects of elevated temperature (561K (550^0)) and environmental conditioning (cured/post-cured, aged, and thermal cycling) were evaluated. Test matrices, specimen fabrication, test procedures and test results are given in the following sections.

Test Matrices

The test matrix to measure bolt bearing, shearout and net tension strength of quasi-isotropic laminates is given in Table 4.7. Specimen configurations are given in Figure 4.1.

Bolted joint designs generally require doublers in the bolt area to provide adequate bearing and net-tension strength. A series of tests were conducted to evaluate efficiencies of bonded versus co-cured doublers. The test matrix is given in Table 4-8 and the specimen configurations are given in Figure 4-2.

Design data for the bonded joints was obtained primarily from the standard joint tests conducted under TASK 2; however, there was some concern over the validity of using data from double lap joints with solid adherends for design of double lap joints where the inner adherend is a honeycomb sandwich. To establish data for comparison, double lap joints with a honeycomb sandwich inner adherend were tested. The test matrix is given in Table 4-8. The specimen configuration is given in Figure 4-3.

Other tests were conducted to evaluate the tension capability of the web attachment concepts. Tension tests were conducted for the three bonded attachment concepts shown in Figures 4-4 through 4-6. The test matrix is given in Table 4-9. No tests were conducted for bolted web attachment concepts because they were not critical for the low design loads.

Throughout this program, a standard specimen numbering system was used to allow easy specimen identification with respect to test matrix, test type and specimen conditioning. The numbering system used is given below.

4A	-	1A	-	2	-	1
Test Matrix Number		Test Number		Specimen Condition Code		Specimen Number

Specimen Fabrication

All "Small Specimen" test specimens were fabricated from Celion 3000/PMR-15. Prepreg lot numbers used for the various test sets are shown in Table 4-10. Quality control test results for these lots are shown in Appendix F. Processing for these specimens was the same as described in Section 5.3.

Test Procedures and Results

The following sections present the test procedures and results for the "Small Specimen" tests conducted.

Table 4-7: TEST MATRIX 4A - SMALL SPECIMEN TESTS (Bolted Joint Allowables)

Test No.	W mm (in.)	e mm (in.)	Laminate	Condition [1]	Specimen* Type	No. of Tests @ RT	No. of Tests @ 561K(550°F)	Total Specimens
1a	63.5(2.5)	19.0 (.75)	$(0,\pm45,90)_{8S}$	1	4A-1	3	3	6
1b	63.5(2.5)	19.0 (.75)	$(0,\pm45,90)_{8S}$	2	4A-1	3	3	6
1c	63.5(2.5)	19.0 (.75)	$(0,\pm45,90)_{8S}$	3	4A-1	3	3	6
2a	63.5(2.5)	33.3 (1.31)	$(0,\pm45,90)_{8S}$	1	4A-1	3	3	6
2b	63.5(2.5)	33.3 (1.31)	$(0,\pm45,90)_{8S}$	2	4A-1	3	3	6
2c	63.5(2.5)	33.3 (1.31)	$(0,\pm45,90)_{8S}$	3	4A-1	3	3	6
3a	33.3 (1.31)	33.3 (1.31)	$(0,\pm45,90)_{8S}$	1	4A-1	3	3	6
3b	33.3 (1.31)	33.3 (1.31)	$(0,\pm45,90)_{8S}$	2	4A-1	3	3	6
3c	33.3 (1.31)	33.3 (1.31)	$(0,\pm45,90)_{8S}$	3	4A-1	3	3	6
4a	47.8 (1.88)	-	$(0,\pm45,90)_{8S}$	1	4A-2	3	3	6
4b	47.8 (1.88)	-	$(0,\pm45,90)_{8S}$	2	4A-2	3	3	6
4c	47.8 (1.88)	-	$(0,\pm45,90)_{8S}$	3	4A-2	3	3	6

[1] CONDITION CODE

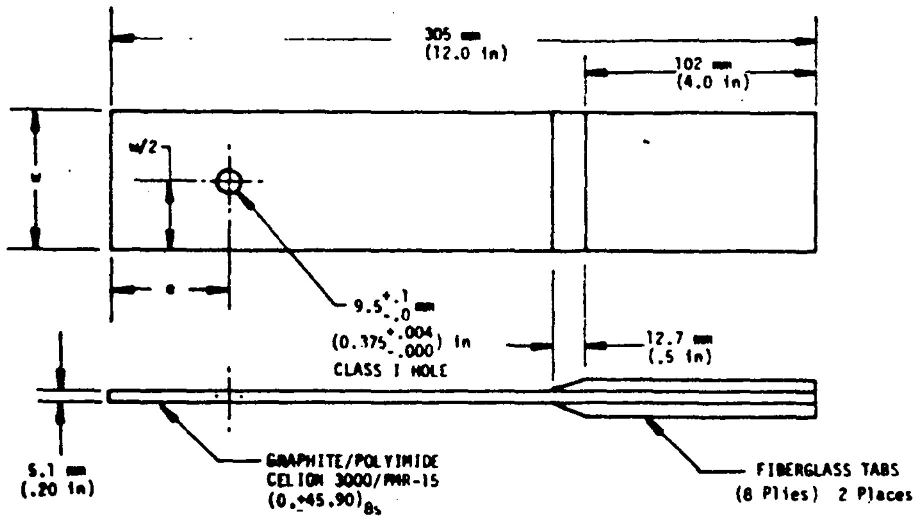
* See Figure 4-1

1 - As cured/postcured

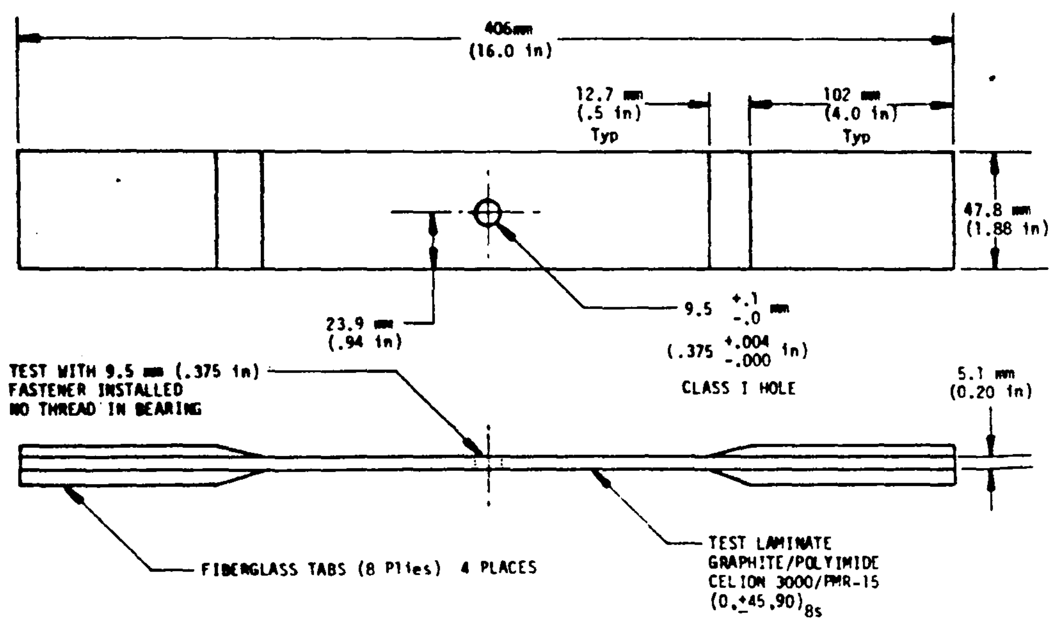
2 - Soaked for 125 hrs at 589K (600°F) in a one (1) atmosphere environment (air).

3 - Thermally cycled 125 times in a temperature range from 116K to 589K (-250°F to 600°F) and in a one (1) atmosphere environment (air).

The cryogenic temperature of 116K (-250°F) shall be held for 1/2 hr and the maximum temperature of 589K (600°F) shall be held for 1 hr per cycle. The heat-up and cool-down rates shall be approximately 8.3K/min (15°F/min).



SPECIMEN 4A-1



SPECIMEN 4A-2

Figure 4-1: SMALL SPECIMEN TESTS

Table 4-8: TEST MATRIX 4B - SMALL SPECIMEN TESTS (Cocured vs. Bonded Doublers)

TEST NO.	La mm (in)	t_1 mm (in)	t_2 or t_3 mm (in)	LAMINATE		CONDITION ▷1	SPECIMEN* TYPE	NO. OF TESTS @		TOTAL SPECIMENS
				1	2			RT	561°F(550°F)	
1a	63.5(2.5)	.51(.02)	1.52(.06)	$(0,\pm45,90)_s$	$(0,\pm45,90)_{3s}$	1	4B-1	3	3	6
1b	63.5(2.5)	.51(.02)	1.52(.06)	$(0,\pm45,90)_s$	$(0,\pm45,90)_{3s}$	2	4B-1	3	3	6
2a	63.5(2.5)	.51(.02)	2.04(.08)	$(0,\pm45,90)_s$	See Fig. 4-2	1	4B-2	3	3	6
2b	63.5(2.5)	.51(.02)	2.04(.08)	$(0,\pm45,90)_s$	See Fig. 4-2	2	4B-2	3	3	6
2c	63.5(2.5)	.51(.02)	2.04(.08)	$(0,\pm45,90)_s$	See Fig. 4-2	3	4B-2	3	3	6
4a	45.7(1.8)	.51(.02)	See Fig. 4-3	$(0,\pm45,90)_s$	See Fig. 4-3	2	4B-3	3	3	6

▷1 CONDITION CODE

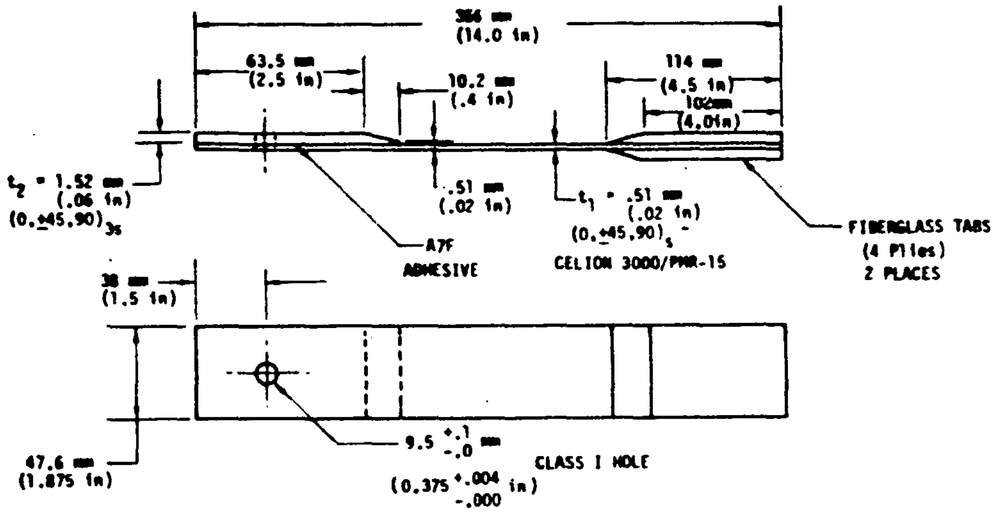
1 - As cured/postcured

2 - Soaked for 125 hrs at 589K (600°F) in a one (1) atmosphere environment (air).

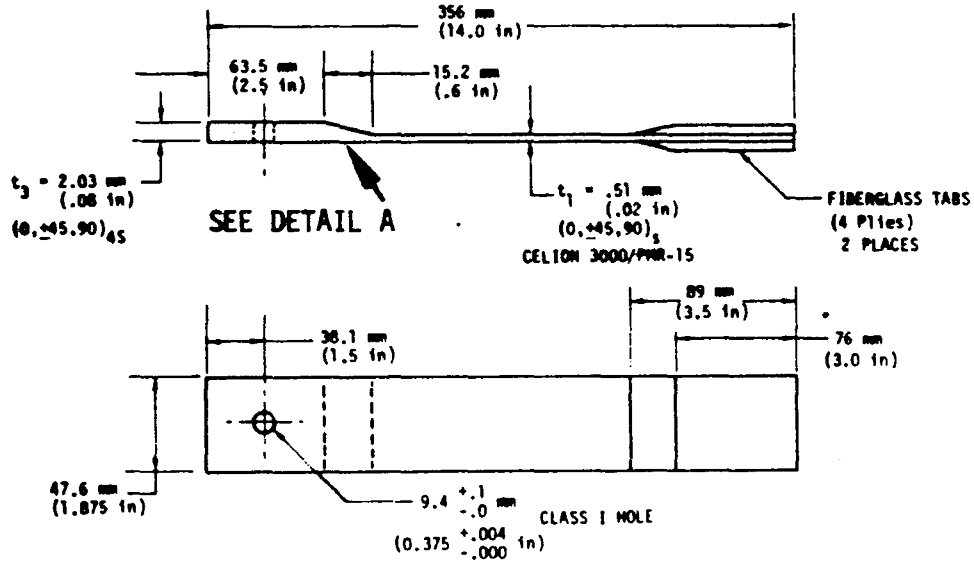
3 - Thermally cycled 125 times in a temperature range from 116K to 589K (-250°F to 600°F) and in a one (1) atmosphere environment (air).

The cryogenic temperature of 116K (-250°F) shall be held for 1/2 hr. and the maximum temperature of 589K (600°F) shall be held for 1 hr per cycle. The heat-up and cool-down rates shall be approximately 8.3K/min (15°F/min).

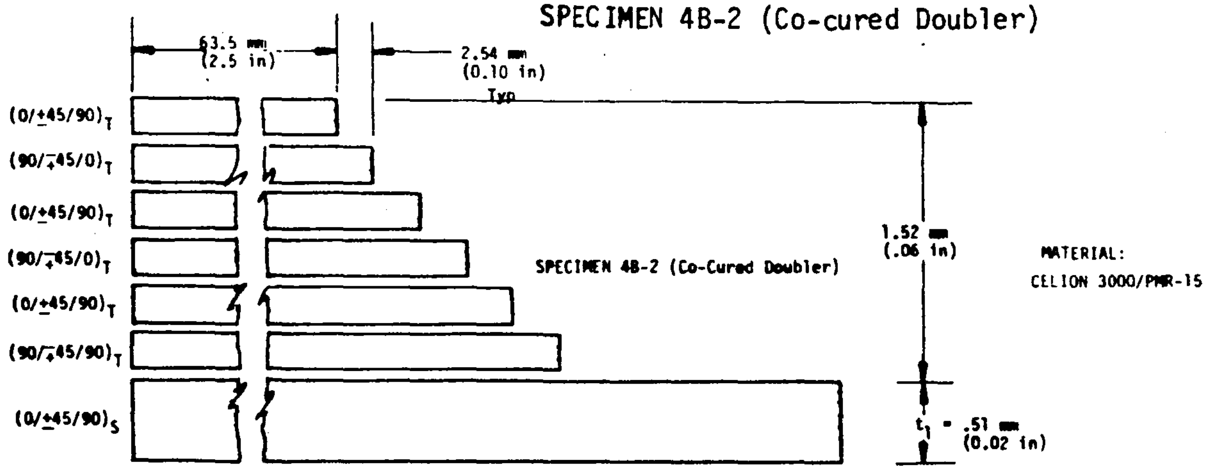
* See Figures 4-2 and 4-3.



SPECIMEN 4B-1 (Bonded Doubler)

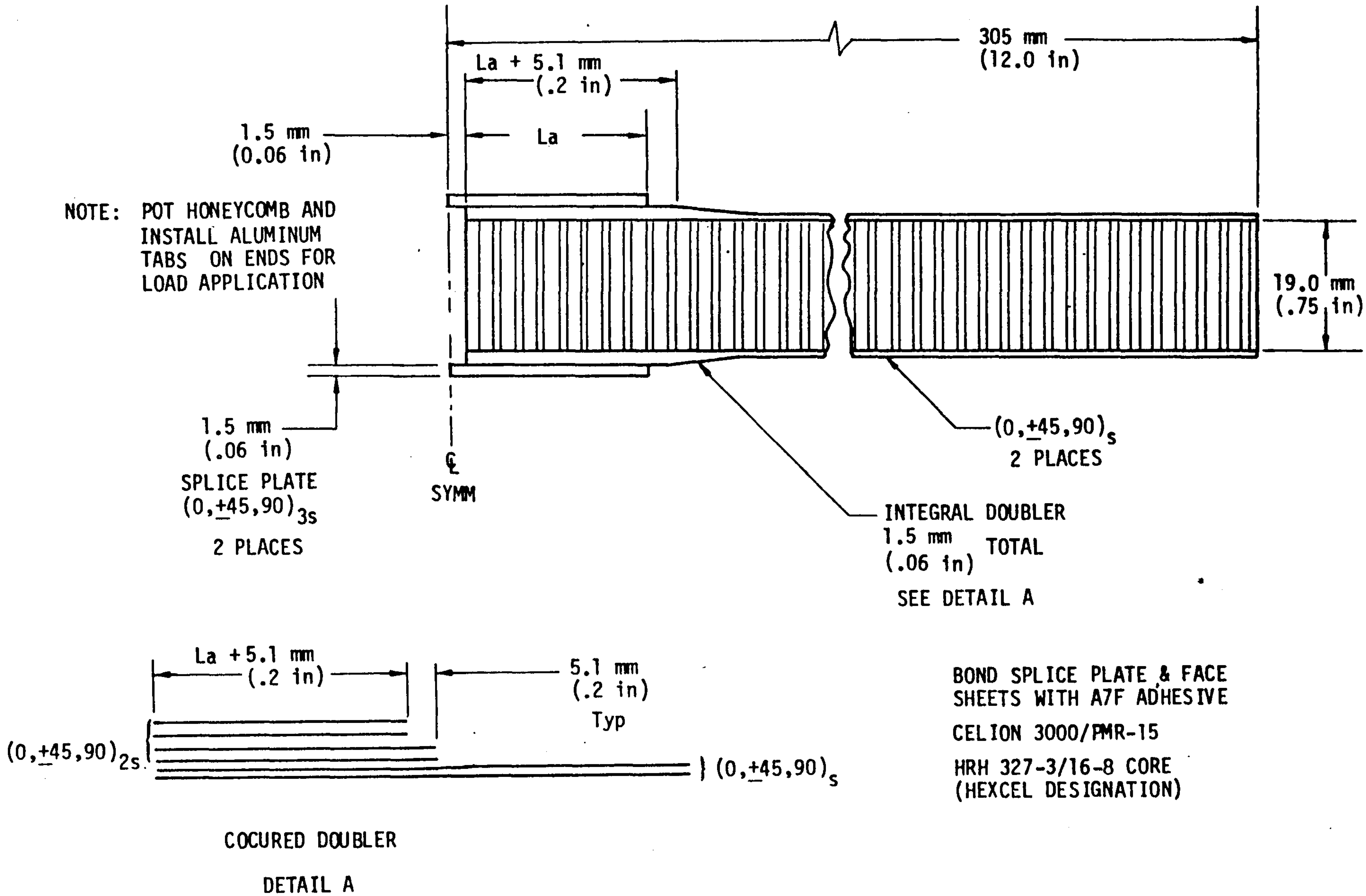


SPECIMEN 4B-2 (Co-cured Doubler)



DETAIL "A"

Figure 4-2: SMALL SPECIMEN TESTS



SPECIMEN 4B-3

Figure 4-3: SMALL SPECIMEN TESTS (Cont.)

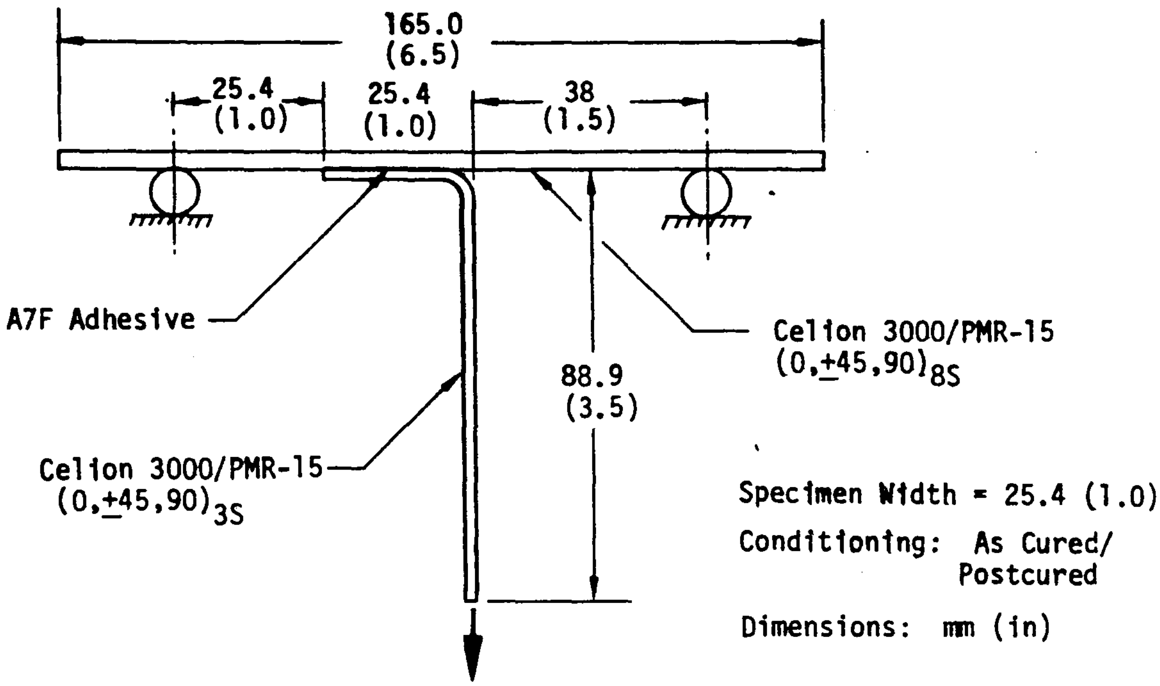


Figure 4-4: MATRIX 4C TEST 1a SINGLE ANGLE PULL-OFF SPECIMEN

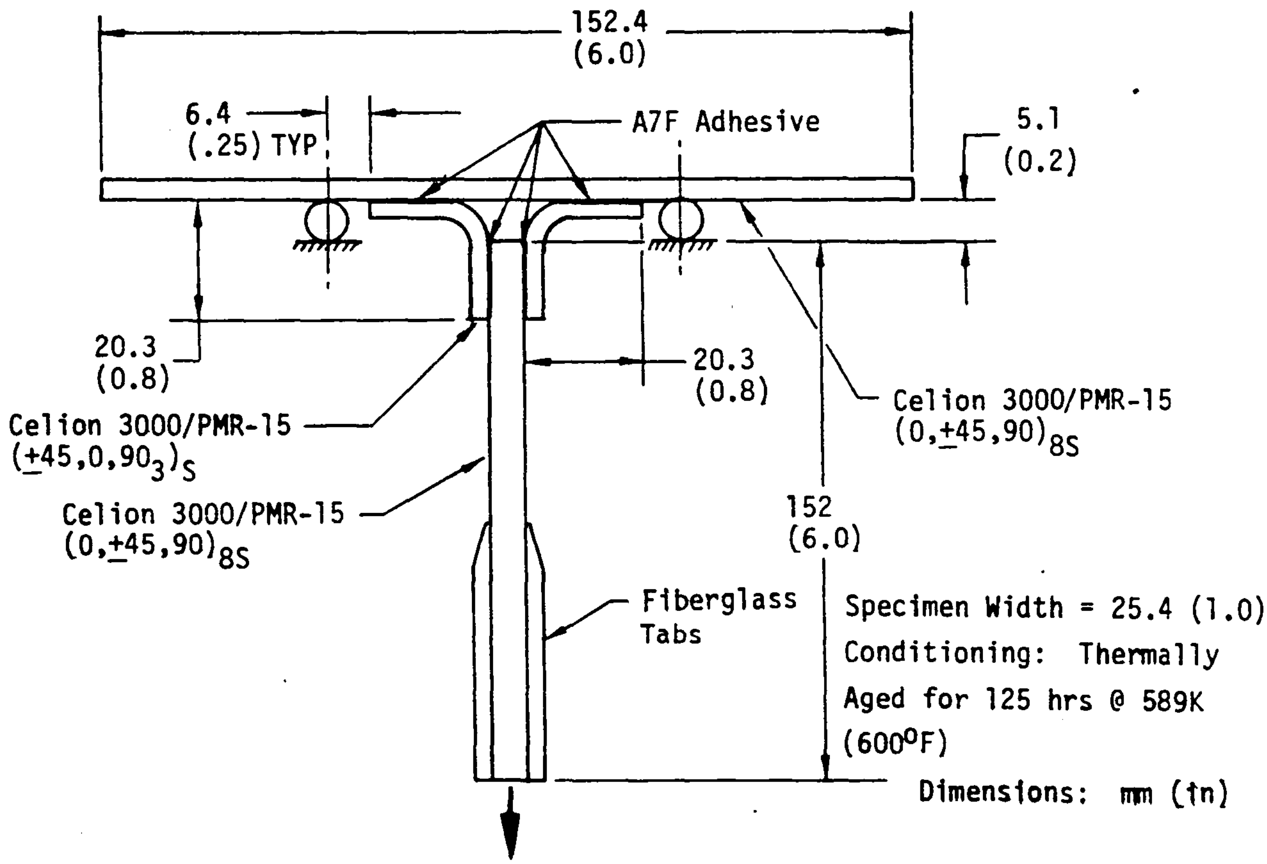
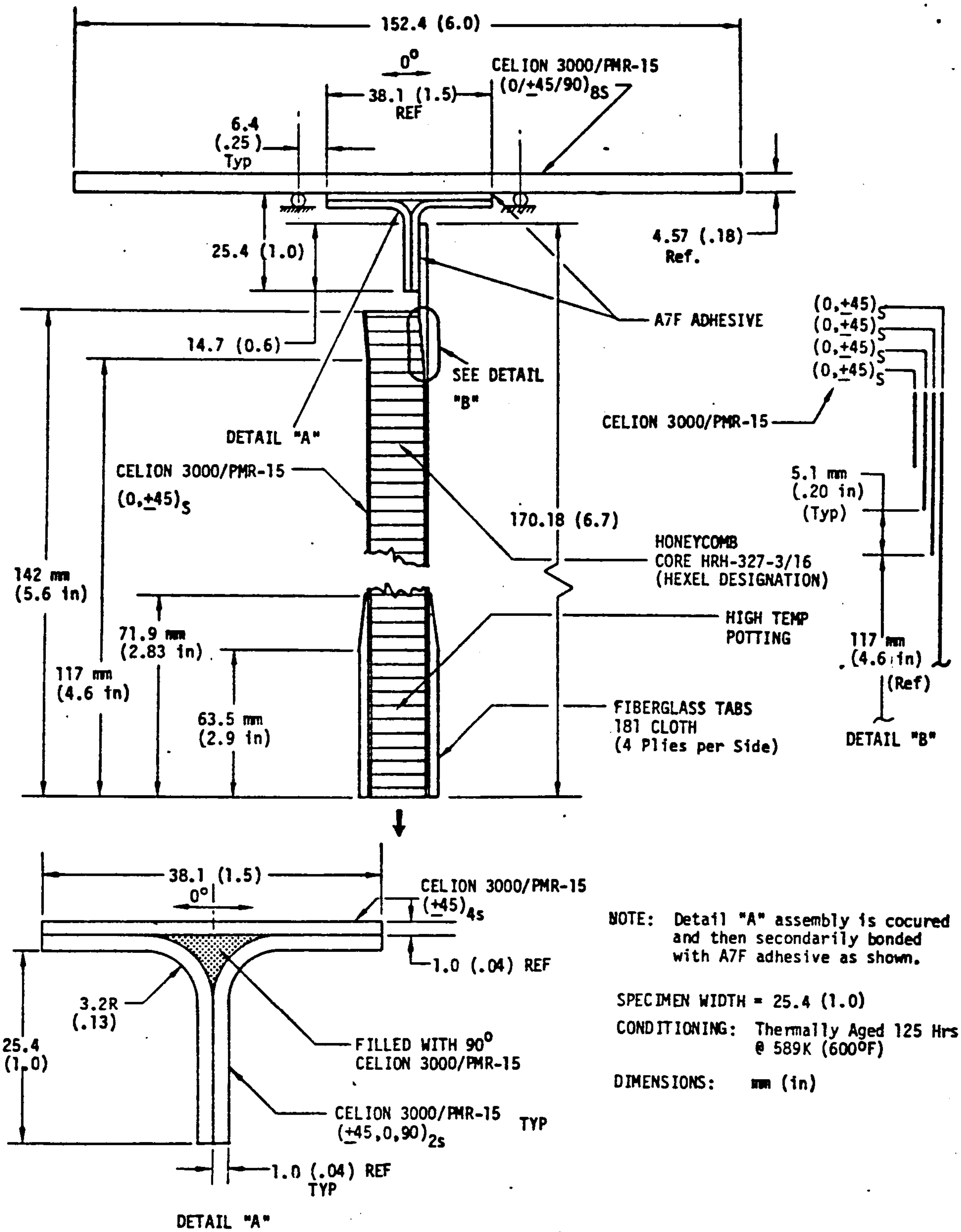


Figure 4-5: MATRIX 4C TEST 2B DOUBLE ANGLE PULL-OFF SPECIMEN



NOTE: Detail "A" assembly is cocured and then secondarily bonded with A7F adhesive as shown.

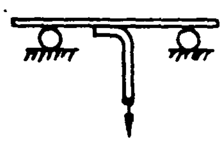
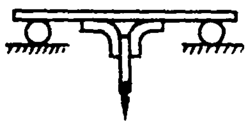
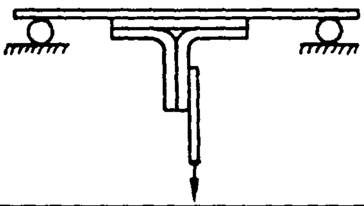
SPECIMEN WIDTH = 25.4 (1.0)

CONDITIONING: Thermally Aged 125 Hrs @ 589K (600°F)

DIMENSIONS: mm (in)

Figure 4-6: MATRIX 4C TEST 3B "T" PULL-OFF SPECIMEN

Table 4-9: TEST MATRIX 4C - SMALL SPECIMEN TESTS

TEST NO.	TEST SCHEMATIC	SPEC. CONFIG.	CONDITION [1]	NO. OF TESTS @ ROOM TEMP.	NO. OF TESTS @ 561K (550°F)	NO. OF SPEC.
1a		Figure 3.2-4	1	3	—	3
2b		Figure 3.2-5	2	3	3	6
3b		Figure 3.2-6	2	3	3	6

[1] CONDITION CODE

1 - As cured/postcured

2 - Soaked for 125 hrs at 589K (600°F) in a one (1) atmosphere environment (air).

3 - Thermally cycled 125 times in a temperature range from 116K to 589K (-250°F to 600°F) and in a one (1) atmosphere environment (air).

Table 4-10: GR/PI PREPREG LOTS USED FOR MATRIX 4

TEST SET	MATERIAL LOT	FIBER TYPE
4A	2W4604 2W4643	3000 3000
4B	2W4604 2W4632 2W4651	3000 3000 3000
4C	3W2020	3000

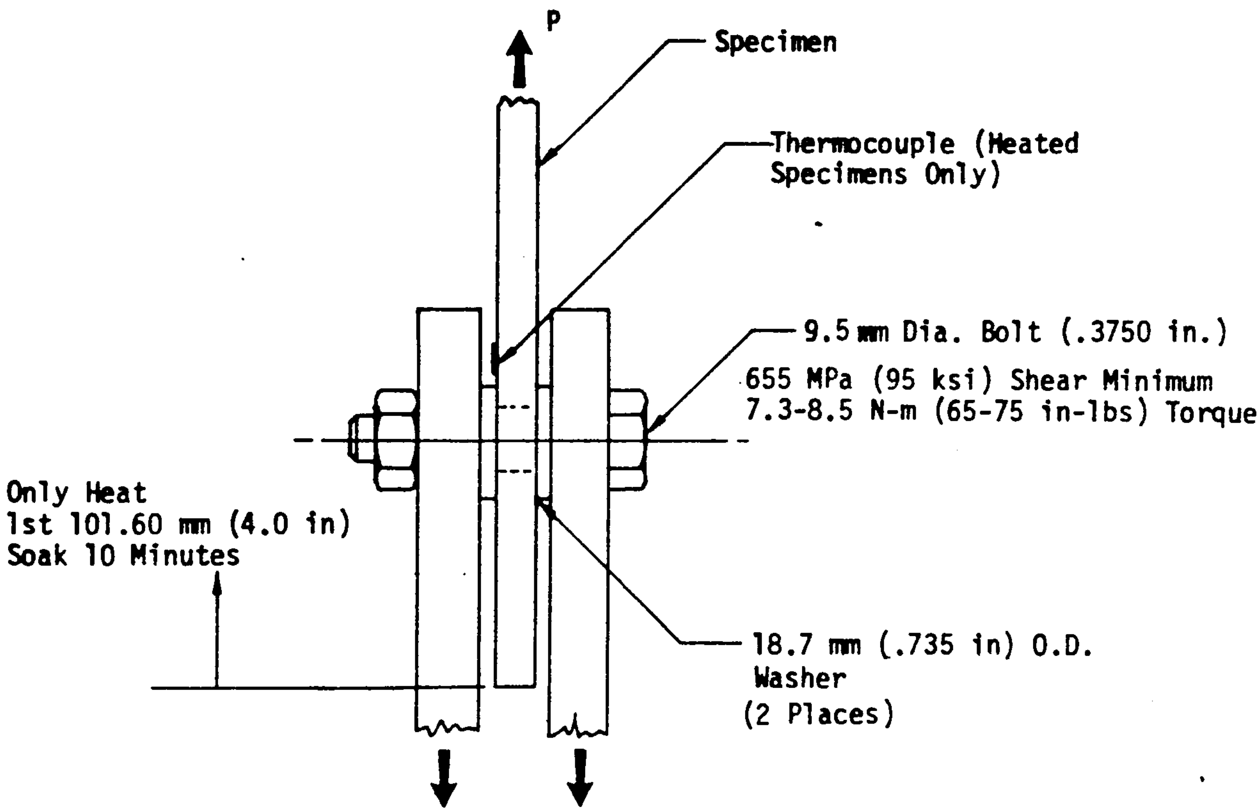


Figure 4-7: TEST SETUP, MATRIX 4A SHEAROUT, BEARING, NET TENSION LOADED HOLE TESTS

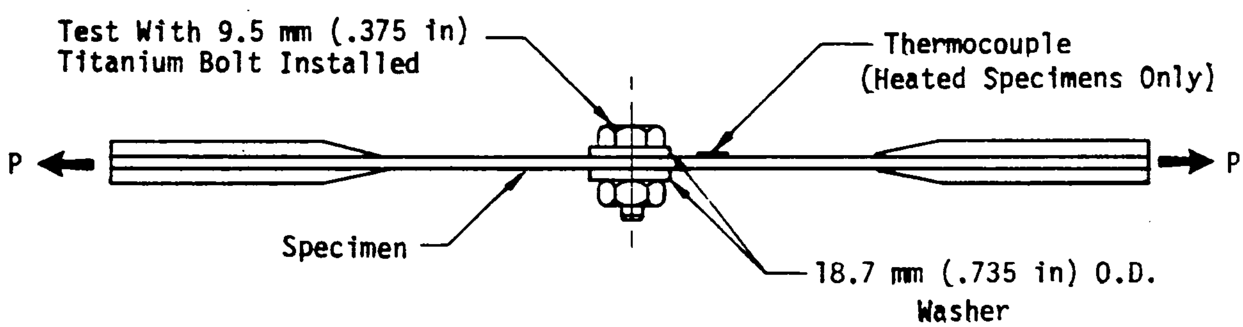


Figure 4-8: TEST SETUP, MATRIX 4A NET TENSION UNLOADED HOLE TESTS

Bolted Joint Allowables

Bolt shearout, bearing, and net tension failure stresses for a loaded hole were determined for a quasi-isotropic $(0/\pm45/90)_{8S}$ laminate. Specimens were loaded as shown in Figure 4-7. Net tension tests were also conducted for an unloaded but filled hole as shown in Figure 4-8. All holes were clamped with a 9mm (.375 inch) bolt and washer torqued to 7.2-8.5 N-m (65-75 in-lbs).

Test results for the shearout, bolt bearing, net tension loaded and net tension unloaded hole tests are shown in Figure 4-9. The data show a drop in strength at elevated temperatures, but no significant change due to the three environmental conditionings. The slight increase in failure stress at elevated temperature for the loaded and unloaded bolt hole test (see Figure 4-9) was caused by a softening of the matrix material. This reduced the severity of stress concentration at the hole edge. This slight increase in failure stress was not observed in the net tension loaded condition 1 tests. An explanation for this is that at elevated temperature the net tension failure mode was changing to a bearing mode. Since the glass transition temperature for condition 1 is lower than that for conditions 2 and 3, the bearing failure mode dominated causing the lower failure stress. Figures 4-10 through 4-13 show typical failed specimens for the shearout, bolt bearing, net tension loaded and net tension unloaded hole tests respectively. Raw data are given in Appendix A, Tables A-1 through A-4.

The net-tension strength is a function of the percentage of load going through the bolt. If a linear relationship is assumed, a plot of net tension strength versus percent load transfer is obtained as shown in Figure 4-14. Figure 4-14 is constructed utilizing minimum stresses for all net tension tests performed. This makes use of the figure conservative for bolted joint design. If there is only one bolt in a joint, there is then 100% load transfer and the minimum net-tension strength should be used for design. If there are two bolts an assumption of 50% load transfer is reasonable and a slightly higher net-tension stress could be used. For three or more bolts a detailed elastic analysis would be required to determine the percent load transfer and the corresponding allowable net tension stress.

L.J. Hart-Smith has postulated that the stress concentration factor around a loaded hole in a composite material, K_{tc}, is related to the elastic isotropic stress concentration factor, K_{te}, for the same specimen geometry (Ref. 7). The relationship is governed by the following equation:

$$K_{tc}-1 = c\ (K_{te}-1)$$

Where the coefficient c is determined by experiment.

The elastic isotropic stress concentration factor is given by

$$K_{te} = 2 + (\frac{w}{d} - 1) + 1.5\ \frac{(\frac{w}{d} - 1)}{(\frac{w}{d} + 1)}$$

With variables as defined in Figure 4-15.

The composite stress concentration factors are given by:

$$K_{tc} = F_{tu}\ t(w-d)/P$$

where

F_{tu}	=	Ultimate tensile strength of base laminate
t	=	Laminate thickness
P	=	Failure load.

The coefficient c is determined by plotting the observed composite stress concentration factor, K_{tc}, versus the corresponding elastic isotropic stress concentration factor, K_{te}. Linear regression is used to fit a line through the data points. The line is forced through the point (1,1) as this corresponds to the case with no hole in the material. The slope of the line is the coefficient c. These curves can then be used to predict the failure loads for different geometries (i.e., varied widths, edge distances, etc.); however, they are only valid for the particular material, laminate, bolt size and environment tested.

Figures 4-16 through 4-18 are plots of composite versus isotropic stress concentration factors for the loaded hole tests from Matrix 4A. Each curve is for a specific test temperature and conditioning. The values of the coefficient c range from 0.371 to 0.575. A typical value for $(0/\pm45/90)_{NS}$ layups of graphite/epoxy, given in Reference 7, is 0.26. This indicates that Gr/PI laminates are more sensitive to holes than Gr/Epoxy laminates.

Note that the stress concentration factor method correlates well with the data even though the failure modes are different (i.e., shearout, bearing, and net tension).

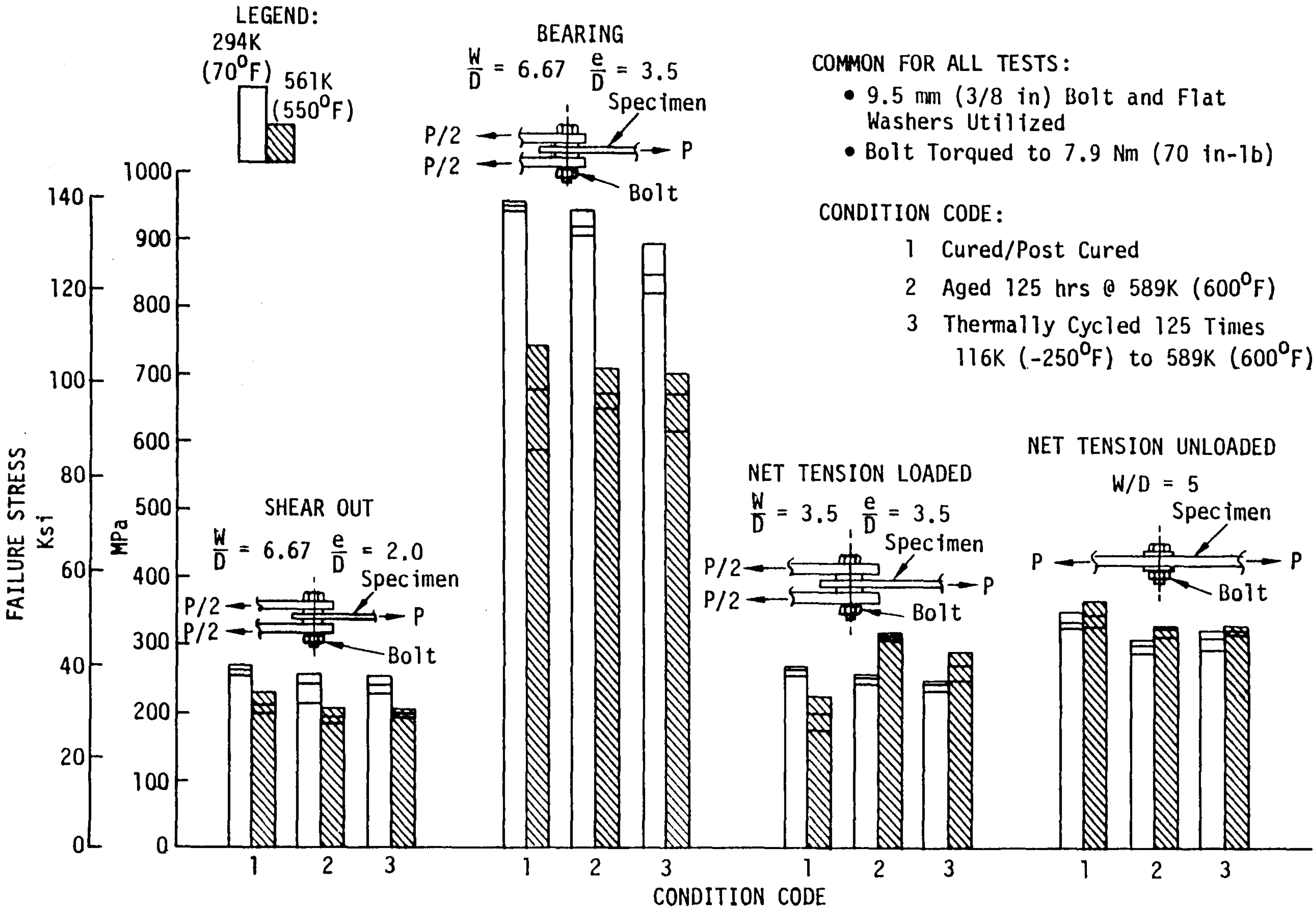


Figure 4-9: SUMMARY OF SMALL COMPONENT BOLTED JOINT TESTS CELION 3000/PMR-15 $(0/\pm45/90)_{8S}$

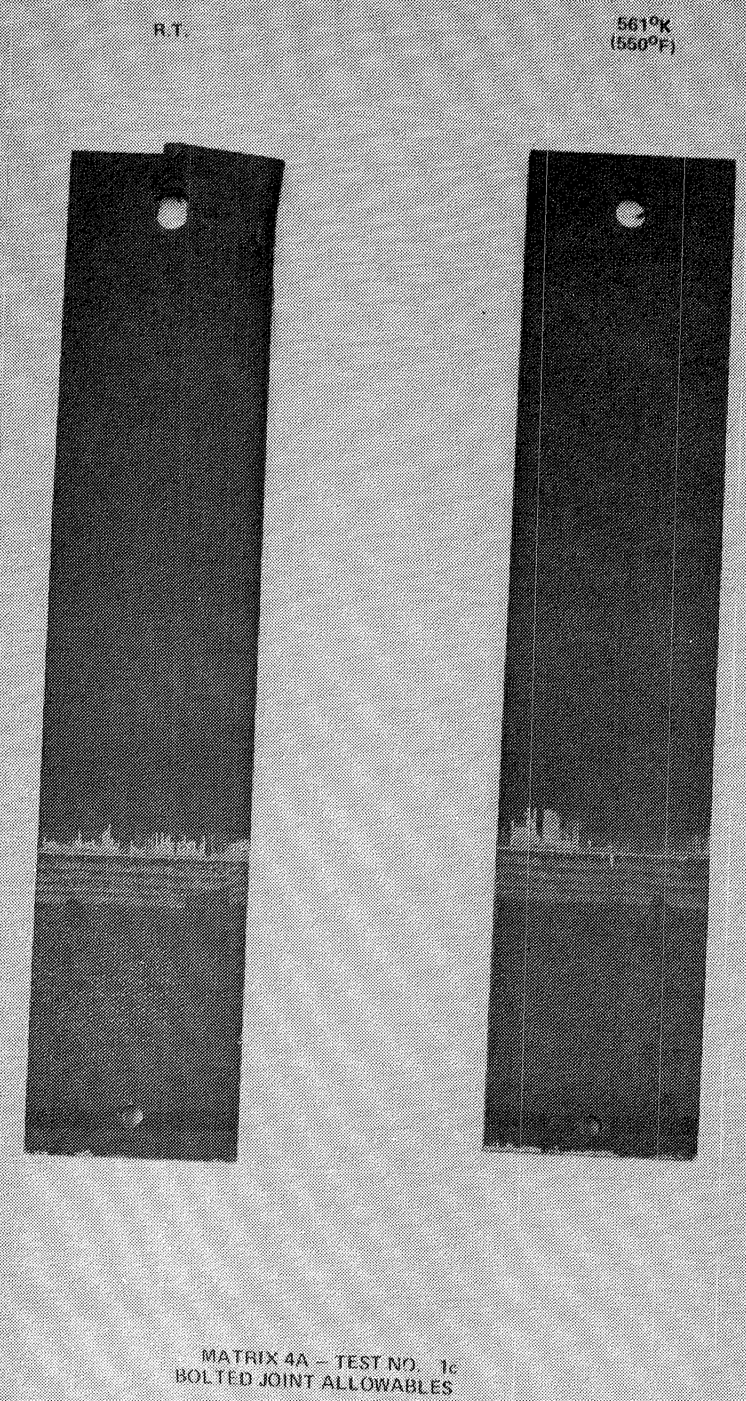


Figure 4-10: MATRIX 4A TEST 1C SHEAROUT TESTS - FAILED SPECIMENS

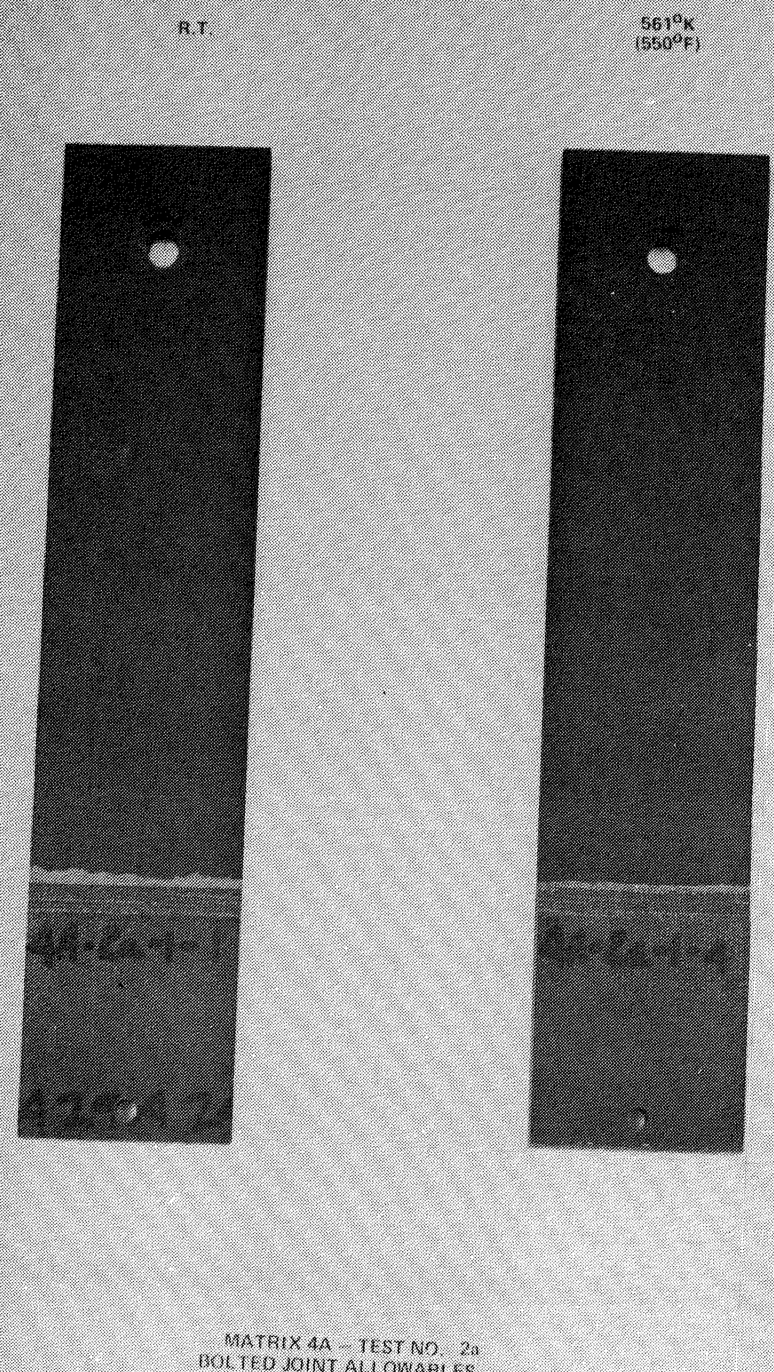


Figure 4-11: MATRIX 4A TEST 2A BEARING TESTS - FAILED SPECIMENS

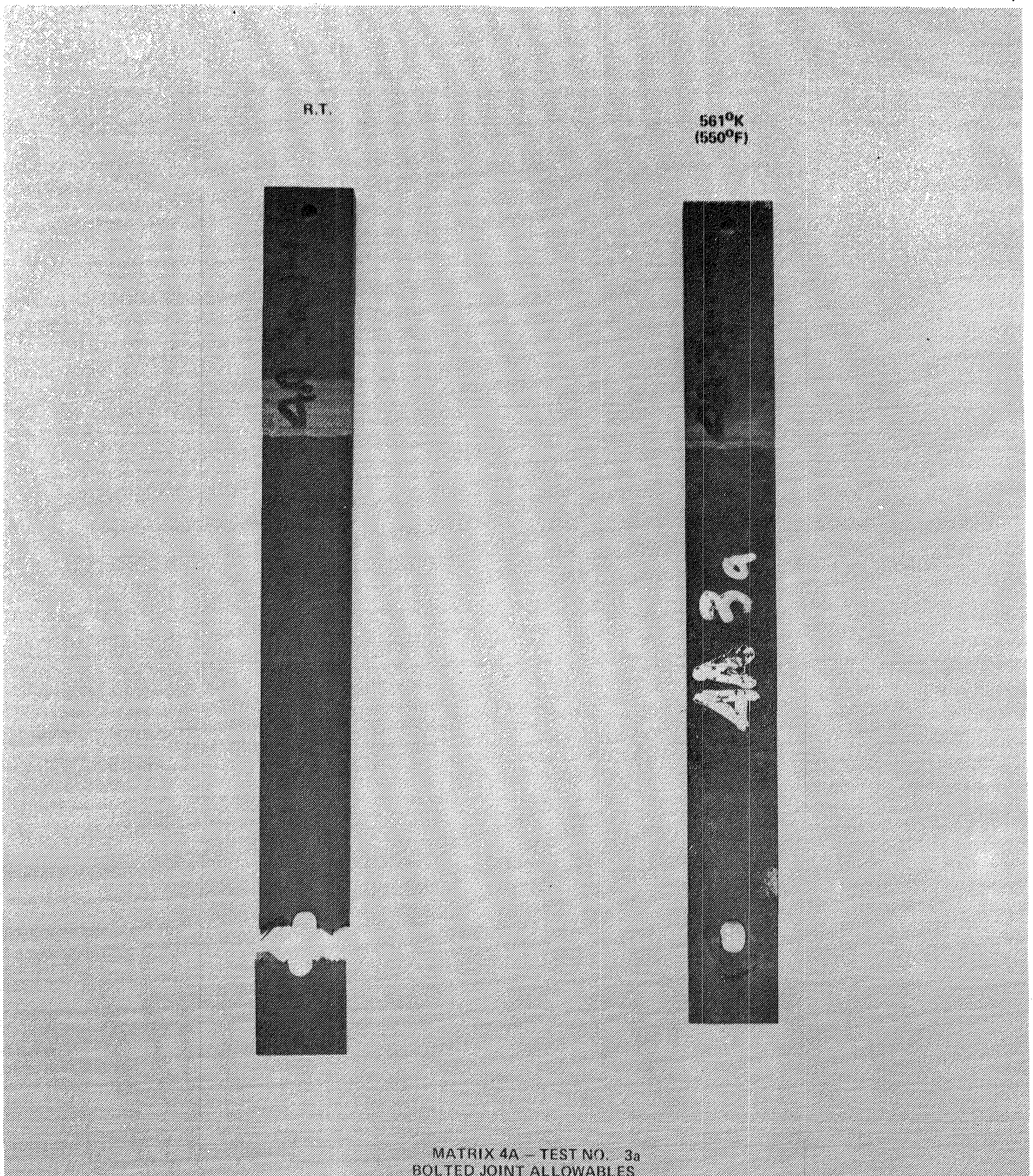


Figure 4-12: MATRIX 4A TEST 3A NET TENSION LOADED HOLE TESTS - FAILED SPECIMENS

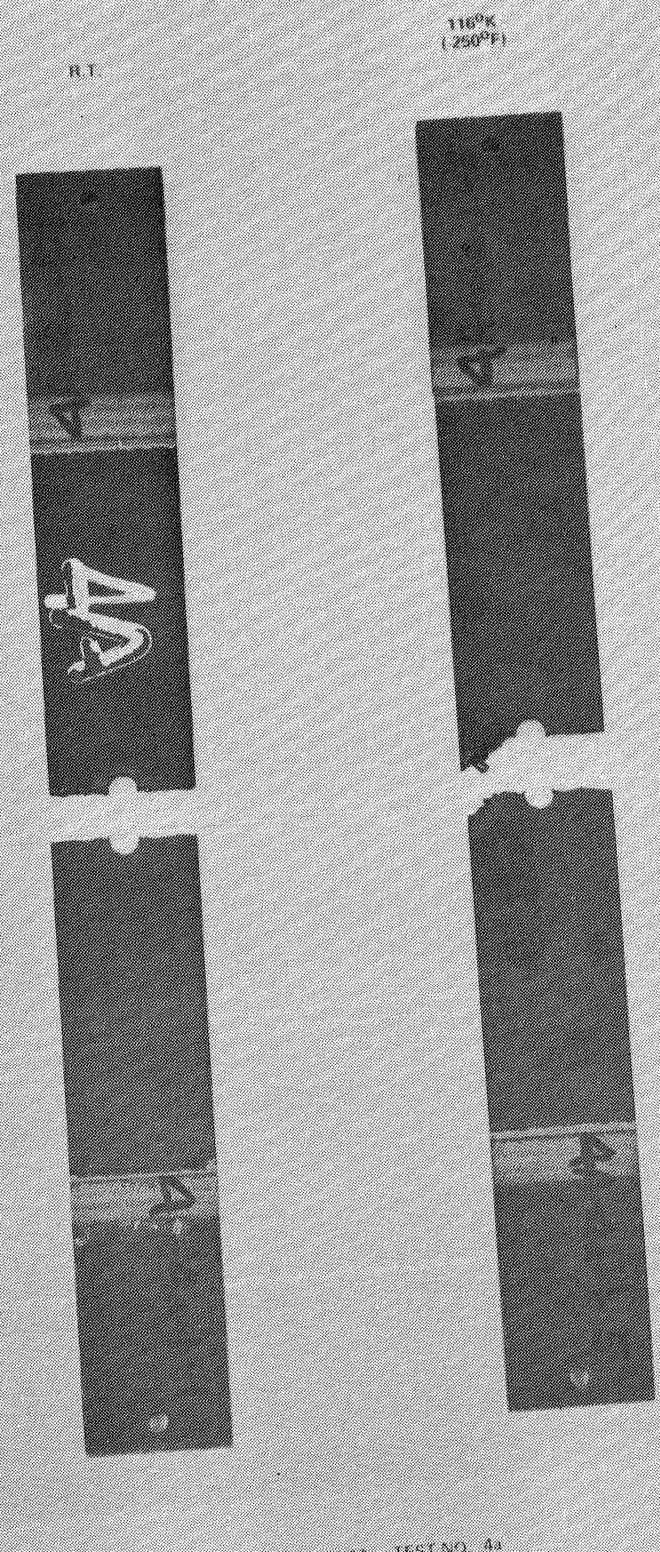


Figure 4-13: MATRIX 4A TEST 4A NET TENSION UNLOADED HOLE TESTS - FAILED SPECIMENS

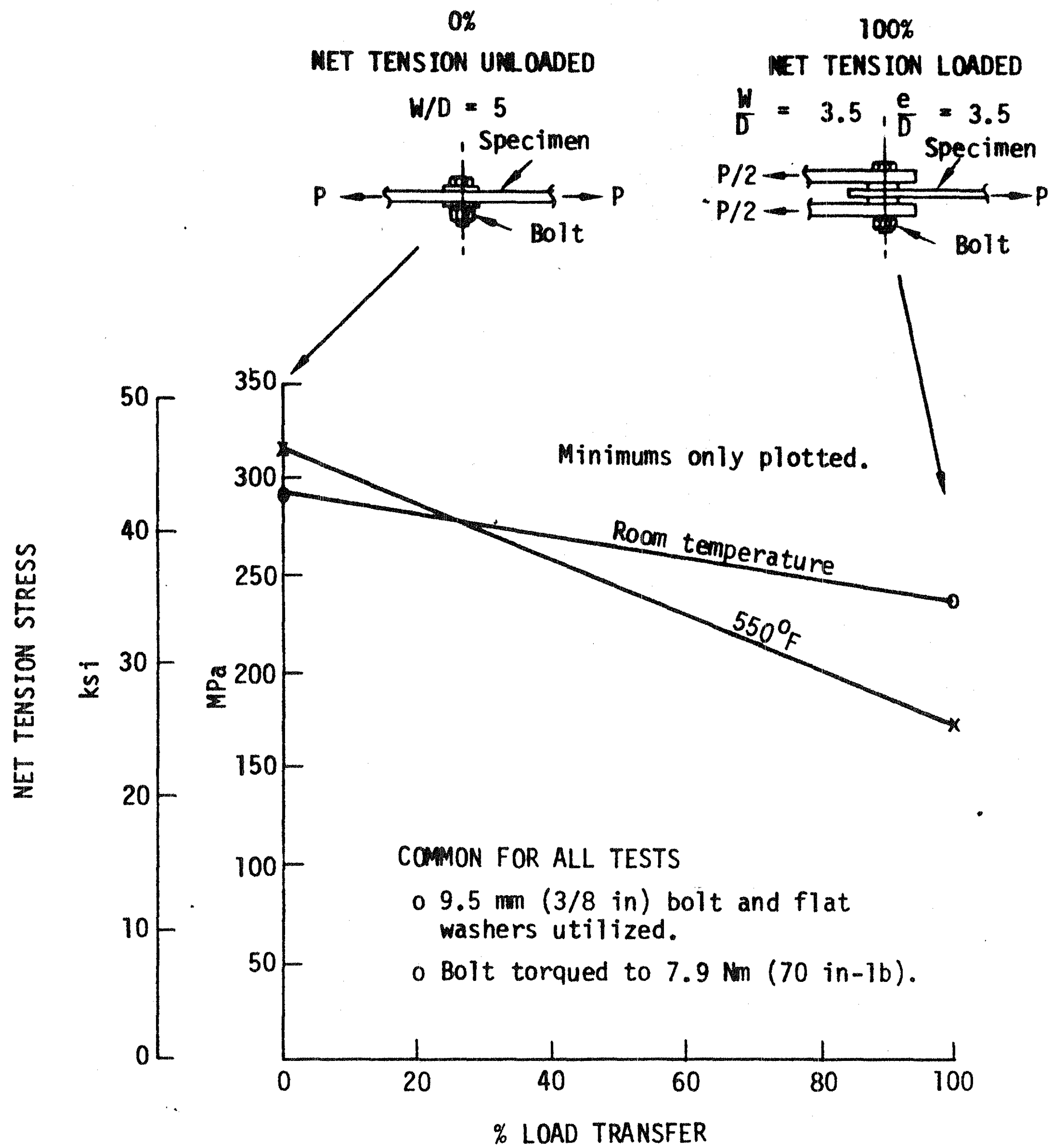
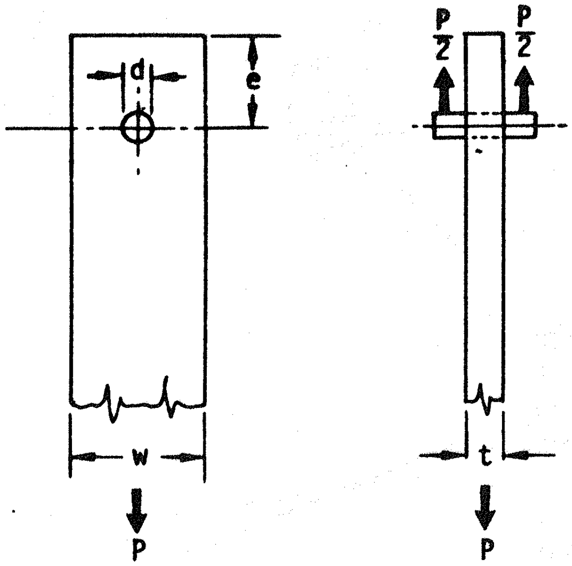


Figure 4-14: MINIMUM LOADED AND UNLOADED HOLE NET TENSION STRESSES $(0,\pm45,90)_{8s}$ CELION 3000/PMR-15



$$k_{te} = 2 + \left(\frac{w}{d} - 1\right) - 1.5 \; \frac{(w/d - 1)}{(w/d + 1)} \; \theta$$

in which the parameter θ is defined as

$$\theta = 1.5 - 0.5/(e/w) \quad \text{for } e/w \leq 1$$
$$\theta = 1 \quad \text{for } e/w \geq 1$$

$$\sigma_{max} = k_{te} \, \frac{P}{t(w - d)}$$

Figure 4-15: ELASTIC ISOTROPIC STRESS CONCENTRATION FACTOR COMPUTATION (REF)

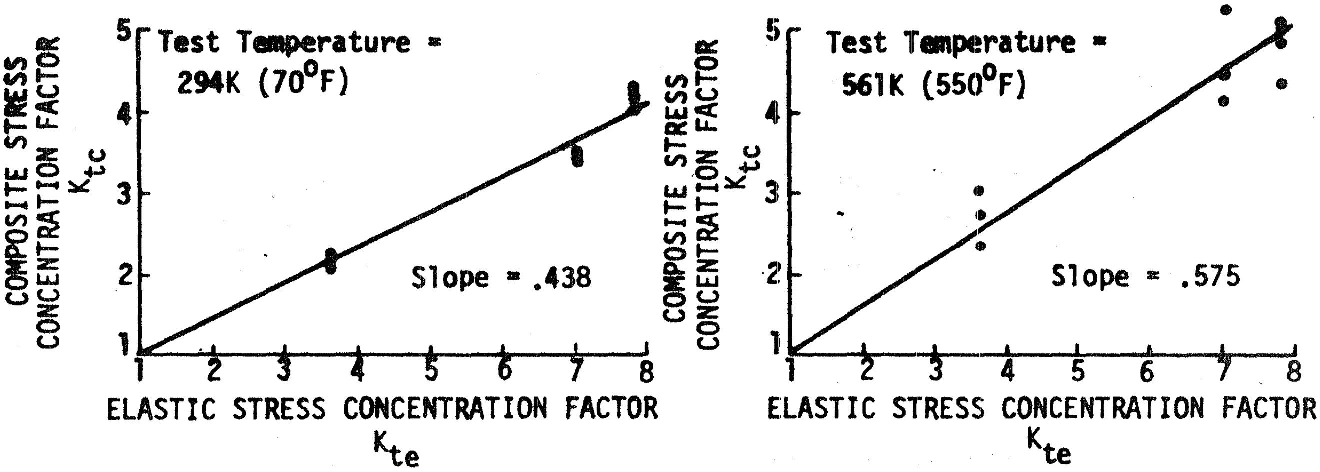


Figure 4-16: CELION 3000/PMR-15 STRESS CONCENTRATION FACTOR CORRELATION (LAMINATE CONDITIONING: AS CURED/POST CURED)

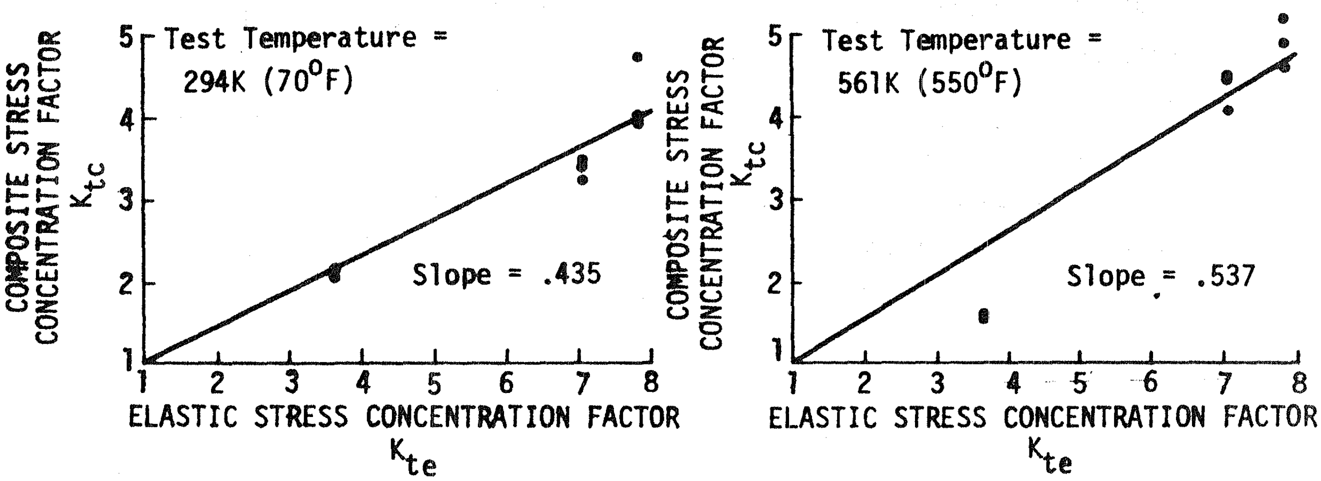


Figure 4-17: CELION 3000/PMR-15 STRESS CONCENTRATION FACTOR CORRELATION (LAMINATE CONDITIONING: THERMALLY AGED)

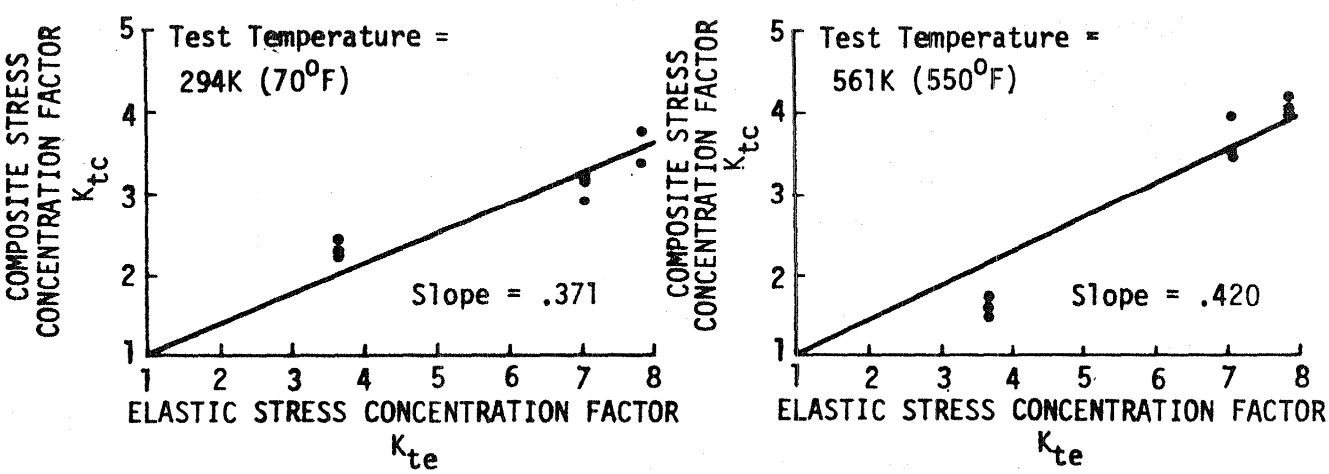


Figure 4-18: CELION 3000/PMR-15 STRESS CONCENTRATION FACTOR CORRELATION (LAMINATE CONDITIONING: THERMALLY CYCLED)

Bonded versus Co-Cured Doubler

Tests of co-cured doublers versus secondarily bonded were conducted using the test set-up shown in Figure 4-19. Each specimen had a clamping washer on only one side. The bolt was torqued to 7.3-8.5 N-m (65-75 in-lbs).

Typical failed specimens are shown in Figures 4-20 and 4-21. Raw data are given in Appendix A, Tables A-5 and A-6. In general, the doubler sheared off the base laminate and then the base laminate failed in net tension at the hole. Simultaneously (based on visual observation) there was a tension failure of the base laminate away from the doubler and bolt hole. Free field laminate stresses at failure were slightly lower than the ultimate stresses measured in the design allowables program. Test results are shown in Figure 4-22. The base laminate stresses away from the hole are plotted so that the relative merits of co-cured versus bonded doublers can be compared. The failure modes were the same in all specimens, with the exception that some failed in the tab area. Bonded doublers failed at lower loads than the co-cured doubler. It was concluded that the co-cured doubler was stronger and it was used for the TASK 1.3 "Static Discriminator" specimens (subsequent tests showed these were not adequate and an interleaved doubler was tested (see section 5.4)).

Bonded Web Attachment Tension Tests

Tension test set-ups and results of the three bonded web attachment concepts are shown in Figure 4-23. Typical failed specimens for these configurations are shown in Figures 4-24 through 4-26. Raw data are given in Appendix A, Tables A-7 through A-9. Results for the room temperature single 90^{o} angle were below the minimum design requirement; therefore, the elevated temperature tests were not conducted. The double angle attachment had average failure loads of 40.1 kN/m (229 lbs/in) and 46.9 kN/m (268 lbs/in) at 294K (70^{o}F) and 561K (550^{o}F) respectively. The "T" attachment averages were 55.3 kN/m (316 lbs/in) and 51.7 kN/m (295 lbs/in) respectively. Since the 90^{o} angles are easier to fabricate than a "T" section and they exceed the maximum design load requirement of 28.7 kN/m (164 lbs/in), they were used for the bonded web attachments for Type 1 and Type 4 joints.

Bonded Double-Lap Joint With Honeycomb Sandwich Inner Adherend

Only 45.7mm (1.8 inch) double lap bonded joints of honeycomb sandwich with concurred doublers (Matrix 4B, test 4A) were tested. All specimens failed in the laminate near the end of the load grip (hydraulic grips were used). Typical failed specimens are shown in Figure 4-27. Raw data are given in Appendix A, Table A-10. Average failure loads at room temperature and 561 K (550^{o}F) were 420 kN/m (2400 lbs/in) and 402 kN/m (2295 lbs/in) respectively. These correspond to average laminate stresses of 409 MPa (59.3 ksi) and 388 MPa (56.3 ksi) which are approximately 73% of ultimate. Some of the specimens had signs of first ply damage in the bonded areas of the load tabs which would explain the low failure loads. Interleaved doublers were used for the Type 1 bonded and bolted joints; therefore, these tests were redundant to the special interleaved doubler tests discussed in Section 5-4. No retesting was performed.

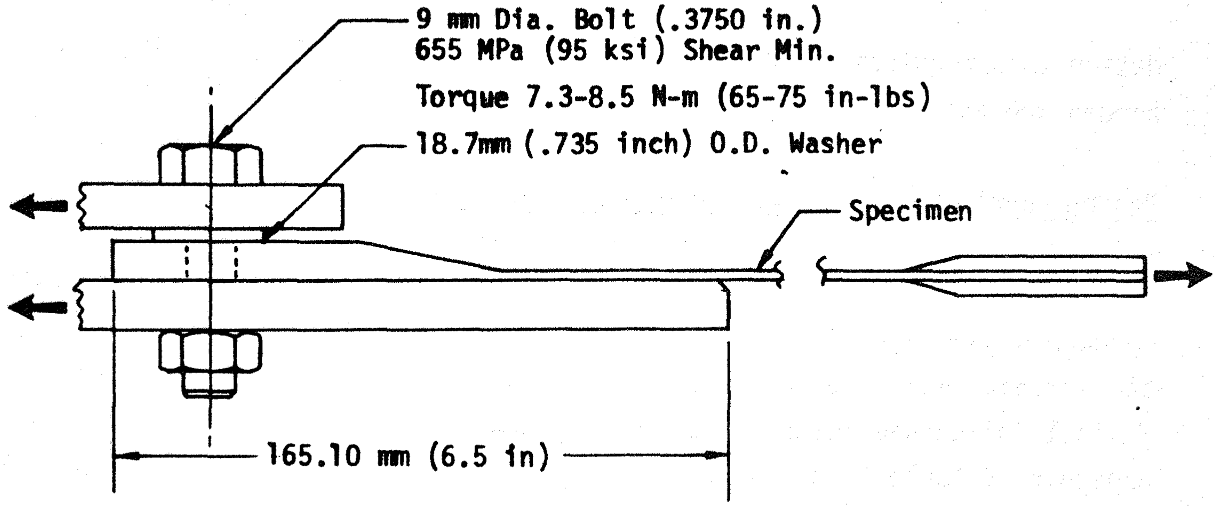


Figure 4-19: TEST SETUP, MATRIX 4B, BONDED VS. CO-CURED DOUBLER TESTS

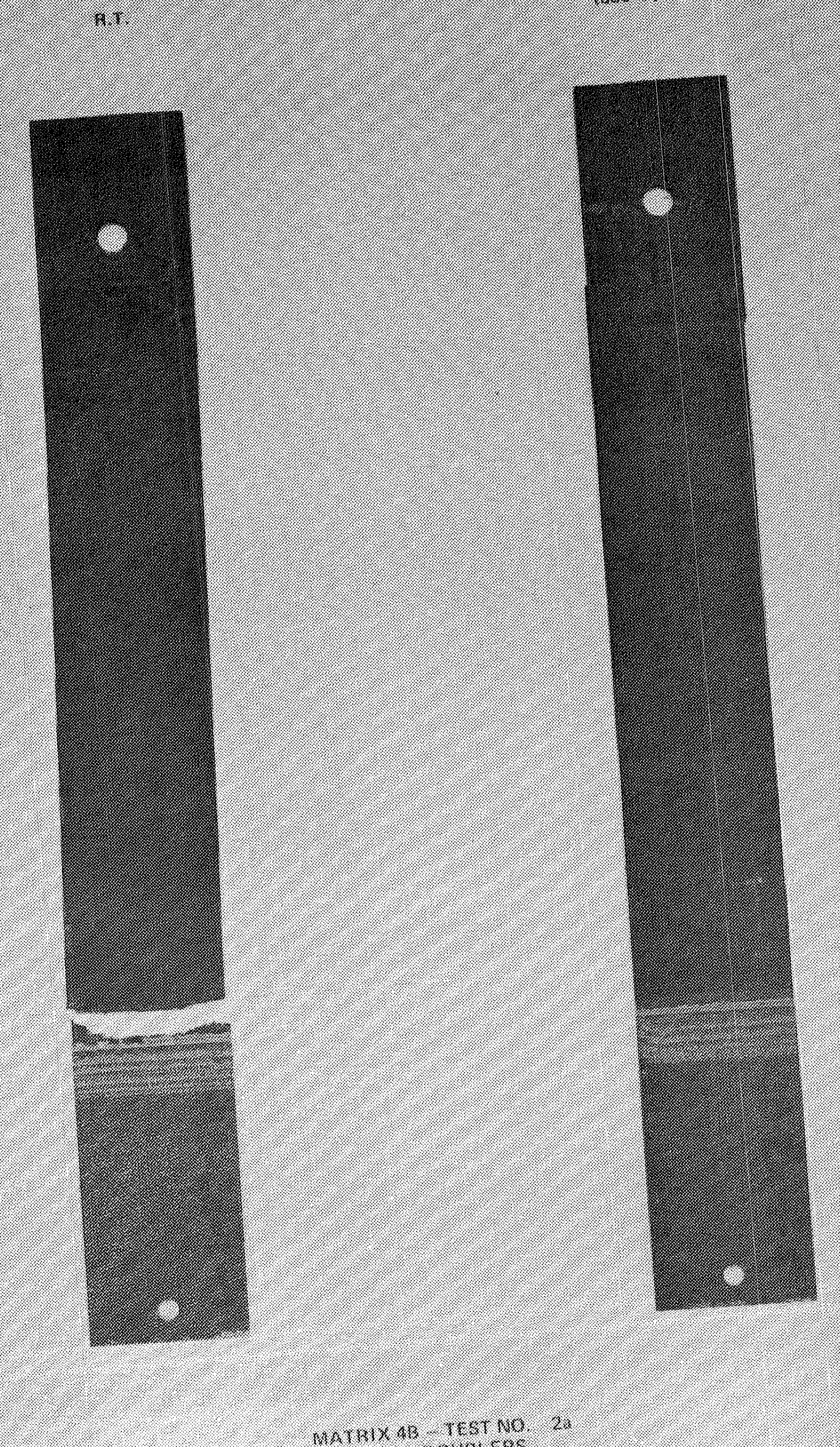


Figure 4-20: MATRIX 4B TEST 2A COCURED DOUBLERS - FAILED SPECIMENS

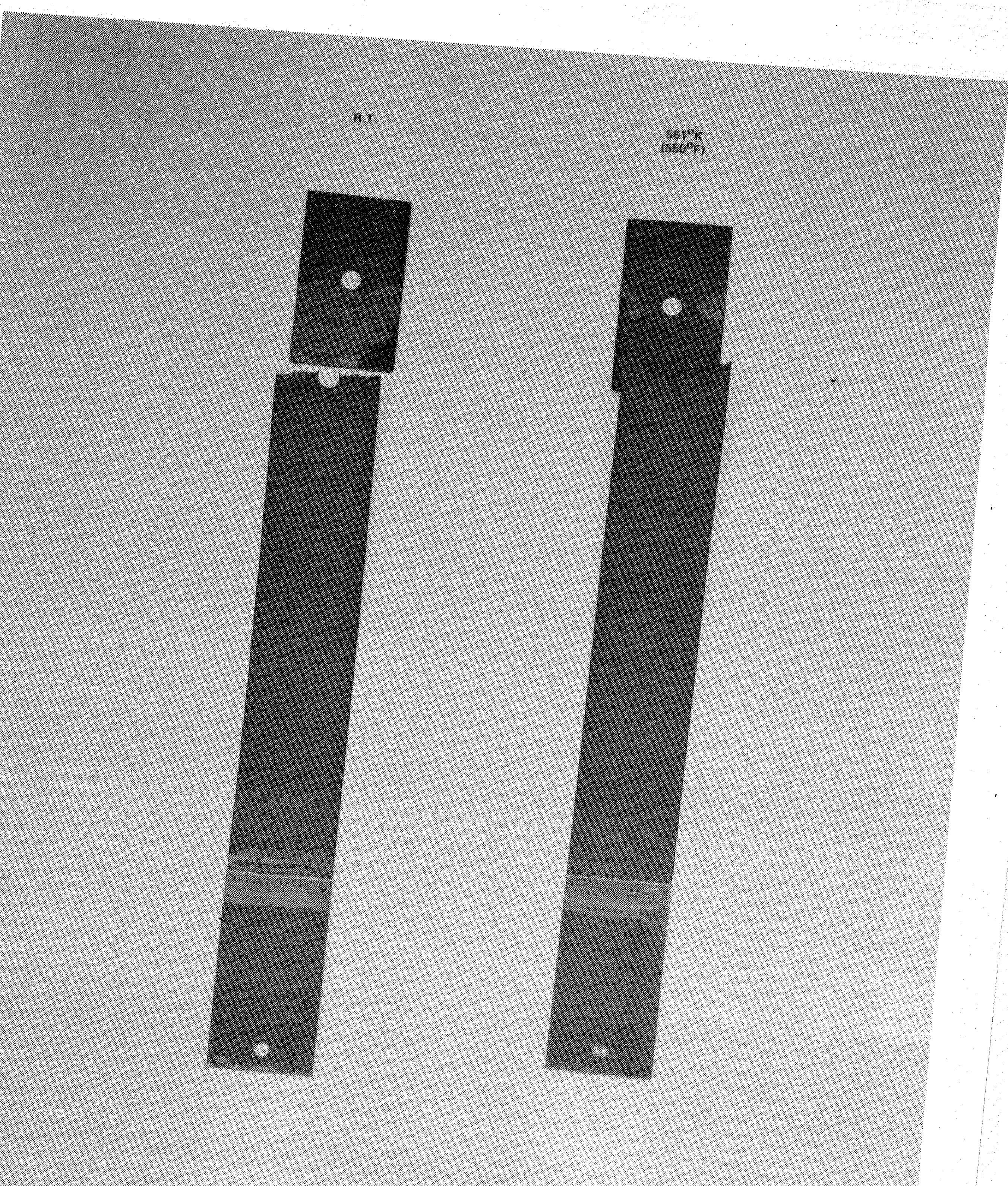


Figure 4-21: MATRIX 4B TEST 1B SECONDARILY BONDED DOUBLERS - FAILED SPECIMENS

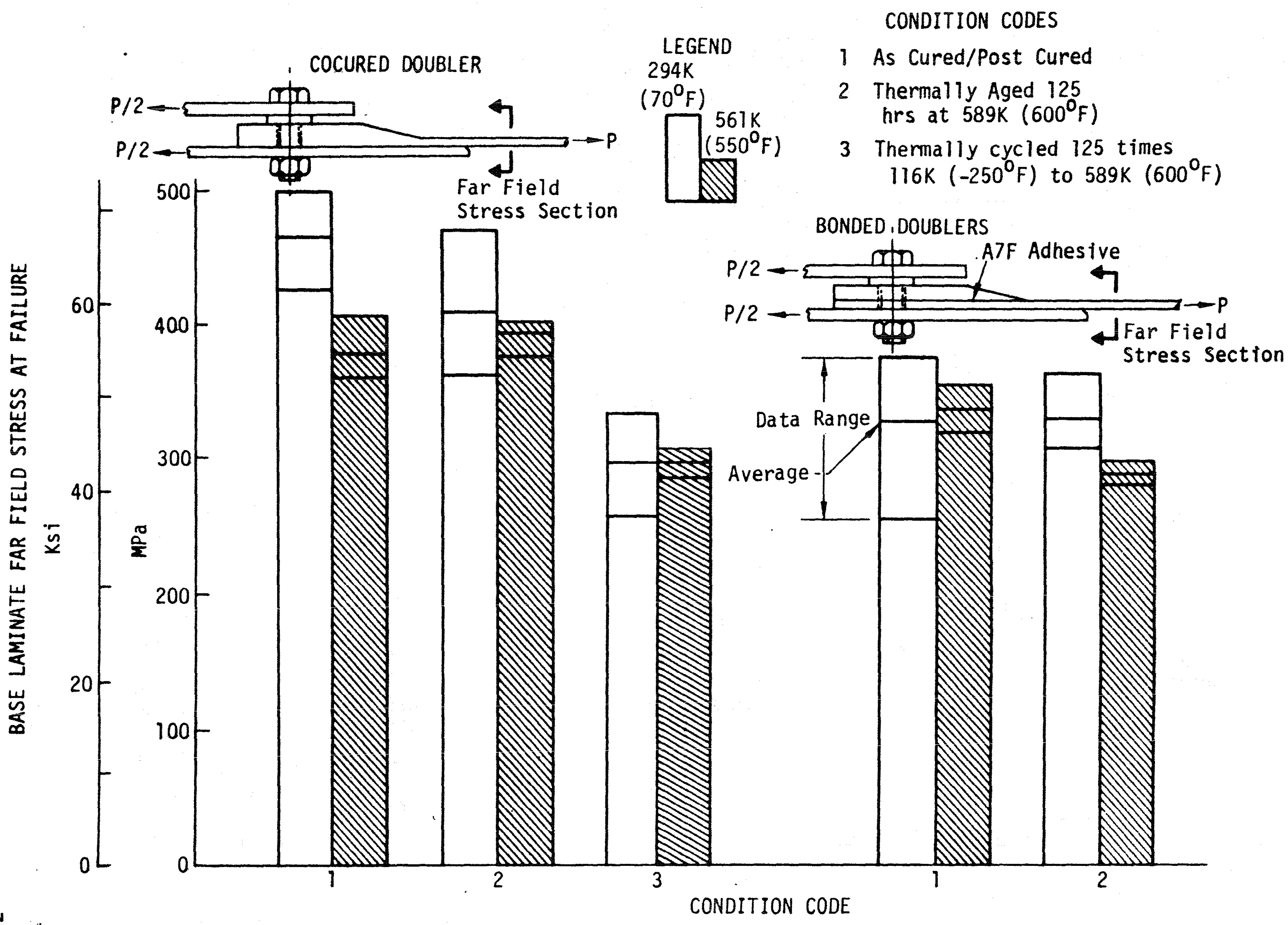


Figure 4-22: SMALL COMPONENT TEST RESULTS OF COCURED AND BONDED DOUBLERS - CELION 3000/PMR-15

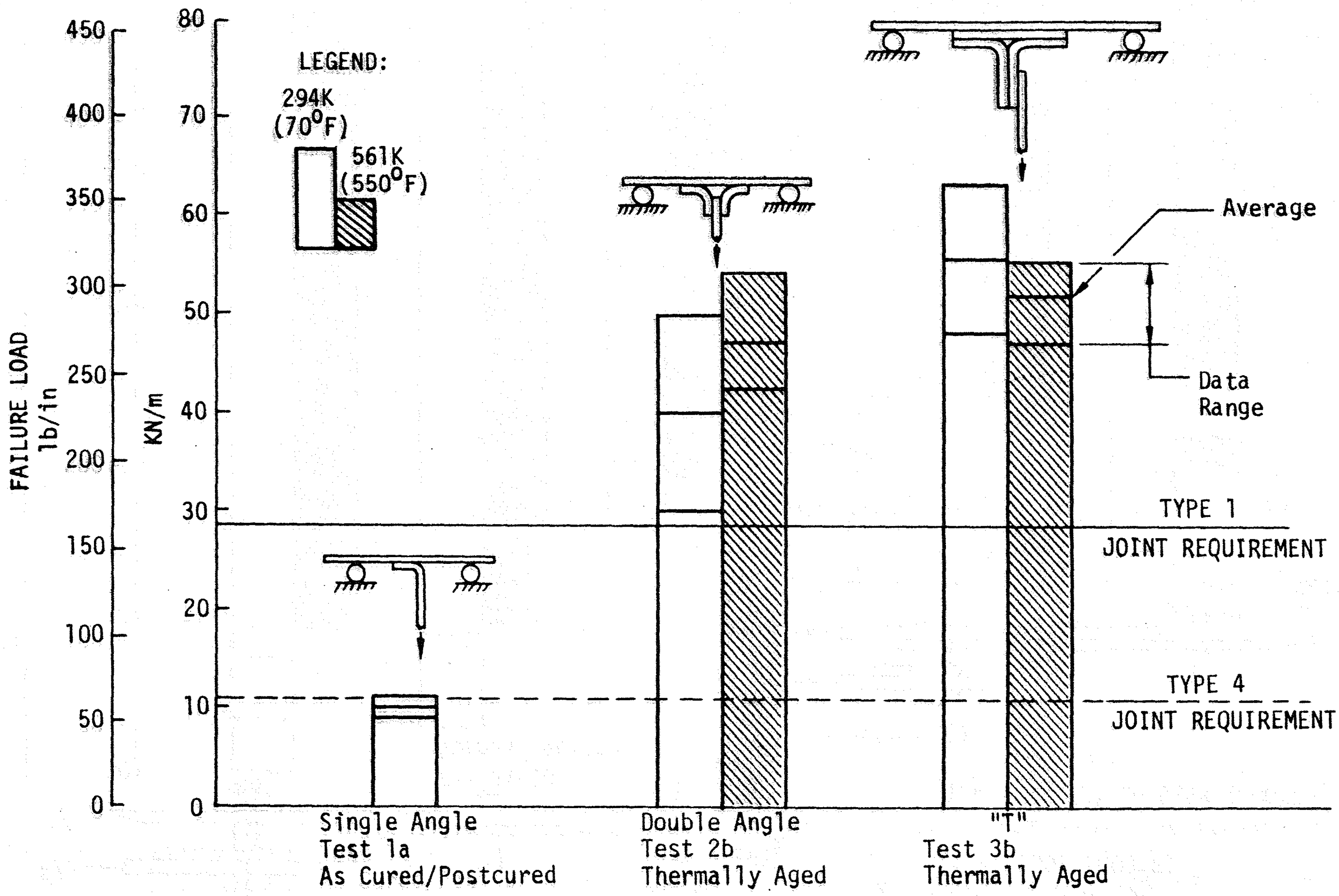


Figure 4-23: SMALL COMPONENT BONDED ATTACHMENT ANGLE PULL-OFF TESTS–CELION 3000/PMR-15

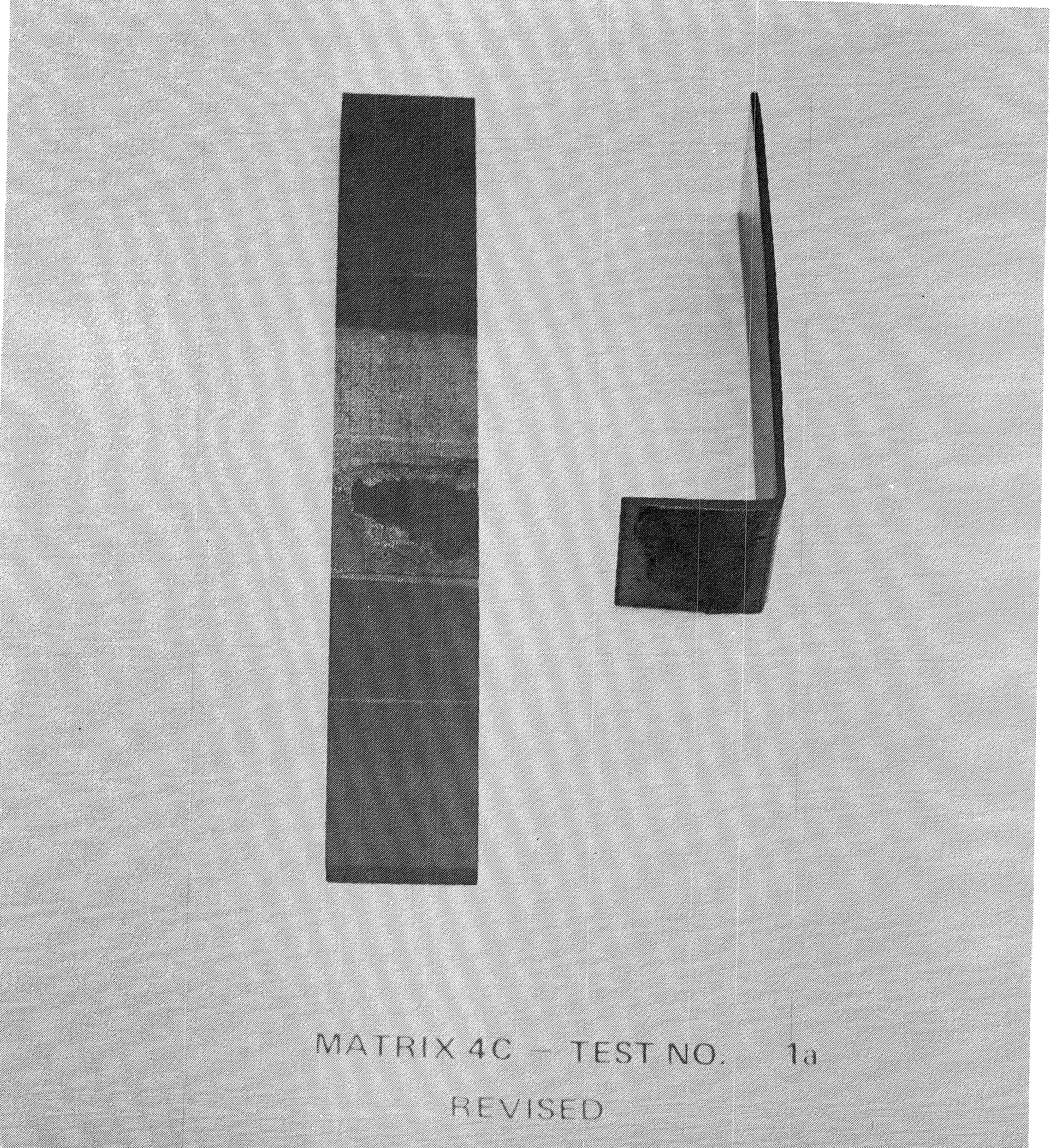


Figure 4-24: MATRIX 4C TEST 1A SINGLE ANGLE PULL-OFF TESTS - FAILED SPECIMEN

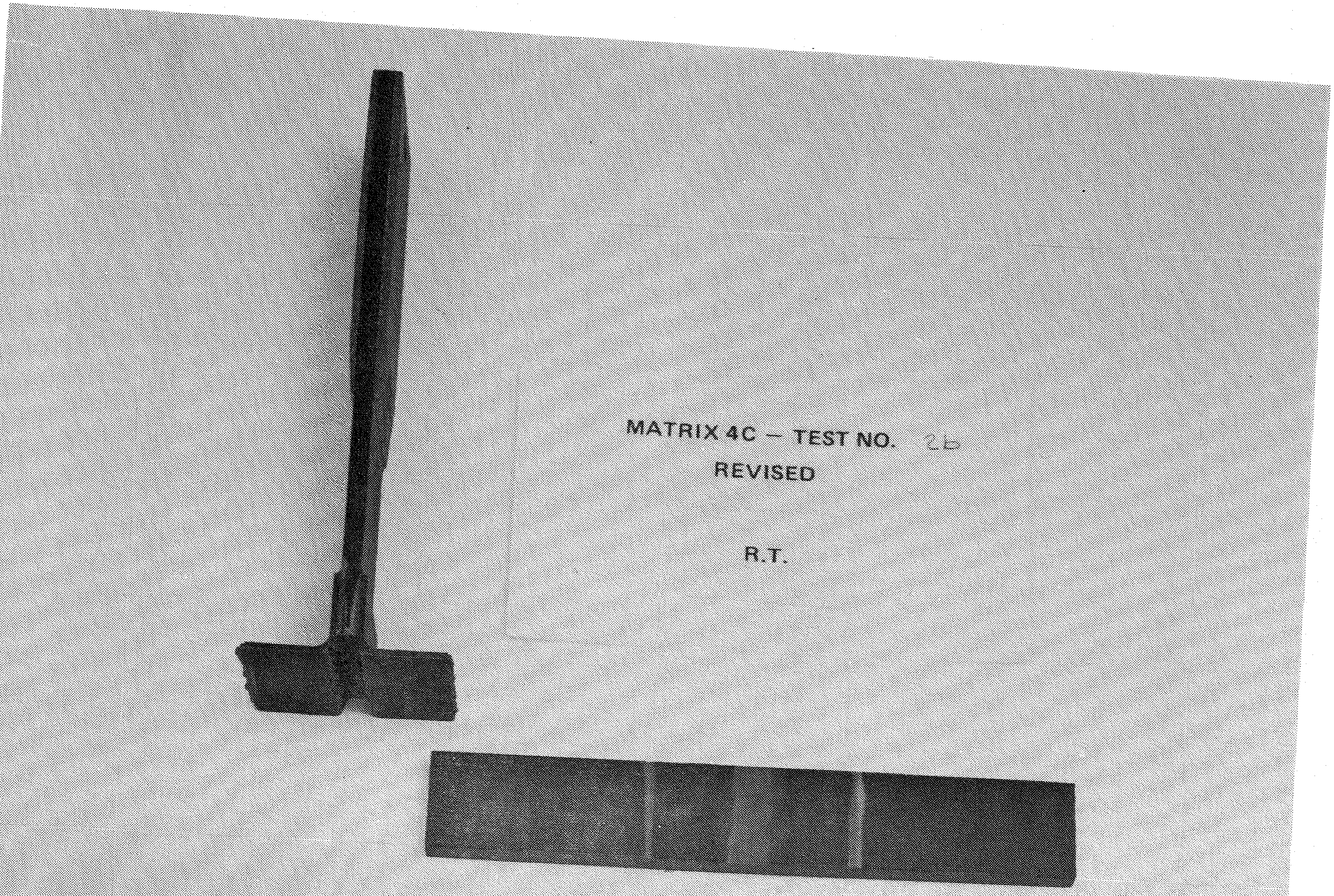


Figure 4-25: MATRIX 4C TEST 2B DOUBLE ANGLE PULL-OFF TESTS - FAILED SPECIMENS

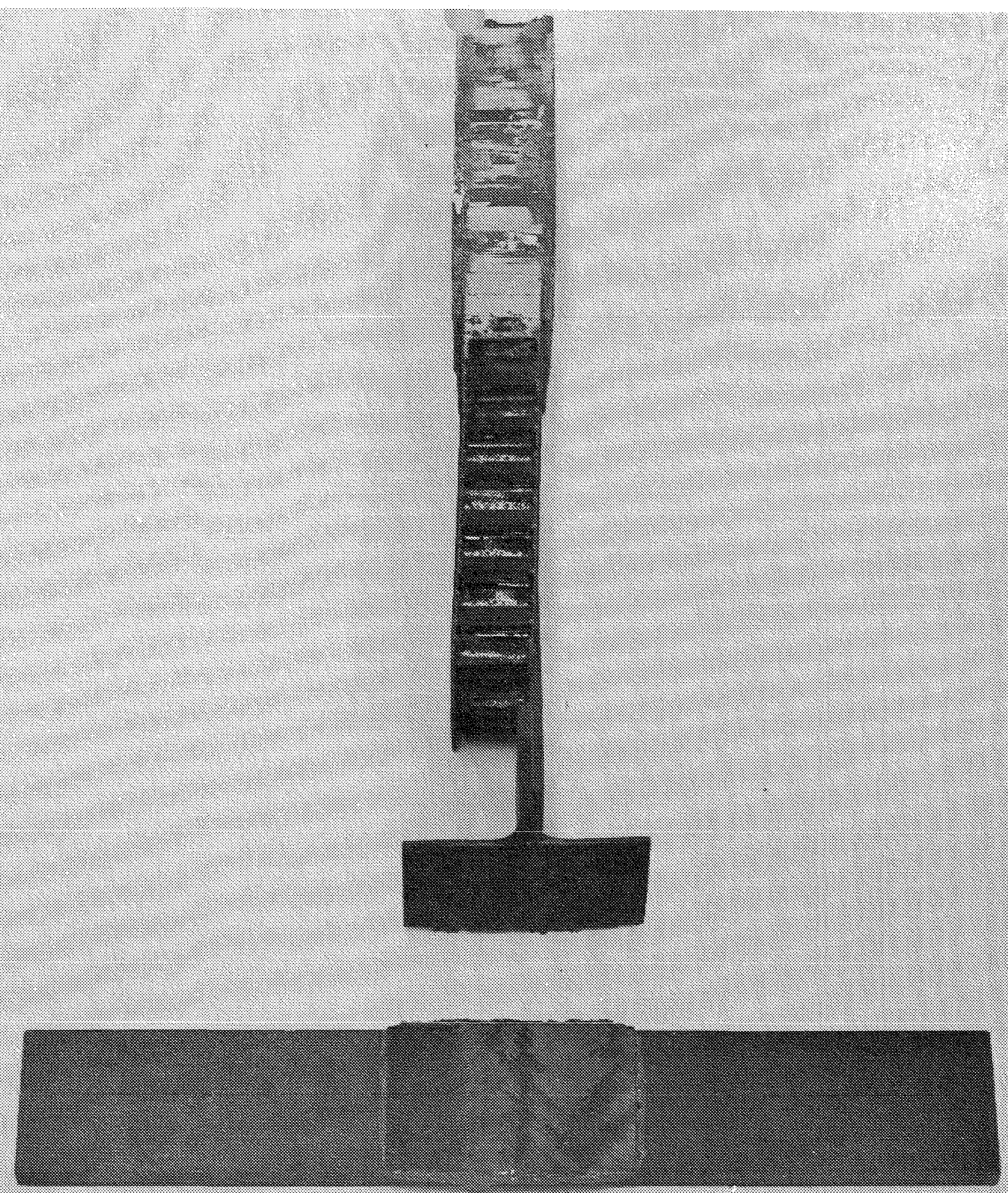


Figure 4-26: MATRIX 4C TEST 4B "T" SECTION PULL-OFF TESTS - FAILED SPECIMEN

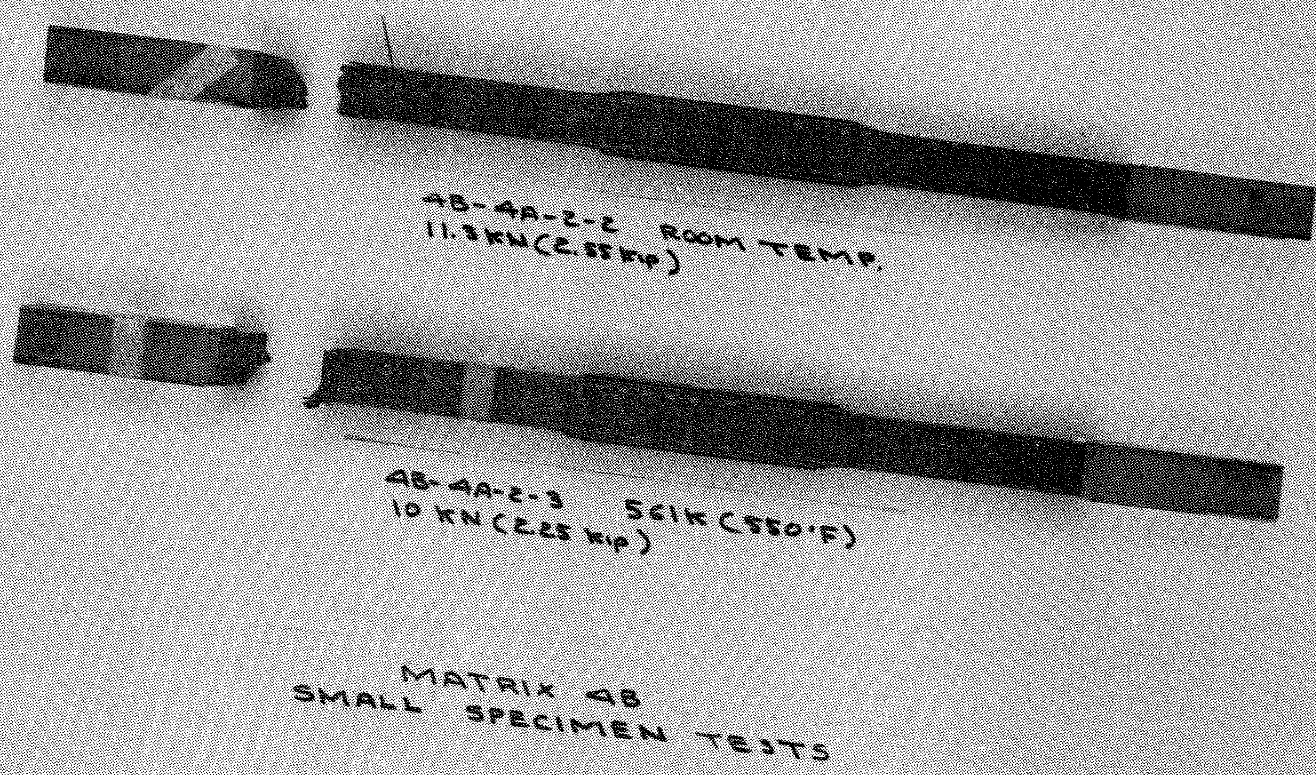


Figure 4-27: MATRIX 4B TEST 4A BONDED DOUBLE LAP JOINT WITH HONEYCOMB SANDWICH INNER ADHEREND - FAILED SPECIMENS

5.0 PRELIMINARY EVALUATION OF ATTACHMENT CONCEPTS

Baseline joint concepts were defined by the screening process discussed in Section 3.7. Design data from the material properties and "Small Specimen" tests discussed in Section 4.0 along with standard bonded joint tests under TASK 2 were used to define the preliminary joint designs presented in this section. This section discusses the selection of the "Static Discriminator" test specimens, their fabrication and processing, test procedures and results and test/analysis correlation.

