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METALLIC COATINGS FOR GRAPHITE/EPOXY COMPOSITES – PHASE II

Christian J. Staebler, Jr.
Bonnie F. Simpers

GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

FINAL REPORT
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Metallic coating systems for graphite/epoxy laminated aircraft structures were developed to provide protection against moisture penetration, electromagnetic interference (EMI), paint strippers and lightning strikes. Foil coatings and pressed powder coatings were evaluated to assess their resistance to these hostile environments. The foil coatings provided a significant reduction in the moisture penetration and the associated strength loss of the laminate after exposure to humidity and humidity-thermal spiking. Techniques

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were developed for the application of foil coatings to graphite/epoxy laminates. Solid and perforated aluminum foil were applied to cured laminates in a secondary bonding operation. Sulfur dioxide/salt spray testing performed on foil-coated laminates did not indicate a severe corrosion problem.

FOREWORD

This final report covers the work performed under Contract No. N00019-78-C-0602 from 16 October 1978 to 31 July 1980. It is published for information only and does not necessarily represent the recommendations, conclusions, or approval of the Navy.

This contractual program with the Grumman Aerospace Corporation, Bethpage, New York, was funded by the Naval Air Systems Command, Washington, D.C. The work was administered under the direction of Mr. M. Stander of the Naval Air Systems Command, Washington, D.C. The program was conducted by Grumman's Advanced Manufacturing and Materials Development Section, Mr. Carl Micillo, Manager. The work reported was directed by Mr. Christian J. Staebler, Jr., Project Engineer. Mrs. Bonnie F. Simpers served as the Principal Investigator. Mrs. Judith Gauland performed the pressed powder bonding and foil repair evaluations. Mr. Phillip Palter of the Elements and Materials Testing Laboratory served as the Program Mechanical Test Engineer. Mr. George Lubin, Chief Scientist of the Manufacturing and Materials Engineering Department, served as overall Project Consultant. Mr. Einar Hoel and Mr. Robert Blackshaw of the Advanced Manufacturing and Materials Development Section fabricated the test panels and applied the coating systems. Mr. Sidney Trink performed the cutting and drilling evaluations. Mr. Edward P. Holzman performed the EMI shielding effectiveness tests.

This report was released for publication in October 1980.

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ILLUSTRATIONS (Cont)

Section 1

INTRODUCTION

1.1 BACKGROUND

Aircraft designed for optimum performance in a wide variety of hostile environments require extensive use of lightweight, durable, and high-strength materials. As a result, advanced composites are being implemented extensively on high-performance aircraft. Utilization of advanced composite structures to their design limits necessitates the protection of these structures against the strength-degrading effects of moisture. Properly applied metallic coatings not only prevent moisture absorption but also improve conductivity for better shielding effectiveness against penetration by electromagnetic energy, reduce the damaging effects of lightning strikes, and provide protection against paint strippers during aircraft refinishing operations.

1.2 OBJECTIVES

The objectives of this program were to demonstrate, by comprehensive testing, the ability of metallic coatings to provide graphite/epoxy substrates with electromagnetic (EM) shielding and resistance to environmental elements, paint strippers, and lightning strikes, and to develop new coating techniques such as pressed-powder bonding and repair techniques for damaged metal-foil coatings.

1.3 APPROACH

Three types of metallic coatings were applied to test panels fabricated from Hercules AS/3501-6 graphite/epoxy preimpregnated tape. These include:

- Solid aluminum foil bonded in a secondary operation
- Perforated aluminum foil bonded in a secondary operation
- Pressed-powder bonded aluminum.

Initially, foil-coated and scribed test panels were prepared using various foil pretreatment techniques and exposed to corrosive environments (5% salt spray and SO_2-salt spray) to determine their galvanic corrosion resistance. One foil pretreatment technique was selected to prepare solid-foil and perforated-foil coated, graphite/epoxy laminates for environmental conditioning at 98% relative humidity/140°F and thermal spiking to 260°F. The degree of strength retention of these panels, as well as electromagnetic shielding effectiveness and machinability of unexposed panels, were then determined.

The development of pressed-powder bond coatings involved determination of the optimum adhesive and aluminum powder to provide the required degree of conductivity, adhesion, and polishability. Selected coating parameters were used to apply pressed-powder bond coatings for moisture resistance, machinability, and EM shielding evaluations.

A foil repair technique was also developed for Class II and Class III damage (Ref. 2). The foil pretreatment and adhesive were selected based on adhesion and conductivity. Repaired foils were then subjected to EM shielding tests.

Coated samples of each system (perforated foil, repaired foil, and pressed-powder bonded aluminum powder) were forwarded to the Navy for lightning strike tests.

Section 2

CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

- Solid or perforated aluminum foil coatings can be applied to graphite/epoxy laminates by secondary bonding with a film adhesive; perforated aluminum foil coatings can also be applied by cocuring with a film adhesive
- The optimum conditions for secondary bonding of solid and perforated foil coatings to cured graphite/epoxy laminates with EA 9628 film adhesive involve the application of 100-psi pressure and 300°F for 15 min under full vacuum
- Sulfur dioxide-salt spray exposure (see Appendix A) of the foil protection system showed that alkaline and acid cleaning, followed by application of EC-2333 primer, give the best foil adhesion and corrosion protection. Testing did not indicate a severe corrosion problem.
- Class II and Class III damage to foil coatings on graphite/epoxy laminates can be effectively repaired using a 0.0025-in.-thick aluminum foil patch bonded with a conductive epoxy adhesive cured with an available, Fleet, portable, temperature-controlled vacuum heater blanket
- Graphite/epoxy laminates can be protected against the strength-degrading effects of moisture penetration due to humidity exposure (90 days at 140°F and 98% relative humidity) by the application of secondary bonded, solid or perforated aluminum foil
  - The 260°F flexural strength of unprotected laminates was reduced by 41%, while that for solid or perforated foil-protected laminates had little or no reduction
  - The 260°F horizontal shear strength of unprotected laminates was reduced by 46%; that for solid foil-protected laminates was not reduced; and that for perforated foil-coated laminates was reduced by only 13%
- The strength-degrading effects of moisture penetration in graphite/epoxy laminates resulting from exposure to 40 cycles of humidity/thermal spiking (3 days at 140°F and 98% relative humidity, followed

by 2 hr at 260°F) was reduced by application of solid or perforated aluminum foil protective coatings

- The 260°F flexural strength of unprotected laminates was reduced by 45% after only 26 cycles, while that for solid foil and perforated foil-coated laminates was reduced by only 16% and 3%, respectively, after 40 cycles
- The 260°F horizontal shear strength of unprotected laminates was reduced by 52% after only 26 cycles, while that for solid foil and perforated foil-coated laminates was reduced by only 12% and 17%, respectively, after 40 cycles

- The electromagnetic interference (EMI) shielding effectiveness of 18-ply graphite/epoxy laminates in E, H, and plane-wave fields at frequencies between 0.014 and 10,000 MHz can be significantly improved by coating both sides with 0.0025-in.-thick perforated foil. Pressed powder bond coatings also improved the EMI shielding effectiveness of graphite/epoxy laminates
- High-quality holes and countersinks can be produced in perforated foil-coated and pressed-powder bond 18-ply graphite/epoxy laminates using solid carbide drills and countersinks at speeds of 21,000 and 5500 rpm, respectively
- Radial sawing at feed rates of 29 to 43 ipm with 60-grit, plated-diamond and 60- to 80-grit sintered-diamond blades gave the best cuts in foil-coated graphite/epoxy laminates.

2.2 RECOMMENDATIONS

Analysis of the results of the work performed under this program, as well as that of internal IR&D efforts, has shown the need for further activity in the following areas:

- Develop cocuring techniques to apply perforated foil using low-resin-content graphite/epoxy prepreg to reduce or eliminate resin bleed-out during cure
- Establish membrane forming techniques to fabricate compound-curvature metal foil preforms for application on production hardware
- Assess impact damage protection provided by metal foil coatings

- Determine fastener compatibility with metal foil coatings under a sulfur dioxide/salt spray environment
- Perform fully reversed bending fatigue testing after accelerated humidity exposure
- Perform long-term, real-time evaluation of metal foil-coated graphite/epoxy specimens under stressed and unstressed conditions
- Establish procedures to apply metal foil coatings to graphite/epoxy prototype production hardware such as the finger panels for the F-14A overwing fairings.

Section 3

MATERIAL QUALIFICATION/BLEEDER PROVE-OUT

3.1 APPROACH

Unidirectional laminates were fabricated and tested to qualify the AS/3501-6 graphite/epoxy tape. In order to assure consistency of results with those of the original program (Ref. 1), the same composite raw material and fabrication techniques were used for this program.

3.2 STUDY AREAS

Study areas involved in the fabrication and testing of the material qualification and bleeder prove-out test panels included:

- Material properties
- Fabrication techniques
- Control testing.

3.3 MATERIAL PROPERTIES

All graphite/epoxy specimens were prepared using AS/3501-6 graphite/epoxy preimpregnated tape supplied by Hercules, Inc. This material is an amine-cured epoxy resin reinforced with unidirectional graphite fibers. Material properties are shown in Figure 3-1. Style 116 fiberglass cloth was used as the bleeder.

3.4 FABRICATION TECHNIQUES

Fabrication of unidirectional material qualification and bleeder prove-out panels, and multidirectional major process screening test panels, was conducted in accordance with established procedures. Eight- and 15-ply unidirectional laminates were fabricated for material qualification and bleeder prove-out evaluation. Major test panels fabricated for process screening and serviceability evaluation were 18 plies thick with a ply orientation of $(+45, -45, 0, 0, 90, 0, 0, +45, -45)_s$. The panels were cured using the following cycle:

- Place vacuum-bagged laminate in autoclave
- Pressure-check autoclave system

PROPERTY	TYPICAL RANGE OF PHYSICAL CHARACTERISTICS
WIDTH, IN.	12.00 ± 0.030
CURED PLY THICKNESS, MILS	5.2 ± 0.3
LENGTH/UNIT WEIGHT, FT/LB	20
RESIN CONTENT, WT %	42 ± 3
FLOW, WT %	25 ± 10
GEL TIME, MINUTES @ 350°F	10 ± 3
VOLATILES, WT %	1% (MAXIMUM)
TACK, MINUTES	30 (MINIMUM)
WORK LIFE, DAYS	7 @ 75 ± 5°F, 40% RH, EXPOSED 14 @ 75 ± 5°F, 50% RH SEALED
STORAGE LIFE, MONTHS	3 @ 40°F 6 @ 0°F

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Figure 3-1 Physical Characteristics of AS/3501-6 Graphite/Epoxy Tape (Hercules Procedure HD-SG-2-6006)

- Apply minimum vacuum of 25 in. of mercury
- Raise the laminate temperature to 350°F ± 5°F at a rate of 3 - 5°F/min. Apply a pressure of 85 psi (+10, -0 psi) when the laminate reaches 275°F ± 5°F
- Hold the above conditions (350°F ± 5°F, 85 psi (+10, -0 psi) and 25 in. Hg) for 120 ± 5 min
- Cool the laminate to 150°F (maximum) in 40 min (minimum)
- Release autoclave vacuum and pressure
- Remove laminate from autoclave
- Remove bleeder pack
- Post-cure laminate for 8 hr at 350°F in an air-circulating oven.

All tooling and caul plates were cleaned, coated with Frekote 33, and baked at 350°F for one hour prior to use. Panels were cured with one ply of peel ply on each side of the laminate. Thermocouples were used to monitor the autoclave cycle.