5.1 Preliminary Joint Designs

The screening results presented in Section 3.7 and "Small Specimen" results of Section 4.3 were used to arrive at preliminary joint designs. Detail drawings of the preliminary designs are shown in Appendix B. Specimens were designed to fail outside the joint area for the design loads given in Section 3.5.

The preliminary joint designs presented in this section were for the "Static Discriminator" test specimens. The "Static Discriminator" tests were to evaluate the proposed joint designs early in the program, on a small scale, to verify that the joints could be fabricated and would carry the design loads. These tests would verify the material properties used and identify any design deficiencies. All specimens tested were cured/post-cured only. There were no tests of environmentally conditioned specimens. A brief description of each specimen design follows.

Type 1 Bonded Joint

As a result of the concept screening a double lap joint with the inner adherend being a laminate and honeycomb core construction was selected for the Type I bonded joint (see Figure 3-19). The bond lap length was selected to result in failure of the basic cover outside the joint area. Results of the Task 2.0 double lap standard bonded joints were used to select the lap length and adherend thickness required. To fail the cover skins away from the joint would require an equivalent line load of 560 kN/m (3200 lbs/in). Results of the standard bonded joint tests showed that a lap length of 33.0mm (1.3 inch) with inner and outer adherend thicknesses of 3.05mm (.12 inch) and 1.52mm (.06 inch) respectively were needed to carry the load. This meant the basic cover had to be reinforced in the joint area. Results of the standard double lap bonded joint tests had also shown a significant increase in joint performance was achieved by tapering the outer adherends and by increasing the laminate axial and flexural stiffness. This was accomplished in the joint design by making the cover reinforcements and splice plates with approximately 33% 45^0 plies and 67% 0^0 plies. Reinforcement plies were stacked on the basic core laminate and co-cured. The splice plates were cured and then had the taper machined. The "Static Discriminator" test specimens were loaded by tension only in the plane of the cover. To reduce specimen costs, the web and web attach angles were deleted since they do not contribute to the primary load path. The stiffness of the bonded on attach angles was simulated by bonding on an equivalent thickness "doubler" of Gr/PI to the lower splice plate.

Type 1 Bolted Joint

Results of the screening study showed the Type 1 Bolted Joint should also be a double lap joint with the inner adherend of laminate and honeycomb core construction (see Figure 3-20). The equivalent line load to break the cover outside the joint was 560 kN/m (3200 lbs/in). Reinforcement of the cover at the joint area was required to carry this load. Bolt bearing, net tension and shear-out strengths for the quasi-isotropic laminate were determined by the bolt allowables tests described in Section 3.2.2. The splice plates were designed to have a bearing failure first to prevent a "two part" catastrophic failure of the plates. Reinforcement of the cover was achieved by stacking the reinforcing plies on the basic laminate and co-curing. Since the web and attachment angles do not contribute to the tension strength, these parts were not included in the joint design.

Type 2 Bonded Joint

Results of the screening study showed the Type 2 Bonded Joint should be of the basic concept shown in Figure 3-21. In this design, the cover and web are bonded to the corner angle in separate operations and proper bonding pressure can be maintained. The corner angle was sized to carry the moment around the corner. Bonded lap lengths were selected to carry the equivalent line loads resulting from the moments.

Type 2 Bolted Joint

The screening study showed the Type 2 Bolted Joint should be of the configuration shown in Figure 3-22. The inner and outer corner angles were sized to carry the design moment around the corner and the resulting bending loads.

Type 3 Bonded Joint

The screening process showed that the Type 3 Bonded Joint would have to be a symmetric step-lap design to carry the large design load (see Figure 3-23). Symmetric step-lap joints were tested during standard bonded joint tests of TASK 2.0 (Ref. 3). During the TASK 2.0 testing it was found that small scale joints could be fabricated and bonded successfully, and it was demonstrated that a Gr/PI to titanium "3-step" symmetric step lap joint could carry loads up to 875 kN/m (5000 lb/in) at 561K (550^{o}F). However, when thicker laminates and longer lap lengths were attempted the bonding was unsuccessful. It was decided to use the "Static Discriminator" tests to conduct additional evaluation of possible co-curing processing techniques for the thicker step lap joints. A simple specimen configuration was chosen to minimize costs while demonstrating the adequacy of the co-curing processing. The first specimens were made by prestaging the adhesive primer to eliminate the adhesive volatiles prior to co-curing. C-scans of the cured specimens showed excessive bondline voids. The second specimens were processed by also prestaging the adhesive as well as increasing the vacuum to aid bleed off of the volatiles. These specimens also had excessive bond line voids visible as a large blister and also shown by the C-scans. It was concluded that bonding and processing of the thick GR/PI laminates were beyond the "state-of-the-art at that time." With NASA concurrence, fabrication and testing of Type 3 Bonded Joints were deleted from the TASK 1.0 statement of work.

Subsequently, work on this program indicated that the bonding problem with the step lap joints may have been due to the uneven heating of the titanium and the composite. Uneven temperatures were caused by the titanium being a good thermal conductor whereas the Gr/PI is only a fair conductor. Since the cure pressure was applied after the entire panel reached the cure temperature, the prepreg that was laid up on the titanium steps had cured or advanced past the gell stage when the pressure was applied. Thus the outer steps of the joint were never bonded well onto the titanium because the PMR-15 resin and A7F primer were cured or partially cured without adequate pressure. During cure of the "Final Evaluation" panels the cure cycle was altered so that the pressure was applied when the thinnest panel section reached the cure temperature. This procedure proved to be successful. It is also expected that it would lead to successful fabrication of thick step-lap joints of the kind required for the Type 3 bonded joint.

Type 3 Bolted Joints

There were two concepts selected during screening for the Type 3 Bolted Joint as indicated in Figure 3-24. They were basically double-lap joints with one concept having a Gr/PI splice plate and the other a titanium splice plate. The joints were designed to carry a minimum load of 2100 kN/m (12,000 lbs/in); however, they must fail in the basic skin outside the joint area. Since the basic skins were to be symmetric quasi-isotropic lay-ups, the minimum gage that would meet the load requirement was 4.06 mm (0.16 in). This gage has a failure load of 2240 kN/m (12,800 lbs/in). Splice plate and cover reinforcement areas were sized for net-tension and bearing allowables determined from the "Small Specimen" tests presented in Section 4-3. The reinforcement area consisted of continuous plies from the basic cover away from the joint interleaved with filler plies to provide the required pad-up thickness. For simplicity the total pad-up thickness was increased to match the basic cover total thickness thus avoiding costly tapered lay-up tooling caul plates.

Type 4 Bonded

The basic Type 4 Bonded Joint selected from the screening process is shown in Figure 3-25. Laminates are unsymmetric lay-ups in order to get the thinnest possible laminate; however, sandwich midplane symmetry was maintained. The cover was reinforced in the joint area for both the bonded and bolted joints. Reinforcement was put on both sides of the sandwich to maintain stiffness balance and assure uniform transfer of in-plane load to both skins. Bonded double 90^{o} attachment angles were used for the web because of simplicity in manufacturing. The "Small Specimen" tests showed they were adequate for the design loads (see Section 4.3). The ± 45 plies were on the outer surface of the attachment angles and cover reinforcement to provide maximum shear strength of the bonds.

Type 4 Bolted

Results of the screening process showed the Type 4 Bolted Joint should be of the basic configuration shown in Figure 3-26. Laminates were unsymmetric lay-ups so they would be as thin as possible; however, sandwich mid-plane symmetry was maintained. Double 90^{o} attachment angles were used for the web. The cover skins on both sides of the core were reinforced in the joint area to account for reduction in strength due to the bolt holes and to maintain a balanced construction for transfer of in-plane loads. Reinforcement thicknesses were determined using net-tension strengths for an unloaded bolt hole defined in Section 4.3.

5.2 Static Discriminator Test Matrices and Procedures

Joint designs and test specimens presented in the preceding section were subjected to "Static Discriminator" tests to verify the design concepts. The test matrix is given in Table 5.1. Each joint type was subjected to a single axis critical design load condition and loaded to failure. Loading conditions are shown in Figures 5-1 through 5-4. Tests were conducted in the Boeing Materials Test Laboratories using Baldwin Universal Test Machines. Typical test set-ups are shown in Figures 5-5 through 5-8. Elevated temperature tests were conducted using resistance heated enclosures or quartz radiant lamps depending on the specimen size and shape. Load-deflection curves were recorded to failure.

See Section 4.3 for the specimen numbering system.

Table 5-1: MATRIX 5 - STATIC DISCRIMINATOR TESTS

TEST NO.	JOINT TYPE [1]	NUMBER OF TESTS AT:	
		294K (70°F)	561K (550°F)
1A	Type 1 Bonded	3	3
1B	Type 1 Bolted	3	3
2A	Type 2 Bonded	3	3
2B	Type 2 Bolted	3	3
3B	Type 3 Bolted (Concept 1)	3	3
3B	Type 3 Bolted (Concept 2)	1	-
4A	Type 4 Bonded	3	3
4B	Type 4 Bolted	3	3
6A	Interleaved Dblr-Bonded	1	3
6B	Interleaved Dblr-Bolted	3	3
		TOTAL TESTS = 53	

[1] See Figures 5-1 through 5-4 for Test Loading Conditions.
Condition: Cured/Postcured.

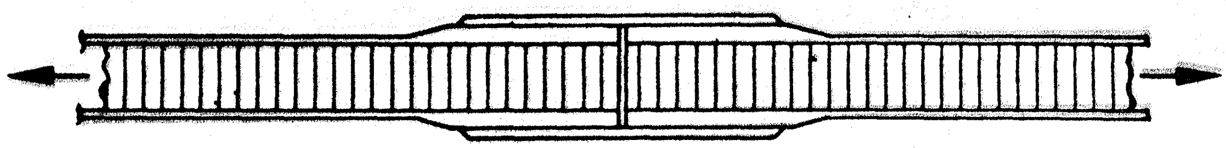


Figure 5-1: MATRIX 5 - TYPE 1 LOADING CONDITION

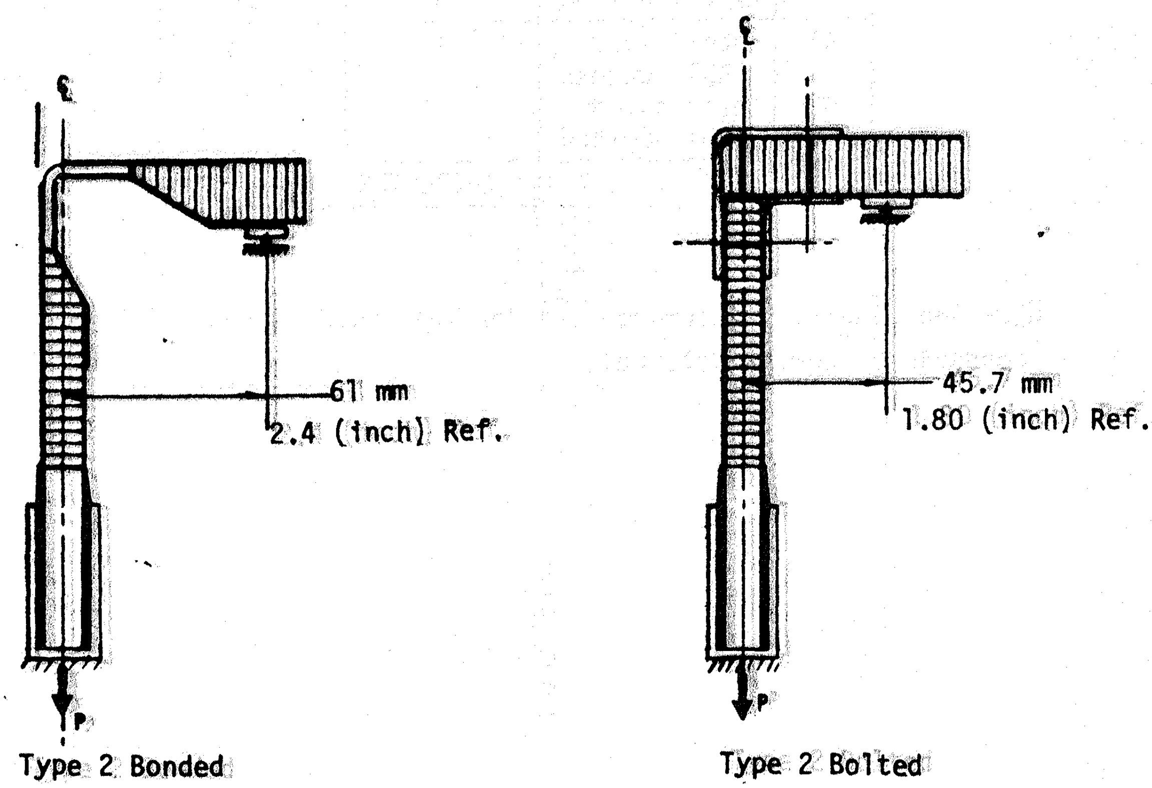


Figure 5-2: MATRIX 5 - TYPE 2 LOADING CONDITIONS

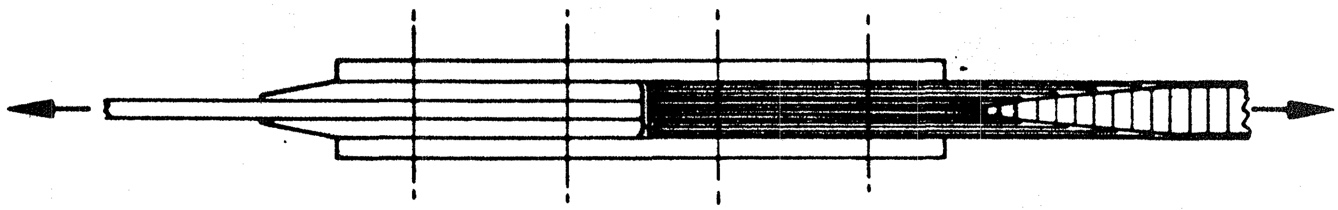


Figure 5-3: MATRIX 5 - TYPE 3 BOLTED LOADING CONDITION

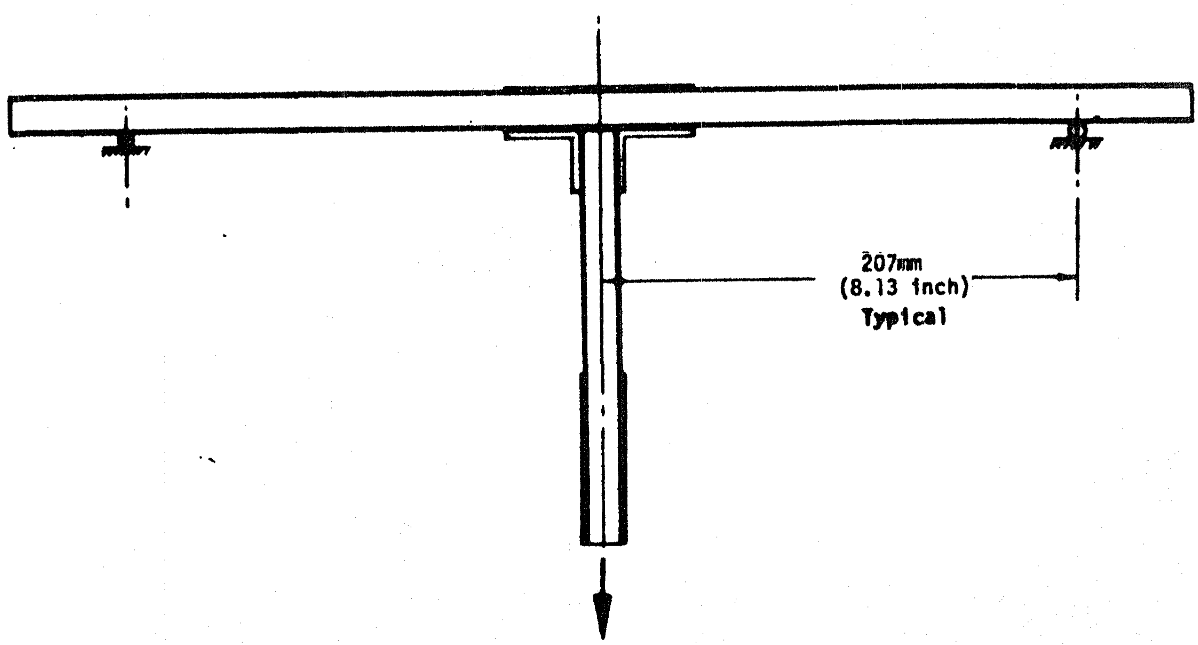


Figure 5-4: MATRIX 5 - TYPE 4 LOADING CONDITION

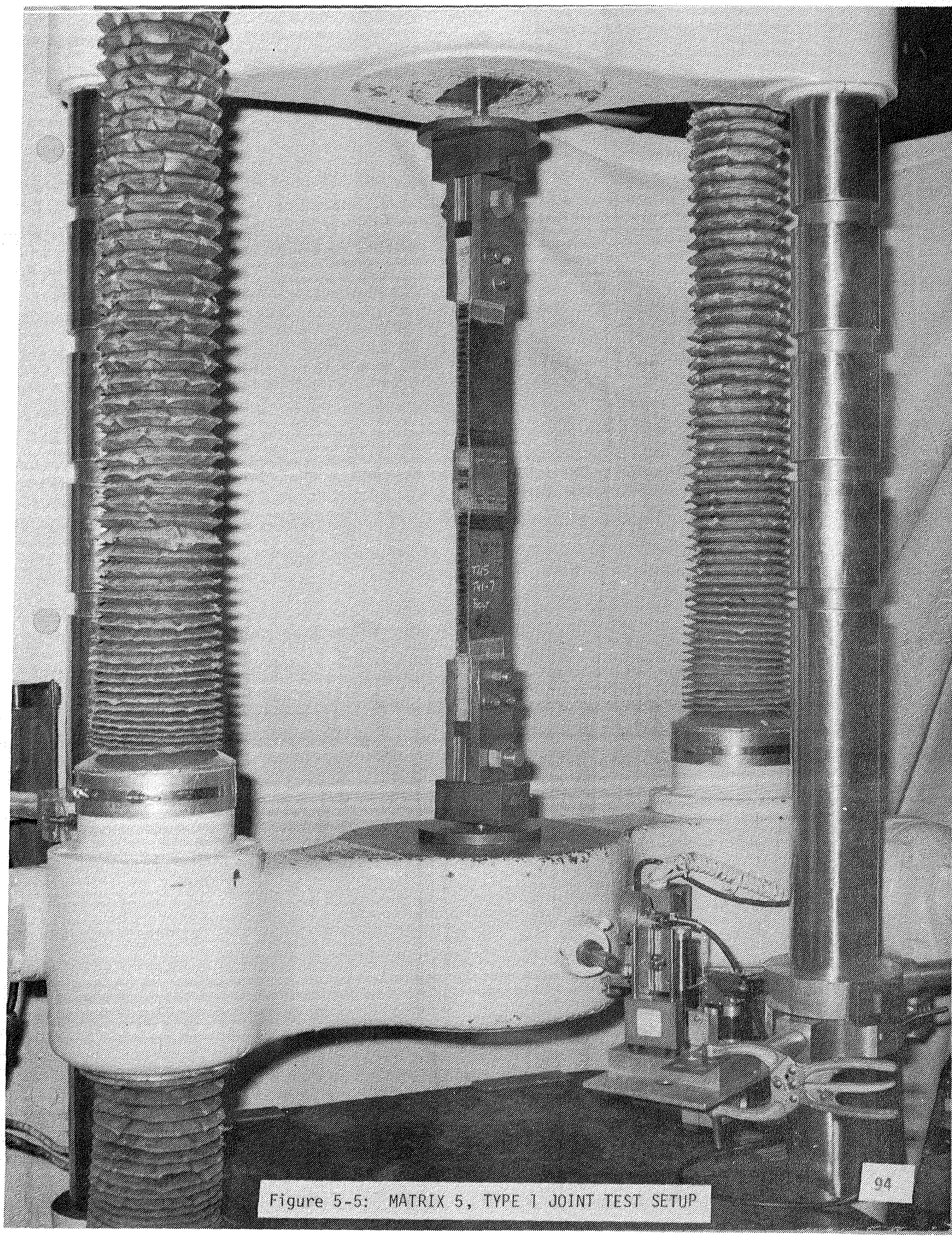


Figure 5-5: MATRIX 5, TYPE 1 JOINT TEST SETUP

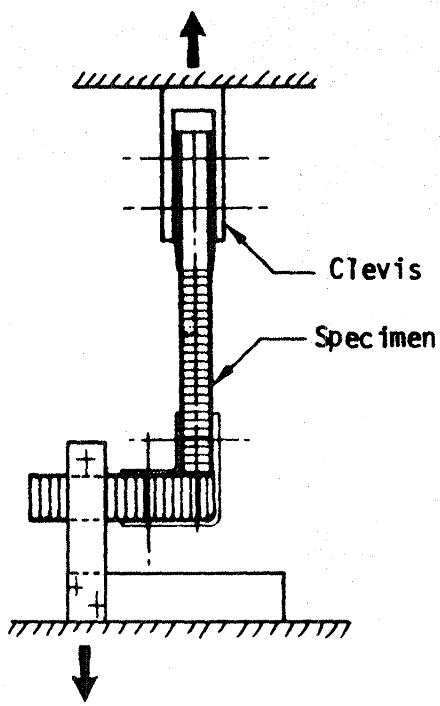


Figure 5-6: TYPE 2 JOINT TEST SETUP

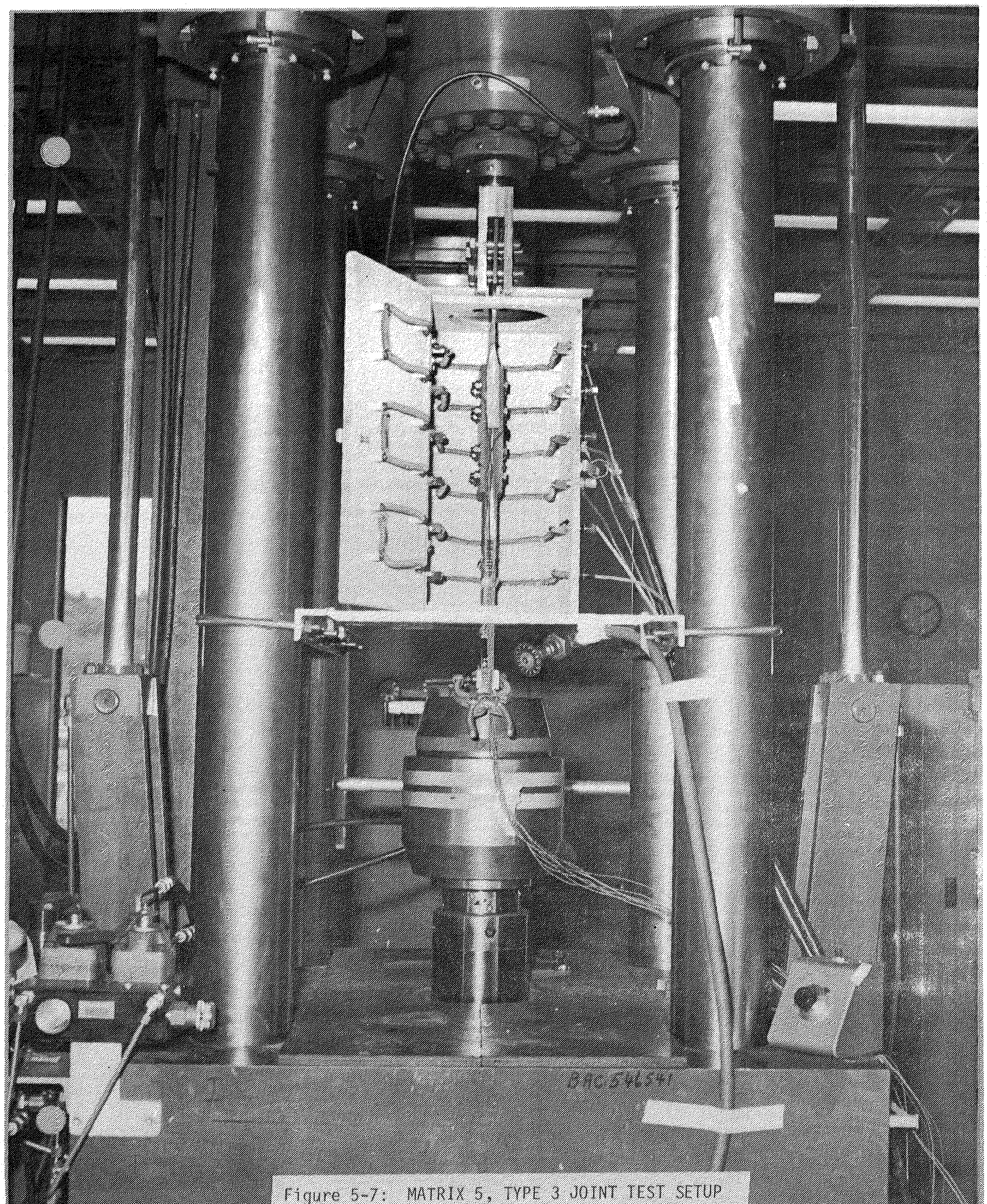


Figure 5-7: MATRIX 5, TYPE 3 JOINT TEST SETUP

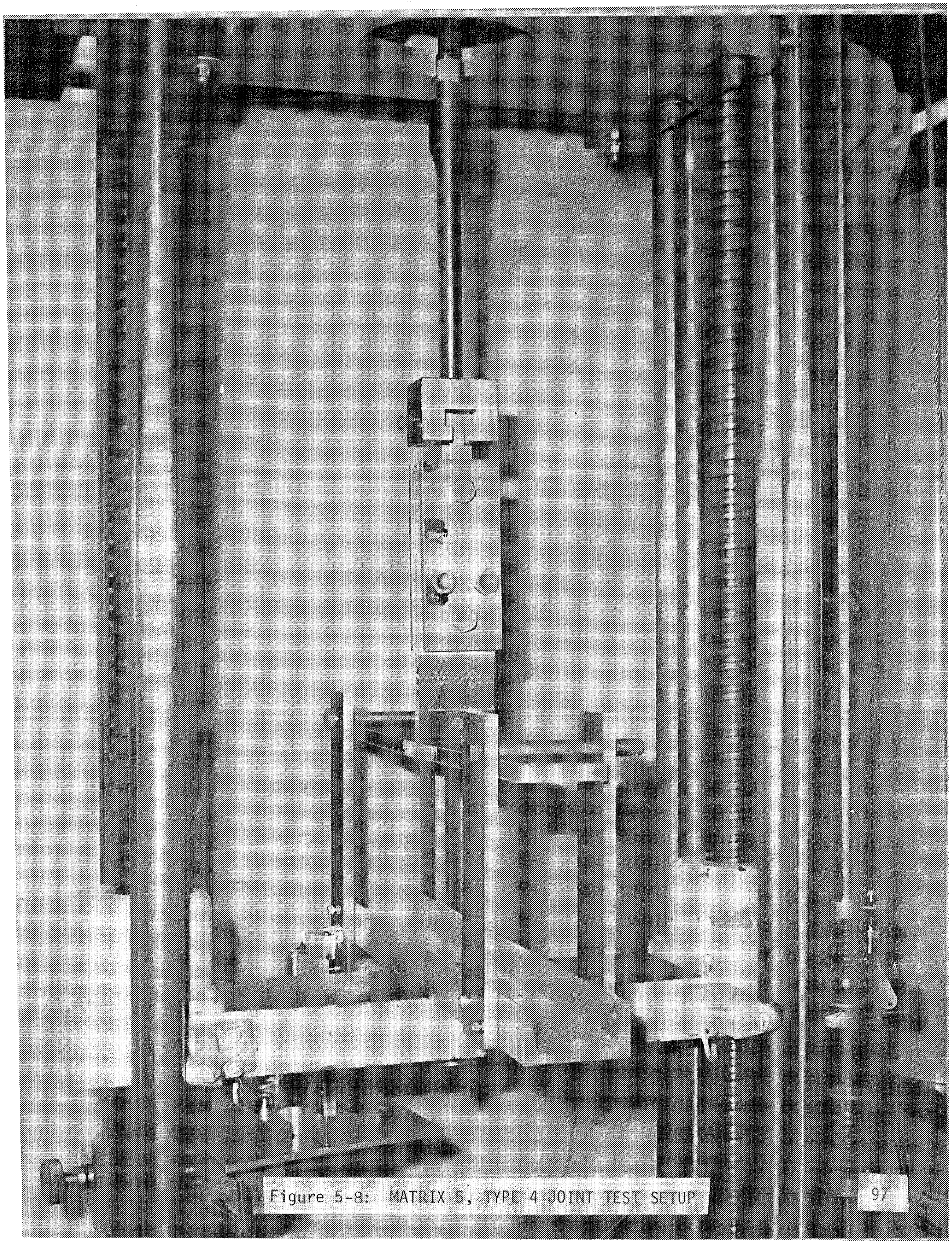


Figure 5-8: MATRIX 5, TYPE 4 JOINT TEST SETUP

5.3 Specimen Fabrication

All specimens for this program were fabricated in the Boeing Materials Technology Laboratories using the procedure flow shown in Figure 5-9. Specimens for the "Static Discriminator" tests, as for the "Small Specimen" tests, were fabricated in small laboratory size panels nominally 0.6m x 1.0m (24 in x 40 in).

Prior to making specimen panels, prepreg received from the vendor was subjected to quality control (Q.C.) tests to assure its acceptability. Tests included mechanical property tests and chemical characterization tests as specified in the material specification (Ref. 5). In some cases, material with Q.C. mechanical properties slightly lower than the specification requirements were accepted. This was because of the experimental nature of this material system, and the fact that the specification requirements were based on a small sample size.

The primary control for acceptance or rejection of the prepreg was the chemical characterization tests of the resin using high pressure liquid chromatography. Liquid chromatography has the sensitivity required to detect small amounts of undesireable resin constituents (reaction products) that affect processing. Results of these tests were considered the principal indicator of material processability.

The prepreg lot numbers used for the various "Static Discriminator" joint types are given in Table 5-2. The Q.C. test results for these prepreg lots are shown in Appendix F.

The Gr/PI prepreg was laid up per the specimen drawings (see Appendix B) and cured according to the autoclave processing procedures outlined in Reference 5. For the "Static Discriminator" specimens, joint Types 1, 2 and 4 were fabricated from Celion 3000/PMR-15 while the Type 3 joints were fabricated from Celion 6000/PMR-15. The cured laminates were non-destructively inspected using C-scan at 5-6 MHz sweep at 4db loss above the water path

(Ref. 8). Panels containing voids or other defects were rejected and new panels made. Typical C-scan results for an acceptable and a rejected laminate are shown in Figure 5-10. Laminates were bonded with A7F adhesive film to the appropriate honeycomb core or other laminates per the procedures in Reference 5.

The first two attempts to fabricate the thick skin laminates for the Type 3 bolted specimens were unsuccessful due to voids in the pad-up area. Another set of panels were made, and C-scans of these panels displayed some very small voids and porosities in the pad-up area of the laminates. These panels were accepted for use in making the test specimens. However, after bonding, cutting and conditioning the finished specimens developed some small delaminations in the thick section of the laminate (see Figure 5-26). These had no effect on the strength of the joints. In addition, the splice plates for the Type 3 joints were initially fabricated from Celion 3000/PMR-15. These parts developed extensive delaminations, believed to be due to the thickness of the plates, 7.1mm (.28 in). The plates were remade with Celion 6000/PMR-15 (material lot 2W4878), which proved satisfactory.

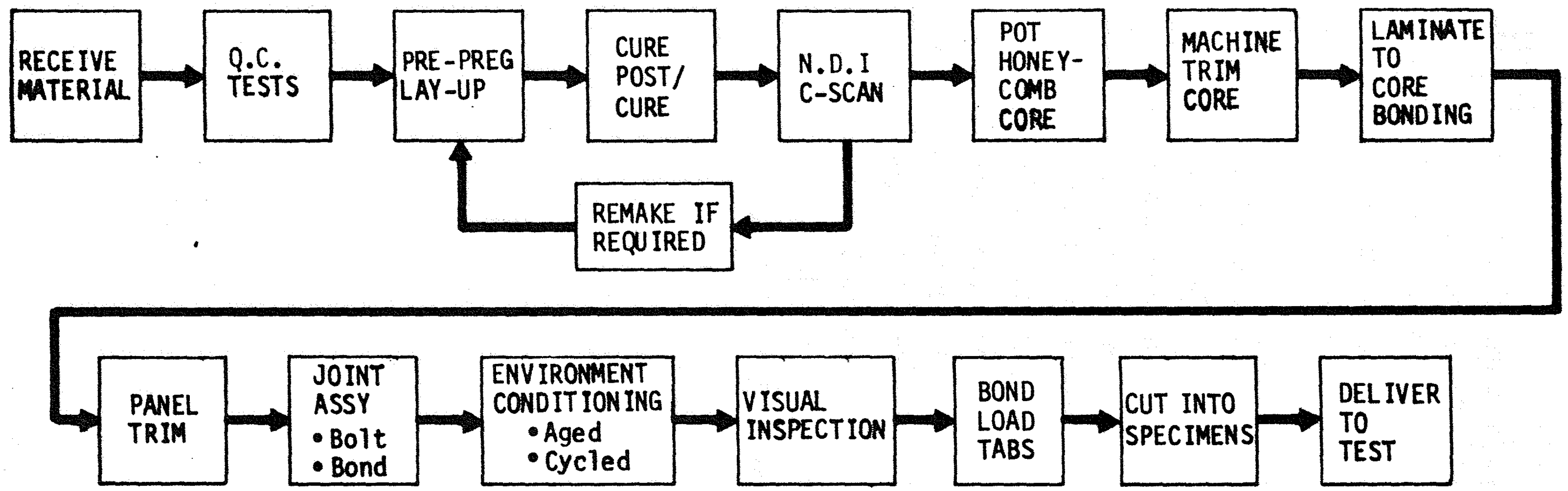
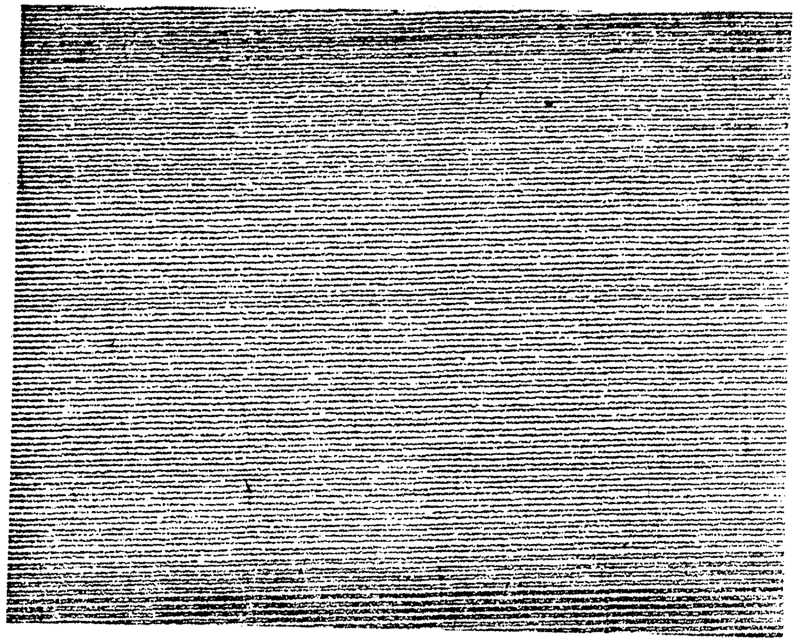


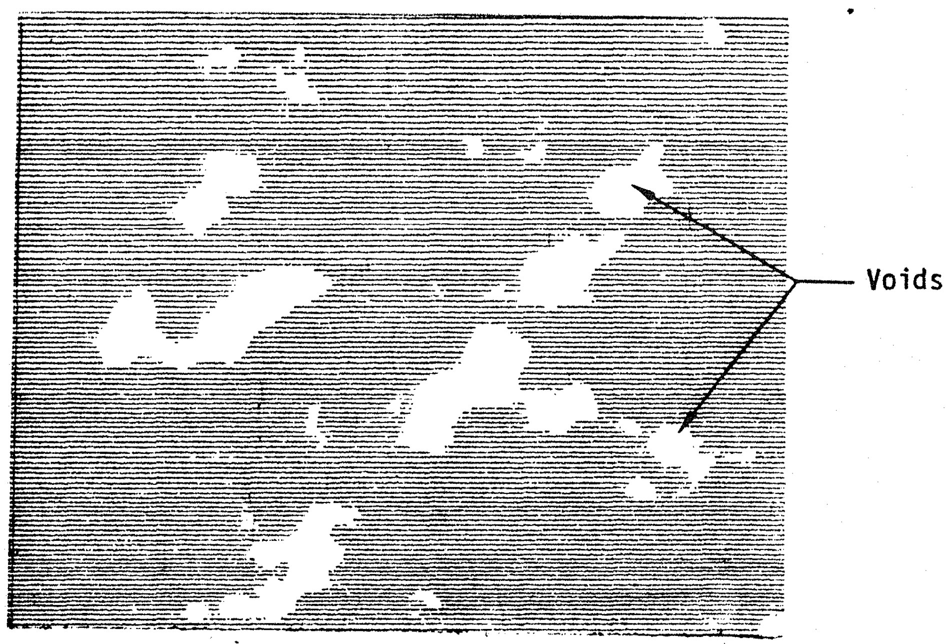
Figure 5-9: SPECIMEN FABRICATION FLOW DIAGRAM

Table 5-2: GR/PI PREPREG LOTS USED FOR MATRIX 5

		MATERIAL LOT	FIBER TYPE
TYPE 1	Bonded Bolted	2W4781 2W4956 3W2020	3000 3000 3000
TYPE 2	Bonded Bolted	2W4781 2W4956 3W2020	3000 3000 3000
TYPE 3	Bolted	2W4878	6000
TYPE 4	Bonded Bolted	3W2020	3000



ACCEPTABLE LAMINATE



REJECTED LAMINATE

Figure 5-10: TYPICAL C-SCAN RESULTS

5.4 Static Discriminator Test Results

Test results for the "Static Discriminator" specimens are summarized in Table 5-3. Test results for the individual specimens for each joint type are contained in Appendix C. The following sections discuss the results for the four joint types tested.

Type 1 Bonded and Bolted Joints

"Static Discriminator" test specimens for Type 1 Bonded and Type 1 Bolted preliminary joint designs are shown in Figures 5-11 and 5-12 respectively. Specimens were loaded in axial tension.

The Type 1 bonded joints had 33 mm (1.3 inches) lap lengths with co-cured doublers on the sandwich face sheets. Specimens were 76.1 mm (3.0 inches) wide. In all cases the specimens failed in interlaminar shear at the doubler to face sheet interface (See Figure 5-13) at loads below the design load of 560 kN/m (3200 lb/in). Average failure loads were 445 kN/m (2545 lb/in) at room temperature and 378 kN/m (2159 lb/in) at 561K (550^{o}F). Loads are transferred from the sandwich 0.51 mm (.02 inch) face sheets, into the co-cured doubler, through the adhesive bond line and into the splice plates. Failure initiated due to combined shear and peel stresses at the tapered end of the doubler resulting in an "unzippering" of the joint.

The Type 1 bolted joints had 4.83 mm (.19 inch) dia. fasteners on 25.4 mm (1.0 inch) spacing. Doublers were co-cured on the sandwich face sheets. Specimens were 76.2 mm (3.0 inches) wide. The ultimate load capability of the face sheets outside the joint was 560 kN/m (3200 lb/in). Two of the room temperature tests resulted in failure in the basic skin outside the joint. Specimen 5-1B-1-2 met the design load and failed at 564 kN/m (3223 lb/in) (see Figure 5-14). Specimen 5-1B-1-1 also failed in the basic skin but in the grip area at a load of 522 kN/m (2980 lb/in). Specimen 5-1B-1-3 failed in the skin at 436 kN/m (2492 lb/in) but it appears the failure was initiated by an interlaminar shear failure at the doubler to face skin interface. All of the elevated temperature tests resulted in an interlaminar shear failure at the doubler to face sheet interface (see Figure 5-16). This then propagated to a net tension failure through the basic face skin thickness only (not the complete doubler), at the fastener row.

Both Type 1 Bonded and Bolted preliminary joint designs had premature failures in the joint area. Schematics of these failure modes are shown in Figures 5-15 and 5-16. Post test examination of the specimens showed the weak link to be the co-cured doubler-to-skin interface. Potential fixes were to increase the doubler length to reduce shear and peel stresses or to interleave the basic face sheet plies with the doubler plies to provide better load transfer into the doubler and reduce the shear stresses. Increasing the doubler length was not considered an effective solution because standard bonded joint tests (Ref. 3) indicated the maximum effective bond length was already exceeded. Therefore, an interleaved doubler concept was selected as the best design solution.

Tests of special interleaved doubler specimens were conducted to evaluate the proposed design changes to the Type 1 bonded and bolted joints. Doubler lay-ups and specimen configurations are shown in Figures 5-17 and 5-18 respectively. Test set-up is shown in Figure 5-19. Test results are summarized in Table 5-4. In all cases the specimens failed in the basic laminate away from the doubler area (see Figure 5-20). It was concluded that the interleaved doublers would eliminate the interlaminar shear failures experienced in the Type 1 "Static Discriminator" tests and would be used for the final designs in TASK 1.4 (see Section 6.1).

Type 2 Bonded and Bolted Joints

"Static Discriminator" test specimens for Type 2 Bonded and Type 2 Bolted preliminary joint designs are shown in Figures 5-21 and 5-22 respectively.

All the Type 2 bonded and bolted joints exceeded the minimum design load of 285 m-N/m (64 in-lb/in). In all cases the specimens failed due to interlaminar delamination of the corner angle. Typical delamination of a corner angle is shown in Figure 5-23. Failure was identified by a sudden drop-off in load as there were no two part failures. Lateral deflections of the room temperature specimens were also measured and are given in Appendix C.

Type 3 Bolted Joints

"Static Discriminator" test specimens for Type 3 Bolted preliminary joint designs are shown in Figures 5-24 and 5-25. Each specimen tested had some delaminations present in the bolt area prior to test as shown in Figure 5-26; however, they did not affect the test results. Specimens were loaded in tension.

In all cases the specimens failed prematurely in the grip area. Typical failed specimens are shown in Figures 5-27 through 5-29. Failure loads varied from 75% to 92% of the design load (exclusive of specimen 5-3B-1-1 which had a bolted grip and failed at 62%). Post test examination of the specimens showed evidence of first ply damage in the load tab area. This probably occurred during preparation of the composite surface for bonding of the aluminum load tabs. In some cases the first ply had been sanded completely through exposing the second ply. The titanium splice plate specimen (5-3B-1-7) had the least evidence of first ply damage and the highest failure load.

Another factor that may have contributed to the grip failure is having the aluminum load tabs bonded to a (0^o) layer at the interface followed by a 90^o ply. Since the 90^o ply would carry very little shear, most of the shear load would be transferred into the first 0^o ply. This coupled with first ply damage discussed above would explain the premature failures.

Type 4 Bonded and Bolted Joints

"Static Discriminator" test specimens for Type 4 Bonded and Bolted preliminary joint designs are shown in Figures 5-30 and 5-31. Specimens were loaded normal to the cover to put the web attachment in tension and the cover in bending.

All of the room temperature Type 4 bonded joints exceeded the design load of 11.2 kN/m (64 lb/in). Two specimens failed in compression in the outer laminate of the cover outside the joint area. The other specimen failed at a higher load; however, it had an interlaminar tension failure of the attachment angles (i.e., the angles pulled off). Failed specimens are shown in Figure 5-32 and 5-33.

Two of the elevated temperature (561K (550^{o}F)) Type 4 bonded joints exceeded the design load of 11.2 kN/m (64 lb/in); however, the third specimen failed at 10.3 kN/m (59 lb/in). Of the two specimens that exceeded the design load, one (5-4A-1-1) had a combined cohesive and interlaminar tension failure at the attach angle to cover interface. The specimen (5-4A-1-3) that did not meet the design load had an identical failure mode. The specimen (5-4A-1-2) with the highest failure load had a compressive failure in the outer laminate of the cover outside the joint area. Typical failed specimens are shown in Figures 5-34 and 5-35.

The interlaminar tension failure of the attach angles on the Type 4 bonded joints was not expected. Results of small specimen tests of double 90^{o} angle attachments showed average failure loads of 40.6 kN/m (232 lbs/in) and 48.3 kN/m (276 lbs/in) at room temperature and 561K (550^{o}F) respectively. The Type 4 bonded joint attachment angles failed at 19.4 kN/m (111 lbs/in) at room temperature and at an average of 12.3 kN/m (70 lbs/in) at 561K (550^{o}F). This large difference in failure load is attributed to the large deflection, up to 21.3 mm (0.84 in), and correspondingly larger surface strains, experienced in the "Static Discriminator" tests. Since such large deflection would not be experienced in actual aerospace hardware, a special test was conducted using a spare Type 4 bonded joint. The support span of 413 mm (16.26 in) shown in Figure 5-4 was changed to 80 mm (3.15 in). The resulting failure load was 2.67 kN (600 lbs) or 35 kN/m (200 lbs/in) which is well above the design requirement. Based on these results, no design changes were made for the Type 4 bonded joints.

All of the Type 4 bolted joints exceeded the design load of 11.2 kN/m (64 lb/in). The specimens failed in compression in the outer laminate of the cover outside the joint area. A typical failed specimen is shown in Figure 5-36. Based on these results, no design changes were made for the Type 4 bolted joints.

Table 5-3: MATRIX 5 STATIC DISCRIMINATOR TEST RESULTS

TEST NO.	JOINT TYPE	TEMPERATURE K (°F)	AVERAGE** FAILURE LOAD kN/m (lb/in)	DESIGN LOAD kN/m (lb/in)	FAILURE MODE
1A	Type 1 Bonded	294 (70)	445 (2542)	560 (3200)	Doubler Shear
		561 (550)	378 (2159)	560 (3200)	Doubler Shear
1B	Type 1 Bolted	294 (70)	546 (3117) 438 (2500)	560 (3200)	Cover Tension (2)* Doubler Shear (1)*
		561 (550)	434 (2476)	560 (3200)	Doubler Shear
2A	Type 2 Bonded	294 (70)	418 [1] (94) [2]	285 [1] (64) [2]	Angle Delamination
		561 (550)	632 (142)	285 (64)	Angle Delamination
2B	Type 2 Bolted	294 (70)	1293 [1] (291) [2]	285 [1] (64) [2]	Angle Delamination
		561 (550)	1453 (327)	285 (64)	Angle Delamination
3B	Type 3 Bolted	294 (70)	1690 (9653) [3]	2100 (12000)	Grip Failure
		561 (550)	1667 (9520)	2100 (12000)	Grip Failure
4A	Type 4 Bonded	294 (70)	19.4 (111)	11.2 (64)	Attach Angle Pull Off (2)* Cover Compression (1)*
		561 (550)	12.3 (70)	11.2 (64)	Attach Angle Pull Off (1)* Cover Compression (2)*
4B	Type 4 Bolted	294 (70)	22.2 (127)	11.2 (64)	Cover Compression
		561 (550)	14.7 (84)	11.2 (64)	Cover Compression

[1] mm-N/mm [2] in-lbs/in [3] One specimen had titanium splice plates

*Number of Specimens (Nominally 3 Per Test)

** Load in direction shown in Figures 5-1 through 5-4 per unit width.

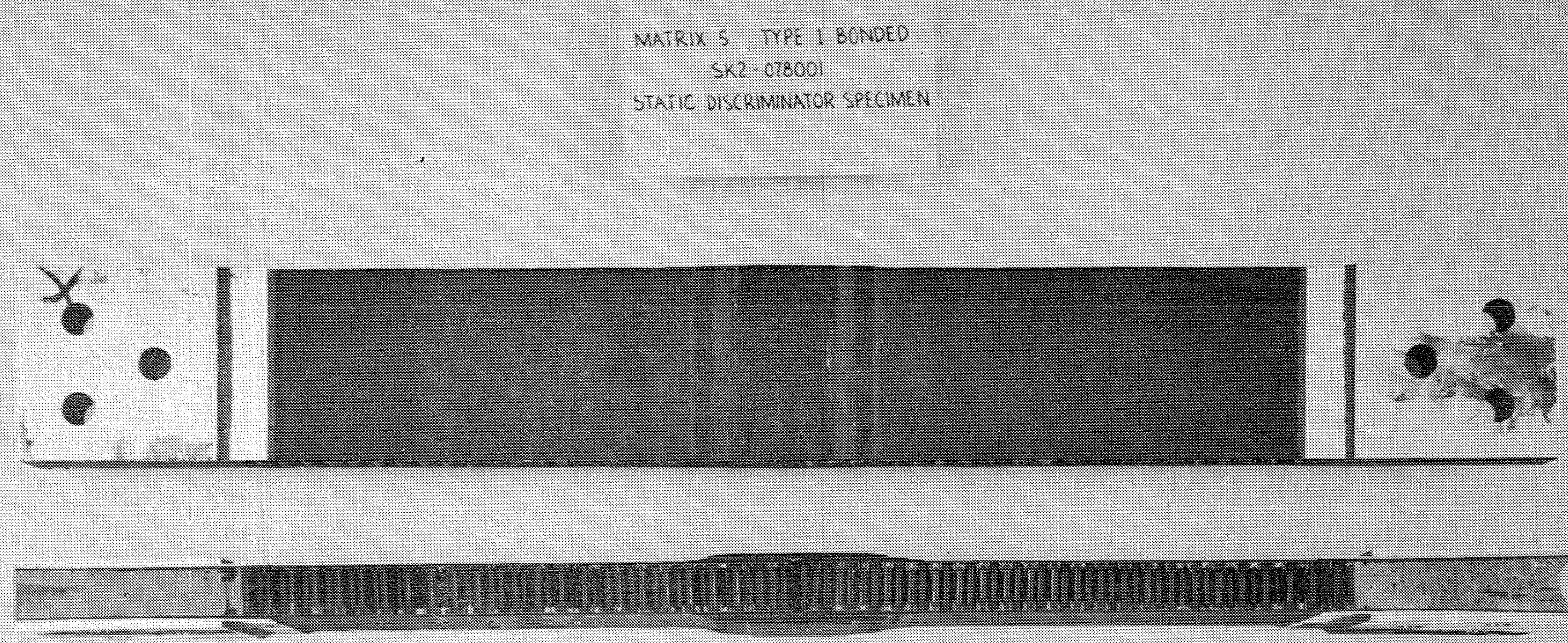


Figure 5-11: PRELIMINARY EVALUATION TYPE 1 BONDED JOINT - BEFORE TEST

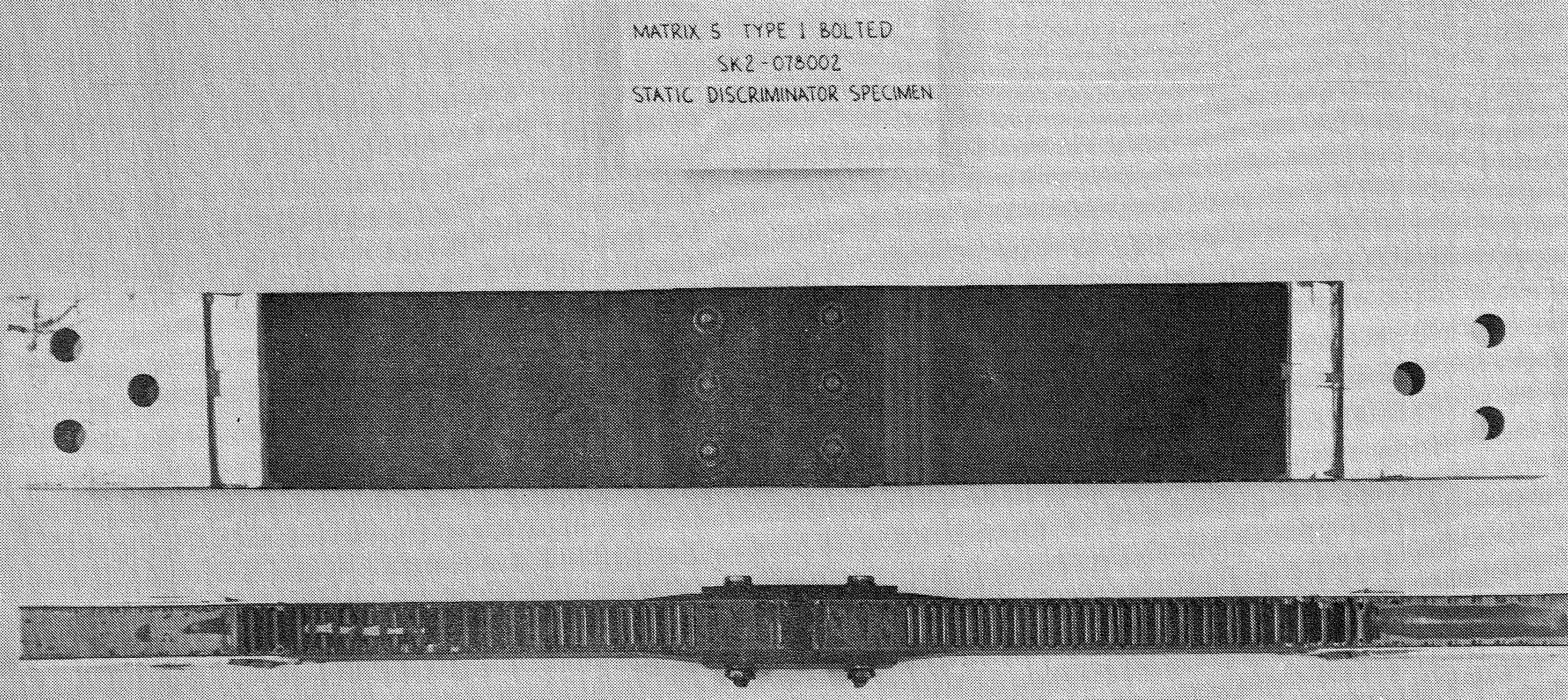


Figure 5-12: PRELIMINARY EVALUATION TYPE I BOLTED JOINT - BEFORE TEST

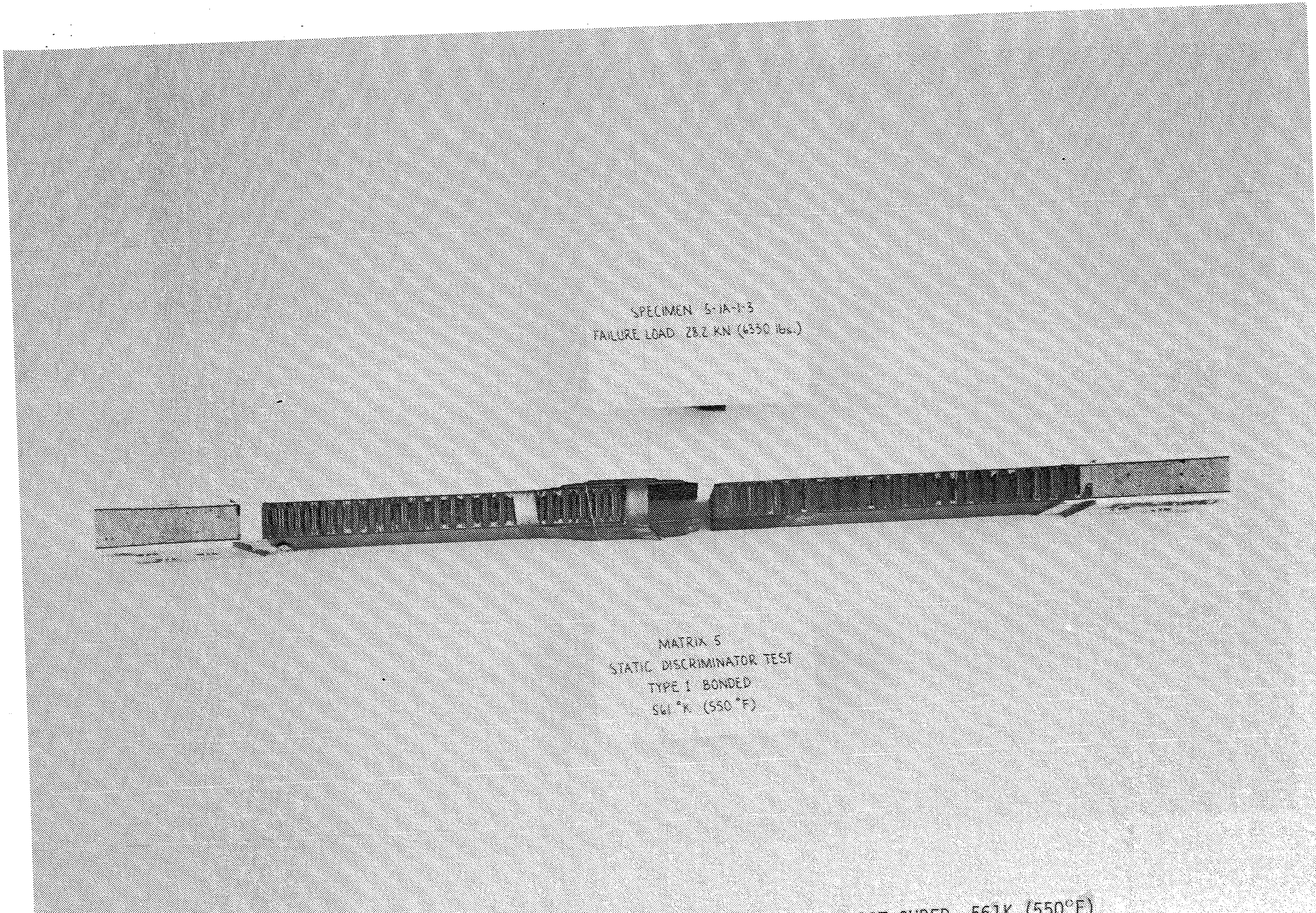


Figure 5-13: TYPE 1 BONDED - TENSION TEST, CURED/POST-CURED, 561K (550°F)

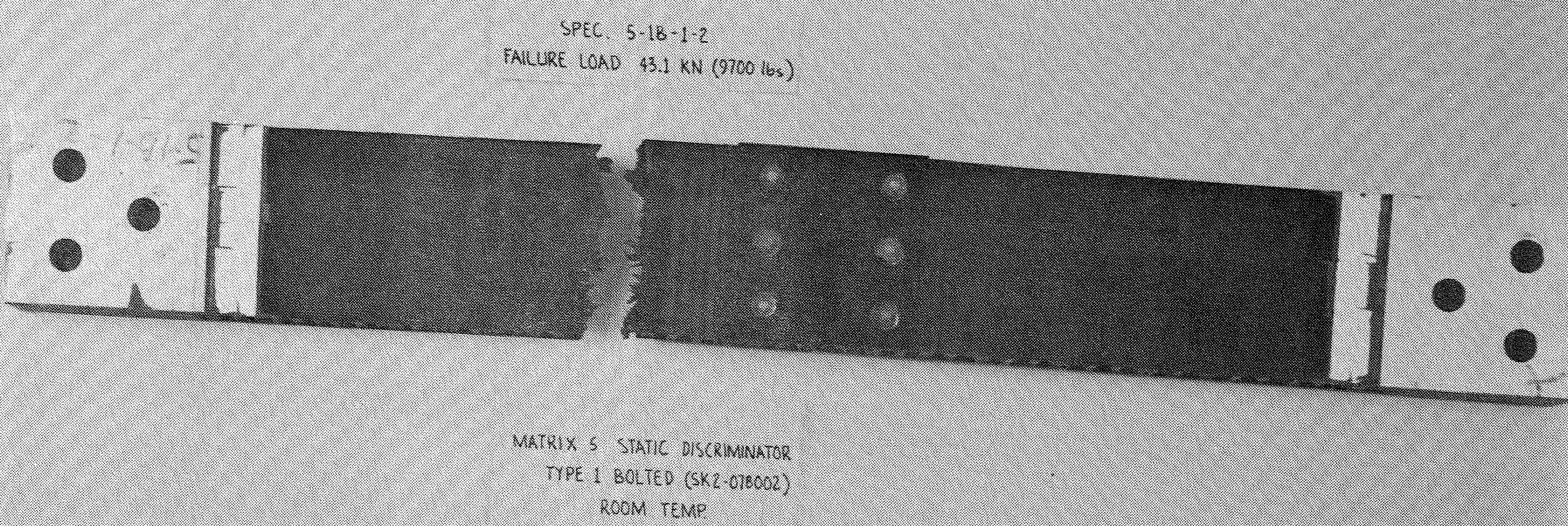


Figure 5-14: TYPE 1 BOLTED - TENSION TEST, CURED/POST-CURED, 294K (70°F)

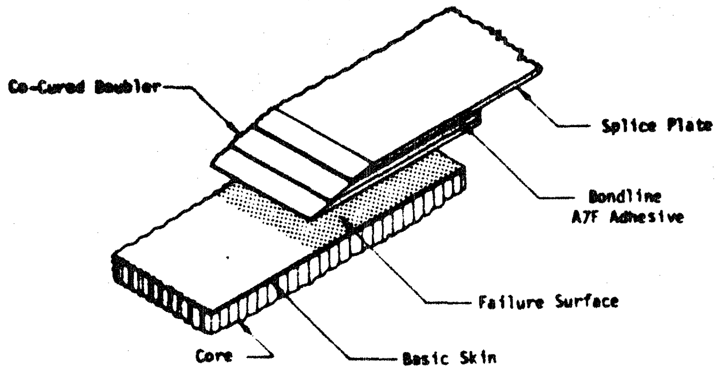


Figure 5-15: STATIC DISCRIMINATOR TESTS, TYPE 1 BONDED, FAILURE MODE

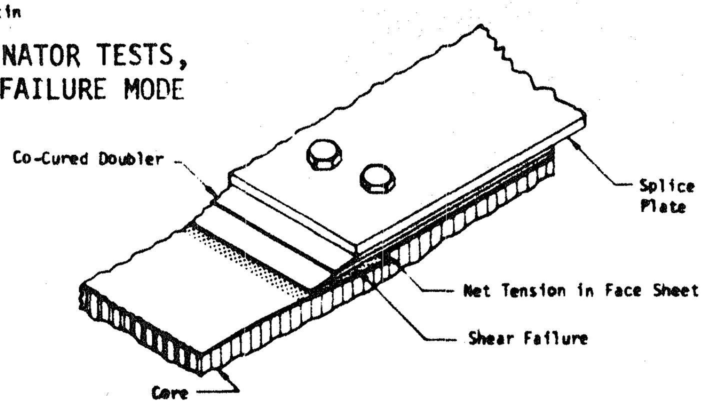


Figure 5-16: STATIC DISCRIMINATOR TESTS, TYPE 1 BOLTED, FAILURE MODE

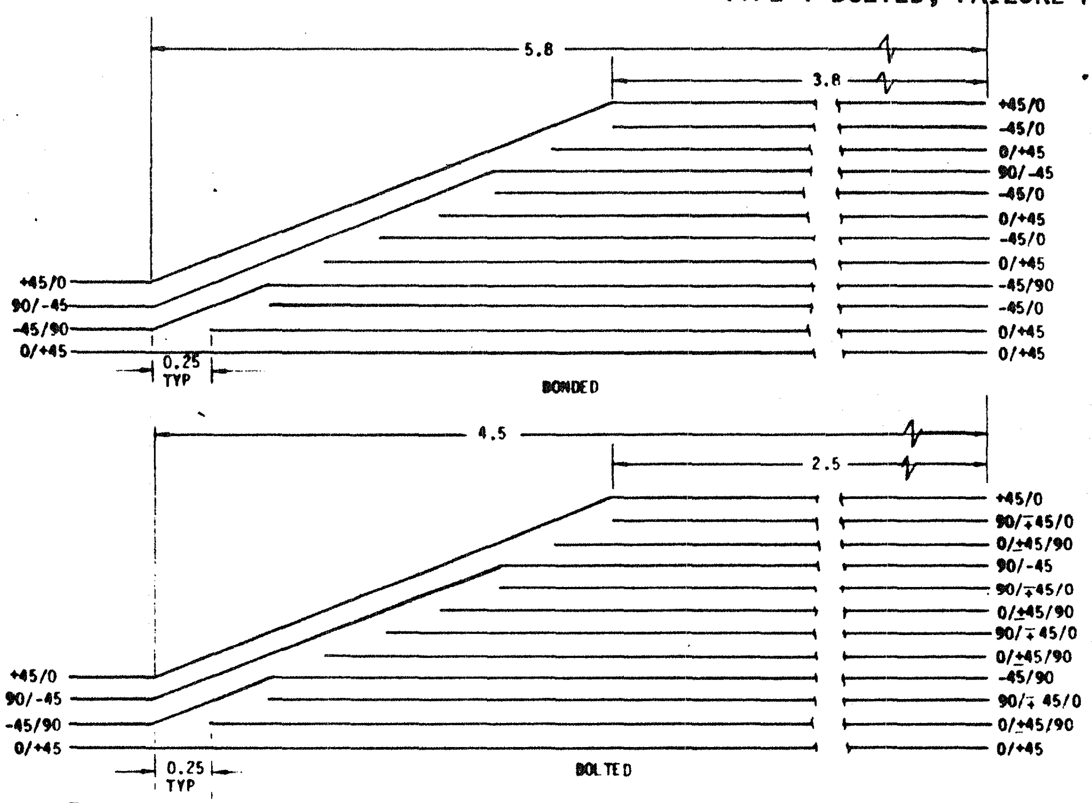


Figure 5-17: INTERLEAVED DOUBLER LAYUPS, STATIC DISCRIMINATOR TYPE 1 JOINTS - ALTERNATE DESIGN

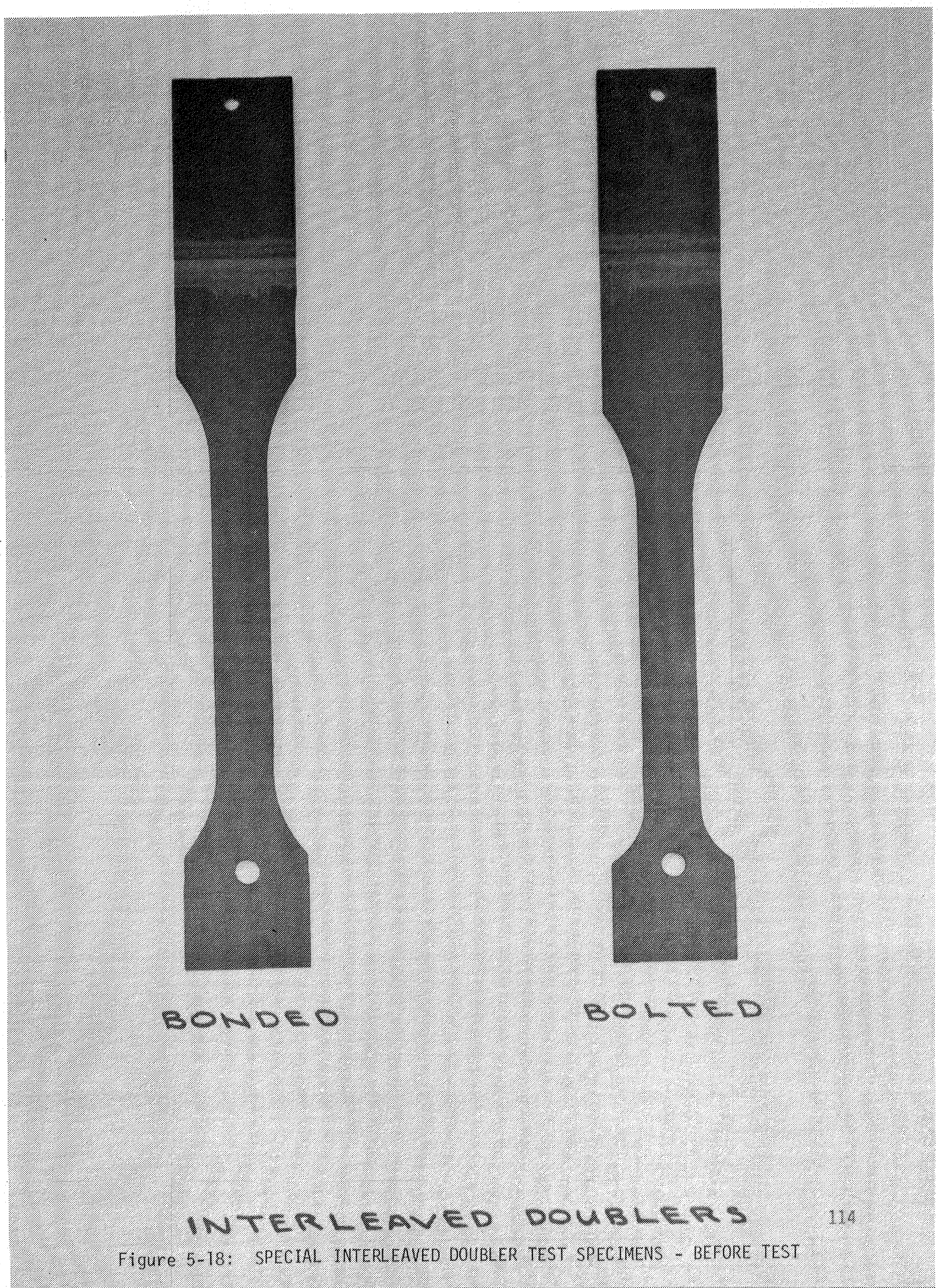


Figure 5-18: SPECIAL INTERLEAVED DOUBLER TEST SPECIMENS - BEFORE TEST

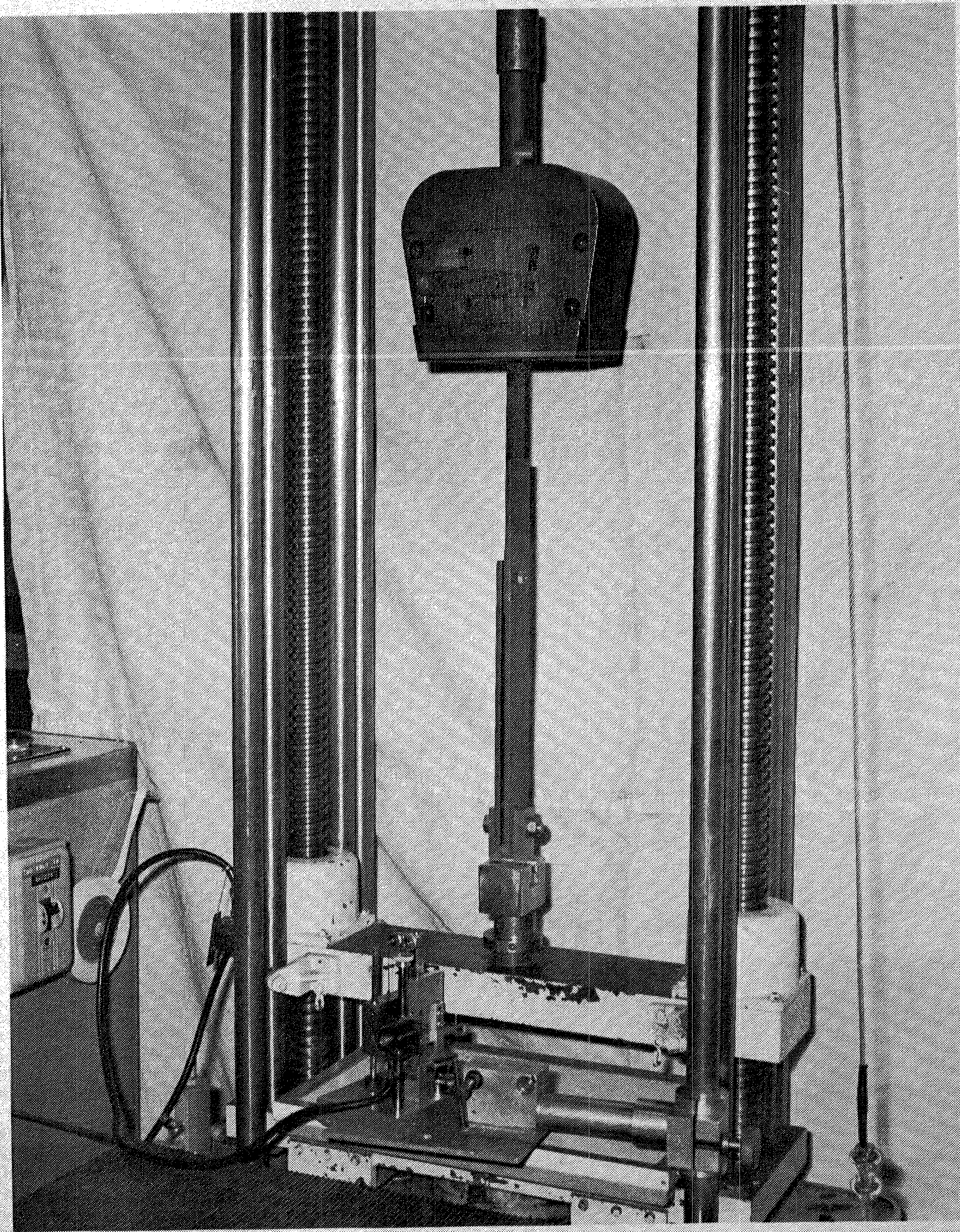


Figure 5-19: INTERLEAVED DOUBLER TEST SETUP

Table 5-4: SPECIAL INTERLEAVED DOUBLER TEST RESULTS

TEST NUMBER	TYPE	TEMPERATURE K (°F)	FAILURE LOAD kN (lb)	LAMINATE STRESS MPa (ksi)
5-6A	Bonded	294 (70) 561 (550)	6.1 (1365) 5.8 (1317)	492 (71.3) 474 (68.8)
5-6B	Bolted	294 (70) 561 (550)	5.8 (1307) 6.6 (1488)	475 (68.8) 517 (75.0)

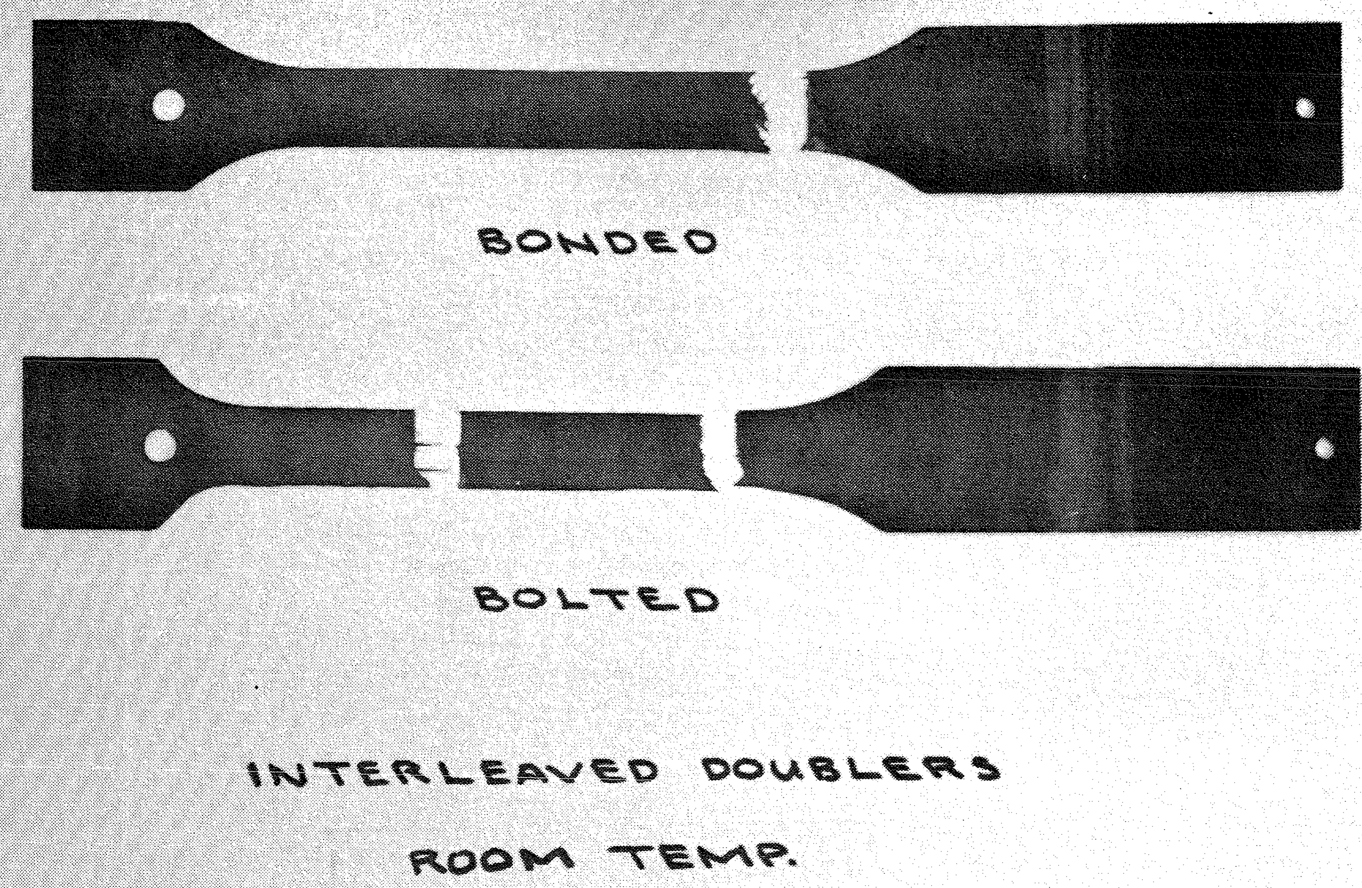


Figure 5-20: INTERLEAVED DOUBLER TYPICAL FAILED SPECIMENS

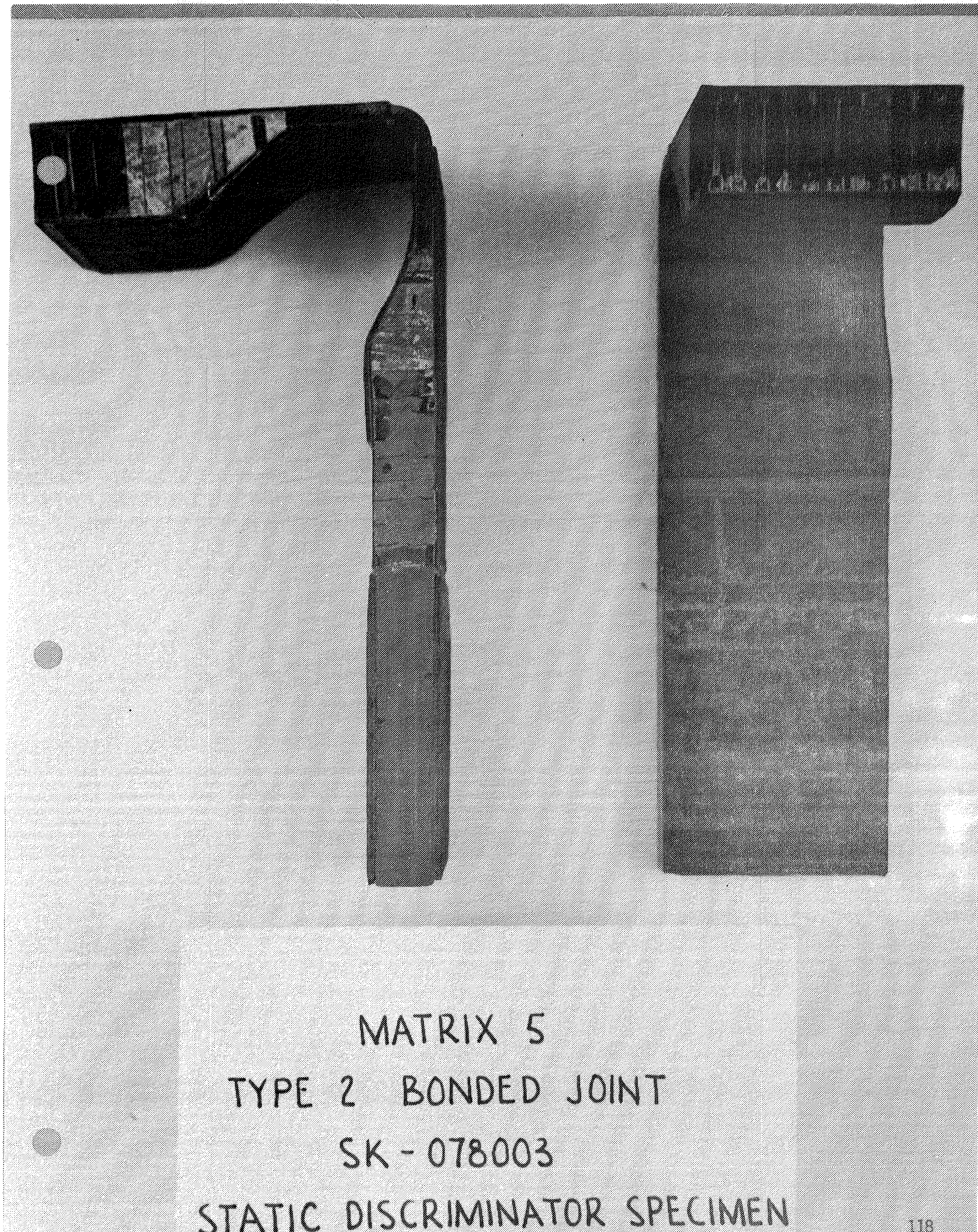


Figure 5-21: PRELIMINARY EVALUATION TYPE 2 BONDED JOINT - BEFORE TEST

Figure 5-22: PRELIMINARY EVALUATION TYPE 2 BOLTED JOINT - BEFORE TEST

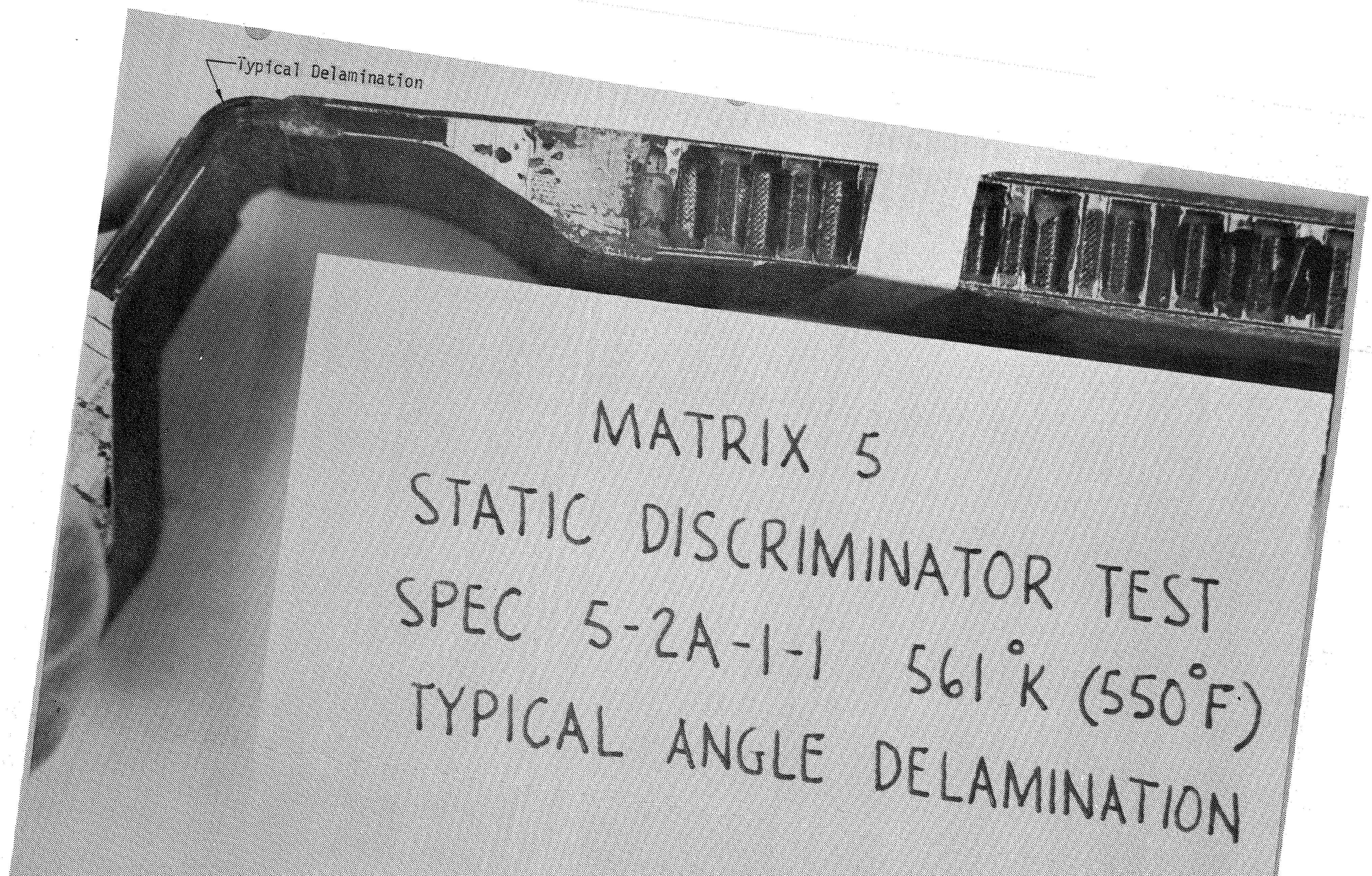


Figure 5-23: TYPE 2 BONDED - BENDING TEST, CURED/POST-CURED, 561K (550°F)