3.5 CONTROL TESTING

Material qualification and bleeder prove-out panels were fabricated from Hercules AS/3501-6 graphite/epoxy tape. One 7 x 12-in., 8-ply unidirectional panel for tensile strength specimens and one 7 x 7-in., 15-ply unidirectional panel for flexural and interlaminar shear strength specimens were fabricated using a 2.5-to-1.0 preimpregnated tape-to-bleeder ratio. Test specimens were cut from the cured panels with a diamond saw and subjected to tensile tests at room temperature (73°F) and flexural and interlaminar shear strength tests at room temperature (73°F) and at 260°F. The results are shown in Figure 3-2. The 2.5-to-1.0 ratio of preimpregnated tape-to-bleeder plies resulted in a low per-ply thickness. A bleeder ratio of 3.0-to-1.0 was subsequently used in the fabrication of all major test panels for process screening and serviceability evaluation.

NUMBER OF UNIDIRECTIONAL LAMINATE PLIES	TEST TEMP, °F	TENSION		FLEXURE		HORIZONTAL SHEAR STRENGTH, KSI
		STRENGTH, KSI	MODULUS, MSI	STRENGTH, KSI	MODULUS, MSI	
8	73	252.8/190**	19.4/18.5**	---	---	---
15	73	---	---	313*/228**	18.3*/17.0**	17.2/12.5**
15	260	---	---	251*/180**	17.8*/16.5**	11.5/8.6**
THICKNESS, IN.	--	0.040 (0.005/PLY)		0.072 (0.0048/PLY)		0.068 (0.0046/PLY)

*NOT NORMALIZED - THICKNESS LESS THAN STANDARD
**GM 3013 MINIMUM REQUIREMENT
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Figure 3-2 Material Qualification Tests: AS/3501-6 Graphite/Epoxy

Section 4

PROCESS SCREENING EVALUATION

4.1 APPROACH

This phase of the program was directed at the development of application parameters for several candidate coating systems and the evaluation of coating performance with respect to corrosion compatibility, adhesion, and moisture resistance.

4.2 STUDY AREAS

The development and evaluation of candidate coatings for process screening involved:

- Selection of candidate coatings and materials
- Development of application parameters for the candidate coatings
- Determination of corrosion resistance
- Determination of moisture resistance.

4.3 BACKGROUND

Phase I of this program (Ref. 1) demonstrated the viability of using foil coatings to protect graphite/epoxy substrates from moisture penetration, paint stripper attack, lightning strikes, and electromagnetic interference (EMI). Work performed in Phase I indicated the need for further development of the foil coatings with respect to corrosion compatibility, foil material and application, and repairability, as well as the development of alternate types of coatings such as pressed-powder bond coatings.

4.4 CANDIDATE COATINGS AND MATERIALS

Four areas of coating development were selected for preliminary evaluation: secondary-bonded solid aluminum foil; secondary-bonded perforated aluminum foil; pressed-powder bonded aluminum; and foil coating repair.

4.4.1 Solid Aluminum Foil

Solid aluminum foil bonded to cured graphite/epoxy laminates provided excellent protection against moisture penetration, paint stripper attack, and EMI. The Phase I evaluation indicated a need for a more corrosion-resistant aluminum alloy. The coating system selected was 0.0019-in.-thick 5052 aluminum alloy bonded with EA 9628 epoxy film adhesive (0.010 lb/ft^2) made by the Hysol Division of the Dexter Corporation. The standard pretreatment involves alkaline cleaning followed by acid cleaning (sulfuric acid - sodium dichromate). The following standard prebonding foil pretreatment systems were evaluated to determine which would provide the optimum coating adhesion and corrosion protection for each of the three types of protective coating systems being studied:

- EC-2333 silane primer
- BR-127 corrosion-inhibiting primer
- Alodine 1200/BR-127 primer
- Phosphoric acid anodize/BR-127 primer

4.4.2 Perforated Aluminum Foil

Perforated aluminum foil bonded in a secondary operation to cured graphite/epoxy laminates was evaluated as a candidate coating material. Phase I studies showed that cocured perforated foil provided excellent moisture protection and assessed the effects of application techniques on moisture resistance. The selected foil was 0.0025 in.-thick, 5052 aluminum alloy perforated with 0.010-in.-diameter holes at a density of 35 holes per square inch. The pretreatment systems and adhesive used for the solid foil was also used for the perforated foil.

4.4.3 Pressed-Powder Bond Coatings

Pressed-powder bond aluminum is a new metallic coating concept, developed and evaluated under this program, that involves pressurized adhesive bonding of aluminum particles to cured composite laminates (Figure 4-1). The following adhesives were evaluated for use with this coating system:

- Metlbond 329A (1 and 2 layers)
- 0.010 lb/ft^2 Dexter Hysol EA 9628 (1, 2, and 3 layers)
- Sheldahl T-400 (1, 2, and 3 layers).

The aluminum powders, adhesives and curing conditions studied are listed in Figure 4-2.

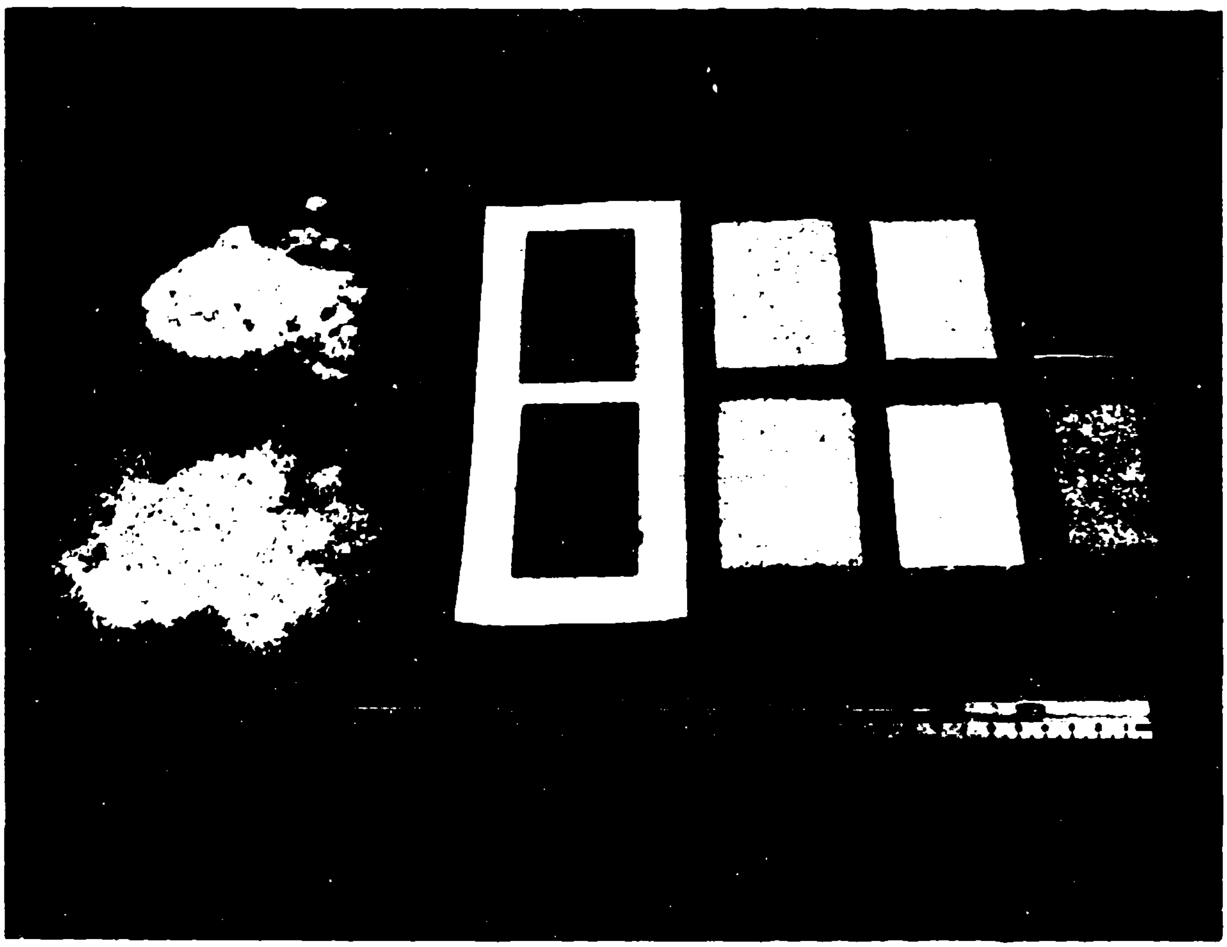

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Figure 4-1 Pressed-Powder Bond Aluminum Coatings

ALUMINUM POWDER	LAYERS							
	DEXTER HYSOL EA 9628*			METLBOND 329A*		SHELDAHL T-400**		
	1	2	3	1	2	1	2	3
ALCOA 12				X	X			
ALCOA 120				X	X			
ALCOA 129				X	X			
ALCOA 1230	X							
AMPAL 604					X			
FISHER A-559	X				X			
METCO 54NS	X			X				
3M EC1101	X			X				
SCIENTIFIC ADVANCES								
• Al FIBER	X	X	X	X	X	X	X	X
• Al FLAKE	X	X	X	X	X	X	X	X
AUTOCLAVE CURE CONDITIONS	300°F/15 MIN/ 85-200 PSI/FULL VACUUM			350°F/60 MIN/ 85-200 PSI/FULL VACUUM		300°F/5 MIN/ FULL VACUUM		

*EPOXY FILM ADHESIVE
**POLYESTER HOT-MELT ADHESIVE

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Figure 4-2 Materials, Adhesives, and Curing Conditions Used in Evaluation of Pressed-Powder Bond Coatings

4.4.4 Repair of Foil Coatings

Repair procedures for Class II and Class III (Figure 4-3) damage, as defined in Ref. 2, to metallic foil-covered graphite/epoxy panels were established. Class II and Class III damage (cuts, dents, scratches, and abrasions) were introduced in the foil and repaired using treated aluminum foil and a conductive adhesive system.

The adhesive systems evaluated included:

- Dexter Hysol K8-4238
- Chromerics Cho-Bond 360-208
- Chromerics Cho-Bond 360-18.

The patch was a 2-in.-diameter circle of perforated 5052 aluminum alloy (Figure 4-4). Curing of the repair patch was accomplished with a portable repair kit that contained a vacuum pump, temperature control system, and heater blanket. This kit is similar to the Grumman-developed advanced composite repair kit that is being used by the Fleet.

4.5 DEVELOPMENT OF APPLICATION PARAMETERS

4.5.1 Solid Aluminum Foil

Solid aluminum foil-coated graphite/epoxy laminates were prepared in accordance with the procedure developed in Phase I of this program (Ref. 1). Further investigation was required to determine the effects of any potential galvanic corrosion between the foil and the composite. As a result, the effects of various corrosion-resistant foil pretreatments on adhesion and corrosion-resistance were determined.

4.5.1.1 Graphite/Epoxy Laminates

AS/3501-6 graphite/epoxy, 18-ply, process-screening test panels with a fiber orientation of $(+45, -45, 0, 0, 90, 0, 0, +45, -45)_s$ were prepared as described in Section 3. Ultrasonic scanning showed that all panels were satisfactory. The panels were cut with a 60-grit diamond-plated saw to the subpanel sizes shown in Figure 4-5.