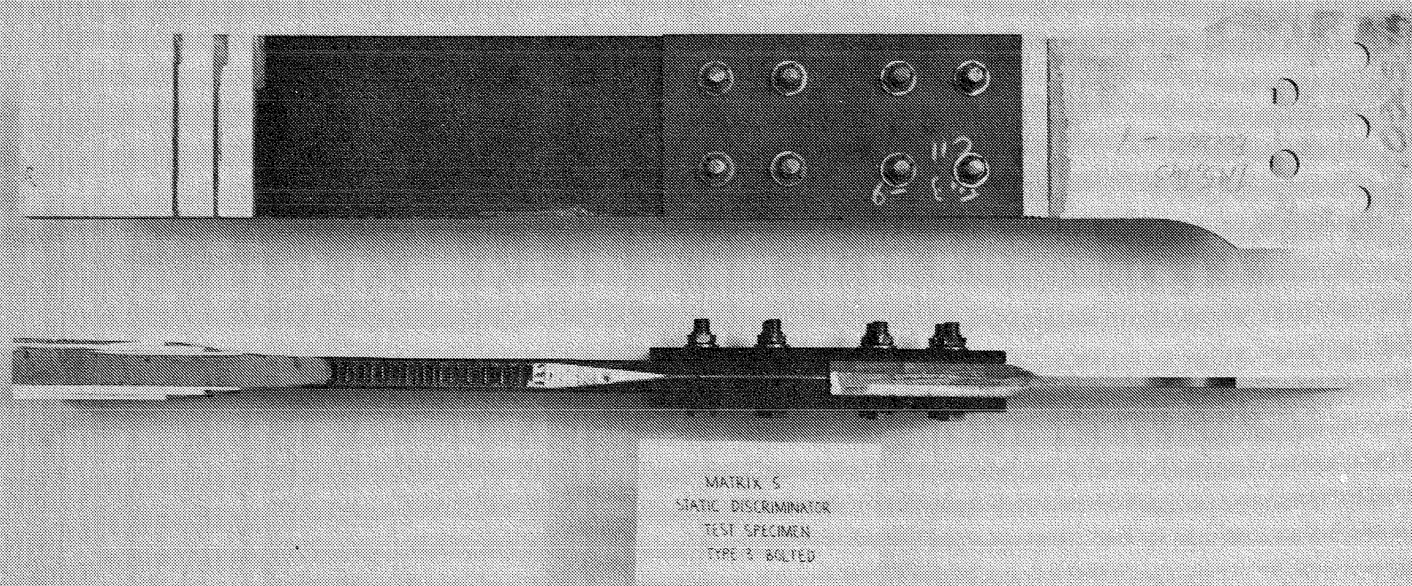


Figure 5-24: PRELIMINARY EVALUATION TYPE 3 BOLTED JOINT (GR/PI SPLICE PLATES) - BEFORE TEST

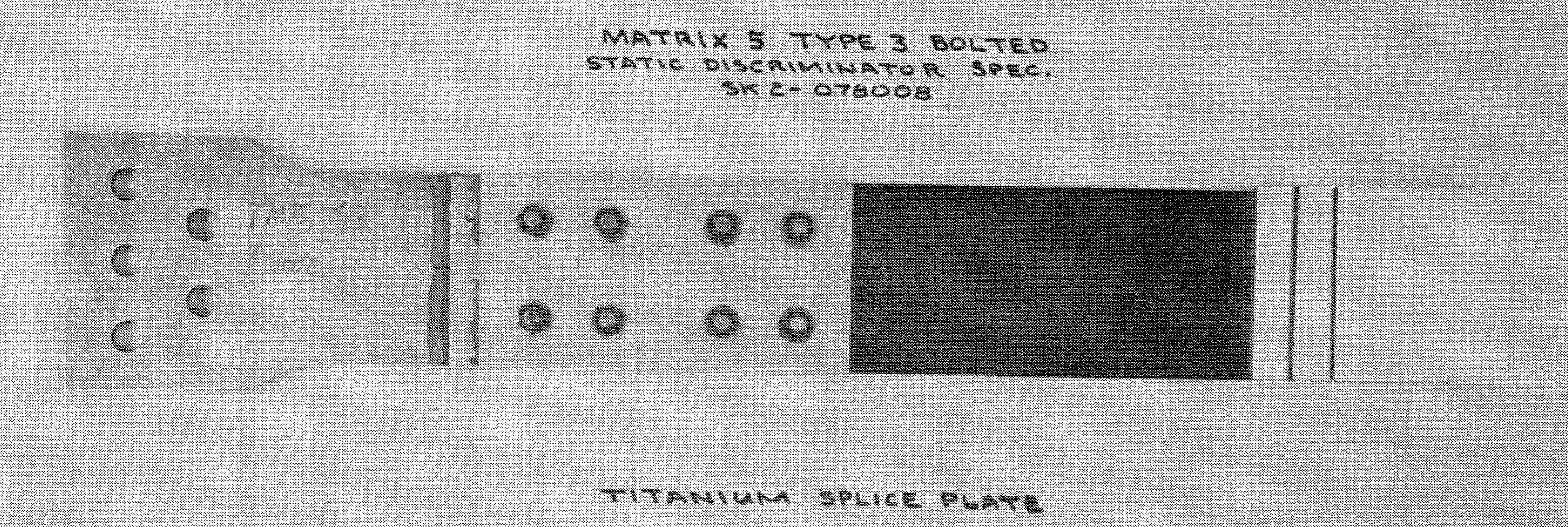


Figure 5-25: PRELIMINARY EVALUATION TYPE 3 BOLTED JOINT (TITANIUM SPLICE PLATES) - BEFORE TEST

Figure 5-26: TYPE 3 BOLTED JOINT - BEFORE TEST - TYPICAL DELAMINATIONS

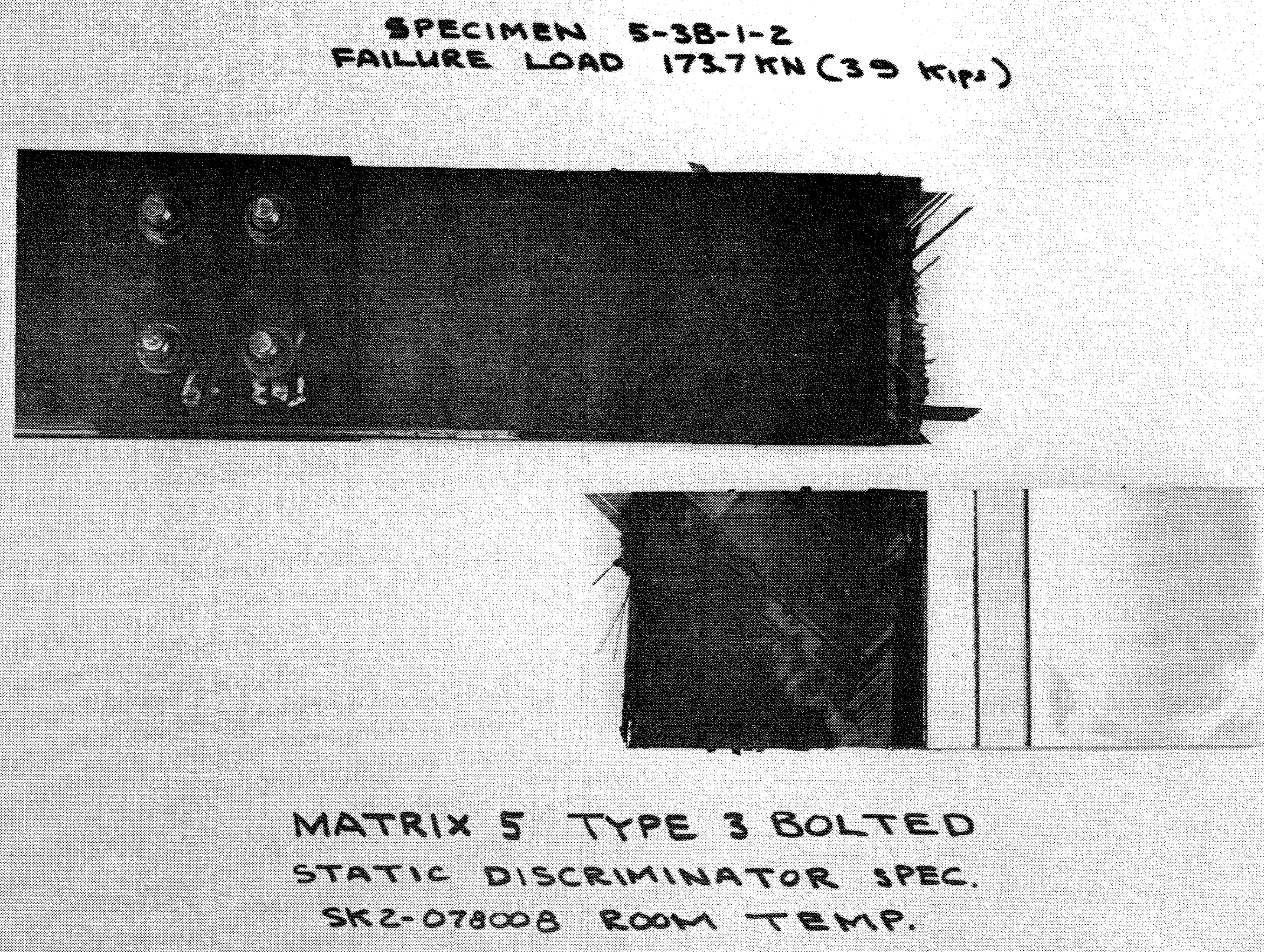


Figure 5-27: TYPE 3 BOLTED - TENSION TEST, CURED/POST-CURED, 294K (70°F)

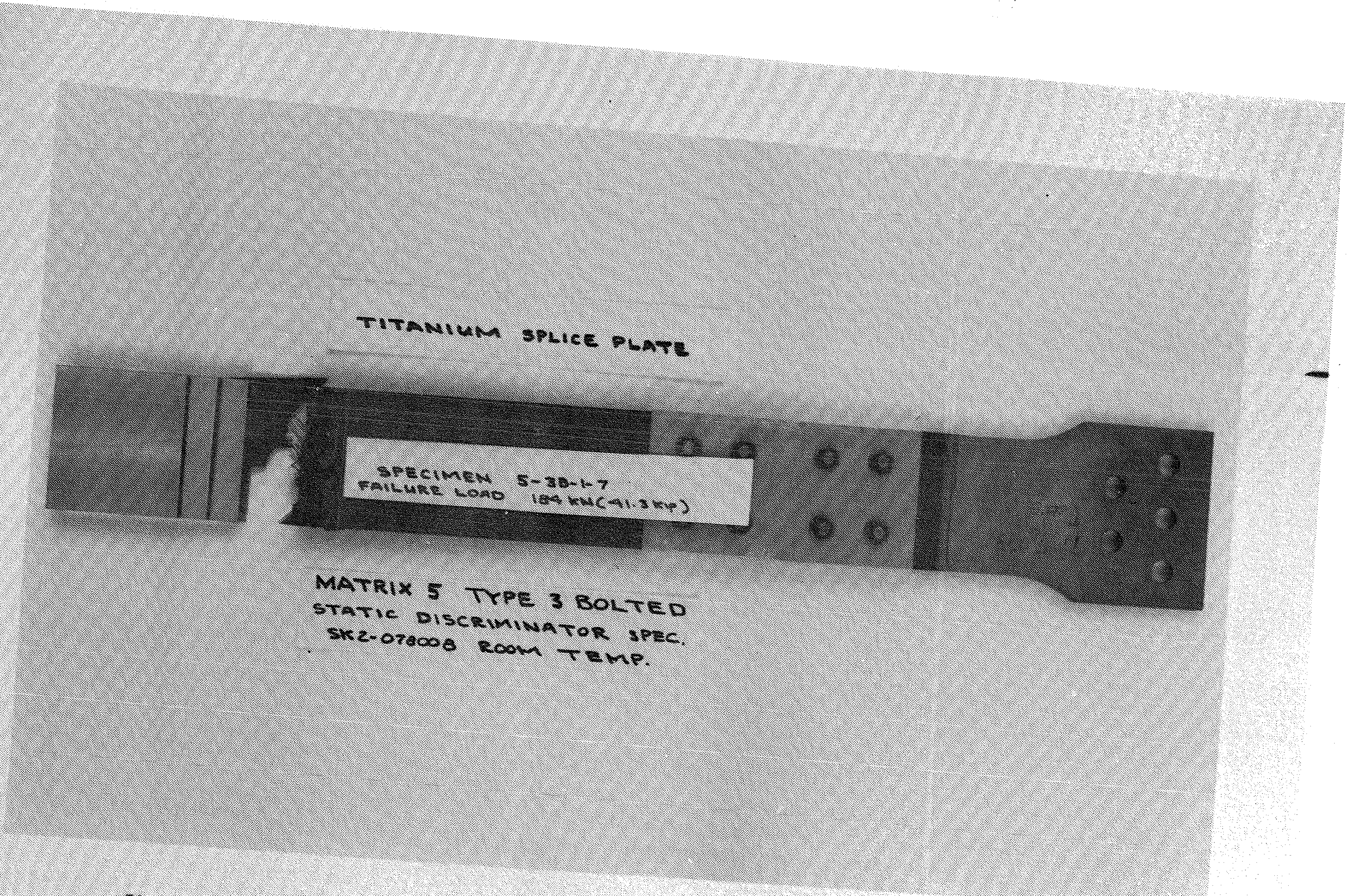


Figure 5-28: TYPE 3 BOLTED (Ti SPLICE PLATES) - TENSION TEST, CURED/POST-CURED, 294K (70°F)

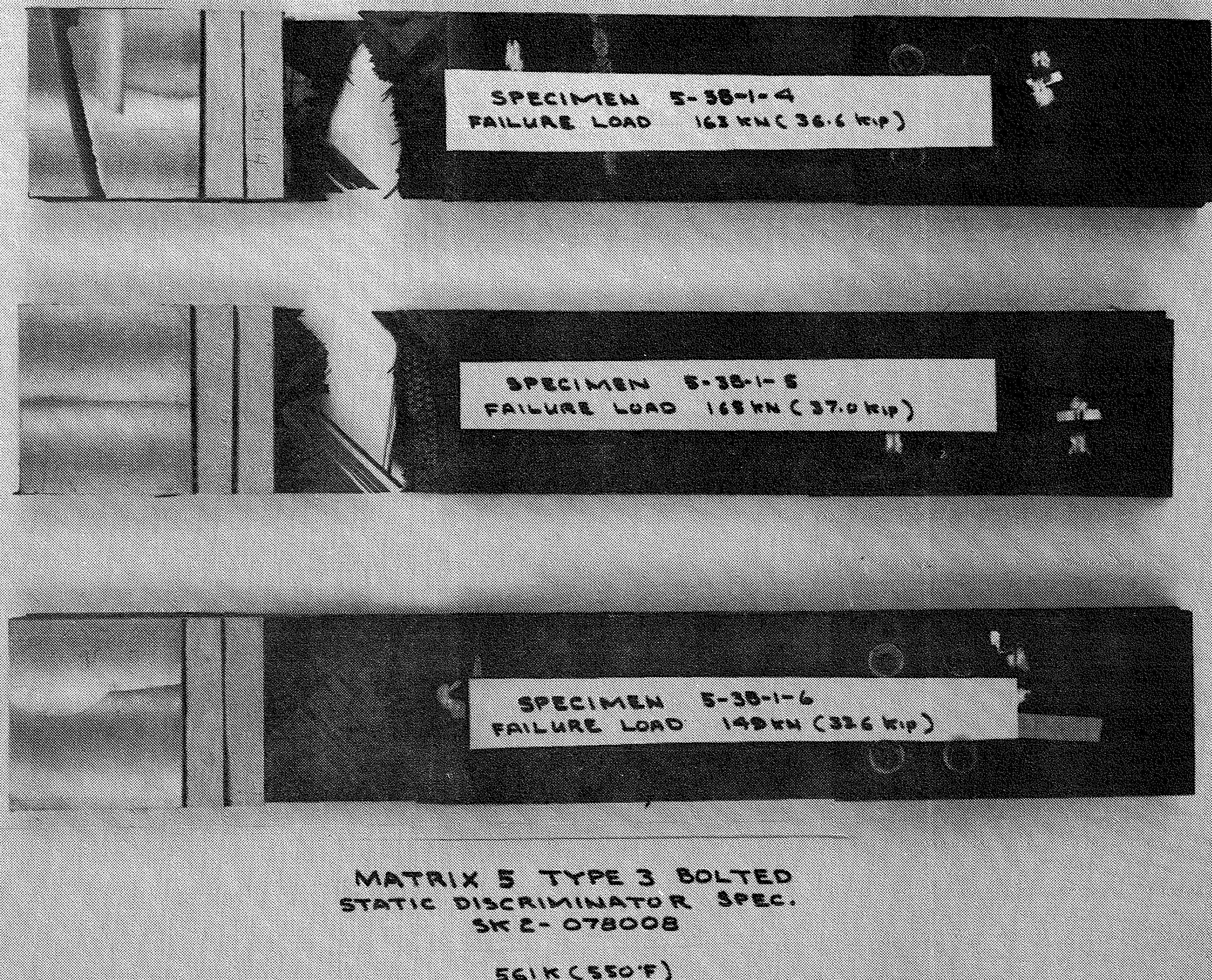


Figure 5-29: TYPE 3 BOLTED - TENSION TEST, CURED/POST-CURED, 561K (550°F)

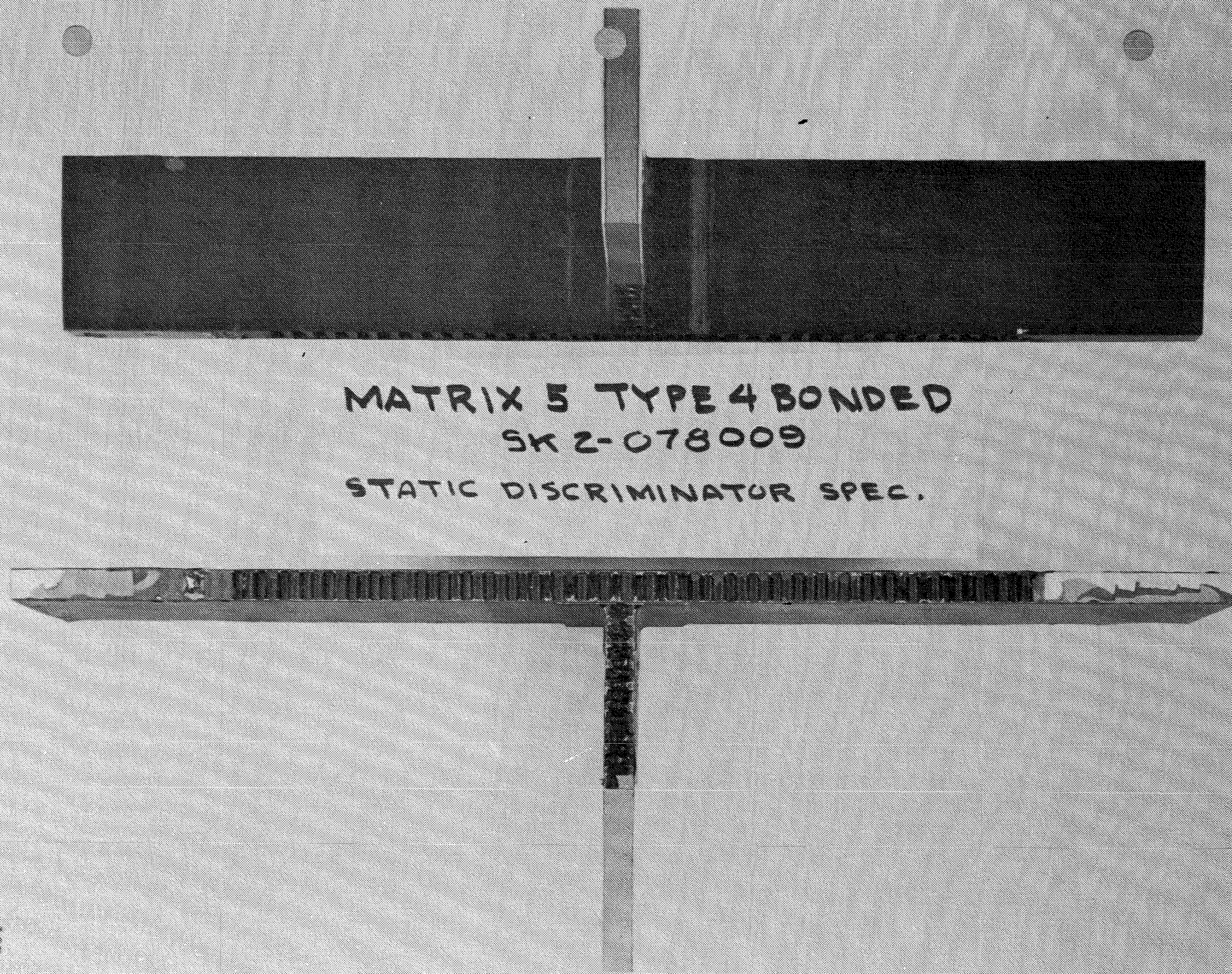


Figure 5-30: PRELIMINARY EVALUATION TYPE 4 BONDED JOINT - BEFORE TEST

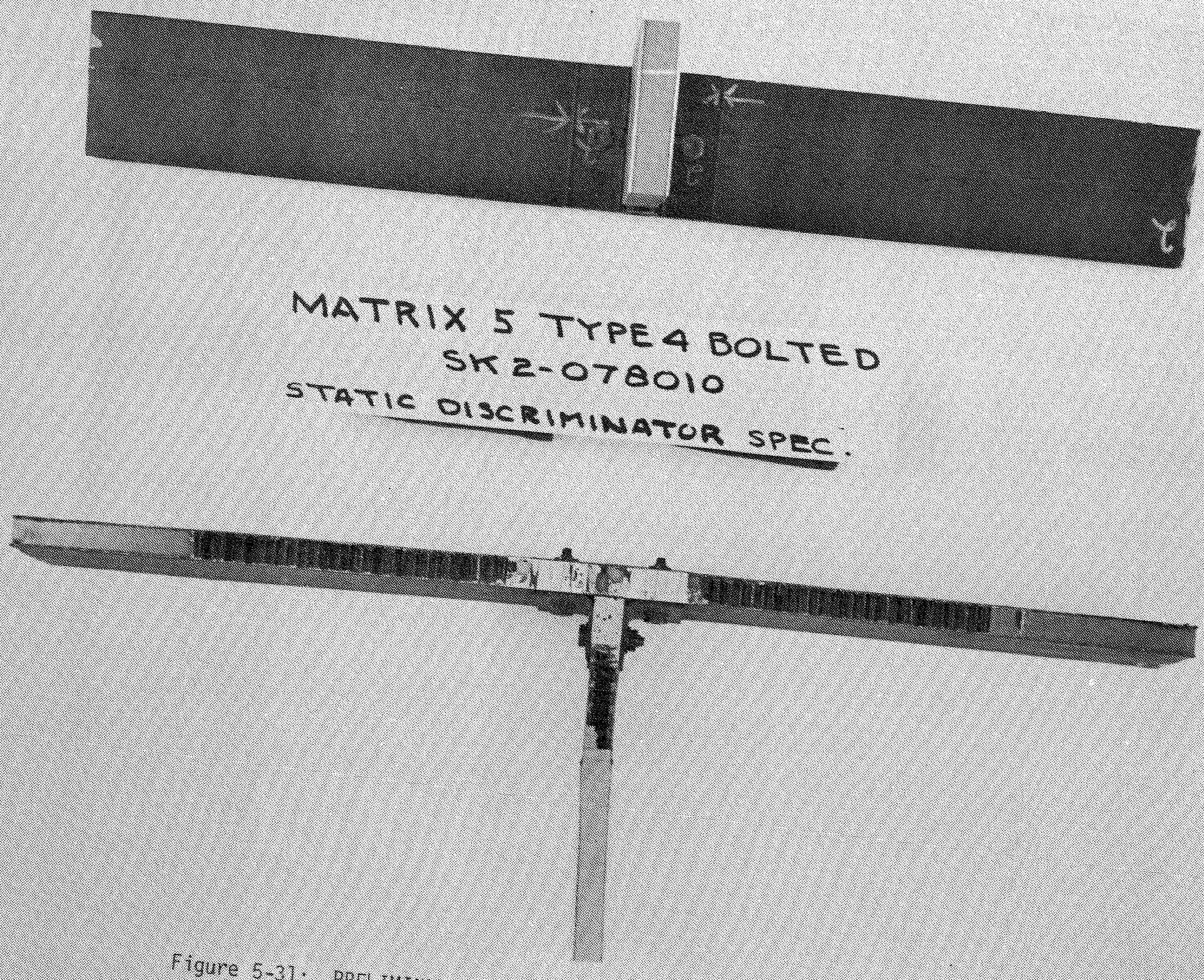


Figure 5-31: PRELIMINARY EVALUATION TYPE 4 BOLTED JOINT - BEFORE TEST

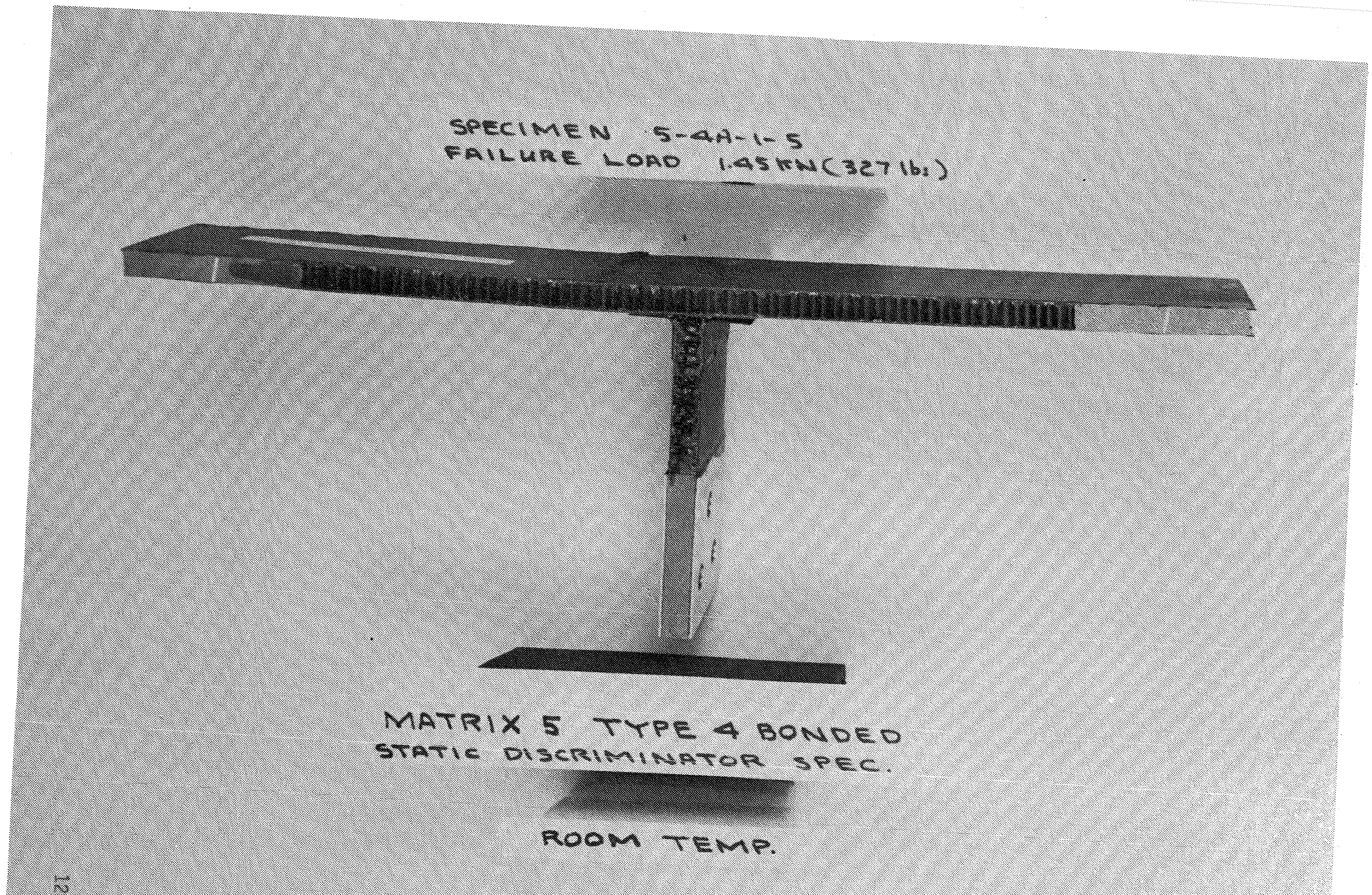


Figure 5-32: TYPE 4 BONDED - BENDING TEST, CURED/POST-CURED, 294K (70°F), COVER COMPRESSION FAILURE

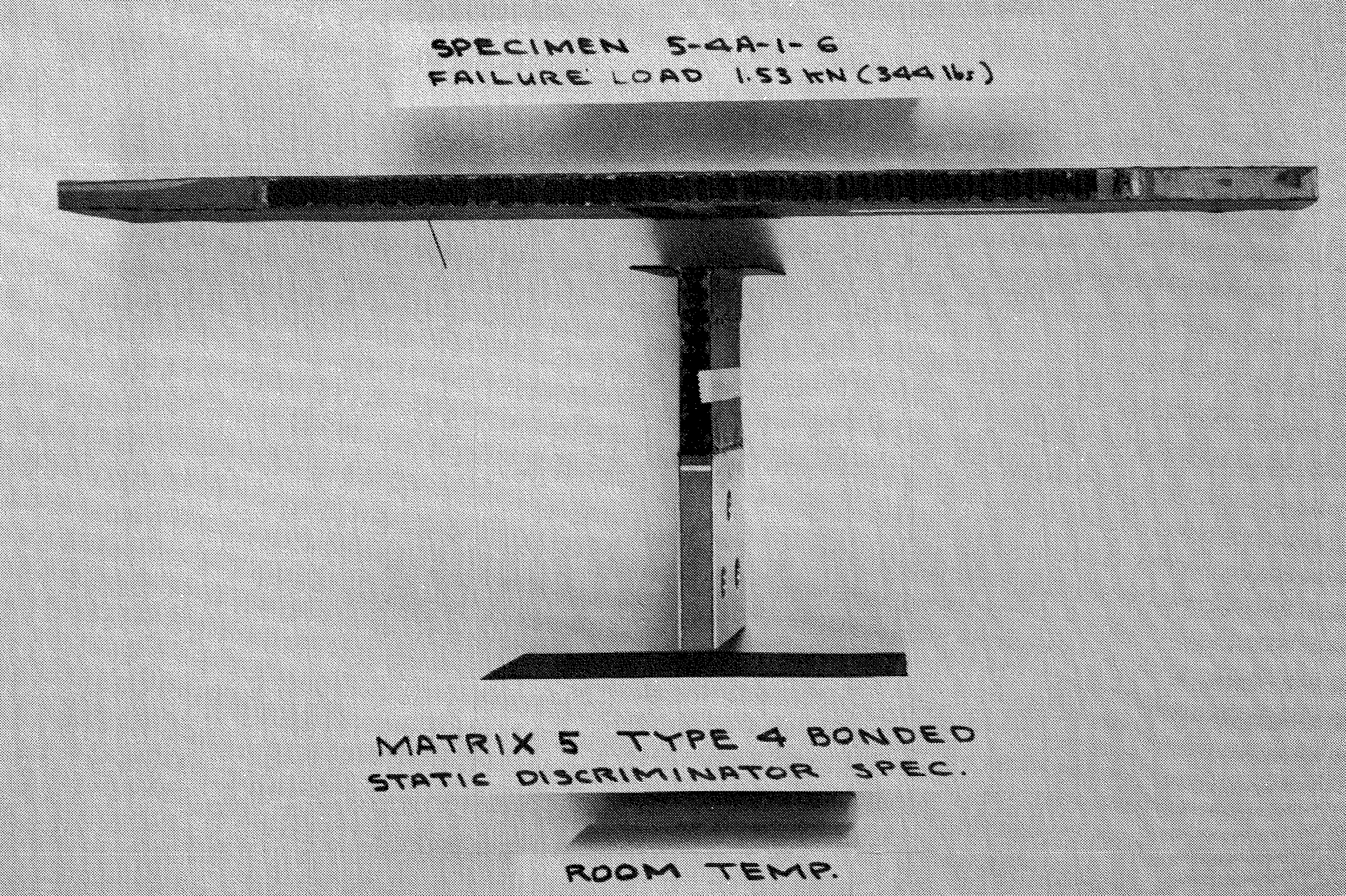


Figure 5-33: TYPE 4 BONDED - BENDING TEST, CURED/POST-CURED, 294K (70°F) ANGLE PULL-OFF FAILURE

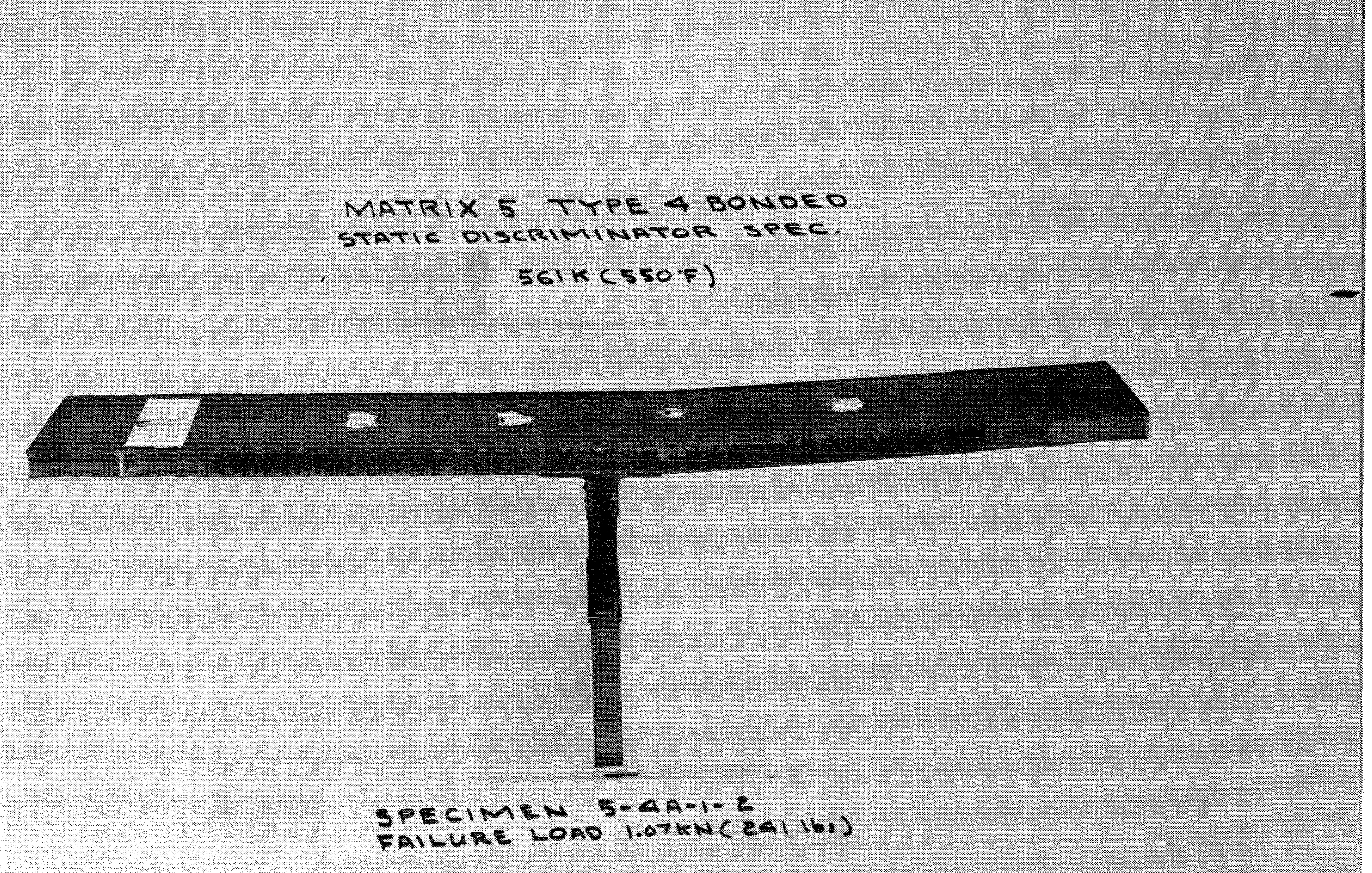


Figure 5-34: TYPE 4 BONDED - BENDING TEST, CURED/POST-CURED, 561K (550°F), COVER COMPRESSION FAILURE

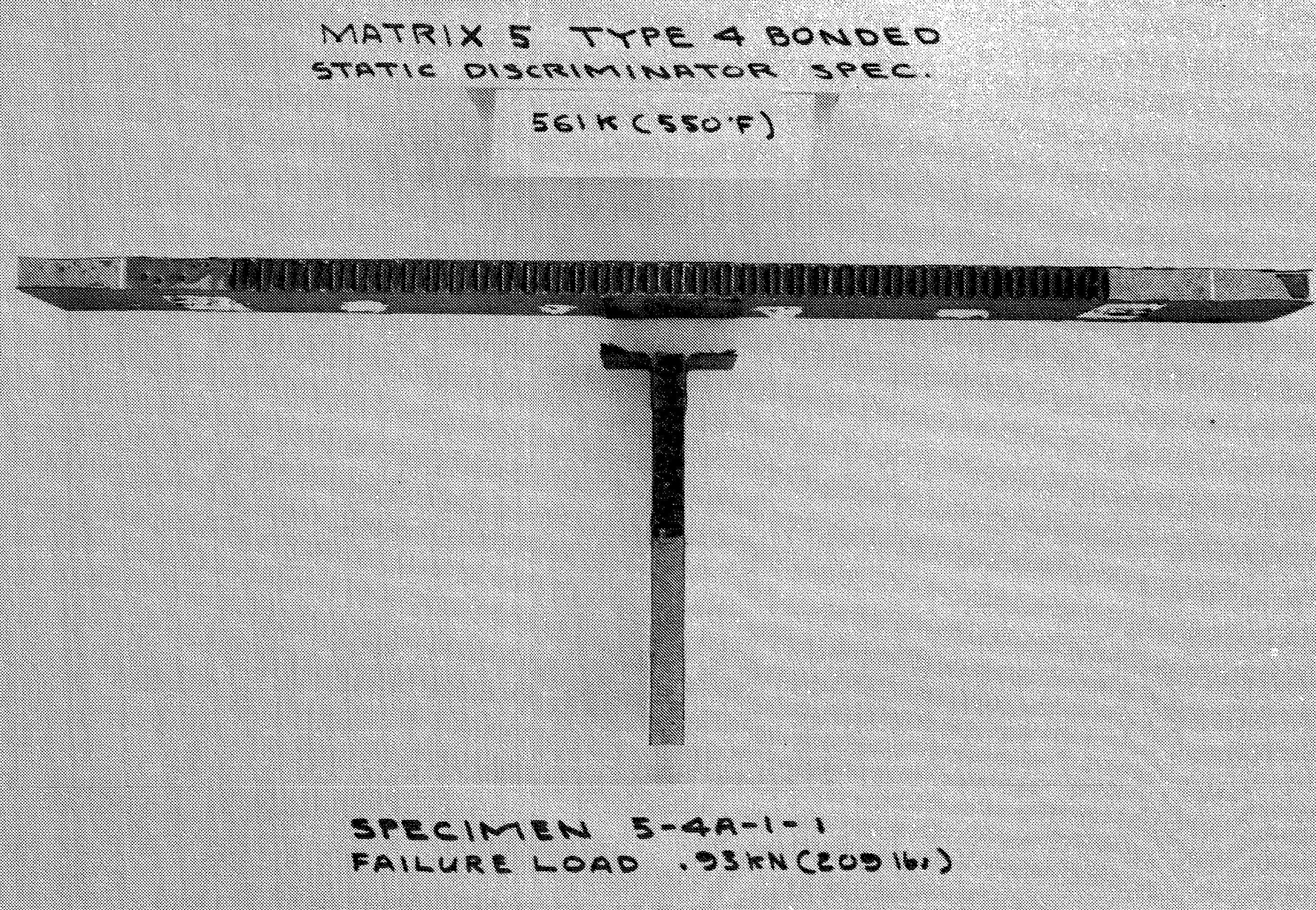


Figure 5-35: TYPE 4 BONDED - BENDING TEST, CURED/POST-CURED, 561K (550°F), ANGLE PULL-OFF FAILURE

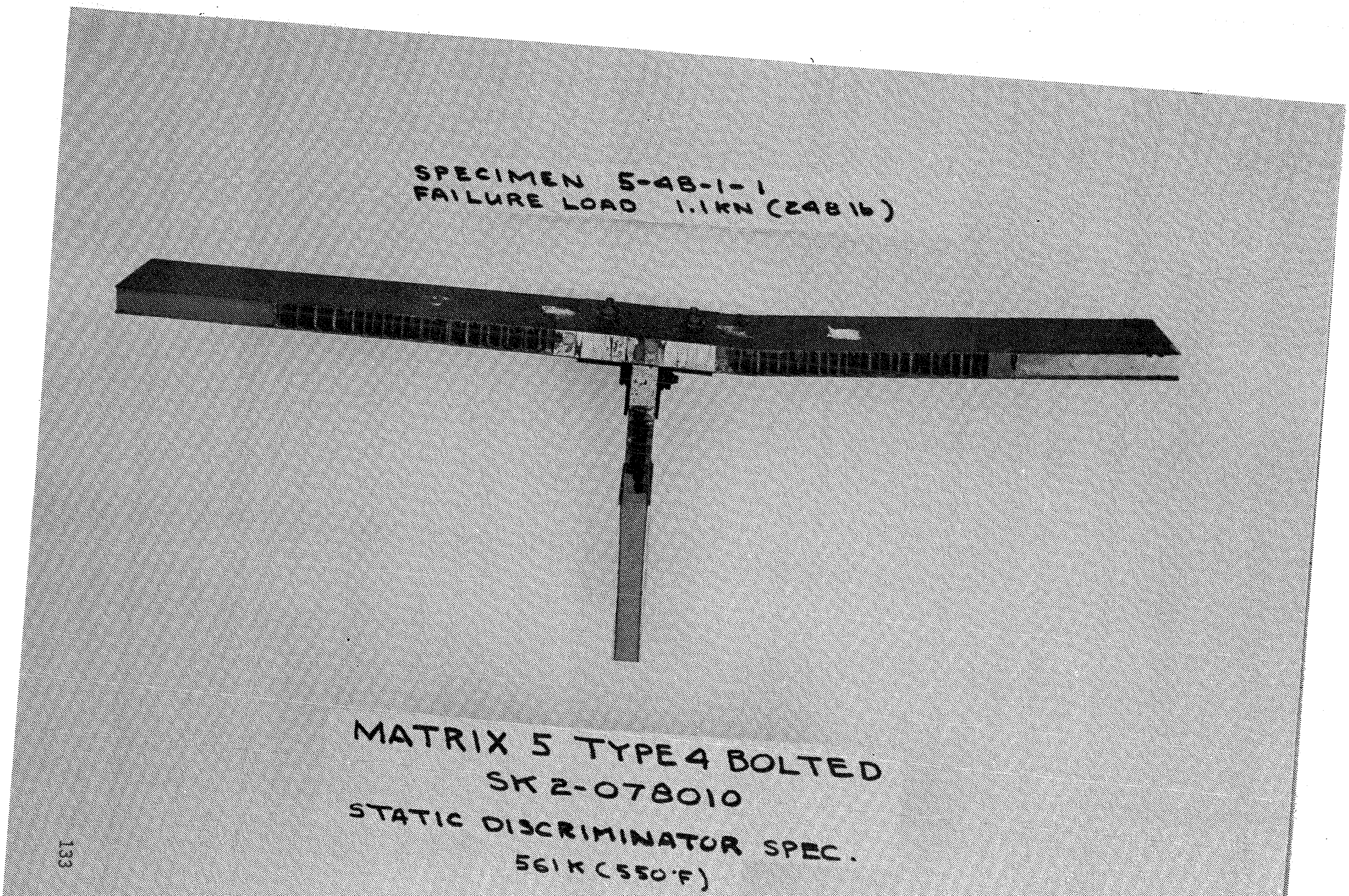


Figure 5-36: TYPE 4 BOLTED - BENDING TEST, CURED/POST-CURED, 561K (550°F)

6.0 FINAL EVALUATION OF ATTACHMENT CONCEPTS

Results of "Static Discriminator" tests of preliminary joint designs presented in Section 5.1 were used to define joint design changes for the "Final Evaluation" phase. The "Final Evaluation" phase was to fabricate joints in a scaled-up size to demonstrate they could be built in lengths needed for a production type program. Specimens were cut from the scaled-up joints and subjected to static "Scale-up Verification" tests to verify that the scaled-up production processing did not result in a loss of joint strength. Other specimens from the scaled-up joint were exposed to aging and thermal cycling environments and subjected to "Static Strength" and "Fatigue" testing to further evaluate joint performance. This section discusses selection of the final joint designs, their fabrication and processing procedures, "Final Evaluation" test procedures and results, and test/analysis correlation.

6.1 Final Joint Designs

Preliminary joint designs presented in Section 5.1 were modified slightly based on the results of the "Static Discriminator" tests. Final specimen designs are shown in Figures 6-1 through 6-7. Detail design drawings are shown in Appendix D. A description of the design changes incorporated for each specimen type, as a result of the "Static Discriminator" tests, is given in the following sections.

Type 1 Bonded and Bolted Joints

Final designs for Type 1 Bonded and Bolted joints are shown in Figures 6-1 and 6-2. These joints were different from the "Static Discriminator" specimens in that the interleaved doublers discussed in Section 5.4 were incorporated. The interleaved doublers eliminate the premature shear failure at the doubler to skin interface experienced during the static discriminator tests by distributing the load transfer from the basic skin over several shear interfaces instead of just one. The other design difference is that the webs were included in the final design. Double attachment angles were used for the bonded joint because of manufacturing simplicity and because small specimen tests (See Section 4.3) showed they were adequate for the design loads.

Type 2 Bonded and Bolted Joints

Final designs for Type 2 Bonded and Bolted joints are shown in Figures 6-3 and 6-4. The only change in the bonded joint from the preliminary design was deletion of the outer skin doublers (parts -8 and -11 of Figure B-3). Static tests showed they were not required. The corner angles of the bolted joint (parts -4 and -10 of Figure B-4) were reduced in thickness because of the higher than required failure loads for the "Static Discriminator" tests (see Table 5-3). These changes were incorporated to simplify fabrication and reduce joint weight.

The "Static Discriminator" tests showed that the Type 2 bonded joints are more flexible than the bolted joints due to a thinner corner cross-section. The bonded joint could produce undesirably large deflections. Deflection limited design criteria would probably require revision of this design.

Type 3 Bolted Joint

The final design for the Type 3 Bolted joint is shown in Figure 6-5. Design changes incorporated in this design were to facilitate fabrication of the thick laminate and to improve load introduction at the grip end. The "Static Discriminator" specimens had extensive delimination in the bolt pad-up area (see Figure 5-26). For the final design this area was made as three pieces secondarily bonded together instead of two. This was so the laminates that had to be layed-up would be thinner and allow for escape of volatiles during curing to preclude delaminations. The lay-up of the basic skin was also changed to put a ± 45 lay-up on the outside surface. This was to provide a "softer" shear transfer zone for load introduction at the hydraulic grip interface. In addition a layer of Gr/PI fabric was co-cured in the grip area to further enhance the load transfer.

Type 4 Bonded and Bolted Joints

Final designs for the Type 4 Bonded and Bolted joints are shown in Figures 6-6 and 6-7. No design changes were made from the preliminary design concepts other than the Type 4 Bonded specimen was made 63.5mm (2.5 inches) wide instead of 76.2mm (3.0 inches) wide.

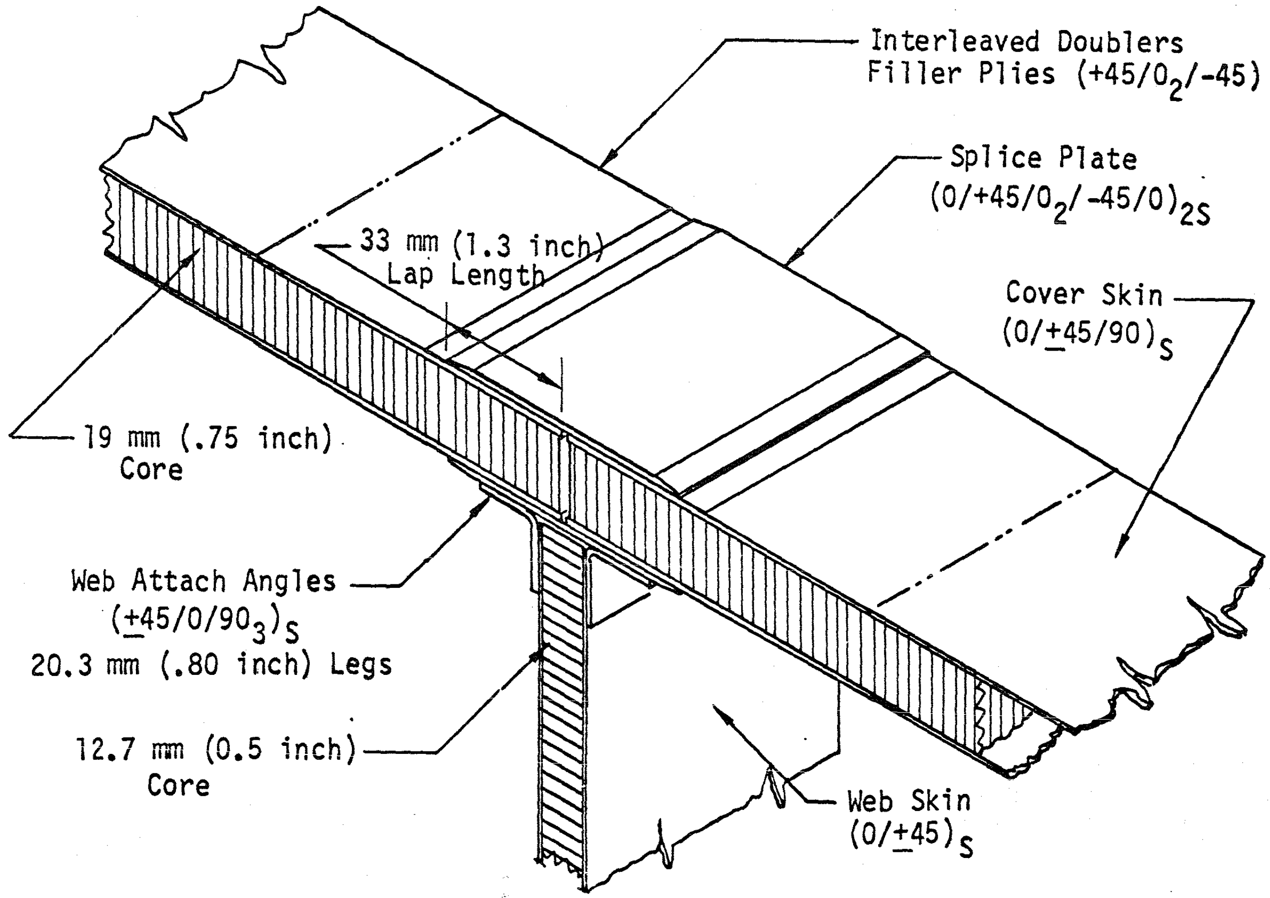


Figure 6-1: FINAL DESIGN TYPE 1 BONDED JOINT

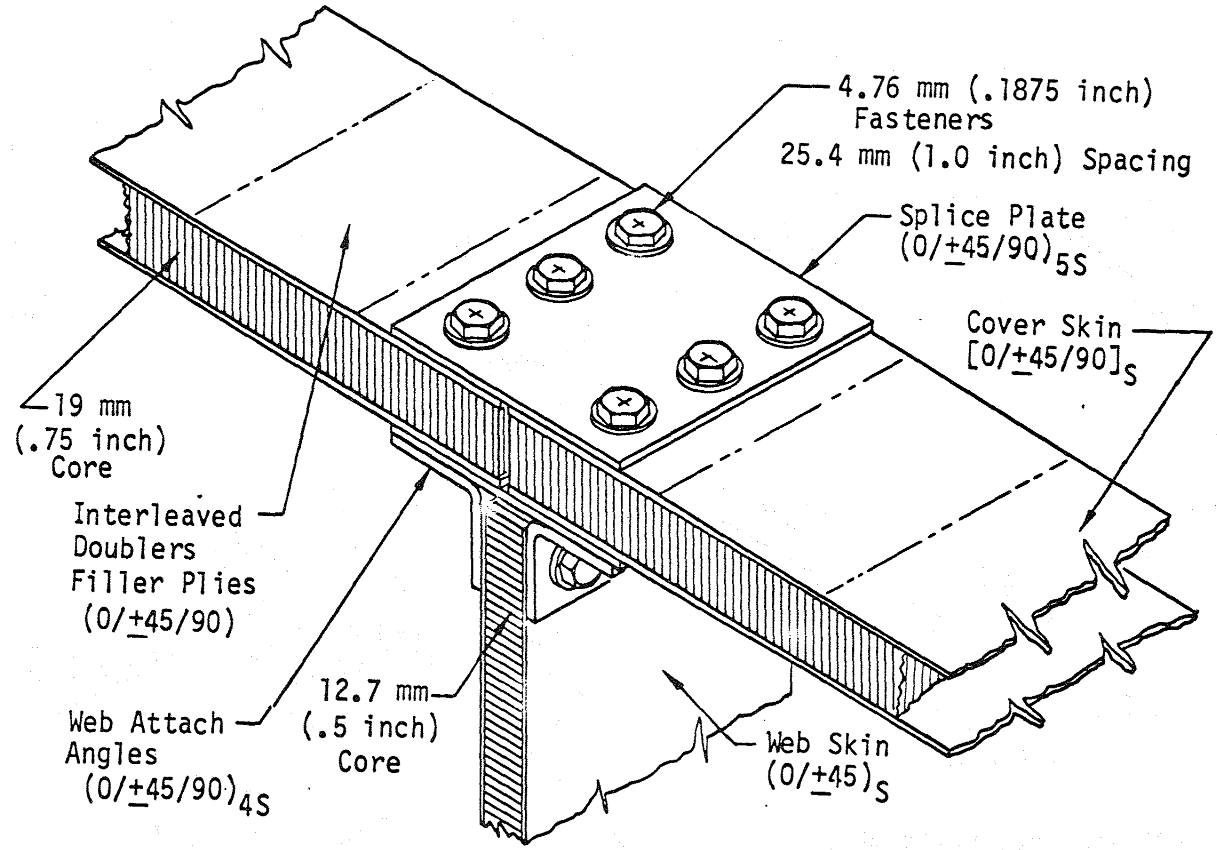


Figure 6-2: FINAL DESIGN TYPE 1 BOLTED JOINT

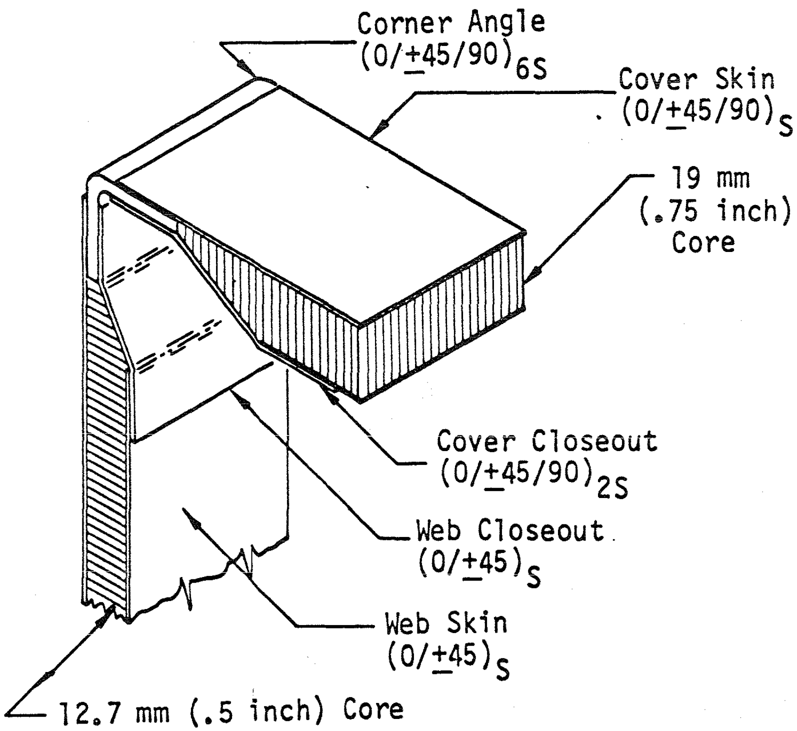


Figure 6-3: FINAL DESIGN TYPE 2 BONDED JOINT

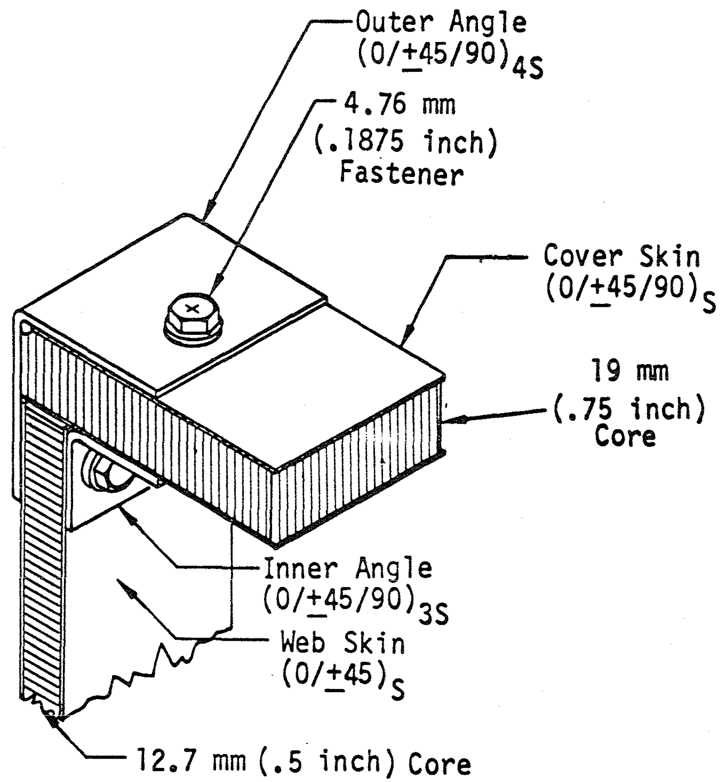


Figure 6-4: FINAL DESIGN TYPE 2 BOLTED JOINT

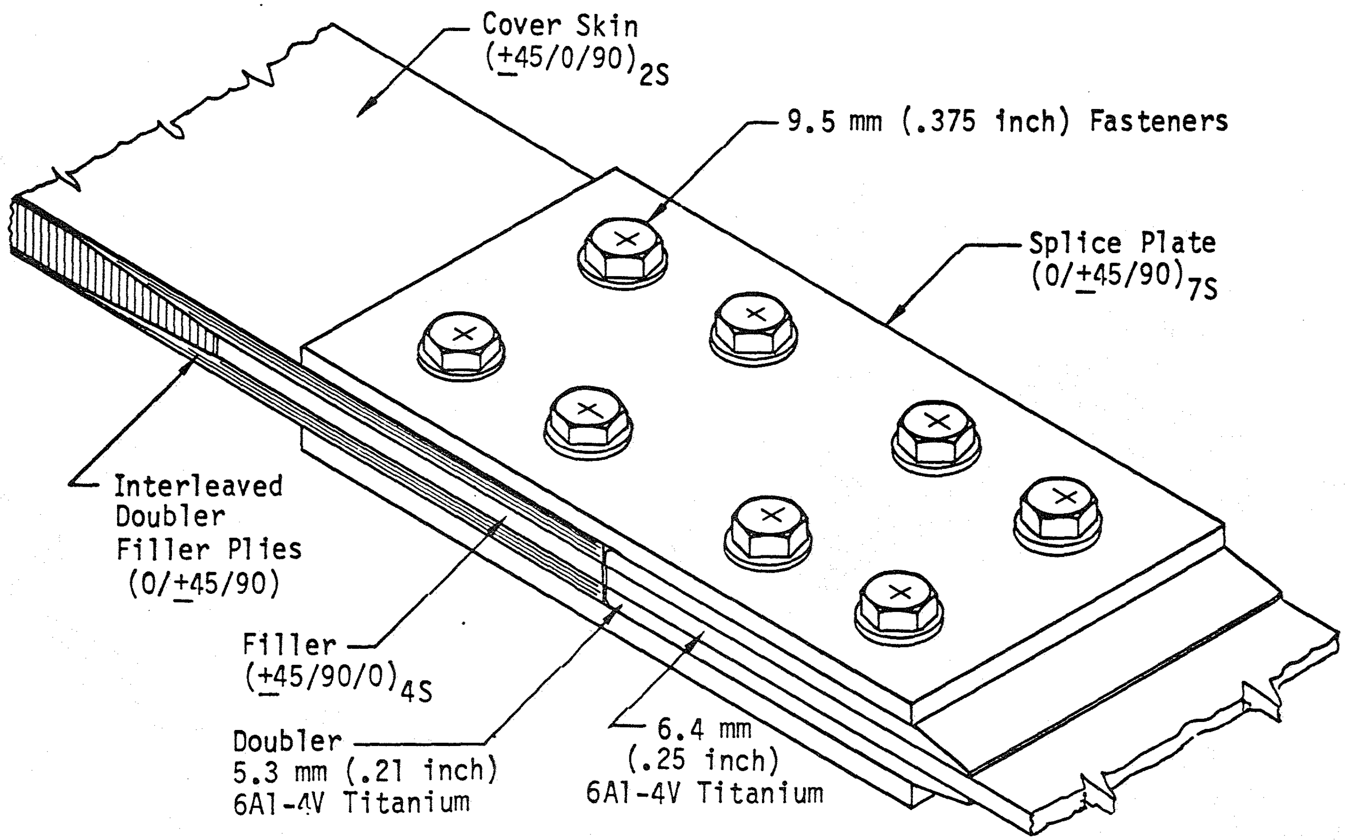


Figure 6-5: FINAL DESIGN TYPE 3 BOLTED JOINT

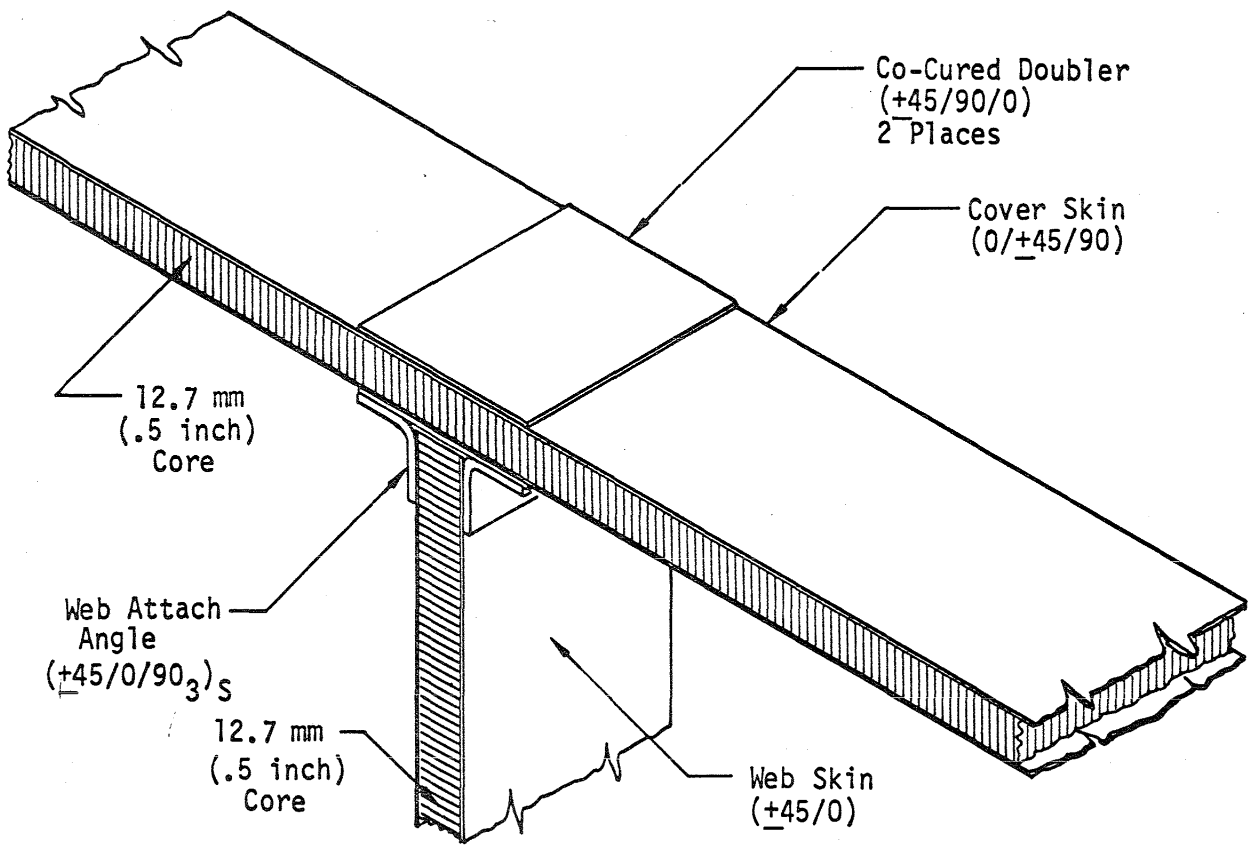


Figure 6-6: FINAL DESIGN TYPE 4 BONDED JOINT

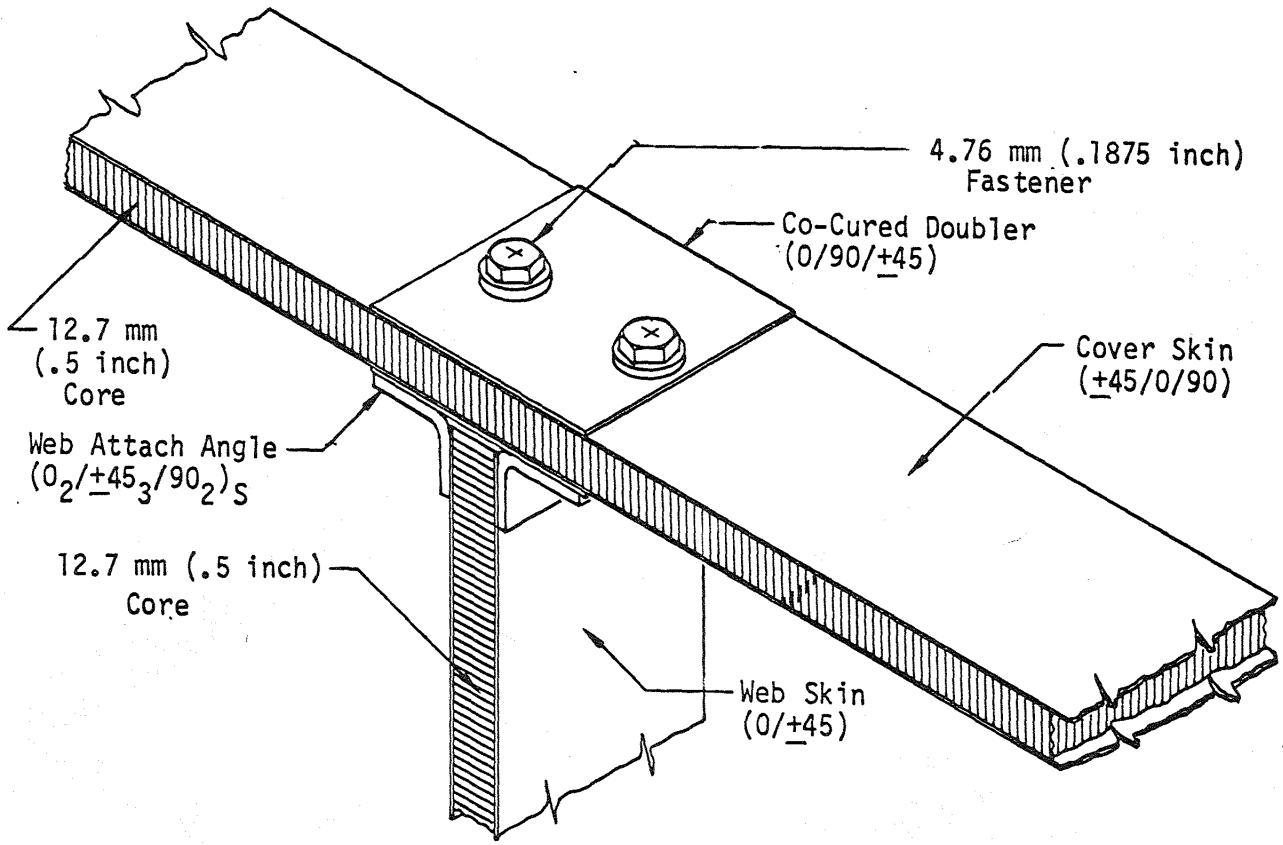


Figure 6-7: FINAL DESIGN TYPE 4 BOLTED JOINT

6.2 Final Evaluation Test Matrices and Procedures

The purpose of the "Final Evaluation" testing was to verify the validity of the scaled-up manufacturing process and to evaluate the structural integrity of the joint designs. To this end a series of static tests (Matrix 7.1), identical to the "Static Discriminator" tests of Section 5.2, were conducted on specimens cut from the scaled-up joints. These tests were to demonstrate that there was no degradation in joint performance due to the scaled-up manufacturing process. Specimens cut from the remaining portions of the scaled-up joint were thermally conditioned and tested in a series of static (Matrix 7.2) and fatigue (Matrix 7.3) tests to evaluate the structural integrity of each joint design. Test matrices for the Scale-up Verification, Static Strength and Fatigue tests are given in Tables 6-1 through 6-3. Loading conditions for the various joint types are shown in Figures 6-8 through 6-13.

Fatigue tests for all joint types were conducted using a maximum load of 67% of the average static failure load for the critical loading condition. The load ratio was +0.05 at 7 cps except the Type 3 joints which were tested at 6 cps. Maximum fatigue loads for each joint type are given in Table 6-4.

All tests were conducted in the Boeing Materials Test Laboratories. Static tests were conducted using Baldwin Universal Test Machines except for specimens requiring hydraulic load grips. These were tested using an Ametek test machine. Typical test setups are shown in Figures 6-14 through 6-23.

Elevated temperature tests were conducted using resistance heated enclosures or radiant lamps depending on specimen size and shape. Specimens were brought to temperature and soaked for 10 minutes prior to test. Temperatures were controlled to $\pm$6K ($\pm 10^{o}$F) by placing thermocouples on the specimens connected to a Thermac Model 624A temperature controller.

See Section 4.3 for specimen numbering system.

Table 6-1: MATRIX 7.1 SCALE-UP VERIFICATION TESTS TASK 1.4.2

TEST NO.	JOINT TYPE	CONDITION CODE [1]	LOAD CONDITION	NUMBER OF TESTS AT: 294K (70°F)	561K (550°F)	TOTAL TESTS
1A	Type 1 Bonded	1	Tension	-	2	2
1B	Type 1 Bolted	1	Tension	-	3	3
2A	Type 2 Bonded	1	Bending(1)	-	3	3
2B	Type 2 Bolted	1	Bending(1)	-	3	3
3B	Type 3 Bolted	1	Tension	-	1	1
4A	Type 4 Bonded	1	Bending	-	3	3
4B	Type 4 Bolted	1	Bending	-	3	3
						TOTAL = 18

Table 6-2: MATRIX 7.2 STATIC STRENGTH TESTS TASK 1.4.4

TEST NO.	JOINT TYPE	CONDITION CODE [1]	LOAD CONDITION	NUMBER OF TESTS AT: 294K (70°F)	561K (550°F)	TOTAL TESTS
1A1	Type 1 Bonded	2	Tension	4	2	6
1A2		2	Bending	3	2	5
1A3		3	Tension	-	3	3
1B1	Type 1 Bolted	2	Tension	3	3	6
1B2		2	Bending	3	3	6
1B3		3	Tension	-	[2]	-
2A1	Type 2 Bonded	2	Bending(1)	3	3	6
2A2		2	Bending(2)	3	5	8
2A3		3	Bending(2)	-	3	3
2B1	Type 2 Bolted	2	Bending(1)	3	3	6
2B2		2	Bending(2)	3	3	6
2B3		3	Bending	-	[2]	-
3B1	Type 3 Bolted	2	Tension	4	4	8
3B3		3	Tension	-	3	3
4A1	Type 4 Bonded	2	Bending	3	2	5
4A2		2	Shear	[3]	[3]	-
4A3		3	Bending	-	[2]	-
4B1	Type 4 Bolted	2	Bending	3	3	6
4B2		2	Shear	3	3	6
4B3		3	Bending	-	[2]	-
						TOTAL = 83

Table 6-3: MATRIX 7.3 FATIGUE TESTS TASK 1.4.5

TEST NO.	JOINT TYPE	CONDITION CODE [1]	LOAD CONDITION	NUMBER OF TESTS AT: 294K (70°F)	561K (550°F)	TOTAL TESTS
1A	Type 1 Bonded	2	Tension	3	3	6
1B	Type 1 Bolted	2	Tension	3	3	6
2A	Type 2 Bonded	2	Bending	3	3	6
2B	Type 2 Bolted	2	Bending	3	3	6
3B	Type 3 Bolted	2	Tension	3	3	6
4A	Type 4 Bonded	2	Bending	[3]	[3]	-
4B	Type 4 Bolted	2	Bending	3	3	6
						TOTAL = 36

[1] CONDITION CODE

1 As cured/postcured

2 Soaked for 125 hrs at 589K (600°F) in a one (1) atmosphere environment (air)

3 Thermally cycled 125 times in temperature range from 116K to 589K (-280°F to 600°F) and in a one (1) atmosphere environment (air)

[2] Specimens destroyed during thermal cycling, see Section 8.2.

[3] Specimens had bad adhesive bonds-- not tested.

Note: Load Case numbers are shown in ( ).

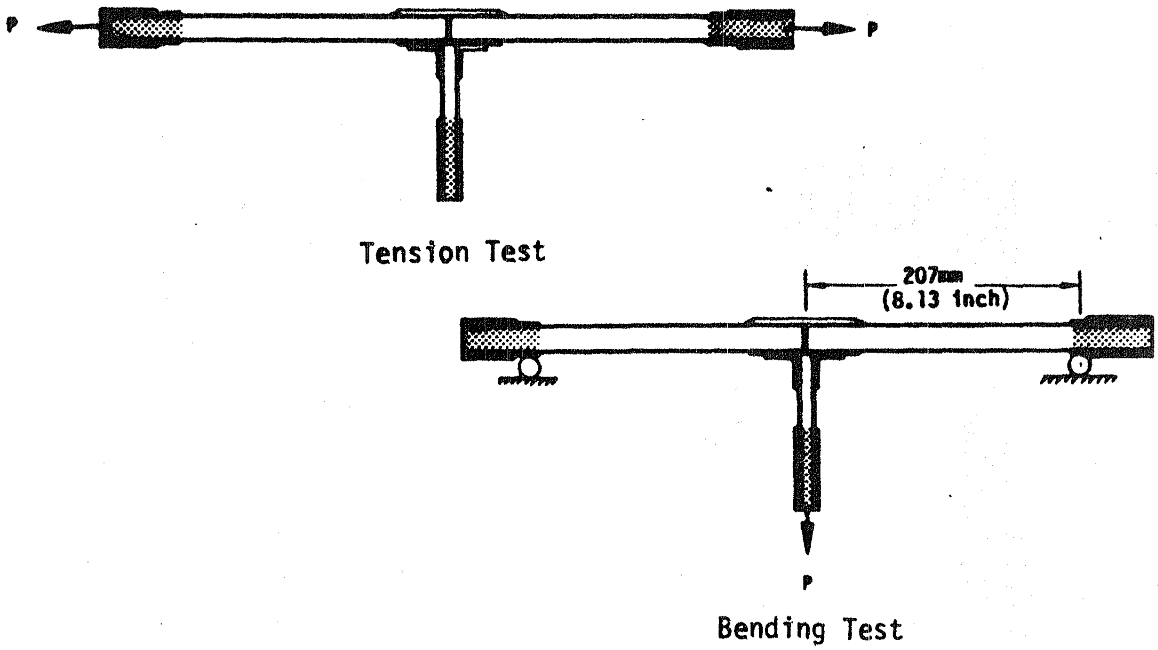


Figure 6-8: TYPE 1 JOINT STATIC LOADING CONDITIONS

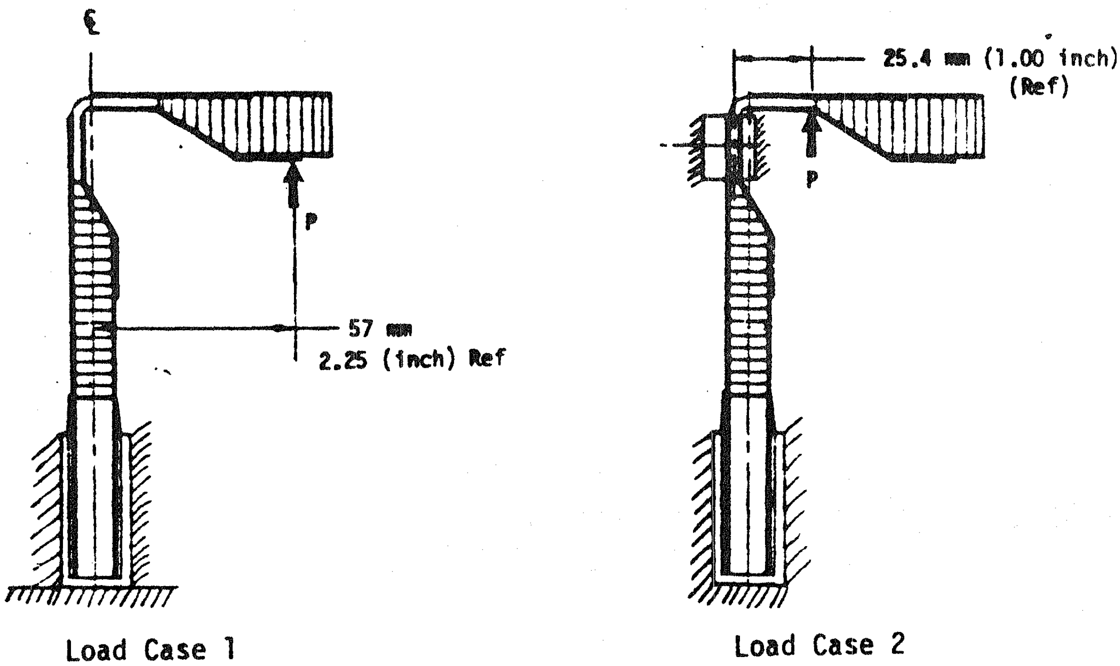


Figure 6-9: TASK 1.4 - TYPE 2 BONDED JOINT STATIC LOADING CONDITIONS

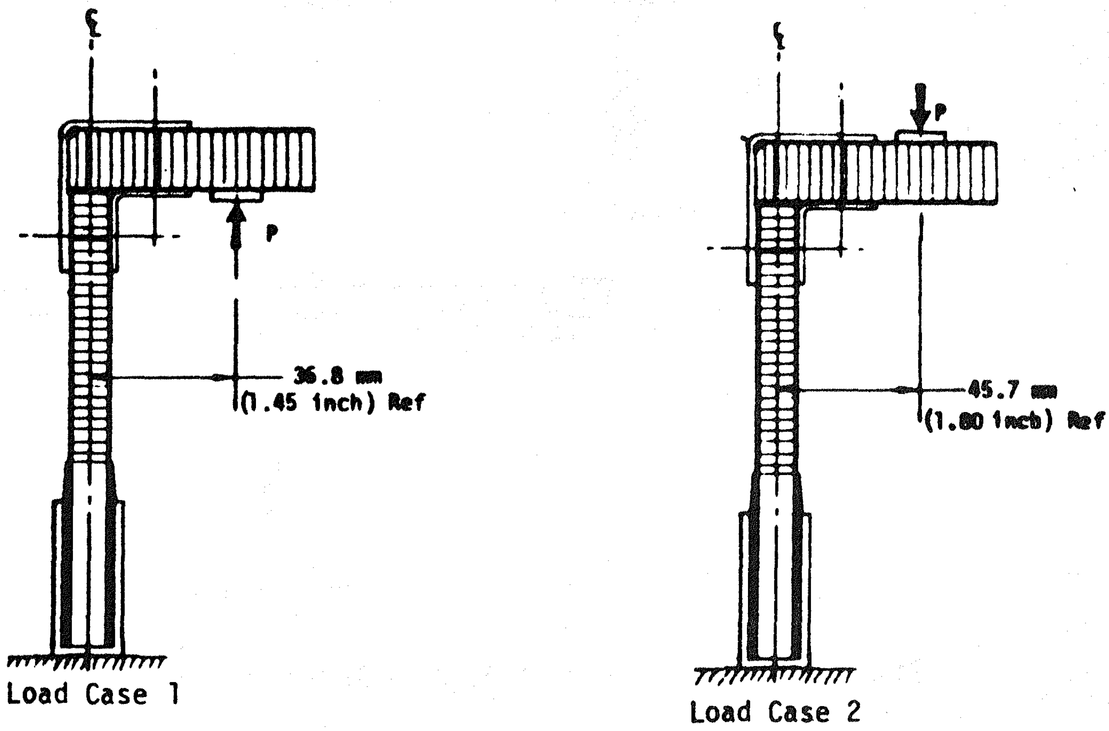


Figure 6-10: TYPE 2 BOLTED STATIC LOADING CONDITIONS

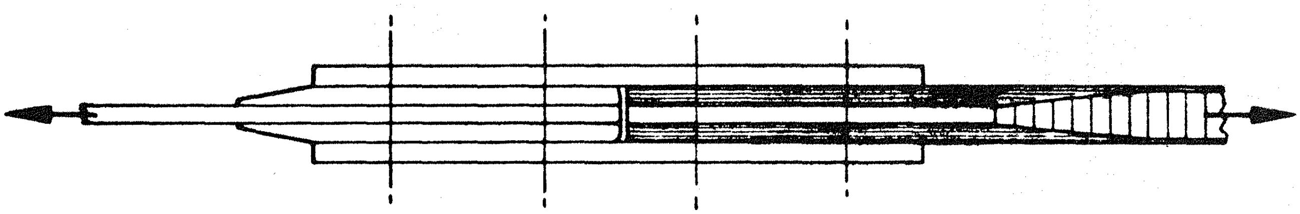
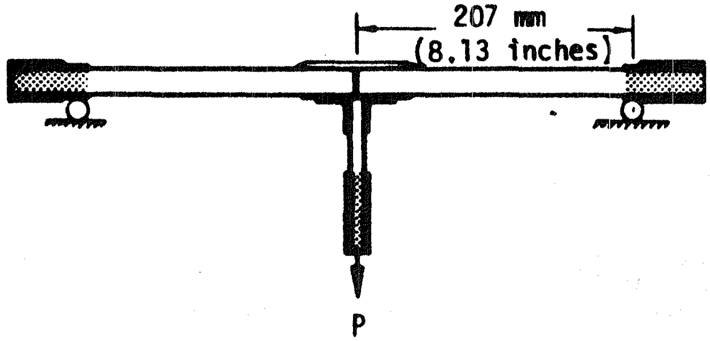


Figure 6-11: TYPE 3 BOLTED STATIC LOADING CONDITION



Bending Test

Figure 6-12: TYPE 4 JOINT STATIC LOADING CONDITION

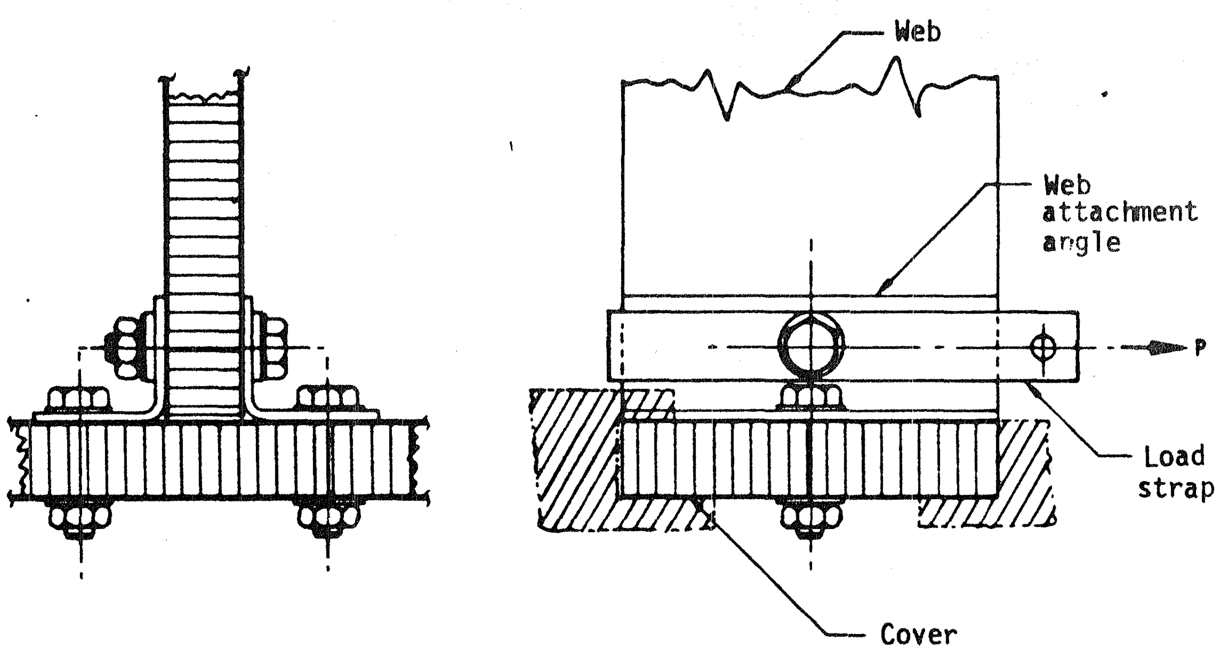


Figure 6-13: TYPE 4 BOLTED WEB ATTACHMENT SHEAR LOADING CONDITION

Table 6-4: MAXIMUM FATIGUE LOADS

JOINT TYPE		MAXIMUM LOAD	
		294K (70°F)	561K (550°F)
TYPE 1	Bonded	292 kN/m (1667 lb/in)	292 kN/m (1667 lb/in)
	Bolted	255 kN/m (1455 lb/in)	223 kN/m (1275 lb/in)
TYPE 2	Bonded	285 N-m/m (64 in-lb/in)	222 N-m/m (50 in-lb/in)
	Bolted	214 N-m/m (48 in-lb/in)	431 N-m/m (97 in-lb/in) (first specimen) 187 N-m/m (42 in-lb/in) (second, third specimens)
TYPE 3	Bolted	1268 kN/m (7242 lb/in)	1162 kN/m (6636 lb/in)
TYPE 4	Bonded	Not tested	Not tested
	Bolted	20.7 kN/m (118 lb/in)* 11.2 kN/m (64 lb/in)**	18.0 kN/m (103 lb/in)* 9.8 kN/m (56 lb/in)**