4.5.1.2 Foil Pretreatment

The 0.0019-in.-thick, 5053 aluminum alloy foil for coating was subjected to a standard pretreatment that consisted of alkaline cleaning with Oakite 164 solution followed by acid cleaning with sulfuric acid - sodium dichromate solution. After

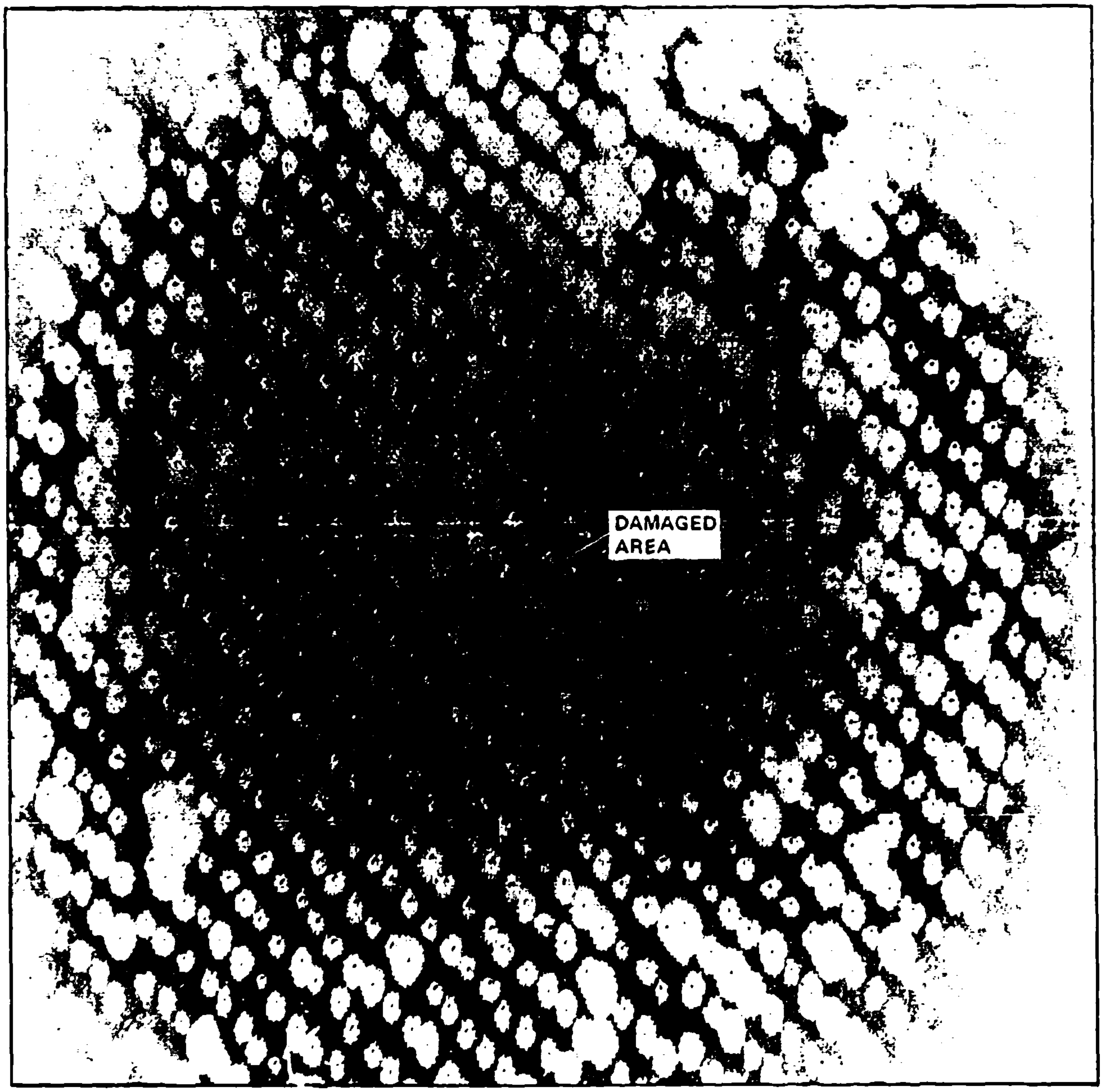

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Figure 4-3 Class II and Class III Damage on Perforated Foil-Coated Graphite/Epoxy Panel

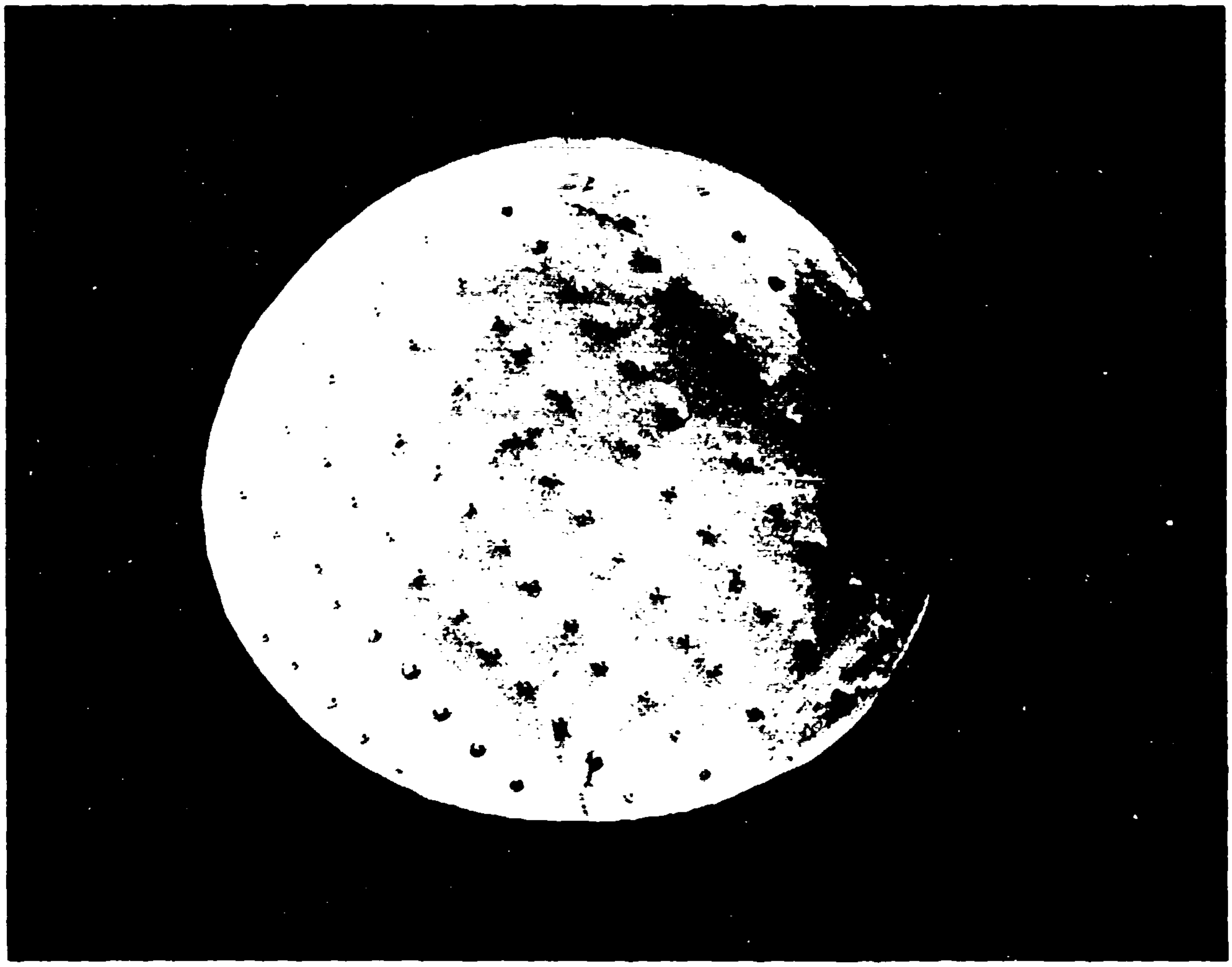

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Figure 4-4 Two-In.-Diameter 5052 Aluminum Alloy Repair Patch

TECHNICAL EFFORT	MAJOR PANELS,* NUMBER (SIZE-INCHES)	SUBPANELS,* NUMBER (SIZE-INCHES)	FLEXURAL STRENGTH 73°F	FLEXURAL STRENGTH 260°F	HORIZONTAL SHEAR STRENGTH 73°F	HORIZONTAL SHEAR STRENGTH 200°F	ROLLER PEEL STRENGTH 73°F	ADHESION (KNIFE OR TAPE) 73°F	IMP[illegible] STRE[illegible] 73[illegible]
Task I – Material Qualification-Bleeder Prove-Out									
• Laminate Molding		1 (5 x 12)**	4	4	4	4			
Task II – Process Screening									
• Foil Coatings									
– Coating Selection	2 (19 x 28)	40 (3 x 6)							
– Environmental Conditioning (Control, Humidity, Spiking)	1 (15 x 23)	3 (6.5 x 14)	9	9	9	9	15		
• Pressed Powder Coating									
– Powder Selection	1 (10 x 12)	3 (1.5 x 8)						3	3
– Adhesive Selection		2 (1.5 x 8)						2	2
– Environmental Conditioning (Control, Spiking)	1 (17 x 33)	4 (7.5 x 15)	6	6	6	6			
• Cold Powder Spray Bonding									
– Adhesive Selection	1 (14 x 26)	2 (12 x 12)						2	2
• Foil Repair	1 (7 x 13)	4 (3 x 6)							
Task III – Serviceability									
• EMI (Foil, Pressed Powder, Repair)	1 (16 x 48)	3 (15 x 15)							
• Cut & Drill (Foil, Pressed Powder)	1 (26 x 26)	4 (12 x 12)							
• Lightning Strike (NAVAIR)	1 (14 x 38)	3 (12 x 12)							
Test Panel Size (Inches)			0.5 x 4.5	0.5 x 45	0.25x0.80	0.25x0.80	1 x 8	2 x 2	2 x
Total Number of Tests	10	68	19	19	19	19	15	7	7

*All Major Panels are 18 Ply, Except Where Noted By**

**16 Ply Subpanel for Tensile Strength Tests

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ADHESION (KNIFE OR TAPE) 73°F	IMPACT STRENGTH 73°F	CORROSION RESISTANCE 5% SALT SPRAY	CORROSION RESISTANCE SO_2 SALT SPRAY	PHOTO-MICRO ANALYSIS	PER-PLY THICKNESS	MOISTURE PICKUP	ULTRA-SONIC SCANNING	TENSILE STRENGTH	EMI	CUT & DRILL	LIGHTNING STRIKE
					10		10	8**			
		20	20								
						2					
3	3			3							
2	2			2							
		4	4			1					
2	2			2							
				4							
									3	2	3
2 x 2	2 x 2	3 x 6	3 x 6	Small Sections as Req'd	Major Panels	Subpanels	Major Panels	0.5 x 11	15 x 15	12 x 12	12 x 12
7	7	24	24	11	10	3	10	8	3	2	3

Figure 4-5 Graphite/Epoxy Subpanel Sizes

pretreatment, one of the five following systems was applied to improve adhesion and corrosion protection:

- EC-2333 silane primer
- BR-127 corrosion-inhibiting primer
- Alodine 1200/BR-127 primer
- Phosphoric acid anodize/BR-127 primer
- EC-2333 silane primer applied with one ply of 104 scrim cloth.

4.5.1.3 Evaluation of Corrosion-Resistance

Painted (standard Navy finish), foil-coated laminates were scribed through the paint and foil and subjected to 5% salt spray and SO_2 salt spray (Appendix A) to determine which of the five foil corrosion-protection systems provided the best protection against corrosion. Four 3 x 6-in. specimens coated with each of the five protection systems were prepared for salt spray exposure (two for 5% salt spray and two for SO_2 salt spray) by painting and scribing through the foil (Figure 4-6). The panels were exposed for 20 days in 5% salt spray and up to 15 cycles in SO_2 salt spray. The panels were visually inspected each day; one section that included a scribe line was periodically removed from each panel for microscopic examination. Photomicrographic analyses of the sections subjected to SO_2 salt spray (Figure 4-7) indicated that corrosion protection was not significantly different for any of the five systems evaluated (Figure 4-8). Panels treated with the EC-2333 and/or BR-127 primers, however, showed somewhat less corrosion through 15 cycles. The degree of corrosion did not increase consistently with time for all specimens; therefore, it was difficult to determine the relative corrosion protection provided by the systems evaluated. The SO_2/salt spray testing did not indicate a severe corrosion problem; however, real-life field-testing should be performed.