* Based on 254 mm (10.0 in) total support span

** Equivalent load for a 413 mm (16.26 in) total support span

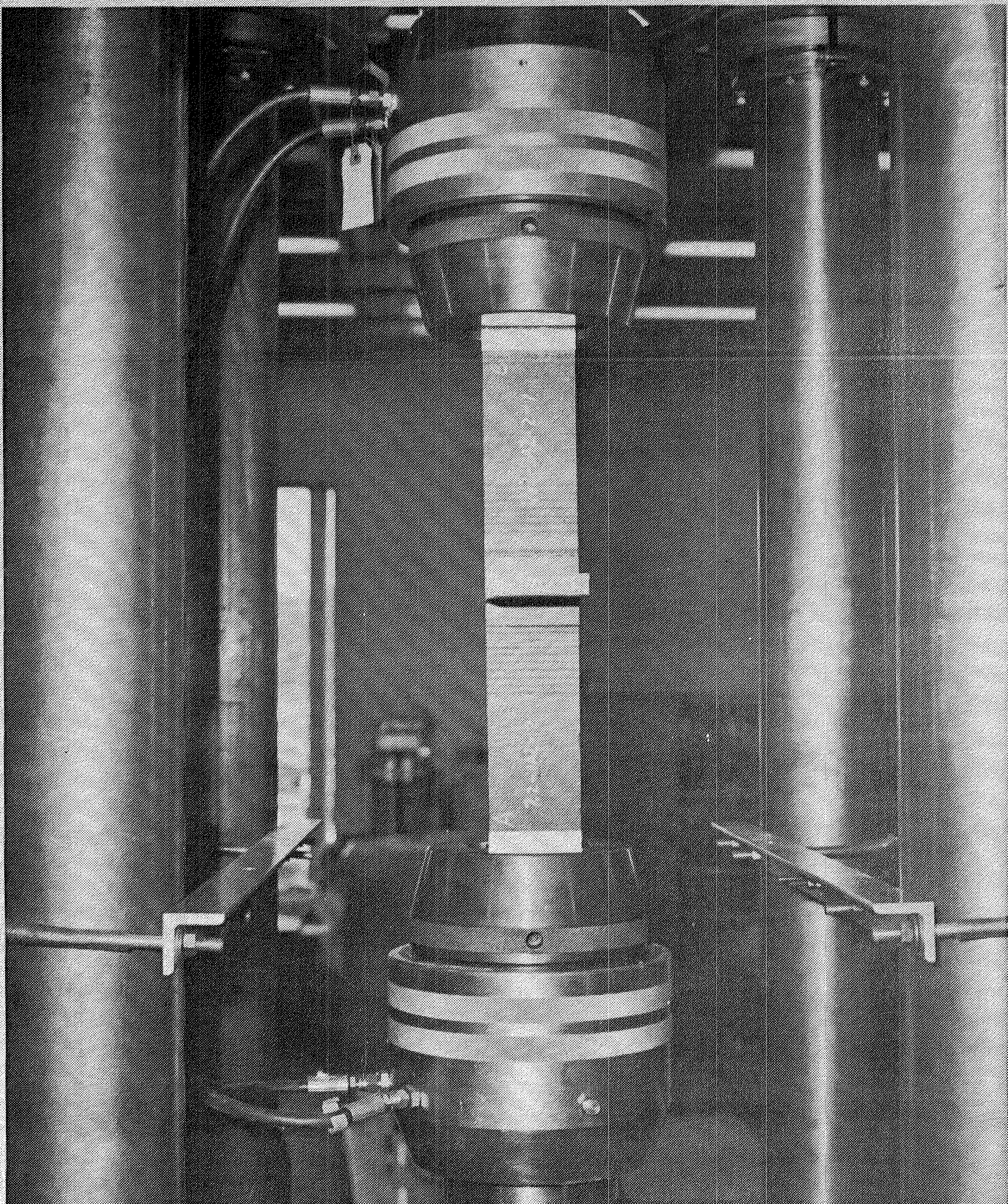


Figure 6-14: MATRIX 7, TYPE 1 JOINT TENSION TEST SETUP

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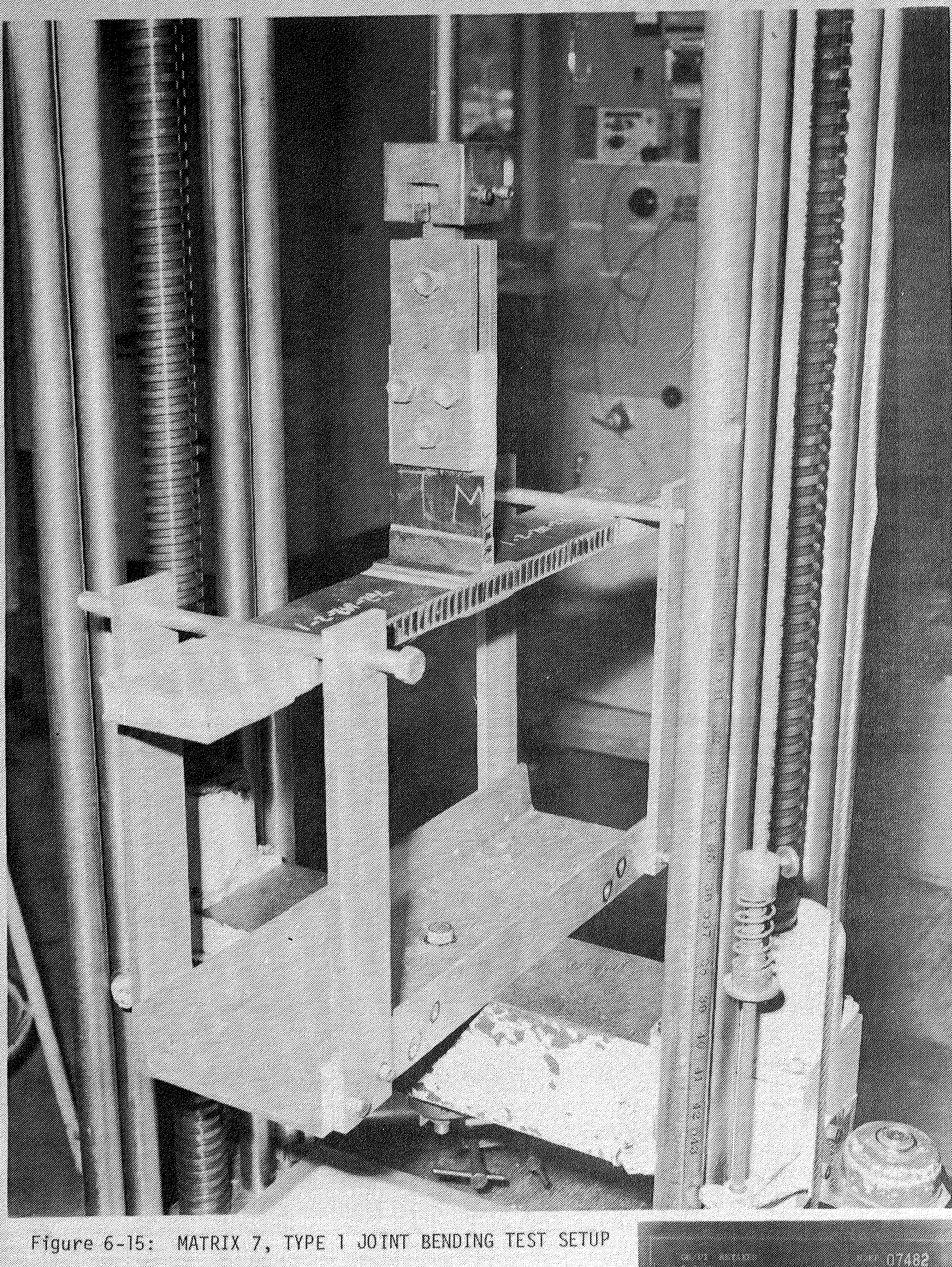


Figure 6-15: MATRIX 7, TYPE 1 JOINT BENDING TEST SETUP

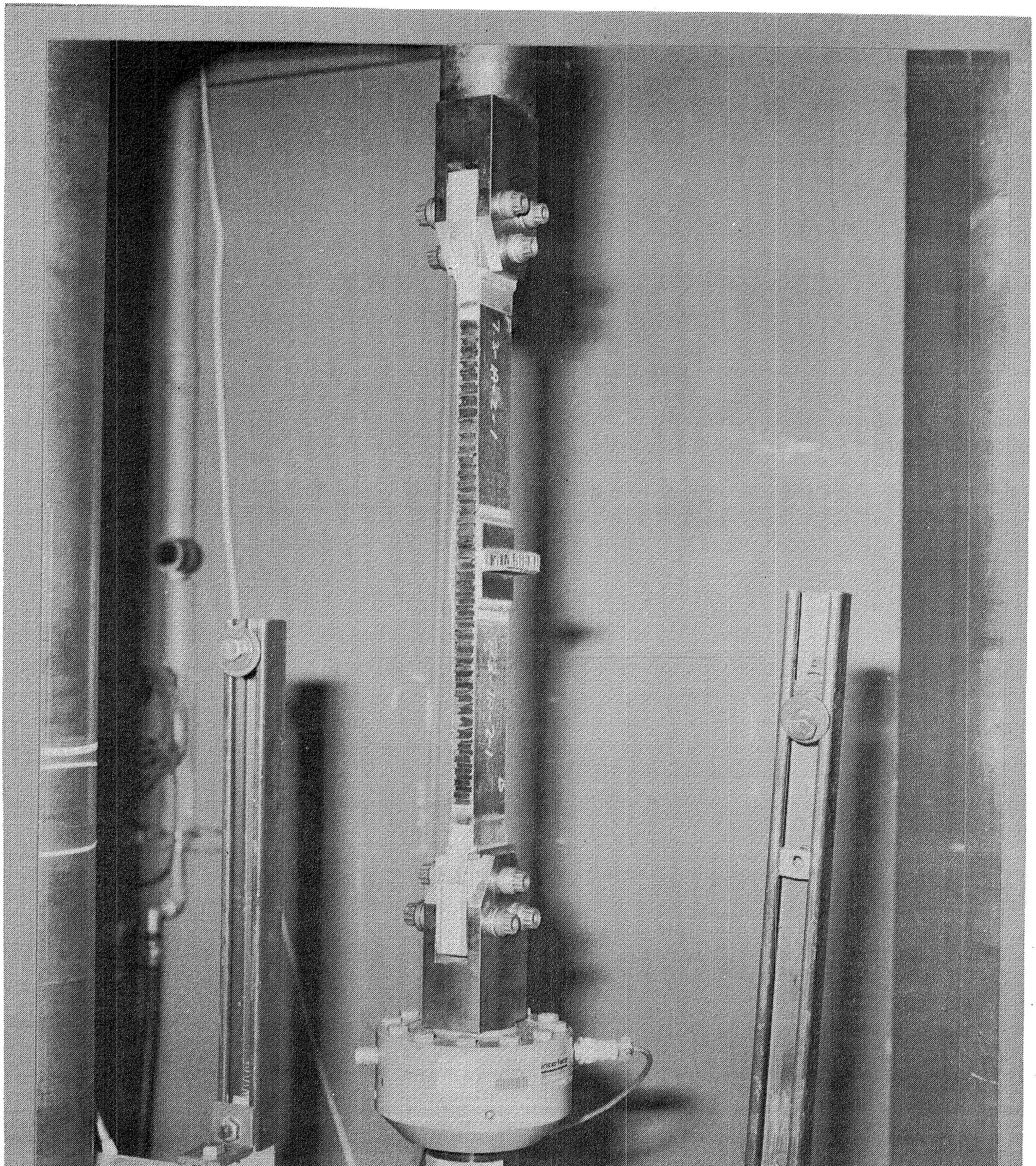


Figure 6-16: MATRIX 7, TYPE 1 JOINT FATIGUE TEST SETUP

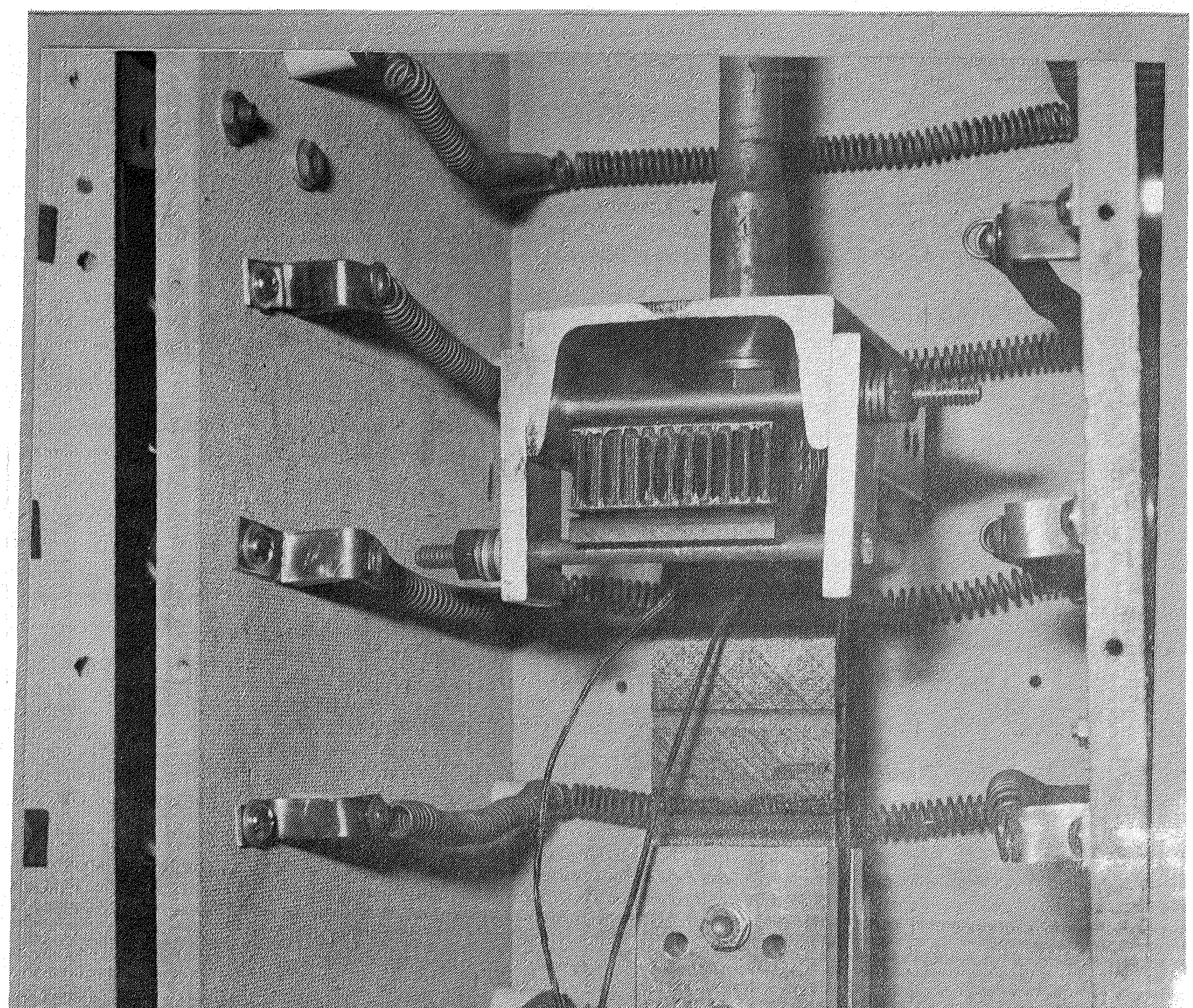


Figure 6-17: MATRIX 7, TYPE 2 BONDED JOINT LOAD CASE 1 TEST SETUP

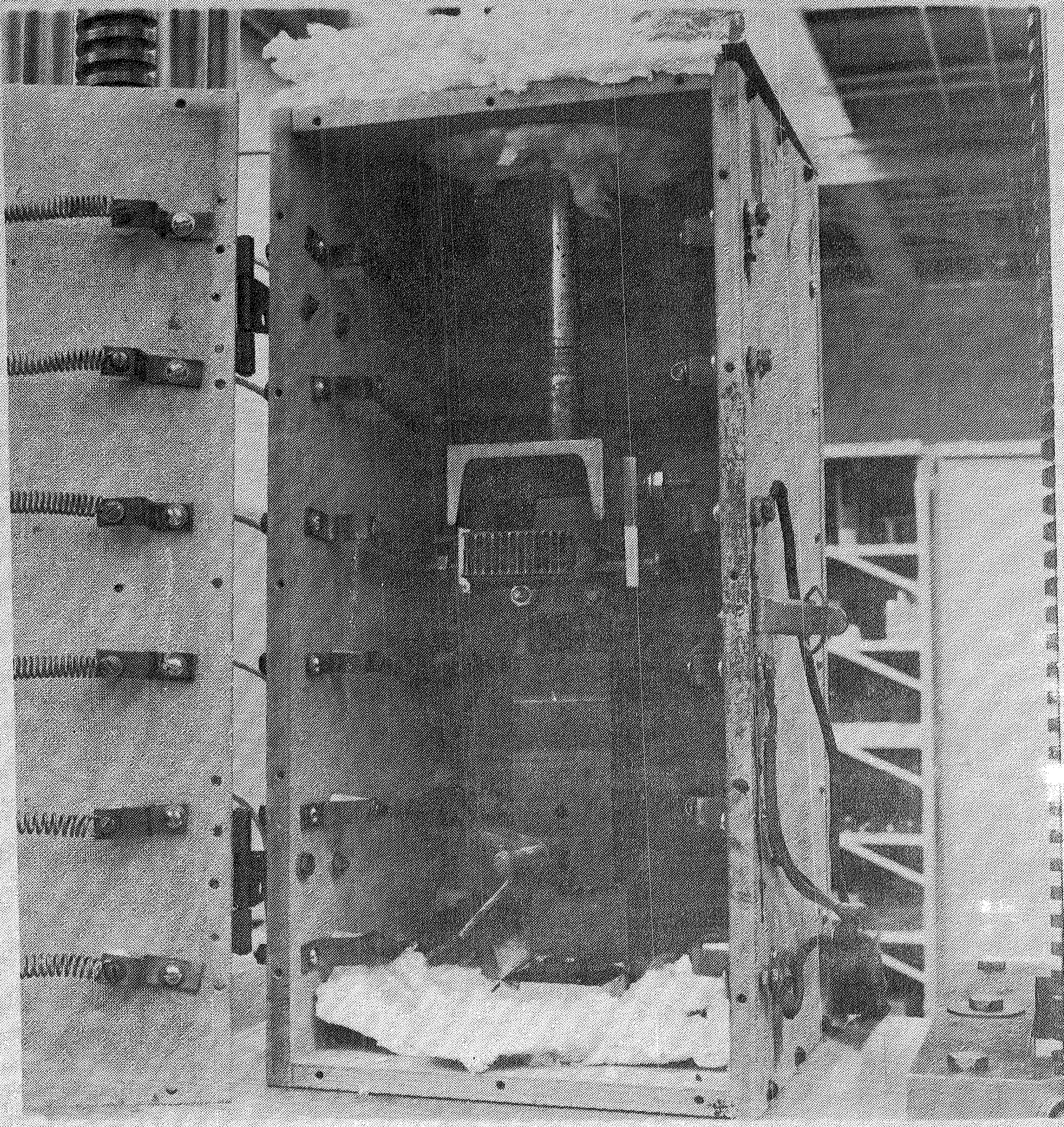


Figure 6-18: MATRIX 7, TYPE 2 BONDED JOINT LOAD CASE 2 TEST SETUP

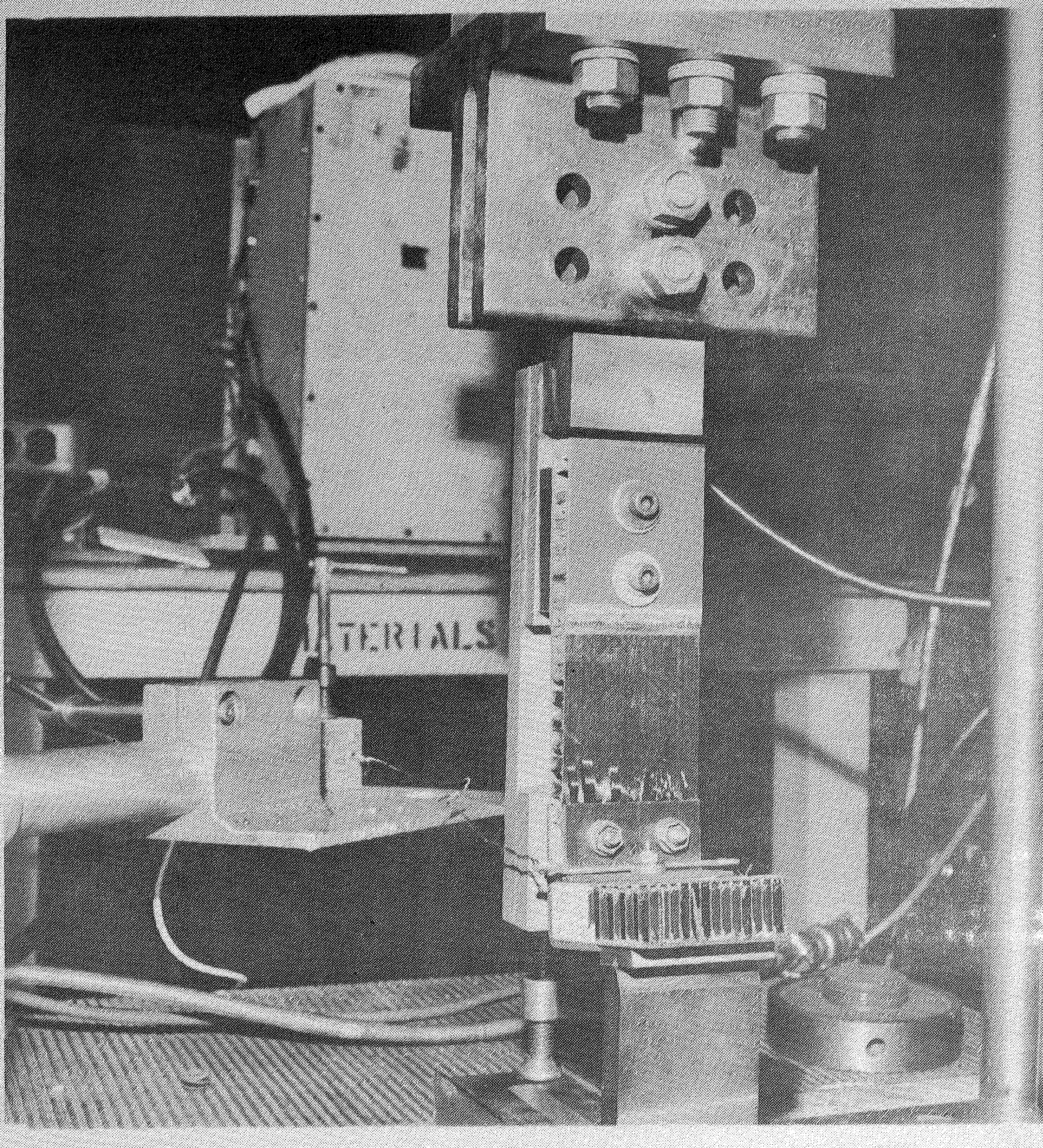


Figure 6-19: MATRIX 7, TYPE 2 BOLTED JOINT LOAD CASE 2 TEST SETUP

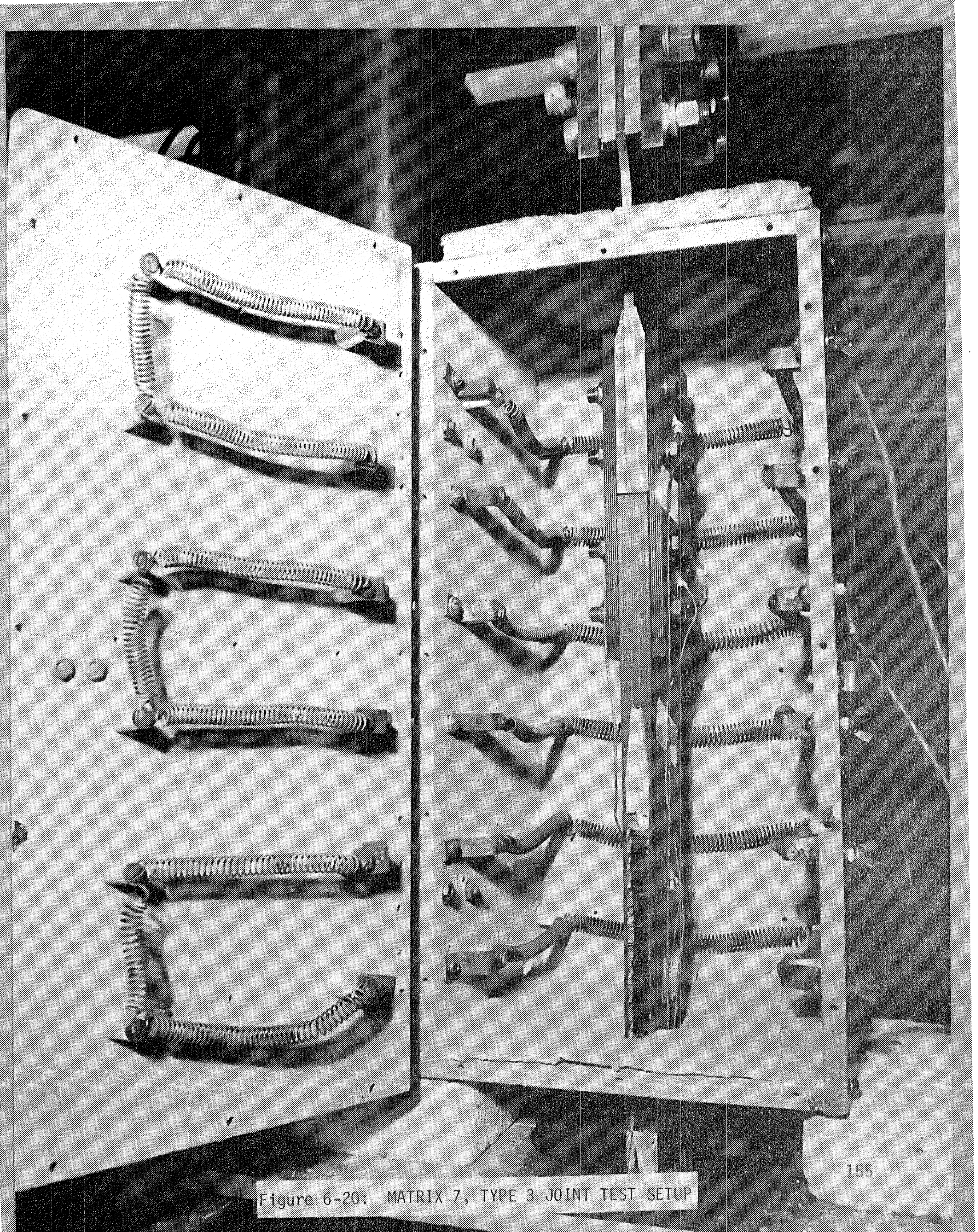


Figure 6-20: MATRIX 7, TYPE 3 JOINT TEST SETUP

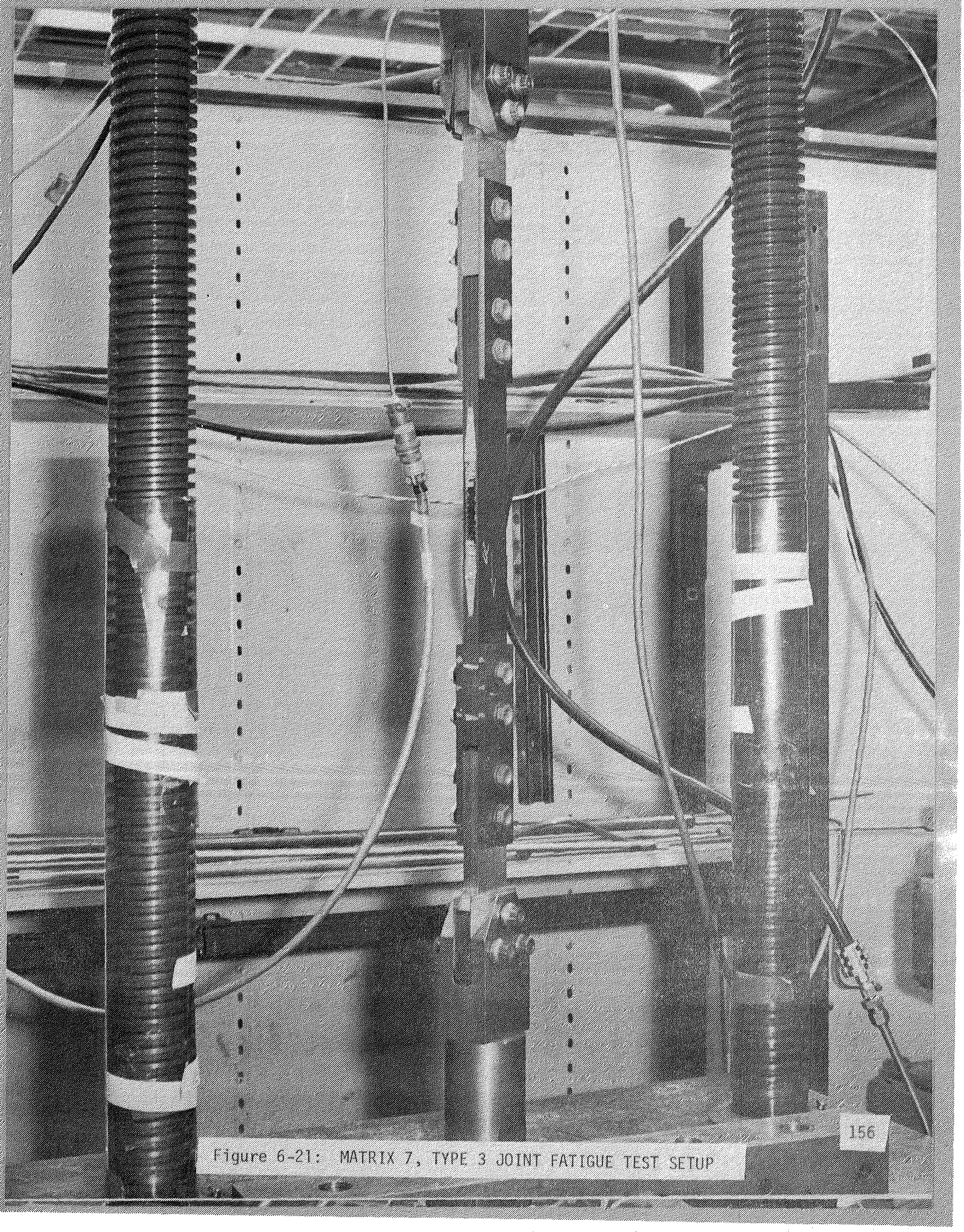


Figure 6-21: MATRIX 7, TYPE 3 JOINT FATIGUE TEST SETUP

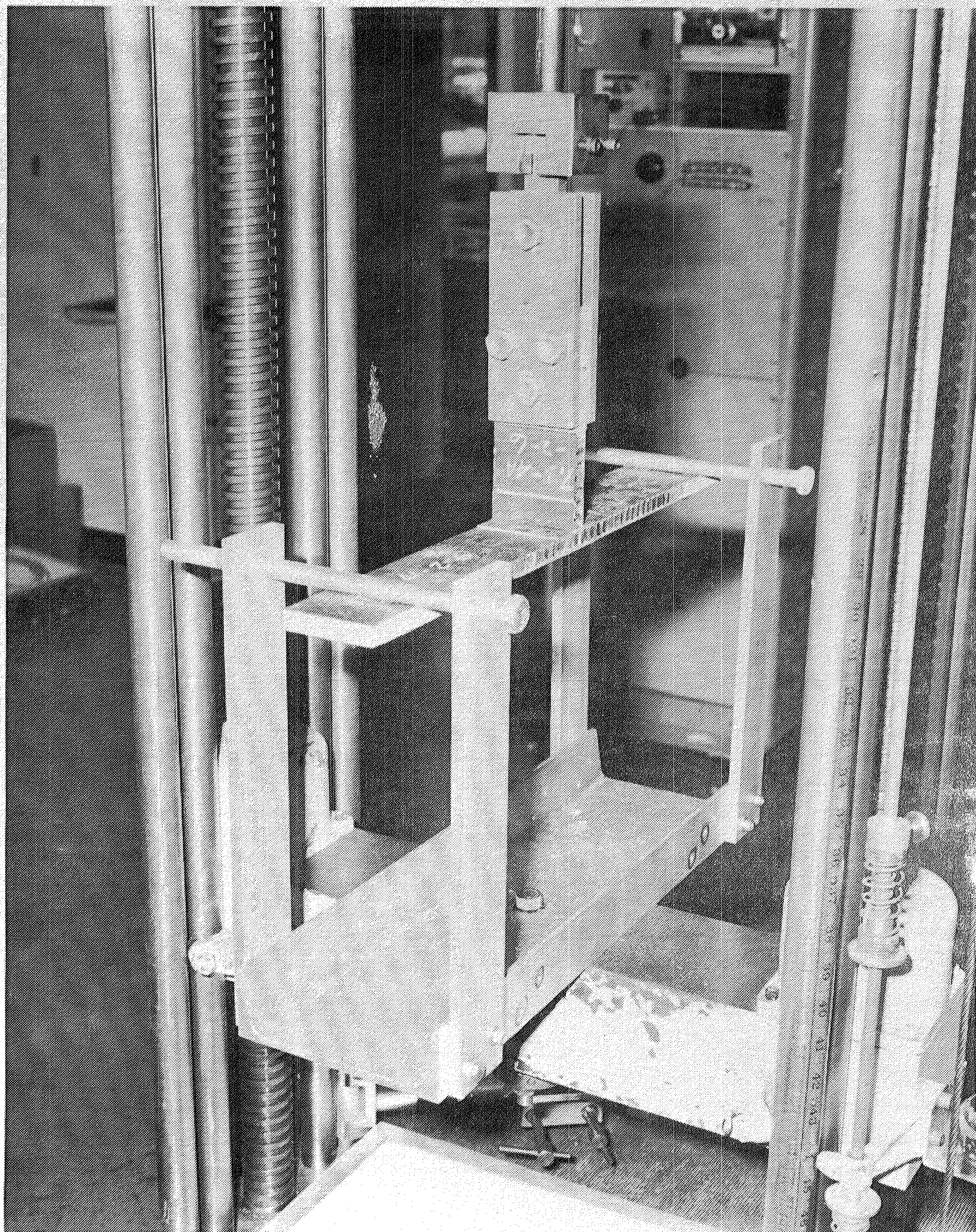


Figure 6-22: MATRIX 7, TYPE 4 JOINT BENDING TEST SETUP

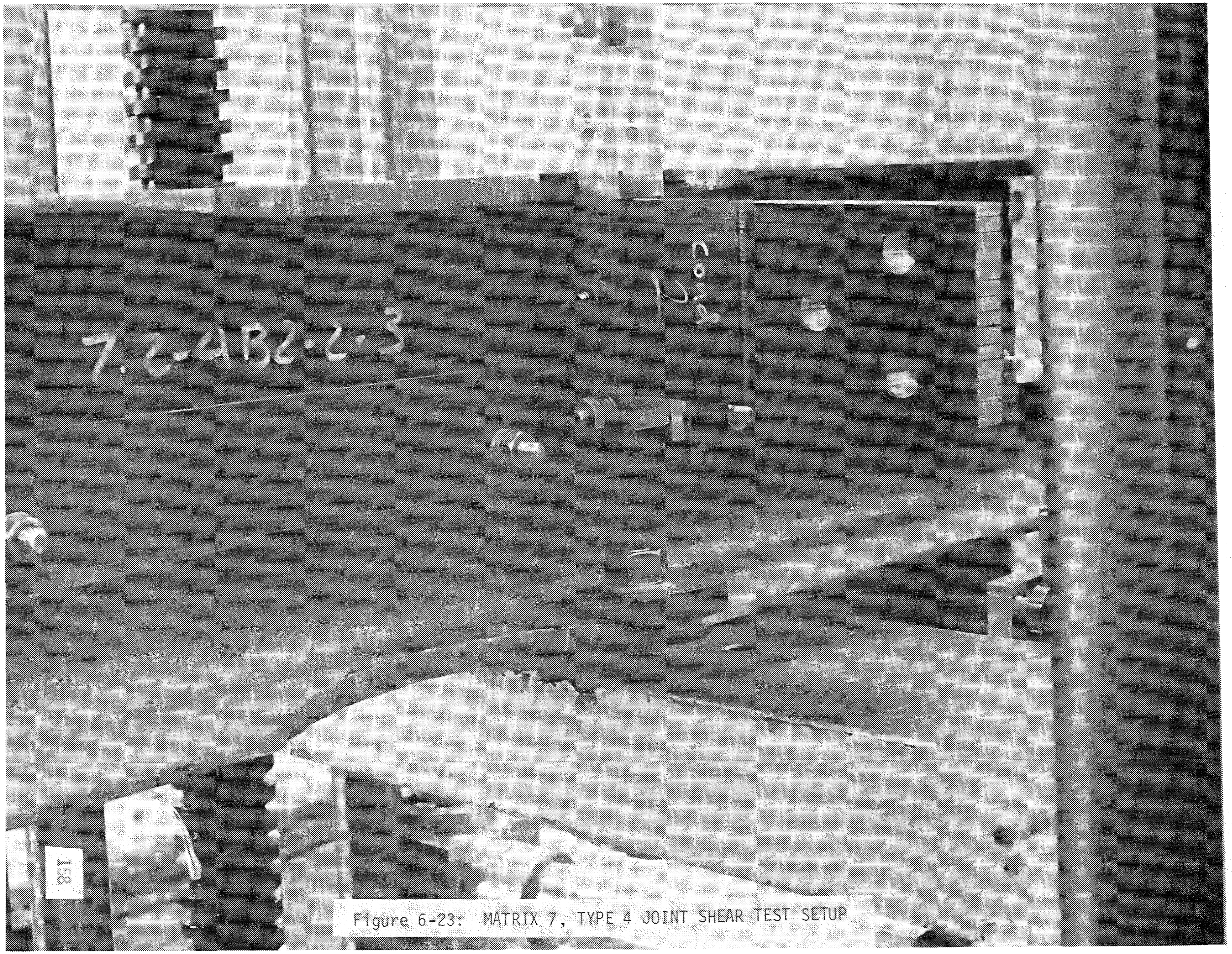


Figure 6-23: MATRIX 7, TYPE 4 JOINT SHEAR TEST SETUP

6.3 Specimen Fabrication

The specimen fabrication procedures for the "Final Evaluation" specimens were the same as for the "Static Discrimator" specimens outlined in Section 5.3, except as noted in the following paragraphs. Specimen panels for the "Final Evaluation" phase were fabricated in scaled-up configurations to demonstrate that the parts could be made in sizes required for production type programs. These parts were made in panels up to 0.6m x 2.1m (24 in x 84 in).

Joint Types 1, 2, and 4 were made from Celion 3000/PMR-15 prepreg, while the Type 3 joints were fabricated from Celion 6000/PMR-15. Table 6-5 gives the prepreg lot numbers used for each joint type. Quality control tests results for these prepreg lots are shown in Appendix F.

Curing of the large panels required modification of the layup tool to assure proper vacuum. A large vacuum tank was added to the bottom of the tool to give a greater vacuum capacity. Additional bleed holes, .16 mm (1/16 in) in diameter on 38 mm (1.5 in) centers, were drilled in the tool surface to assure a uniform vacuum over the entire panel area. The modified tool is shown in Figure 6-24.

Curing of panels with variable thickness (i.e., thin laminates with doublers) was also adjusted slightly from standard procedures. The cure temperature at which pressure was applied was controlled based on the temperature of the thin section of the laminate rather than the thick portion. This was to assure that the resin had not started to gell while the thick portion was reaching temperature and thus preventing proper resin flow when the pressure was applied. This procedure proved successful in preventing delaminations and disbonds.

Figures 6-25 through 6-30 show the scaled-up joint detail parts for the various joint types prior to cutting into specimens. The Type 4 joints were similar to the Type 1 joints shown.

Table 6-5: GR/PI PREPREG LOTS USED FOR MATRIX 7

		MATERIAL LOT	FIBER TYPE	JOINT PART NUMBER(SEE APPENDIX D DRAWINGS)										
				-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14
TYPE 1	Bonded	2W5077	3000								●	●	●	
		2W5141	3000	●	●									
	Bolted	2W5077	3000		●							●	●	
		2W5197	3000	●							●			
TYPE 2	Bonded	2W4956	3000			●	●							
		2W5077	3000							●		●	●	●
		2W5141	3000	●										
	Bolted	2W4956	3000			●								
		2W5077	3000				●							
		2W5141	3000	●						●				
TYPE 3	Bolted*	2W5233	6000		●	●	●			●				
	Fatigue	2W5232	6000		●	●	●		●					
TYPE 4	Bonded	2W5197	3000	●		●	●	●	●		●	●		
	Bolted	2W5197	3000	●		●	●	●	●		●	●		

* (Static)

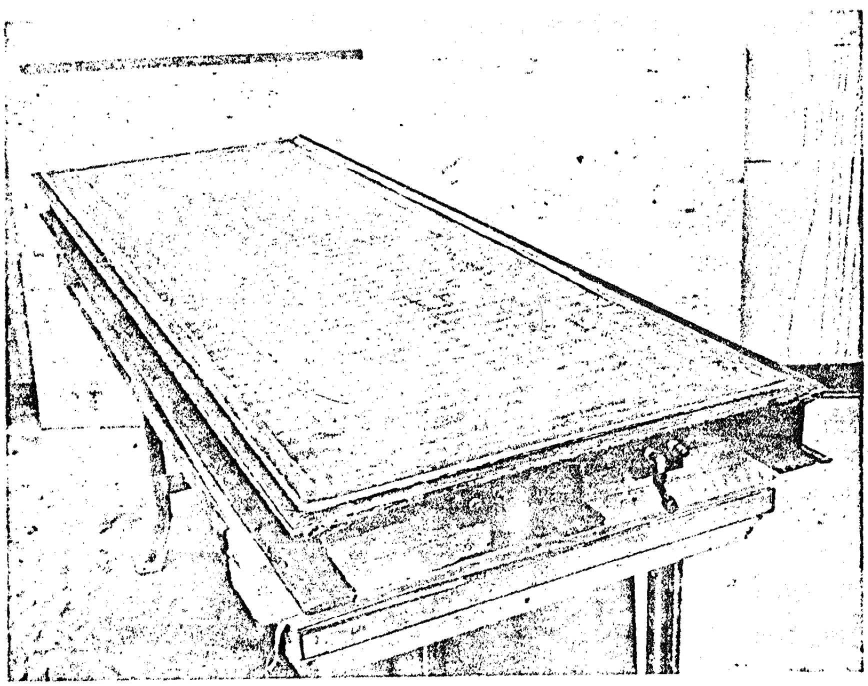


Figure 6-24: COMPOSITE PANEL LAYUP TOOL

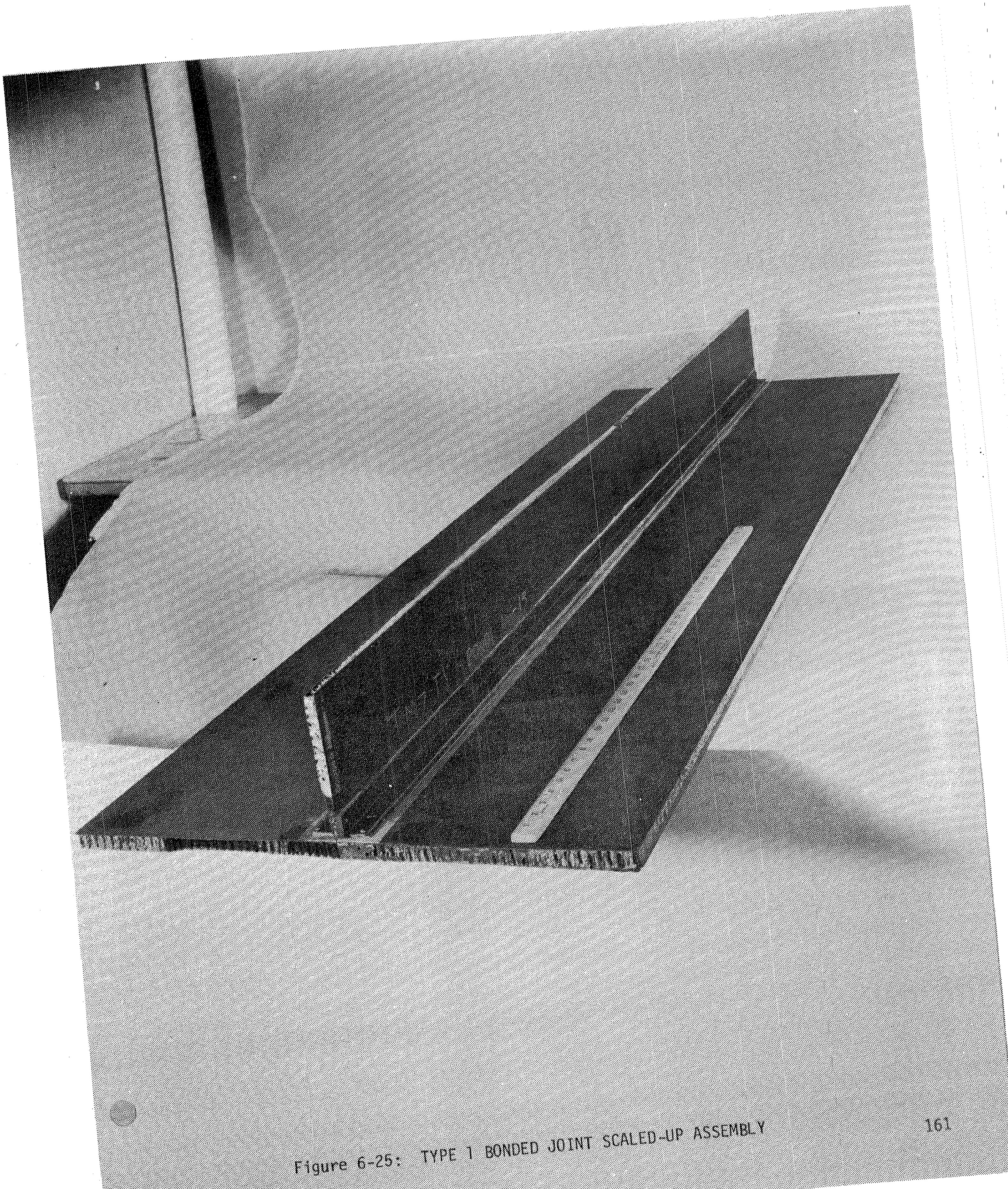


Figure 6-25: TYPE 1 BONDED JOINT SCALED-UP ASSEMBLY

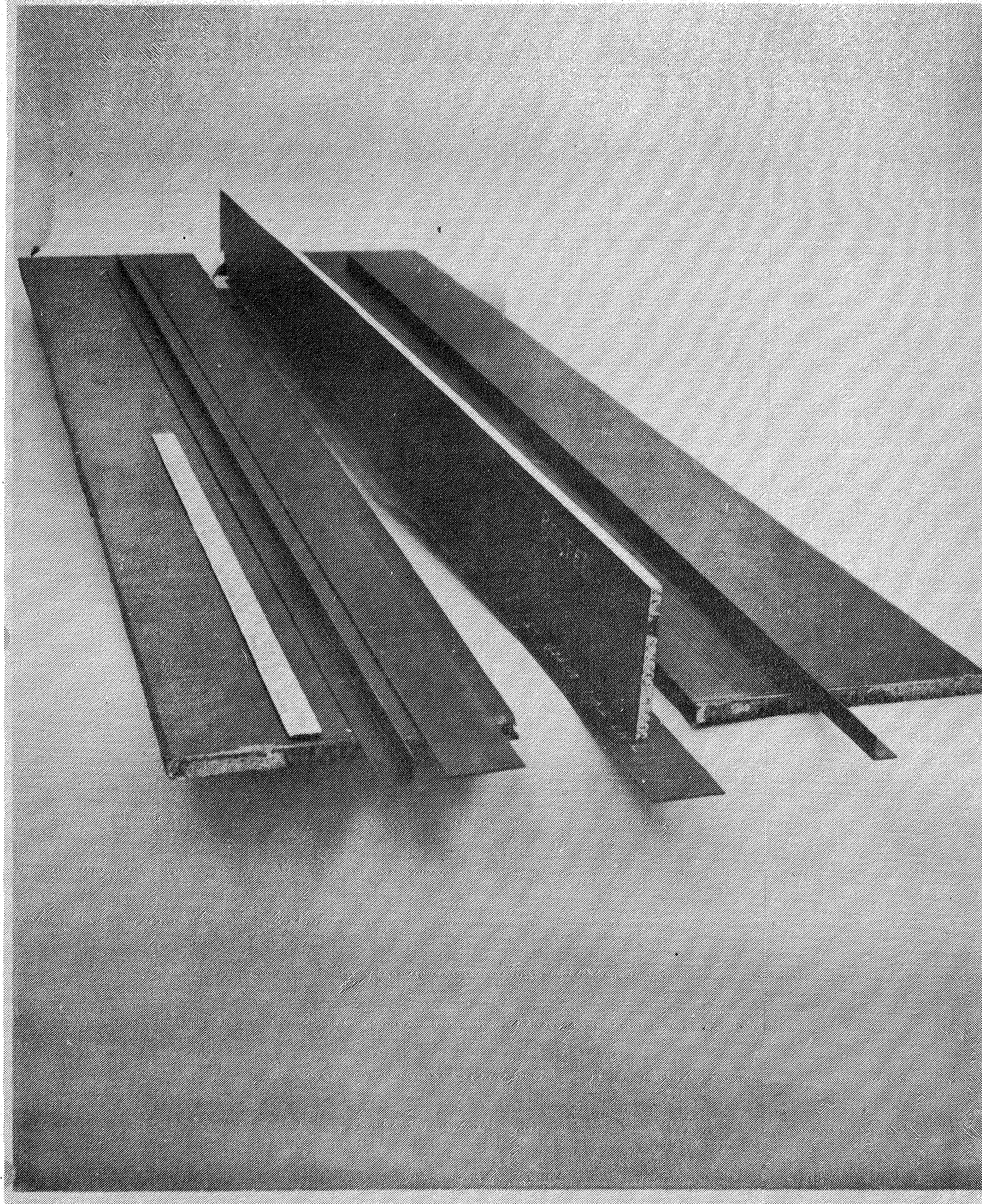


Figure 6-26: TYPE 1 BOLTED JOINT SCALED-UP COMPONENTS

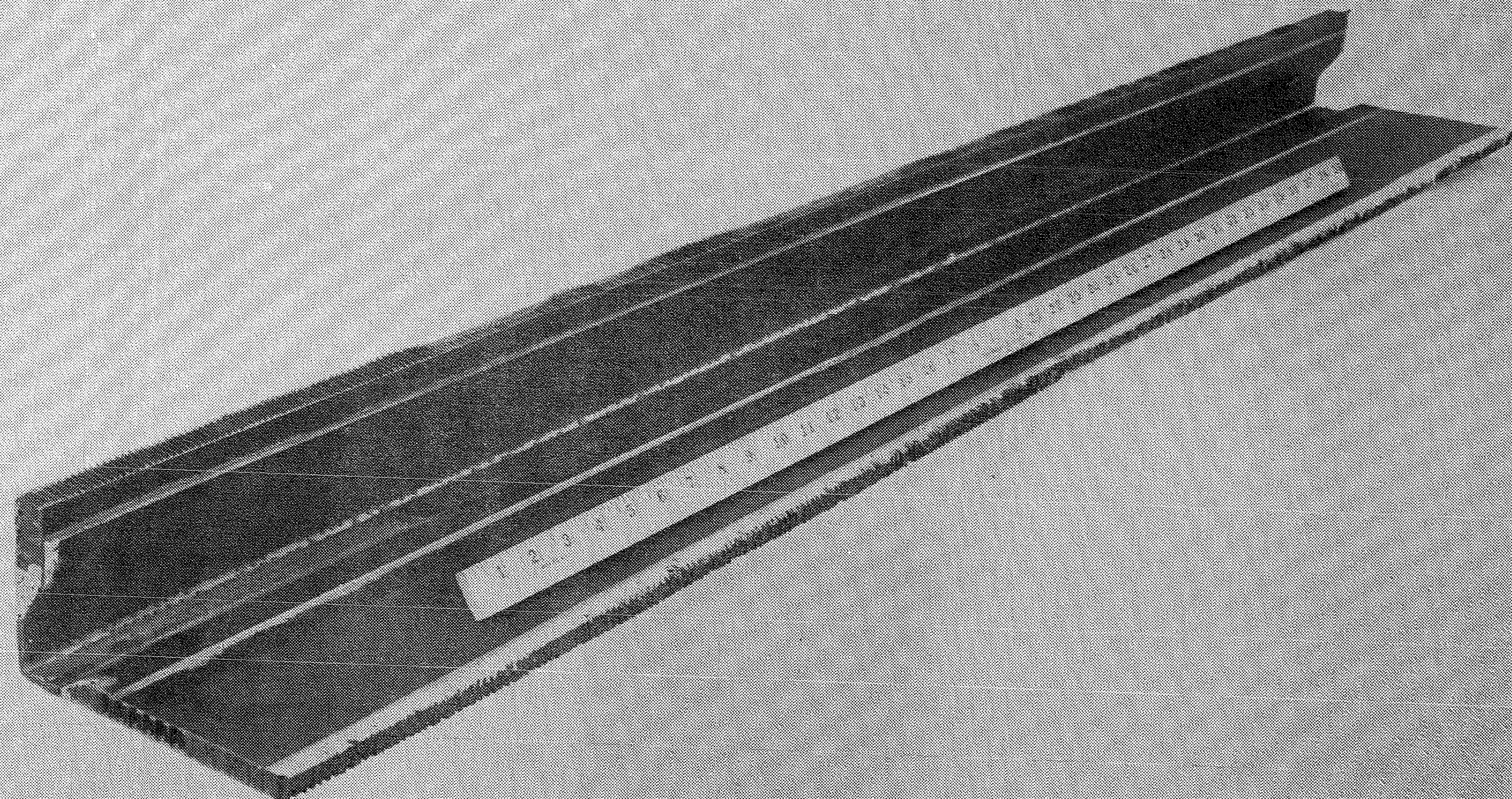


Figure 6-27: TYPE 2 BONDED JOINT SCALED-UP ASSEMBLY

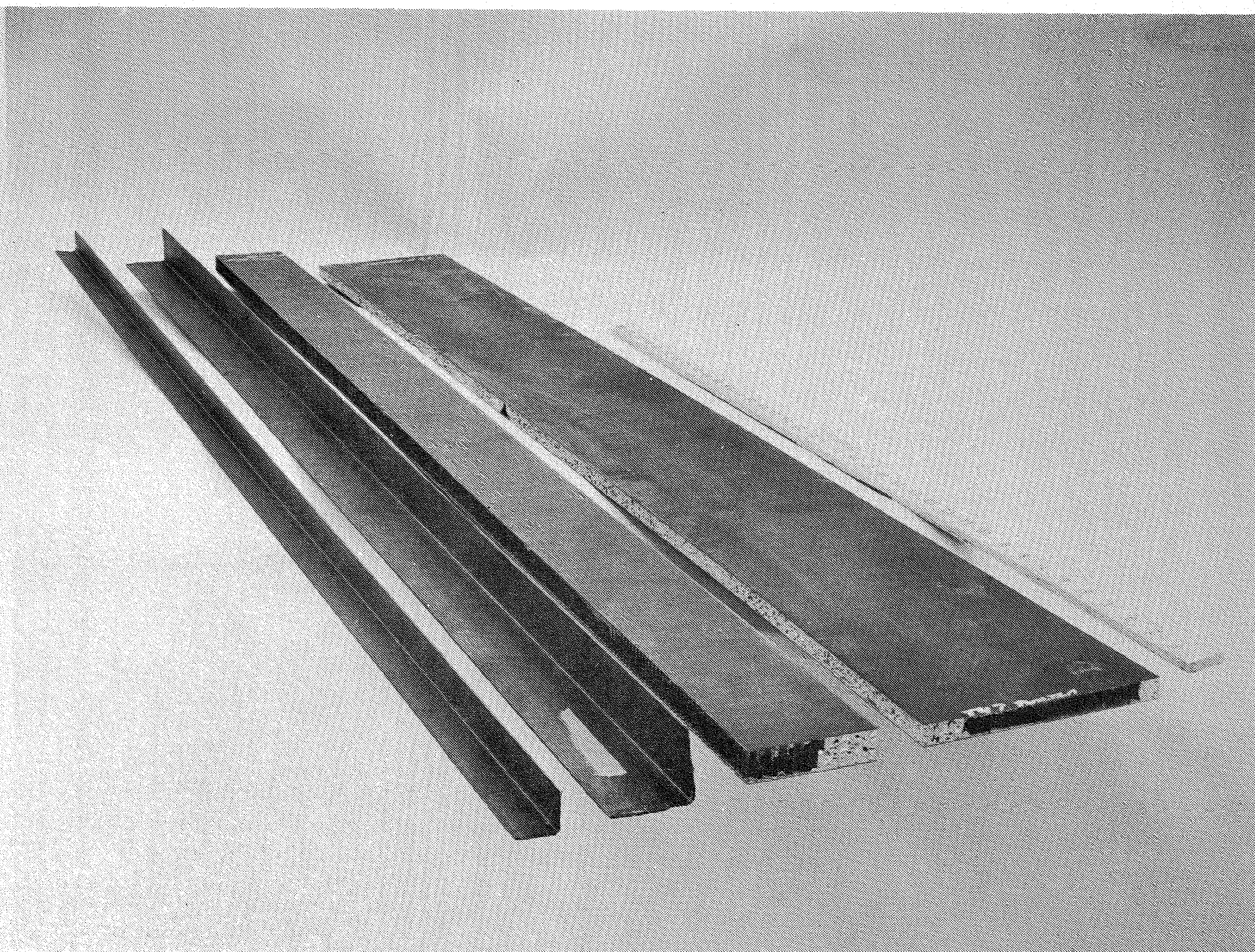


Figure 6-28: TYPE 2 BOLTED JOINT SCALED-UP COMPONENTS

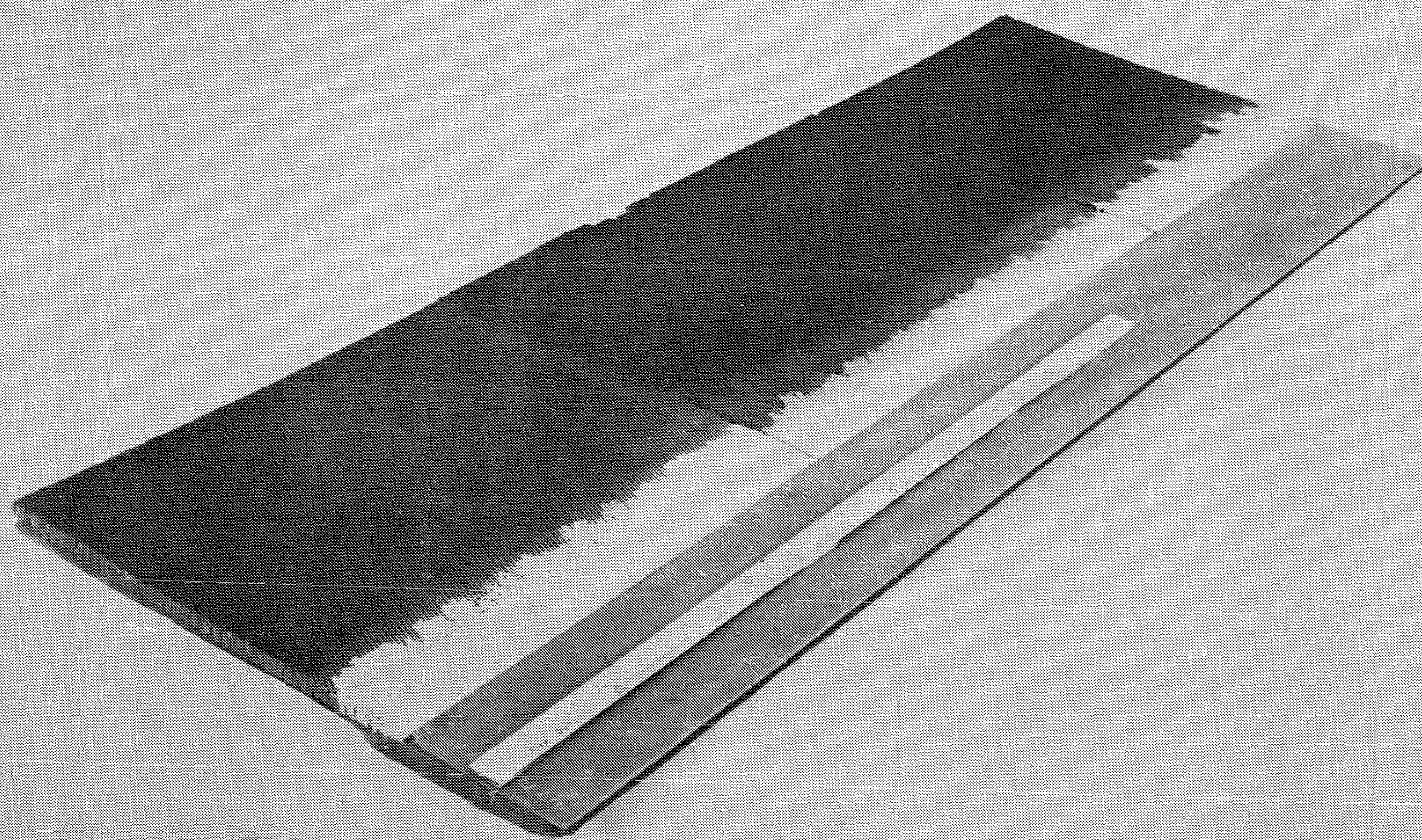


Figure 6-29: TYPE 3 BOLTED JOINT SCALED-UP ASSEMBLY

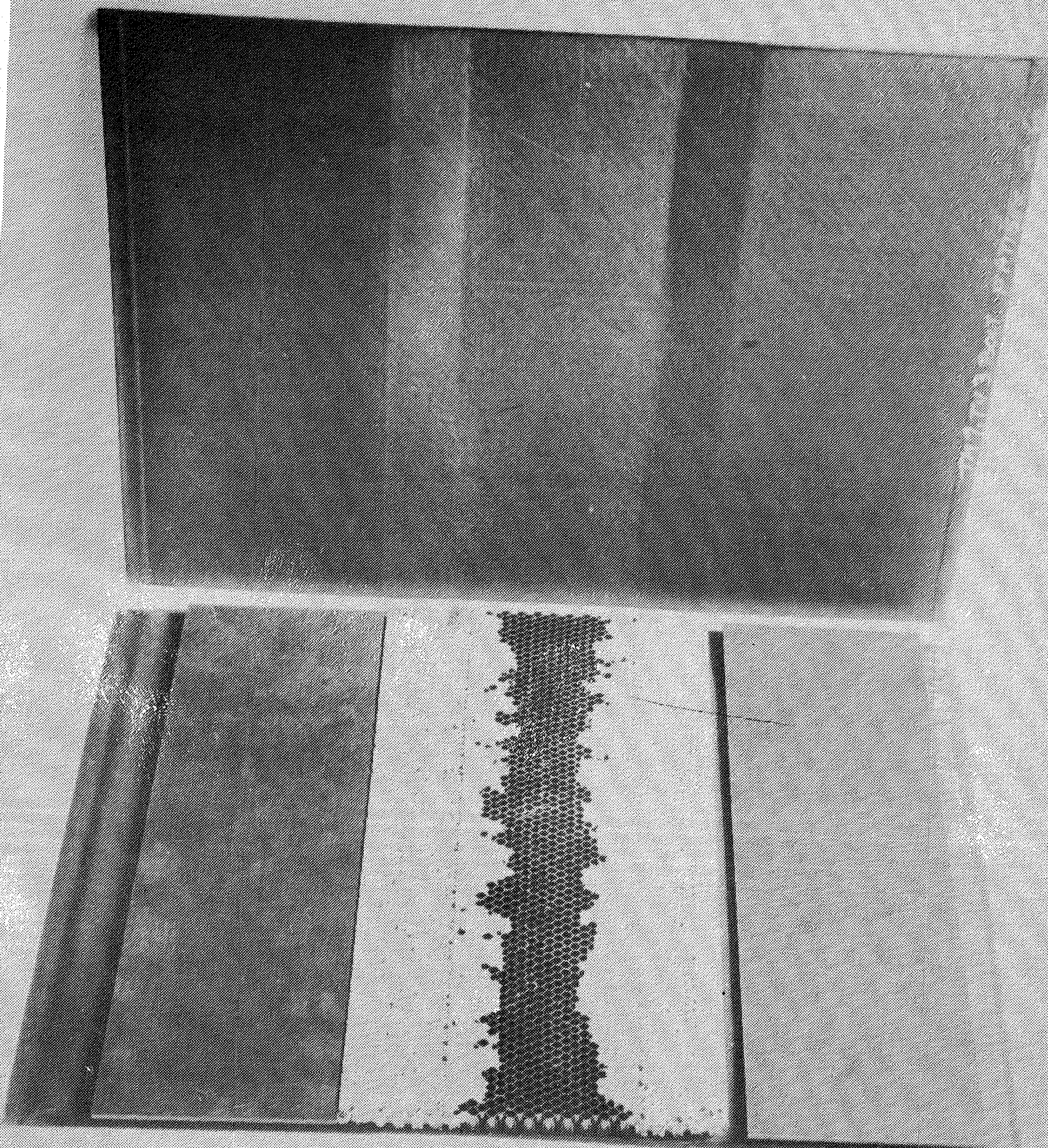


Figure 6-30: TYPE 3 BOLTED FATIGUE JOINT SCALED-UP ASSEMBLY

6.4 Final Evaluation Test Results

This section presents a summary of the "Final Evaluation" test results followed by detailed discussions of the results and failure modes for each joint type tested. Large variations in test results are attributed to resin chemistry and adhesive processing problems which are also discussed.

6.4.1 Summary of Test Results

<u>Static Tests</u>

Results for the "Final Evaluation" static tests of each joint type are summarized and compared to the design loads and predicted failure loads in the figures noted below.

Type 1 Bonded	Figure 6-31
Type 1 Bolted	Figure 6-32
Type 2 Bonded	Figure 6-33
Type 2 Bolted	Figure 6-34
Type 3 Bolted	Figure 6-35
Type 4 Bonded	Figure 6-36
Type 4 Bolted	Figure 6-37

Each figure shows the average failure load and data range for each temperature, specimen conditioning and load case tested. Residual strengths after fatigue testing are also shown if applicable.

For all joint types there were large variations in failure loads and failure modes. The various failure modes are summarized in Tables 6-6 through 6-9 and include failures for the "Static Discriminator" tests (Section 5.4) for easy comparison. Results for the individual specimens are contained in Appendix E.

Despite the large variations in failure loads and failure modes, in all cases there were some specimens that met or exceeded the design load, except for

Type 4 bonded joints (see Figure 6-36). The identical Type 4 bonded joint design exceeded the design load during the "Static Discriminator" tests (see Table 5-3).

A summary of maximum failure loads for each joint type is given in Table 6-10. Failures occurred outside the joint area except for Type 2 joints. Typical failures of specimens that met the design load for each joint type are referenced in Tables 6-6 through 6-9. It is concluded that these type joints can be fabricated from a Celion 3000-6000/PMR-15 material system and that they will sustain the load levels specified in this program for control surfaces on advanced aerospace vehicles and space transportation systems.

The low failure loads and failure modes experienced during testing are attributed to grip problems and in some cases to resin chemistry and adhesive processing problems which are discussed in Section 6.4.3. The resin problem was demonstrated by extensive delamination of laminates that failed in tension and that had outer ply buckling and peeling of laminates under compression, with corresponding low failure loads. Typical grip failures and specimens with excessive delaminations and laminate buckling/peeling are also referenced in Tables 6-6 through 6-9. There were some specimens which were not tested that had laminates or adhesive bonds which were badly damaged during aging or thermal cycling.

Because of the large variations in failure loads and modes, no firm conclusion can be drawn regarding the effects of aging and thermal cycling on joint performance. Trends do indicate, however, that the effects are small for tension loading conditions (see Figure 6-31). This is consistent with the results of design allowables testing reported in Reference 4. Results for Type 2 bonded joints indicate a significant loss in strength due to thermal cycling if the failure mode is transverse tension or peel (see Figure 6-33). The large loss in strength may be attributable to microcracking observed in thermally cycled laminates during design allowables testing (Ref. 4).

Fatigue Tests

Each joint was subjected to fatigue testing using the critical load condition for the static tests. Results of fatigue tests for each joint type are summarized in Table 6-11.

The Type 1 bonded joints had premature failures in the grip area, however, one room temperature specimen did go 953,000 cycles without a joint failure. It is concluded that the Type 1 bonded joints are good for 10^6 fatigue cycles at room temperature. At elevated temperature the joints can sustain at least 553,000 cycles. All of the Type 1 bolted joints sustained 10^6 cycles without failure. The ply delaminations experienced during cycling are attributed to the material problem discussed in Section 6.4.3. Residual strength tests showed that the joint itself was not degraded due to fatigue cycling.

The Type 2 joints sustained 10^6 cycles at room temperature without failure but not at elevated temperature; however, even though three specimens had angles delaminate at elevated temperature, they were still able to carry the design load up to 10^6 cycles.

Two room temperature Type 3 bolted joints sustained 10^6 cycles, while the third failed at 914,000 cycles. Only a small decrease in residual strength was experienced, indicating that these joints can withstand the fatigue environment at room temperature. However at elevated temperature the Type 3 joints sutained a maximum of only 383,000 cycles. It is believed that these premature failures are due to the material problems discussed in Section 6.4.3.

No firm conclusions can be drawn regarding the Type 4 bolted joints because of the large variations in failure loads and failure modes. Although the attach angles delaminated in all cases, they were still able to sustain the design load. Two specimens sustained 10^6 cycles without cover failures which indicate the laminates are adequate for the fatigue environment.

The large differences in fatigue tests results are attributed to the resin chemistry and adhesive processing problems discussed in Section 6.4.3.

Residual strengths of those specimens that did sustain 10^6 cycles showed both a 39% increase and a 10% decrease as compared to non-fatigued specimens; however, the changes were well within the range of data scatter. The data indicate the joints can sustain the fatigue environment without a catastrophic reduction in residual strength. It should be noted that the potting compound used to reinforce the honeycomb core around the bolts in the joints was placed in a band across the entire joint along the line of bolts. In full-scale production hardware potting would most likely be only placed locally around each hole. It is possible that fatigue lives may be reduced when the potting is applied only locally around a hole.

Detail discussions of failure loads and failure modes for the static and fatigue tests of each joint type are presented below.

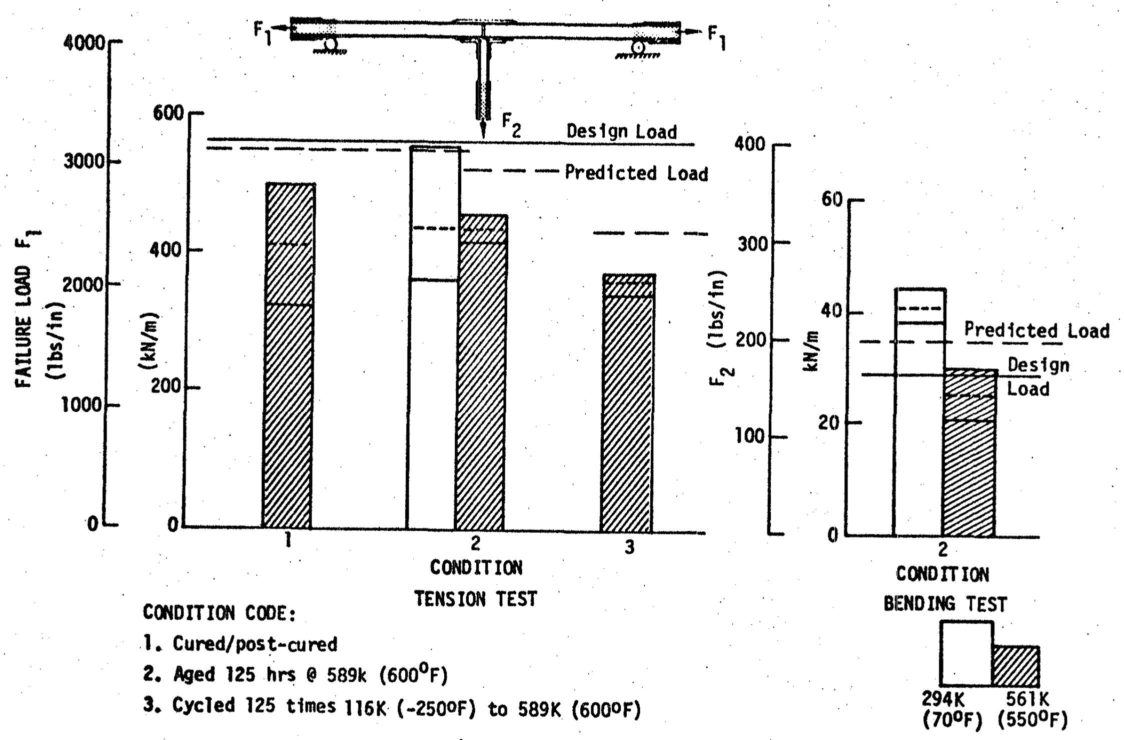


Figure 6-31: TYPE 1 BONDED JOINT STATIC TEST RESULTS

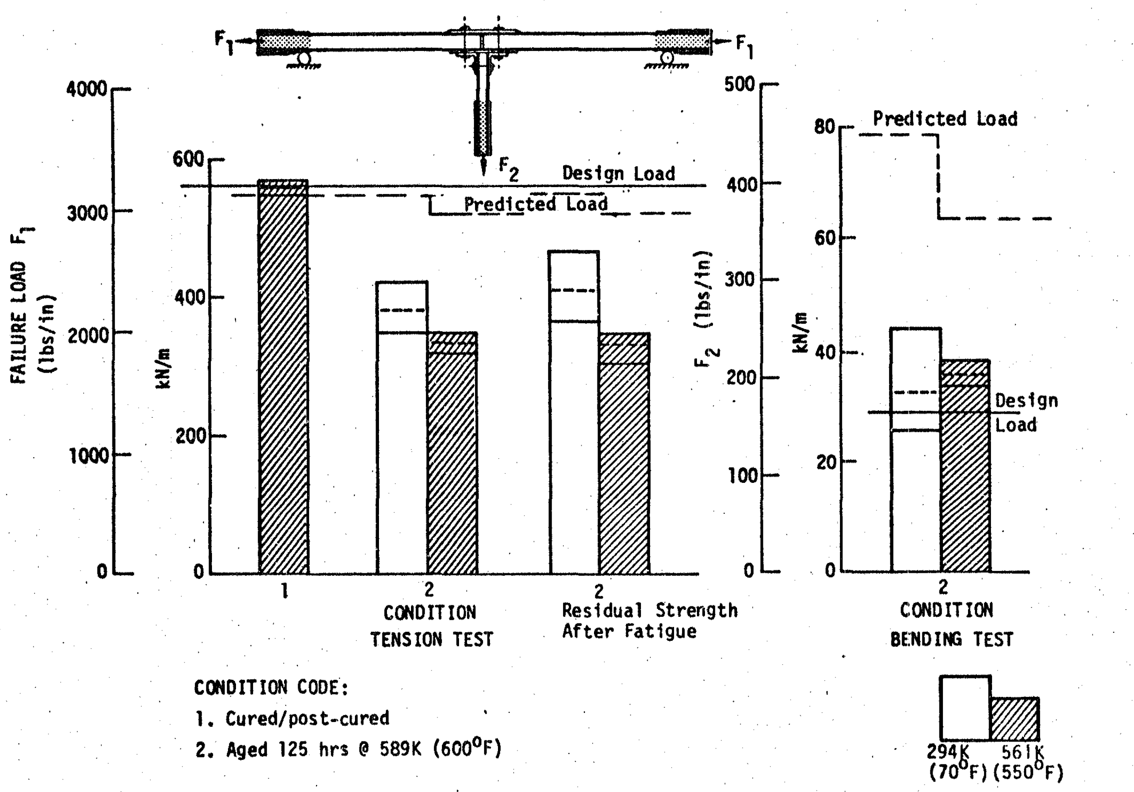


Figure 6-32: TYPE 1 BOLTED JOINT STATIC TEST RESULTS

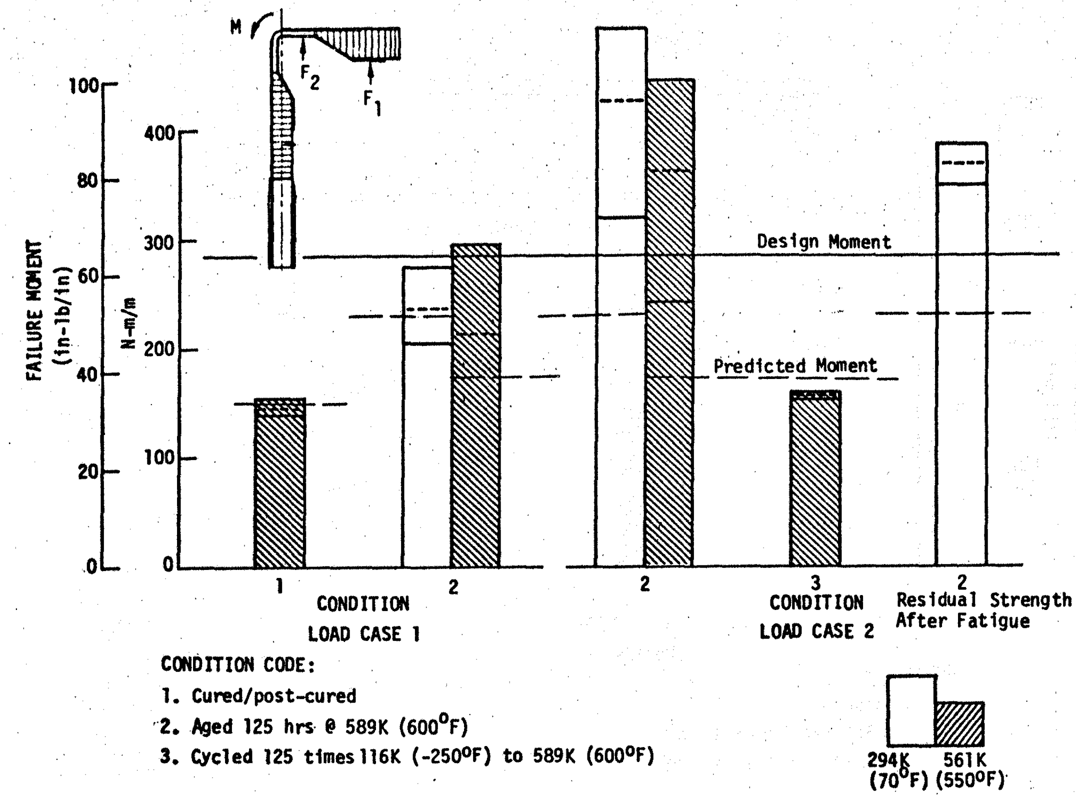


Figure 6-33: TYPE 2 BONDED JOINT STATIC TEST RESULTS

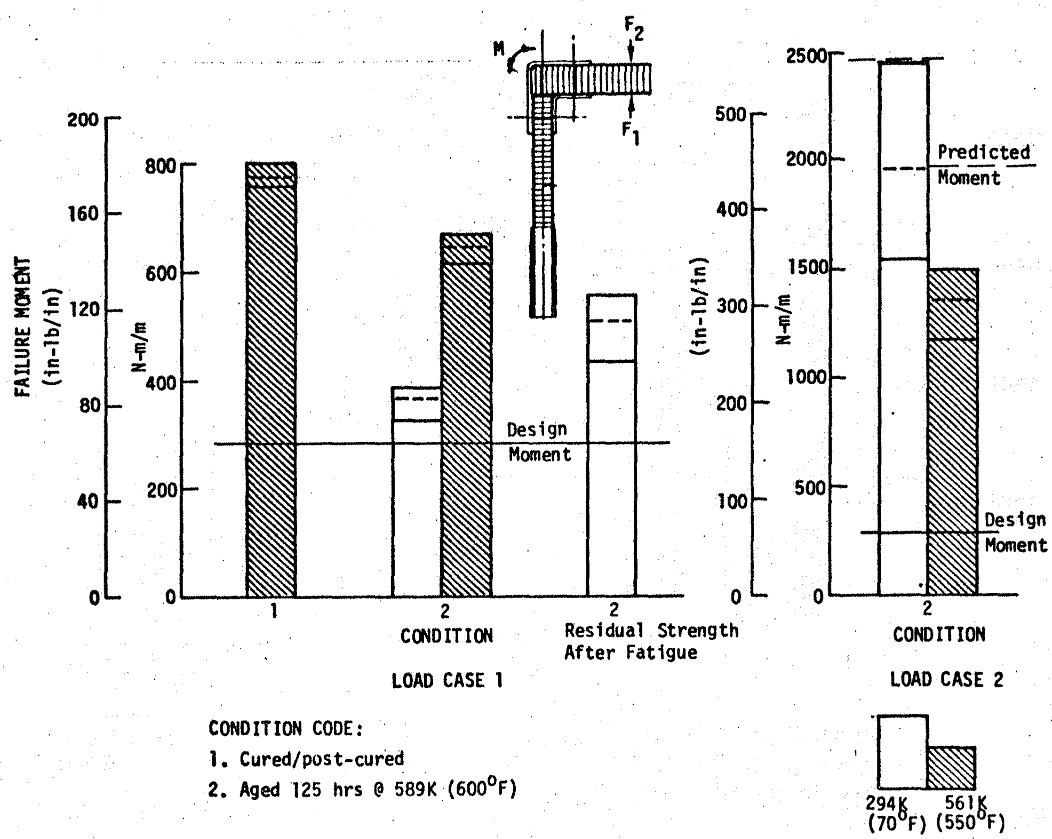


Figure 6-34: TYPE 2 BOLTED JOINT STATIC TEST RESULTS

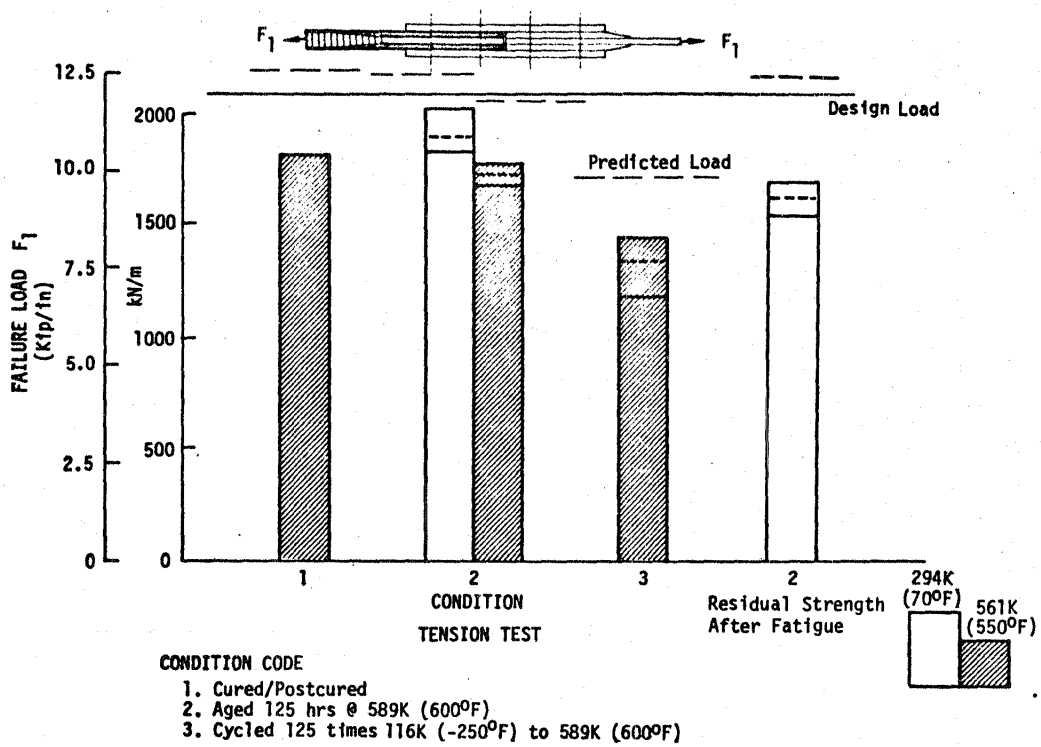


Figure 6-35: TYPE 3 BOLTED JOINT STATIC TEST RESULTS

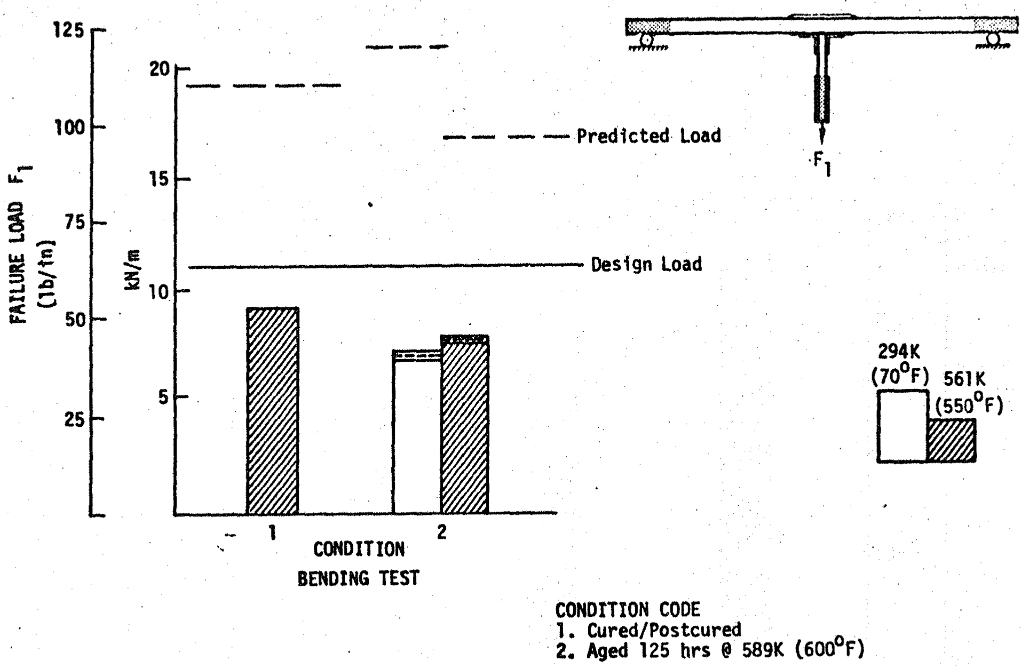


Figure 6-36: TYPE 4 BONDED JOINT STATIC TEST RESULTS

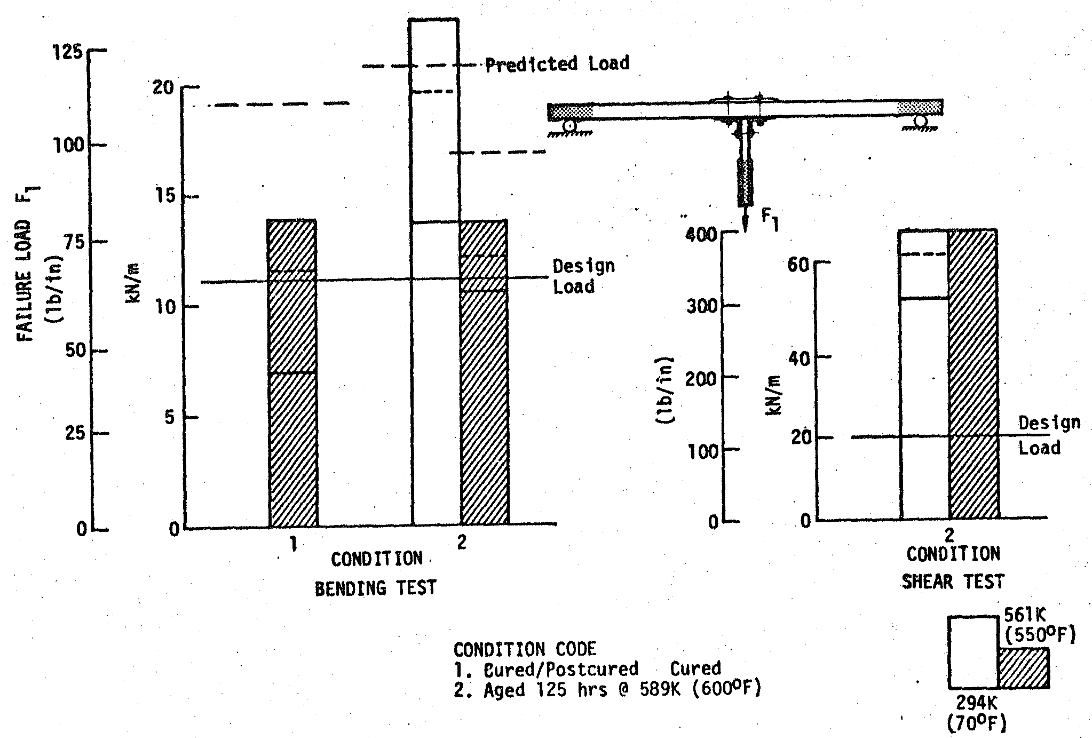


Figure 6-37: TYPE 4 BOLTED JOINT STATIC TEST RESULTS

Table 6-6: TYPE 1 JOINT FAILURE SUMMARY

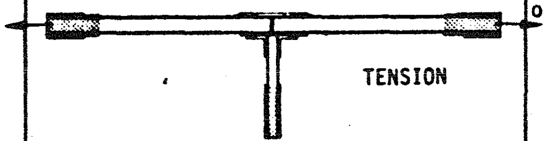
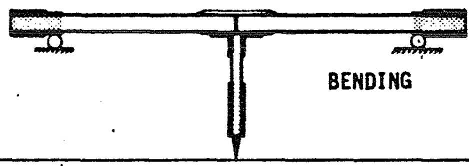
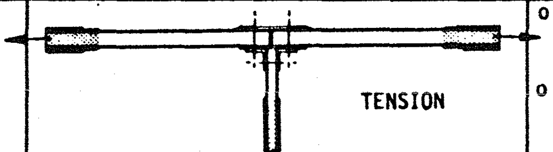
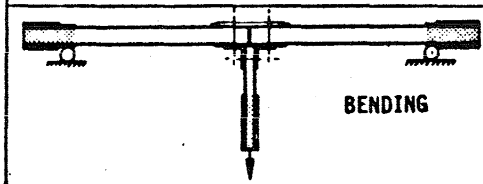
JOINT TYPE	TEST LOAD CONDITION	TASK 1.3 PRELIMINARY EVALUATION	TASK 1.4 FINAL EVALUATION		
		STATIC DISCRIMINATOR MATRIX 5 CURED/POST CURED	SCALE-UP VERIFICATION MATRIX 7.1 CURED/POST-CURED	STATIC STRENGTH EVALUATION MATRIX 7.2	
				AGED	THERMAL CYCLED
BONDED	 TENSION	o Interlamina Shear Failure at Doubler (6) (See Fig. 5-13)	o Grip Failure (2) (See Fig. 6-39)	294K (70°F) o Cover Skin Failure in Tension (1) o Grip Failure (2) (See Fig. 6-40) 561K (550°F) o Grip Failure (2)	o Grip Failure (3)
	 BENDING	—	—	294K (70°F) o Cover Skin Compression Failure (1) o Angle Pull-Off (2) (See Fig. 6-42) 561K (550°F) o Angle Pull-Off (2)	—
BOLTED	 TENSION	o Cover Skin Failure in Tension (2) (See Fig. o Interlamina Shear Failure at Doubler (4) (See Fig. 5-14)	o Cover Skin Failure in Tension (3) (See Fig. 6-49)	o Cover Skin Failure in Tension (6). Extensive Delamination (See Fig. 6-50)	o Not Tested Spec. Destroyed During Thermal Cycling
	 BENDING	—	—	o Cover Skin Failure in Compression (6). Plies Delaminated (See Fig. 6-51)	—

Table 6-7: TYPE 2 JOINT FAILURE SUMMARY

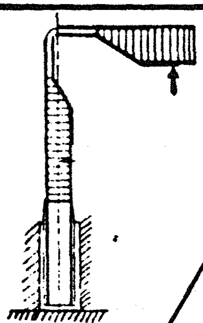
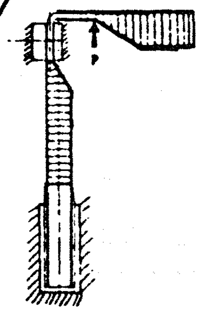
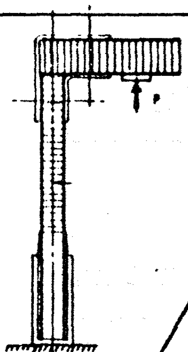
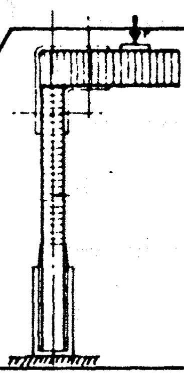
JOINT TYPE	TEST LOAD CONDITION	TASK 1.3 PRELIMINARY EVALUATION	TASK 1.4 FINAL EVALUATION PHASE		
		STATIC DISCRIMINATOR MATRIX 5 CURED/POST-CURED	SCALE-UP VERIFICATION MATRIX 7.1 CURED/POST-CURED	STATIC STRENGTH EVALUATION MATRIX 7.2	
				AGED	THERMAL CYCLED
BONDED	 BENDING	o Delamination in Corner Angle (6) (See Fig. 5-23)	o Peel Failure of Honeycomb Closeout (3) (See Fig. 6-57)	o Peel Failure of Honeycomb Closeout (6) (See Fig. 6-57)	—
BONDED	 BENDING (Angle Only)	—	—	o Delamination of Corner Angle (6) (see Fig. 6-58)	o Delamination of Corner Angle (3) (See Fig. 6-58)
BOLTED	 BENDING	o Delamination of Inner Angle (6) (See Fig. 5-23)	o Delamination of Inner Angle + Compression of Outer Plies on Outer Angle (3) (See Fig. 6-62)	o Delamination of Inner Angle + Compression of Outer Plies on Outer Angle (6) (See Fig. 6-62)	o Not Tested Spec. Destroyed During Thermal Cycling
BOLTED	 BENDING	—	—	o Compression Failure of Inner Web Skin (5) (See Fig. 6-64) o Net Tension Outer Web Skin Bolt (1) (See Fig. 6-63)	—

Table 6-8: TYPE 3 JOINT FAILURE SUMMARY

JOINT TYPE	TEST LOAD CONDITION	TASK 1.3 PRELIMINARY EVALUATION	TASK 1.4 FINAL EVALUATION PHASE		
		STATIC DISCRIMINATOR MATRIX 5	SCALE-UP VERIFICATION MATRIX 7.1	STATIC STRENGTH EVALUATION MATRIX 7.2	
		CURED/POST-CURED	CURED/POST-CURED	AGED	THERMAL CYCLED
BOLTED	 TENSION	o Grip Failure (6)	o Cover Skin Tension at Pad-Up Transition (1) (See Fig. 6-66)	o Cover Skin Tension at Pad-Up Transition (8)	o Cover Skin Tension at Pad-Up Transiton (3) Extensive Ply Delamination (See Fig. 6-68) (These Spec. had Bad Laminate-to-Cure Bonds after Thermal Cycling)

Table 6-9: TYPE 4 JOINT FAILURE SUMMARY

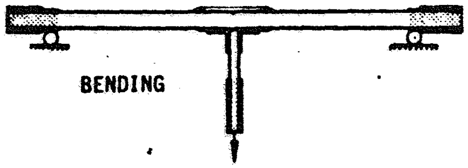
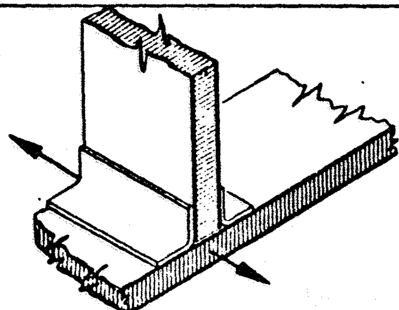
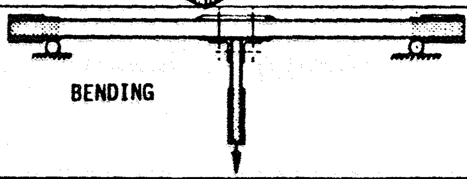
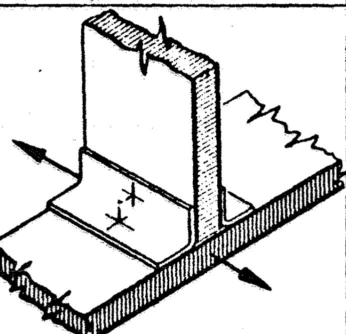
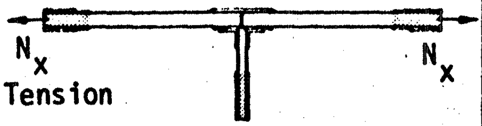
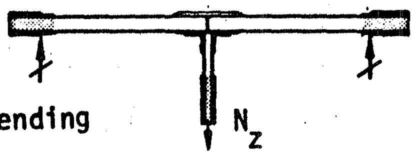
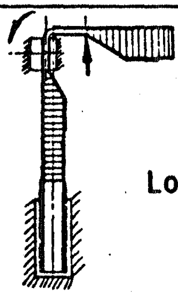
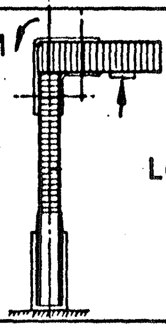
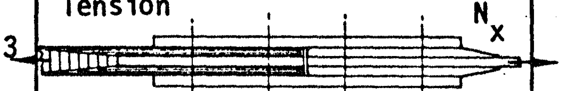
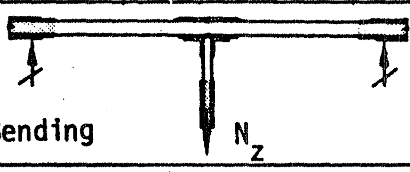
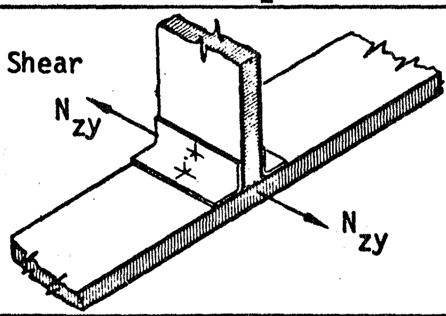
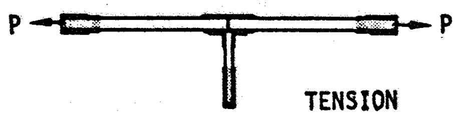
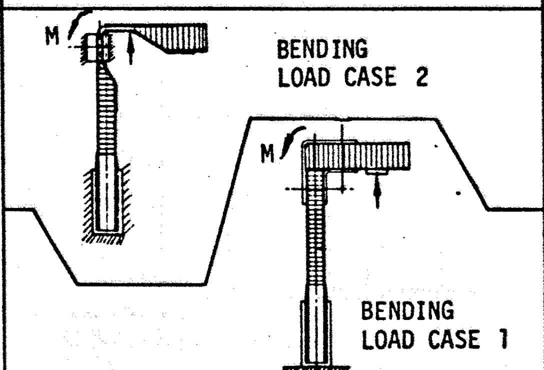
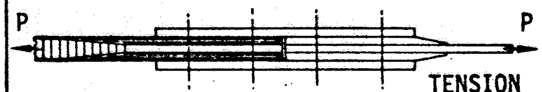
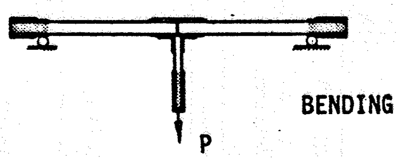
JOINT TYPE	TEST LOAD CONDITION	TASK 1.3 PRELIMINARY EVALUATION	TASK 1.4 FINAL EVALUATION PHASE		
		STATIC DISCRIMINATOR MATRIX 5 CURED/POST-CURED	SCALE-UP VERIFICATION MATRIX 7.1 CURED/POST-CURED	STATIC STRENGTH EVALUATION MATRIX 7.2	
				AGED	THERMAL CYCLED
BONDED	BENDING 	o Outer Cover Skin Compression Failure (3) (See Fig. 5-32) o Pulled Off Web Attach Angle (3) (See Fig. 5-33)	o Outer Cover Skin Compression Failure (3)	o Outer Cover Skin Compression Failure (5) Plies Delaminated (See Fig. 6-73) Also Pulled Off Web Attach Angles (Bad Adhesive Bond). (See Fig. 6-72)	o Not Tested Spec. Destroyed During Thermal Cycling
	SHEAR 	——	——	o Not Tested Adhesive Bond Destroyed During Aging	——
BOLTED	BENDING 	o Outer Cover Skin Compression Failure (6) (See Fig. 5-34)	o Outer Cover Skin Compression Failure (3) One Spec. Delaminated (See Fig. 6-75)	o Outer Cover Skin Compression Failure (5) o Net Tension Failure Inner Cover Skin (1) (See Fig. 6-77)	o Not Tested Spec. Destroyed During Thermal Cycling
	SHEAR 	——	——	o No 2-Part Failures (6) Tests Terminated at 273% to 350 % of Design Load (See Fig. 6-78)	——

Table 6-10 : SUMMARY OF MAXIMUM FAILURE LOADS

JOINT TYPE	LOAD CONDITION	MAXIMUM FAILURE LOAD kN/m (lbs/in)		DESIGN LOAD kN/m (lbs/in)
		BONDED	BOLTED	
TYPE 1	 N_x Tension N_x	N_x 556 (3174)	N_x 562 (3208)	N_x 560 (3200)
TYPE 1	 Bending N_z	N_z 44.5(254)	N_z 44.1(252)	N_z 28.7 (164)
TYPE 2	 M Bending Load Case 2	M 494 (111)*		M 285* (64)*
TYPE 2	 M Bending Load Case 1		M 792 (178)*	M 285* (64)*
TYPE 3	Tension  N_x	—	2021 N_x (11,540)	N_x 2100 (12,000)
TYPE 4	 Bending N_z	N_z 9.2 (52.8)	N_z 23.1 (132)	N_z 11.2 (64)
TYPE 4	Shear  N_{zy} N_{zy}	Not Tested	N_{zy} Greater Than 55.9 (319)	N_{zy} 20.0 (114)

* m-N/m (in-lbs/in)

Table 6-11: SUMMARY OF FATIGUE TEST RESULTS (AGED SPECIMENS)

JOINT TYPE	LOAD CONDITION	CONFIGURATION	TEMPERATURE K (°F)	NUMBER OF CYCLES*	FAILURE MODE	RESIDUAL STRENGTH % CHANGE
TYPE 1	 P P TENSION	BONDED	294 (70)	953,000 (1) 573,000 (1) 303,000 (1)	Grips (See Fig. 6-47)	NA
			561 (550)	553,000 (1) 30,000 (1) 100 (1)	Grips (See Fig. 6-47)	NA
		BOLTED	294 (70)	10^6 (3)	No 2 Part Failures Plies Delaminated	+7% (See Fig. 6-54)
			561 (550)	10^6 (3)	No 2 Part Failures	-1%
TYPE 2	 M BENDING LOAD CASE 2 M BENDING LOAD CASE 1	BONDED	294 (70)	10^6 (3)	No Failure	-14% (See Fig. 6-60)
			561 (550)	10^6 (2) 3,000 (1)	Corner Angle Delaminated (See Fig. 6-60)	NA
		BOLTED	294 (70)	10^6 (3)	No Failure	+39% (See Fig. 6-60)
			561 (550)	10^6 (1) 100 (1)	Corner Angle Delaminated (See Fig. 6-60)	NA
TYPE 3	 P P TENSION	BOLTED	294 (70)	10^6 (2) 914,000 (1)	No Failure Cover Tension at Pad-up	-15 % (See Fig. 6-74)
			561 (550)	383,000 (1) 117,000 (1) 307,000 (1)	Cover Tension at Pad-up	N.A.
TYPE 4	 P BENDING	BONDED	294 (70)	Not Tested	—	—
			561 (550)	Not Tested	—	—
		BOLTED	294 (70)	10^6 (1)	▷1	-10% ▷2
			561 (550)	53,000 (1) 10^6 (1) 49,600 (1)	Outer Cover Compression ▷1 Outer Cover Compression	NA +19% ▷3 NA

* Number of Spec. shown in ( ).

▷1 No 2 Part Failure. Attach Angles Delaminated (See Fig. 6-85)

▷2 Failed Attach Angles (See Fig. 6-86)

▷3 Failed Attach Angles (See Fig. 6-88)

6.4.2 Detail Discussion of Test Results

Type 1 Bonded - Static Tests

Static test specimens for Type 1 Bonded joints are shown in Figure 6-38. Specimens were loaded in tension and bending as shown in Figure 6-8. Test results are summarized in Figure 6-31 and are discussed below. Predicted loads shown for the tension tests are based on skin tension failures using data from the design allowables testing (see Section 4.2). Predicted loads for the bending test are based on attachment angle pull-off failure using loads from the "Static Discriminator" tests.

A direct comparison of the Scale-up Verification (Matrix 7.1) tension test results with the "Static Discriminator" tests (Section 5.4) was not possible because of the design change to interleaved doublers. In addition there were extensive problems with the load grips. A deviation was made from the drawings to simplify specimen assembly. BMS 8-28 Type 6 low temperature potting called out for in the grip areas was replaced with BMS 8-126 high temperature structural potting. The was done so the core could be potted prior to secondarily bonding on the laminates, which is done at 589K (600^{o}F). Using the low temperature potting requires the laminates to be bonded to the core first. Then the core is subsequently cut out of the grip area and the low temperature potting is installed. The specimens were originally supplied with holes for the bolted grips. Because of trouble with the bolted grips during Matrix 7.2 testing the first Scale-up Verification test was conducted using hydraulic grips, however, with the bolt holes present. The specimen, 7.1-1A-1-1, failed prematurely at 331 kN/m (1890 lbs/in) due to shear and net tension in the grip area. The other specimens were reworked by cutting the bolted grip off, and installing hydraulic grips (no bolt holes) using the low temperature potting. One of the reworked specimens had improper grip alignment and could not be tested. The other specimen, 7.1-1A-1-3, had laminate damage on one edge so it was trimmed to 67.8mm (2.67 inches) wide. This specimen went to 494 kN/m (2823 lbs/in) but also failed prematurely in the grip area (see Figure 6-39). None of the specimens failed in the joint.

Specimen 7.1-1A-1-3 went to 90% of design load and still did not fail due to shear at the doubler like the "Static Discriminator" specimens. This indicates the doubler design change was adequate. No firm conclusions can be drawn with regard to scale-up effects; however, apparently there were none.

The first Static Strength (Matrix 7.2) room temperature tension specimen was tested with bolted grips and failed in the cover at a load of 430 kN/m (2460 lbs/in). This is lower than the 560 kN/m (3200 lb/in) predicted; however, it appears that the failure initiated in the grip area. The failed specimen is shown in Figure 6-40. The next two specimens failed prematurely due to shear and net tension in the bolted grips. As a result the grip areas on these specimens were cut off and the specimens reworked as discussed above to enable use of hydraulic grips without bolt holes. After rework specimen 7.2-1A1-2-2 failed close to the design load, failing at 556 kN/m (3174 lb/in) in the cover outside the joint area. Figure 6-41 shows the failed specimen. The other specimen could not be tested because of improper grip alignment.

Elevated temperature tension tests were attempted on specimens with bolt holes in the grip area; however, using hydraulic grips. The first specimen also failed in shear and net tension at the grip area, therefore, all the specimens were reworked as described above to eliminate the bolt holes and to enable use of hydraulic grips. The thermal cycled specimens had not had the bolt holes drilled, therefore, they were tested without any rework; however, with hydraulic grips. These specimens had BMS 8-126 high temperature structural potting in the grip area.

As can be seen in Figure 6-31, all the elevated temperature specimens failed at loads lower than predicted. Examination of these specimens indicate that all the failures may have initiated in the grip area. This can be partially attributed to residual thermal stresses resulting from the aluminum load tabs as well as stress concentrations and peel loads at the grip ends. The magnitude of the failure loads, however, do demonstrate that bonded joints can be fabricated that will carry loads up to 560 kN/m (3200 lb/in).

Results of room and elevated temperature bending tests (Matrix 7.2) of Type 1 bonded joints are also shown in Figure 6-31. The predicted failure mode for these tests was interlaminar tension of the attach angles at the cover bond line (i.e., to pull off the attach angles). Typical failed specimens are shown in Figures 6-42 through 6-45. Failure loads are about as expected based on previous "Static Discriminator" tests. A special room temperature static bending test of a Type 4 joint, Matrix 5, with the same attachment concept failed at 35.0 kN/m (200 lb/in). The Matrix 5 tests demonstrated that the stiffness of the cover assembly and the support span has a significant effect on the failure load. Failure of specimen 7.2-1A2-2-1 (see Fig. 6-44) by compression in the cover was not expected. The cover skin failure stress was 241 MPa (35 ksi) which is significantly lower than the ultimate of approximately 586 MPa (85 ksi) for this laminate. Observations during test were that the outer plies of the cover began to delaminate and buckle as load was increased. Post test examination indicated that the outer 0^{o} and $+45^{o}$ plies (25% of the laminate thickness) had delaminated. This means they were not carrying any load and the remaining laminate subsequently failed at an apparent low stress. Examination of specimen 7.2-1A2-2-4 showed evidence of a partially bad bond on one of the attach angles (see Fig. 6-45). This would explain the low failure load of 20.7 kN/m (118 lb/in).

Type 1 Bonded - Fatigue Tests

Results of room and elevated temperature fatigue tests of Type 1 bonded joints are given in Table 6-11. Specimens were tested in tension. Because of grip problems with the static test specimens, the fatigue specimens were machined down to a 50.8 mm (2.0 inch) width in the test section. This was to reduce the maximum load required in the grip and thereby prevent a premature grip failure. Specimens before test are shown in Figure 6-46. Fatigue loads are given in Table 6-4. Despite the specimen rework described above, all specimens failed at the narrow end of the grip as shown in Figure 6-47. There were no bonded joint failures. The elevated temperature (561 K (550^{o}F)) specimens had only the joint area heated, not the grips; therefore, the earlier failures of these specimens cannot be attributed to temperature effects. There is no apparent explanation for the wide spread in failure cycles. Since one of the specimens went to 953,000 cycles, it seems that the bonded joint itself is satisfactory and would survive the fatigue environment.

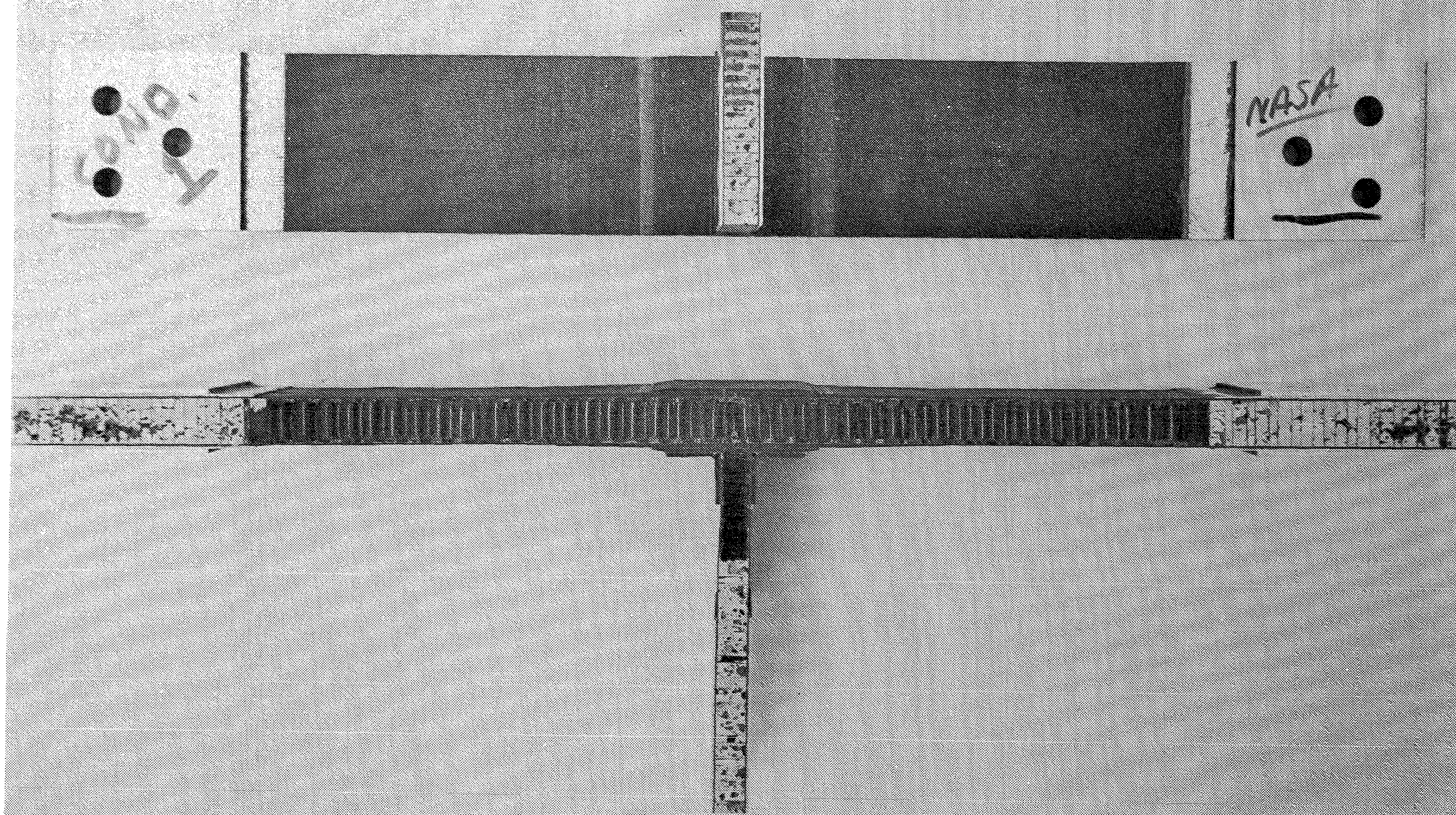


Figure 6-38: FINAL EVALUATION, TYPE 1 BONDED JOINT - BEFORE TEST

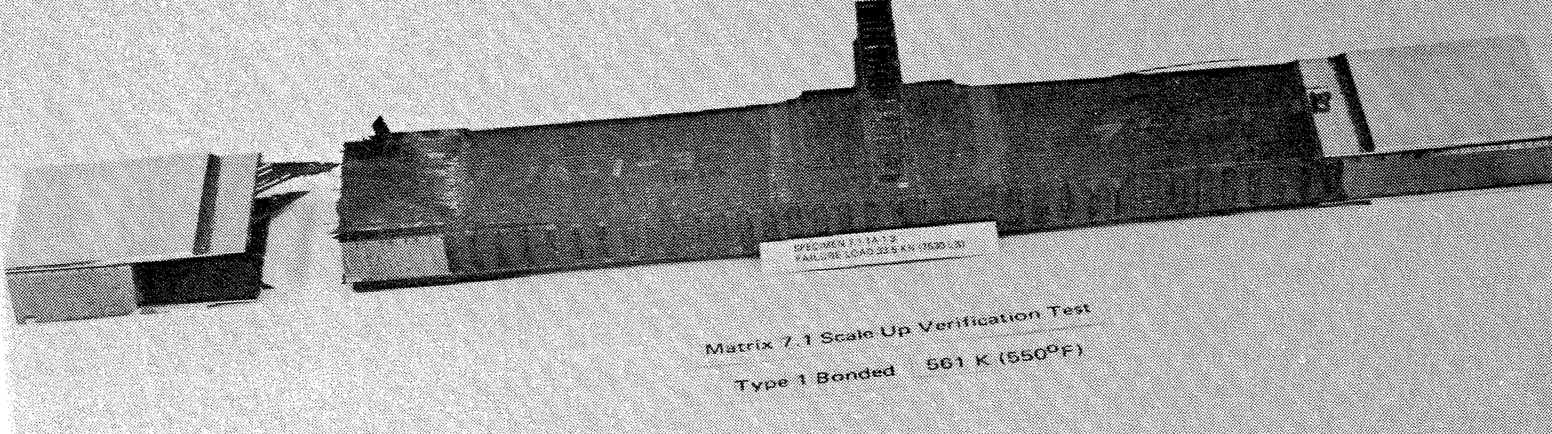
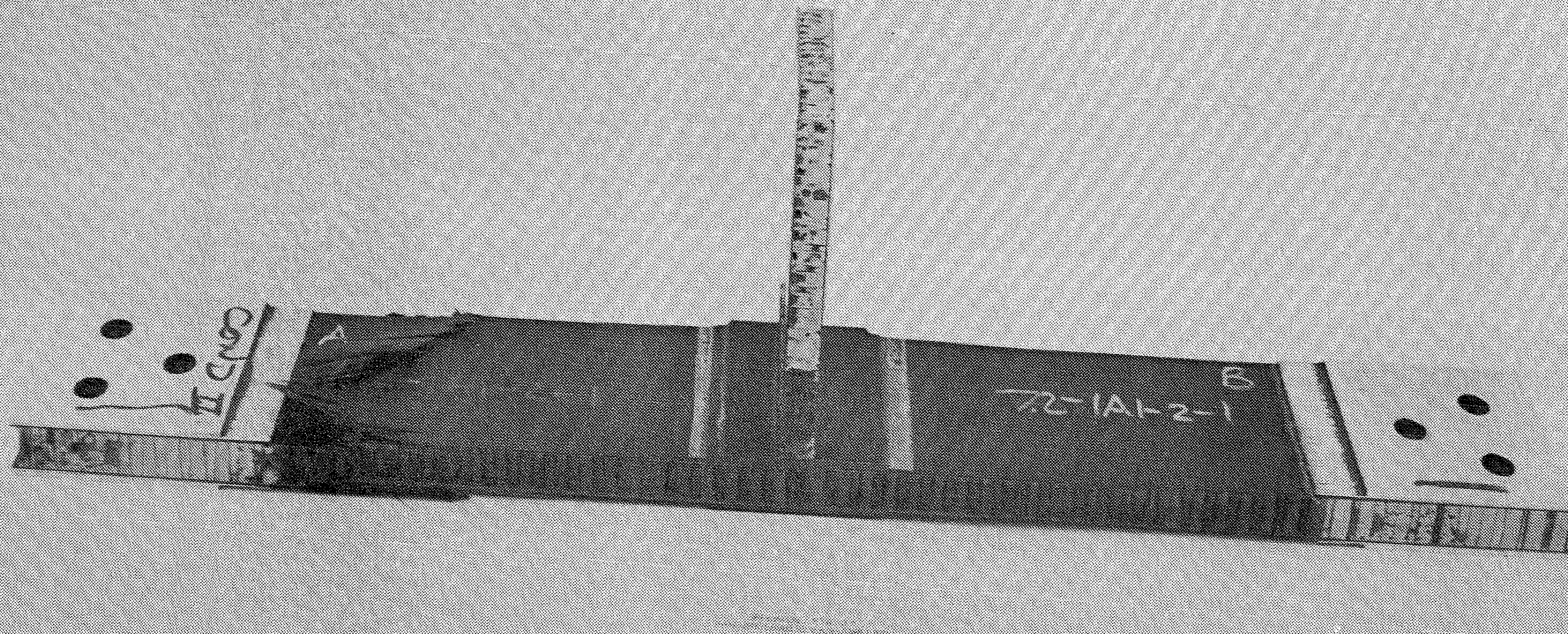


Figure 6-39: TYPE 1 BONDED - TENSION TEST, CURED/POST-CURED, 561K (550°F)



Matrix 7.2 Static Strength Test

Type 1 Bonded   Room Temp.

Figure 6-40: TYPE 1 BONDED - TENSION TEST, AGED, 294K (70°F)

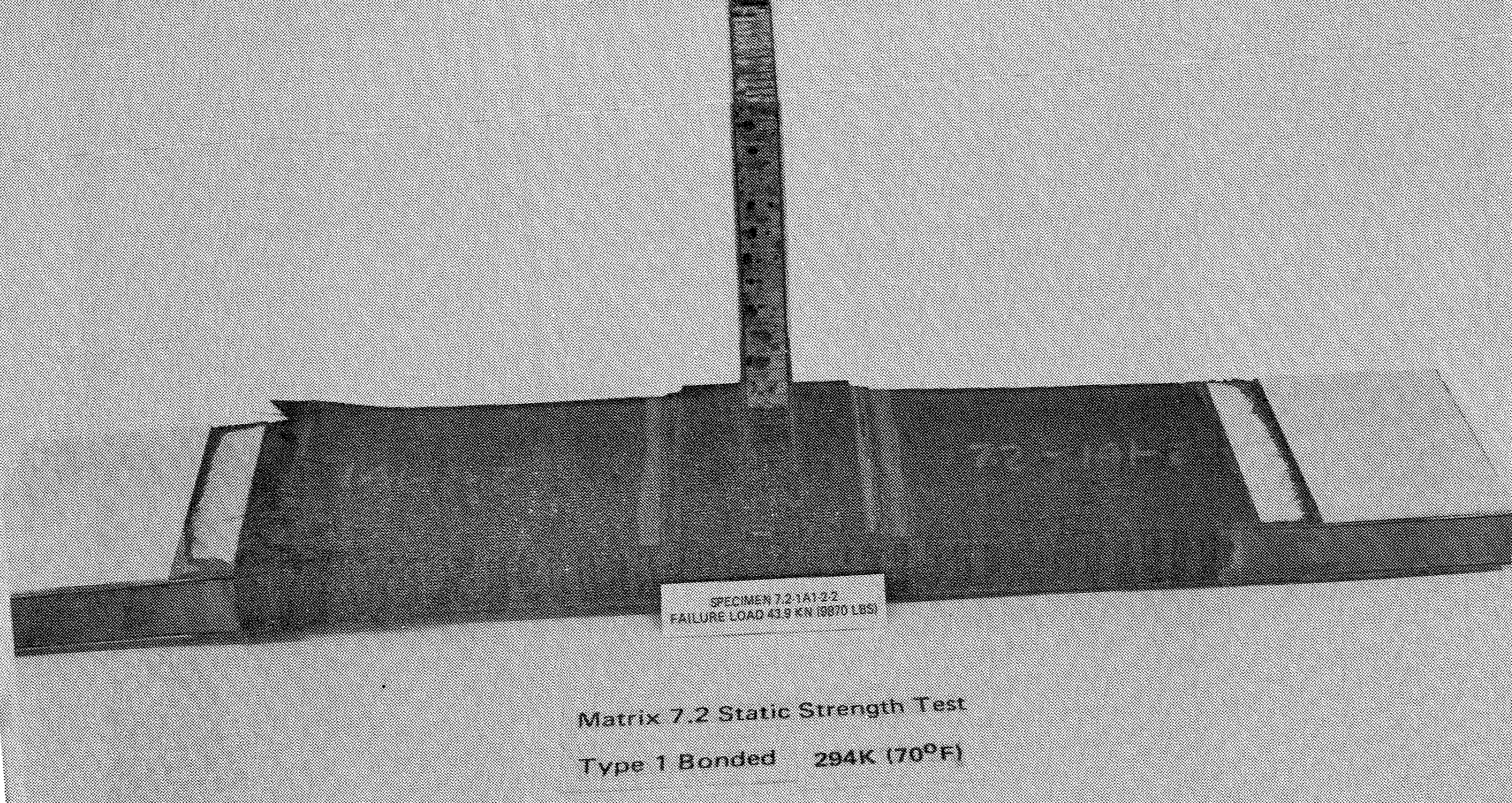


Figure 6-41: TYPE 1 BONDED - TENSION TEST, AGED, 294K (70°F)

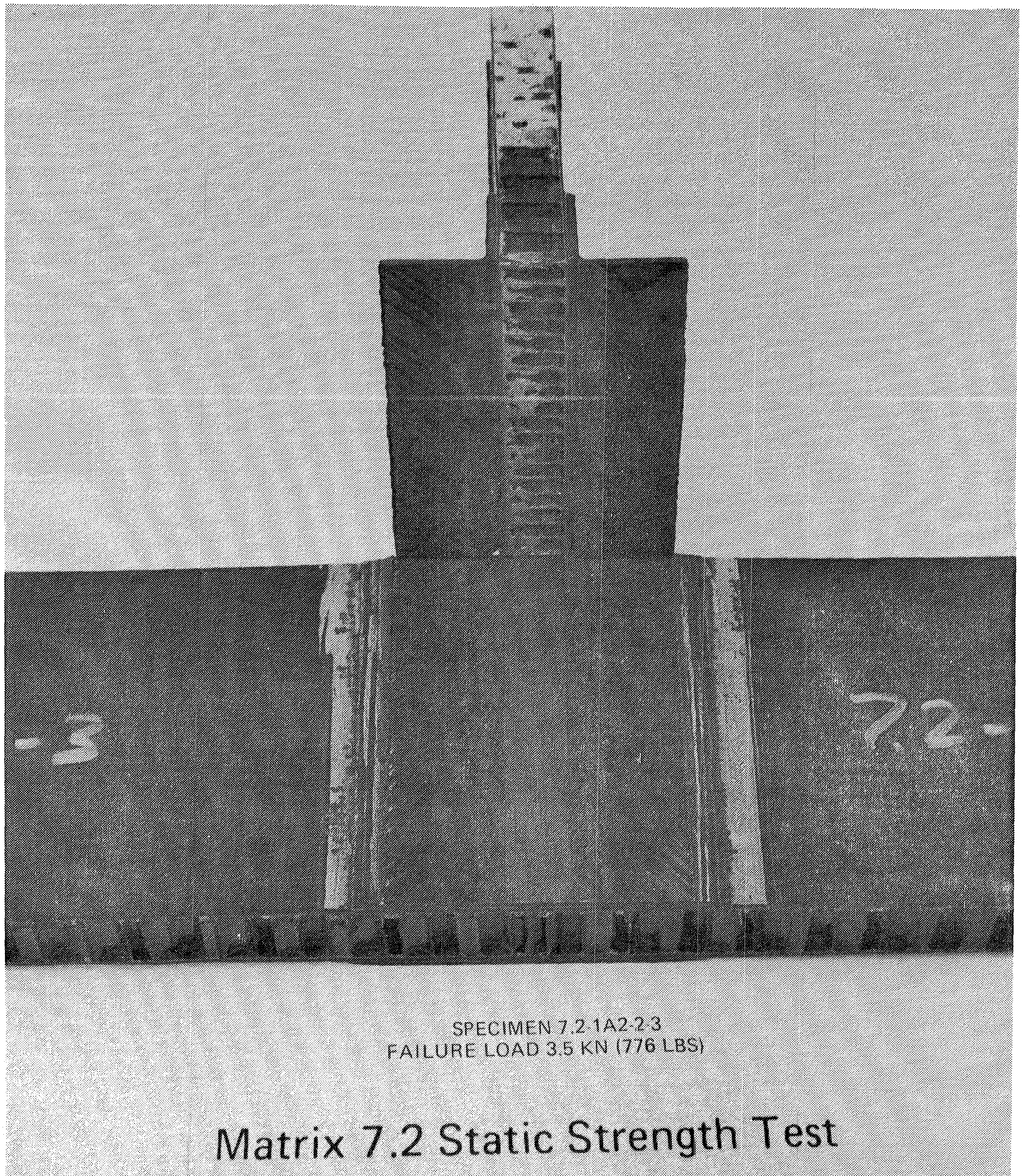
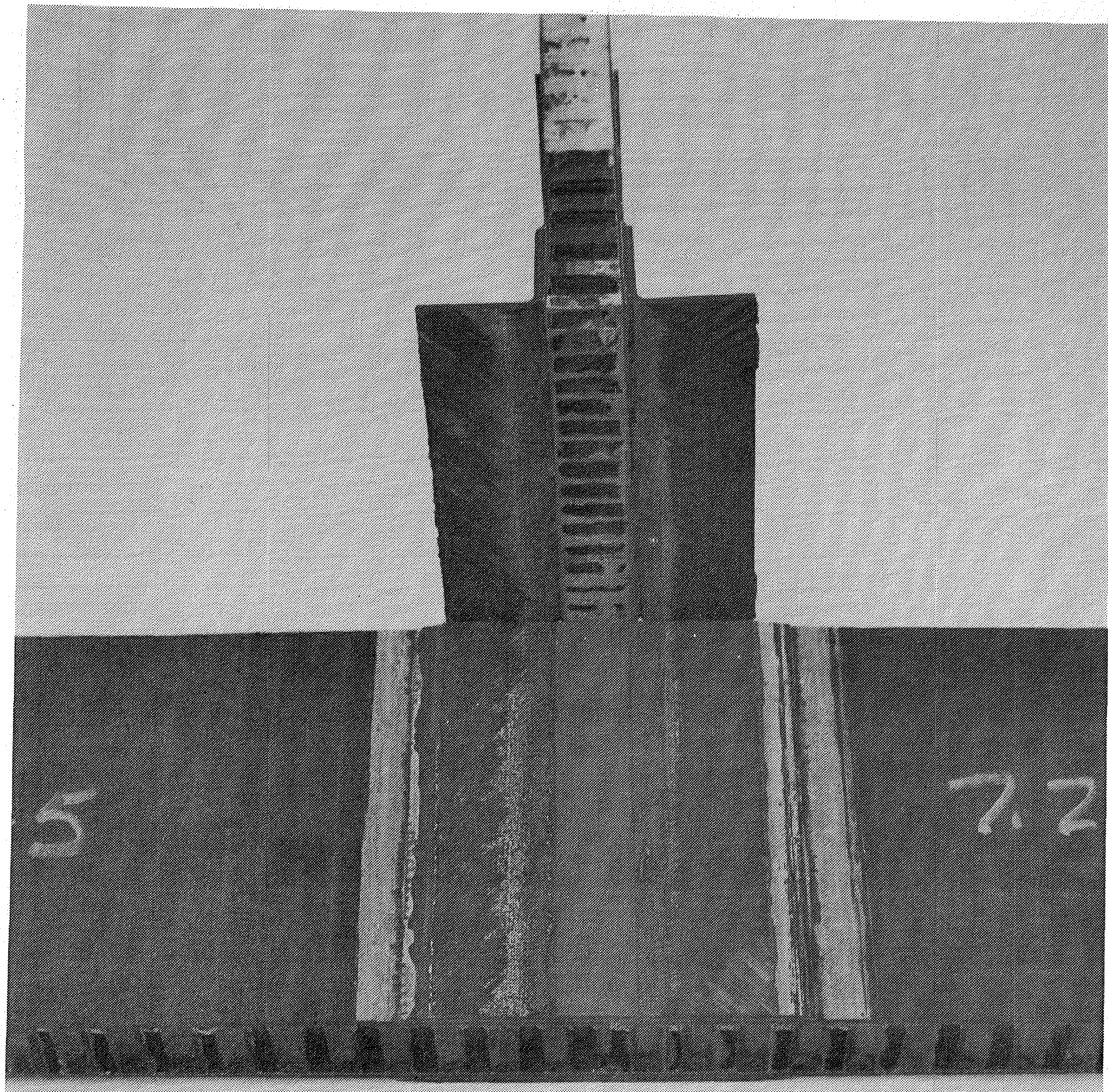


Figure 6-42: TYPE 1 BONDED - BENDING TEST, AGED, 294K (70°F)



SPECIMEN 7.2-1A2-2-5
FAILURE LOAD 2.4 KN (534 LBS)

Matrix 7.2 Static Strength Test

Type 1 Bonded 561 K (550°F)

Figure 6-43: TYPE 1 BONDED - BENDING TEST, AGED, 561K (550°F)

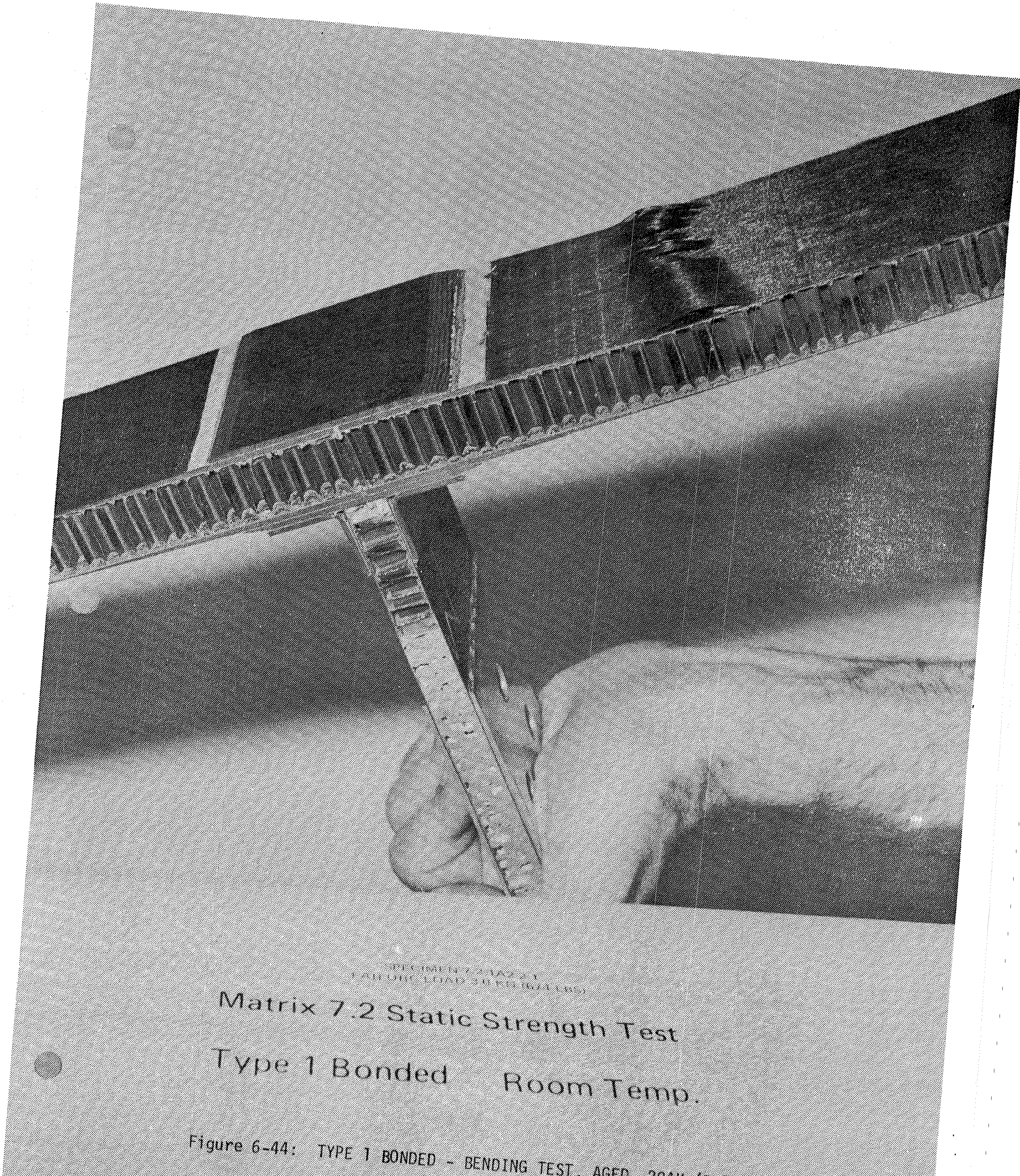


Figure 6-44: TYPE 1 BONDED - BENDING TEST, AGED, 294K (70°F)

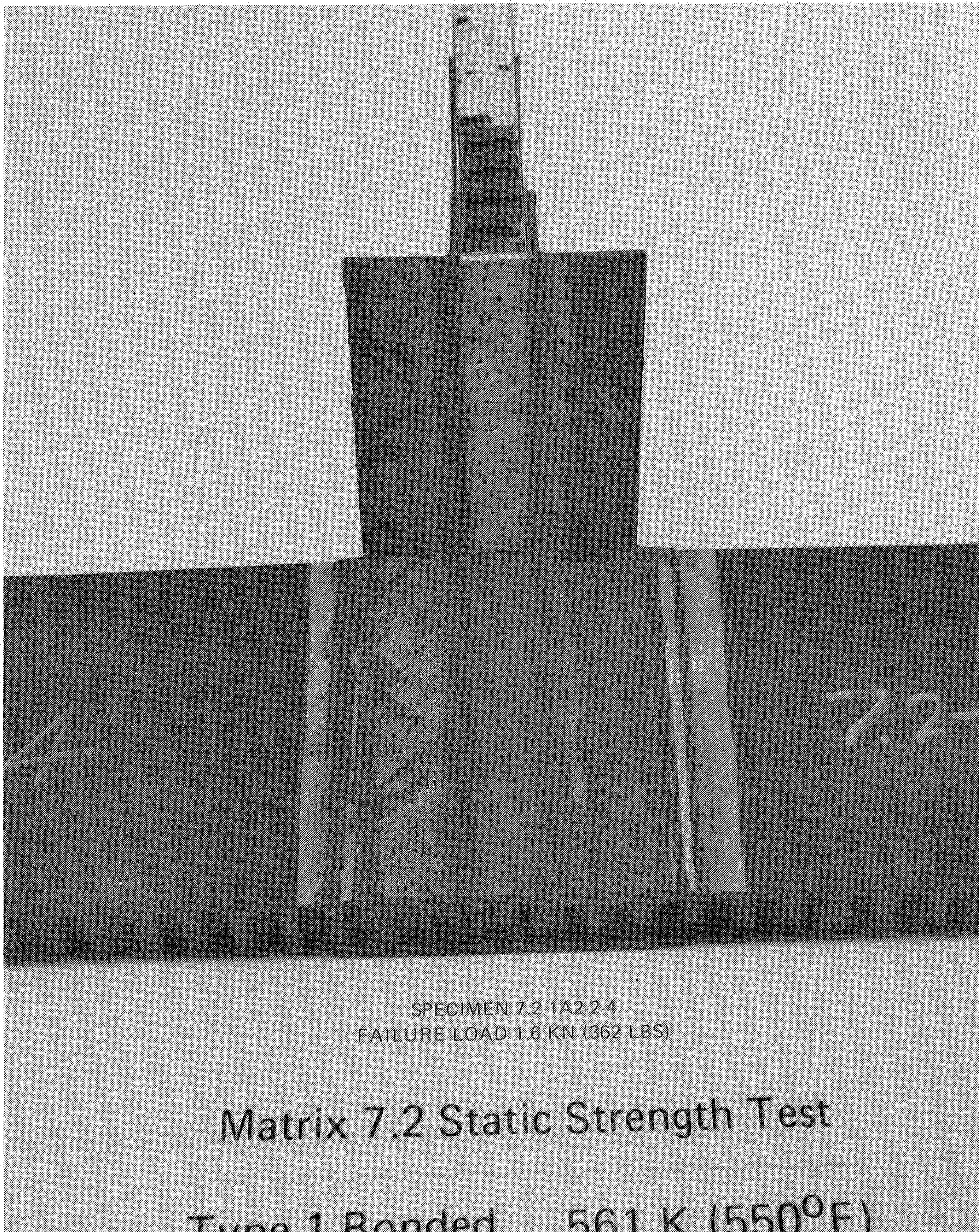


Figure 6-45: TYPE 1 BONDED - BENDING TEST, AGED, 561K (550°F)

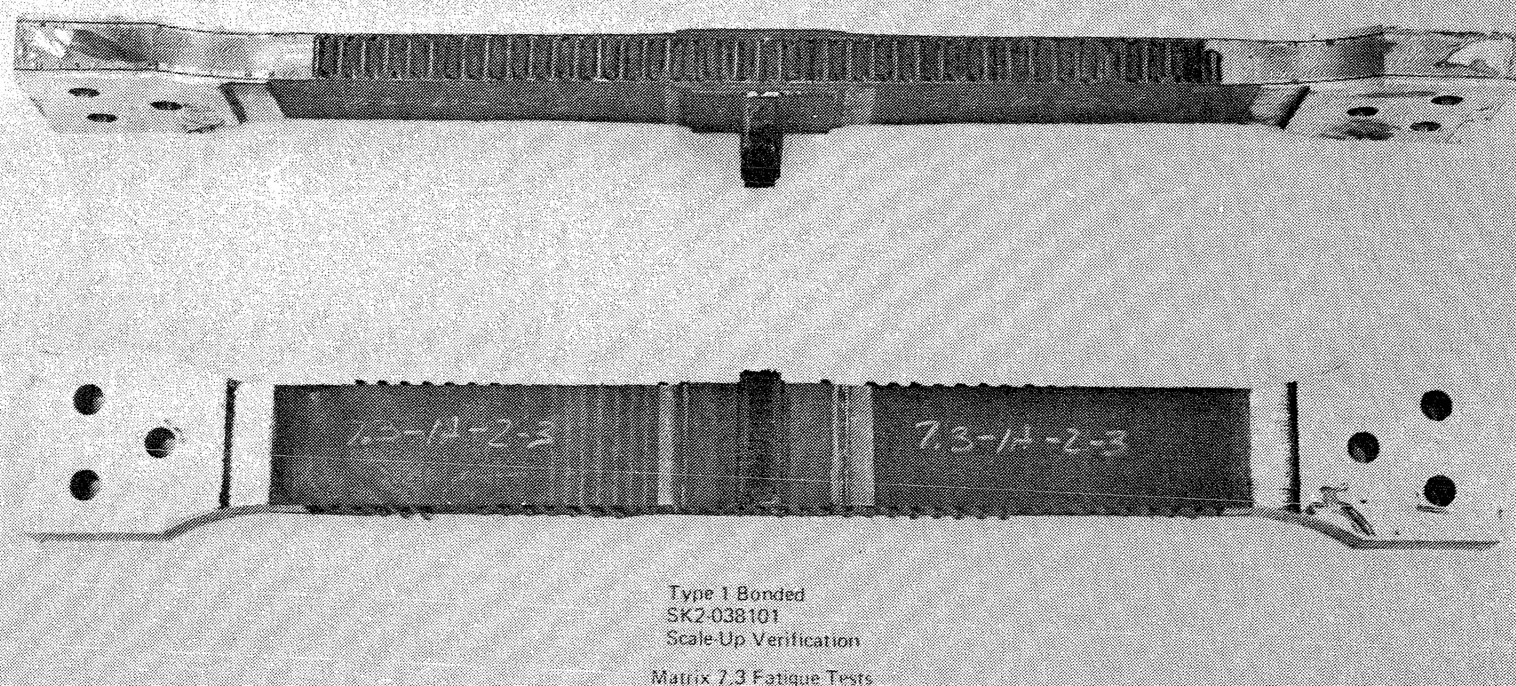


Figure 6-46: FINAL EVALUATION, TYPE 1 BONDED JOINT (FATIGUE TEST) - BEFORE TEST

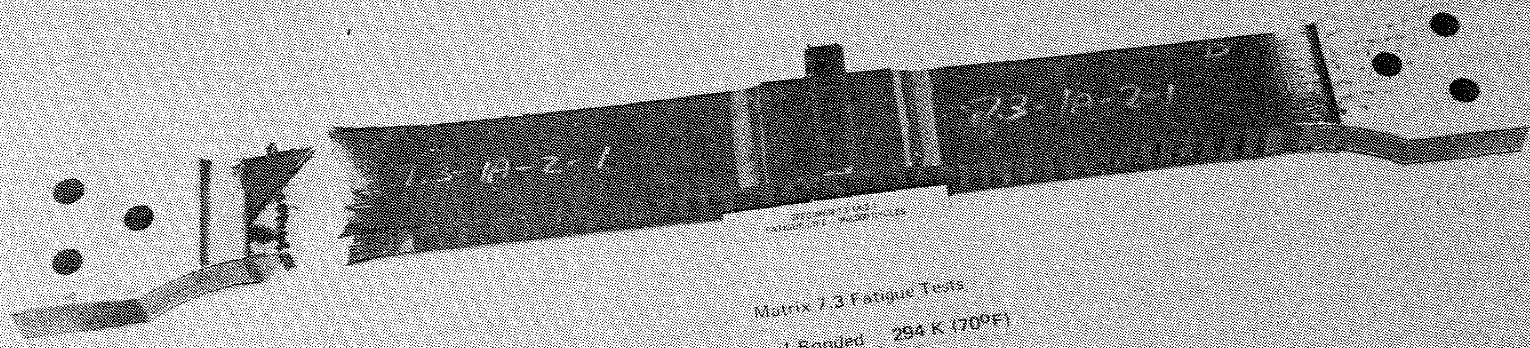


Figure 6-47: TYPE 1 BONDED - FATIGUE TEST, AGED, 294K (70°F)

Type 1 Bolted - Static Tests

Static test specimens for Type 1 Bolted joints are shown in Figure 6-48. Specimens were loaded in tension and bending as shown in Figure 6-8. Test results are summarized in Figure 6-32 and are discussed below. Predicted loads shown for the tension tests are based on skin tension failures using data from the design allowables testing (see Section 4.2). Predicted loads for the bending test are based on a compression failure of the cover outer skin laminate using the design allowables data.

Because of grip problems during testing of the Type 1 Bonded joints the grips on the bolted joints were revised. Fiberglass load pads were used instead of aluminum to eliminate some of the residual thermal stresses. In addition, no bolt holes were drilled in the cover grips because tension tests were run using hydraulic grips. All the Scale-up Verification (Matrix 7.1) cured/post cured specimens failed in the cover outside the joint at an average of 99% of the predicted load. Failed specimens are shown in Figure 6-49. The failure load matched that obtained during "Static Discriminator" tests for the same failure mode. Test results demonstrate that the interleaved doublers were an acceptable design and that the scaling-up did not affect material or joint performance.

Static Strength (Matrix 7.2) tests of aged specimens all had failure loads well below the predicted loads. Examination of the failed specimens showed extensive delamination of the laminates. In two of the tension tests the cover inner ply delaminated and the complete core simply slid out from between the covers (see Figure 6-50). During the bending tests the outer plies could be seen buckling up as load was applied (see Figure 6-51). These plies are then not carrying any load and the inner plies fail in compression at a much lower load than predicted. The failure surface of one of the bending specimens was examined microscopically and it was found there was effectively no resin. The laminate was delaminated before test. This problem is attributed to a resin loss during aging and is discussed in detail in Section 6.4.3.

No tests were conducted on thermally cycled specimens because they were destroyed during cycling. When the specimens were removed from the chamber they had evidence of burning or charring on the laminate edges. In addition, the laminate-to-core adhesive on the covers was a powdery white residue. The laminates were completely disbonded except in the thick built-up region (see Figure 6-52). The web laminate did not disbond. The glass-polyimide core also had resin burned out in some places. All the specimens were damaged by what appears to be severe overheating. Specimens cut from the same joint assembly and then aged 125 hrs at 589K (600°F) show no evidence of damage.

The thermal cycling chamber used for cycling is controlled by a feedback system and has an overheat switch that automatically shuts of the chamber if a preset temperature is exceeded. The shut-off temperature was set at 604K (628°F). In addition there is a completely separate temperature monitoring circuit that provides a continuous strip chart recording of the chamber temperature history. Review of these recordings showed no temperature overshoot or other anomalies. Therefore it is concluded that the degradation of the thermal cycled specimens is attributable to the resin chemistry and adhesive processing problems discussed in Section 6.4.3.

Type 1 Bolted - Fatigue Tests

Fatigue specimens for the Type 1 Bolted joints were the same configuration as the bonded joint specimens shown in Figure 6-46. Examination of the specimens prior to test showed some delamination and, in one case, broken fibers in the grip area.

Fatigue loadings are shown in Table 6-4. All room temperature and elevated temperature specimens sustained 10^6 cycles without two part failures; however, there was delamination of the basic cover skin on all specimens (see Figure 6-53). The specimens were tested statically to failure to determine their residual strength. Results are shown in Figure 6-32 and show a slight increase in static strength over the non-fatigued aged specimens at room temperature, with no difference at elevated temperature. However the non-fatigued specimens had premature failures as discussed above. The failed fatigue specimens also showed evidence of delaminations (see Figures 6-54 and 6-55). In contrast to the Type 1 bonded fatigue specimens, there were no grip failures of the Type 1 bolted fatigue specimens. This may be attributable to the lower fatigue load levels for the bolted joints.

Fatigue test results indicated that the joints can sustain 10^6 cycles without two part failure. Because of the premature failure of non-fatigued aged specimens, no comparison can be made regarding the residual strength after fatigue testing. Delamination during fatigue testing and in evidence after static tests to failure is attributed to the resin chemistry problem discussed in Section 6.4.3.

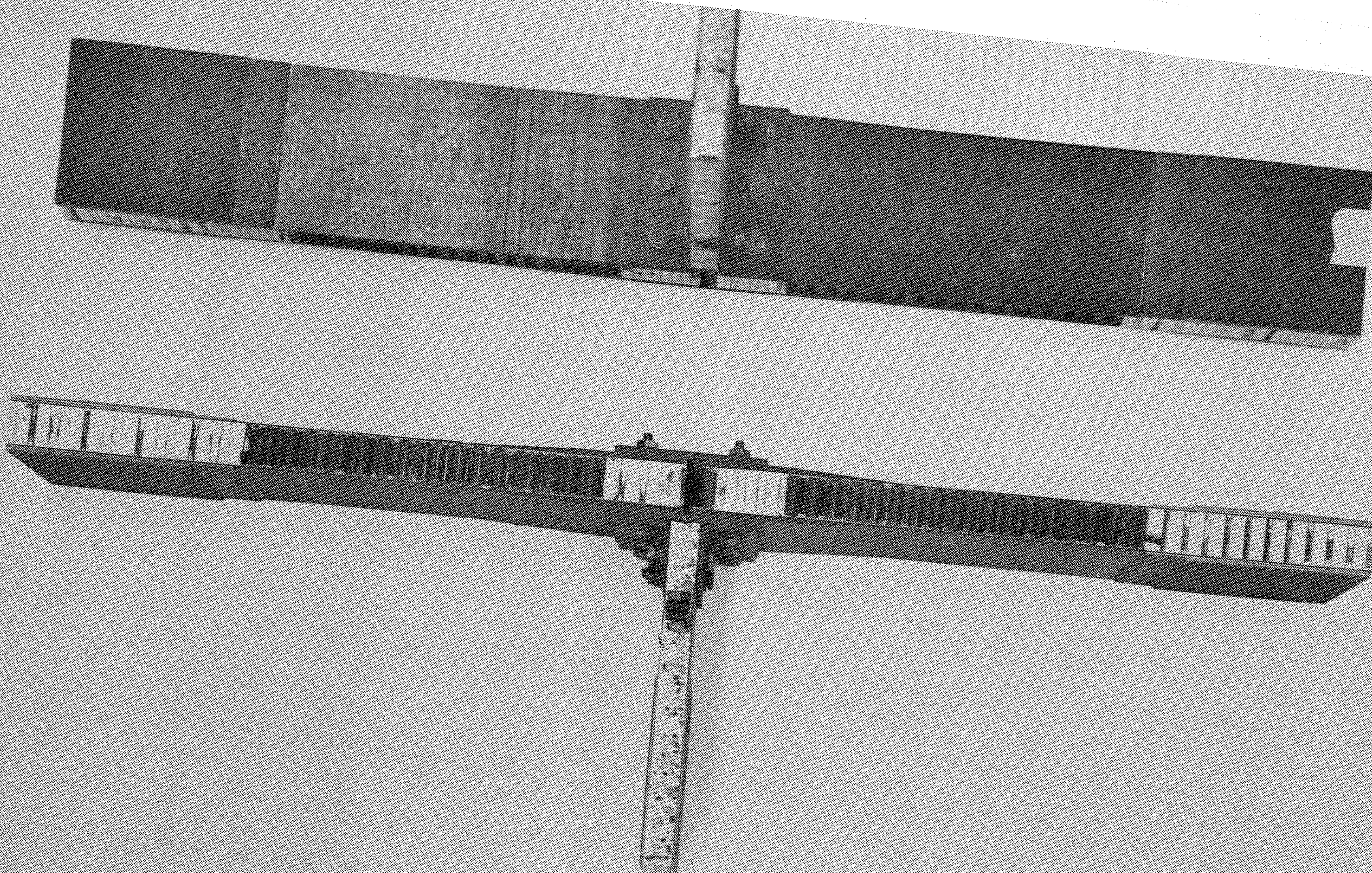


Figure 6-48: FINAL EVALUATION, TYPE 1 BOLTED JOINT - BEFORE TEST

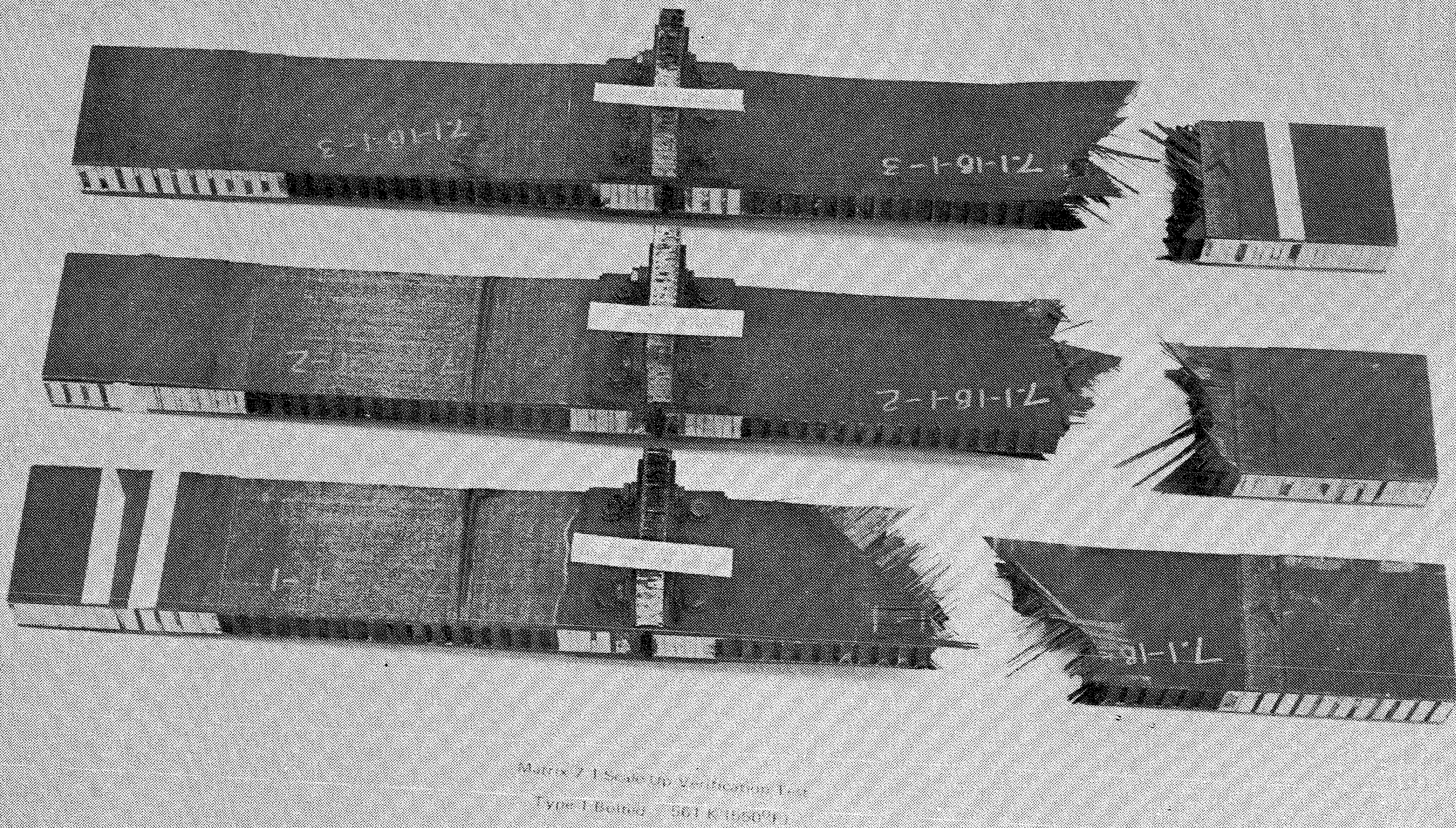
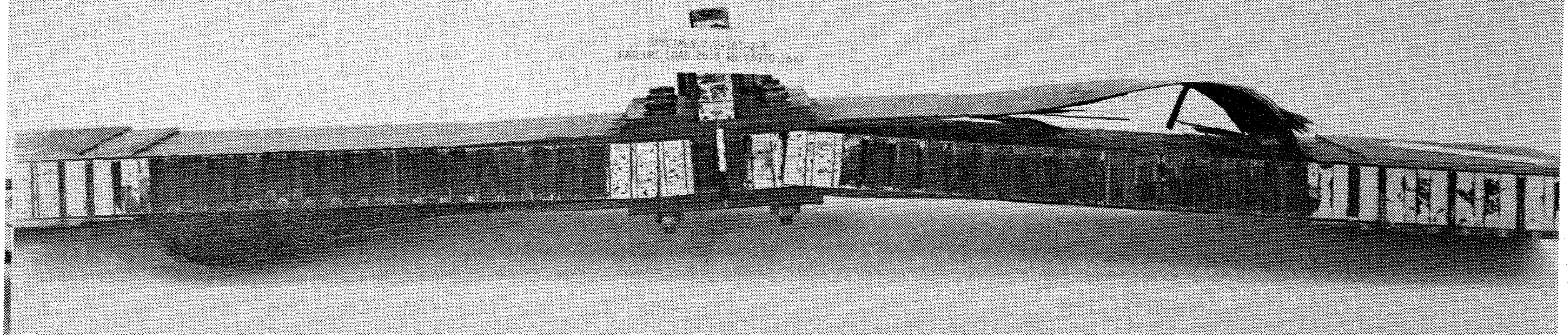


Figure 6-49: TYPE 1 BOLTED - TENSION TEST, CURED/POST-CURED, 561K (550°F)



Matrix 7.2 Static Strength Test

Type 1 Bolted 561 K (550°F)

Figure 6-50: TYPE 1 BOLTED - TENSION TEST, AGED, 561K (550°F)

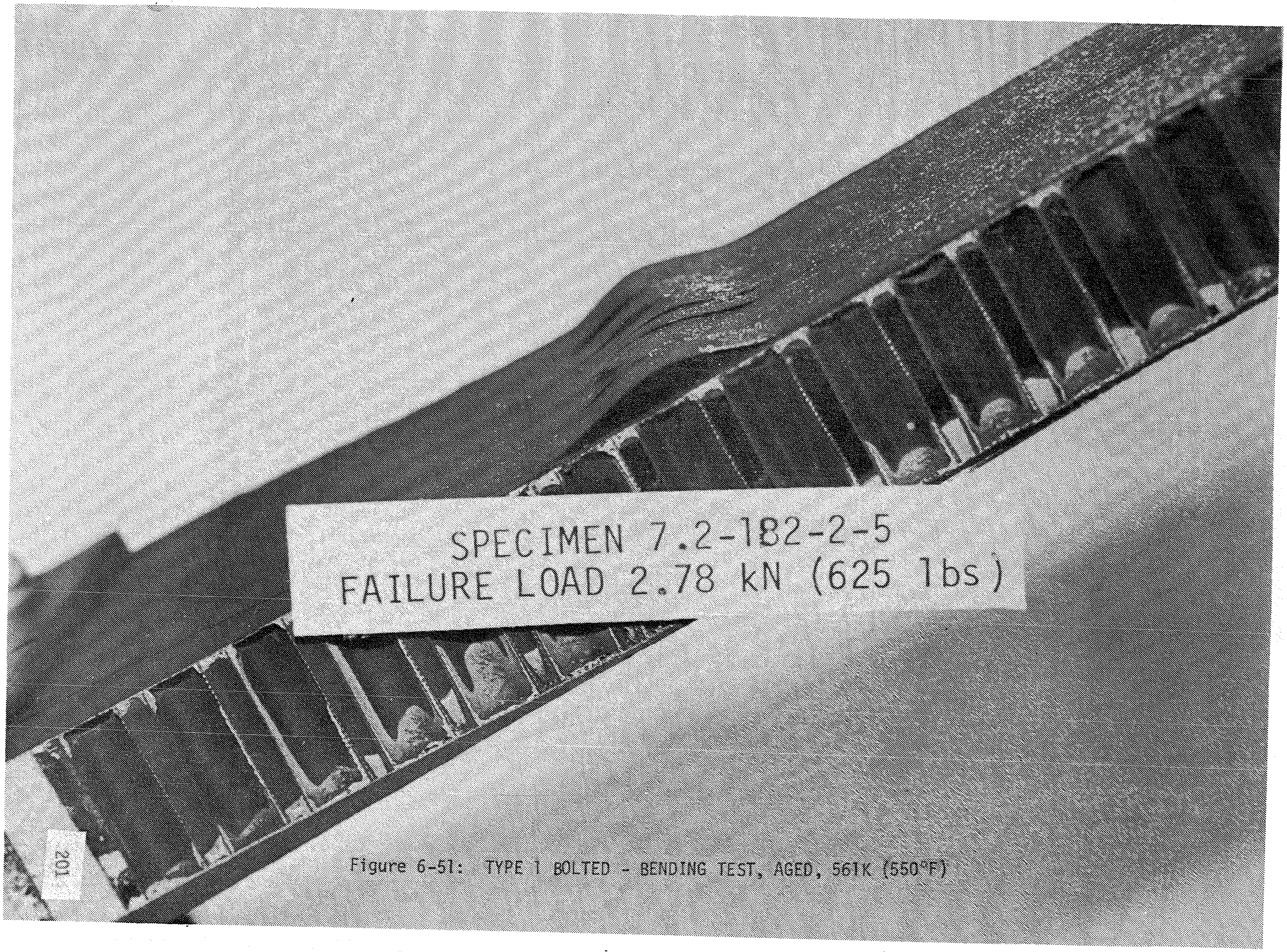


Figure 6-51: TYPE I BOLTED - BENDING TEST, AGED, 561K (550°F)

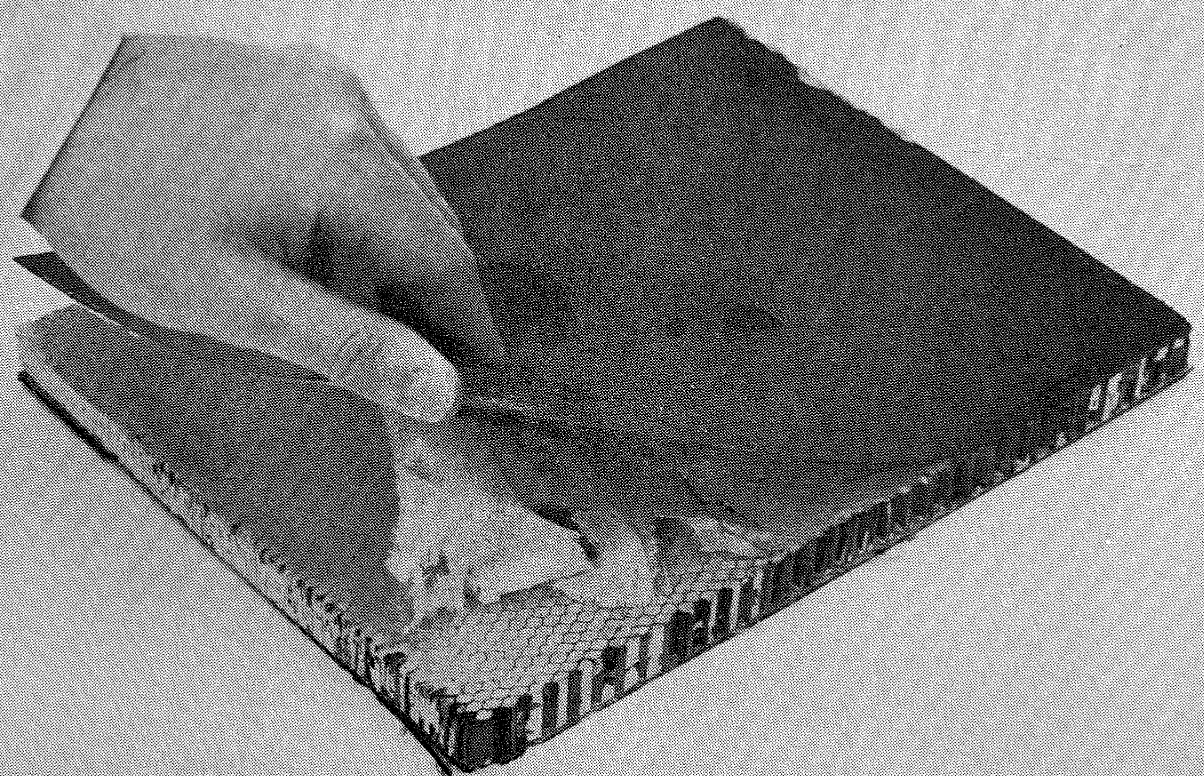


Figure 6-52: TYPE I BOLTED - THERMALLY CYCLED PANEL (BAD MATERIAL)

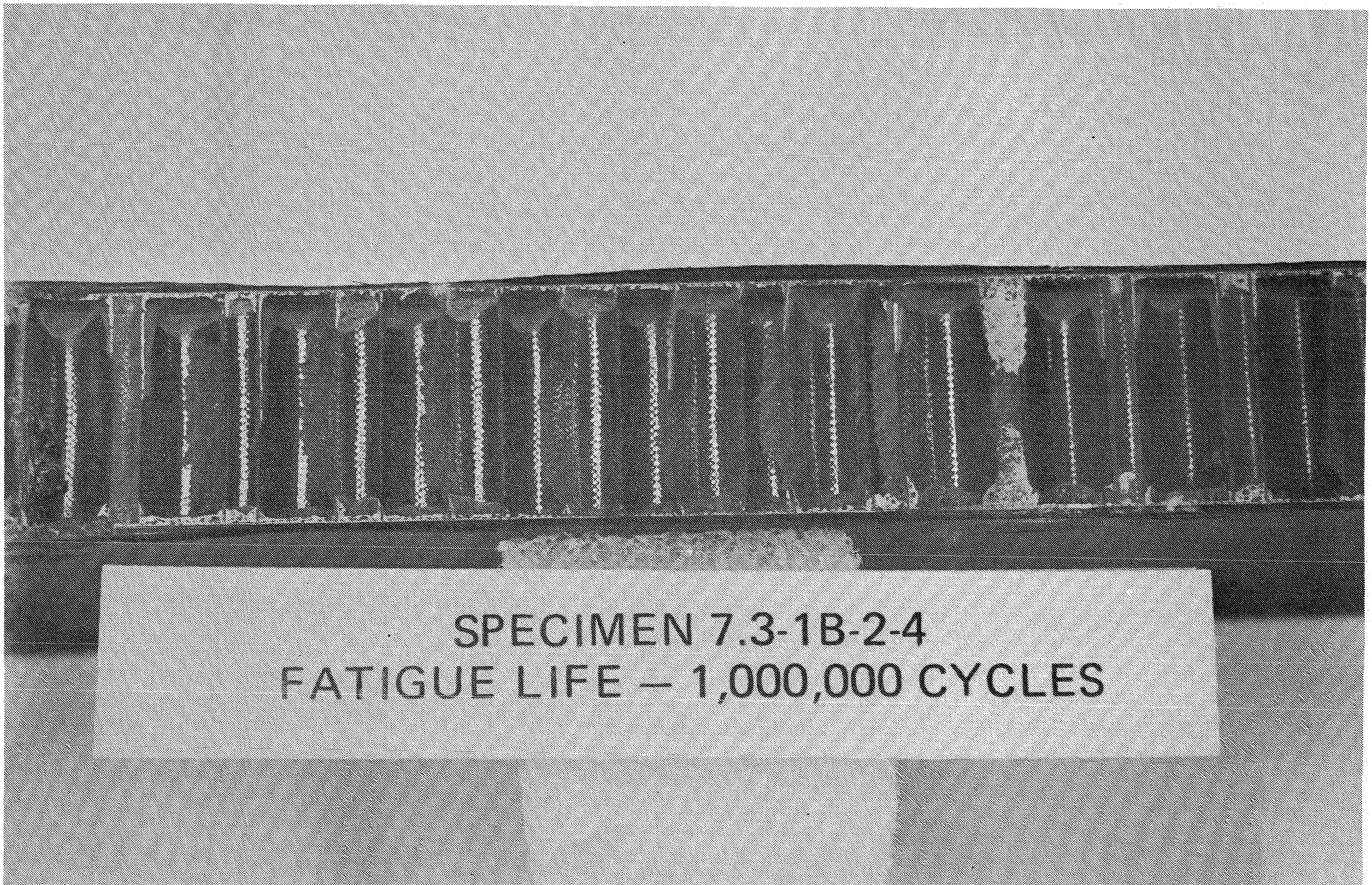


Figure 6-53: TYPE 1 BOLTED - FATIGUE TEST, AGED, 561K (550°F) - TYPICAL DELAMINATIONS

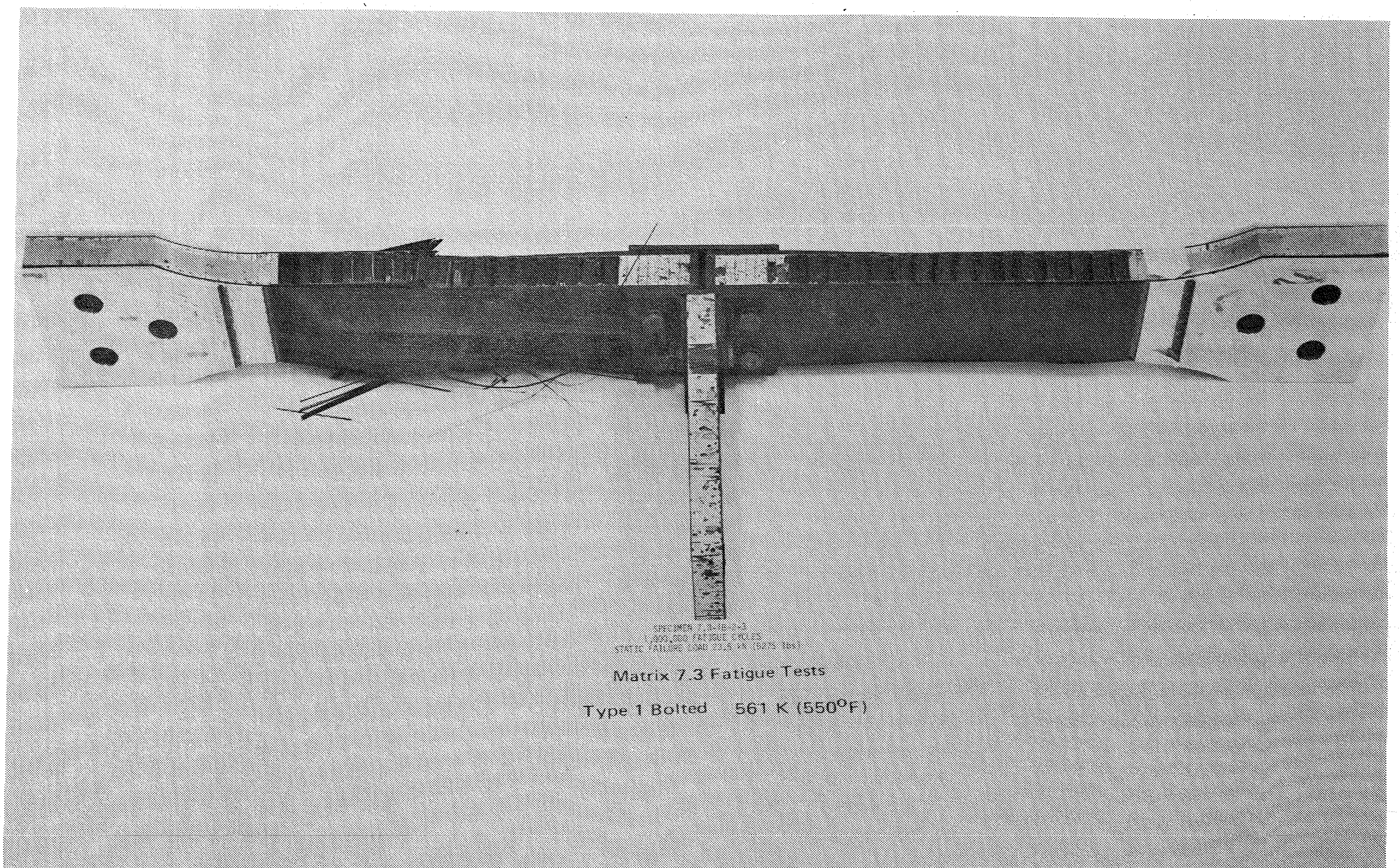


Figure 6-54: TYPE 1 BOLTED - FATIGUE TEST AND RESIDUAL STRENGTH TEST, AGED, 294K (70°F)

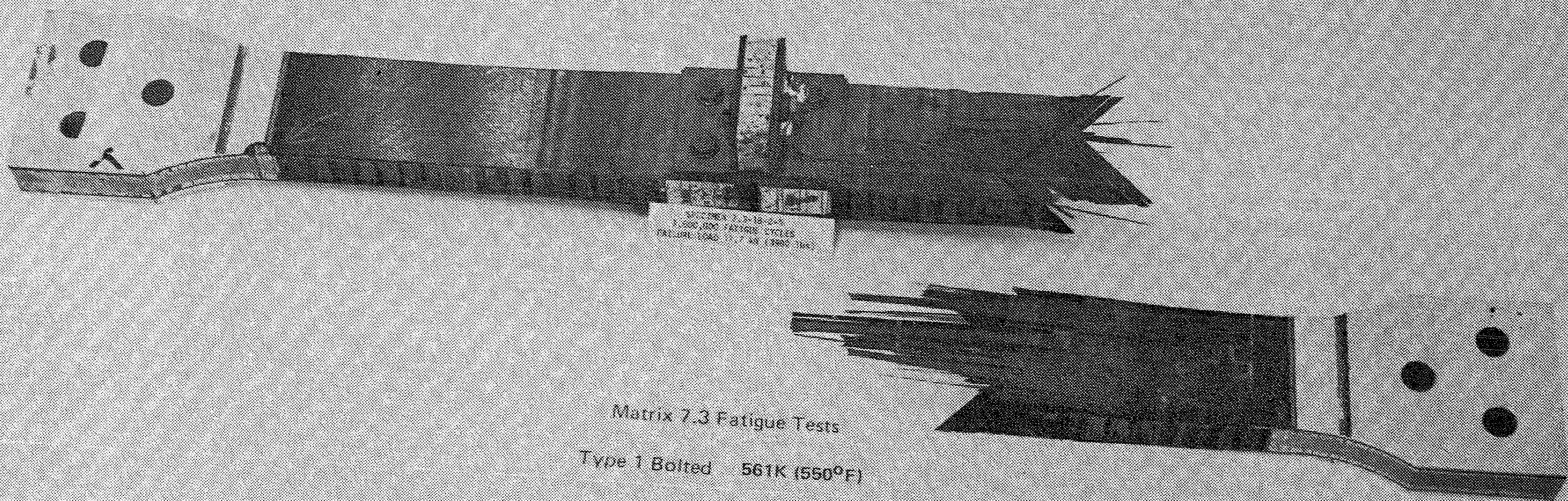


Figure 6-55: TYPE 1 BOLTED - FATIGUE TEST AND RESIDUAL STRENGTH TEST, AGED, 561K (550°F)

Type 2 Bonded - Static Tests

The static test specimen for the Type 2 Bonded joint is shown in Figure 6-56. Specimens were loaded as shown in Figure 6-9. Test results are presented in Figure 6-33 and are discussed below.

Scale-up Verification (Matrix 7.1) tests were performed at 561K (550^{o}F) on cured/post-cured specimens using load case 1 (see Figure 6-9). In all cases the specimens failed prematurely due to peel in the honeycomb close out area (see Figures 6-57 and 6-59). Static Strength (Matrix 7.2) tests were performed at 294K (70^{o}F) and 561K (550^{o}F) on thermally aged specimens. The first load case was identical to that used for the Scale-up Verification tests. These specimens also failed prematurely due to peel in the honeycomb close-out area. The premature failures are attributed to poor bonds on the laminate to core in the honeycomb close-out area. This was caused by tolerance buildup and gaps during scale-up which did not allow adequate pressure during bonding.

The second load case was originally planned to put the bond joint in shear. One specimen was tested in shear and went to 6.4kN (1440 lbs) before a brooming compression failure of the angle at the load reaction point occured. This corresponds to an average shear stress in the bondline of 3.1 MPa (450 psi) which is approximately 2.3 times the load requirement. It was concluded that the shear load was not critical. Because of the premature failures in the first load case it was decided to change the second load case from shear to a condition that would load the corner angle only and force a failure of the angle similar to that experienced in the "Static Discriminator" tests (i.e., interlaminar tension failure at the corner). This was accomplished by clamping one leg of the angle and applying a vertical load at the end of the other leg of the angle (see Figure 6-9, Load Case 2). All specimens exceeded the design load except one which failed at 95%. Specimens failed in interlaminar tension (delamination) at the corner (see Figure 6-58).

Static Strength (Matrix 7.2) tests of thermal cycled Type 2 Bonded joints were only conducted at 561K (550^{o}F) using load case 2. All specimens failed due to delamination of the corner angle. A comparison with aged specimens tested in the same manner shows a 49% loss in average strength due to the thermal cycling. No comparison was made to cured/post cured specimens since they had a different failure mode. The large loss in strength due to thermal cycling may be attributable to microcracking observed in thermally cycled quasi-isotropic laminates during design allowables testing (Ref. 4).

Type 2 Bonded - Fatigue Tests

Room and elevated temperature fatigue tests (Matrix 7.3) were conducted on aged Type 2 Bonded joints using load case 2 (Figure 6-9). Specimen configuration was the same as for the static tests. Fatigue loads, determined from load case 2, are shown in Table 6-4. All three room temperature specimens went to 10^6 cycles without failure. Room temperature static strength tests were then conducted on these specimens to determine their residual strength after fatigue. Specimens were tested using load case 2. Test results are shown in Figure 6-33. A comparison of static strength before and after fatigue shows approximately a 14% drop in strength after fatigue cycling. Residual static strengths are still above the design load of 285 N-m/m (64 in-lb/in).

The first two elevated temperature specimens went to 10^6 cycles; however, when the specimens were removed from the heating chamber they were found to have delaminations in the corner angle as shown in Figure 6-60. The number of cycles when the delaminations occured are not known. The third specimen also had delaminations in the corner angle; however, it failed at 3000 cycles. No firm conclusion can be drawn from the elevated temperature fatigue tests.

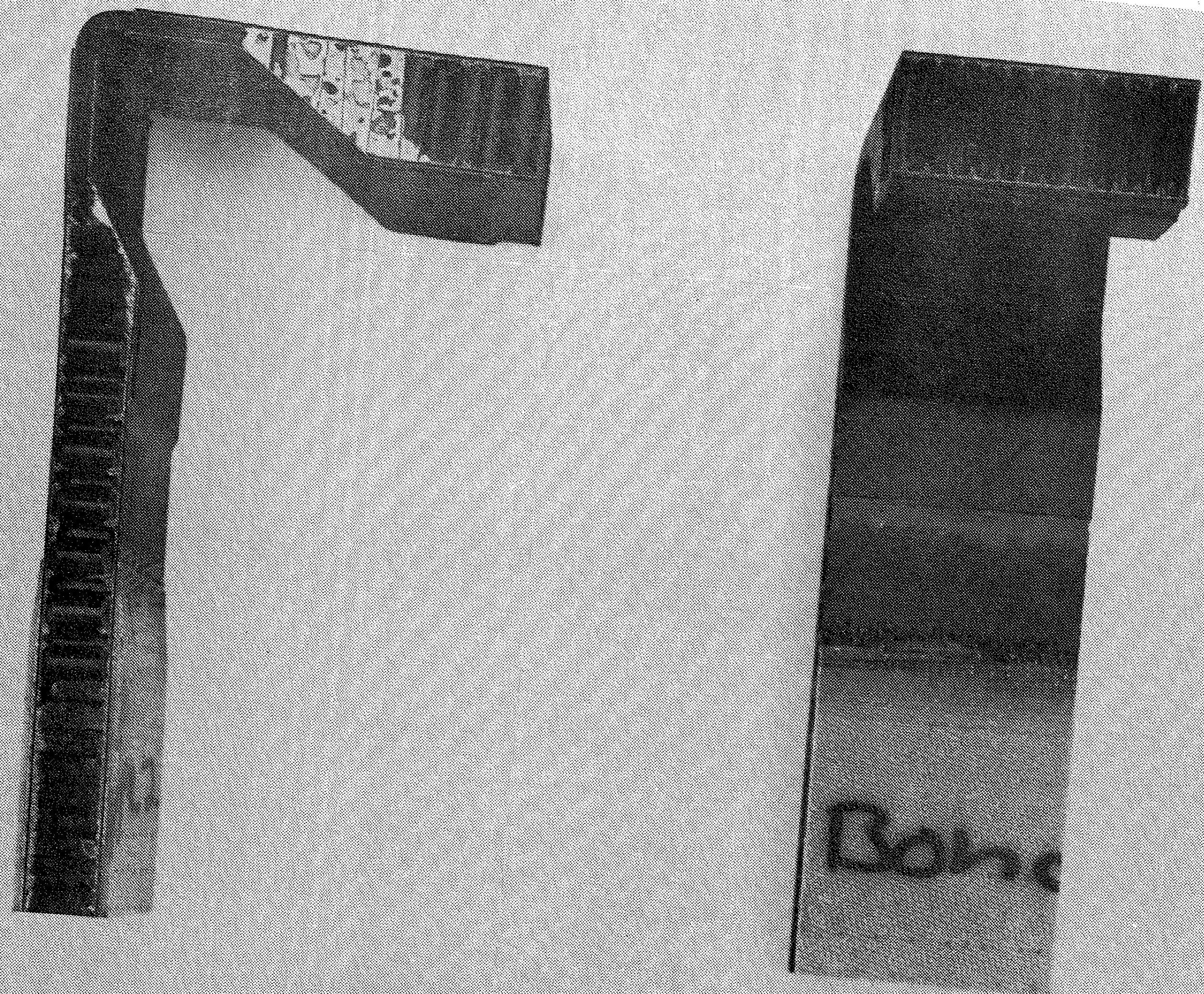


Figure 6-56: FINAL EVALUATION, TYPE 2 BONDED JOINT - BEFORE TEST

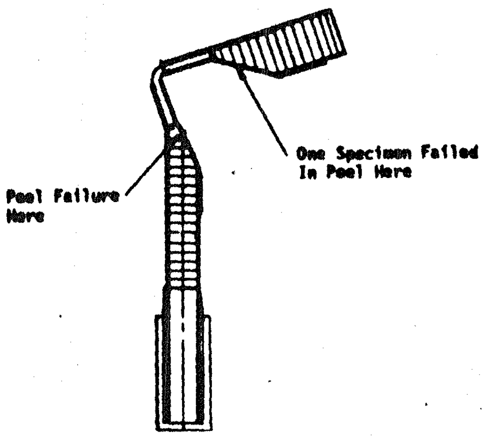


Figure 6-57: TYPE 2 BONDED JOINT
LOAD CASE 1 FAILURE MODE

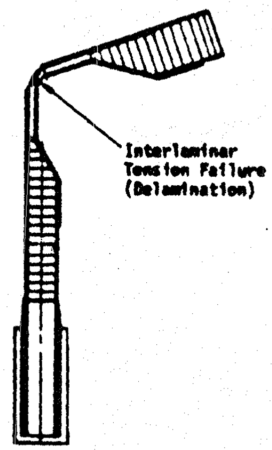


Figure 6-58: TYPE 2 BONDED JOINT
LOAD CASE 2 FAILURE MODE

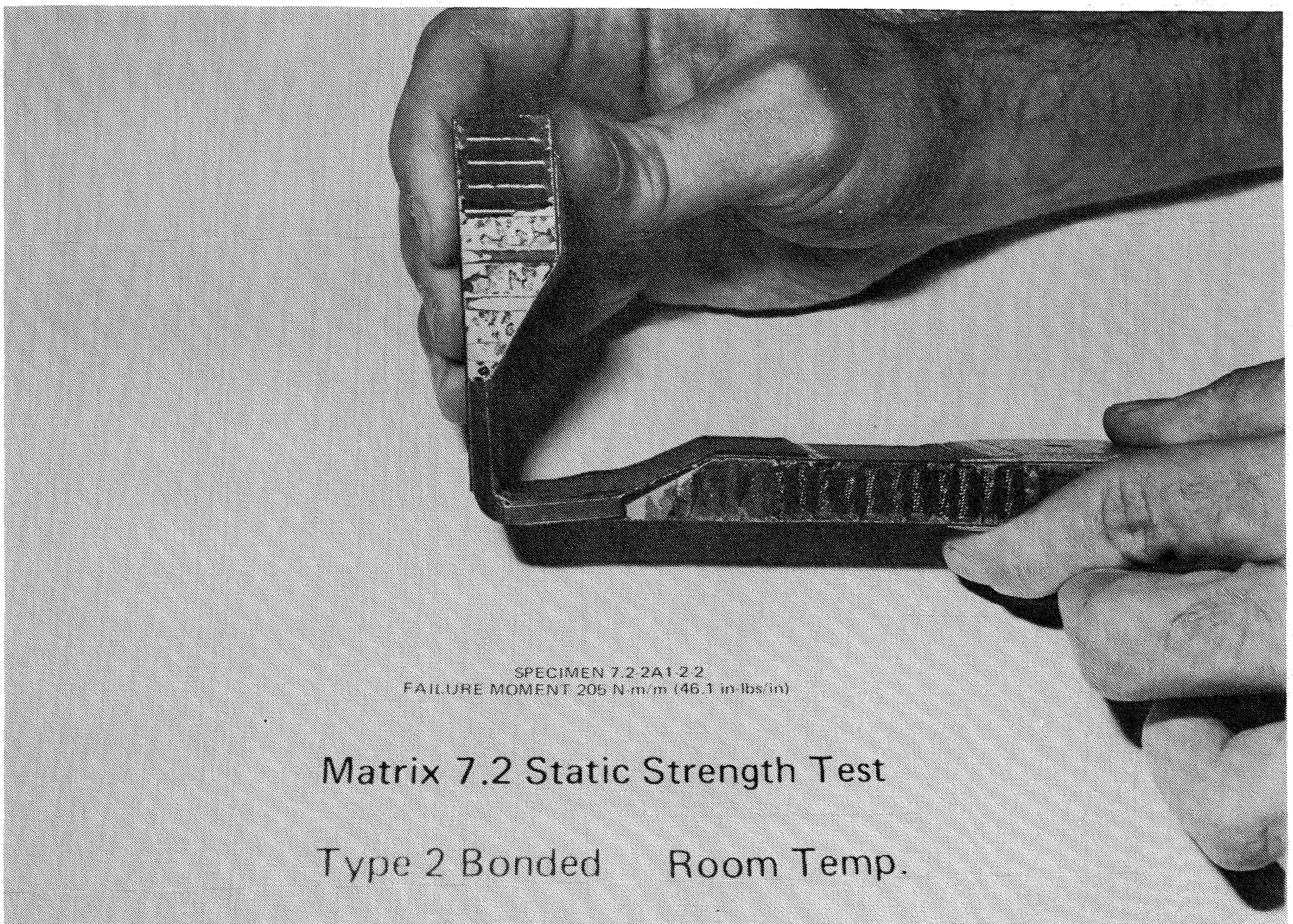


Figure 6-59: TYPE 2 BONDED - LOAD CASE 1, AGED, 294K (70°F)

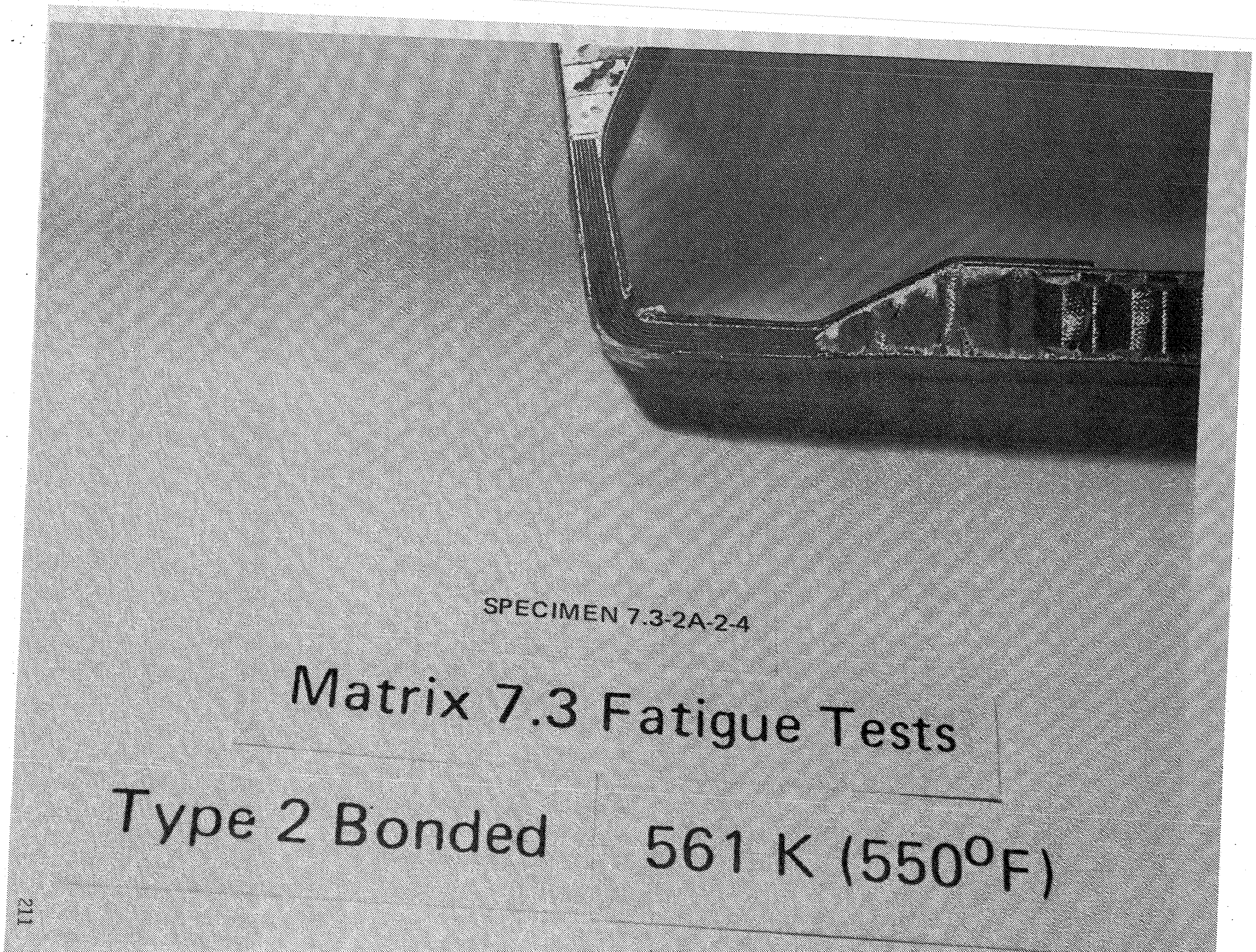


Figure 6-60: TYPE 2 BONDED - FATIGUE TEST, AGED, 561K (550°F)

Type 2 Bolted - Static Tests

The static test specimen for the Type 2 Bolted joint is shown in Figure 6-61. Test results were conducted for two load cases as shown in Figure 6-10. Test results are presented in Figure 6-34 and are discussed below.