4.5.1.4 Evaluation of Foil Adhesive

The foil pretreatments did have an effect on foil adhesion to the graphite/epoxy substrate. Foil adhesion was determined by the peel test described in ASTM Test Method B571-72. Analysis of th test results showed that the EC-2333 silane primer provided the best adhesion; the BR-127 primer was second best (Figure 4-9). The BR-127 primer separated from both the alodined and anodized foil, allowing the foil to easily peel from substrates treated with these systems. The peel test used gives an indication of relative adhesive strengths only; absolute values can be provided by other test methods.

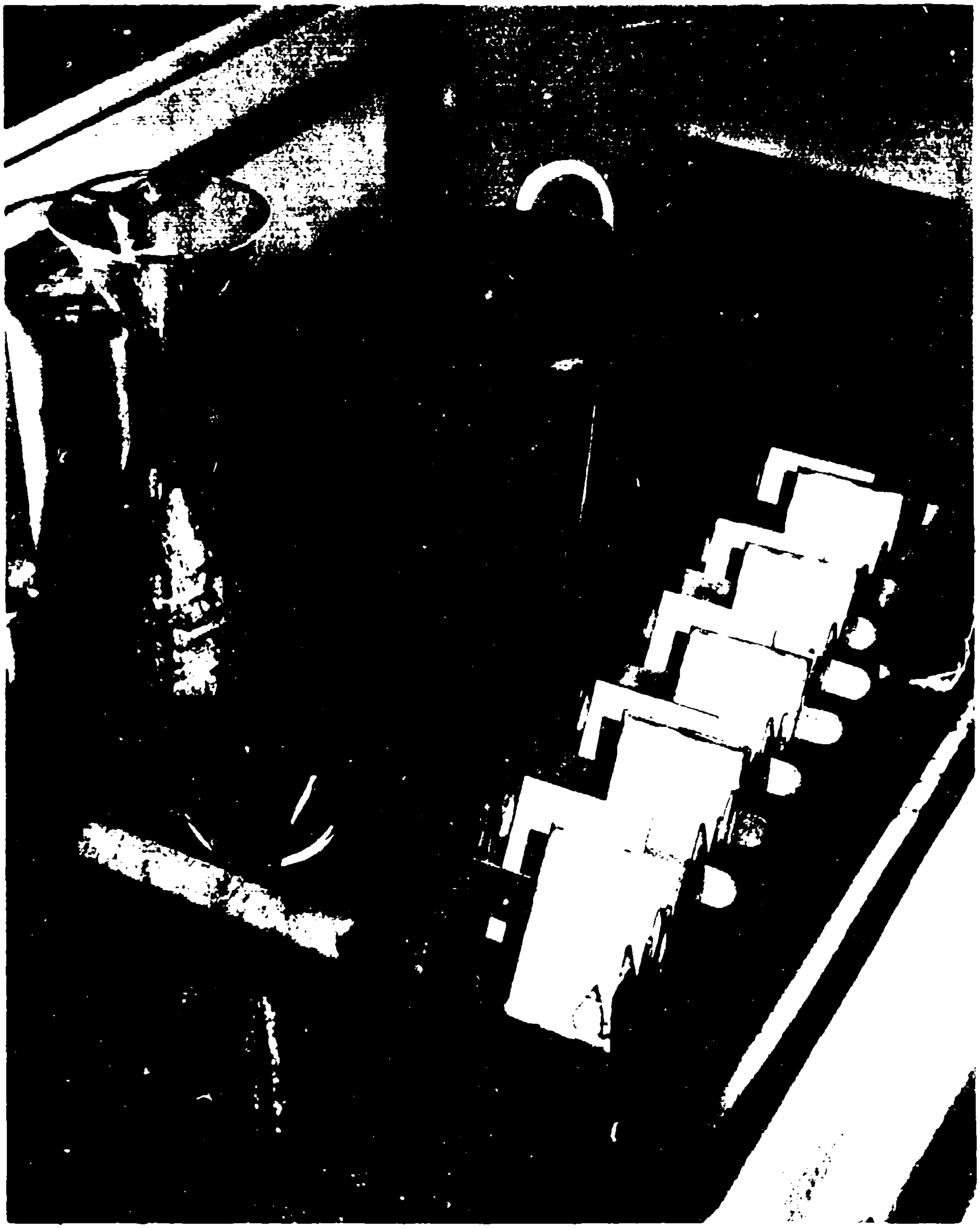

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Figure 4-6 Scribed, 3 x 4-In., Salt-Spray-Exposure, Foil-Coated and [illegible]ted Test Panels

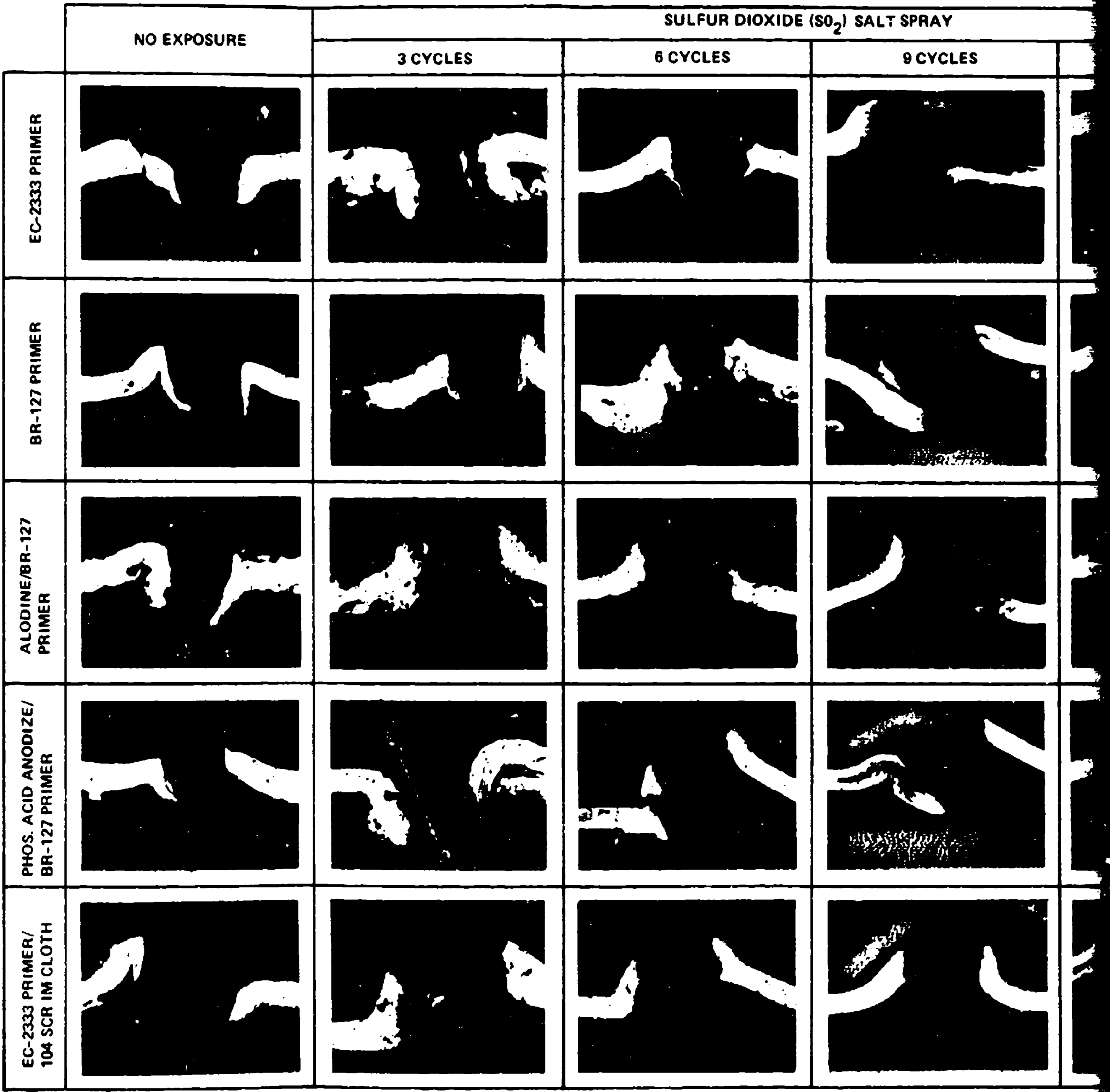

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Figure 4-7 Photomi
Panels Su
Salt Spra

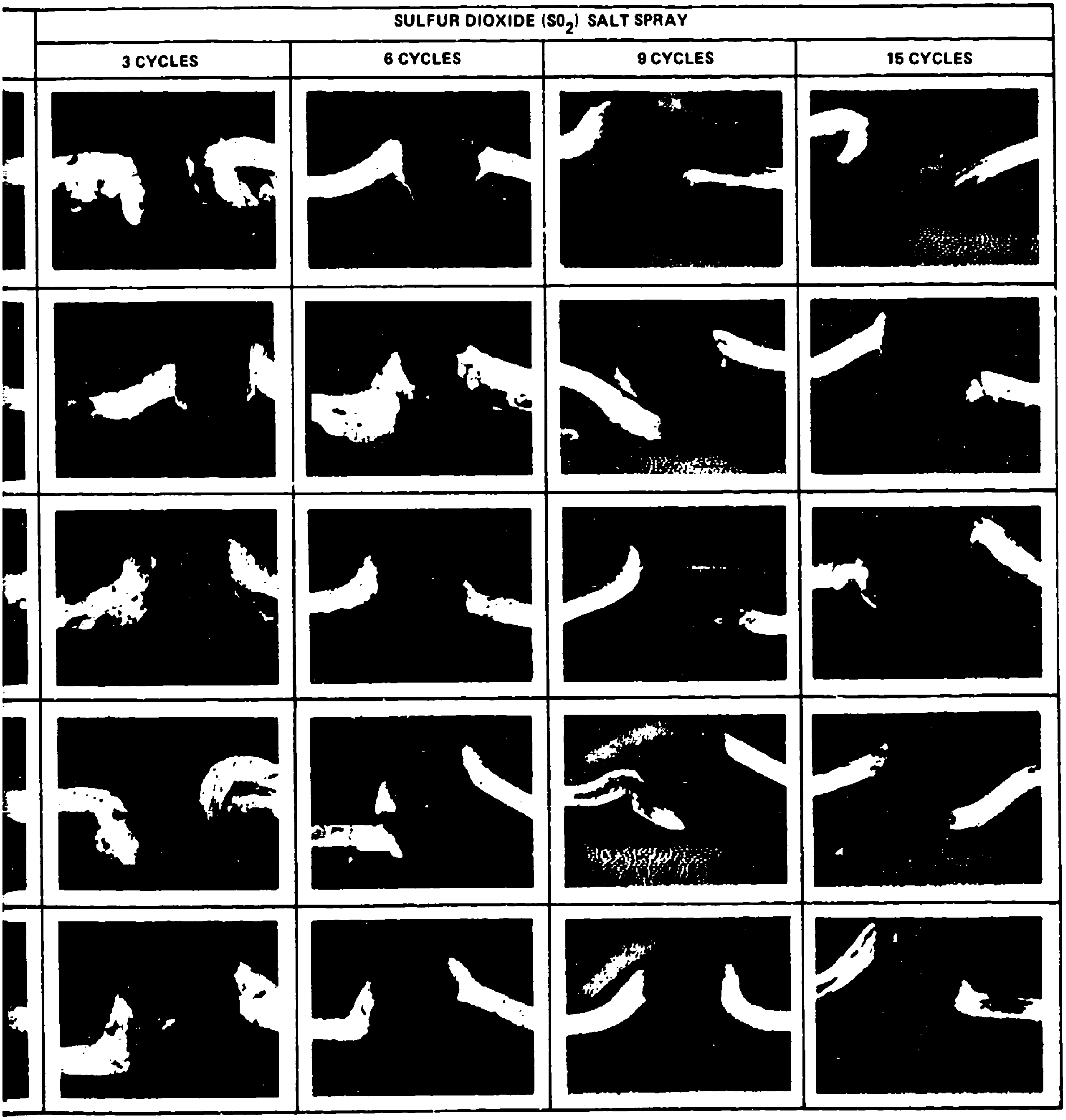

Figure 4-7 Photomicrographs of Foil-Coated Test Panels Subjected To Sulfur Dioxide Salt Spray (80X Magnification)