All Scale-up Verification (Matrix 7.1) and Static Strength (Matrix 7.2) specimens exceeded the minimum design load of 285 N-m/m (64 in-lb/in). Specimens for load case 1 failed due to interlaminar tension and delamination at the bend radius of the inner attach angle. There was also a compression failure and delamination of the outer plies of the outer attach angle at the row of web attachment bolts. Failure modes for load case 1 are shown schematically in Figure 6-62 with a typical specimen shown in Figure 6-64. For load case 2 all specimens except one had compression failures of the web inner skin due to the bending moment. One specimen failed in net tension on the outer skin at the row of web attachment bolts. Failures are shown schematically in Figure 6-63 and typical specimens are shown in Figures 6-65 and 6-66.

After thermal cycling the Type 2 bolted joints had delaminations of the inner attach angle and resin burnout and charring on the edges of the laminates. In addition the specimens had a bright shiny clean appearance uncharacteristic of previous thermally cycled specimens. All the specimens were damaged by what appeared to be overheating and were not tested. These specimens were cycled at the same time as the Type 1 Bolted specimens. The laminate degradation is again attributed to the resin chemistry problem discussed in Section 6.4.3.

Type 2 Bolted - Fatigue Tests

Room and elevated temperature fatigue tests of Type 2 bolted joints were conducted using load case 1 (Figure 6-10). Fatigue loadings are given in Table 6-4.

All three room temperature specimens went 10^6 cycles without failure. The specimens were then tested statically to determine their residual strength after fatigue. A comparison of static strengths before and after fatigue is shown in Figure 6-34 and shows an average increase in joint strength of 39% due to fatigue. There is no apparent explanation for this phenomenon.

The static strength of elevated temperature specimens was significantly higher than the room temperature specimens. Therefore, the elevated temperature fatigue tests were started at a higher load than the room temperate tests. The first specimen failed at less than 100 cycles, therefore, it was decided to run the elevated temperature tests at the same load as the room temperature tests. One specimen was destroyed because of a hydraulic servo valve failure. The other specimen went to 10^6 cycles; however, specimen examination after removal from the heating enclosure showed a delamination in the bend of the inner attachment angle. It is not known when the failure occured. No conclusion can be drawn from results of the high temperature fatigue tests.

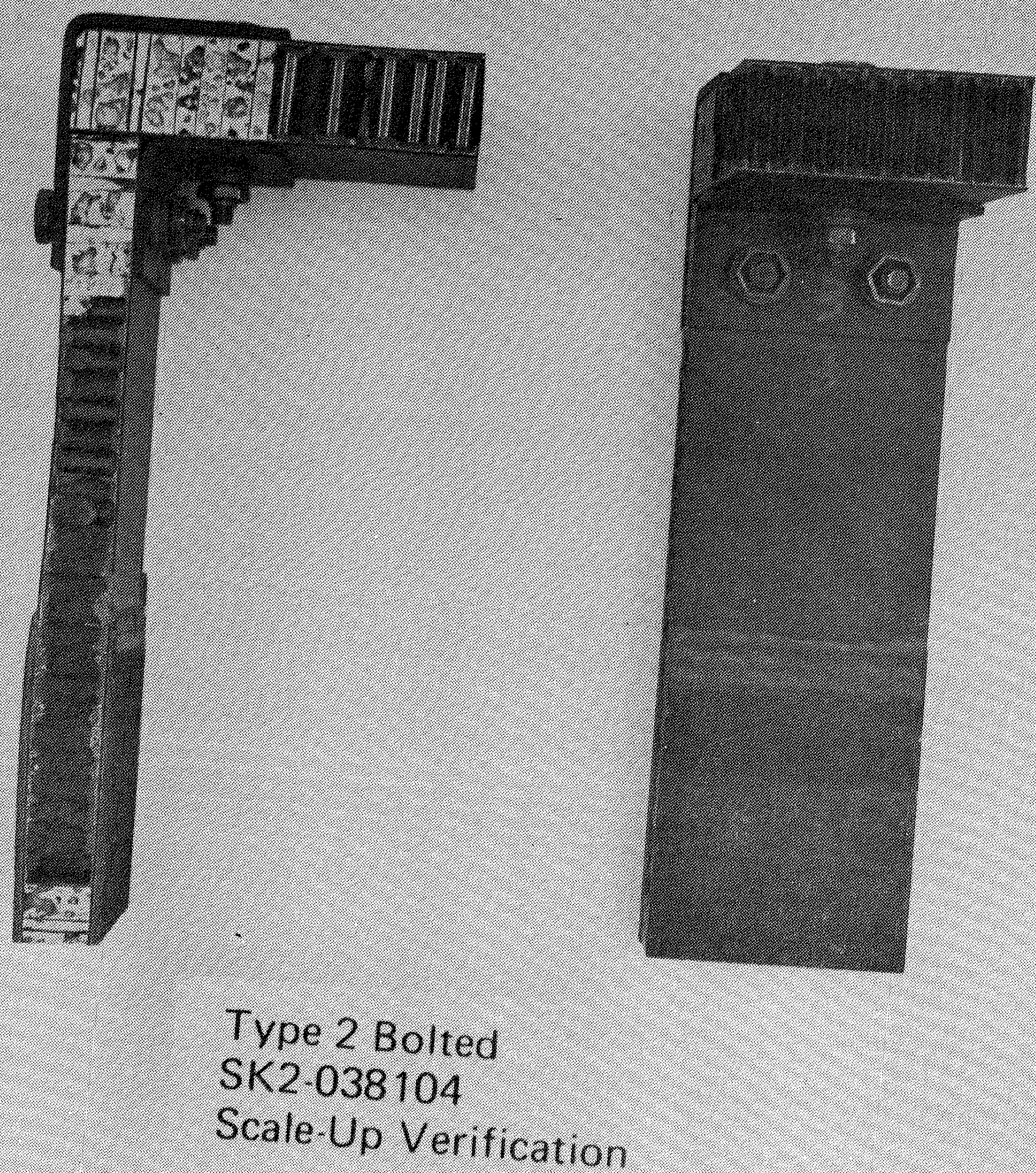


Figure 6-61: FINAL EVALUATION, TYPE 2 BOLTED JOINT - BEFORE TEST

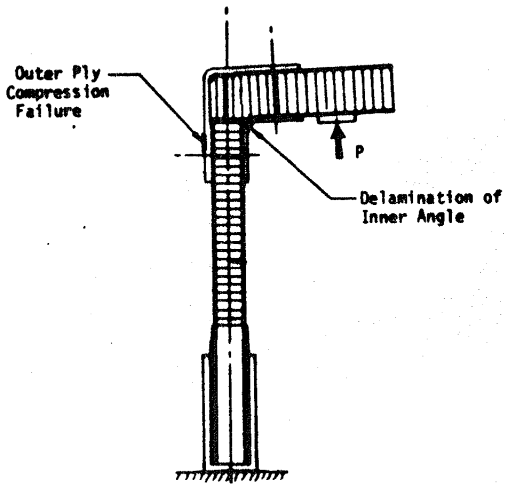


Figure 6-62: TYPE 2 BOLTED JOINT, FAILURE MODE - LOAD CASE 1

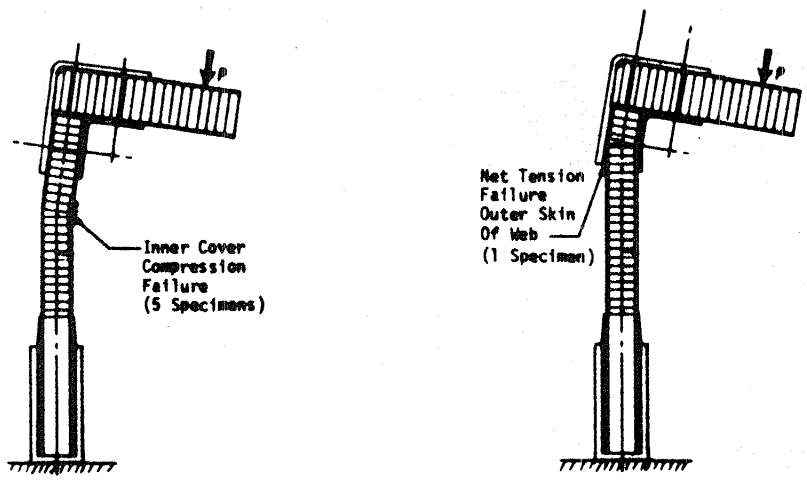
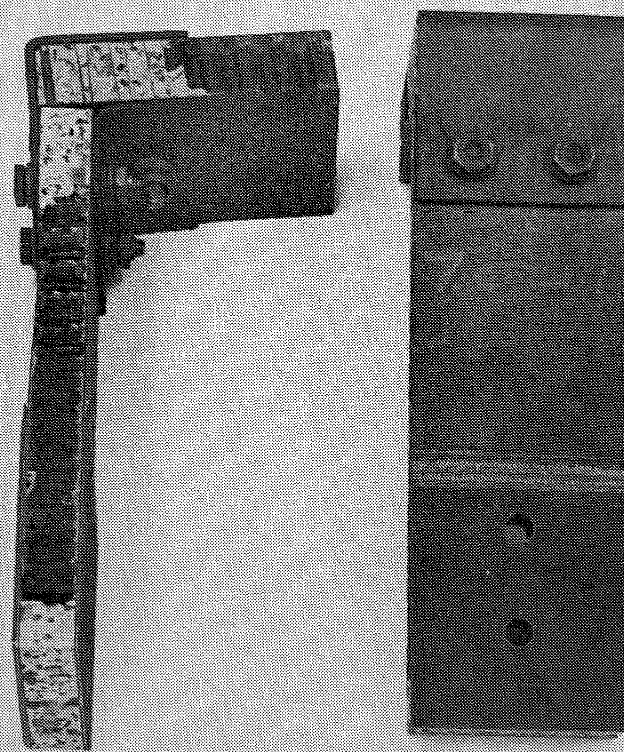


Figure 6-63: TYPE 2 BOLTED JOINT, FAILURE MODE - LOAD CASE 2

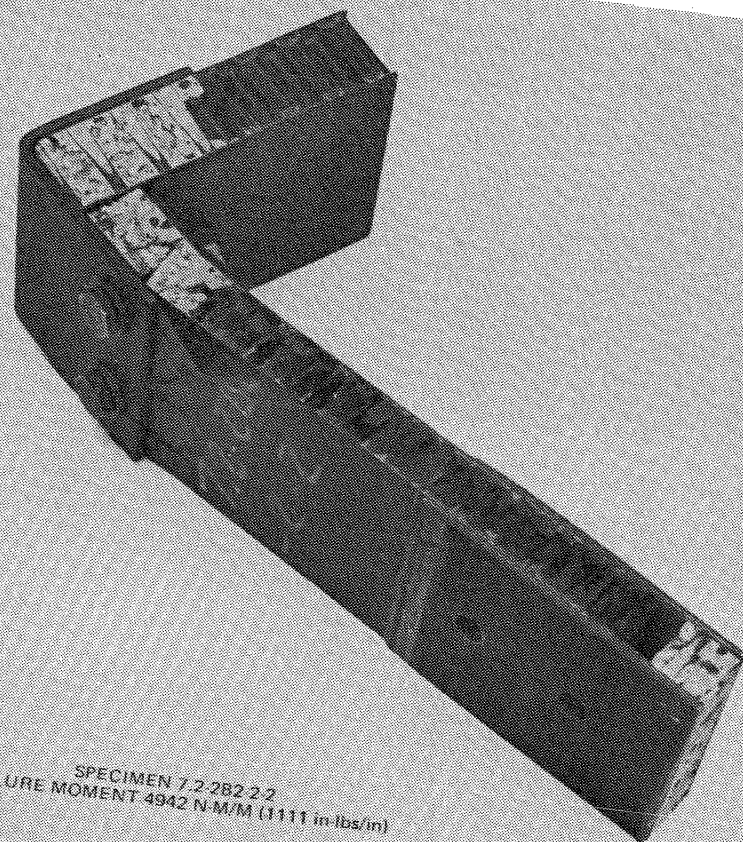


Matrix 7.2 Static Strength Test

Type 2 Bolted 561 K (550°F)

Load Case 1

Figure 6-64: TYPE 2 BOLTED - LOAD CASE 1, AGED, 561K (550°F)



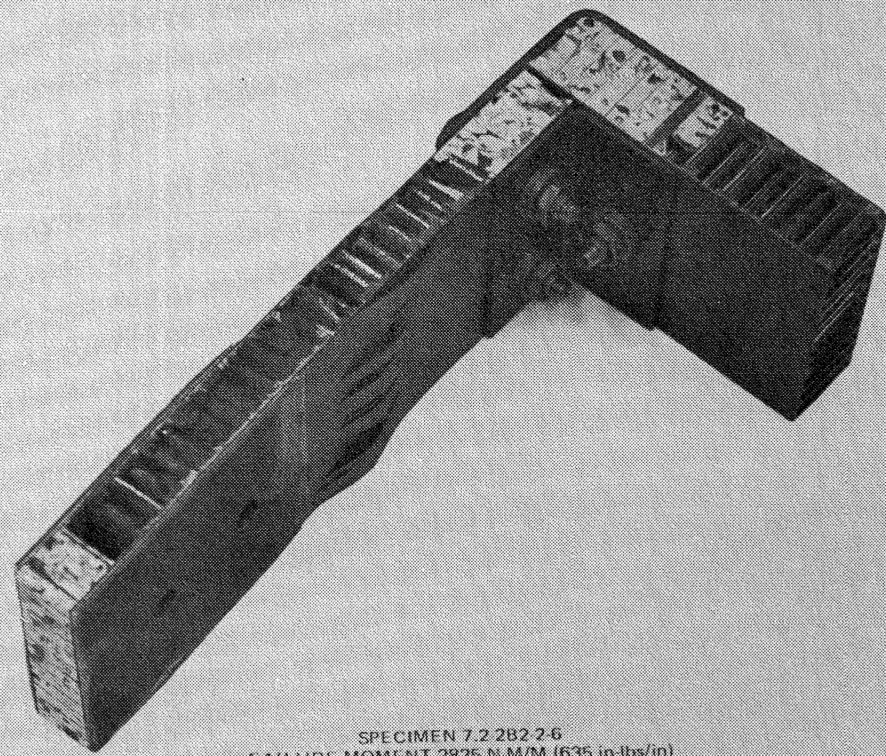
SPECIMEN 7.2-2B2-2-2
FAILURE MOMENT 4942 N-M/M (1111 in-lbs/in)

Matrix 7.2 Static Strength Test

Type 2 Bolted 294 K (70°F)

Load Case 2

Figure 6-65: TYPE 2 BOLTED - LOAD CASE 2, AGED, 294K (70°F)



SPECIMEN 7.2.282-2-6
FAILURE MOMENT 2825 N-M/M (635 in-lbs/in)

Matrix 7.2 Static Strength Test

Type 2 Bolted 561 K (550°F)

Load Case 2

Figure 6-66: TYPE 2 BOLTED - LOAD CASE 2, AGED, 561K (550°F)

Type 3 Bolted - Static Tests

Type 3 joints were loaded in tension. Figure 6-67 shows a static test specimen before test. Static test results for Type 3 bolted jonts are summarized in Figure 6-35. Predicted loads are based on skin tension failures using data from the design allowables testing (see Section 4.2).

All specimens failed in tension at the skin-to-pad-up transition section. Typical failed specimens are shown in Figures 6-68 and 6-69. This is a different failure mode than occurred for the "Static Discriminator" specimens which all failed in the grip area, however, at similar load levels (see Section 5.4). The pad-up section on the "Final Evaluation" specimens had been redesigned so that it was three pieces secondarily bonded as compared to the original ("Static Discriminator" specimen) two pieces. The transition section, however, was basically the same interleaved design, only shorter in length. It is concluded that the change in failure mode is related to the resin chemistry problem observed in the Type 1 and Type 4 joint tests and discussed in Section 6.4.3.

The one cured/post-cured specimen failed at 82% of the predicted load. Aged specimens had failure loads ranging from 81% to 92% of the predicted load.

All of the thermally cycled specimens had evidence of bad laminate-to-core adhesive bond after removal from the cycling chamber. There was a white powdery residue on the exposed edges. Since these specimens are loaded in tension, and the core acts only as a spacer, the load grips were added and the specimens tested. On the average, thermal cycled specimens failed at 78% of the predicted load. The failed specimens had extensive delamination of the laminate and the laminate-to-core bond was bad, as had been expected (see Figure 6-70). Since the aged specimens showed less damage, it appears that thermal cycling tends to degrade the PMR-15 resin to a greater extent than thermal aging; however, the laminate degradations are attributed to the resin chemistry problem discussed in Section 6.4.3.

Type 3 Bolted - Fatigue Tests

Fatigue tests of Type 3 bolted joints were conducted using the test specimen shown in Figure 6-71. It had a Gr/PI splice plate at one end and a titanium splice plate on the other end. Fatigue loads are shown in Table 6-4. Results of room and elevated temperature fatigue tests are given in Table 6-11.

For the first room temperature test the titanium splice plate failed in net tension at 130,000 cycles. The titanium splice plates were doubled (two on each side) and testing continued. The splice plate broke again at an additional 215,600 cycles and at the same time the 9.5 mm (3/8 inch) bolts broke (they had a total of 345,600 cycles). Gr/PI splice plates were installed on both ends of the test specimen using new bolts. The bolts broke at 96,800 cycles. The tests demonstrated that the bolts and titanium splice plates were not adequate for the fatigue environment. The specimens were redrilled to install 12.7 mm (1/2 inch) bolts and the titanium splice plates were replaced with 6.4 mm (.25 inch) thick steel plates.

Two room temperature specimens sustained 10^6 cycles; however, there was some delamination of the outer plies at the specimen edges and the cover skin delaminated from the honeycomb core on one side of the panel (see Figure 6-72). In addition there was a significant amount of wear on the Gr/PI surfaces at the panel/splice plate interface, although this did not appear to affect the joint strength (see Figure 6-73). These two specimens were tested statically, and resulted in a residual strength 15% lower than non-fatigued specimens (see Figure 6-35). Both of these specimens failed in the cover at the beginning of the pad-up transition sections as shown in Figure 6-74.

The remaining room temperature specimen failed after 914,000 cycles, while the elevated temperature specimens failed after 383,000, 307,000 and 117,000 cycles. All specimens failed at the beginning of the pad-up transition section (see Figure 6-75). The early failures at elevated temperature were not expected based on the room temperature results, and are attributed to the resin chemistry problem.

The fatigue tests indicate that the Type 3 bolted joints can sustain 10^6 cycles without failure, provided 12.7 mm (1/2 inch) bolts are used. Premature failures at elevated temperature are attributed to material problems and not the joint design. The titanium splice plates as designed - 3.18 mm (.125 inch) thick - are not adequate for the fatigue environment, while the Gr/PI splice plates experienced no failures during static and fatigue testing.

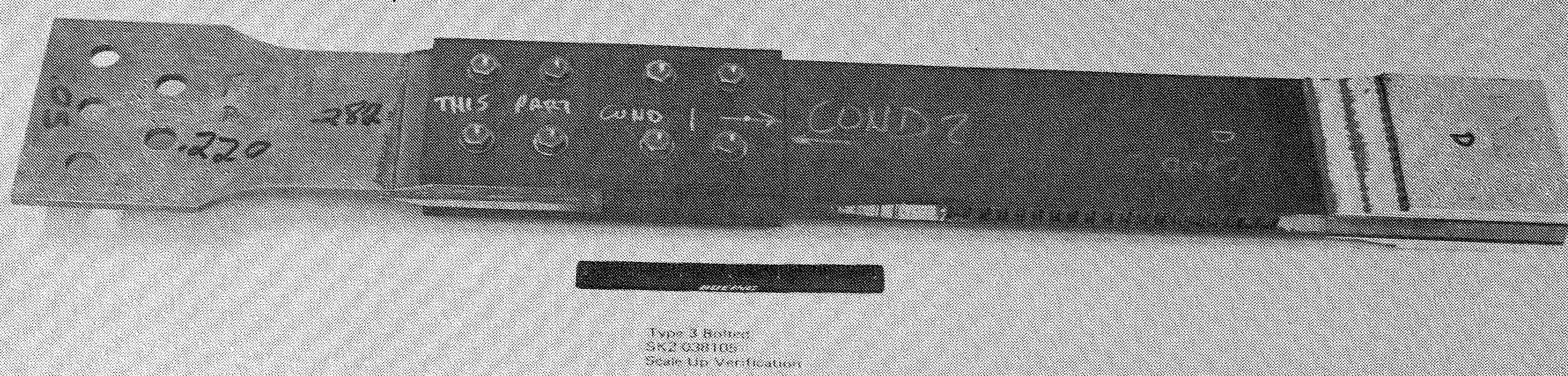
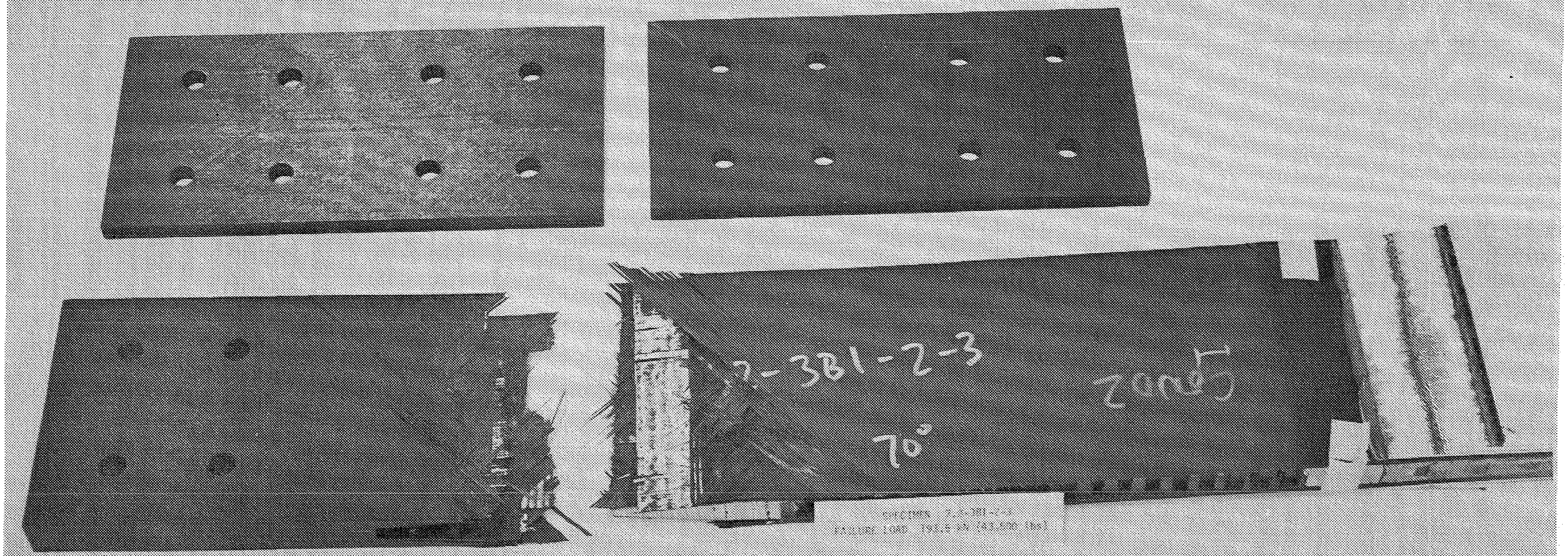


Figure 6-67: FINAL EVALUATION, TYPE 3 BOLTED JOINT - BEFORE TEST



Matrix 7.2 Static Strength Test

Type 3 Bolted 294 K (70°F)

Figure 6-68: TYPE 3 BOLTED - TENSION TEST, AGED, 294K (70°F)

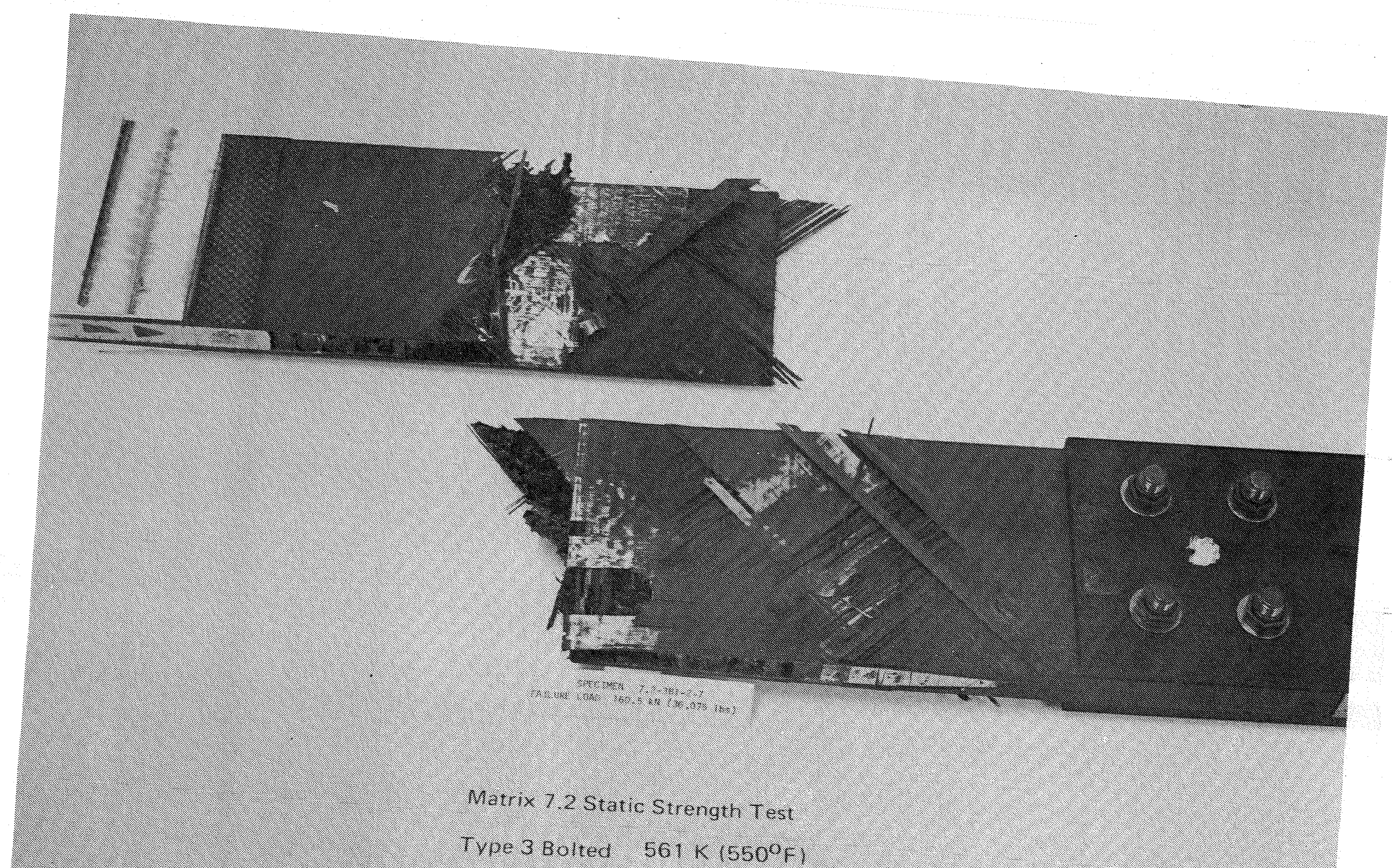


Figure 6-69: TYPE 3 BOLTED - TENSION TEST, AGED, 561K (550°F)

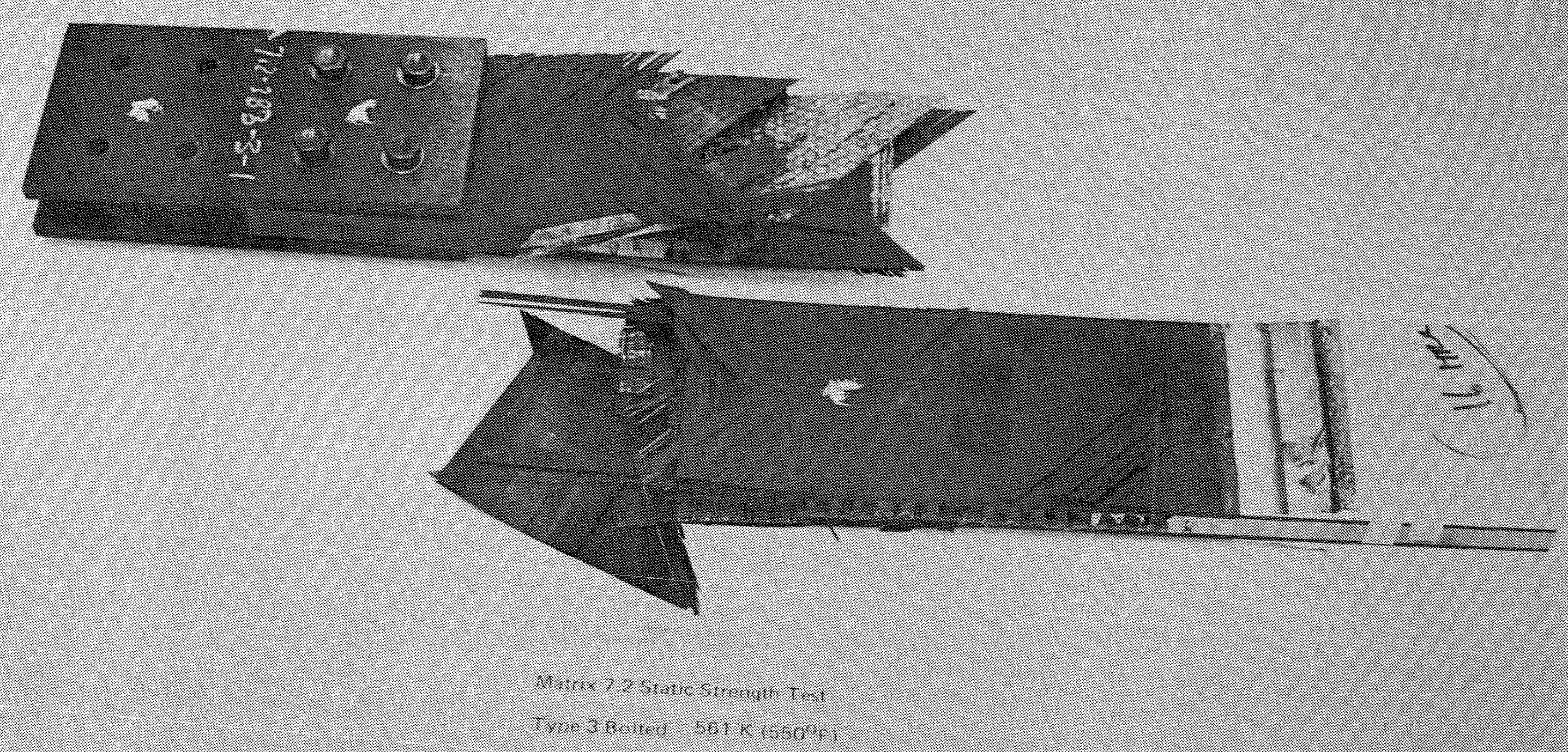


Figure 6-70: TYPE 3 BOLTED - TENSION TEST, THERMAL CYCLED, 561K (550°F)

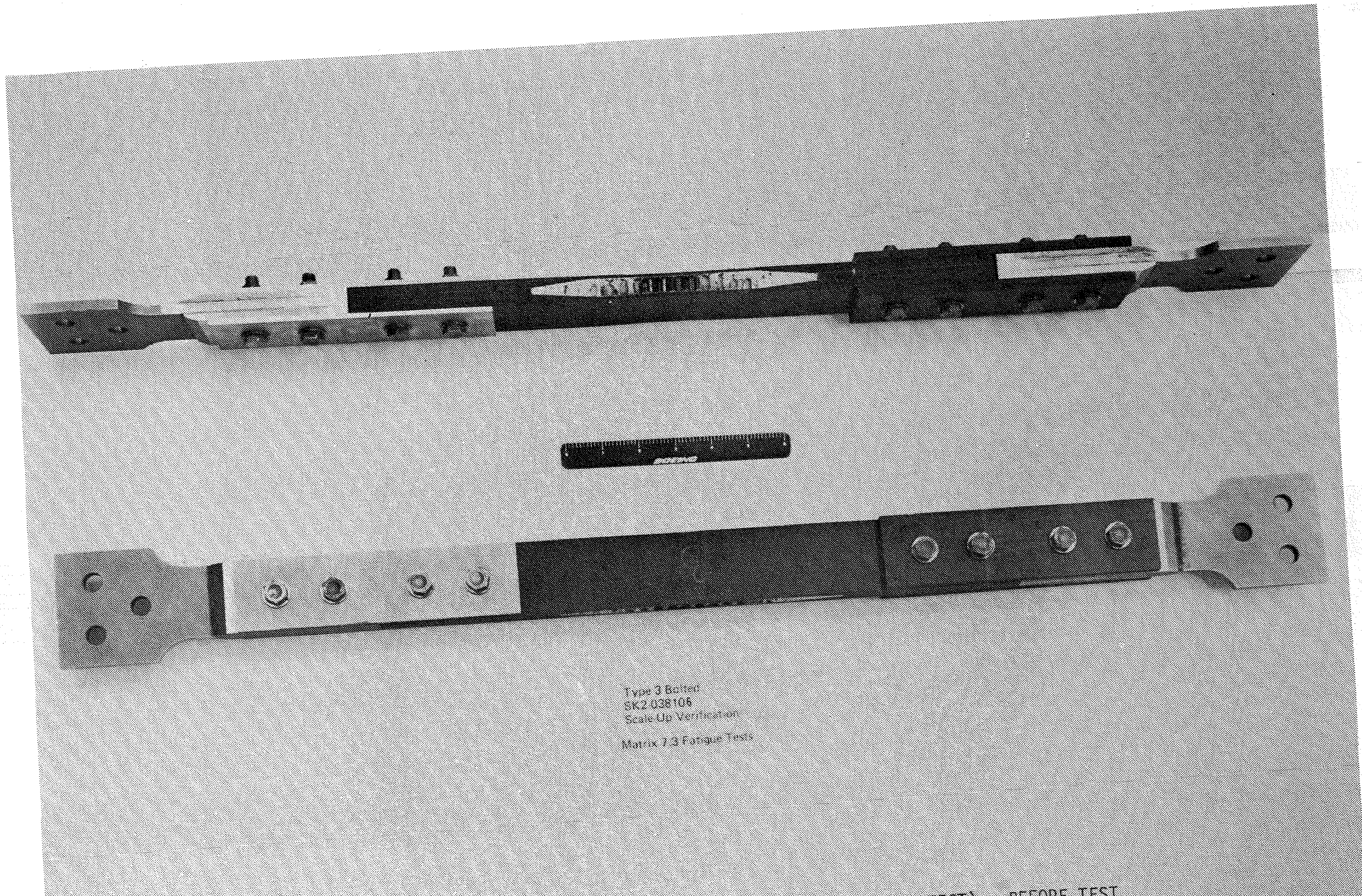


Figure 6-71: FINAL EVALUATION, TYPE 3 BOLTED JOINT (FATIGUE TEST) - BEFORE TEST

Figure 6-72: TYPE 3 BOLTED - FATIGUE TEST, AGED, 294K (70°F) - TYPICAL DELAMINATIONS

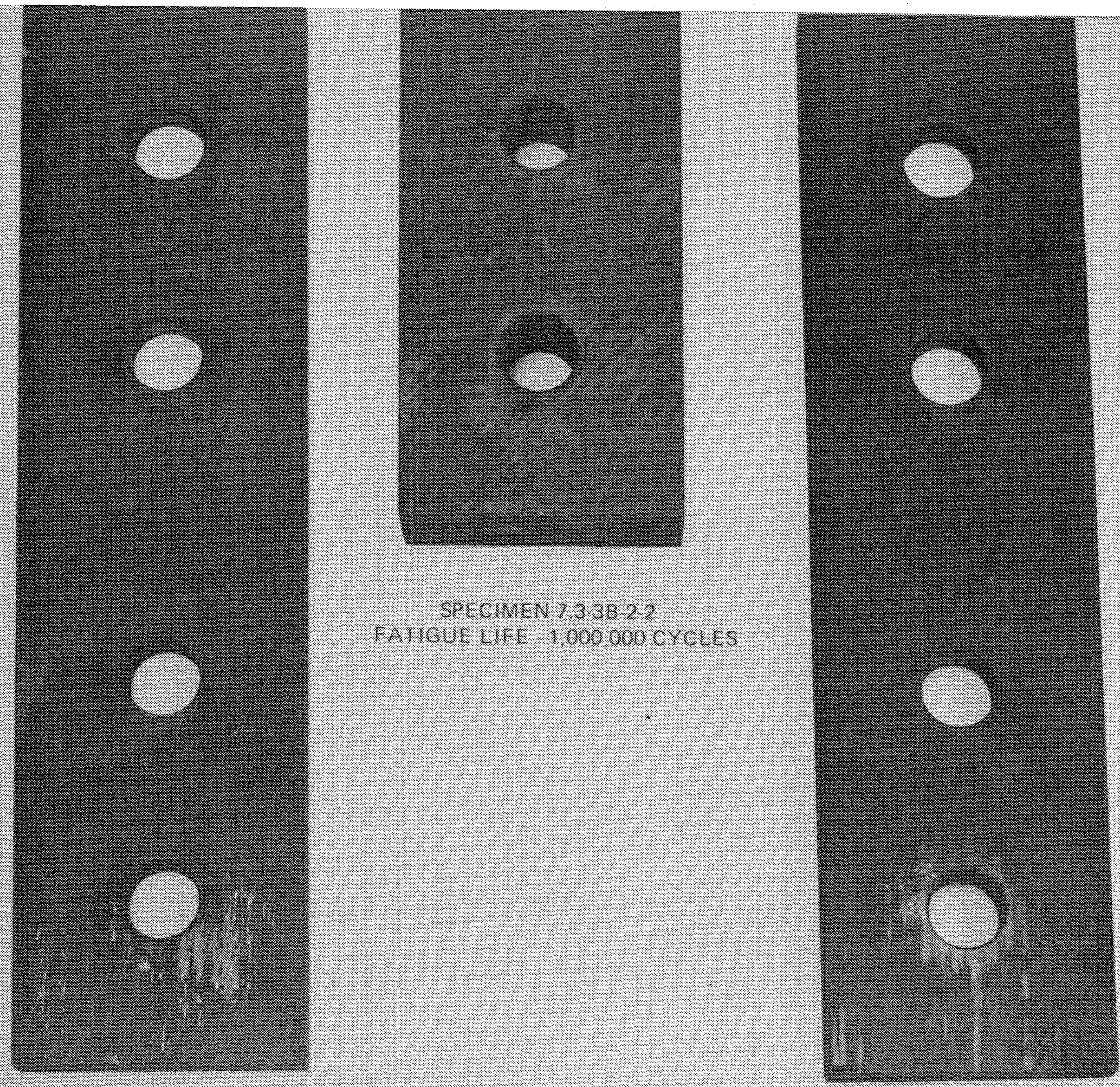
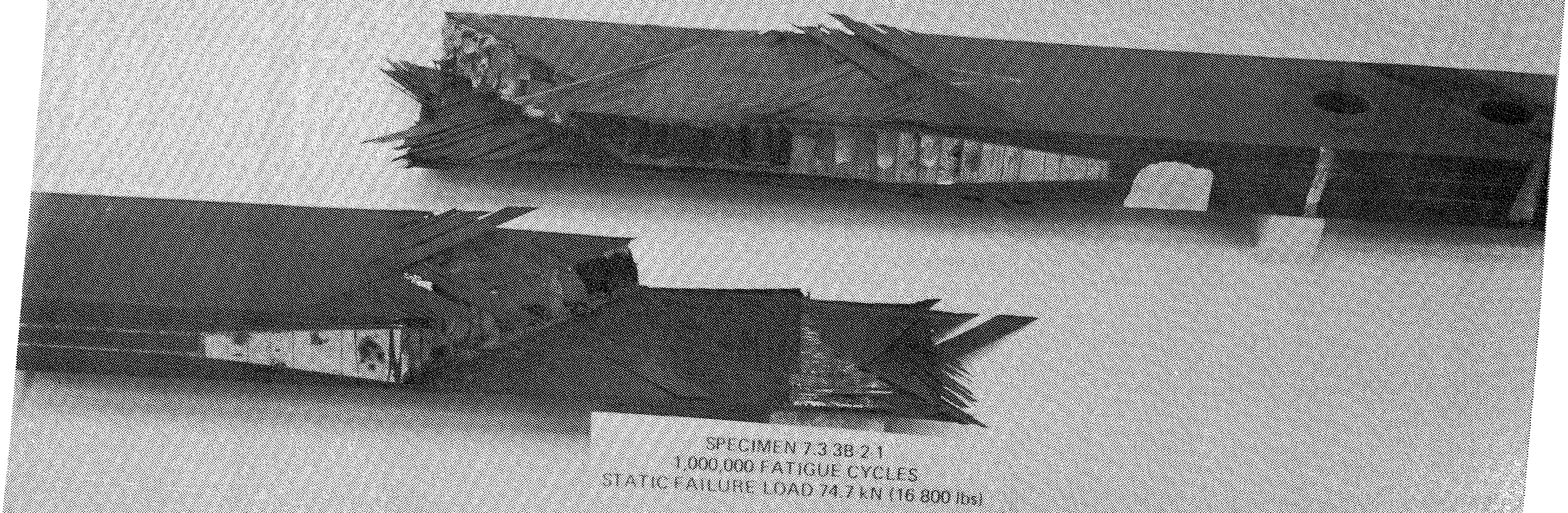


Figure 6-73: TYPE 3 BOLTED - FATIGUE TEST, AGED, 294K (70°F) - JOINT SURFACE WEAR



Matrix 7.3 Fatigue Tests

Type 3 Bolted 294 K (70°F)

Figure 6-74: TYPE 3 BOLTED - FATIGUE TEST AND RESIDUAL STRENGTH TEST, AGED, 294K (70°F)

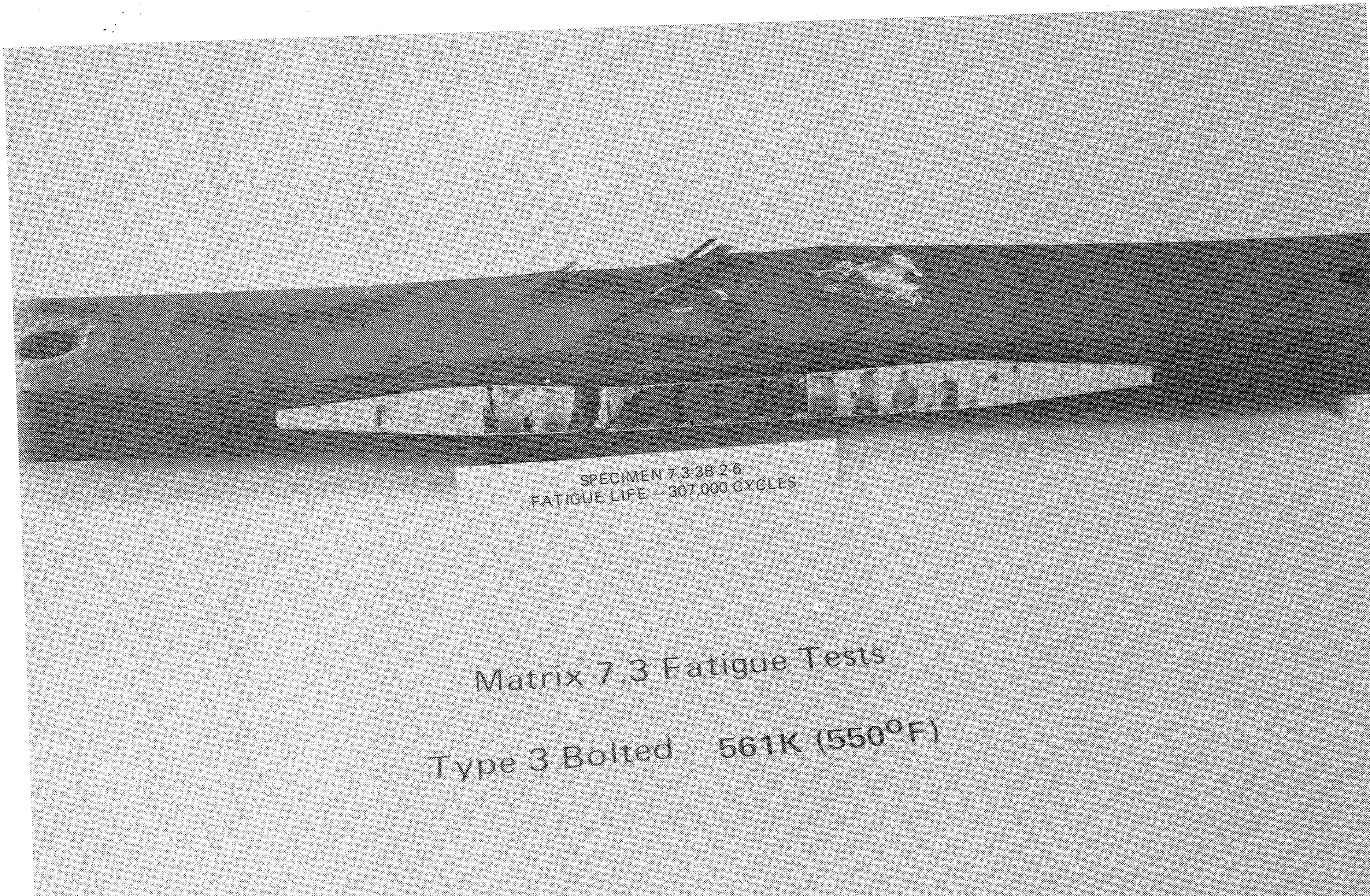


Figure 6-75: TYPE 3 BOLTED - FATIGUE TEST, AGED, 561K (550°F)

Type 4 Bonded - Static Tests

Static test specimens for Type 4 Bonded joints are shown in Figure 6-76. Specimens were loaded in bending as shown in Figure 6-12. Test results are summarized in Figure 6-36 and are discussed below. Predicted loads for the bending tests are based on a compression failure in the upper cover skin using data from the design allowables testing (see Section 4.2).

Scale-up Verification (Matrix 7.1) specimens failed in compression in the outer cover (see Figure 6-77); however, at a lower load than predicted for that failure mode. The expected failure mode was to pull off the attachment angles at a load of 13.5 kN/m (77.2 lbs/in). For the compression failure mode actually experienced, the load should have been approximately 14.3 kN/m (81.6 lbs/in) as compared to actual average of 9.2 kN/m (52.7 lbs/in). The design load was 11.2 kN/m (64 lbs/in). The reason for the low failure load is not known. Although the failed areas did not show sign of delamination, there may have been resin problems as occurred for the Static Strength tests (see below).

In all cases the Static Strength (Matrix 7.2) aged specimens tested in bending failed in compression of the outer cover; however at loads approximately one half of what would be expected for that failure mode. In addition the web attachment angles pulled off because of bad adhesive. All the compression failures had extensive delamination of the cover laminates. The laminates were also darker in color than the cured/post cured specimens and had some areas that were "fuzzy", indicating no resin. The adhesive had all the resin missing, with just a white powdery residue and scrim left on one side. Failed compression areas and bad adhesives are shown in Figures 6-78 and 6-79.

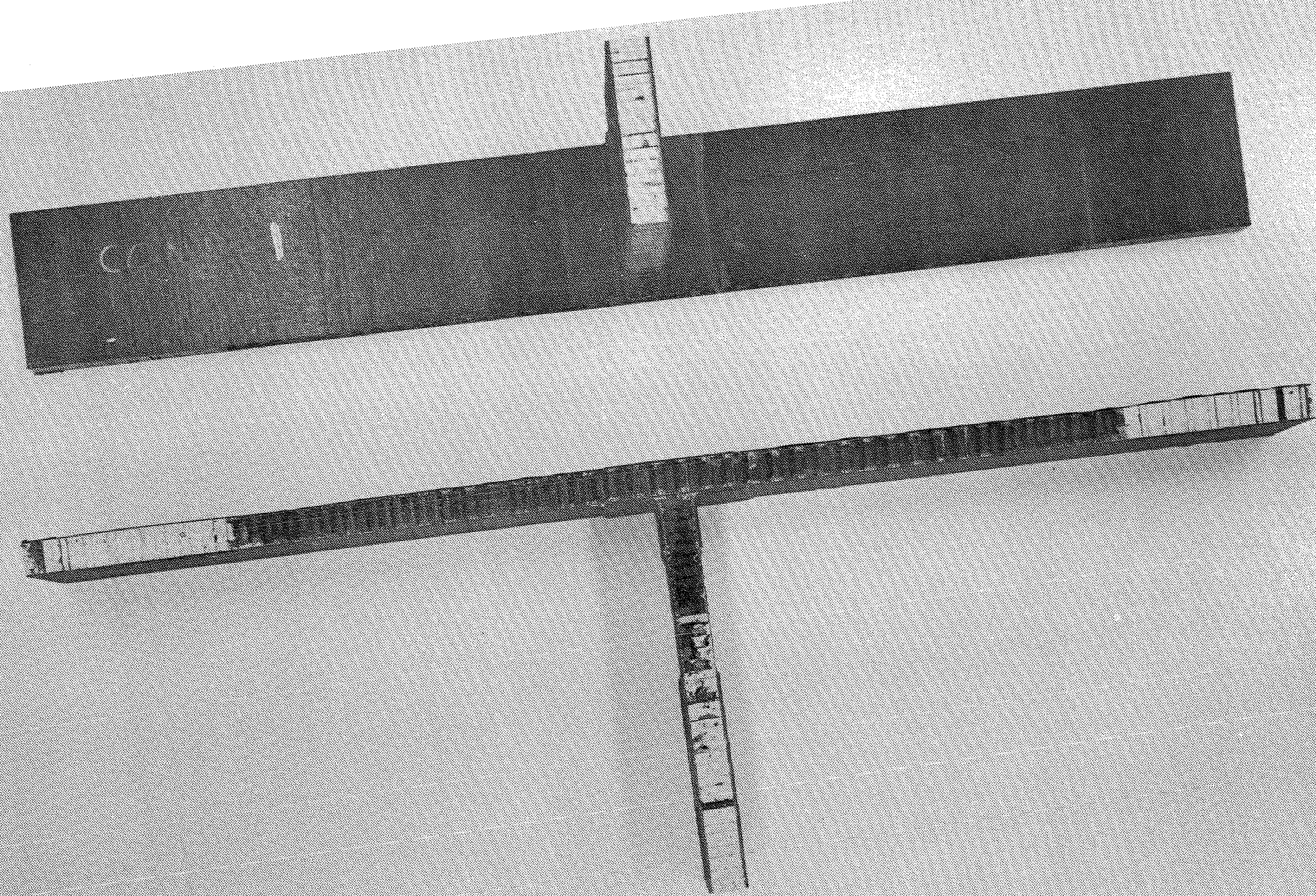
Examination of the remaining specimens planned for shear tests of the adhesive bond showed the same white powdery residue at the edges of the bond line. The shear tests were deleted because of the bad bonds and laminates.

Specimens removed from the thermal cycling chamber also had bad adhesive bonds and evidence of resin starved laminates. The attachment web had actually fallen off, therefore, no tests were conducted on thermal cycled specimens.

The degradation of the laminates is attributed to the resin chemistry problem, while the bad adhesive bonds are due to the adhesive processing problem. Both are discussed in Section 6.4.3.

Type 4 Bonded - Fatigue Tests

Specimens planned for fatigue tests had been aged and showed bad adhesive bonds as well as evidence of resin starved laminates. No fatigue tests were conducted on Type 4 bonded joints.



Type 4 Bonded
SK2 038107
Scale Up Verification

Figure 6-76: FINAL EVALUATION, TYPE 4 BONDED JOINT - BEFORE TEST

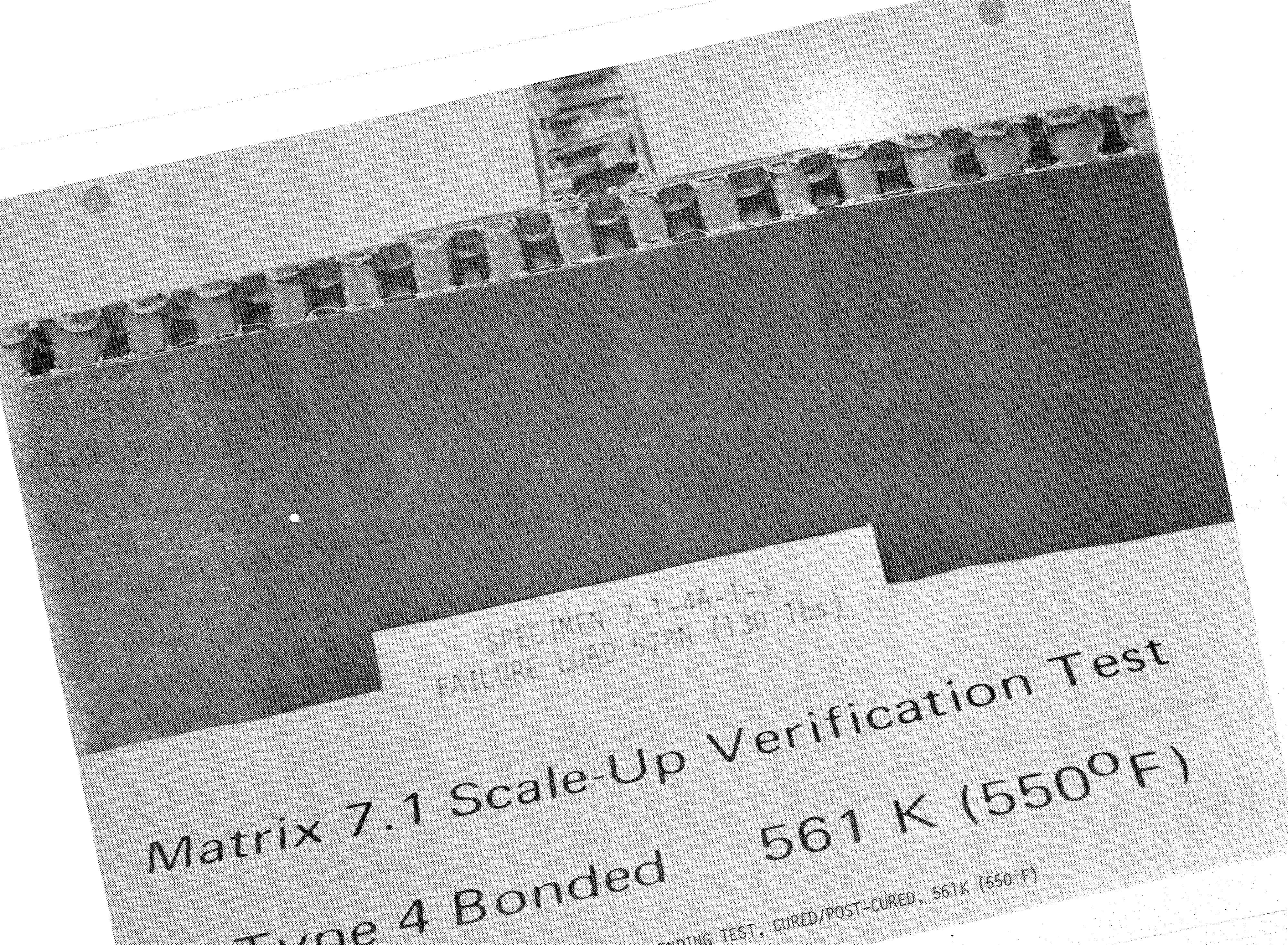


Figure 6-77: TYPE 4 BONDED - BENDING TEST, CURED/POST-CURED, 561K (550°F)

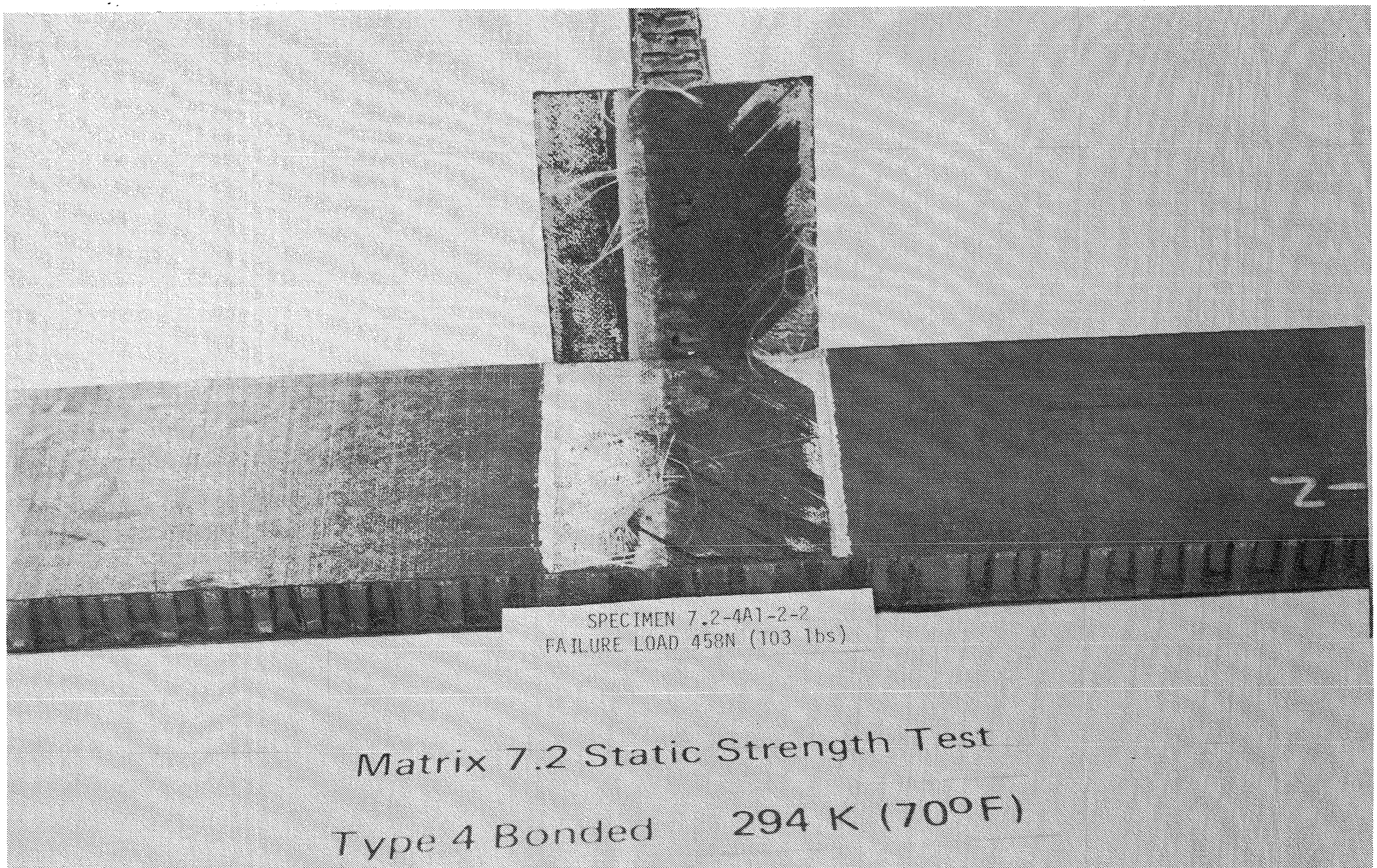


Figure 6-78: TYPE 4 BONDED - BENDING TEST, AGED, 294K (70°F)

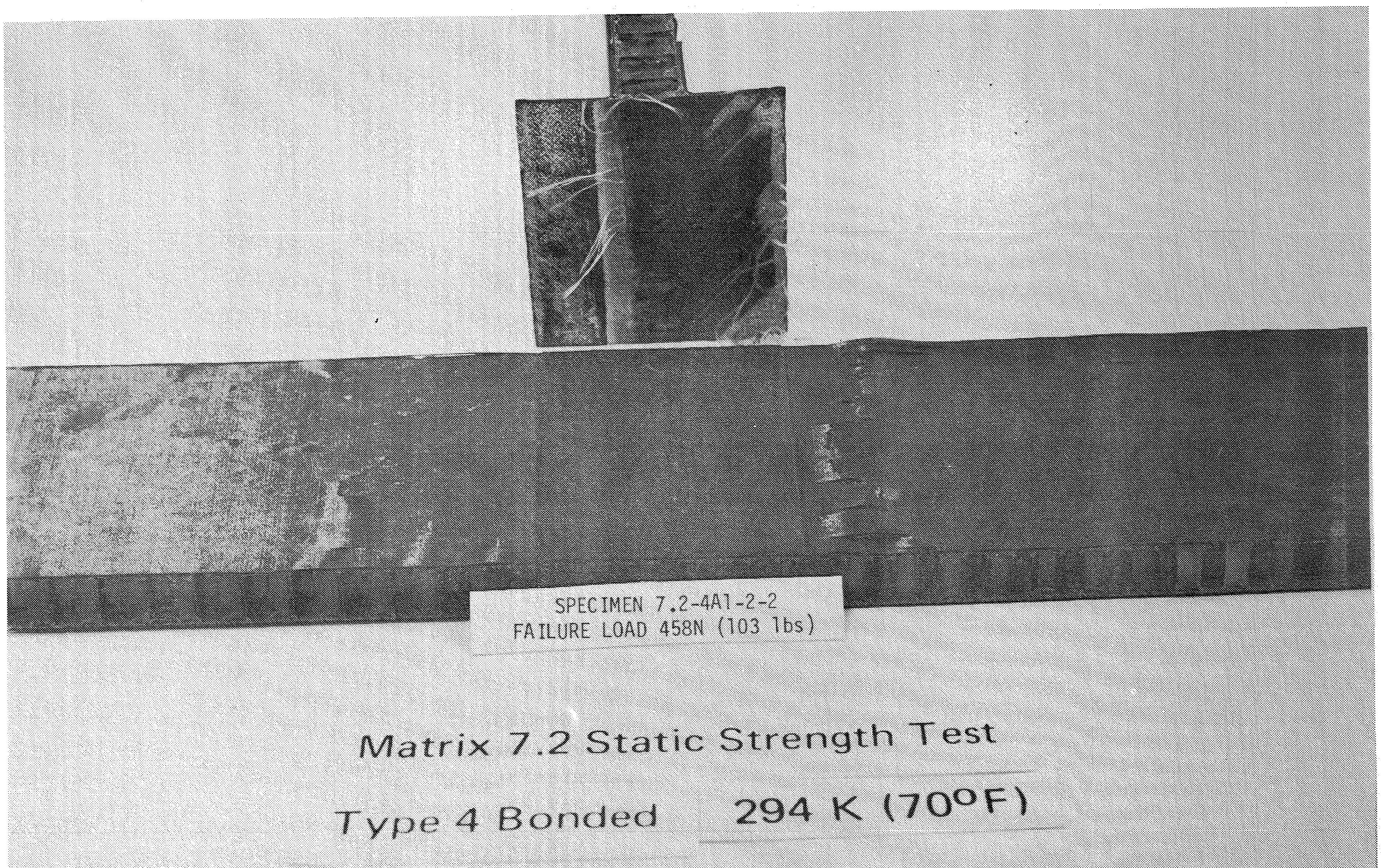


Figure 6-79: TYPE 4 BONDED - BENDING TEST, AGED, 294K (70°F)

Type 4 Bolted - Static Tests

Static test specimens for Type 4 Bolted joints are shown in Figure 6-80. Specimens were loaded in bending and shear as shown in Figures 6-12 and 6-13. Test results are summarized in Figure 6-37 and are discussed below. Predicted loads for the bending tests are based on a compression failure in the upper cover skin using data from the design allowables testing (see Section 4.2). All specimens, except two, exceeded the design load of 11.2 kN/m (64 lbs/in); however, there were large variations in performance.

Scale-up Verification (Matrix 7.1) specimens failed in compression in the outer cover as shown in Figure 6-81. One specimen had cover delamination and failed at one-half the predicted load while the other two did not have delamination and failed at 96% and 98% of the predicted ultimate. These two had failure loads 50% higher than the Type 4 Bonded joints which had identical laminates and failure modes. The average failure load of the two good specimens was only 5% lower than that of the corresponding "Static Discriminator" tests indicating scale-up had no significant effect on joint performance.

All Static Strength (Matrix 7.2) aged specimens tested in bending failed in compression of the outer cover (see Figure 6-82) except one which had a net tension failure of the inner cover at the bolt hole (see Figure 6-83). This specimen had the highest failure load. The specimen with the lowest failure load, specimen 7.2-4B1-2-5, had delamination of the outer cover. Failure loads varied from 74% to 140% of predicted. All the aged specimens were darker in color than the cured/post cured specimens indicating apparent resin loss; however, the aged specimens failed at higher loads than the cured/post cured specimens which is the opposite of what happened for the Type 4 Bonded joints. The large variation in test results indicative of the resin chemistry problem discussed in Section 6.4.3.

Test results for aged specimens tested in shear are shown in Figure 6-37. Failure loads ranged from 273% to 350% of the required design load. In all cases there was bending and delamination of the attachment angle but there were no two part failures. Tests were terminated arbitrarily when there was significant deformation and deflection of the attachment angle. A typical tested specimen is shown in Figure 6-84. The Type 4 bolted joint is not critical for this loading condition.

Specimens exposed to thermal cycling were examined after removal from the cycling chamber. The specimens had several areas of delamination in the laminates; therefore, no tests were conducted on thermal cycled specimens.

Type 4 Bolted - Fatigue Tests

Type 4 Bolted fatigue tests at room temperature were initiated using the same support span that was used for the static tests. The desired test frequency could not be maintained because of the relatively large deflections and the first specimen was inadvertently overloaded. The support span was shortened to 254 mm (10 inches) and the maximum load adjusted to yield the same compressive stress in the outer cover laminate. Fatigue loads are given in Table 6-4.

The second room temperature specimen failed statically in the outer cover laminate at 9.1 kN/m (52 lb/in) during test set-up. The third specimen sustained 10^6 cycles without failure of the cover laminate; however, there was delamination of the attachment angles (see Figure 6-85). The angles delaminated early in the test cycle but were still able to carry the desired load. Static test after cycling resulted in failure at 32.6 kN/m (186 lbs/in). The cover attachment bolts pulled through the attachment angles (see Figure 6-86).

Two of the elevated temperature fatigue specimens had compression failures of the outer cover laminate (see Figure 6-87) at 53,000 and 49,600 cycles respectively. The third specimen sustained 10^6 cycles without failing the outer cover laminate; however, the attachment angles delaminated as discussed above for the room temperature tests. Static test at room temperature after cycling resulted in failure at 27 kN/m (154 lb/in). The web failed in shear out of the attachment bolt (see Figure 6-88).

Because of the wide range of failure modes and failure loads during fatigue cycling of the Type 4 Bolted joints no firm conclusions can be drawn from these tests. The wide variations are attributed to the resin chemistry problem. The data do indicate that the Type 4 Bolted joints can sustain the fatigue environment without two-part failure; however, there may be delamination of the attachment angle.

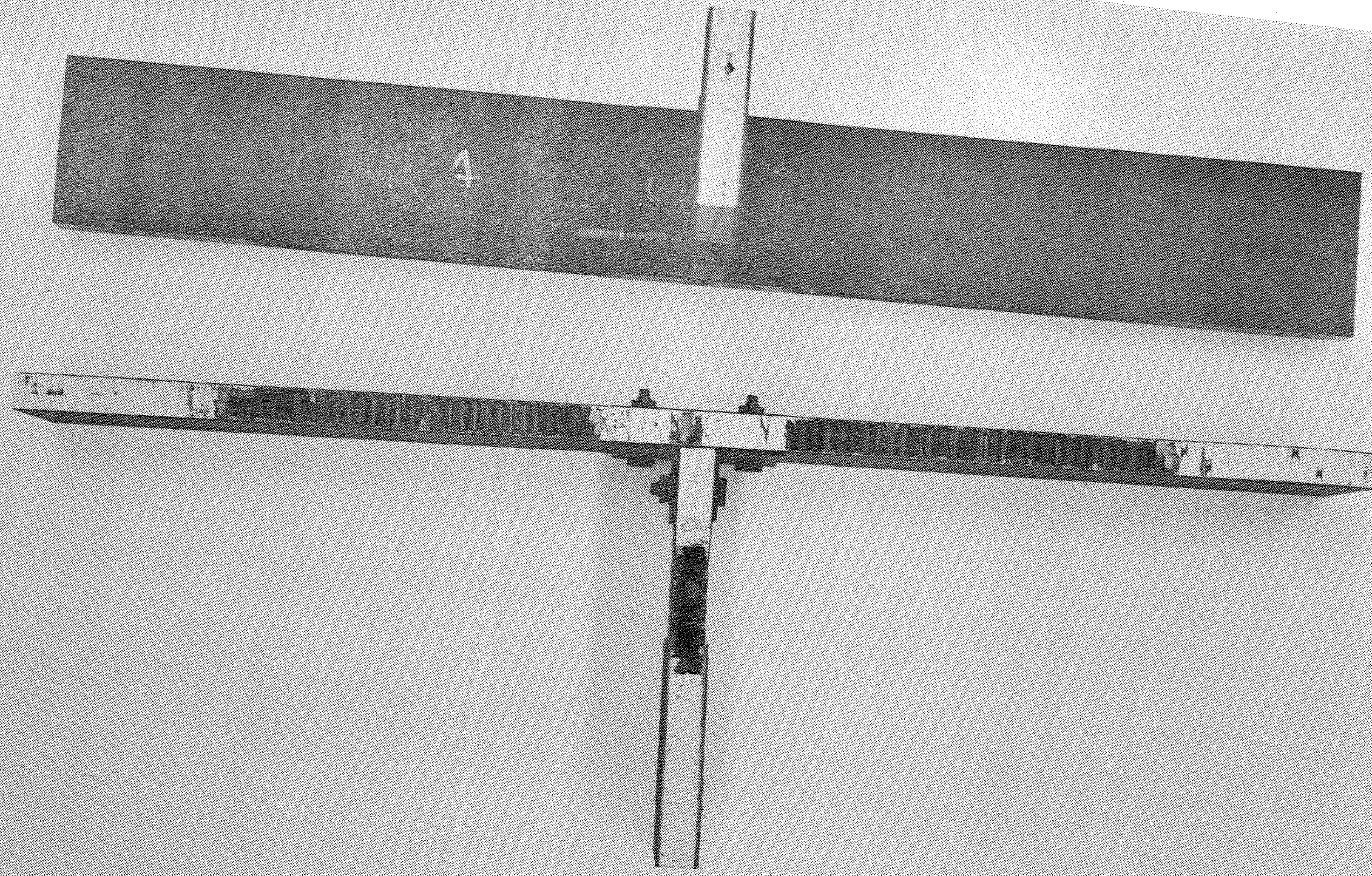


Figure 6-80: FINAL EVALUATION, TYPE 4 BOLTED JOINT - BEFORE TEST

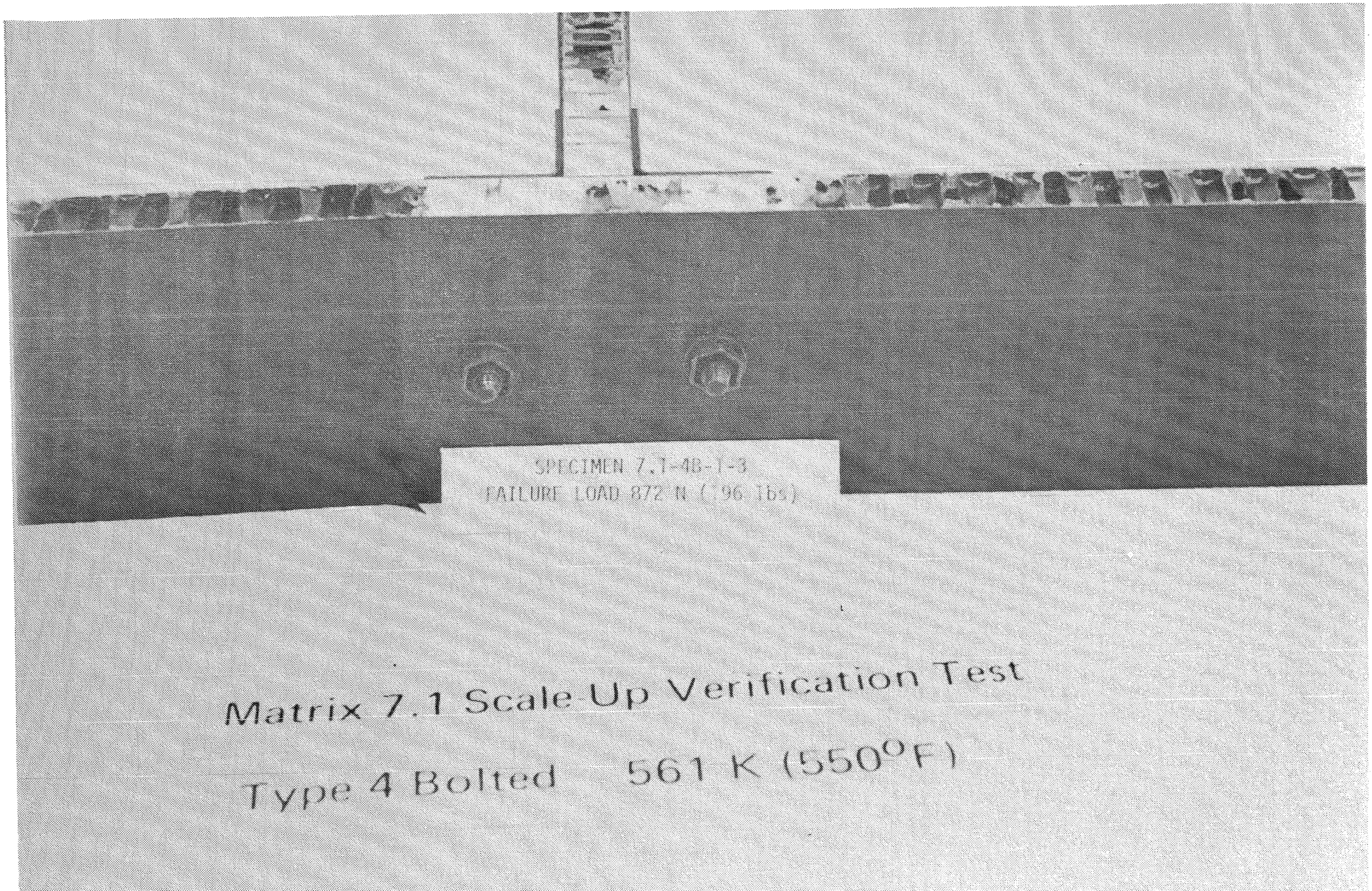


Figure 6-81: TYPE 4 BOLTED - BENDING TEST, CURED/POST-CURED, 561K (550°F)

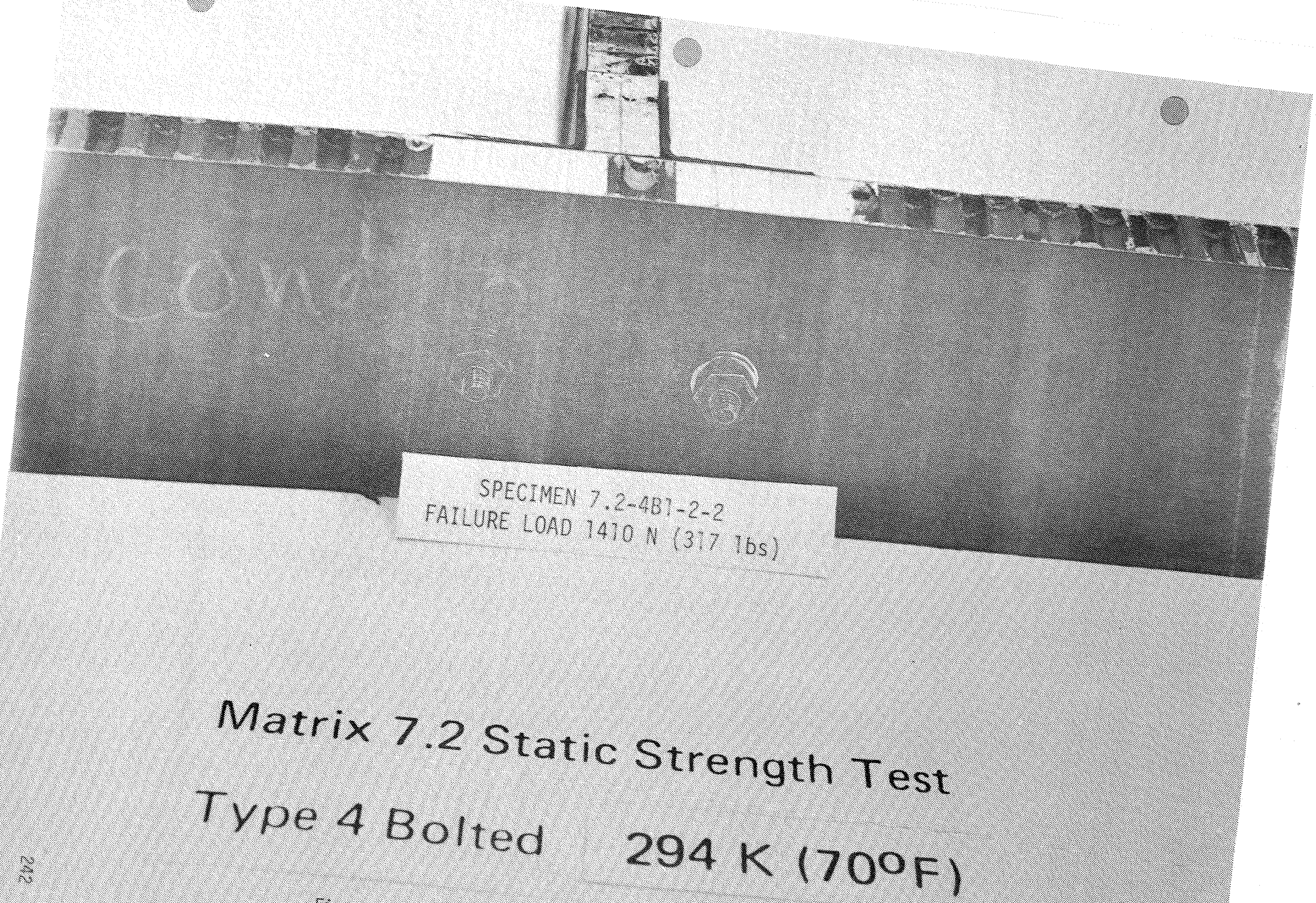


Figure 6-82: TYPE 4 BOLTED - BENDING TEST, AGED, 294K (70°F)

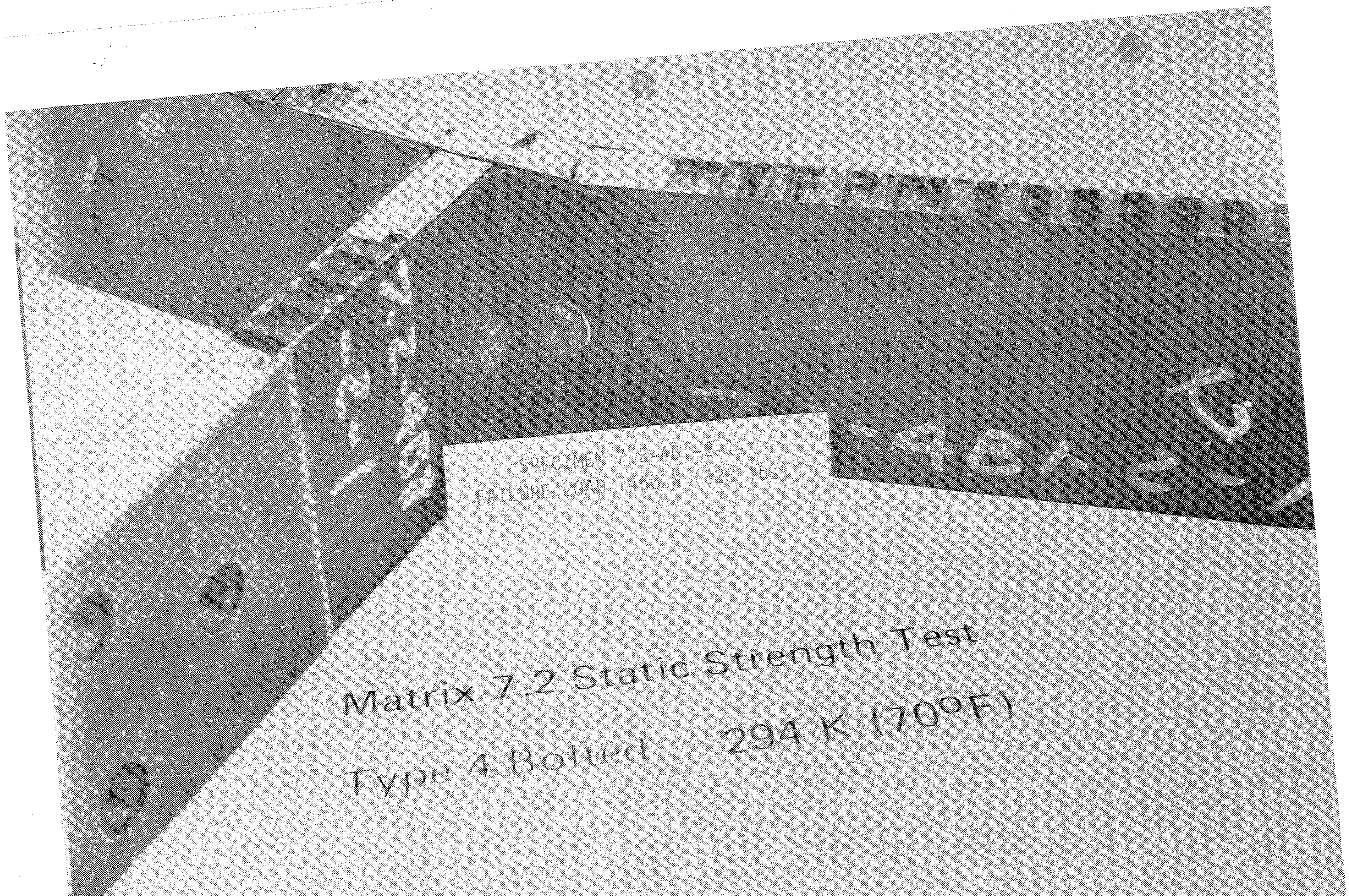
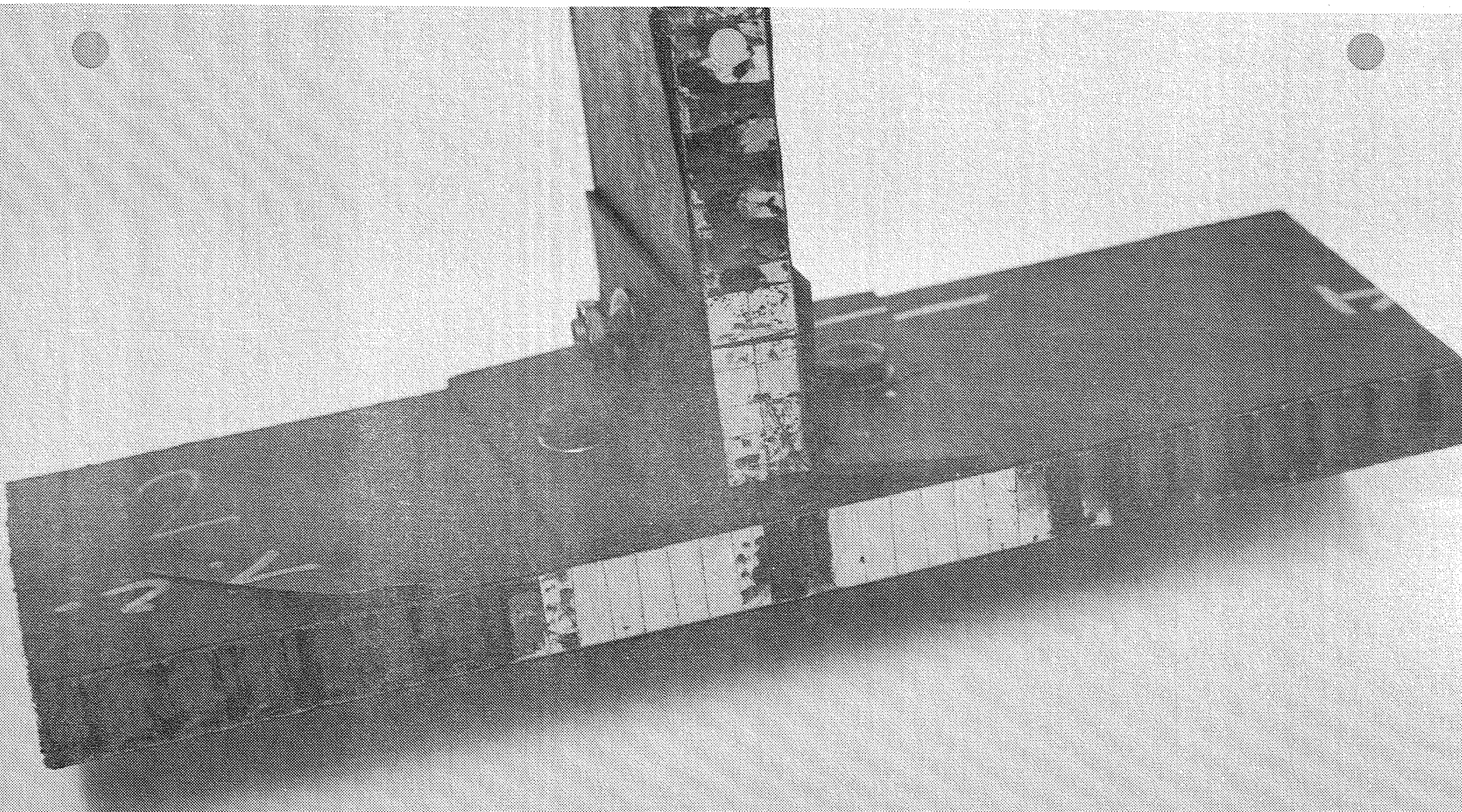


Figure 6-83: TYPE 4 BOLTED - BENDING TEST, AGED, 294K (70°F)

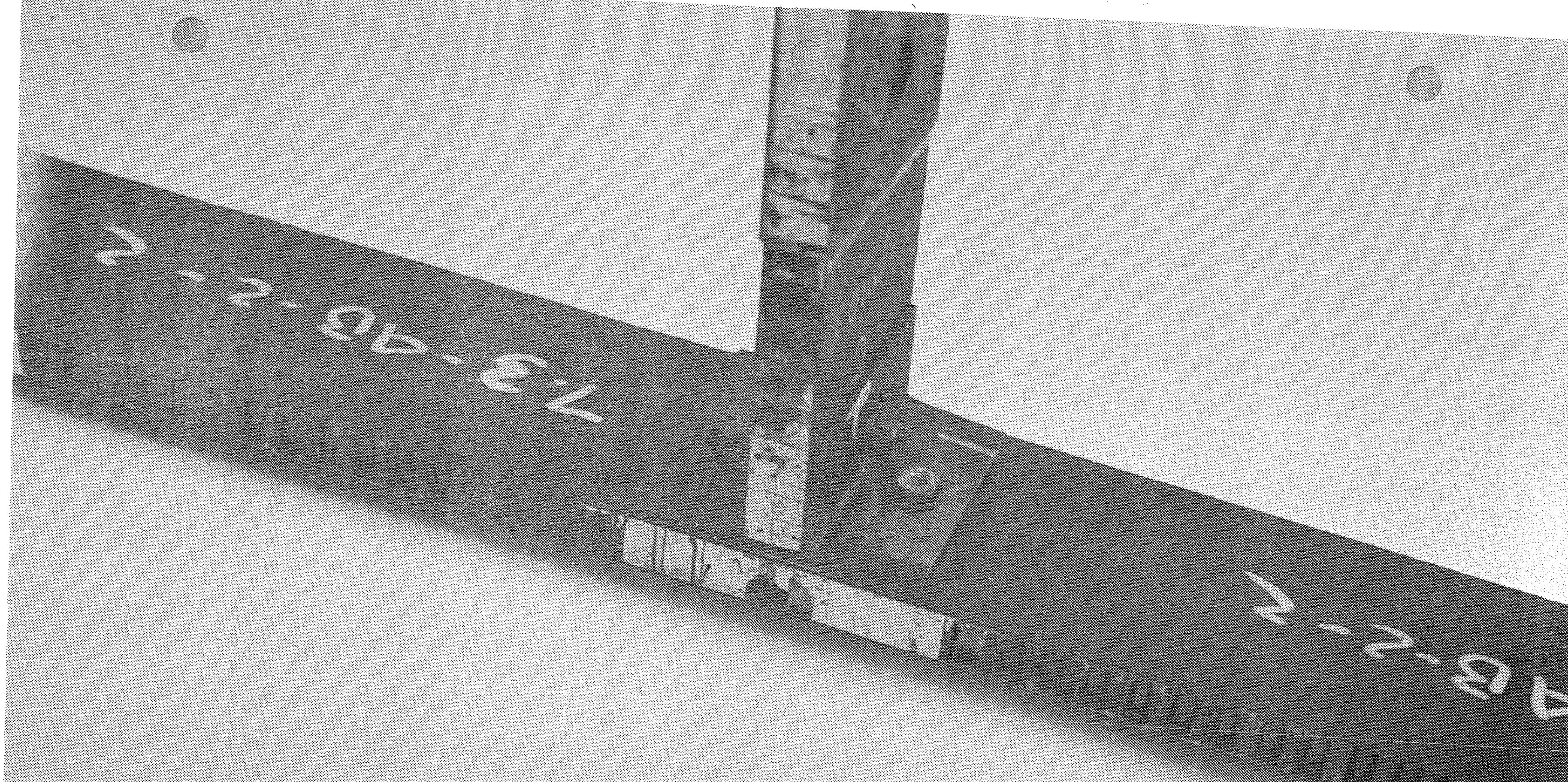


SPECIMEN 7.2-4B2-2-4
FAILURE LOAD 4.45 kN (1000 lbs)

Matrix 7.2 Static Strength Test

Type 4 Bolted 561 K (550°F)

Figure 6-84: TYPE 4 BOLTED - SHEAR TEST, AGED, 561K (550°F)



SPECIMEN 7.3-4B-2-2
FATIGUE LIFE - 1,000,000 CYCLES

Matrix 7.3 Fatigue Tests

Type 4 Bolted   294 K (70°F)

Figure 6-85: TYPE 4 BOLTED - FATIGUE TEST, AGED, 294K (70°F)

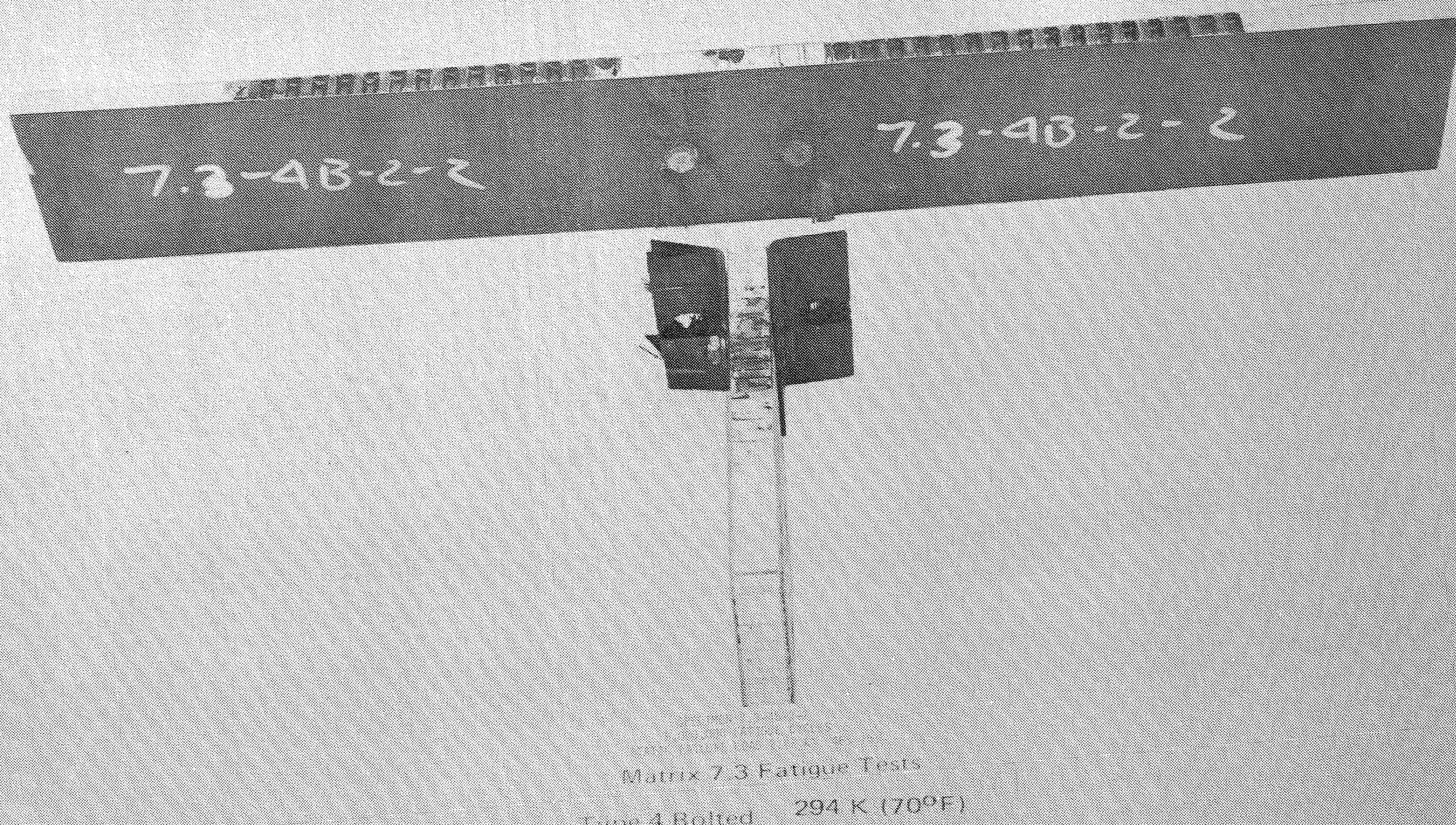
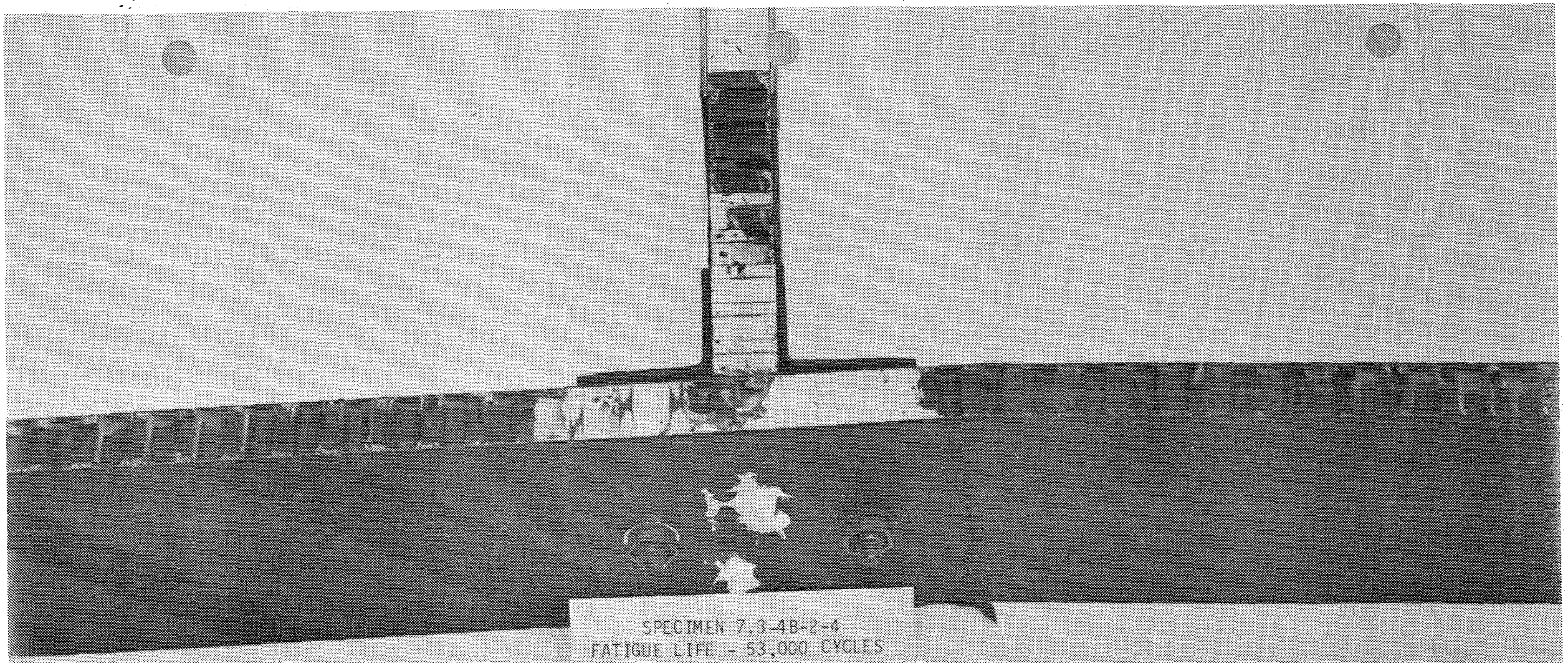


Figure 6-86: TYPE 4 BOLTED - FATIGUE TEST AND RESIDUAL STRENGTH TEST, AGED, 294K (70°F)



Matrix 7.3 Fatigue Tests

Type 4 Bolted 561 K (550^{o}F)

Figure 6-87: TYPE 4 BOLTED - FATIGUE TEST, AGED, 561K (550°F)

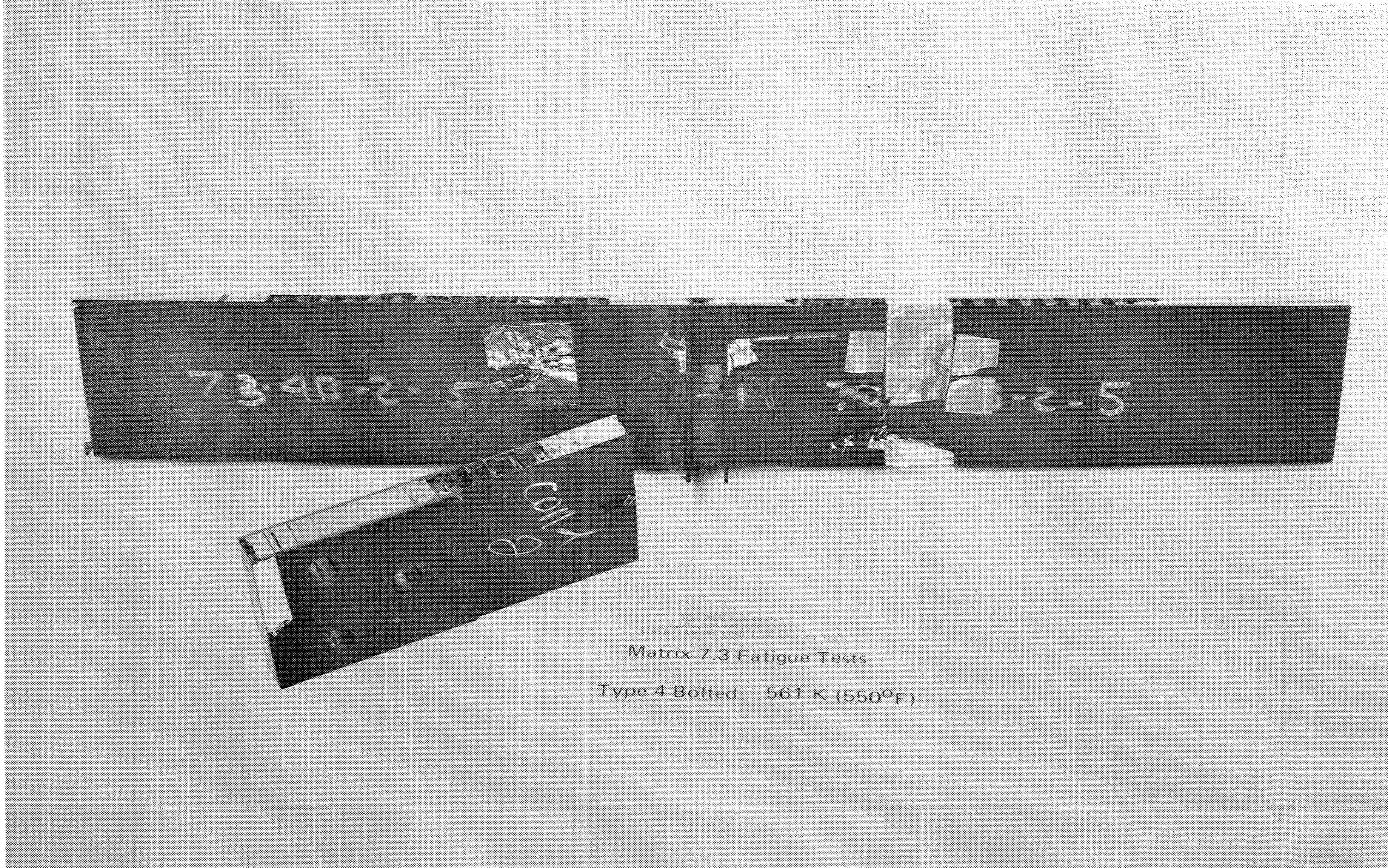


Figure 6-88: TYPE 4 BOLTED - FATIGUE TEST AND RESIDUAL STRENGTH TEST, AGED, 561K (550°F)

6.4.3 Material Processing Problems

During specimen conditioning and testing for the "Final Evaluation" phase of this program (Task 1.4) several problems and anomalies occurred which appear to be material variability and processing problems. In several cases, there were extensive laminate delaminations under tension or compression loads with resultant failures at much lower loads than predicted. Visual examination of specimens after aging and thermal cycling showed a much darker appearance than cured/post-cured specimens indicating a loss of resin. Some specimens had "fuzzy" surface areas which were actually bare fibers. Specimens from earlier design allowables and "Small Specimen" tests, which had also undergone aging and thermal cycling, were reexamined to see if they had any evidence of delamination or resin loss. There was not evidence of material change due to the conditioning environments, nor did the test results indicate any changes in material performance during these earlier tests (see Figure 4-10).