CORROSION PROTECTION SYSTEM	NUMBER OF SO_2 SALT-SPRAY CYCLES				
	NONE	3	6	9	15
EC–2333 SILANE PRIMER	NO CORROSION	SLIGHT CORROSION* BOTH SIDES	SLIGHT CORROSION BOTH SIDES	SLIGHT CORROSION (L) SOME CORROSION* (R)	SLIGHT CORROSION (L) HEAVY CORROSION* (R)
BR–127 PRIMER	NO CORROSION	HEAVY CORROSION (L)** SLIGHT CORROSION (R)**	SLIGHT CORROSION BOTH SIDES	SLIGHT CORROSION (L) SOME CORROSION (R)	SLIGHT CORROSION (L) SOME CORROSION (R)
ALODINE 1200/ BR–127 PRIMER	NO CORROSION	SOME CORROSION BOTH SIDES	SOME CORROSION BOTH SIDES	SLIGHT CORROSION (L) SOME CORROSION (R)	SOME CORROSION BOTH SIDES
PHOSPHORIC ACID ANODIZE/BR–127 PRIMER	NO CORROSION	SOME CORROSION BOTH SIDES	SLIGHT CORROSION BOTH SIDES	HEAVY CORROSION (L) SLIGHT CORROSION (R)	SOME CORROSION BOTH SIDES
EC–2333 PRIMER/ 104 SCRIM	NO CORROSION	SOME CORROSION (L) SLIGHT CORROSION (R)	SOME CORROSION (L) SLIGHT CORROSION (R)	SLIGHT CORROSION BOTH SIDES	HEAVY CORROSION BOTH SIDES

*SLIGHT, SOME, AND HEAVY ARE RELATIVE VALUATIONS OF THE DEGREE OF CORROSION.

** (L)–LEFT SIDE OF SCRIBE; (R)–RIGHT SIDE OF SCRIBE.

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Figure 4-8 Corrosion Evaluation of Foil Coating Protection Systems: SO_2 Salt Spray

CORROSION PROTECTION SYSTEM	FOIL ADHESION (RELATIVE)
EC 2333 PRIMER ONLY	GOOD ADHESION
BR-127 PRIMER ONLY	FAIR ADHESION
ALODINE 1200 WITH BR-127	PRIMER SEPARATED FROM FOIL - POOR
PHOSPHORIC ACID ANODIZE WITH BR-127	PRIMER SEPARATED FROM FOIL - POOR
104 SCRIM WITH EC 2333	FAIR ADHESION
PRETREATMENT- ALKALINE CLEAN, ACID CLEAN (DICHROMATE) BR-127 CURED 250°F/60 MIN FOIL BONDED WITH DEXTER HYSOL 9628 FILM ADHESIVE @ 300°F/15 MIN/100 PSI/FULL VACUUM	

R80-1922-011P

Figure 4-9 Adhesion of Aluminum Foil to Graphite/Epoxy Substrates Subjected to Various Foil Treatments

4.5.1.5 Selection of Foil Pretreatments

Based on the results of the adhesion tests (corrosion tests were inconclusive), EC-2333 silane primer was selected as the foil treatment for all further tests. This pretreatment system has the additional advantage of requiring only a minimum of processing.

4.5.2 Perforated Aluminum Foil

Perforated aluminum foil-coated graphite/epoxy laminates were prepared according to the procedure developed in Phase I for secondary bonding applications. The foil pretreatment selected for the solid foil coating was also used for the perforated foil coating. The subpanels used were taken from major process screening test panels as described in Subsection 4.5.1.1.

4.5.3 Pressed-Powder Bond Coatings

This technique involves pressurized application of aluminum powder, fiber, or flake to cured graphite/epoxy substrates, followed by curing and polishing/buffing to give a smooth finish. The type of surface produced depends on the particular aluminum form and adhesive used, the application pressure, and final machining/polishing procedure.

4.5.3.1 Materials

All substrate test panels were laminated from 12-in.-wide, preimpregnated AS-3501-6 graphite/epoxy tape. Three types of aluminum powder (Alcoa No. 12, 120, and 129) and one type each of aluminum flake and fiber were evaluated as potential coating materials. Three types of adhesives (Metlbond 329 epoxy, Dexter Hysol EA 9628 epoxy, and Sheldahl T-400 polyester hot-melt) were evaluated.

4.5.3.2 Flat Panel Tests

4.5.3.2.1 Procedure - A 1/4-in.-thick, aluminum tooling plate was covered with TX 1040 nonporous fabric. After the graphite/epoxy panels had been positioned on the TX 1040-covered tooling plate, cork dams were positioned around each edge. Nylon tape was then applied to the inner surface of each dam. A layer or layers of adhesive film was positioned over the graphite/epoxy panels. Aluminum powder, flake, or fiber was spread evenly over the adhesive film. A 1/8-in.-thick, silicone rubber sheet was then placed over the assembly to provide uniform pressure distribution over the entire surface. An aluminum tooling plate was positioned over the silicone rubber sheet so that it was flush with the top of the cork dam. A typical test panel layup is shown in Figure 4-10. The entire assembly was then vacuum-bagged with nylon film as shown in Figure 4-11 and autoclave-cured per the schedules shown in Figure 4-12. Excess coating material was removed after curing. Several types of abrasive flap wheels (Figure 4-13) were used to sand and burnish the cured flat panels, including 2-in.-, 4-in.-, and 6-in.-diameter brush-backed, 120-grit flap wheels. When a reasonably smooth surface was obtained, the panels were gently wet-sanded using 600A-grit abrasive paper. Further burnishing was accomplished on a polishing wheel using a coarse abrasive compound followed by a finer polishing compound, and then without compound.

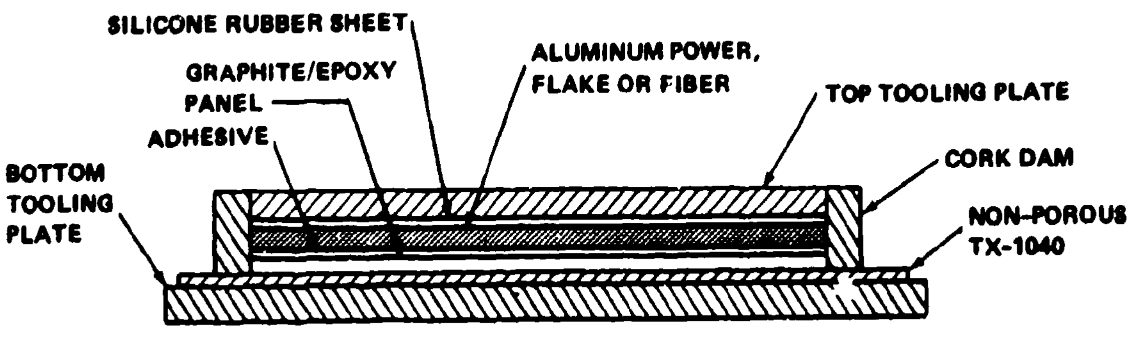

Figure 4-10 Typical Test Panel Layup

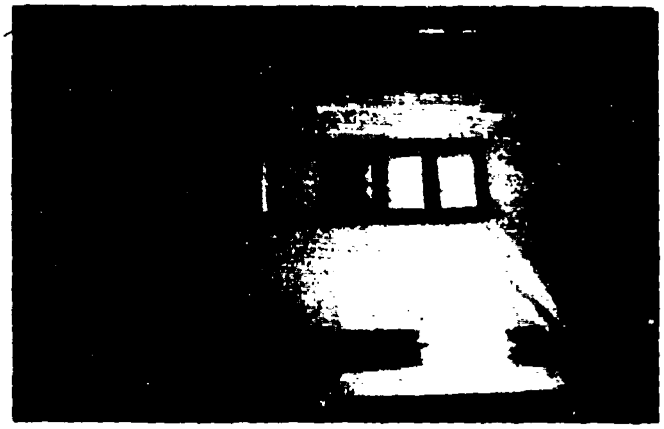

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Figure 4-11 Vacuum-Bagged Test Panels

ADHESIVE		ALUMINUM COATING MATERIAL				
		POWDER (ALCOA)				
TYPE	NUMBER OF LAYERS	NO. 12	NO. 120	NO. 129	FLAKE	FIBER
EPOXY (METLBOND 329)	1	X	X	X	X	X
350°F/60 MIN	2	X	X	X	X	X
EPOXY (DEXTER	1				X	X
HYSOL EA 9628)	2				X	X
300°F/15 MIN	3				X	X
POLYESTER HOT MELT	1				XX	XX
(SHELDAHL T-400)	2				XX	XX
300°F/5 MIN	3				XX	XX

X - APPLICATION PRESSURE: FULL VACUUM PLUS 200 PSI
XX - APPLICATION PRESSURE: FULL VACUUM

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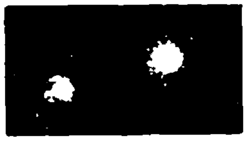
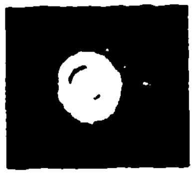
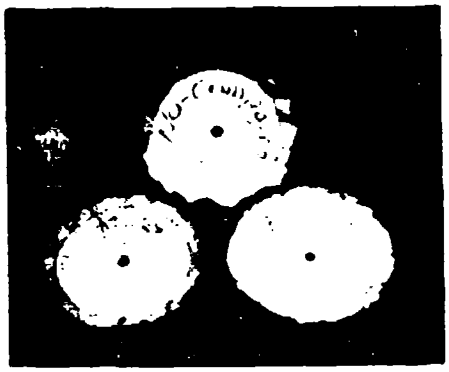
Figure 4-12 Autoclave Curing Conditions for Flat Test Panels



2- AND 4-IN.-DIA
SANDING FLAP WHEELS



6-IN.-DIAM. BRUSH-BACKED
BURNISHING FLAP WHEEL



POLISHING WHEELS

R80-1922-016P

Figure 4-13 Finishing Wheels

4.5.3.2.2 Results - The pressed-powder systems were evaluated for adhesion, polishability and conductivity; data obtained are presented in Figure 4-14. The Metlbond 329 epoxy adhesive was found to provide by far the best adhesion of the three systems evaluated. Panels bonded with the 9628 and polyester hot-melt adhesives delaminated during sanding and polishing, and had interstices in the coating. Panels containing the various aluminum powders, flake, and fibers could be sanded and polished to give reasonably smooth surfaces; aluminum powders give slightly better surfaces. Conductivity (as determined with a Simpson ohmmeter) of panels containing aluminum flake and fiber was considerably higher than that for powder-coated panels. Resistance values ranged from one to five ohms for the flake- and fiber-coated panels, compared to thousands of ohms for the powder-coated panels. Analysis of these results indicates that the optimum system is aluminum flake or fiber bonded to graphite/epoxy substrates with Metlbond 329 epoxy adhesive. No improvement was observed by using two layers of the adhesive.