In some cases, conditioning of the "Final Evaluation" specimens resulted in a complete loss of the A7F adhesive bond. All of the adhesive resin was destroyed leaving a residue of scrim cloth and aluminum powder. The adhesive loss occurred at laminate-to-core bonds (see Figure 6-52) and laminate-to-laminate bonds (see Figure 6-78) but was not consistent. Specimens cut from the same full scale joint assembly panel lost adhesive during thermal cycling but not during aging while others lost the adhesive during both aging and thermal cycling. No specimens lost adhesive during cure/post-cure.

The degradation of the Gr/PI laminates due to thermal aging and cycling is attributed to a low percentage of Nadic Ester (NE) in the PMR-15 polyimide resin. Based on past experience PMR-15 resin which contains 2.8% NE has a shelf life of 60 days when kept at a temperature of $0^{o}C$. However, the later batches of prepreg used for the "Final Evaluation" panels (material lots 2W5197, 2W5232 and 2W5233) had an initial NE content of 2.5%. Quality control panels, which were made from these batches had good mechanical properties after both thermal aging and cycling. Based on the mechanical property results this material was accepted for use. However, as discussed above laminates which were made from this material experienced a loss of matrix resin after thermal aging and cycling. Upon review of liquid chromatography data on NE from fresh and 45 day aged PMR-15 resins, it is apparent that the PMR-15 resin loses NE with time, even while stored at $0^{o}C$. Compare the NE content shown in Figures 6-89 and 6-90 for fresh and 45 aged PMR-15 resin respectively. Thus, even though the PMR-15 resin with the low NE content showed good mechanical properties initially, its shelf life was reduced, resulting in the use of material which had an insufficient NE content to achieve proper cure of the PMR-15 resin. Therefore it is recommended that a shelf life be determined from the initial NE content of the resin, and upon expiration of that life quality control tests be repeated before the material is used for fabrication.

The degradation of the A7F adhesive has been attributed to overheating of the adhesive during the DMF solvent stripping process prior to coating onto the 112 E-glass scrim. The adhesive film for the "Final Evaluation" panels was prepared by US Polymeric. The DMF solvent was not used in the process used by the Boeing Materials Technology labs to prepare the previous batches of adhesive used in this program and thus the stripping difficulties were not encountered earlier. Only one of the two batches of A7F adhesive prepared by US Polymeric resulted in bad bonds. During the stripping of the DMF solvent from the second batch of adhesive the AI-1130 L amide-imide resin was advancing (partially curing) due to overheating. Therefore the properties of the adhesive were degraded, resulting in a loss of bond strength after thermal aging and cycling.

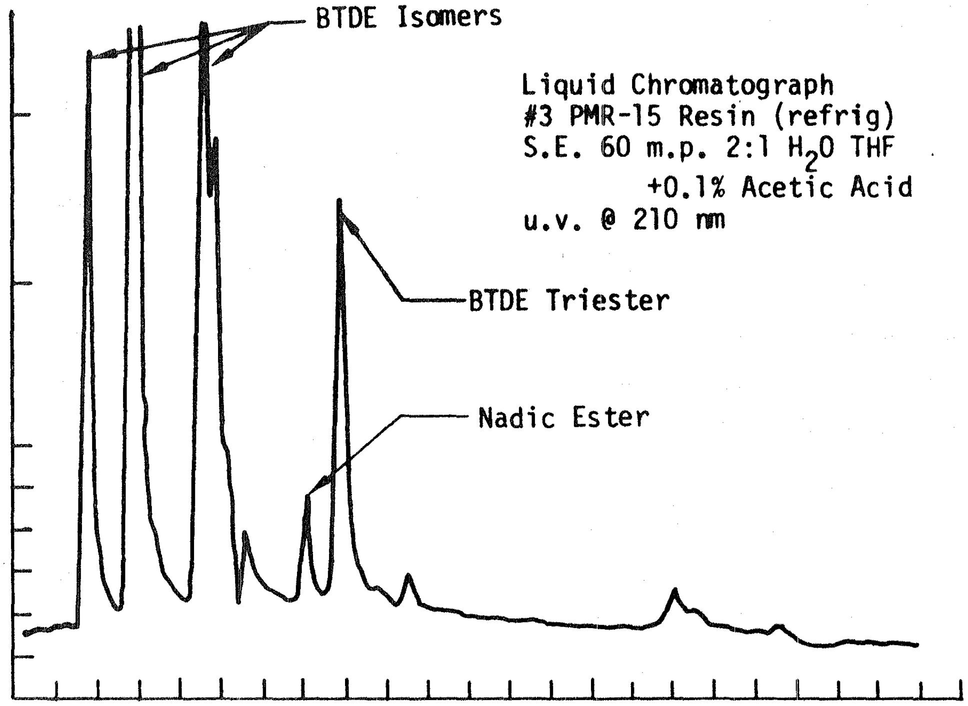


Figure 6-89: LIQUID CHROMATOGRAPHY OF PMR-15 FRESH RESIN

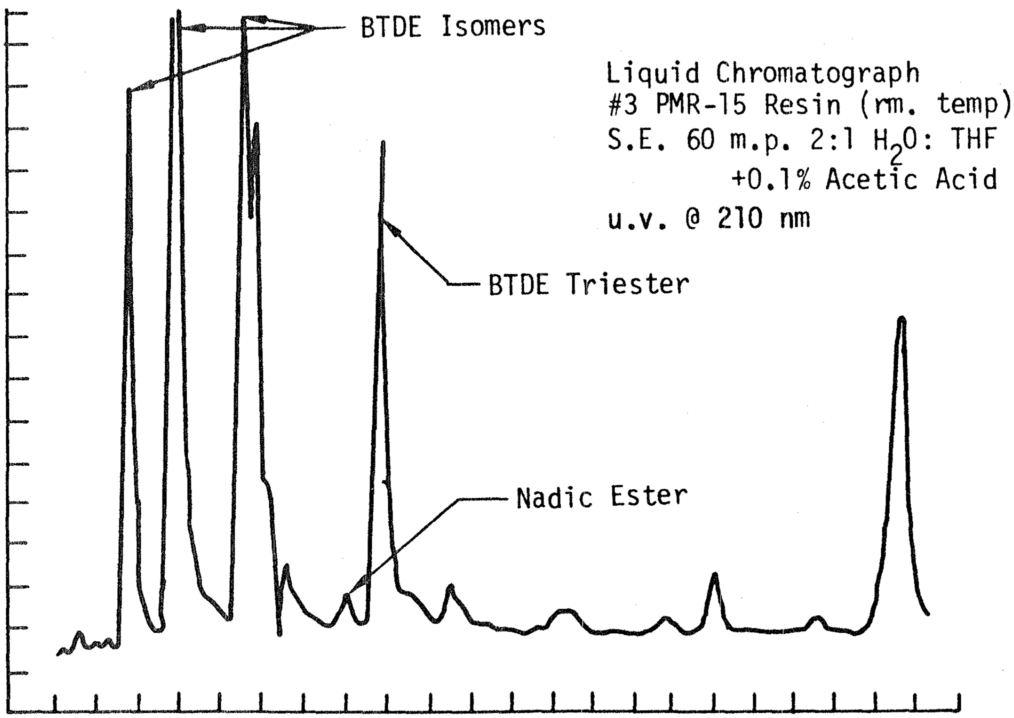


Figure 6-90: LIQUID CHROMATOGRAPHY OF PMR-15 AGED 45 DAYS

6.5 Test/Analysis Correlation

The Type 1, 3 and 4 joints were designed to fail outside the joint area; therefore, prediction techniques for the actual failure modes experienced were for tension or compression failures of the cover laminates. The Type 2 joints failed, as expected, in the joint region. Strength predictions for these joints by hand analyses was much more difficult because of the complex load paths and transverse stresses due to bending of angles. Table 6-12 shows the prediction methods used. Material strengths used in the analyses are given in Table 6-13.

For the Types 1, 3 and 4 joints and the Type 2 Bolted (Load Case 2) joints strength predictions were based on simple tension or compression failures. No correlation is possible for the Type 4 Bolted shear test as these tests were terminated based on observed deflections.

For the Type 2 Bonded and Type 2 Bolted (Load Case 1) classical curved beam theory was used to predict the failure loads due to the applied moments. The critical stresses in the corner angles are the radial stresses, which induce the delaminations experienced by the test specimens. The radial stresses (σ_{rr}) are calcualted from (Ref. 9):

$$\sigma_{rr} = \left(\frac{2\ (c-a) \ln(\frac{r}{a}) - 2\ (r-a)\ \ln(\frac{c}{a})}{r\ (c-a)\ \left((a+c)\ \ln(\frac{c}{a}) - 2\ (c-a) \right)} \right) \left(\frac{M_x}{b}\right)$$

where

- a - inner radius of beam
- b - beam width
- c - outer radius of beam
- r - radial distance to a point in beam
- M_x - applied moment

The radial distance (r) where the maximum radial stress occurs is given by:

$$r = a \exp \left(1 - \frac{a \ln(\frac{c}{a})}{(c-a)} \right)$$

The predicted angle strengths for the Type 2 joints were based on allowable radial stresses equal to the faltwise tension strengths shown in Table 6-13. These predictions, however, should be viewed as "first ply" failures only and not as the ultimate strength of the angles.

The joint strength predictions are shown on Figure 6-31 through 6-37, which also show the static strength results for the "Final Evaluation" testing. In some cases, the predicted strengths fall below the design loads. This is because the design loads were based on preliminary material properties, while the predicted strengths were based on material properties from the design allowables testing (Ref. 4). In most cases, the predicted loads were greater than the actual failure loads. This can be attributed to grip problems (Type 1 joints), the material variability problem discussed in Section 6.4.3, and to the fact that the material strengths used for the predictions were averages from the design allowables testing.

Table 6-12: SUMMARY OF JOINT STRENGTH PREDICTION TECHNIQUES

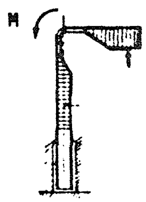
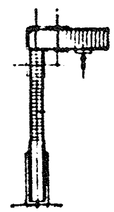
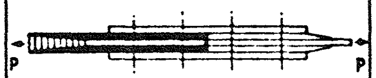
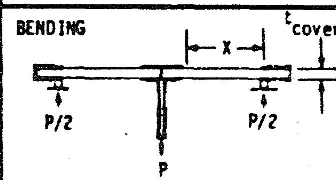
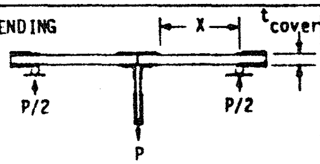
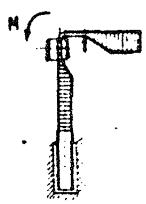
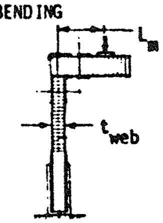
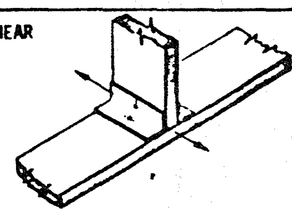
LOAD CASE	TYPE 1 JOINTS	TYPE 2 JOINTS		TYPE 3 JOINTS	TYPE 4 JOINTS
		BONDED	BOLTED		
1	TENSION  $P_{ult} = 2F^{tu}t_{skin}$	BENDING  M_{ult} based on radial (interlaminar) stresses in corner angle calculated from curved beam theory.	BENDING  M_{ult} based on radial (interlaminar) stresses in corner angle calculated from curved beam theory.	TENSION  $P_{ult} = 2F^{tu}\, t_{skin}$	BENDING  Cover Compression $P_{ult} = \frac{2t_{cover}t_{skin}F^{cu}}{x}$
2	BENDING  Cover Compression $P_{ult} = \frac{2t_{cover}t_{skin}F^{cu}}{x}$ Angle Pull-Off P_{ult} based on "Static Discriminator" Type 4 loads.	BENDING (Angle Only)  M_{ult} based on radial (interlaminar) stresses in corner angle calculated from curved beam theory.	BENDING  Inner Web Skin Compression $P_{ult} = \frac{F^{cu}t_{skin}}{[\frac{1}{2} + \frac{L_m}{t_{web}}]}$	———	SHEAR  Joints not critical for shear. Tests terminated based on observed deflections.

Table 6-13: ULTIMATE STRENGTHS USED FOR JOINT STRENGTH PREDICTIONS

Celion 3000/PMR-15, Normalized to 58% Fiber Volume $(0/\pm45/90)_{NS}$ Laminate

	TEMPERATURE	ULTIMATE STRESS, MPa (ksi)		
		CURED/ POST-CURED	THERMALLY AGED	THERMALLY CYCLED
TENSION (F^{TU})	294K (70°F)	572 (83.5)	539 (78.2)	453 (65.7)
	561K (550°F)	544 (78.3)	510 (74.0)	424 (61.5)
COMPRESSION (F^{CU})	294K (70°F)	601 (87.2)	578 (83.8)	599 (86.9)
	561K (550°F)	530 (76.9)	466 (67.6)	506 (73.3)
FLATWISE TENSION LAMINATE TO LAMINATE	294K (70°F)	26.43 (3.833)	13.32 (1.932)	
	561K (550°F)	8.84 (1.282)	9.97 (1.447)	

7.0 BONDED VERSUS BOLTED JOINT COMPARISONS

This program has demonstrated that both bonded and bolted Gr/PI composite joints can be designed and fabricated to carry loads up to 500 kN/m (3200 lb/in). Furthermore, bolted Gr/PI to titanium joints can be designed and fabricated to carry loads up to 2100 kN/m (12000 lb/in). Bonded joints currently cannot be fabricated to carry this load level, due to bonding difficulties. However, Gr/PI to titanium "3-step" symmetric step lap joints were fabricated under Task 2.0 and achieved a load carrying capability of 875 kN/m (5000 lb/in) at 561K (550^{0}F).

As expected, bolted joints have wieghts 2 to 7 times that of the corresponding bonded joint. Computed weights per unit width for each joint type are shown in Table 7-1.

Although the bolted designs are heavier than the bonded versions, they give improvements in reliability and repairability. Bolted joints can be disassembled far easier than a bonded joint, thus allowing for efficient repair of damaged parts. The occurrence of bad bonds in bonded joint fabrication are difficult to detect and can lead to reliability problems, whereas bolted joints maintain structural integrity.

Bonded attachment angles, used on the Type 1 and Type 4 bonded joints are susceptable to peel stresses when the joints experience large deflections under bending, resulting in premature failure. Bolted attachment angles can withstand these large deflections without two part failures.

The Type 2 bonded design is more flexible then the bolted version because of a thinner corner cross-section. This could lead to undesirably large deflections. Deflection limited design criteria would probably require revision of this design.

Bonded joints demonstrated fabrication advantages over bolted joints in this program. Bonding proved to be faster and less costly than the procedures required for a bolted joint. In addition bonded joints have a lower part count than the corresonding bolted version.

Due to the variability of the test results, no firm conclusions can be drawn about the relative fatigue resistance of bonded and bolted joints.

Table 7-1: COMPARISON OF JOINT WEIGHTS FOR THE VARIOUS JOINT TYPES

JOINT TYPE	JOINT WEIGHT				PRIMARY DESIGN LOAD
	BONDED		BOLTED		
	kg/m	(lb/in)	kg/m	(lb/in)	
Type 1	.98	(.055)	3.77	(.211)	560 kN/n (3200 lb/in) Tension
Type 2	.77	(.043)	1.78	(.100)	285 N-n/n (64 in-lb/in) Moment
Type 3	--	--	14.3	(.811)	2100 kN/n (12,000 lb/in) Tension
Type 4	.142	(.008)	.96	(.054)	11.2 kN/n (64 lb/in) Bending

12.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations have resulted from this program.

Conclusions

- Bonded and bolted graphite/polyimide composite joints can be designed and fabricated to transfer the loads commensurate with the loads experienced on lightly load control surfaces for advanced space transportation systems and high-speed aircraft. This load carrying capability is maintained at temperatures up to 561K (550°F). It is also maintained after 125 hours of thermal aging and thermal cycling, except for the Type 2 bonded joints which, as designed, are susceptible to failures resulting from microcracking experienced during thermal cycling. The joints can withstand a fatigue environment of 10^6 cycles without a catastrophic loss in strength, although the fatigue results are limited due to the material problems experienced.

- Fabrication of joints in scaled-up sizes that would be required for production type programs can be accomplished with state-of-the-art tooling. No degradation in joint load carrying capability results from fabricating large scale panels.

- Bonded joints are significantly lighter in weight than bolted joints designed for the same load transfer requirement. Bonded joints are cheaper to fabricate and have lower part counts than the corresponding bolted joints. However, bolted joints offer advantages in reliability and repairability.

- While initial attempts at cocuring bonded Gr/PI-titanium joints to carry loads up to 2100 kN/m (12,000 lb/in) were unsuccessful, it appears that a hybrid cure and sequenced pressure application would result in successful fabrication. It was demonstrated under Task 2.0 of this program that loads up 875 kN/m (5000 lb/in) could be carried by a bonded Gr/PI-titanium step-lap joint.

- The time and temperature at which pressure is applied during laminate cure is critical to laminate processing and varies with part thickness.

- The cured PMR-15 resin is susceptible to degradation after exposure to 589K (600°F) for periods of time well under 125 hr. when the amount of nadic ester in the PMR-15 resin is low prior to laminate cure.

Recommendations

- Strict quality control procedures should be imposed to insure that the chemical composition of the PMR-15 resin is correctly maintained. Shelf lives should be determined from the initial chemical composition of the resin, with quality control tests to be repeated upon expiration of these lives before the material is used for fabrication.

- Conduct studies of cocured bonded composite to titanium joints to increase load carrying capabilities.

- Develop better NDI techniques for the acceptance of production hardware. Detection of bad bonds, delaminations and poorly cured laminates should be stressed.

APPENDIX A

"SMALL SPECIMEN" TEST RESULTS

TABLE A-1: MATRIX 4A SMALL SPECIMEN SHEAROUT TESTS
WIDTH = 63.5 mm (2.5 in) EDGE MARGIN = 19.1 mm (.75 in)

CONDITION CODE	SPECIMEN NUMBER	TEMPERATURE K (°F)	HOLE DIAMETER mm (in)	LAMINATE THICKNESS mm (in)	1st YIELD LOAD kN (kip)	1st YIELD SHEAROUT STRESS MPa (ksi)	ULTIMATE FAILURE LOAD kN (kip)	ULTIMATE FAILURE SHEAROUT STRESS MPa (ksi)	NOTES
1	4A-1A-1-1	294 (70)	9.497 (.3739)	4.501 (.1772)	30.2 (6.78)	234 (34.0)	34.8 (7.83)	271 (39.2)	
1	4A-1A-1-2	294 (70)	9.492 (.3737)	4.465 (.1758)	28.9 (6.50)	226 (32.8)	33.1 (7.45)	259 (37.6)	
1	4A-1A-1-3	294 (70)	9.479 (.3732)	4.542 (.1788)	29.5 (6.64)	227 (33.0)	33.0 (7.42)	254 (36.8)	
1	4A-1A-1-4	561 (550)	9.495 (.3738)	4.468 (.1759)	26.5 (5.95)	207 (30.0)	29.9 (6.72)	234 (33.9)	
1	4A-1A-1-5	561 (550)	9.482 (.3733)	4.658 (.1834)	-- --	-- --	28.0 (6.30)	210 (30.5)	
1	4A-1A-1-6	561 (550)	9.477 (.3731)	4.392 (.1729)	24.4 (5.48)	194 (28.1)	25.3 (5.68)	201 (29.2)	
2	4A-1B-2-1	294 (70)	9.479 (.3732)	4.475 (.1762)	28.2 (6.35)	225 (32.0)	32.9 (7.40)	257 (37.3)	
2	4A-1B-2-2	294 (70)	9.444 (.3718)	4.440 (.1748)	27.1 (6.10)	213 (30.9)	32.0 (7.20)	252 (36.5)	
2	4A-1B-2-3	294 (70)	9.451 (.3721)	4.351 (.1713)	25.8 (5.80)	207 (30.0)	26.8 (6.02)	215 (31.2)	
2	4A-1B-2-4	561 (550)	9.454 (.3722)	4.542 (.1788)	15.3 (3.43)	117 (17.0)	25.5 (5.73)	196 (28.4)	
2	4A-1B-2-5	561 (550)	9.451 (.3721)	4.448 (.1751)	22.2 (5.00)	175 (25.3)	26.4 (5.93)	207 (30.0)	
2	4A-1B-2-6	561 (550)	9.469 (.3728)	4.366 (.1719)	14.2 (3.20)	114 (16.5)	23.0 (5.18)	184 (26.7)	
3	4A-1C-3-1	294 (70)	9.505 (.3742)	4.338 (.1708)	26.7 (6.00)	215 (31.2)	31.5 (7.08)	254 (36.8)	
3	4A-1C-3-2	294 (70)	9.500 (.3740)	4.209 (.1657)	25.8 (5.80)	214 (31.1)	27.5 (6.19)	229 (33.2)	
3	4A-1C-3-3	561 (550)	9.505 (.3742)	4.402 (.1733)	19.1 (4.30)	152 (22.0)	25.8 (5.79)	205 (29.7)	
3	4A-1C-3-4	561 (550)	9.500 (.3740)	4.498 (.1771)	18.7 (4.20)	145 (21.1)	25.0 (5.61)	194 (28.1)	
3	4A-1C-3-5	561 (550)	9.505 (.3742)	4.516 (.1778)	18.8 (4.22)	145 (21.1)	26.0 (5.85)	202 (29.2)	

TABLE A-2: MATRIX 4A SMALL SPECIMEN BEARING TESTS
WIDTH = 63.5 mm (2.5 in) EDGE MARGIN = 33.3 mm (1.31 in)

CONDITION CODE	SPECIMEN NUMBER	TEMPERATURE K (°F)	BOLT DIAMETER mm (in)	LAMINATE THICKNESS mm (in)	1st YIELD LOAD kN (kip)	1st YIELD BEARING STRESS MPa (ksi)	ULTIMATE FAILURE LOAD kN (kip)	ULTIMATE FAILURE BEARING STRESS MPa (ksi)	NOTES
1	4A-2A-1-1	294 (70)	9.467(.3727)	4.577(.1802)	39.7(8.92)	916(132.8)	40.7(9.16)	940(136.4)	
1	4A-2A-1-2	294 (70)	9.467(.3727)	4.679(.1842)	30.0(6.75)	678(98.3)	42.3(9.51)	955(138.5)	
1	4A-2A-1-3	294 (70)	9.467(.3727)	4.714(.1856)	36.2(8.13)	810(117.5)	42.2(9.48)	945(137.0)	
1	4A-2A-1-4	561 (550)	9.467(.3727)	4.602(.1812)	24.5(5.5)	561(81.4)	30.3(6.81)	695(100.8)	
1	4A-2A-1-5	561 (550)	9.467(.3727)	4.643(.1828)	17.8(4.0)	405(58.7)	25.8(5.81)	588(85.3)	
1	4A-2A-1-6	561 (550)	9.467(.3727)	4.509(.1775)	21.7(4.88)	509(73.8)	31.6(7.1)	740(107.3)	
2	4A-2B-2-1	294 (70)	9.467(.3727)	4.618(.1818)	29.8(6.7)	682(98.9)	39.4(8.86)	901(130.7)	
2	4A-2B-2-2	294 (70)	9.467(.3727)	4.514(.1777)	29.0(6.52)	678(98.4)	38.7(8.7)	906(131.4)	
2	4A-2B-2-3	294 (70)	9.467(.3727)	4.478(.1763)	33.0(7.41)	778(112.8)	39.9(8.96)	940(136.4)	
2	4A-2B-2-4	561 (550)	9.467(.3727)	4.384(.1726)	22.8(5.13)	550(79.7)	29.4(6.6)	707(102.6)	
2	4A-2B-2-5	561 (550)	9.467(.3727)	4.491(.1768)	15.6(3.51)	367(53.3)	27.7(6.22)	651(94.4)	
2	4A-2B-2-6	561 (550)	9.467(.3727)	4.602(.1812)	17.8(4.0)	408(59.2)	28.6(6.43)	656(95.2)	
3	4A-2C-3-1	294 (70)	9.431(.3713)	4.653(.1832)	29.3(6.58)	667(96.7)	39.1(8.78)	890(129.1)	
3	4A-2C-3-2	294 (70)	9.431(.3713)	4.656(.1833)	31.6(7.1)	719(104.3)	35.9(8.08)	818(118.7)	
3	4A-2C-3-3	294 (70)	9.431(.3713)	4.648(.1830)	35.9(8.08)	820(118.9)	36.3(8.17)	829(120.2)	
3	4A-2C-3-4	561 (550)	9.431(.3713)	4.608(.1814)	18.2(4.1)	420(60.9)	26.8(6.02)	616(89.4)	
3	4A-2C-3-5	561 (550)	9.431(.3713)	4.618(.1818)	28.1(6.32)	645(93.6)	30.5(6.85)	700(101.5)	
3	4A-2C-3-6	561 (550)	9.431(.3713)	4.404(.1734)	24.5(5.5)	589(85.4)	28.7(6.45)	691(100.2)	

TABLE A-3: MATRIX 4A SMALL SPECIMEN NET TENSION LOADED HOLE TESTS
WIDTH = 33.3 mm (1.31 in) EDGE MARGIN = 33.3 mm (1.31 in)
HOLE DIAMETER = 9.53 mm (.375 in)

CONDITION CODE	SPECIMEN NUMBER	TEMPERATURE		LAMINATE THICKNESS		ULTIMATE FAILURE				NOTES
						LOAD		NET TENSION STRESS		
		K	(°F)	mm	(in)	kN	(kip)	MPa	(ksi)	
1	4A-3A-1-1	294	(70)	4.17	(.164)	25.7	(5.77)	259	(37.6)	
1	4A-3A-1-2	294	(70)	4.17	(.164)	26.9	(6.05)	272	(39.4)	
1	4A-3A-1-3	294	(70)	4.19	(.165)	26.6	(5.98)	268	(38.8)	
1	4A-3A-1-4	561	(550)	4.24	(.167)	17.9	(4.03)	178	(25.8)	Bearing Failure
1	4A-3A-1-5	561	(550)	4.11	(.162)	22.1	(4.96)	225	(32.7)	Bearing Failure
1	4A-3A-1-6	561	(550)	4.24	(.167)	19.8	(4.44)	196	(28.4)	Bearing Failure
2	4A-3B-2-1	294	(70)	4.22	(.1660)	24.9	(5.60)	249	(36.1)	
2	4A-3B-2-2	294	(70)	4.21	(.1656)	26.0	(5.84)	260	(37.7)	
2	4A-3B-2-3	294	(70)	4.21	(.1657)	25.9	(5.82)	259	(37.6)	
2	4A-3B-2-4	561	(550)	4.13	(.1626)	30.5	(6.85)	311	(45.1)	Bearing Failure
2	4A-3B-2-5	561	(550)	4.17	(.1641)	31.4	(7.06)	317	(46.0)	
2	4A-3B-2-6	561	(550)	4.16	(.1639)	31.7	(7.13)	321	(46.5)	
3	4A-3C-3-1	294	(70)	4.37	(.172)	24.5	(5.51)	236	(34.3)	
3	4A-3C-3-2	294	(70)	4.39	(.173)	26.0	(5.84)	249	(36.1)	
3	4A-3C-3-3	294	(70)	4.29	(.169)	25.2	(5.67)	248	(35.9)	
3	4A-3C-3-4	561	(550)	4.37	(.172)	29.9	(6.73)	288	(41.8)	Bearing Failure
3	4A-3C-3-5	561	(550)	4.37	(.172)	25.5	(5.74)	246	(35.7)	Bearing Failure
3	4A-3C-3-6	561	(550)	4.39	(.173)	28.5	(6.40)	273	(39.6)	Bearing Failure

Table A-4: SMALL SPECIMEN NET TENSION UNLOADED HOLE TESTS

CONDITION CODE	SPECIMEN NUMBER	TEMPERATURE K (°F)	HOLE DIAMETER mm (in)	LAMINATE THICKNESS mm (in)	LAMINATE WIDTH mm (in)	FAILURE LOAD kN (kip)	NET TENSION FAILURE STRESS MPa (ksi)	NOTES
1	4A-4A-1-1	294 (70)	9.55 (.376)	4.50 (.177)	47.96 (1.888)	56.85 (12.78)	329 (47.8)	
1	4A-4A-1-2	294 (70)	9.53 (.375)	4.47 (.176)	47.98 (1.889)	60.50 (13.60)	352 (51.0)	
1	4A-4A-1-3	294 (70)	9.55 (.376)	4.45 (.175)	47.93 (1.887)	57.12 (12.84)	335 (48.6)	
1	4A-4A-1-4	561 (550)	9.55 (.376)	4.45 (.175	47.98 (1.889)	62.81 (14.12)	368 (53.3)	
1	4A-4A-1-5	561 (550)	9.55 (.376)	4.57 (.180)	47.90 (1.886)	57.78 (12.99)	330 (47.8)	
1	4A-4A-1-6	561 (550)	9.58 (.377)	4.50 (.177)	47.93 (1.887)	58.81 (13.22)	341 (49.5)	
2	4A-4B-2-1	294 (70)	9.515 (.3746)	4.425 (.1742)	48.26 (1.900)	49.64 (11.16)	290 (42.0)	
2	4A-4B-2-2	294 (70)	9.403 (.3702)	4.442 (.1749)	47.85 (1.884)	52.62 (11.83)	308 (44.7)	
2	4A-4B-2-3	294 (70)	9.512 (.3745)	4.567 (.1798)	48.01 (1.890)	53.38 (12.00)	304 (44.0)	
2	4A-4B-2-4	561 (550)	9.512 (.3745)	4.496 (.1770)	47.88 (1.885)	56.94 (12.80)	330 (47.9)	
2	4A-4B-2-5	561 (550)	9.507 (.3743)	4.542 (.1788)	47.90 (1.886)	56.94 (12.80)	327 (47.4)	
2	4A-4B-2-6	561 (550)	9.505 (.3742)	4.590 (.1807)	47.75 (1.880)	55.42 (12.46)	316 (45.8)	
3	4A-4C-3-1	294 (70)	9.58 (.377)	4.39 (.173)	47.90 (1.886)	52.49 (11.80)	312 (45.2)	
3	4A-4C-3-2	294 (70)	9.60 (.378)	4.45 (.175)	47.90 (1.885)	50.89 (11.44)	299 (43.4)	1
3	4A-4C-3-3	294 (70)	9.60 (.378)	4.52 (.178)	47.96 (1.888)	56.05 (12.60)	323 (46.9)	
3	4A-4C-3-5	294 (70)	9.55 (.376)	4.52 (.178)	47.93 (1.887)	55.07 (12.38)	317 (46.0)	
3	4A-4C-3-4	561 (550)	9.55 (.376)	4.50 (.177)	47.98 (1.889)	56.40 (12.68)	326 (47.3)	
3	4A-4C-3-6	561 (550)	9.55 (.376)	4.52 (.178)	47.98 (1.889)	57.47 (12.92)	331 (48.0)	
3	4A-4C-3-7	561 (550)	9.55 (.376)	4.50 (.177)	47.96 (1.888)	54.98 (12.36)	318 (46.2)	

1 Loaded to 1200 lb, Switched load range; failed @ 11440 lb

Table A-5: SMALL SPECIMEN TESTS COCURED DOUBLER CELION 3000/PMR-15

a) SI UNITS

CONDITION CODE	SPECIMEN NUMBER	TEMPERATURE	DIAMETER HOLE/BOLT	THICKNESS DOUBLER/LAMINATE	WIDTH	1st YIELD LOAD	1st YIELD BEARING STRESS	ULTIMATE FAILURE LOAD	ULTIMATE FAILURE BEARING STRESS	ULTIMATE FAILURE NET TENSION STRESS DOUBLER/LAMINATE	ULTIMATE FAILURE FREE FIELD LAMINATE STRESS	NOTES
		K	mm mm	mm mm	mm	kN	MPa	kN	MPa	MPa MPa	MPa	
1	4B-2A-1-1	294	9.474/9.464	2.174/.569	47.63	8.05	391	11.5	558	138/529	424	
1	4B-2A-1-2	294	9.479/9.464	2.217/.559	47.63	8.59	409	13.2	630	156/620	496	
1	4B-2A-1-3	294	9.479/9.464	2.182/.546	47.63	5.74	278	12.1	588	146/583	467	
1	4B-2A-1-4	561	9.482/9.464	2.192/.564	47.63	6.23	300	10.5	506	126/488	391	
1	4B-2A-1-5	561	9.484/9.464	2.306/.549	47.63	6.14	281	9.61	440	109/459	368	
1	4B-2A-1-6	561	9.469/9.464	2.205/.584	47.63	5.34	256	9.96	478	118/447	358	
2	4B-2B-2-1	294	9.528/9.464	2.230/.544	47.63	5.38	255	10.1	481	119/490	391	
2	4B-2B-2-2	294	9.500/9.464	2.179/.541	47.63	2.89	140	9.25	449	111/449	359	
2	4B-2B-2-3	294	9.520/9.464	2.156/.533	47.63	6.14	301	11.8	580	144/582	466	
2	4B-2B-2-4	561	9.512/9.464	2.240/.541	47.63	—	—	10.3	485	120/498	399	
2	4B-2B-2-5	561	9.502/9.464	2.136/.569	47.63	None	Apparent	10.1	499	124/466	373	
2	4B-2B-2-6	561	9.505/9.464	2.151/.544	47.63	6.54	321	10.3	507	126/498	399	
3	4B-2C-3-1	294	9.53/9.53	2.11/.559	47.63	6.58	328	7.83	390	97.5/368	294	
3	4B-2C-3-2	294	9.60/9.53	2.21/.584	47.63	None	Apparent	7.07	336	84.2/318	254	
3	4B-2C-3-3	294	9.58/9.53	2.16/.533	47.63	5.74	279	8.36	407	102/412	329	
3	4B-2C-3-4	561	9.60/9.53	2.18/.533	47.63	7.03	338	7.21	346	86.8/355	284	[1]
3	4B-2C-3-5	561	9.63/9.53	2.16/.559	47.63	None	Apparent	8.05	392	98.1/379	303	[1]
3	4B-2C-3-6	561	9.86/9.53	2.13/.559	47.63	None	Apparent	7.74	381	96.0/367	291	[1]

[1] Tested with washer on each side.

Table A-5: Concluded

b) U.S. CUSTOMARY UNITS

CON-DITION CODE	SPECIMEN NUMBER	TEMPER-ATURE	DIAMETER HOLE/BOLT	THICKNESS DOUBLER/LAMINATE	WIDTH	1st YIELD LOAD	1st YIELD BEARING STRESS	ULTIMATE FAILURE LOAD	ULTIMATE FAILURE BEARING STRESS	ULTIMATE FAILURE NET TENSION STRESS DOUBLER/LAMINATE	ULTIMATE FAILURE FREE FIELD LAMINATE STRESS	NOTES
		F	in in	in in	in	kip	ksi	kip	ksi	ksi ksi	ksi	
1	4B-2A-1-1	70	.3730/.3726	.0856/.0224	1.875	1.81	56.7	2.58	80.9	20.1/76.7	61.4	
1	4B-2A-1-2	70	.3732/.3726	.0873/.0220	1.875	1.93	59.3	2.97	91.3	22.7/89.9	72.0	
1	4B-2A-1-3	70	.3732/.3726	.0859/.0215	1.875	1.29	40.3	2.73	85.3	21.2/84.5	67.7	
1	4B-2A-1-4	550	.3733/.3726	.0863/.0222	1.875	1.40	43.5	2.36	73.4	18.2/70.8	56.7	
1	4B-2A-1-5	550	.3734/.3726	.0908/.0216	1.875	1.38	40.8	2.16	63.8	15.8/66.6	53.3	
1	4B-2A-1-6	550	.3728/.3726	.0868/.0230	1.875	1.20	37.1	2.24	69.3	17.2/64.8	51.9	
2	4B-2B-2-1	70	.3751/.3726	.0878/.0214	1.875	1.21	37.0	2.28	69.7	17.3/71.0	56.7	
2	4B-2B-2-2	70	.3740/.3726	.0858/.0213	1.875	.65	20.3	2.08	65.1	16.2/65.1	52.1	
2	4B-2B-2-3	70	.3748/.3726	.0849/.0210	1.875	1.38	43.6	2.66	84.1	20.9/84.4	67.6	
2	4B-2B-2-4	550	.3745/.3726	.0882/.0213	1.875	—	—	2.31	70.3	17.5/72.3	57.8	
2	4B-2B-2-5	550	.3741/.3726	.0841/.0224	1.875	None	Apparent	2.27	72.4	18.0/67.5	54.0	
2	4B-2B-2-6	550	.3742/.3726	.0847/.0214	1.875	1.47	46.6	2.32	73.5	18.3/72.2	57.8	
3	4B-2C-3-1	70	.375/.375	.083/.022	1.875	1.48	47.6	1.76	56.5	14.1/53.3	42.7	
3	4B-2C-3-2	70	.378/.375	.087/.023	1.875	None	Apparent	1.59	48.7	12.2/46.2	36.9	
3	4B-2C-3-3	70	.377/.375	.085/.021	1.875	1.29	40.5	1.88	59.0	14.8/59.8	47.7	
3	4B-2C-3-4	550	.378/.375	.086/.021	1.875	1.58	49.0	1.62	50.2	12.6/51.5	41.1	[1]
3	4B-2C-3-5	550	.379/.375	.085/.022	1.875	None	Apparent	1.81	56.8	14.2/55.0	43.9	[1]
3	4B-2C-3-6	550	.388/.375	.084/.022	1.875	None	Apparent	1.74	55.2	13.9/53.2	42.2	[1]

[1] Tested with washer on each side.

Table A-6: SMALL SPECIMEN TESTS BONDED DOUBLER CELION 3000/PMR-15

a) SI UNITS

CONDITION CODE	SPECIMEN NUMBER	TEMPERATURE K	DIAMETER HOLE/BOLT mm mm	THICKNESS DOUBLER/ LAMINATE mm mm	WIDTH mm	1st YIELD LOAD kN	1st YIELD BEARING STRESS MPa	ULTIMATE FAILURE LOAD kN	ULTIMATE FAILURE BEARING STRESS MPa	ULTIMATE FAILURE NET TENSION STRESS DOUBLER/ LAMINATE MPa MPa	ULTIMATE FAILURE FREE FIELD LAMINATE STRESS MPa	NOTES
1	4B-1A-1-1	294	9.500/9.525	2.395/.599	47.63	—	—	7.30	320	79.9/319	256	1
1	4B-1A-1-2	294	9.502/9.525	2.416/.582	47.63	6.58	286	9.47	412	103/427	342	2
1	4B-1A-1-3	294	9.507/9.525	2.403/.579	47.63	4.98	218	10.3	449	112/465	373	3
1	4B-1A-1-4	561	9.352/9.525	2.410/.592	47.63	6.58	287	9.92	432	108/438	352	
1	4B-1A-1-5	561	9.507/9.525	2.438/.607	47.63	5.78	249	9.16	395	98.6/396	317	
1	4B-1A-1-6	561	9.479/9.525	2.393/.610	47.63	5.87	258	9.65	424	106/415	332	
2	4B-1B-2-1	294	9.477/9.525	2.372/.584	47.63	—	—	10.0	443	111/449	360	
2	4B-1B-2-2	294	9.492/9.525	2.459/.577	47.63	7.21	308	8.63	368	92.0/392	314	
2	4B-1B-2-3	294	9.484/9.525	2.316/.597	47.63	5.65	256	8.72	395	98.7/383	307	
2	4B-1B-2-4	561	9.492/9.525	2.464/.574	47.63	5.65	241	8.10	345	86.2/370	296	
2	4B-1B-2-5	561	9.489/9.525	2.446/.602	47.63	6.27	269	8.18	351	87.7/357	285	
2	4B-1B-2-6	561	9.462/9.525	2.438/.599	47.63	6.09	262	8.01	345	86.0/350	280	

b) US CUSTOMARY UNITS

CONDITION CODE	SPECIMEN NUMBER	TEMPERATURE °F	DIAMTER HOLE/BOLT in	THICKNESS DOUBLER/ LAMINATE in in	WIDTH in	1st YIELD LOAD kip	1st YIELD BEARING STRESS ksi	ULTIMATE FAILURE LOAD kip	ULTIMATE FAILURE BEARING STRESS ksi	ULTIMATE FAILURE NET TENSION STRESS DOUBLER/ LAMINATE ksi	ULTIMATE FAILURE FREE FIELD LAMINATE STRESS ksi	NOTES
1	4B-1A-1-1	70	.3740/.375	.0943/.0236	1.875	—	—	1.64	46.4	11.6/46.3	37.1	1
1	4B-1A-1-2	70	.3741/.375	.0951/.0229	1.875	1.48	41.5	2.13	59.7	14.9/62.0	49.6	2
1	4B-1A-1-3	70	.3743/.375	.0946/.0228	1.875	1.12	31.6	2.31	65.1	16.3/67.5	54.0	3
1	4B-1A-1-4	550	.3682/.375	.0949/.0233	1.875	1.48	41.6	2.23	62.7	15.6/63.5	51.0	
1	4B-1A-1-5	550	.3743/.375	.0960/.0239	1.875	1.30	36.1	2.06	57.2	14.3/57.4	46.0	
1	4B-1A-1-6	550	.3732/.375	.0942/.0240	1.875	1.32	37.4	2.17	61.4	15.3/60.2	48.2	
2	4B-1B-2-1	70	.3731/.375	.0934/.0230	1.875	—	—	2.25	64.2	16.0/65.1	52.2	
2	4B-1B-2-2	70	.3737/.375	.0968/.0227	1.875	1.62	44.6	1.94	53.4	13.3/56.9	45.6	
2	4B-1B-2-3	70	.3734/.375	.0912/.0235	1.875	1.27	37.1	1.96	57.3	14.3/55.5	44.5	
2	4B-1B-2-4	550	.3737/.375	.0970/.0226	1.875	1.27	34.9	1.82	50.0	12.5/53.6	42.9	
2	4B-1B-2-5	550	.3736/.375	.0963/.0237	1.875	1.41	39.0	1.84	51.0	12.7/51.7	41.4	
2	4B-1B-2-6	550	.3725/.375	.0960/.0236	1.875	1.37	38.1	1.80	50.0	12.5/50.8	40.7	

1 Tab failure
2 Doubler Bond Failure
3 Tab and Doubler Bond failure

Table A-7: MATRIX 4C SINGLE ANGLE PULL-OFF TESTS

CONDITION CODE	SPECIMEN NUMBER	TEMPERATURE K	(°F)*	WIDTH mm	(in)	FAILURE LOAD kN/m	(lb/in)	NOTES
1	4C-1A-1-1	294	(70)	25.	(1.0)	9.77	(55.8)	
1	4C-1A-1-3	294	(70)	25.	(1.0)	9.12	(52.1)	
1	4C-1A-1-4	294	(70)	25.	(1.0)	11.5	(65.6)	

* Elevated Temperature Tests were not run because of low failure loads at room temperature.

Table A-8: MATRIX 4C DOUBLE ANGLE PULL-OFF TESTS

CONDITION CODE	SPECIMEN NUMBER	TEMPERATURE K	(°F)	WIDTH mm	(in)	FAILURE LOAD kN/m	(lb/in)	NOTES
2	4C-2B-2-1	294	(70)	25.	(1.0)	40.6	(232)	
2	4C-2B-2-2	294	(70)	25.	(1.0)	30.1	(172)	
2	4C-2B-2-3	294	(70)	25.	(1.0)	49.7	(284)	
2	4C-2B-2-4	561	(550)	25.	(1.0)	53.8	(307)	
2	4C-2B-2-5	561	(550)	25.	(1.0)	42.4	(242)	
2	4C-2B-2-6	561	(550)	25.	(1.0)	44.7	(255)	

Table A-9: MATRIX 4C "T" PULL-OFF TESTS

CONDITION CODE	SPECIMEN NUMBER	TEMPERATURE K	(°F)	WIDTH mm	(in)	FAILURE LOAD N/m	(lb/in)	NOTES
2	4C-3B-2-1	294	(70)	25.	(1.0)	62.9	(359)	1
2	4C-3B-2-2	294	(70)	25.	(1.0)	55.2	(315)	2
2	4C-3B-2-3	294	(70)	25.	(1.0)	48.0	(274)	2
2	4C-3B-2-4	561	(550)	25.	(1.0)	46.9	(268)	1
2	4C-3B-2-5	561	(550)	25.	(1.0)	52.7	(301)	1
2	4C-3B-2-6	561	(550)	25.	(1.0)	55.3	(316)	1

1 Adhesive to laminate failure on beam.

2 Interlaminar tension failure on "T"

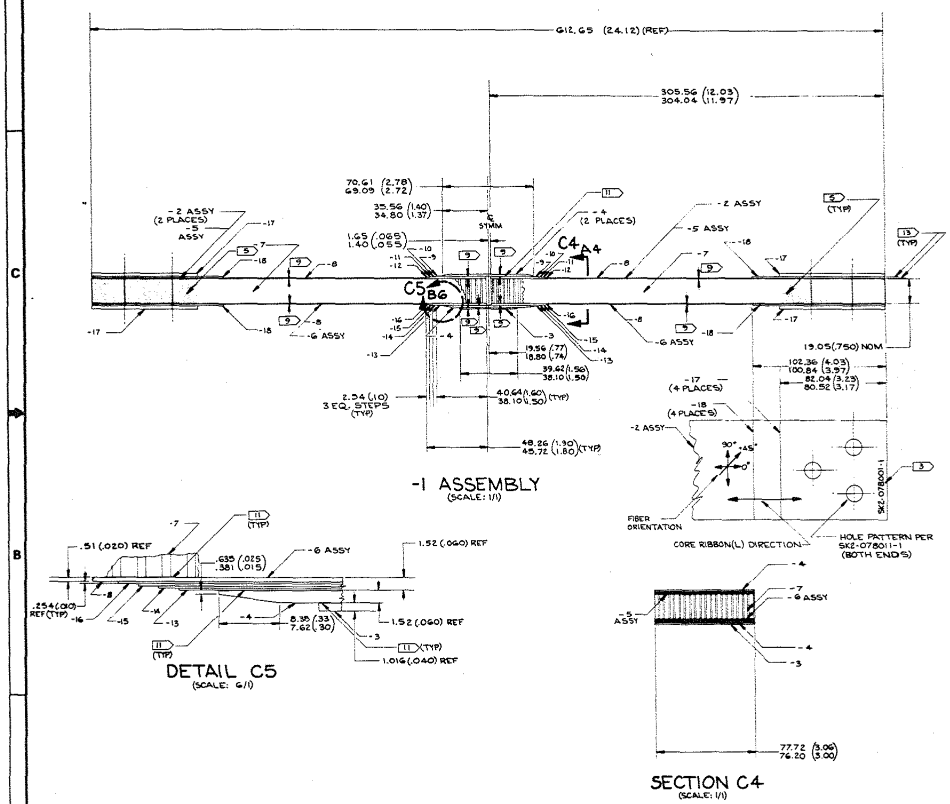
Table A-10: COCURED DOUBLER WITH HONEYCOMB SANDWICH INNER ADHERENDS

CONDITION CODE	SPECIMEN NUMBER	TEMPERATURE K	(°F)	WIDTH mm	(in)	FAILURE LOAD kN	(lb)	FAILURE STRESS* MPa	(Ksi)
2	4B-4A-2-1	294	(70)	25.46	(1.0025)	9.34	(2100)	361	(52.4)
2	4B-4A-2-6	294	(70)	25.70	(1.012)	11.3	(2550)	434	(63.0)
2	4B-4A-2-2	294	(70)	25.86	(1.018)	11.3	(2550)	432	(62.6)
2	4B-4A-2-4	561	(550)	25.93	(1.021)	9.61	(2160)	365	(52.9)
2	4B-4A-2-5	561	(550)	25.86	(1.018)	11.0	(2475)	419	(60.8)
2	4B-4A-2-3	561	(550)	25.86	(1.018)	10.0	(2250)	381	(55.3)

* Based on Nominal Skin Thickness of .51 mm (.02 in)

APPENDIX B

PRELIMINARY JOINT DESIGN DRAWINGS



NOTES

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)
   FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300 — BOLT & NUT INSTALLATION PER BAC 5009
   RIVET INSTALLATION & SYMBOLS PER BAC 5004 — PART MARKING PER BAC 5307
   FINISH CODES PER DOCUMENT D2-4000
2. XX.XXX MILLIMETERS (XX.XX INCHES)
   TOLERANCE ON ANGLES: ±1°
3. PART MARK USING FELT TIP PEN AT LOCATION INDICATED
4. FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPREG". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.
5. FINAL ASSEMBLY OPERATION: REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5-28 TYPE 5 OR TYPE 6.
6. INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDI TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".
7. INSPECT LAMINATE TO LAMINATE BONDED JOINTS USING ULTRASONIC 'C' SCAN TEST METHODS. SENSITIVITY OF 'C' SCAN TO BE DETERMINED
8. IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMOLIES.
9. RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.
10. THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, e.g.: (0/90/±45) — 0, 90, +45, -45
11. A7F-BLENDED AND PROCESSED PER D180-20545-5A, EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 psi. WHEN TESTED PER BSS 7202, TYPE V. THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSEMBLY
12. HRH-327 - 3/16-8 [128.2 kg/m^3 (8 lb/ft^3)] FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.
13. BMS 5-51, TYPE 2, GRADE 10 OR BMS 5-101, TYPE 2, GRADE 10. BOND IN ACCORDANCE WITH BAC 5514. ITEMS -17 & -18 to ASSY OF ITEMS -2, -3 & -4.
14. CELION 3000 (NR 150B2G FINISH)/PMR-15 PREPREG PER D180-20545-4A.
15. CLEAN PER BAC 5514

PARTS LIST

QTY REQD	QTY REQD	QTY REQD -6	QTY REQD -5	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	WT TR	FINISH	FT INK	REV LTR
				AR	AR		A7F	ADHESIVE		11					
					AR		BMS 5-51	ADHESIVE		13					
				AR			BMS 5-28	POTTING		5					
					4		-18	DOUBLER		.020 × 4.05 × 3.05 2024-T4 ALUM SHEET 15					
					4		-17	DOUBLER		.080 × 3.25 × 3.05 2024-T4 ALUM SHEET 15					
		1					-16	REINFORCEMENT		.01(REF) (0₂/-45/0) LAYUP 14 10					
		1					-15			.01(REF) (0/+45/0₂) LAYUP 14 10					
		1					-14			.01(REF) (0₂/-45/0) LAYUP 14 10					
		1					-13			.01(REF) (0/+45/0₂) LAYUP 14 10					
			1				-12			.01(REF) (0₂/+45/0) LAYUP 14 10					
			1				-11			.01(REF) (0/-45/0₂) LAYUP 14 10					
			1				-10	REINFORCEMENT		.01(REF) (0₂/+45/0) LAYUP 14 10					
			1				-9	REINFORCEMENT		.01(REF) (0/-45/0₂) LAYUP 14 10					
		1	1				-8	SKIN		.02(REF) (0/±45/90)ₛ LAYUP 14 10					
				1			-7	CORE		.75 × 3.00 × 12.00 12					
		–		1			-6	SKIN ASSY		CO-CURE -8, -13, -14, -15 & -16 4 9 6					
			–	1			-5	SKIN ASSY		CO-CURE -8, -9, -10, -11 & -12 4 9 6					
					2		-4	SPLICE PLATE		.06(REF) (0/+45/0₂/-45/0)₂ₛ LAYUP 14 4 9 10 6					
					1		-3	DOUBLER		.04(REF) (±45) LAYUP 14 4 9 10 6					
				–	2		-2	COVER ASSY		4 6					
					–		-1	SPECIMEN, TYPE I, BONDED ASSY		4 7 8				3	

DIMENSIONING & TOLERANCING PER ANSI (USASI) Y14.5
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN 2

CONTRACT NUMBER NAS1-15644
DRN K.W. OSBORNE 7-10-80

THE BOEING COMPANY
CORPORATE OFFICES SEATTLE, WASHINGTON

SPECIMEN, TYPE I BONDED - ADV. Gr/R COMPOSITE JOINTS, CONCEPT DISCRIMINATOR TESTS

SIZE J CODE IDENT NO 81205 SK2-078001

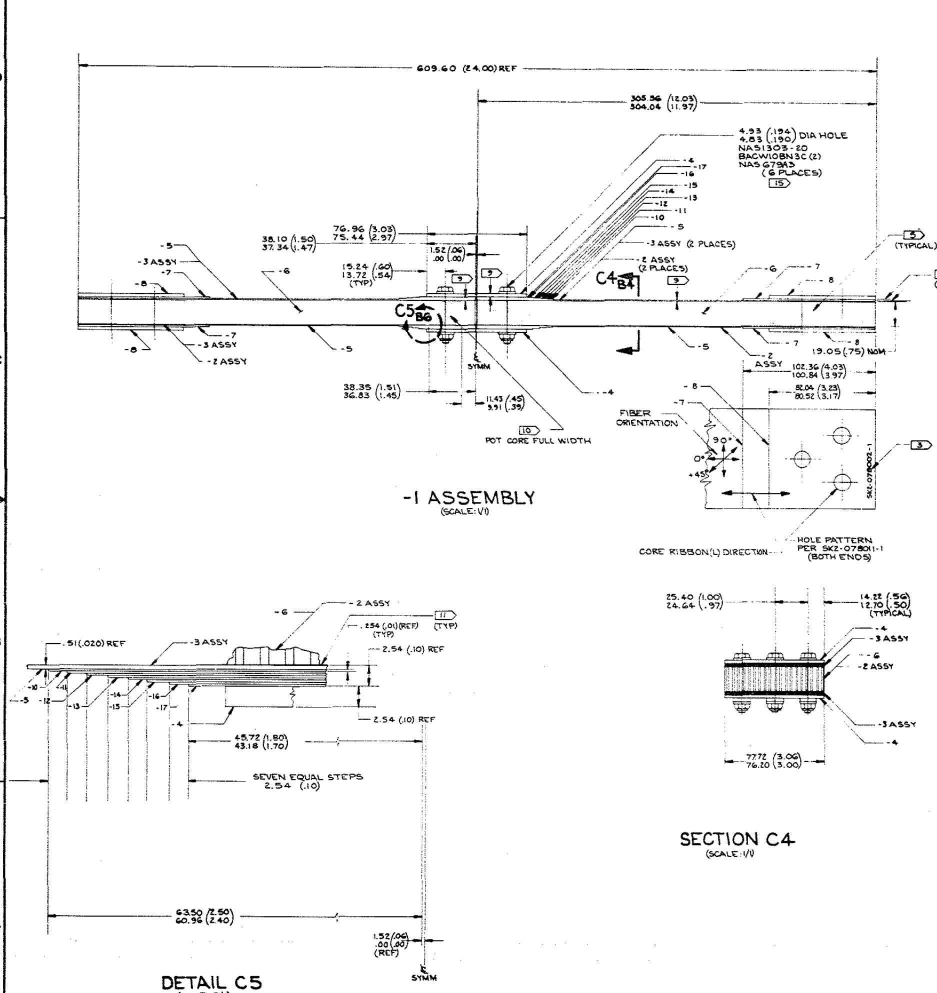
PART NUMBER	NEXT ASSY	USED ON	EFFECTIVITY
-1	TEST MATRIX 5	TEST ONLY	

APPLICATION

FASTENER CODES

FIGURE B-1

[18] THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, i.e. (0/90/±45)



NOTES

1 SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)
FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300 — BOLT & NUT INSTALLATION PER BAC 5009
RIVET INSTALLATION & SYMBOLS PER BAC 5004 — PART MARKING PER BAC 5307
FINISH CODES PER DOCUMENT D2 6000

[2] XX.XXX MILLIMETERS (XX.XX INCHES)
TOLERANCE ON ANGLES: ±1°

[3] PART MARK USING FELT TIP PEN AT LOCATION INDICATED

[4] FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPREG". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.

[5] FINAL SPECIMEN ASSEMBLY OPERATION: REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5-28 TYPE 5 OR TYPE 6.

[6] INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDI TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".

[8] IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMOLIES.

[9] RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.

[10] BMS 8-126 TYPE I, POLYIMIDE STRUCTURAL FOAM. INSTALL FOAM TO FULL DEPTH OF CORE, OVER THE AREA DESIGNATED, PRIOR TO ASSEMBLY OF CORE AND FACE SKINS. CURE AND POSTCURE FOAM PER BMS 8-126.

[11] A7F-BLENDED AND PROCESSED PER D180-20545-5A; EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 psi WHEN TESTED PER BSS 7202 TYPE V. THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSY

[12] HRH-327 - 3/16-8 [128.2 kg/m³ (8 lb/ft³)] FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.

[13] BMS 5-51, TYPE 2, GRADE 10 or BMS 5-101, TYPE 2, GRADE 10, BOND IN ACCORDANCE WITH BAC 5514. ITEMS -7 AND -8 TO ASSY OF -3 & -6

[14] CELION 3000 (NR 150B2G FINISH)/PMR-15 PREPREG PER D180-20545-4A.

[15] TIGHTEN NUTS WITHIN TORQUE RANGE OF 18 TO 20 INCH POUNDS.

[16] CLEAN PER BAC 5514

[17] STRIP PER BAC 5771, APPLY DRY FILM LUBRICANT PER BAC 5811, TYPE VIII, CLASS I.

REV STATUS: SH | LTR

REVISIONS: ZONE | LTR | DESCRIPTION | DATE | APPROVED

PARTS LIST

QTY REQD	QTY REQD	QTY REQD	QTY REQD -3	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	HT TR	FINISH	PT MK	REV LTR
					AR		BMS 5-28	POTTING		[5]					
				AR			A7F	ADHESIVE		[11]					
					AR		BMS 5-51	ADHESIVE		[13]					
				AR			BMS 8-126	POTTING		[10]					
					12		BACW10BN-3C	WASHER							
					6		NAS679A3	NUT		[17]					
					6		NAS1303-20	BOLT		[17]					
			1				-17	REINFORCEMENT		.01(REF) (0/±45/90) LAYUP [14] [18]					
			1				-16	REINFORCEMENT		.01(REF) (90/±45/0) LAYUP [14] [18]					
			1				-15			.01(REF) (0/±45/90) LAYUP [14] [18]					
			1				-14			.01 (REF) LAYUP [14] [18] (90/±45/0)					
			1				-13			.010(REF) (0/±45/90) LAYUP [14] [18]					
			1				-12	REINFORCEMENT		.020(REF) (90/±45/0) LAYUP [14] [18]					
			1				-11	REINFORCEMENT		.020(REF) (0/±45/90) LAYUP [14] [18]					
			1				-10	REINFORCEMENT		.020(REF) (90/±45/0) LAYUP [14] [18]					
					4		-8	DOUBLER		.080×3.05×3.25 2024-T4 AL SHEET [16]					
					4		-7	DOUBLER		.020×3.05×4.05 2024-T4 AL SHEET [16]					
				1			-6	CORE		.75×3.05×12.05 [12]					
			1				-5	SKIN		.02(REF) $(0/\pm45/90)_s$ LAYUP [14] [18] [9]					
					2		-4	SPLICE PLATE		.100(REF) $(0/\pm45/90)_{10s}$ LAYUP [14] [6] [18] [9]					
			-	2			-3	SKIN ASSY		CO-CURE -5, -9, -10, -11, -12, -13, -14, -15, -16 [4] [6]					
				-	2		-2	COVER ASSY		[4] [6]					
					-		-1	SPECIMEN, TYPE I BOLTED ASSY		[8]				[3]	

FASTENER CODES

PART NUMBER	NEXT ASSY	USED ON	EFFECTIVITY	DWG SH NUMBER	REV LTR
	TEST MATRIX 5		TEST ONLY		

APPLICATION

CONTRACT NUMBER NAS1-15644

DRN K.W. OSBORNE 7-14-80

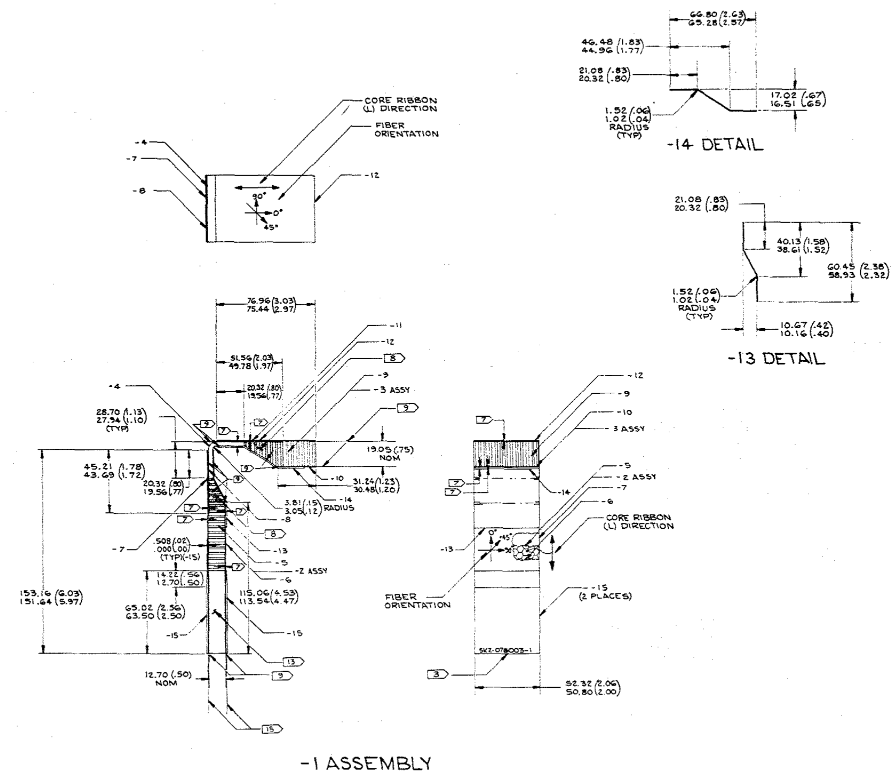
THE BOEING COMPANY — CORPORATE OFFICES, SEATTLE, WASHINGTON

SPECIMEN, TYPE I BOLTED-ADV. Gr/PI COMPOSITE JOINTS CONCEPT DISCRIMINATOR TESTS

SIZE J — CODE IDENT NO 81205 — SK2-078002

SK2-078002

FIGURE B-2



NOTES

1 SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)

FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300 — BOLT & NUT INSTALLATION PER BAC 5009

RIVET INSTALLATION & SYMBOLS PER BAC 5004 — PART MARKING PER BAC 5307

FINISH CODES PER DOCUMENT D2-4800

[2] XX.XXX MILLIMETERS (XX.XX INCHES) TOLERANCE ON ANGLES: ±1°

[3] PART MARK USING FELT TIP PEN AT LOCATION INDICATED.

[4] FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPREGS". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.

[5] INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDI TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".

[6] IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMALIES.

[7] RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.

[8] BMS 8-126 TYPE I, POLYIMIDE STRUCTURAL FOAM. INSTALL FOAM TO FULL DEPTH OF CORE, OVER THE AREA DESIGNATED, PRIOR TO ASSEMBLY OF CORE AND FACE SKINS. CURE AND POSTCURE FOAM PER BMS 8-126.

[9] A7F-BLENDED AND PROCESSED PER D180-20545-5A: EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 PSI, WHEN TESTED PER BSS 7202, TYPE V, THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSY.

[10] HRH-327-3/16-8 (128.2 kg/m^3 (8 lb/ft^3)) FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.

[11] HRH-327-3/16-4 (64.1 kg/m^3 (4 lb/ft^3)), FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.

[12] CELION 3000 (NR 150B2G FINISH)/PMR-15 PREPREG PER D180-20545-4A.

[13] FINAL ASSEMBLY OPERATION: REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5-28 TYPES 5 OR TYPE 6.

[14] THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, e.g.:

(±45/90/0)
-45
+45
90
0

[15] BOND -15 TO -2 ASSY WITH BMS 5-104, PER BAC 5514.

[16] INSPECT LAMINATE TO LAMINATE BONDED JOINTS USING ULTRASONIC 'C' SCAN TEST METHODS. SENSITIVITY OF 'C' SCAN TO BE DETERMINED.

REV STATUS | SH | LTR

REVISIONS: ZONE | LTR | DESCRIPTION | DATE | APPROVED

QTY REQD	QTY REQD	QTY REQD	QTY REQD -3	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	HT TR	FINISH	PT MK	REV LTR
			AR	AR	AR		A7F	ADHESIVE		[9]					
					AR		BMS 5-104	ADHESIVE		[15]					
			AR	AR			BMS 8-126	POTTING		[8]					
					AR		BMS 5-28	POTTING		[13]					
				2			-15	TAB, REINFORCEMENT		.040 (REF) 4 LAYERS FABRIC, BMS 8-139					
					1		-14	REINFORCEMENT		.040 (REF) (0,±45,90)2S LAYUP [5] [12] [14]					
					1		-13	REINFORCEMENT		.030 (REF) (0,±45)2S LAYUP [5] [12] [14]					
			1				-12	SKIN		.020 (REF) CO-CURE WITH -11 (0,±45,90)S LAYUP [5] [12] [14]					
			1				-11	SKIN		.020 (REF) CO-CURE WITH -12 (0,±45,90)S LAYUP [5] [12] [14]					
			1				-10	SKIN		.020 (REF) (0,±45,90)S LAYUP [5] [12] [14]					
			1				-9	CORE		.75 × 2.05 × 3.25 [10]					
				1			-8	SKIN		.015 (REF) CO-CURE WITH -7 (0,±45)S LAYUP [5] [12] [14]					
				1			-7	SKIN		.015 (REF) CO-CURE WITH -8 (0,±45)S LAYUP [5] [12] [14]					
				1			-6	SKIN		.015 (REF) (0,±45)S LAYUP [5] [12] [14]					
				1			-5	CORE		.50 × 2.05 × 5.25 [11]					
					1		-4	ANGLE		.120 (REF) (0,±45,90)2S LAYUP [5] [12] [14]					
			-		1		-3	COVER ASSY		[4] [5]					
				-	1		-2	WEB ASSY		[4] [5]					
					-		-1	SPECIMEN, TYPE 2, BONDED ASSY		[4] [6] [16]				[3]	

PARTS LIST

DIMENSIONING & TOLERANCING PER ANSI (USASI) Y14.5

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN [illegible]

TOLERANCES: ANGLES ± [2]
DECIMALS .XX ±
DECIMALS .XXX ±
RIVET & BOLT EDGE MARGINS ±.05
BEND RADII ± .XX ON .03 & .06, ±.03 ON .09 & GREATER
SHEET METAL CORNER RADII INT .19 .16 EXT .25 .00

REVIEW & APPROVAL
DRG QUAL
STRUCT — 9/11/80
MATL & PRCS
CHANGE/ITEM NUMBER

CONTRACT NUMBER NAS1-15644
DRN K.W. OSBORNE 9-9-80
CHK — 9/11/80
ENGR — 9/11/80
GRG
PROJECT APPROVAL — 9/7/80

THE BOEING COMPANY
CORPORATE OFFICES SEATTLE, WASHINGTON

SPECIMEN, TYPE 2, BONDED-ADV. G/R. COMPOSITE JOINT, CONCEPT DISCRIMINATOR TESTS

SIZE J | CODE IDENT NO 81205 | SK2-078003

SCALE 1/1 | SH | OF

DWG ORIG BY (ORG) 2-3614

APPLICATION: PART NUMBER | NEXT ASSY | USED ON: TEST MATRIX 5 | EFFECTIVITY: TEST ONLY | DWG SH NUMBER | REV LTR

FASTENER CODES

DRAWING RECORDS CLERK

SK2-078003

FIGURE B-3

NOTES

1 SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)

FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300 — BOLT & NUT INSTALLATION PER BAC 5009

RIVET INSTALLATION & SYMBOLS PER BAC 5004 — PART MARKING PER BAC 5307

FINISH CODES PER DOCUMENT D2-5000

2. XX.XXX MILLIMETERS (XX.XX INCHES) TOLERANCE ANGLES: ±1°

3. PART MARK USING FELT TIP PEN AT LOCATION INDICATED

4. FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPREG". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.

5. INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDI TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".

7. IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMALIES.

8. RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.

9. BMS 8-126 TYPE 1, POLYIMIDE STRUCTURAL FOAM. INSTALL FOAM TO FULL DEPTH OF CORE, OVER THE AREA DESIGNATED, PRIOR TO ASSEMBLY OF CORE AND FACE SKINS. CURE AND POSTCURE FOAM PER BMS 8-126.

10. A7F-BLENDED AND PROCESSED PER D180-20545-5A; EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 psi. WHEN TESTED PER BSS 7202, TYPE V. THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSY.

11. HRH-327 -3/16-8(128.2 kg/m³) (8lb/ft³)). FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.

12. HRH-327-3/16-4 (64.1 kg/m³ (8lb/ft³)). FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.

14. CELION 3000 (NR 150B2G FINISH)/PMR-15 PREPREG PER D180-20545-4A.

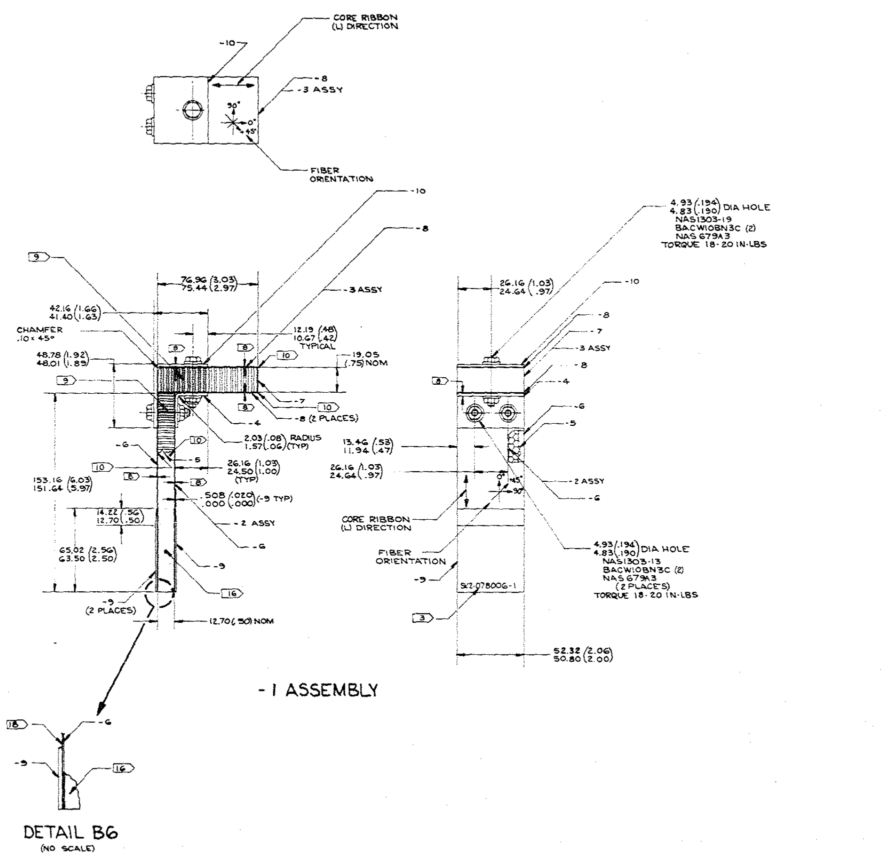
15. STRIP PER BAC 5771, APPLY DRY FILM LUBRICANT PER BAC 5811, TYPE VIII, CLASS I.

16. FINAL ASSEMBLY OPERATION: REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5-28 TYPE 5 OR TYPE 6.

17. THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, e.g.,

(0/90/±45)
0
90
+45
-45

18. BOND ITEM -9 TO -2 ASSY WITH BMS 5-104 PER BAC 5514



QTY REQD	QTY REQD	QTY REQD	QTY REQD -3	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	HT TR	FINISH	PT MK	REV LTR
			AR	AR			BMS8-126	POTTING		9					
				AR			BMS5-28	POTTING		16					
			AR	AR			A7F	ADHESIVE		10					
				AR			BMS5-104	ADHESIVE		18					
					6		BACW10BN3C	WASHER		15					
					3		NAS679-3	NUT		15					
					1		NAS1303-19	BOLT		15					
					2		NAS1303-13	BOLT		15					
					1		-10	ANGLE, CORNER		.120 (REF) (0, ±45, 90)6s LAYUP 14 17 5					
				2			-9	REINFORCEMENT		.040 (REF) 4 LAYERS FABRIC, BMS 8-139					
			2				-8	SKIN		.020 (REF) (0, ±45, 90)s LAYUP 14 17 5					
			1				-7	CORE		.75 × 2.05 × 3.05 11					
				2			-6	SKIN		.015 (REF) (0 ±45)s LAYUP 14 17 5					
				1			-5	CORE		.50 × 2.05 × 6.05 12					
					1		-4	ANGLE CLIP		.100 (REF) (0, ±45, 90)2s LAYUP 14 17 5					
			–		1		-3	COVER ASSY		4 5					
				–	1		-2	WEB ASSY		4 5					
					–		-1	SPECIMEN, TYPE 2, BOLTED ASSY		4 7				3	

PARTS LIST

TEST MATRIX 5	TEST ONLY		
PART NUMBER	NEXT ASSY	USED ON	EFFECTIVITY
APPLICATION			

FASTENER CODES

DIMENSIONING & TOLERANCING PER ANSI (USASI) Y14.5
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ANGLES 2
DECIMALS XX ±
DECIMALS XXX ±
RIVET & BOLT EDGE MARGINS
BEND RADII
SHEET METAL CORNER RADII

REVIEW & APPROVAL
DRG QUAL
CHANGE/ITEM NUMBER

CONTRACT NUMBER NAS1-15644
DR K.W. OSBORNE 7-28-80
CHK
ENGR
GRP
PROJECT APPROVAL

THE BOEING COMPANY
CORPORATE OFFICES SEATTLE, WASHINGTON

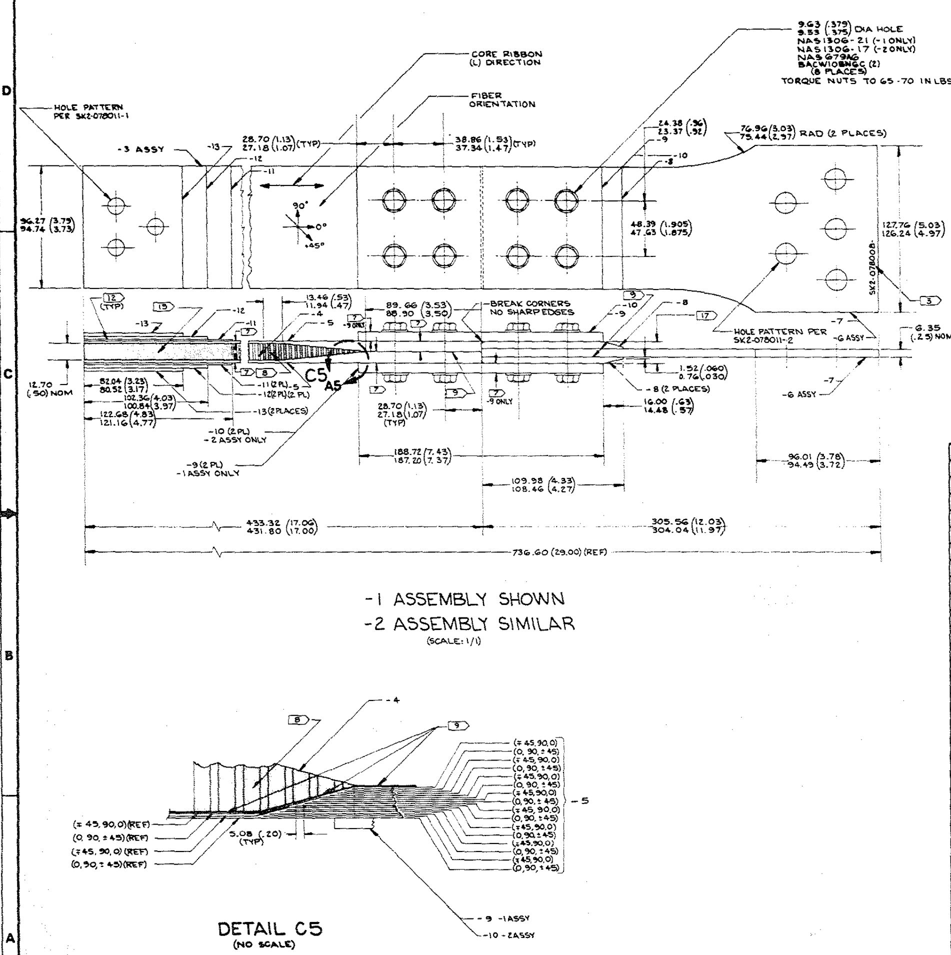
SPECIMEN, TYPE 2, BOLTED-ADV. G/P. COMPOSITE JOINT, CONCEPT DISCRIMINATOR TESTS

SIZE J CODE IDENT NO 81205 SK2-078006
SCALE 1/1

DWG ORIG BY (ORG) 2-3614

FIGURE : B-4

SK2-078006



NOTES

1 SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)

FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300 — BOLT & NUT INSTALLATION PER BAC 5009

RIVET INSTALLATION & SYMBOLS PER BAC 5004 — PART MARKING PER BAC 5307

FINISH CODES PER DOCUMENT D2 4000

2. XX. XXX MILLIMETERS (XX.XX INCHES) TOLERANCE ANGLES: ±1°

3. PART MARK USING FELT TIP PEN AT LOCATION INDICATED.

4. FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPREG". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.

5. INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDI TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".

6. IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMALIES.

7. RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.

8. BMS 8-126 TYPE 1, POLYIMIDE STRUCTURAL FOAM. INSTALL FOAM TO FULL DEPTH OF CORE, OVER THE AREA DESIGNATED, PRIOR TO ASSEMBLY OF CORE AND FACE SKINS. CURE AND POSTCURE FOAM PER BMS 8-126.

9. A7F-BLENDED AND PROCESSED PER D180-20545-5A, EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 psi. WHEN TESTED PER BSS 7202, TYPE V. THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSY.