EVALUATION CRITERIA	ALUMINUM POWER (ALCOA)						ALUMINUM FLAKE (TRANSMET CORP)								ALUMINUM FIBER (TRANSMET CORP)							
	NO. 12		NO. 120		NO. 129																	
ADHESIVE	329		329		329		329		9628			HOT MELT			329		9628			HOT MELT		
NO. OF LAYERS	x1	x2	x1	x2	x1	x2	x1	x2	x1	x2	x3	x1	x2	x3	x1	x2	x1	x2	x3	x1	x2	x3
ADHESION	G	G	G	G	G	G	G	G	P	P	P	VP	VP	VP	G	G	P	P	P	VP	VP	VP
POLISHABILITY	G	G	G	G	G	G	G	G							G	G						
CONDUCTIVITY	VP	VP	VP	VP	VP	VP	VG	VG							VG	VG						

LEGEND:

VG – VERY GOOD
G – GOOD
P – POOR
VP – VERY POOR

R80-1922-016P

Figure 4-14 Evaluation of Aluminum Coating Systems on Flat Panels

4.5.3.3 Contoured Panel Tests

4.5.3.3.1 Procedure - The optimum coating system developed for flat panels was modified to permit implementation on contoured graphite/epoxy structures. Two methods were developed for coating contoured parts: the aluminum fiber technique and the aluminum flake technique.

The aluminum fiber coating technique (Figure 4-15) involves casting of a Glass-rock, contoured female mold which is then covered, in turn, with Teflon tape, aluminum fiber, one layer of Metlbond 329 epoxy adhesive, and the graphite/epoxy panel. Several sheets of silicone rubber are then placed over the stack-up to provide uniform pressure over the panel surface. The entire assembly is then wrapped with Style 1000 fiberglass cloth and bagged with nylon film as shown in Figure 4-16. After applying full vacuum, the bagged assembly is autoclave-cured at 90 psi and 350°F for 60 min. The cured panel is sanded, burnished, and polished using the previously described techniques.

The aluminum flake coating technique (Figure 4-17) does not involve use of a mold. A porous TX 1040 bag is fabricated and filled with aluminum flake. After a layer of Metlbond 329 adhesive is applied to a contoured graphite/epoxy panel, the adhesive-coated panel is placed face-down in the bag, which is wrapped with Style 1000 fiberglass cloth and bagged with nylon film. After applying full vacuum, the bagged assembly is autoclave-cured at 90 psi and 350°F for 60 min. The cured panel is sanded, burnished, and polished using the previously described techniques.

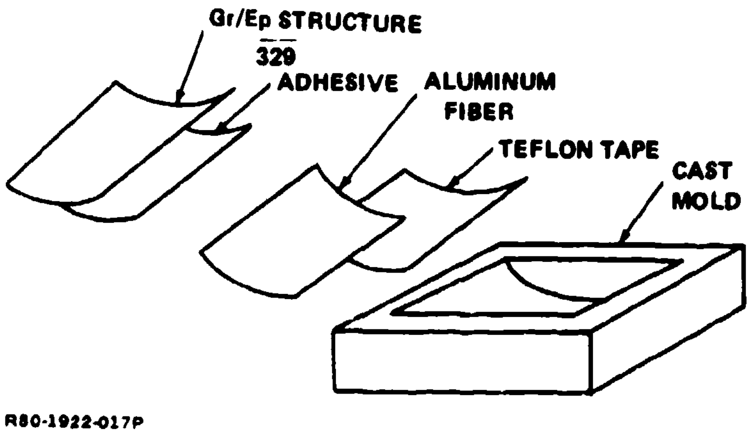


Figure 4-15 Cast Mold Coating Procedure for Compound - Curvature Components with Aluminum Fiber

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Figure 4-16 Vacuum - Bagged Compound - Complex Curvature Component

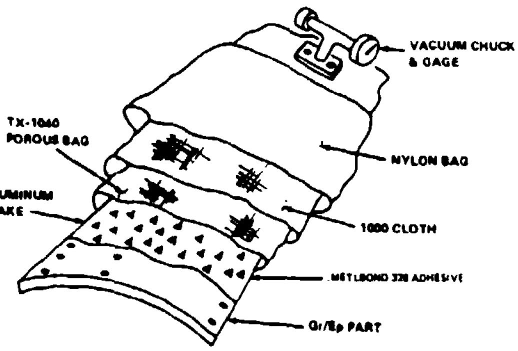

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Figure 4-17 Vacuum Bag Procedure for Coating Compound-Curvature Components With Aluminum Flake

4.5.3.2.2 Results - Both the aluminum fiber and flake coating methods gave positive results. Panels prepared using each technique were well-bonded and polishable, and had very good conductivity (Figure 4-18).

4.5.4 Repair Procedure for Foil Coatings

Parameters were established to repair Class II and Class III damage in a metallic foil-covered graphite/epoxy panel. The technique involves use of a portable repair kit which includes a vacuum pump, temperature control system, and heater blanket. Several conductive adhesives were evaluated and an optimum cure cycle was established.

4.5.4.1 Procedure

Two types of damage (Class II and Class III)were introduced in a 3 x 5-in. foil-coated graphite/epoxy panel. The damage included a 1.0 x 0.125-in. scratch which exposed the bare composite, as well as several small scratches. A 2-in.-diameter circle cut from pretreated 0.0025-in.-thick 5052 aluminum alloy foil was applied over the damaged area. The edge of the patch was feathered to allow a closer fit. The patch, with the adhesive, was placed over the damaged area. The cure was accomplished under a vacuum of 28.5 in. of mercury. The manufacturer's recommended cure cycle was followed (Chromerics' Cho-Bond 360 with No. 18 hardener cured at 260°F for 45 minutes).

Of the three adhesives evaluated, Chromerics' Cho-Bond 360 with No. 18 hardener, was easiest to apply in a thin coat. This system was used to prepare the panels for EMI shielding and lightning strike tests.

AUTOCLAVE CURING CONDITIONS	NUMBER OF LAYERS	ALUMINUM POWDER (ALCOA)						ALUMINUM FLAKE (TRANSMET CORP)		ALUMINUM FIBER (TRANSMET CORP)	
		NO. 12		NO. 120		NO. 129					
		ADH (1)	COND (2)	ADH (1)	COND(2)	ADH (1)	COND(2)	AHD (1)	COND (2)	ADH (1)	COND (2)
350°F/60 MIN	1					GOOD	FAIR	GOOD	VERY GOOD	—	—
75 PSI/FULL VACUUM	2	GOOD	FAIR	GOOD	GOOD	GOOD	GOOD	GOOD	VERY GOOD	—	—
350°F/60 MIN	1	GOOD	POOR	GOOD	POOR	GOOD	POOR	GOOD	VERY GOOD	GOOD	VERY GOOD
200 PSI/FULL VACUUM	2	GOOD	POOR	GOOD	POOR	GOOD	POOR	GOOD	VERY GOOD	GOOD	VERY GOOD

(1) ADHESION (KNIFE TEST AND WORKABILITY) – METLBOND 329A ADHESIVE

(2) CONDUCTIVITY (RESISTANCE IN OHMS BY SIMPSON METER):

VERY GOOD	1-5
GOOD	5-100
FAIR	100-1000
POOR	1000-10,000
VERY POOR	10,000-100,000

(3) POLISHABILITY WAS GOOD FOR EACH OF THE POWER COATINGS.
POLISHABILITY WAS EXCELLENT FOR THE FLAKE AND FIBER COATINGS.

R80-1922-020P

Figure 4-18 Selected Pressed-Powder Bond Coatings Application: Parameters and Test Results

4.5.4.2 Results

A 2-in.-diameter patch was successfully applied over the damaged area of a perforated-foil-coated graphite/epoxy panel (Figure 4-19). Since a conductive adhesive was used, the application of a patch did not alter the conductivity of the panel. EMI shielding measurements showed no significant change in electromagnetic shielding of the repaired panel. A perforated-foil-coated and repaired panel was sent to the Navy for lightning strike evaluation.

4.6 EVALUATION OF MOISTURE RESISTANCE

The moisture resistance of the two selected coating systems [solid (Figure 4-20) and perforated (Figure 4-21) aluminum foil] was evaluated by exposing several coated and painted panels to humidity and humidity/thermal spiking. Moisture pickup and strength retention of the various coated panels were compared with that for the coated panels evaluated in Phase I of this program (Ref. 1) to assess the relative abilities of the coatings to provide the moisture protection needed for graphite/epoxy laminates.

The moisture resistance of aluminum flake-coated and aluminum fiber-coated graphite/epoxy was also determined and compared to that for bare graphite/epoxy (Figure 4-22). Evaluation of the test panels after 73 days of exposure showed that panels coated with aluminum flake and fiber picked up 2.0 and 1.6% moisture, respectively, compared to a moisture pickup of 1.3% for the bare panel. Since the flake and fiber coatings did not provide adequate moisture protection, further moisture testing of these panels was discontinued.

4.6.1 Humidity Exposure

Graphite/epoxy panels protected by the selected coating systems and paint were conditioned at 140°F and 98% relative humidity (RH) for 90 days. Periodic weight measurements were taken and the percent weight gain determined for each of the exposed panels. The weight pickups of the solid foil-coated and perforated foil-coated (secondary bonded) specimens were significantly less than that of the uncoated (painted) control specimens (Figure 4-23). The solid 5052 aluminum alloy foil and the secondary bonded perforated foil coatings reduced moisture pickup by 81% and 52%, respectively. These results compare favorably with those obtained in Phase I (solid 2024 aluminum alloy foil and cocured (unpainted) perforated foil coatings reduced moisture pickup by 90% and 68%, respectively). It was shown in Ref. 1 that moisture

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Figure 4-19 Repaired Area in Aluminum Foil-Coated Graphite/Epoxy Panel

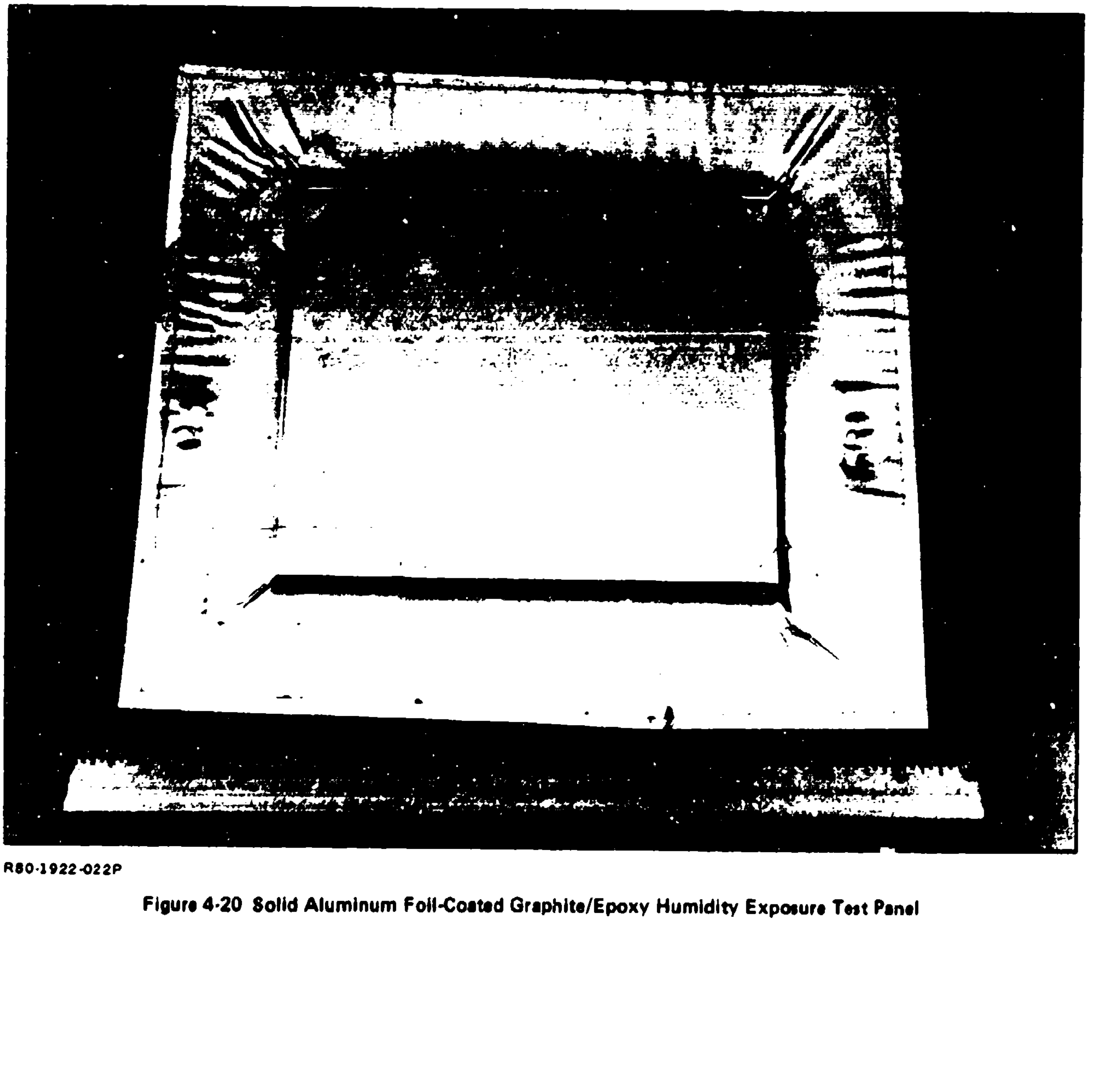

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Figure 4-20 Solid Aluminum Foil-Coated Graphite/Epoxy Humidity Exposure Test Panel