10. HRH-327-3/16-4 (64.1 kg/m³ (816/ft³)) FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.

12. BMS 5-51, TYPE 2, GRADE 10 OR BMS 5-101, TYPE 2, GRADE 10. BOND IN ACCORDANCE WITH BAC 5514. ITEM -11, -12, & -13 TO -3 ASSY

13. CELION 6000 (NR 150B2G FINISH)/PMR-15 PREPREG PER D180-20545-4A.

14. STRIP PER BAC 5771, APPLY DRY FILM LUBRICANT PER BAC 5811, TYPE VIII, CLASS 1.

15. FINAL ASSEMBLY OPERATION: REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5-28 TYPES TYPE 5 OR TYPE 6.

16. THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, e.g., (0/90/±45)

0
90
+45
-45

17. AFTER BONDING -8 TO -7 THIS THICKNESS SHALL BE CHEM-MILLED TO MATCH TOTAL THICKNESS OF THE -3 COVER ASSY

18. 6AL-4V TITANIUM PLATE PER MIL-T-9046, TYPE III, COMP C, ANNEALED

PARTS LIST

QTY REQD	QTY REQD	QTY REQD -6	QTY REQD -3	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	HT TR	FINISH	PT MK	REV LTR
				16	16		BACW10BNGC	WASHER		14					
				8	8		NAS679A3	NUT		14					
					8		NAS1306-21	BOLT		14					
				8			NAS1306-17	BOLT		14					
		AR	AR				A7F	ADHESIVE		9					
			AR				BMS 8-126	POTTING		8					
				AR	AR		BMS 5-51	ADHESIVE		12					
			AR				BMS 5-28	POTTING		15					
				2	2		-13	REINFORCEMENT		.100 × 3.85 × 3.25 2024-T4 ALUM SHEET 12					
				2	2		-12	REINFORCEMENT		.100 × 3.85 × 4.05 2024-T4 ALUM SHEET 12					
				2	2		-11	REINFORCEMENT		.050 × 3.85 × 4.85 2024-T4 ALUM SHEET 12					
				2			-10	SPLICE PLATE		.125 × 3.85 × 7.45 18					
					2		-9	SPLICE PLATE		$(0, \pm 45, 90)_{7S}$ LAYUP 5 13 16					
		2					-8	DOUBLER		.250 × 3.85 × 4.30 18					
		1					-7	PLATE		.250 × 5.05 × 12.05 18					
		—		1	1		-6	PLATE ASSY		6 9					
			2				-5	SKIN		LAYUP (SEE DET C5) 5 13					
			1				-4	CORE		.50 × 3.80 × 14.00 10					
				1	1		-3	COVER ASSY		4 5					
				—			-2	SPECIMEN, TYPE 3, BOLTED-TITANIUM SPLICE PLATE		4 6					
					—		-1	SPECIMEN, TYPE 3, BOLTED Gr/Pi SPLICE PLATE		4 6				3	

CONTRACT NUMBER	NAS1-15644
DRN	E.W. OSBORNE 7-21-80
THE BOEING COMPANY	CORPORATE OFFICES SEATTLE, WASHINGTON
TITLE	SPECIMEN, TYPE 3, BOLTED-ADV. Gr/Pi COMPOSITE JOINT, CONCEPT DISCRIMINATOR TESTS
SIZE / CODE IDENT NO	J 81205
DRAWING NO	SK2-078008
SCALE	NOTED
DWG ORIG BY (ORG)	2-3614

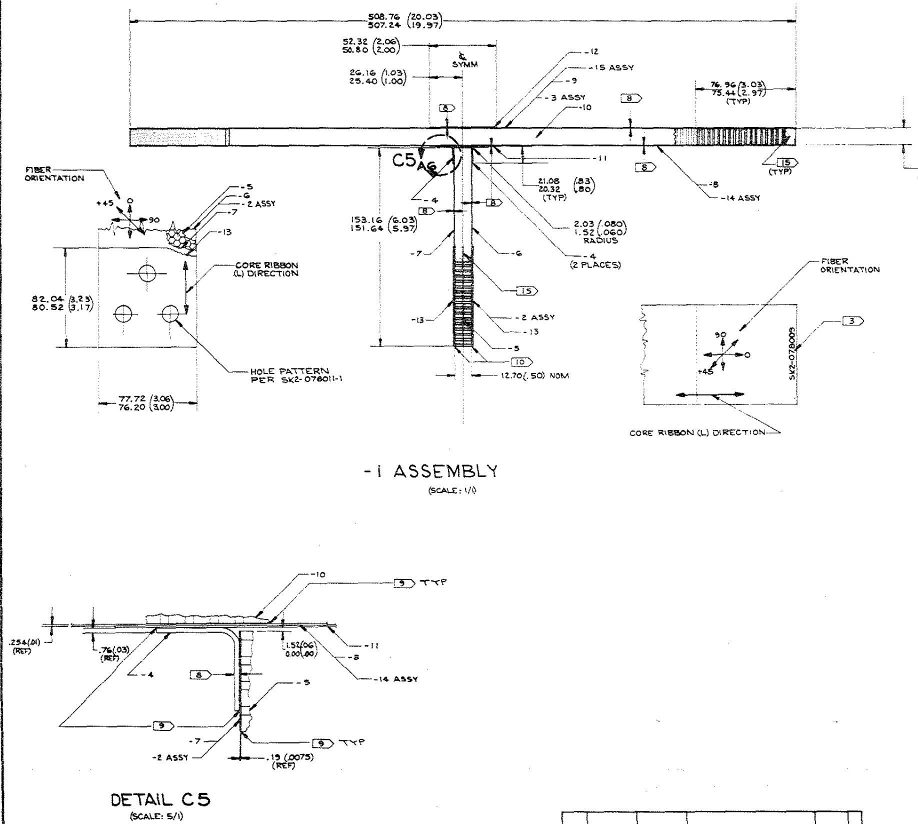
TEST MATRIX 5	TEST ONLY
APPLICATION	

SK2-078008

, FIGURE B-5

NOTES

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE).
   FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300 — BOLT & NUT INSTALLATION PER BAC 5009
   RIVET INSTALLATION & SYMBOLS PER BAC 5004 — PART MARKING PER BAC 5307
   FINISH CODES PER DOCUMENT D2-5000
2. XX.XXX MILLIMETERS (XX.XX INCHES) TOLERANCE ON ANGLES: ±1°
3. PART MARK USING FELT TIP PEN AT LOCATION INDICATED.
4. FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPREG". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.
5. INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDI TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".
6. INSPECT LAMINATE TO LAMINATE BONDED JOINTS USING ULTRASONIC 'C' SCAN TEST METHODS. SENSITIVITY OF 'C' SCAN TO BE DETERMINED.
7. IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMOLIES.
8. RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.
9. A7F-BLENDED AND PROCESSED PER D180-20545-5A; EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 psi., WHEN TESTED PER BSS 7202, TYPE V. THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSY.
10. BMS 5-51, TYPE 2, GRADE 10 or BMS 5-101, TYPE 2, GRADE 10. BOND IN ACCORDANCE WITH BAC 5514. ITEM -13 TO ASSY. OF -5, -6 & -7
11. CELION 3000 (NR 150B2G FINISH)/PMR-15 PREPREG PER D180-20545-4A.
12. HRH-327 -3/16-4 (64.1 kg/m^3 (4lb/ft^3)) FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.
13. CLEAN PER BAC 5514.
14. THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, e.g.:
    -45 / +45 / 90 / 0 — (0/90/±45)
15. FINAL ASSEMBLY OPERATION: REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5-28 TYPE 5 OR TYPE 6.



PARTS LIST

QTY REQD	QTY REQD -15	QTY REQD -14	QTY REQD -3	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	HT TR	FINISH	PT MK	REV LTR
				AR			BMS 5-51	ADHESIVE		10					
			AR	AR	AR		A7F	ADHESIVE		9					
					AR		BMS 5-28	POTTING		15					
	-		1				-15	SKIN ASSY		CO-CURE -9 & -12 4 5 8					
		-	1				-14	SKIN ASSY		CO-CURE -8 & -11 4 5 8					
				2			-13	DOUBLER		.040 × 3.05 × 3.25 2024-T4 ALUM SHEET 13					
	1						-12	REINFORCEMENT		.010 REF (±45,90,0) LAYUP 11 14					
		1					-11	REINFORCEMENT		.010 REF (±45,90,0) LAYUP 11 14					
			1				-10	CORE		.50 × 3.00 × 20.00 12					
	1						-9	SKIN		.010 REF (0,90,±45) LAYUP 11 14					
		1					-8	SKIN		.010 REF (0,90 ±45) LAYUP 11 14					
				1			-7	SKIN		.0075 REF (±45,0) LAYUP 8 11 14 5					
				1			-6	SKIN		.0075 REF (±45,0) LAYUP 11 14 8 5					
				1			-5	CORE		.50 × 3.00 × 6.00 12					
					2		-4	ANGLE CLIP		.030 REF (±45,0,90$_3$)$_s$ LAYUP 11 14 8					
			-		1		-3	COVER ASSY		4 5					
				-	1		-2	WEB ASSY		4 5					
					-		-1	SPECIMEN, TYPE 4, BONDED ASSY		4 6 7				3	

DIMENSIONING & TOLERANCING PER ANSI Y14.5
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN [illegible]
TOLERANCES: ANGLES ±1 2
CONTRACT NUMBER NAS1-15644
DR KW. OSBORNE 7-22-80
THE BOEING COMPANY — CORPORATE OFFICES SEATTLE, WASHINGTON
SPECIMEN, TYPE 4, BONDED-ADV. G$_r$/P$_i$ COMPOSITE JOINT, CONCEPT DISCRIMINATOR TESTS
J 81205 SK2-078009

PART NUMBER	NEXT ASSY	USED ON	EFFECTIVITY	DWG IN NUMBER	REV LTR
		TEST MATRIX 3	TEST ONLY		

APPLICATION

FASTENER CODES

2-3614

SK2-078009

FIGURE B-6

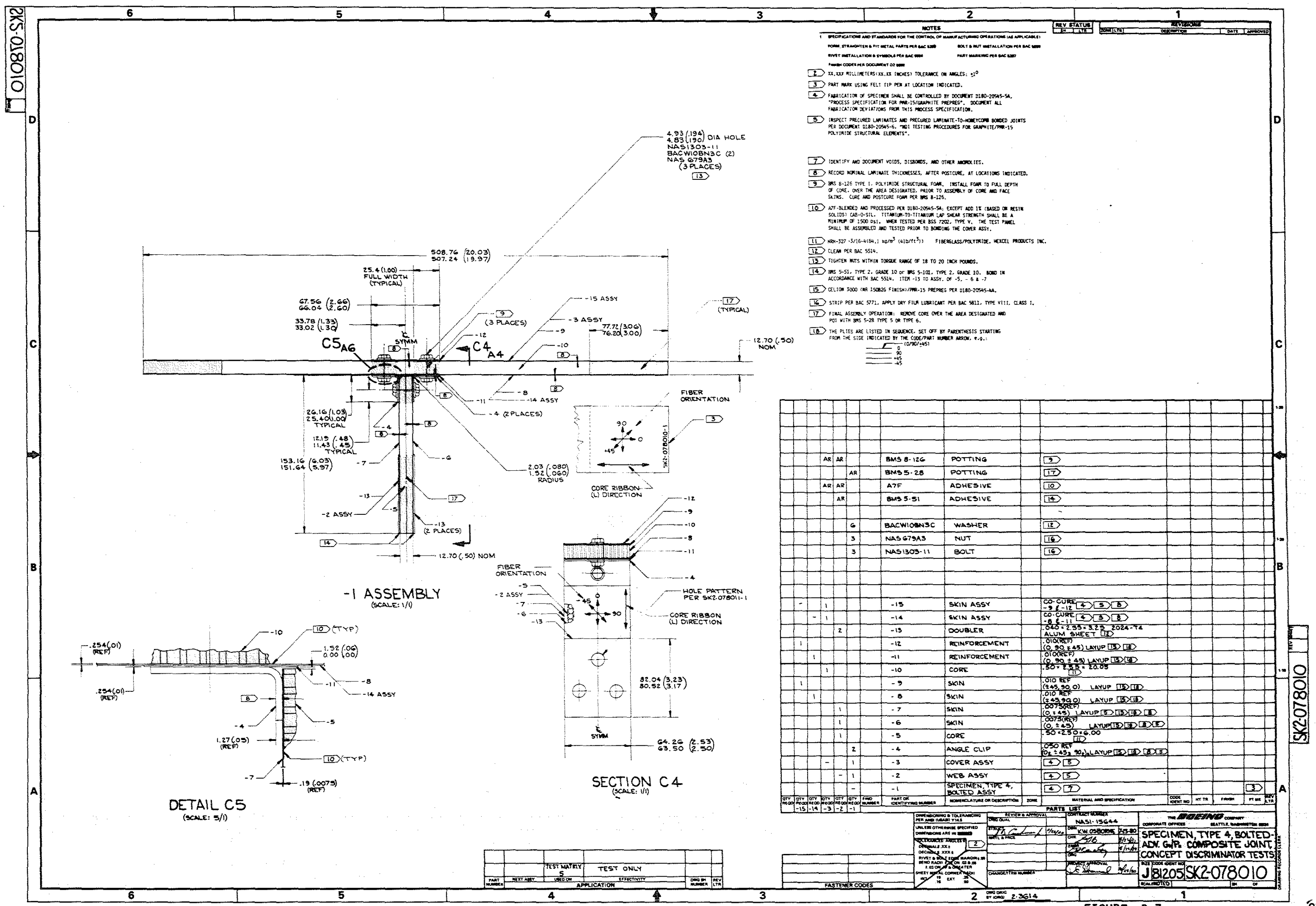

NOTES
1 SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)
2 XX.XXX MILLIMETERS (XX.XX INCHES) TOLERANCE ON ANGLES: ±1°
3 PART MARK USING FELT TIP PEN AT LOCATION INDICATED.
4 FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPREG". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.
5 INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDI TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".
7 IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMOLIES.
8 RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.
9 BMS 8-126 TYPE I. POLYIMIDE STRUCTURAL FOAM. INSTALL FOAM TO FULL DEPTH OF CORE, OVER THE AREA DESIGNATED, PRIOR TO ASSEMBLY OF CORE AND FACE SKINS. CURE AND POSTCURE FOAM PER BMS 8-126.
10 A7F-BLENDED AND PROCESSED PER D180-20545-5A; EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 psi, WHEN TESTED PER BSS 7202, TYPE V. THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSY.
11 HRH-327 -3/16-4(64.1 kg/m³ (4lb/ft³)) FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.
12 CLEAN PER BAC 5514.
13 TIGHTEN NUTS WITHIN TORQUE RANGE OF 18 TO 20 INCH POUNDS.
14 BMS 5-51, TYPE 2, GRADE 10 or BMS 5-101, TYPE 2, GRADE 10. BOND IN ACCORDANCE WITH BAC 5514. ITEM -13 TO ASSY. OF -5, - 6 & -7
15 CELION 3000 (NR 150B2G FINISH)/PMR-15 PREPREG PER D180-20545-4A.
16 STRIP PER BAC 5771. APPLY DRY FILM LUBRICANT PER BAC 5811, TYPE VIII, CLASS I.
17 FINAL ASSEMBLY OPERATION: REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5-28 TYPE 5 OR TYPE 6.
18 THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, e.g.: (0/90/±45)
-1 ASSEMBLY (SCALE: 1/1)
DETAIL C5 (SCALE: 5/1)
SECTION C4 (SCALE: 1/1)
PARTS LIST
BMS 8-126 POTTING
BMS 5-28 POTTING
A7F ADHESIVE
BMS 5-51 ADHESIVE
BACW10BN3C WASHER
NAS679A3 NUT
NAS1303-11 BOLT
-15 SKIN ASSY
-14 SKIN ASSY
-13 DOUBLER
-12 REINFORCEMENT
-11 REINFORCEMENT
-10 CORE
-9 SKIN
-8 SKIN
-7 SKIN
-6 SKIN
-5 CORE
-4 ANGLE CLIP
-3 COVER ASSY
-2 WEB ASSY
-1 SPECIMEN, TYPE 4, BOLTED ASSY
NAS1-15644
THE BOEING COMPANY
SPECIMEN, TYPE 4, BOLTED-ADV. G/P. COMPOSITE JOINT, CONCEPT DISCRIMINATOR TESTS
J81205 SK2-078010

FIGURE B-7

APPENDIX C

"STATIC DISCRIMINATOR" TEST RESULTS

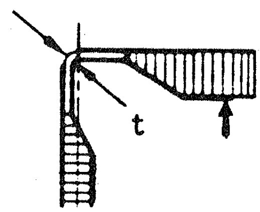
Table C-1: STATIC DISCRIMINATOR TEST RESULTS

TYPE 1 BONDED

SPECIMEN NUMBER	TEMPERATURE K	(°F)	WIDTH mm	(in)	ULTIMATE LOAD kN/m	(lb/in)
5-1A-1-4	294	(70)	74.9	(2.99)	451	(2575)
5-1A-1-6	294	(70)	76.2	(3.00)	457	(2613)
5-1A-1-7	294	(70)	75.2	(2.96)	434	(2480)
5-1A-1-1	561	(550)	76.2	(3.00)	404	(2307)
5-1A-1-2	561	(550)	76.2	(3.00)	361	(2060)
5-1A-1-3	561	(550)	76.2	(3.00)	370	(2110)

TYPE 1 BOLTED

5-1B-1-1	294	(70)	76.7	(3.02)	522	(2980)
5-1B-1-2	294	(70)	76.4	(3.01)	564	(3223)
5-1B-1-3	294	(70)	76.4	(3.01)	436	(2492)
5-1B-1-5	561	(550)	76.4	(3.01)	455	(2598)
5-1B-1-6	561	(550)	76.4	(3.01)	390	(2226)
5-1B-1-7	561	(550)	76.4	(3.01)	451	(2578)



TYPE 2 BONDED

SPECIMEN NUMBER	TEMPERATURE K	(°F)	WIDTH mm (in)	MOMENT ARM mm (in)	ULTIMATE MOMENT N-m/m (in-lb/in)	LATERAL DEFLECTION mm (in)	ANGLE THICKNESS (t) mm (in)
5-2A-1-4	294	(70)	51.3 (2.02)	63.2 (2.49)	463 (104)	2.54 (.100)	2.41 (.095)
5-2A-1-5	294	(70)	51.3 (2.02)	60.5 (2.38)	423 (95)	2.24 (.088)	2.74 (.108)
5-2A-1-6	294	(70)	51.3 (2.02)	60.5 (2.38)	360 (81)	2.03 (.080)	2.41 (.095)
5-2A-1-1	561	(550)	51.3 (2.02)	60.5 (2.38)	1201 (270)	- -	2.72 (.107)
5-2A-1-2	561	(550)	51.1 (2.01)	60.5 (2.38)	343 (77)	- -	2.84 (.112)
5-2A-1-3	561	(550)	51.3 (2.02)	61.0 (2.40)	334 (75)	- -	2.41 (.095)

TYPE 2 BOLTED

5-2B-1-1	294	(70)	51.1 (2.01)	46.5 (1.83)	1281 (288)	- -
5-2B-1-2	294	(70)	50.5 (1.99)	46.2 (1.82)	1286 (289)	11.2 (.440)
5-2B-1-3	294	(70)	51.1 (2.01)	46.0 (1.81)	1290 (290)	12.2 (.480)
5-2B-1-4	561	(550)	50.8 (2.00)	46.2 (1.82)	1352 (304)	- -
5-2B-1-5	561	(550)	51.1 (2.01)	46.5 (1.83)	1677 (377)	- -
5-2B-1-6	561	(550)	50.5 (1.99)	62.7 (2.47)	1343 (302)	- -

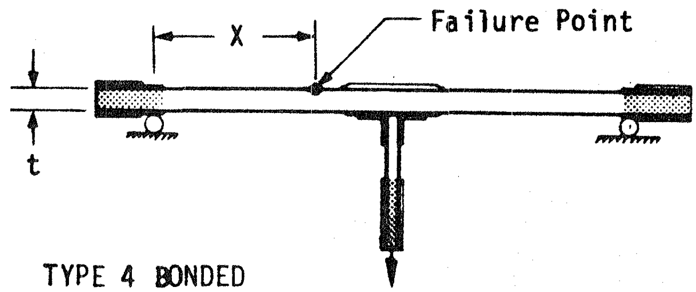
Table C-1 CONTINUED

TYPE 3 BOLTED

SPECIMEN NUMBER	TEMPERATURE K	(°F)	WIDTH mm	(in)	ULTIMATE LOAD kN/m	(lb/in)	
5-3B-1-1	294	(70)	95.8	(3.77)	1315	(7507)	
5-3B-1-1	294	(70)	95.8	(3.77)	1296	(7400)	1
5-3B-1-2	294	(70)	95.5	(3.76)	1819	(10386)	
5-3B-1-3	294	(70)	95.5	(3.76)	1707	(9747)	
5-3B-1-4	561	(550)	95.5	(3.76)	1702	(9721)	
5-3B-1-5	561	(550)	95.5	(3.76)	1723	(9840)	
5-3B-1-6	561	(550)	95.5	(3.76)	1565	(8936)	
5-3B-1-7	294	(70)	95.0	(3.74)	1934	(11043)	2

1 Specimen grips reworked and retested

2 Titanium splice plates



TYPE 4 BONDED

SPECIMEN NUMBER	TEMPERATURE K	(°F)	WIDTH mm	(in)	COVER THICKNESS (t) mm	(in)	X=MOMENT ARM AT FAILURE PT. • mm	(in)	ULTIMATE LOAD kN/m	(lb/in)
5-4A-1-4	294	(70)	77.2	(3.04)	13.3	(.523)	156	(6.13)	480	(108)
5-4A-1-5	294	(70)	76.7	(3.02)	13.4	(.526)	172	(6.78)	480	(108)
5-4A-1-6	294	(70)	77.5	(3.05)	13.4	(.526)	1		503	(113)
5-4A-1-1	561	(550)	77.5	(3.05)	13.5	(.530)	1		307	(69)
5-4A-1-2	561	(550)	77.0	(3.03)	13.5	(.530)	1		356	(80)
5-4A-1-3	561	(550)	77.0	(3.03)	13.4	(.528)	181	(7.13)	262	(59)
5-4A-1-7	294	(70)	77.0	(3.03)	13.4	(.529)	1		881	(198) 2

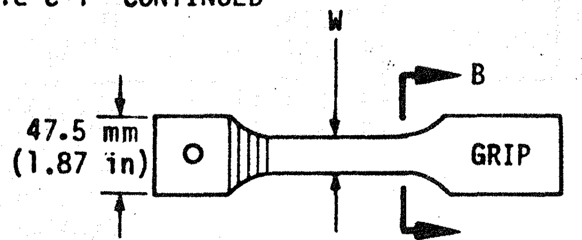
1 Web attachment angles pulled off.

2 Support span was 80 mm (3.15 in), all other specimens were 413 mm (16.26 in)

TYPE 4 BOLTED

5-4B-1-4	294	(70)	63.2	(2.49)	13.3	(.523)	147	(5.80)	614	(138)
5-4B-1-5	294	(70)	63.5	(2.50)	13.2	(.518)	162	(6.38)	538	(121)
5-4B-1-6	294	(70)	63.5	(2.50)	13.3	(.525)	154	(6.06)	543	(122)
5-4B-1-1	561	(550)	63.5	(2.50)	13.2	(.520)	165	(6.48)	440	(99)
5-4B-1-2	561	(550)	63.2	(2.48)	13.2	(.518)	172	(6.78)	311	(70)
5-4B-1-3	561	(550)	63.0	(2.49)	13.2	(.520)	173	(6.83)	374	(84)

Table C-1 CONTINUED



INTERLEAVED DOUBLERS

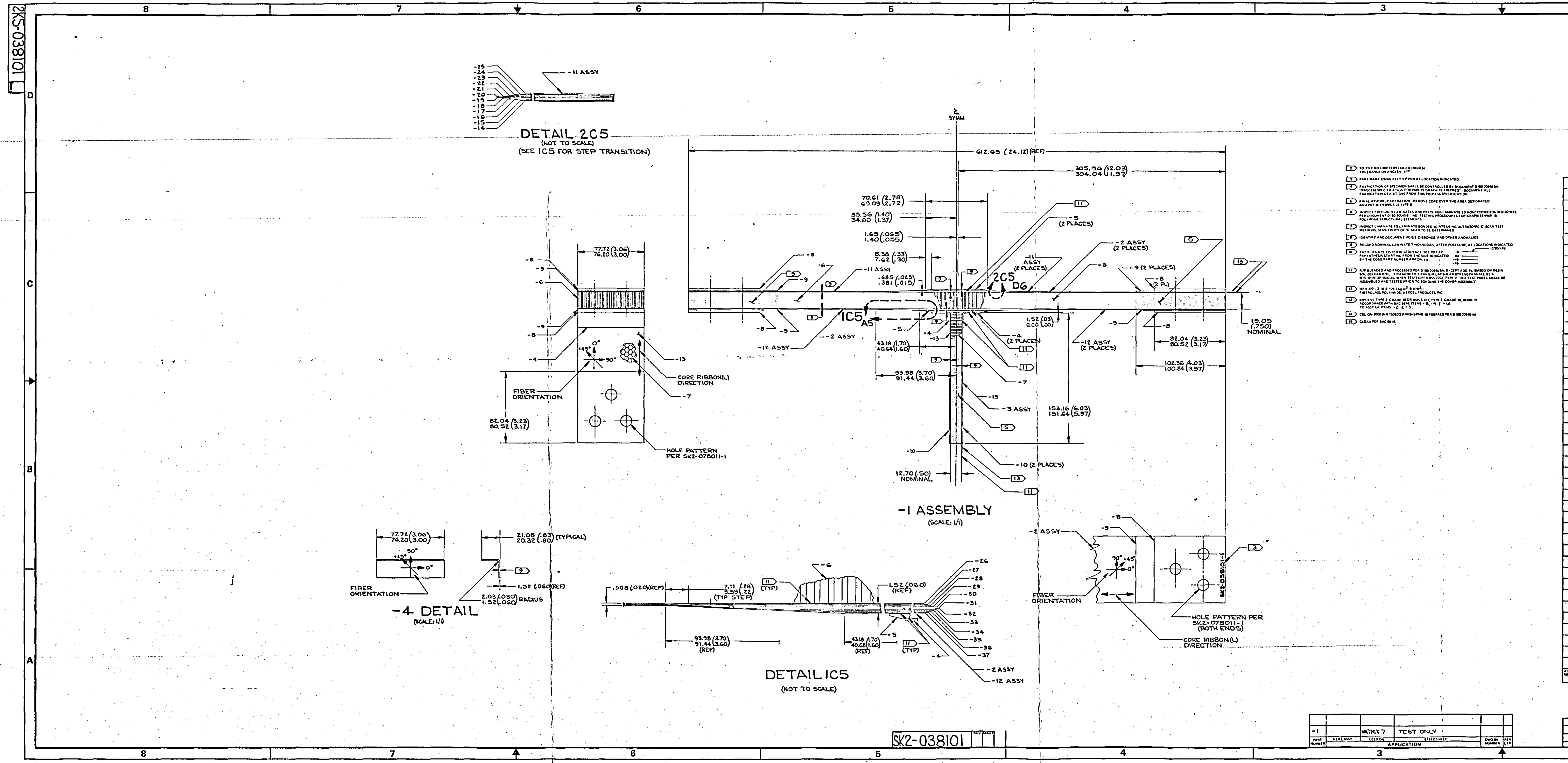
SPECIMEN NUMBER	TEMPERATURE K (°F)	DOUBLER THICKNESS mm (in)	NECK THICKNESS mm (in)	NECK WIDTH (W) mm (in)	ULTIMATE LOAD kN (lb)	ULTIMATE STRESS @ SECTION B MPa (ksi)	
5-6A-1-1	294 (70)	1.73(.068)	.56(.022)	48.0(1.891)	7.96(1790)	296 (43.0)	1
5-6A-1-2	294 (70)	1.70(.067)	.56(.022)	48.4(1.904)	8.90(2000)	328 (47.5)	1
5-6A-1-3	294 (70)	1.73(.068)	.56(.022)	47.3(1.861)	7.45(1675)	279 (40.5)	1
5-6A-1-4	294 (70)	1.70(.067)	.56(.022)	22.1 (.870)	6.07(1365)	490 (71.0)	2
5-6A-1-5	561 (550)	1.70(.067)	.56(.022)	21.7 (.856)	5.32(1195)	431 (62.5)	2
5-6A-1-6	561 (550)	1.75(.069)	.56(.022)	22.2 (.874)	6.05(1360)	490 (71.0)	2
5-6A-1-7	561 (550)	1.83(.072)	.56(.022)	22.2 (.873)	6.21(1395)	493 (71.5)	2
5-6B-1-1	294 (70)	2.87(.112)	.58(.023)	21.8 (.859)	6.23(1400)	496 (72.0)	2
5-6B-1-2	294 (70)	2.87(.113)	.56(.022)	22.0 (.868)	6.01(1350)	490 (71.0)	2
5-6B-1-3	294 (70)	2.87(.113)	.56(.022)	21.8 (.859)	5.20(1170)	434 (63.0)	2
5-6B-1-4	561 (550)	2.84(.112)	.58(.023)	22.2 (.874)	6.43(1445)	493 (71.5)	2
5-6B-1-5	561 (550)	2.84(.112)	.58(.023)	22.1 (.871)	6.94(1560)	531 (77.0)	2
5-6B-1-6	561 (550)	2.92(.115)	.56(.022)	22.0 (.866)	6.49(1460)	521 (75.5)	2

1 Failure at grip end.

2 Failed in necked down area.

APPENDIX D

FINAL JOINT DESIGN DRAWINGS



QTY REQD	QTY REQD -12	QTY REQD -11	QTY REQD -3	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	HT TR	FINISH	PT MK	REV LTR
			AR	AR	AR		A7F	ADHESIVE		11					
					AR		BMS 5-51	ADHESIVE		13					
			AR	AR			BMS 5-28	POTTING		5					
	1						-37	FIBER LAYUP		(-45/0) 10 14					
	1						-36			(+45/0)					
	1						-35			(0/-45)					
	1						-34			(90/+45)					
	1						-33			(+45/0)					
	1						-32			(0/-45)					
	1						-31			(+45/0)					
	1						-30			(0/-45)					
	1						-29			(+45/90)					
	1						-28			(+45/0)					
	1						-27			(0/-45)					
	1						-26			(0/-45)					
		1					-25			(+45/0)					
		1					-24			(-45/0)					
		1					-23			(0/+45)					
		1					-22			(90/-45)					
		1					-21			(-45/0)					
		1					-20			(0/+45)					
		1					-19			(-45/0)					
		1					-18			(0/+45)					
		1					-17			(-45/90)					
		1					-16			(-45/0)					
		1					-15			(0/+45)					
		1					-14	FIBER LAYUP		(0/+45) 10 14					
			2				-13	SKIN ASSY		$(0/\pm 45)_S$ 4 6 9 10 14					
	–			1			-12	SKIN ASSY		CO-CURE -26 THRU-37 4 6 9					
		–		1			-11	SKIN ASSY		CO-CURE -14 THRU-25 4 6 9					
					2		-10	DOUBLER		.040 × 3.05 × 3.20 2024-T4 ALUM SHEET 15					
					4		-9	DOUBLER		.020 × 3.05 × 4.05 2024-T4 ALUM SHEET 15					
					4		-8	DOUBLER		.080 × 3.05 × 3.25 2024-T4 ALUM SHEET 15					
			1				-7	CORE		.50 × 3.00 × 6.00 12					
				1			-6	CORE		.75 × 3.00 × 12.00 12					
					2		-5	SPLICE PLATE		$(0/+45/0_2/-45/0)_{2S}$ LAYUP 4 6 9 10 14					
					2		-4	ANGLE		$(\pm 45/0/90_3)_{2S}$ LAYUP 4 6 9 10 14					
			–		1		-3	WEB ASSY		4 6					
				–	2		-2	COVER ASSY		4 6					
					–		-1			4 7 8				3	

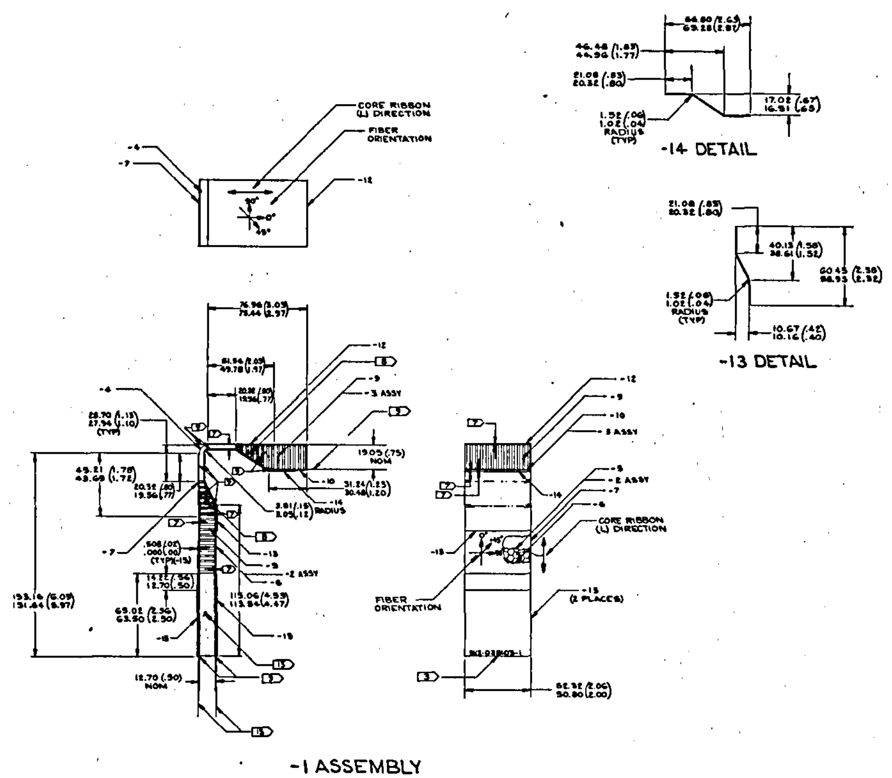
PARTS LIST

CONTRACT NUMBER NAS1-15644
DWN K.W. OSBORNE
THE BOEING COMPANY
CORPORATE OFFICES SEATTLE, WASHINGTON
SPECIMEN, TYPE 1 BONDED-Gr/Pi COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4
J 81205 SK2-038101

Figure D-1


DETAIL 2C5
(NOT TO SCALE)
(SEE 1C5 FOR STEP TRANSITION)
B5
(SCALE: 1/1)
-4
(SCALE: 1/1)
-1 ASSEMBLY
(SCALE: 1/1)
DETAIL 1C5
(NOT TO SCALE)
FIBER ORIENTATION
HOLE PATTERN PER SK2-078011-1
CORE RIBBON (L) DIRECTION
NOTES
PARTS LIST
SPECIMEN, TYPE I, BOLTED Gr/PI COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4
SK2-038102
TEST ONLY
2K5-038105

Figure D-2



QTY -3	QTY -2	QTY -1	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	MATERIAL AND SPECIFICATION
AR	AR	AR	A7F	ADHESIVE	5
		AR	BMS 5-104	ADHESIVE	15
AR	AR		BMS 8-126	POTTING	8
		AR	BMS 5-28	POTTING	13
	2		-15	TAB, REINFORCEMENT	.040(REF) 4 LAYERS FABRIC, BMS 8-139
		1	-14	REINFORCEMENT	.040(REF) (0,±45,90)2S LAYUP 5 11 14
		1	-13	REINFORCEMENT	.030(REF) (0,±45)2S LAYUP 5 11 14
1			-12	SKIN	.020(REF) (0,±45,90)S LAYUP 5 10 14
1			-10	SKIN	.020(REF) (0,±45,90)S LAYUP 5 10 14
1			-9	CORE	.75 × 2.05 × 3.25 10
	1		-7	SKIN	.015(REF) (0,±45)S LAYUP 5 12 14
	1		-6	SKIN	.015(REF) (0,±45)S LAYUP 5 12 14
	1		-5	CORE	.50 × 2.05 × 5.25 11
		1	-4	ANGLE	.120(REF) (0,±45,90)2S LAYUP 5 11 14
-		1	-3	COVER ASSY	4 5
	-	1	-2	WEB ASSY	4 5
		-	-1	SPECIMEN, TYPE 2, BONDED ASSY	4 6 16

PARTS LIST

CONTRACT NUMBER NAS1-15644

K.W. OSBORNE 1-7-81

THE BOEING COMPANY

SPECIMEN, TYPE 2, BONDED-Gr/PI COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4

J 81205 SK2-038103

TEST ONLY

Figure D-3

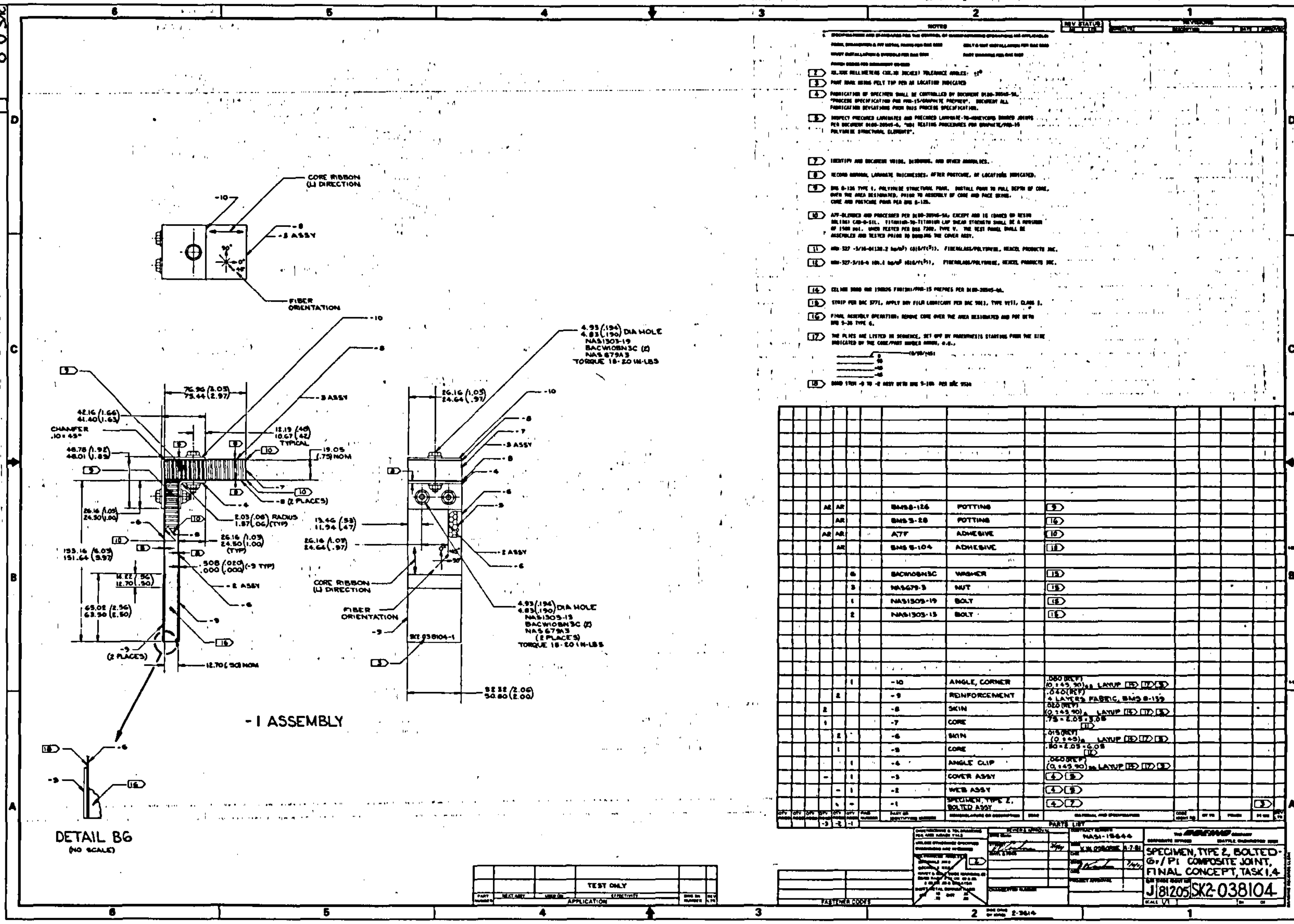
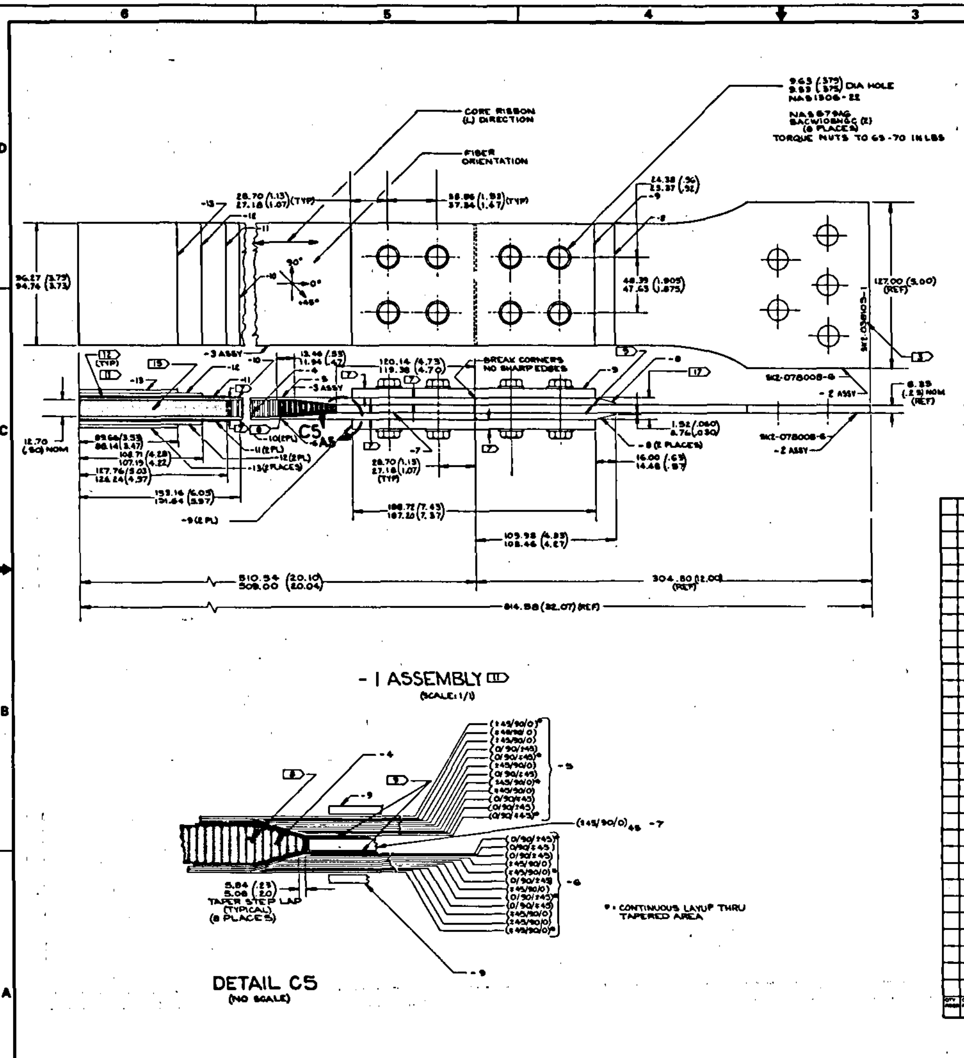

SK2-038104
- I ASSEMBLY
DETAIL BG
(NO SCALE)
CORE RIBBON (L) DIRECTION
FIBER ORIENTATION
4.93 (.194) 4.83 (.190) DIA HOLE
NAS1303-19
BACW10BN3C (2)
NAS679A3
TORQUE 18-20 IN-LBS
4.93 (.194) 4.83 (.190) DIA HOLE
NAS1303-13
BACW10BN3C (2)
NAS679A3
(2 PLACES)
TORQUE 18-20 IN-LBS
CHAMFER .10 × 45°
19.05 (.75) NOM
12.70 (.50) NOM
TEST ONLY
APPLICATION
NOTES
REVISIONS
PARTS LIST
BMS8-126 POTTING
BMS5-28 POTTING
A7F ADHESIVE
BMS8-104 ADHESIVE
BACW10BN3C WASHER
NAS679-3 NUT
NAS1303-19 BOLT
NAS1303-13 BOLT
-10 ANGLE, CORNER
-9 REINFORCEMENT
-8 SKIN
-7 CORE
-6 SKIN
-5 CORE
-4 ANGLE CLIP
-3 COVER ASSY
-2 WEB ASSY
-1 SPECIMEN, TYPE 2, BOLTED ASSY
NAS1-15644
SPECIMEN, TYPE 2, BOLTED-Gr/PI COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4
J81205 SK2-038104
FASTENER CODES

Figure D-4



QTY -3	QTY -2	QTY -1	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	MATERIAL AND SPECIFICATION
	1		SK2-078008-6	PLATE	
		16	BACW10BN6C	WASHER	14
		8	NAS679A6	NUT	14
		8	NAS1306-22	BOLT	14
AR	AR		A7F	ADHESIVE	9
AR			BMS8-126	POTTING	8
		AR	BMS5-51	ADHESIVE	12
AR			BMS5-28	POTTING	15
		2	-13	REINFORCEMENT	.100 × 3.85 × 5.25 2024-T4 ALUM SHEET 12 19
		2	-12	REINFORCEMENT	.100 × 3.85 × 4.05 2024-T4 ALUM SHEET 12 19
		2	-11	REINFORCEMENT	.050 × 3.85 × 4.85 2024-T4 ALUM SHEET 12 19
		2	-10	REINFORCEMENT	
		2	-9	SPLICE PLATE	$(0, \pm 45, 90)_{76}$ LAYUP 5 13 16
	2		-8	DOUBLER	.250 × 3.85 × 4.30 18
1			-7	FILLER	LAYUP (SEE DET C5) 5 13
1			-6	SKIN ASSY	LAYUP (SEE DET C5) 5 13
1			-5	SKIN ASSY	LAYUP (SEE DET C5) 5 13
1			-4	CORE	.50 × 3.80 × 14.00 10
		1	-3	COVER ASSY	4 5
	–	1	-2	PLATE ASSY	6 5
		–	-1	SPECIMEN, TYPE 3, BOLTED Gr/PI SPLICE PLATE	4 6

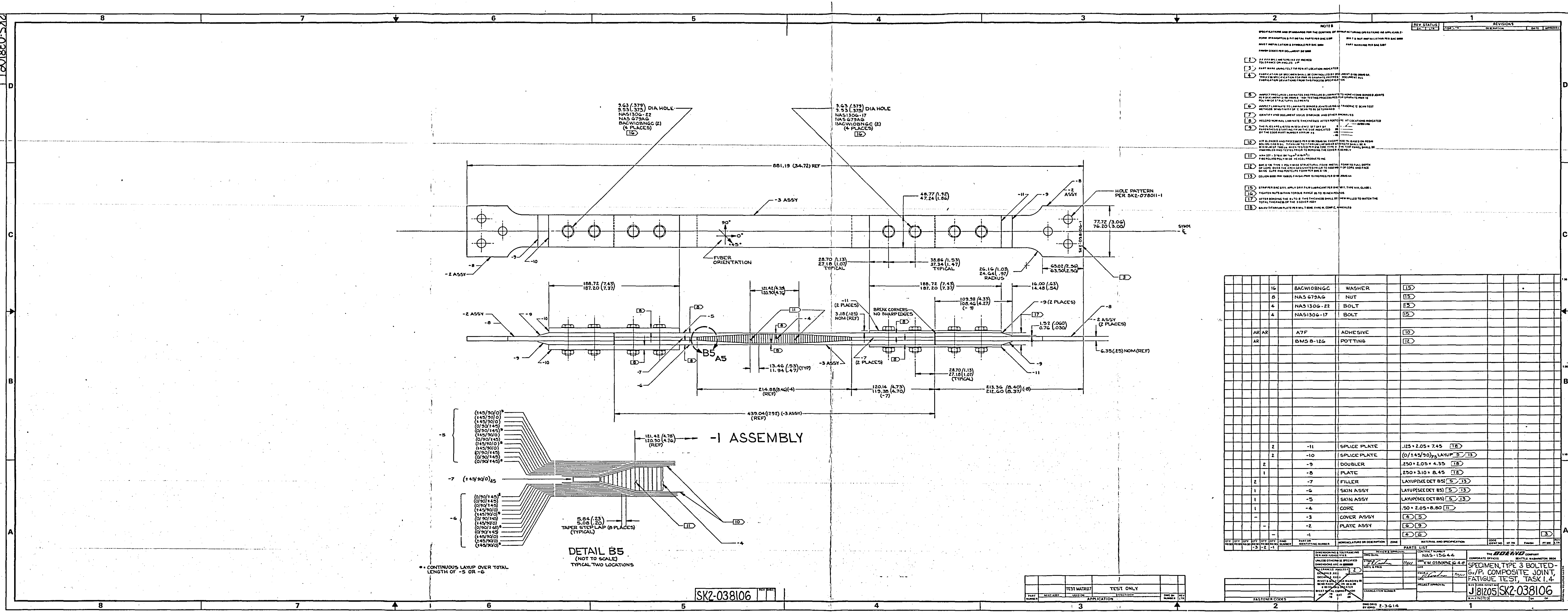
PARTS LIST

CONTRACT NUMBER NAS1-15644

SPECIMEN, TYPE 3, BOLTED-Gr/PI COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4

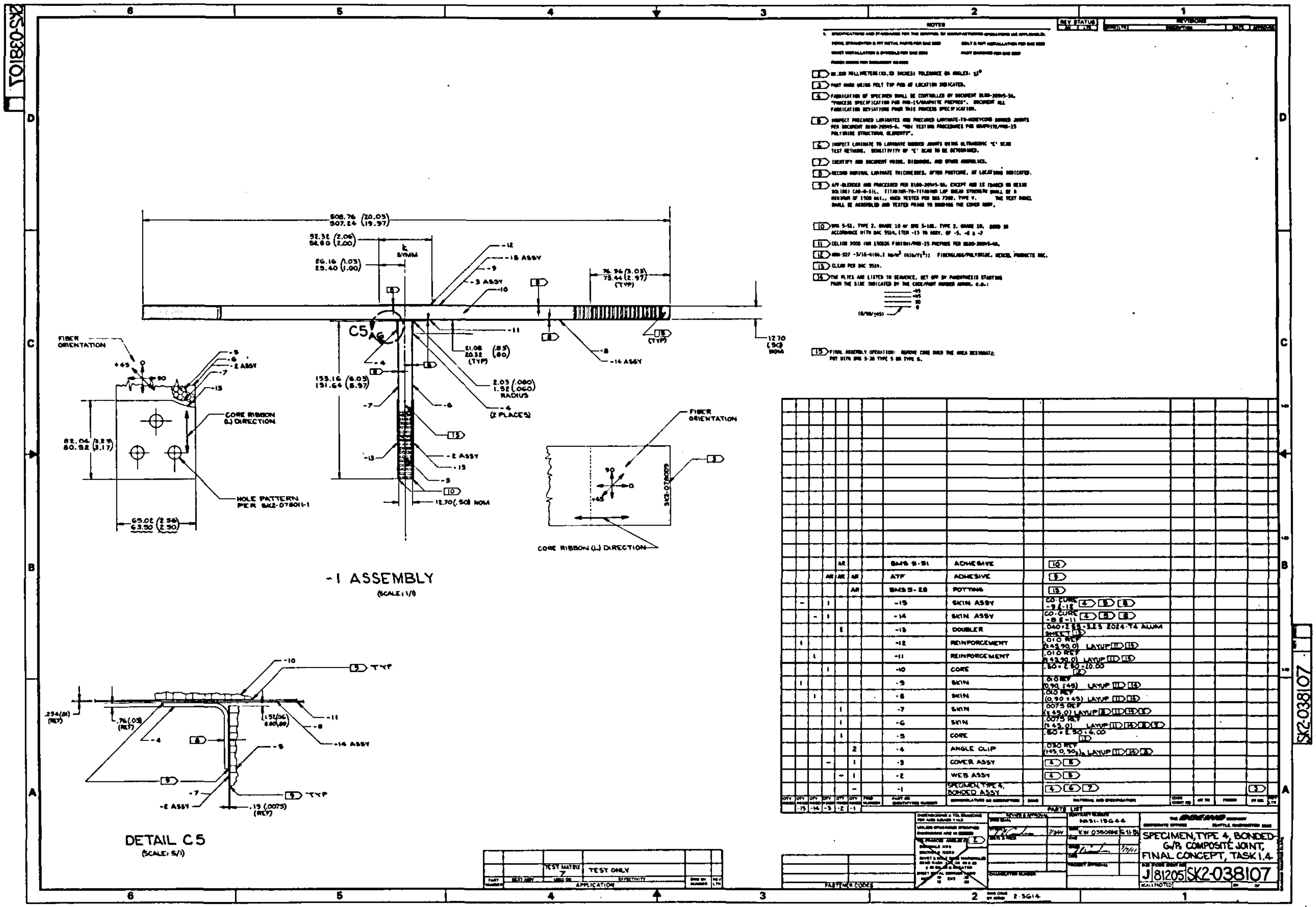
J 81205 SK2-038105

Figure D-5



-1 ASSEMBLY
DETAIL B5
(NOT TO SCALE)
TYPICAL TWO LOCATIONS
HOLE PATTERN PER SK2-078011-1
FIBER ORIENTATION
BREAK CORNERS NO SHARP EDGES
* CONTINUOUS LAYUP OVER TOTAL LENGTH OF -5 OR -6
TAPER STEP LAP (8 PLACES) (TYPICAL)
PARTS LIST
16 BACW10BNGC WASHER
8 NAS 679AG NUT
4 NAS1306-22 BOLT
4 NAS1306-17 BOLT
AR AR A7F ADHESIVE
AR BMS 8-126 POTTING
2 -11 SPLICE PLATE .125 × 2.05 × 7.45
2 -10 SPLICE PLATE (0/±45/90)7S LAYUP
2 -9 DOUBLER .250 × 2.05 × 4.35
1 -8 PLATE .250 × 3.10 × 8.45
2 -7 FILLER LAYUP (SEE DET B5)
1 -6 SKIN ASSY LAYUP (SEE DET B5)
1 -5 SKIN ASSY LAYUP (SEE DET B5)
1 -4 CORE .50 × 2.05 × 8.80
-3 COVER ASSY
-2 PLATE ASSY
-1
FASTENER CODES
CONTRACT NUMBER NAS-15644
THE BOEING COMPANY
CORPORATE OFFICES SEATTLE, WASHINGTON
DWN K.W. OSBORNE
SPECIMEN, TYPE 3 BOLTED-Gr/P. COMPOSITE JOINT, FATIGUE TEST, TASK 1.4
J 81205 SK2-038106
SCALE NOTED
DWG ORIG BY (ORG) 2-3614
TEST MATRIX TEST ONLY
APPLICATION
SK2-038106

Figure D-6.



SPECIMEN, TYPE 4, BONDED G/R COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4
J 81205 SK2-038107
NAS1-15644
K W OSBORNE
-1 ASSEMBLY
(SCALE: 1/4)
DETAIL C5
(SCALE: 5/1)
FIBER ORIENTATION
CORE RIBBON (L) DIRECTION
HOLE PATTERN PER SK2-078011-1
TEST ONLY
APPLICATION
PARTS LIST
BMS 5-51 ADHESIVE
ATF ADHESIVE
BMS 5-28 POTTING
-15 SKIN ASSY CO-CURE -9 & -12
-14 SKIN ASSY CO-CURE -8 & -11
-13 DOUBLER .040×2.55×3.25 2024-T4 ALUM SHEET
-12 REINFORCEMENT .010 REF (±45,90,0) LAYUP
-11 REINFORCEMENT .010 REF (±45,90,0) LAYUP
-10 CORE .50×2.50×20.00
-9 SKIN .010 REF (0,90,±45) LAYUP
-8 SKIN .010 REF (0,90,±45) LAYUP
-7 SKIN .0075 REF (±45,0) LAYUP
-6 SKIN .0075 REF (±45,0) LAYUP
-5 CORE .50×2.50×6.00
-4 ANGLE CLIP .030 REF (±45,0,90) LAYUP
-3 COVER ASSY
-2 WEB ASSY
-1 SPECIMEN, TYPE 4, BONDED ASSY

Figure D-7

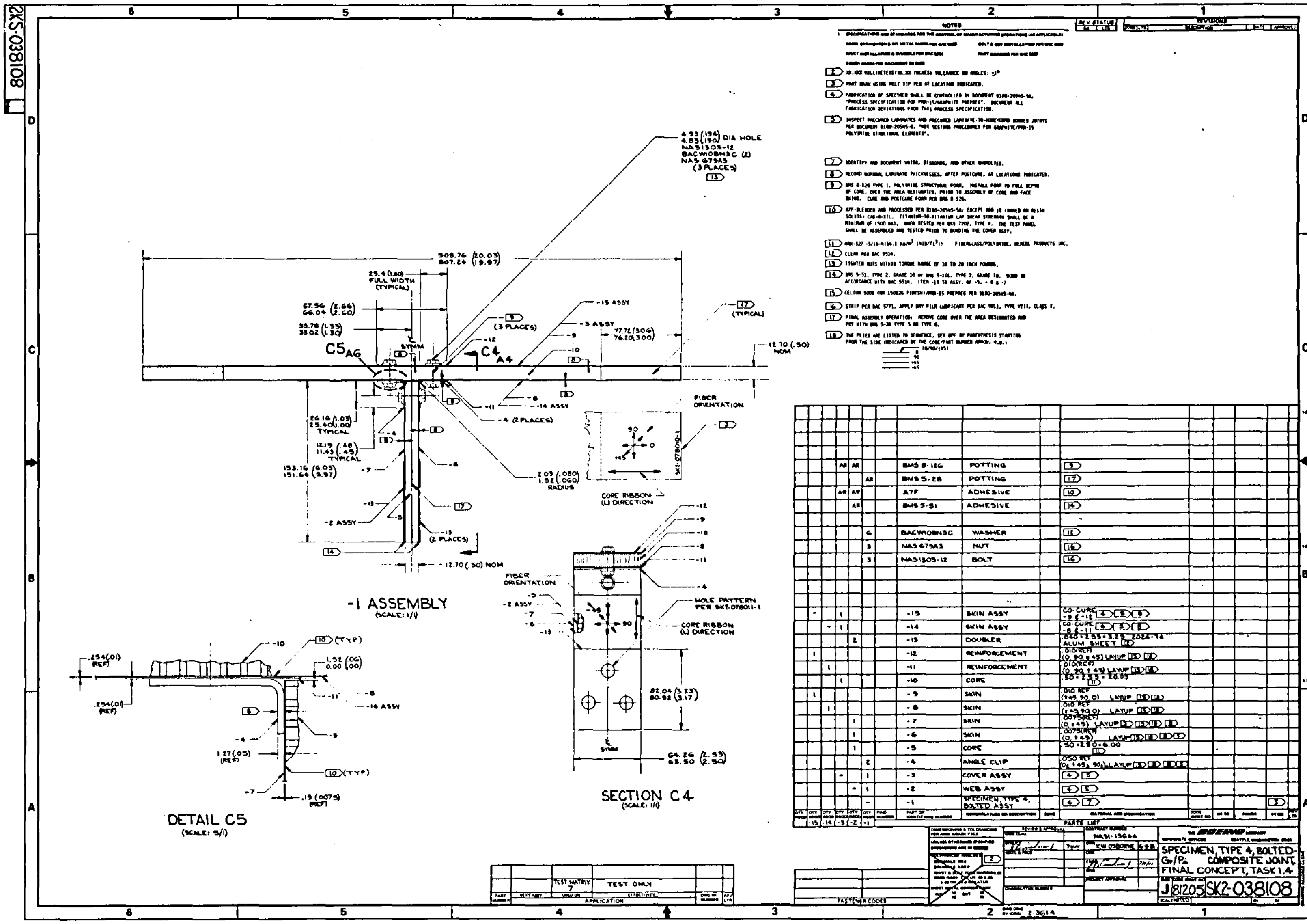
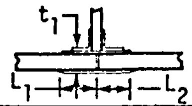

-1 ASSEMBLY
(SCALE: 1/1)
DETAIL C5
(SCALE: 5/1)
SECTION C4
(SCALE: 1/1)
NOTES
FIBER ORIENTATION
CORE RIBBON (L) DIRECTION
HOLE PATTERN PER SK2-078011-1
4.93 (.194) 4.83 (.190) DIA HOLE
NAS1303-12
BACW10BN3C (2)
NAS679A3
(3 PLACES)
BMS 8-126 POTTING
BMS 5-28 POTTING
A7F ADHESIVE
BMS 5-51 ADHESIVE
BACW10BN3C WASHER
NAS679A3 NUT
NAS1303-12 BOLT
-15 SKIN ASSY
-14 SKIN ASSY
-13 DOUBLER
-12 REINFORCEMENT
-11 REINFORCEMENT
-10 CORE
-9 SKIN
-8 SKIN
-7 SKIN
-6 SKIN
-5 CORE
-4 ANGLE CLIP
-3 COVER ASSY
-2 WEB ASSY
-1 SPECIMEN, TYPE 4, BOLTED ASSY
PARTS LIST
NAS1-15644
SPECIMEN, TYPE 4, BOLTED-
Gr/P: COMPOSITE JOINT
FINAL CONCEPT, TASK 1.4
J81205 SK2-038108
TEST MATRIX 7
TEST ONLY
APPLICATION
FASTENER CODES
SK2-038108

Figure D-8

APPENDIX E

"FINAL EVALUATION" TEST RESULTS

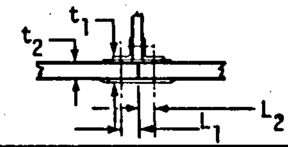
Table E-1: TYPE 1 BONDED FINAL EVALUATION TEST RESULTS



SPECIMEN NUMBER	LOAD CONDITION	TEMPERATURE K (°F)	LAP LENGTH L_1 mm (in)	LAP LENGTH L_2 mm (in)	WIDTH (mm (in)	JOINT THICKNESS (t) mm (in)	ULTIMATE LOAD kN/m (lb/in)	FAILURE MODE	NOTES
7.1-1A-1-1	Tension	561 (550)	36.1 (1.42)	33.0 (1.30)	78.0 (3.07)	28.55 (1.124)	323 (1847)	Grip Failure	1, 5
7.1-1A-1-3		561 (550)	34.8 (1.37)	34.3 (1.35)	67.8 (2.67)	28.55 (1.124)	494 (2822)	Grip Failure	1, 3
7.2-1A1-2-1	Tension	294 (70)	35.6 (1.40)	33.0 (1.30)	79.0 (3.11)	28.17 (1.109)	416 (2373)	Grip Failure	2
7.2-1A1-2-2		294 (70)	36.6 (1.44)	30.5 (1.20)	79.0 (3.11)	28.47 (1.121)	397 (2267)	Grip Failure	2
7.2-1A1-2-2		294 (70)	36.6 (1.44)	30.5 (1.20)	79.0 (3.11)	28.47 (1.121)	556 (3174)	Cover Tension	1, 3, 4
7.2-1A1-2-3		294 (70)	36.6 (1.44)	31.8 (1.25)	78.7 (3.10)	28.60 (1.126)	360 (2055)	Grip Failure	2
7.2-1A1-2-5		561 (550)	36.6 (1.44)	32.3 (1.27)	77.2 (3.04)	28.60 (1.126)	454 (2595)	Grip Failure	2, 3
7.2-1A1-2-6		561 (550)	36.6 (1.44)	31.8 (1.25)	79.0 (3.11)	28.50 (1.122)	415 (2372)	Grip Failure	1, 3
7.2-1A2-2-1	Bending	294 (70)	35.8 (1.41)	33.0 (1.30)	77.5 (3.05)	28.60 (1.126)	38.7 (221)	Cover Compression	
7.2-1A2-2-2		294 (70)	36.1 (1.42)	32.5 (1.28)	77.5 (3.05)	28.50 (1.122)	40.3 (230)	Angle Disbond	
7.2-1A2-2-3		294 (70)	36.6 (1.44)	32.8 (1.29)	77.5 (3.05)	28.40 (1.118)	44.5 (254)	Angle Disbond	
7.2-1A2-2-4		561 (550)	36.3 (1.43)	32.5 (1.28)	77.7 (3.06)	28.65 (1.128)	20.7 (118)	Angle Disbond	
7.2-1A2-2-5		561 (550)	36.3 (1.43)	31.8 (1.25)	79.2 (3.12)	28.58 (1.125)	29.9 (171)	Angle Disbond	
7.2-1A3-3-1	Tension	561 (550)	36.6 (1.44)	33.5 (1.32)	76.2 (3.00)	28.58 (1.125)	365 (2085)	Grip Failure	1, 6
7.2-1A3-3-2		561 (550)	36.3 (1.43)	33.3 (1.31)	76.7 (3.02)	28.60 (1.126)	369 (2106)	Grip Failure	1, 6
7.2-1A3-3-3		561 (550)	36.1 (1.42)	33.3 (1.31)	76.5 (3.01)	28.60 (1.126)	343 (1958)	Grip Failure	1, 6
							NUMBER OF CYCLES		
7.3-1A-2-1	Tension-Fatigue	294 (70)	36.3 (1.43)	32.5 (1.28)	50.8 (2.00)	28.60 (1.126)	953,000	Grip Failure	2, 3
7.3-1A-2-3		294 (70)	36.6 (1.44)	32.3 (1.27)	50.8 (2.00)	28.58 (1.125)	573,000	Grip Failure	2, 3
7.3-1A-2-5		294 (70)	35.8 (1.41)	32.8 (1.29)	50.8 (2.00)	28.42 (1.119)	303,000	Grip Failure	2, 3
7.3-1A-2-2		294 (70)	36.6 (1.44)	32.0 (1.26)	50.8 (2.00)	28.58 (1.125)	30,000	Grip Failure	2, 3
7.3-1A-2-4		294 (70)	36.6 (1.44)	32.0 (1.26)	50.8 (2.00)	28.52 (1.123)	553,000	Grip Failure	2, 3
7.3-1A-2-6		294 (70)	35.8 (1.41)	32.5 (1.28)	50.8 (2.00)	28.68 (1.129)	100	Grip Failure	2, 3

1 Hydraulic grips
2 Bolted grips
3 Grips reworked (high density potting)
4 Specimen retested
5 Original grips with bolt holes (low density potting)
6 Original grips with no bolt holes (low density potting)

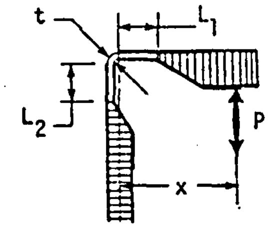
Table E-2: TYPE 1 BOLTED FINAL EVALUATION TEST RESULTS 3



SPECIMEN NUMBER	LOAD CONDITION	TEMPERATURE K (°F)	BOLT-CENTER DISTANCE L_1 mm (in)	L_2 mm (in)	WIDTH mm (in)	JOINT THICKNESS (t_1) mm (in)	COVER THICKNESS (t_2) mm (in)	ULTIMATE LOAD kN/m (lb/in)	FAILURE MODE	NOTES
7.1-1B-1-1	Tension	561 (550)	21.3 (.84)	20.6 (.81)	77.0 (3.03)	32.99 (1.299)	19.8 (.780)	562 (3208)	Cover Tension	
7.1-1B-1-2		561 (550)	20.8 (.82)	20.8 (.82)	77.0 (3.03)	32.97 (1.298)	19.9 (.782)	548 (3.29)	Cover Tension	
7.1-1B-1-2		561 (550)	20.1 (.79)	20.3 (.80)	77.0 (3.03)	32.99 (1.299)	19.9 (.782)	547 (3124)	Cover Tension	
7.2-1B1-2-1	Tension	294 (70)	20.1 (.79)	21.1 (.83)	76.2 (3.00)	33.20 (1.307)	20.1 (.793)	349 (1990)	Grip Failure	1
7.2-1B1-2-2		294 (70)	20.3 (.80)	20.3 (.80)	76.7 (3.02)	32.97 (1.298)	20.1 (.792)	364 (2076)	Grip Failure	1
7.2-1B1-2-3		294 (70)			76.2 (3.00)			427 (2437)	Grip Failure	1
7.2-1B1-2-4		561 (550)	20.3 (.80)	20.8 (.82)	77.0 (3.03)	33.02 (1.300)	19.8 (.781)	327 (1866)	Grip Failure	1
7.2-1B1-2-5		561 (550)	20.6 (.81)	20.6 (.81)	76.5 (3.01)	33.17 (1.306)	20.1 (.790)	320 (1829)	Grip Failure	1
7.2-1B1-2-6		561 (550)	20.1 (.79)	20.3 (.80)	77.5 (3.05)	33.10 (1.303)	19.9 (.784)	343 (1957)	Grip Failure	1
7.2-1B2-2-1	Bending	294 (70)	19.1 (.75)	20.8 (.82)	76.5 (3.01)	32.97 (1.298)	19.8 (.779)	27.1 (158)	Cover Compression	2
7.2-1B2-2-2		294 (70)	20.6 (.81)	20.3 (.80)	76.5 (3.01)	32.97 (1.298)	19.9 (.782)	25.6 (146)	Cover Compression	2
7.2-1B2-2-3		294 (70)	20.3 (.80)	20.3 (.80)	76.2 (3.00)	32.99 (1.299)	19.9 (.785)	44.1 (252)	Cover Compression	2
7.2-1B2-2-4		561 (550)	20.1 (.79)	20.8 (.82)	76.5 (3.01)	32.89 (1.295)	20.6 (.810)	34.9 (199)	Cover Compression	2
7.2-1B2-2-5		561 (550)	20.6 (.81)	20.3 (.80)	76.5 (3.01)	32.92 (1.296)	20.2 (.795)	36.4 (208)	Cover Compression	2
7.2-1B2-2-6		561 (550)	19.6 (.77)	19.6 (.77)	76.5 (3.01)	32.97 (1.298)	20.1 (.792)	33.4 (191)	Cover Compression	2
								NUMBER OF CYCLES		
7.3-1B-2-1	Tension	294 (70)			50.8 (2.00)			10^6		
7.3-1B-2-2		294 (70)			50.8 (2.00)			10^6		
7.3-1B-2-3		294 (70)			50.8 (2.00)			10^6		
7.3-1B-2-4		561 (550)			50.8 (2.00)			10^6		
7.3-1B-2-5		561 (550)			50.8 (2.00)			10^6		
7.3-1B-2-6		561 (550)			50.8 (2.00)			10^6		
								N/m (lb/in)		
7.3-1B-2-1	Tension	294 (70)			50.8 (2.00)			364 (2076)	Cover Tension	4
7.3-1B-2-2		294 (70)			50.8 (2.00)			398 (2272)	Cover Tension	4
7.3-1B-2-3		294 (70)			50.8 (2.00)			462 (2638)	Cover Tension	4
7.3-1B-2-4		561 (550)			50.8 (2.00)			337 (1925)	Cover Tension	4
7.3-1B-2-5		561 (550)			50.8 (2.00)			349 (1990)	Cover Tension	4
7.3-1B-2-6		561 (550)			50.8 (2.00)			306 (1750)	Cover Tension	4

1 Extensive delamination of laminates.
2 Delamination and local buckling of lamina in skin.
3 Fiberglass/PI load tabs on all static test specimens.
4 Residual strength after fatigue

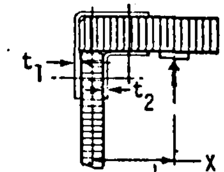
Table E-3: TYPE 2 BONDED FINAL EVALUATION TEST RESULTS



SPECIMEN NUMBER	LOAD CASE [4]	TEMPERATURE K (°F)	LAP LENGTH L_1 mm (in)	LAP LENGTH L_2 mm (in)	WIDTH mm (in)	ANGLE THICKNESS(t) mm (in)	MOMENT ARM (X) mm (in)	ULTIMATE MOMENT N-m/m (in-lb/in)	FAILURE MODE [5]	NOTES
7.1-2A-1-1	1	561 (550)	21.4 (.841)	21.7 (.853)	50.8 (2.00)	3.56 (.140)	57.2 (2.25)	157 (35.3)	1	
7.1-2A-1-2	1	561 (550)	21.1 (.832)	21.7 (.856)	50.5 (1.99)	3.66 (.144)	57.2 (2.25)	141 (31.8)	1	
7.1-2A-1-3	1	561 (550)	21.0 (.828)	21.8 (.858)	50.8 (2.00)	3.63 (.143)	57.2 (2.25)	140 (31.5)	1	
7.2-2A1-2-1	1	294 (70)			50.8 (2.00)	3.30 (.130)	57.2 (2.25)	275 (61.9)	1	
7.2-2A1-2-2	1	294 (70)			50.8 (2.00)	3.15 (.124)	57.2 (2.25)	205 (46.1)	1	
7.2-2A1-2-3	1	294 (70)			50.8 (2.00)	3.07 (.121)	57.2 (2.25)	235 (52.9)	1	
7.2-2A1-2-4	1	561 (550)	20.7 (.813)	20.5 (.808)	50.8 (2.00)	3.56 (.140)	57.2 (2.25)	229 (51.4)	1	
7.2-2A1-2-5	1	561 (550)	22.3 (.876)	20.9 (.821)	50.8 (2.00)	3.40 (.134)	57.2 (2.25)	296 (66.6)	1	
7.2-2A1-2-6	1	561 (550)	22.6 (.889)	21.1 (.829)	50.8 (2.00)	3.71 (.146)	57.2 (2.25)	117 (26.3)	1	
7.2-2A1-2-4	2	561 (550)	20.7 (.813)	20.5 (.808)	50.8 (2.00)	3.56 (.140)	25.4 (1.00)	343 (77.0)	2	[1]
7.2-2A1-2-5	2	561 (550)	22.3 (.876)	20.9 (.821)	50.8 (2.00)	3.40 (.134)	25.4 (1.00)	445 (100.0)	2	[1]
7.2-2A1-2-6	2	561 (550)	22.6 (.889)	21.1 (.829)	50.8 (2.00)	3.71 (.146)	25.4 (1.00)	445 (100.0)	2	[1]
7.2-2A2-2-1	2	294 (70)	22.6 (.890)	21.2 (.836)	50.8 (2.00)	3.43 (.135)	25.4 (1.00)	467 (105.0)	2	
7.2-2A2-2-2	2	294 (70)	21.1 (.832)	20.3 (.801)	50.8 (2.00)	3.51 (.138)	22.9 (.90)	320 (72.0)	2	
7.2-2A2-2-3	2	294 (70)	22.5 (.886)	21.2 (.836)	50.8 (2.00)	3.48 (.137)	25.4 (1.00)	494 (111.0)	2	
7.2-2A2-2-4	2	561 (550)	20.9 (.824)	21.1 (.832)	50.8 (2.00)	3.53 (.139)	25.4 (1.00)	242 (54.5)	2	
7.2-2A2-2-5	2	561 (550)	22.5 (.884)	21.4 (.842)	50.5 (1.99)	3.38 (.133)	25.4 (1.00)	451 (101.5)	1	
7.2-2A2-2-6	2	561 (550)	22.5 (.884)	21.4 (.842)	50.5 (1.99)	3.38 (1.33)	25.4 (1.00)	344 (77.4)	2	[2]
7.2-2A3-3-1	2	561 (550)	21.0 (.825)	21.6 (.850)	50.8 (2.00)	3.53 (.139)	21.6 (.85)	157 (35.3)	2	
7.2-2A3-3-2	2	561 (550)	20.3 (.800)	21.6 (.850)	50.8 (2.00)	3.30 (.130)	21.1 (.83)	157 (35.3)	2	
7.2-2A3-3-3	2	561 (550)	20.7 (.815)	21.6 (.850)	50.8 (2.00)	3.48 (.137)	21.1 (.83)	161 (36.1)	2	
								NUMBER OF CYCLES		
7.3-2A-2-1	2	294 (70)			50.8 (2.00)	3.53 (.139)	21.6 (.85)	10^6		
7.3-2A-2-2	2	294 (70)			50.8 (2.00)	3.63 (.143)	21.6 (.85)	10^6		
7.3-2A-2-3	2	294 (70)			50.8 (2.00)	3.61 (.142)	21.6 (.85)	10^6		
7.3-2A-2-4	2	561 (550)			50.8 (2.00)	3.58 (.138)	21.6 (.85)	10^6	2	
7.3-2A-2-5	2	561 (550)			50.8 (2.00)	3.53 (.139)	21.6 (.85)	10^6	2	
7.3-2A-2-6	2	561 (550)			50.8 (2.00)	3.53 (.139)	21.6 (.85)	3000	2	
								N-m/m in-lb/in		
7.3-2A-2-1	2	294 (70)			50.8 (2.00)	3.53 (.139)	21.6 (.85)	369 (82.9)	2	[3]
7.3-2A-2-2	2	294 (70)			50.8 (2.00)	3.63 (.143)	21.6 (.85)	387 (87.1)	2	[3]
7.3-2A-2-3	2	294 (70)			50.8 (2.00)	3.61 (.142)	21.6 (.85)	350 (78.6)	2	[3]

[1] Specimen originally tested under Load Case 1, retested under Load Case 2.
[2] Specimen retested.
[3] Residual strength test of fatigue specimen.
[4] See Figure 6-9 for load case diagrams.
[5] See Figures 6-57 and 6-58 for failure mode diagrams.

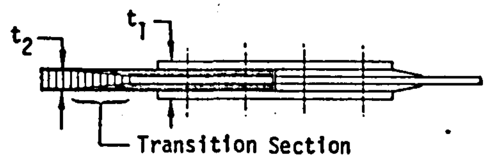
Table E-4: TYPE 2 BOLTED FINAL EVALUATION TEST RESULTS



SPECIMEN NUMBER	LOAD CASE [1]	TEMPERATURE K (^oF)	ANGLE THICKNESS OUTSIDE (t_1) mm (in)	ANGLE THICKNESS INSIDE (t_2) mm (in)	WIDTH mm (in)	MOMENT ARM (X) mm (in)	ULTIMATE MOMENT N-m/m in-lb/in	FAILURE MODE [2]	NOTES
7.1-2B-1-1	1	561 (550)	1.88 (.074)	1.35 (.053)	51.6 (2.03)	35.1 (1.38)	743 (167)	1	
7.1-2B-1-2	1	561 (550)	1.91 (.075)	1.42 (.056)	51.6 (2.03)	35.6 (1.40)	752 (169)	1	
7.1-2B-1-3	1	561 (550)	1.88 (.074)	1.35 (.053)	51.6 (2.03)	35.3 (1.39)	792 (178)	1	
7.2-2B1-2-1	1	294 (70)	2.01 (.079)	1.32 (.052)	51.6 (2.03)	36.8 (1.45)	321 (72.1)	1	
7.2-2B1-2-2	1	294 (70)	2.01 (.079)	1.40 (.055)	51.6 (2.03)	34.8 (1.37)	381 (85.7)	1	
7.2-2B1-2-3	1	294 (70)	2.03 (.080)	1.37 (.054)	51.6 (2.03)	36.8 (1.45)	350 (78.6)	1	
7.2-2B1-2-4	1	561 (550)	1.98 (.078)	1.32 (.052)	51.6 (2.03)	35.3 (1.39)	605 (136)	1	
7.2-2B1-2-5	1	561 (550)	1.93 (.076)	1.32 (.052)	51.6 (2.03)	35.8 (1.41)	663 (149)	1	
7.2-2B1-2-6	1	561 (550)	1.98 (.078)	1.37 (.054)	51.6 (2.03)	35.6 (1.40)	645 (145)	1	
7.2-2B2-2-1	2	294 (70)	1.98 (.078)	1.32 (.052)	51.6 (2.03)	36.8 (1.45)	1520 (341)	2	[4]
7.2-2B2-2-2	2	294 (70)	2.06 (.081)	1.32 (.052)	51.6 (2.03)	45.7 (1.80)	2430 (547)	2	
7.2-2B2-2-3	2	294 (70)	1.85 (.073)	1.27 (.050)	51.6 (2.03)	46.0 (1.81)	1830 (412)	2	
7.2-2B2-2-4	2	561 (550)	1.98 (.078)	1.35 (.053)	50.8 (2.00)	45.7 (1.80)	1490 (335)	2	
7.2-2B2-2-5	2	561 (550)	1.93 (.076)	1.32 (.052)	51.6 (2.03)	46.0 (1.81)	1160 (260)	2	
7.2-2B2-2-6	2	561 (550)	2.03 (.080)	1.37 (.054)	51.6 (2.03)	46.2 (1.82)	1392 (313)	2	
							NUMBER OF CYCLES		
7.3-2B-2-4	1	294 (70)	2.13 (.084)	1.35 (.053)	51.3 (2.02)	35.6 (1.40)	10^6		
7.3-2B-2-5	1	294 (70)	1.98 (.078)	1.30 (.051)	51.8 (2.04)	35.6 (1.40)	10^6		
7.3-2B-2-6	1	294 (70)	2.03 (.080)	1.30 (.051)	51.3 (2.02)	35.6 (1.40)	10^6		
7.3-2B-2-1	1	561 (550)	1.98 (.078)	1.37 (.054)	51.6 (2.03)	44.5 (1.75)	10^6	1	
7.3-2B-2-3	1	561 (550)	2.03 (.080)	1.32 (.052)	51.6 (2.03)	35.6 (1.40)	10^6	1	
7.3-2B-2-4	1	294 (70)	2.13 (.084)	1.35 (.053)	51.3 (2.02)	35.6 (1.40)	547 (123)	1	[3]
7.3-2B-2-5	1	294 (70)	1.98 (.078)	1.30 (.051)	51.8 (2.04)	36.1 (1.42)	525 (118)	1	[3]
7.3-2B-2-6	1	294 (70)	2.03 (.080)	1.30 (.051)	51.3 (2.02)	36.1 (1.42)	427 (96)	1	[3]

[1] See Figure 6-10 for load case diagrams.
[2] See Figures 6-62 and 6-63 for failure mode diagrams.
[3] Residual strength test of fatigue specimens.
[4] Net tension failure.

Table E-5: TYPE 3 BOLTED FINAL EVALUATION TEST RESULTS

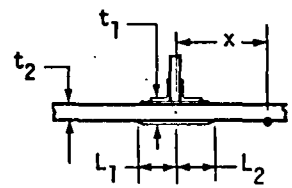


SPECIMEN NUMBER	LOAD CONDITION	TEMPERATURE K (°F)	WIDTH mm (in)	JOINT THICKNESS(t_1) mm (in)	COVER THICKNESS (t_2) mm (in)	ULTIMATE LOAD kN/m (lb/in)	FAILURE MODE	NOTES
7.1-3B-1-1	Tension	561 (550)	96.3 (3.79)	33.30 (1.311)	16.5 (.651)	1813 (10350)	Transition Section	
7.2-3B1-2-1	Tension	294 (70)	96.0 (3.78)	32.99 (1.299)	16.9 (.665)	1859 (10615)	Transition Section	
7.2-3B1-2-2		294 (70)	96.0 (3.78)	32.79 (1.291)	16.9 (.667)	1852 (10575)	Transition Section	
7.2-3B1-2-3		294 (70)	95.8 (3.77)	32.94 (1.297)	17.0 (.669)	2021 (11538)	Transition Section	
7.2-3B1-2-4		294 (70)	95.8 (3.77)	33.20 (1.307)	16.9 (.665)	1829 (10444)	Transition Section	
7.2-3B1-2-5		561 (550)	95.8 (3.77)	32.84 (1.293)	16.9 (.667)	1766 (10086)	Transition Section	
7.2-3B1-2-6		561 (550)	96.0 (3.78)	32.21 (1.268)	16.8 (.663)	1734 (9901)	Transition Section	
7.2-3B1-2-7		561 (550)	96.0 (3.78)	33.15 (1.305)	16.8 (.662)	1671 (9544)	Transition Section	
7.2-3B1-2-7		561 (550)	95.8 (3.77)	33.07 (1.302)	16.1 (.633)	1756 (10027)	Transition Section	
7.2-3B3-2-1	Tension	561 (550)	96.5 (3.80)			1407 (8033)	Transition Section	1
7.2-3B3-2-2		561 (550)	96.0 (3.78)	33.25 (1.309)	17.4 (.684)	1390 (7937)	Transition Section	1
7.2-3B3-2-3		561 (550)	96.3 (3.79)	33.02 (1.300)	16.5 (.651)	1181 (6741)	Transition Section	1
						NUMBER OF CYCLES		
7.3-3B-1-1	Tension	294 (70)	47.6 (1.88)			10^6		
7.3-3B-1-2		294 (70)	47.6 (1.88)			10^6		
7.3-3B-1-3		294 (70)	47.6 (1.88)			914,600	Cover/Transition	
7.3-3B-1-4		561 (550)	47.6 (1.88)			117,600	Cover/Transition	
7.3-3B-1-5		561 (550)	47.6 (1.88)			383,100	Cover/Transition	
7.3-3B-1-6		561 (550)	47.6 (1.88)			307,900	Cover/Transition	
						kN/m (lb/in)		
7.3-3B-1-1		294 (70)	47.6 (1.88)			1569 (8960)	Cover/Transition	2
7.3-3B-1-2		294 (70)	47.6 (1.88)			1602 (9150)	Cover/Transition	2

1 Extensive delamination of cover skin laminates, bad laminate to core bonds

2 Residual strength test of fatigue specimens

Table E-6: TYPE 4 BONDED FINAL EVALUATION TEST RESULTS

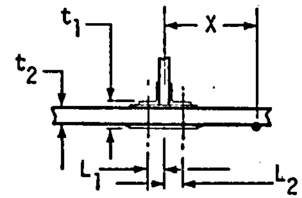


SPECIMEN NUMBER	LOAD CONDITION	TEMPERATURE K (°F)	LAP LENGTH L_1 mm (in)	LAP LENGTH L_2 mm (in)	WIDTH mm (in)	JOINT THICKNESS (t_1) mm (in)	COVER THICKNESS (t_2) mm (in)	DISTANCE TO FAILURE POINT (x) mm (in)	ULTIMATE LOAD kN/m (lb/in)	FAILURE MODE [1]
7.1-4A-1-1	Bending	561 (550)	27.7 (1.09)	27.4 (1.08)	63.5 (2.50)	15.0 (.589)	13.4 (.527)	33.0 (1.30)	9.25 (52.8)	[2]
7.1-4A-1-2		561 (550)	27.7 (1.09)	27.4 (1.08)	64.0 (2.52)	14.9 (.588)	13.4 (.528)	33.0 (1.30)	9.25 (52.8)	[2]
7.1-4A-1-3		561 (550)	27.7 (1.09)	27.4 (1.08)	63.2 (2.49)	15.0 (.591)	13.3 (.525)	33.0 (1.30)	9.14 (52.2)	[2]
7.2-4A1-2-1	Bending	294 (70)	27.9 (1.10)	27.9 (1.10)	63.5 (2.50)	15.0 (.591)	13.3 (.525)	40.6 (1.60)	7.01 (40.0)	[2]
7.2-4A1-2-2		294 (70)	27.9 (1.10)	27.4 (1.08)	63.8 (2.51)	14.8 (.584)	13.3 (.522)	38.1 (1.50)	7.18 (41.0)	[2]
7.2-4A1-2-3		294 (70)	27.9 (1.10)	27.4 (1.08)	63.8 (2.51)	14.9 (.588)	13.4 (.527)	33.0 (1.30)	6.90 (39.4)	[2]
7.2-4A1-2-5		561 (550)	27.9 (1.10)	27.4 (1.08)	63.5 (2.50)	15.0 (.589)	13.4 (.527)	33.0 (1.30)	7.64 (43.6)	[2]
7.2-4A1-2-6		561 (550)	27.9 (1.10)	27.7 (1.09)	63.2 (2.49)	14.9 (.588)	13.4 (.527)	31.8 (1.25)	7.88 (45.0)	[2]

[1] All specimens had bad adhesive bonds, web attachment angles fell off after testing.

[2] Cover Compression

Table E-7: TYPE 4 BOLTED FINAL EVALUATION TEST RESULTS.



SPECIMEN NUMBER	LOAD CONDITION	TEMPERATURE K (°F)	BOLT-CENTER DISTANCE L_1 mm (in)	BOLT-CENTER DISTANCE L_2 mm (in)	WIDTH mm (in)	JOINT THICKNESS (t_1) mm (in)	COVER THICKNESS (t_2) mm (in)	DISTANCE TO FAILURE POINT (X) mm (in)	ULTIMATE LOAD kN/m (lb/in)	FAILURE MODE
7.1-4B-1-1	Bending	561 (550)	21.1 (.83)	21.1 (.83)	64.5 (2.54)	15.2 (.598)	12.7 (.499)	53.3 (2.10)	7.0 (40.0)	Cover Compression
7.1-4B-1-2		561 (550)	21.1 (.83)	21.1 (.83)	64.5 (2.54)	15.2 (.597)	13.3 (.522)	39.4 (1.55)	13.9 (79.1)	Cover Compression
7.1-4B-1-3		561 (550)	20.8 (.82)	21.1 (.83)	64.3 (2.53)	15.1 (.596)	13.2 (.521)	33.0 (1.30)	13.6 (77.5)	Cover Compression
7.2-4B1-2-1	Bending	294 (70)	21.1 (.83)	21.1 (.83)	63.2 (2.49)	14.9 (.587)	13.4 (.526)	21.6 (.85)	23.1 (131.7)	Net Tension
7.2-4B1-2-2		294 (70)	21.1 (.83)	20.8 (.82)	64.3 (2.53)	15.1 (.594)	13.0 (.512)	38.1 (1.50)	21.9 (125.3)	Cover Compression
7.2-4B1-2-3		294 (70)	20.8 (.82)	20.1 (.79)	63.2 (2.49)	15.3 (.603)	13.1 (.514)	53.3 (2.10)	13.8 (78.7)	Cover Compression
7.2-4B1-2-4		561 (550)	20.6 (.81)	20.1 (.79)	63.2 (2.49)	15.1 (.595)	13.0 (.512)	38.1 (1.50)	13.9 (79.1)	Cover Compression
7.2-4B1-2-5		561 (550)	21.1 (.83)	20.8 (.82)	64.3 (2.53)	15.2 (.597)	13.2 (.520)	69.9 (2.75)	10.5 (59.7)	Cover Compression
7.2-4B1-2-6		561 (550)	20.8 (.82)	20.8 (.82)	63.2 (2.49)	15.0 (.591)	13.0 (.512)	47.0 (1.85)	12.5 (71.5)	Cover Compression
7.2-4B2-2-1	Shear	294 (70)			63.5 (2.50)				54.6 (312) [1]	Angle Buckling
7.2-4B2-2-2		294 (70)			64.0 (2.52)				63.0 (360) [1]	Angle Buckling
7.2-4B2-2-3		294 (70)			63.5 (2.50)				70.1 (400) [1]	Angle Buckling
7.2-4B2-2-4		561 (550)			63.5 (2.50)				70.1 (400) [1]	Angle Buckling
7.2-4B2-2-5		561 (550)			64.0 (2.52)				70.1 (400) [1]	Angle Buckling
7.2-4B2-2-6		561 (550)			63.5 (2.50)				70.1 (400) [1]	Angle Buckling
									NUMBER OF CYCLES	
7.3-4B-2-2	Bending	294 (70)			63.5 (2.50)				10^6	
7.3-4B-2-3		294 (70)			63.5 (2.50)			57.2 (2.25)	0 [2]	Cover Compression
7.3-4B-2-4		561 (550)			63.5 (2.50)			41.9 (1.65)	53,000	Cover Compression
7.3-4B-2-5		561 (550)			63.5 (2.50)				10^6	
7.3-4B-2-6		561 (550)			63.5 (2.50)			48.3 (1.90)	49,000	Cover Compression
7.3-4B-2-2	Bending	294 (70)			63.5 (2.50)				32.6 (186)	Angle Failure [3]
7.3-4B-2-5		294 (70)			63.5 (2.50)				27.0 (154)	Web Shear Out [3]

[1] Load arbitrarily stopped - no two part failures
[2] Failed statically at 9.1 kN/m (52 lb/in)
[3] Residual strength after fatigue, 254 mm (10 in) support span

APPENDIX F

QUALITY CONTROL TEST RESULTS

Table F-1: SUMMARY OF QUALITY CONTROL TEST RESULTS

PROPERTY		REQUIREMENTS	MATERIAL LOT NUMBER												
			2W4604	2W4632	2W4643	2W4651	2W4781	2W4878	2W4956	2W5077	2W5141	2W5197	2W5232	2W5233	3W2020
FIBER TYPE		--	3000	3000	3000	3000	3000	6000	3000	3000	3000	3000	6000	6000	3000
Fiber Volume, %(Volume)		58 ±2	58.5	57.3	57.8	58.0	51.2	57.1	60.0	55.7	60.6	61.6	63.5	61.6	58.3
Resin Content, %(Weight)		30 ±3	34.4	35.4	33.9	34.6	41.5	36.0	32.7	36.7	32.5	30.9	30.1	31.0	34.7
Specific Gravity g/cc		1.54	1.57	1.56	1.54	1.56	1.54	1.57	1.57	1.55	1.58	1.57	1.60	1.57	1.57
Void Content, %		< 1	< 0	.3	2.0	.5	< 0	< 0	.5	.5	< 0	1.0	< 0	1.0	< 0
Flexural Strength MPa (ksi)	At Ambient	1515 (220)	1282 (186)	1544 (224)	1538 (223)	1517 (220)	1489 (216)	--	1558 (226)	1448 (210)	1572 (228)	1482 (215)	1475 (214)	1551 (225)	1379 (200)
	At 589K (600°F)	757 (110)	807 (117)	889 (129)	862 (125)	772 (112)	634 (92)	--	827 (120)	923 (134)	1034 (150)	816 (118)	889 (129)	869 (126)	855 (124)
	Aged, at 589K (600°F)	757 (110)	896 (130)	951 (138)	1000 (145)	862 (125)	--	--	931 (135)	--	--	--	1006 (146)	903 (131)	862 (125)
Flexural Modulus GPa (msi)	At Ambient	117 (17)	113 (16.4)	113 (16.4)	122 (17.7)	118 (17.1)	135 (19.6)	123 (17.9)	159 (23.0)	115 (16.7)	161 (23.4)	108 (15.6)	98 (14.2)	108 (15.7)	115 (16.7)
	At 589K (600°F)	103 (15)	112 (16.2)	128 (18.6)	114 (16.5)	105 (15.2)	110 (16.0)	108 (15.7)	137 (19.8)	117 (16.9)	161 (23.3)	100 (14.5)	103 (15.0)	99 (14.3)	110 (15.9)
	Aged, at 589K (600°F)	103 (15)	127 (18.4)	137 (19.8)	114 (16.5)	107 (15.5)	--	134 (19.4)	117 (16.9)	--	--	--	119 (17.3)	121 (17.6)	104 (15.1)
Short Beam Shear Strength MPa (ksi)	At Ambient	96 (14)	98 (14.2)	105 (15.2)	94 (13.7)	95 (13.8)	93 (13.5)	92 (13.3)	88 (12.8)	94 (13.6)	90 (13.1)	100 (14.5)	97 (14.1)	99 (14.3)	97 (14.0)
	At 589K (600°F)	41 (6)	56 (8.1)	50 (7.2)	52 (7.5)	50 (7.2)	48 (6.9)	59 (8.5)	53 (7.7)	57 (18.3)	56 (8.1)	52 (7.6)	54 (7.9)	61 (8.8)	57 (8.3)
	Aged, at 589K (600°F)	41 (6)	56 (8.1)	54 (7.9)	52 (7.6)	52 (7.5)	--	59 (8.6)	53 (7.7)	--	--	--	47 (6.8)	49 (7.1)	56 (8.1)

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15. Supplementary Notes

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16. Abstract

This report summarizes the design, analysis and testing performed to develop four types of graphite/polyimide (Gr/PI) bonded and bolted composite joints for lightly loaded control surfaces on advanced space transportation systems that operate at temperatures up to 561K (550°F). Material properties and "Small Specimen" tests were conducted to establish design data and to evaluate specific design details. "Static Discriminator" tests were conducted on preliminary designs to verify structural adequacy. Scaled-up specimens of the final joint designs, representative of production size requirements, were subjected to a series of static and fatigue tests to evaluate joint strength. Effects of environmental conditioning were determined by testing aged (125 hours @ 589K (600°F)) and thermal cycled (116K to 589K (-250°F to 600°F), 125 times) specimens. It is concluded Gr/PI joints can be designed and fabricated to carry the specified loads. Test results also indicate a possible resin loss or degradation of laminates after exposure to 589K (600°F) for 125 hours.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Composite, Composite Joints, Bonded Joints, Bolted Joint, Graphite/Polyimide, Celion 3000/PMR-15, Celion 6000/PMR-15	Unclassified-- Unlimited Subject Category 39

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