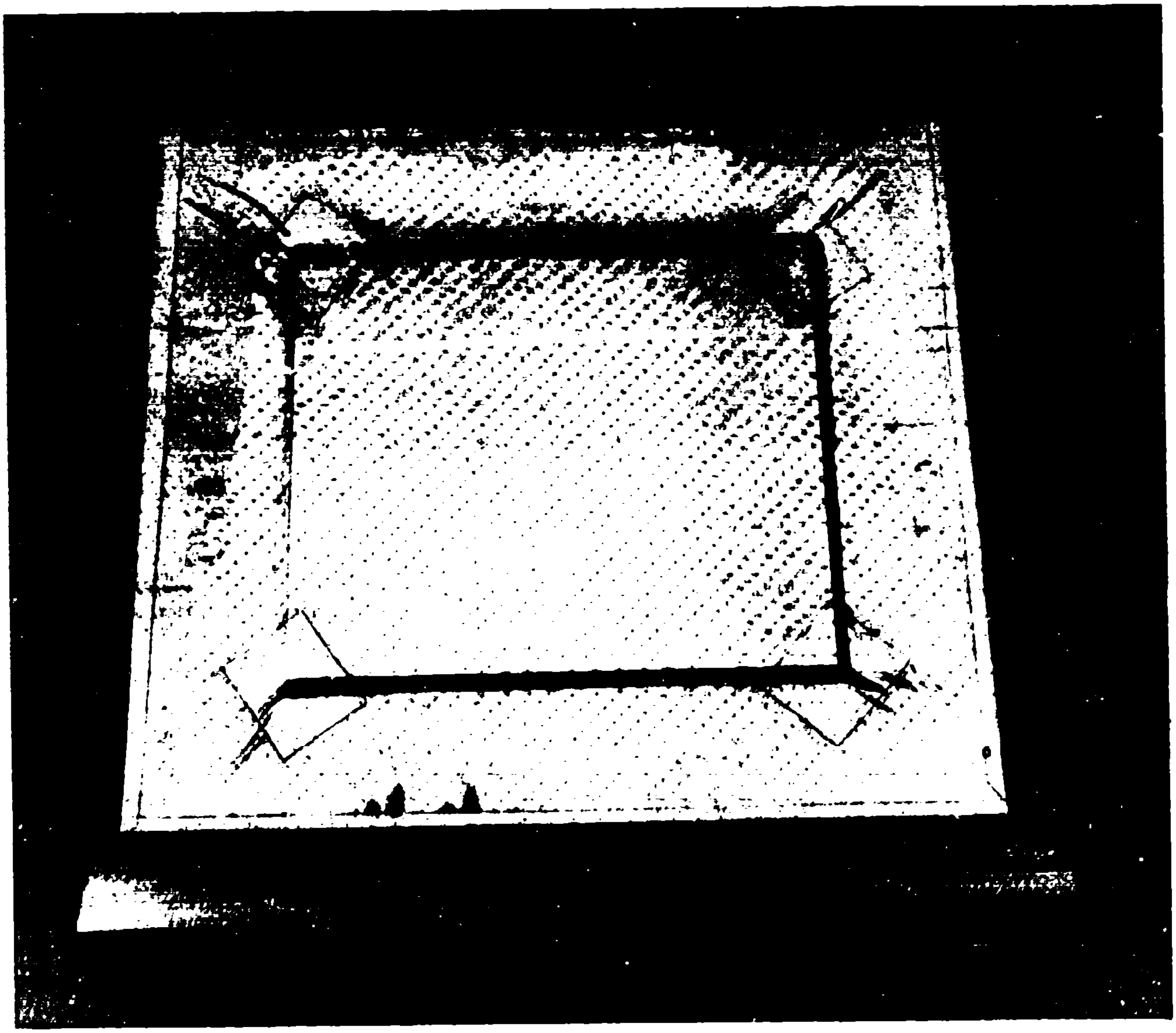

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Figure 4-21 Perforated Aluminum Foil-Coated Graphite/Epoxy Humidity Exposure Test Panel

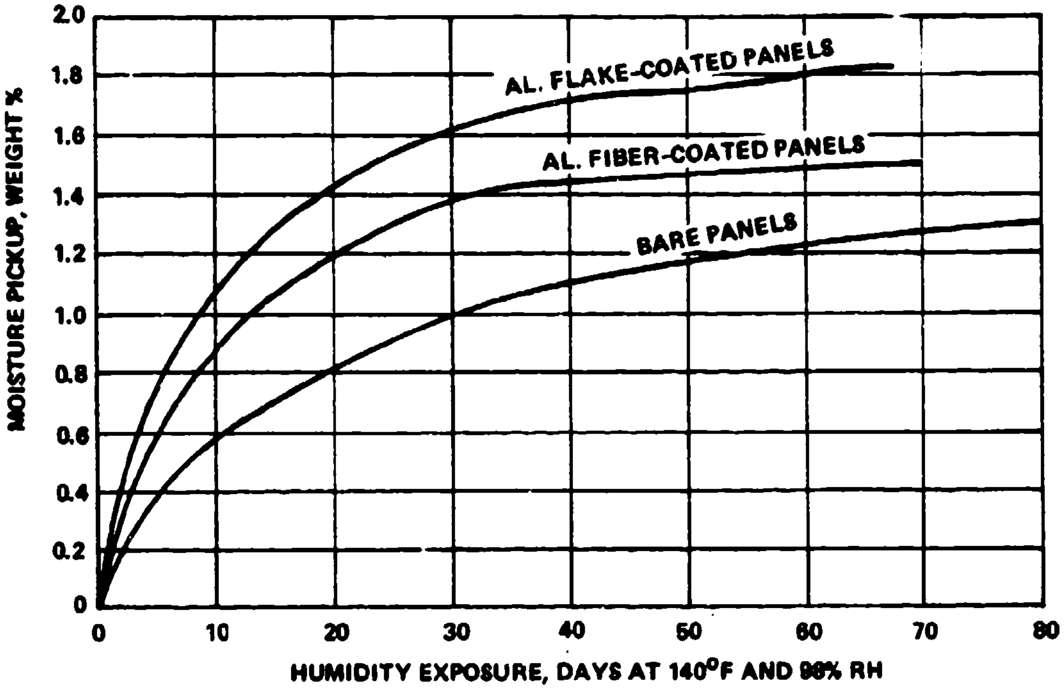

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Figure 4-22 Preliminary Moisture Pickup of Pressed-Powder Bond - Coated Graphite/Epoxy Test Panels

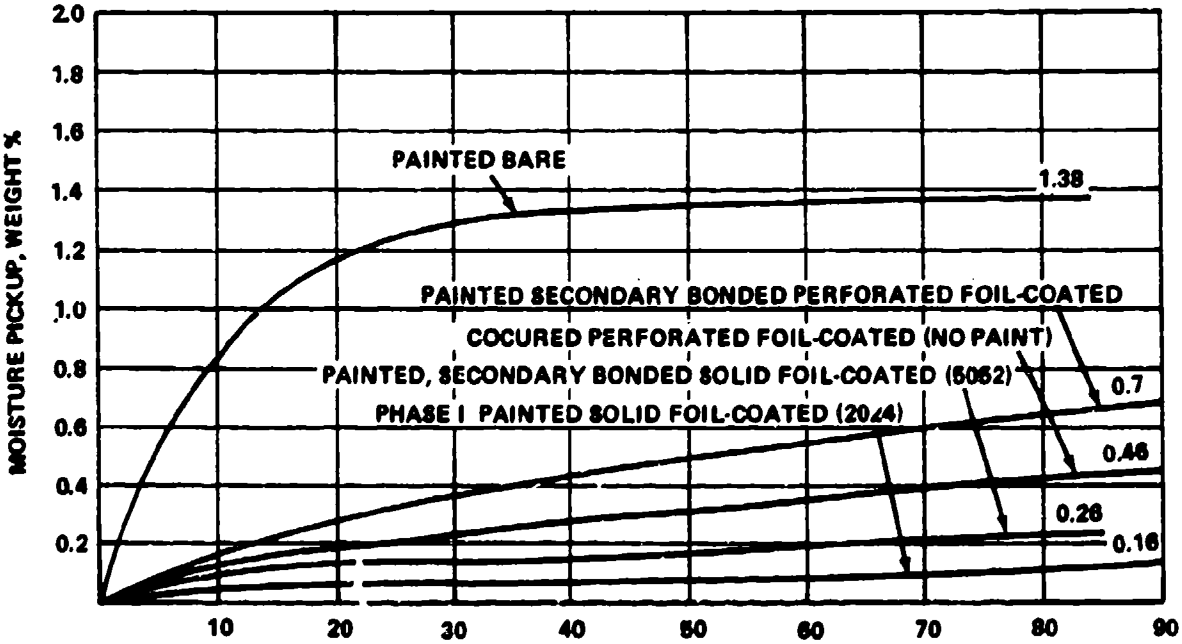

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Figure 4-23 Relative Moisture-Resistance Effectiveness of Aluminum Foil Coating Systems pickup is expected to be greater for painted specimens. Although moisture pickup of the perforated-foil coated specimens [both cocured (Phase I) and secondary bonded] were greater than that of the solid foil-coated specimens, mechanical properties of both types of specimens were not as divergent (see Subsection 4.6.3).

4.6.2 Thermal Spiking Exposure

Graphite/epoxy panels protected with the selected foil coating systems and paint were subjected to thermal spiking (40 cycles at 140°F and 98% RH for 3 days followed by 2 hr at 260°F). Panel weights were determined before and after each thermal spike; the percent weight gain for each of the exposed panels was then calculated. Moisture pickups of the solid and perforated (secondary bonded) foil-coated specimens were significantly less than that of the uncoated (painted) control specimens (Figure 4-24). Moisture pickups after thermal spiking were reduced by 77% and 50% by the solid and perforated foil coatings, respectively. In Phase I, the solid 2024 aluminum foil coatings reduced moisture pickup by 89% after 25 cycles, while the cocured perforated foil coating (unpainted) reduced moisture pickup by 74%. As was the case with the specimens exposed to humidity only, the moisture pickup of the perforated foil-coated specimens (both cocured and secondary bonded) was greater than that for the solid foil-coated specimens, while mechanical properties of both specimen types were not as divergent (see Subsection 4.6.3).

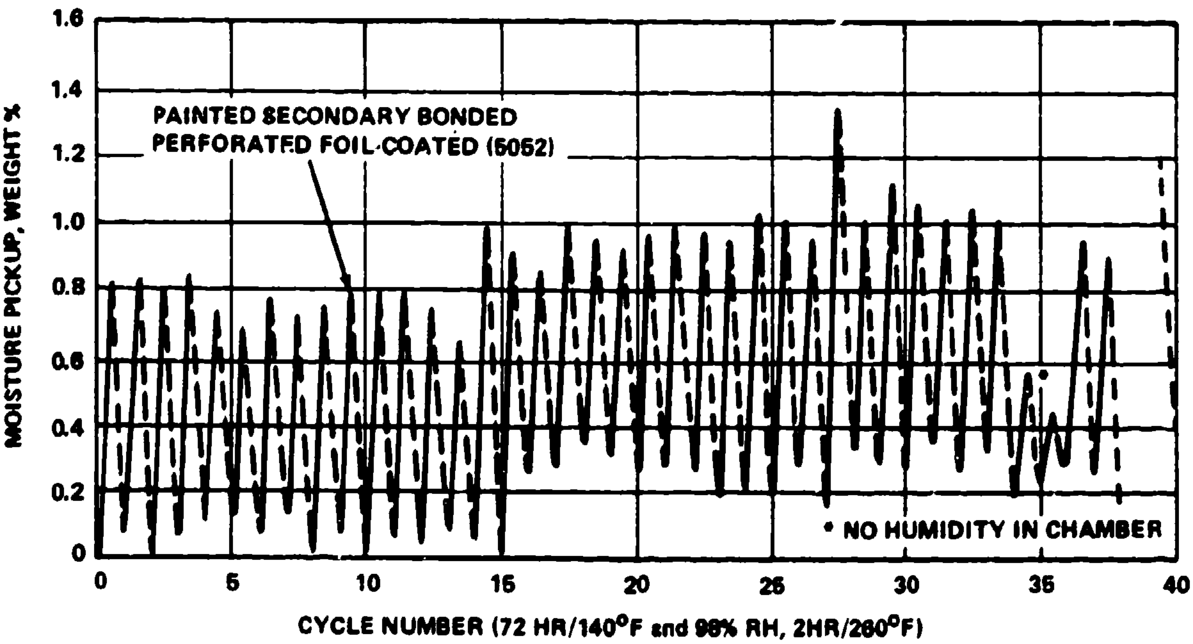

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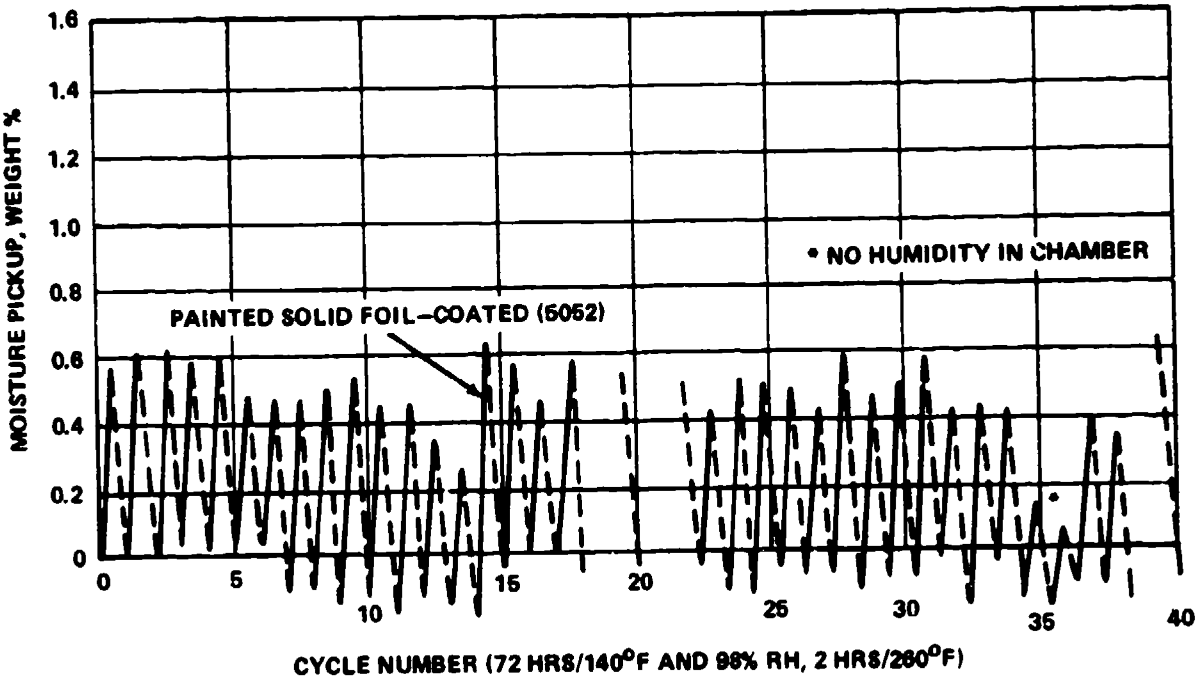
Figure 4-24 Relative Humidity/Thermal Spiking Effectiveness of Aluminum Foil Coating (Sheet 1 of 2)



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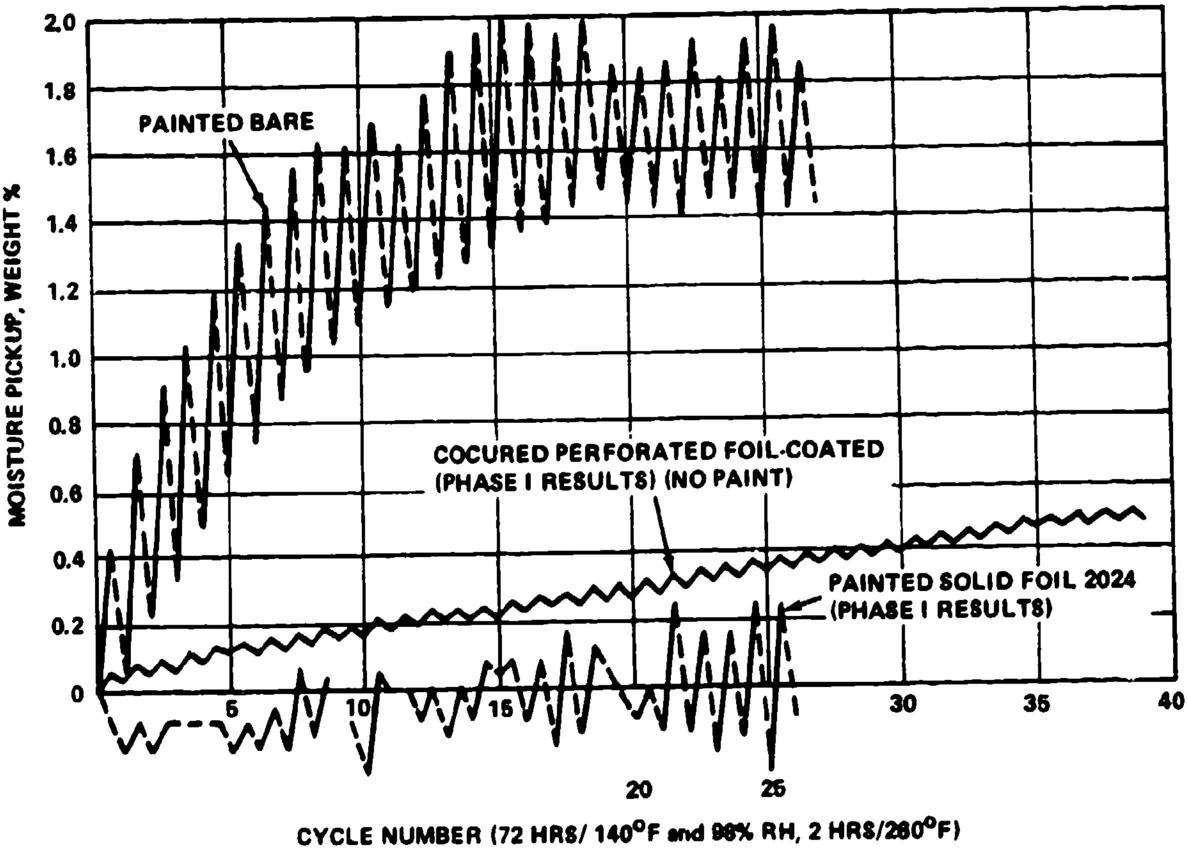

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Figure 4-24 Relative Humidity/Thermal Spiking Effectiveness of Aluminum Foil Coating (Sheet 2 of 2)

4.6.3 Evaluation of Mechanical Properties

Mechanical properties of the exposed and unexposed specimens were determined after humidity and thermal spiking exposure. Flexural and horizontal shear strength were determined at room (73°F) and elevated (260°F) temperatures to assess the degree of protection provided by each of the coatings. The results of these tests are shown in Figure 4-25. The Phase I test results are included for comparison. Each system, except for the cocured perforated foil coating, was painted. The coated specimens were humidity-conditioned for 90 days prior to testing. The uncoated (painted) control specimens and the 2024 aluminum alloy foil-coated specimens were exposed to 26 thermal cycles; the remaining specimens were exposed to 40 thermal cycles.

Phase I of this program showed that humidity and thermal spiking severely affect the mechanical properties of unprotected graphite/epoxy laminates (40-45% reduction in 260°F flexural stress and 45-52% reduction in 260°F horizontal shear strength). Each of the four foil coating systems evaluated in Phases I and II markedly improved the degree of strength retention after exposure to both humidity and thermal spiking. Flexural strength loss at 260°F was limited to 2% or less after humidity exposure for each of the foil coating systems evaluated. No loss of 260°F shear strength occurred after humidity exposure in those specimens protected with solid aluminum foil coatings. Degradation of 260°F shear strength after humidity exposure was limited to 13% by the secondary bonded/perforated foil coating and to 7% by the cocured perforated foil coating. After thermal spiking, the secondary bonded/perforated foil coating provided the best protection after 40 cycles, limiting the loss of 260°F flexural strength to 3% and the loss of 260°F horizontal shear strength to 17%. The solid, 5052 aluminum foil coating limited the loss of 260°F flexural and horizontal shear strengths to 16% and 12%, respectively. The cocured, perforated foil coating limited the loss of 260°F flexural and horizontal shear strengths to 26% and 17%, respectively. An improvement in the degree of strength retention of the cocured, foil-coated specimens is anticipated by using paint in addition to the foil coating. Specimens coated with solid, 2024 aluminum alloy foil and subjected to 26 thermal cycles experienced no loss in either 260°F flexural or horizontal shear strength. Analysis of preliminary test data from unpainted/coated specimens after 40 thermal cycles showed a significant loss in both flexural and horizontal shear strengths (Ref. 1). As a result, no conclusion can be drawn regarding the protective capability of the solid, 2024 aluminum alloy foil coating compared to that for the other three foil coating systems under thermal spiking conditions.

PROPERTY	UNCOATED-PAINTED*			5052 SOLID FOIL-PAINTED			5052 PE
	CONTROL	HUMIDITY	SPIKING	CONTROL	HUMIDITY	SPIKING	CONTRO
LENGTH OF EXPOSURE ● DAYS ● CYCLES	85	83	26	85	86	40	85
MOISTURE LEVEL, % AT TEST (BEFORE SPIKE)	0.13	1.38	1.45 (1.85)	0.03	0.26%	-0.03 (0.64)	-0.06
FLEXURAL STRESS, KSI, @ 73°F (% CHANGE)	163.8	157.6 (-4)	167.2 (+2)	134.8	142.5 (+6)	117.4 (-13)	135.2
@ 260°F (% CHANGE)	158.0	93.0 (-41)	87.3 (-45)	118.9	124.8 (+5)	100.2 (-16)	111.2
FLEXURAL MODULUS, KSI @ 73°F (% CHANGE)	7.9	7.5 (-5)	8.0 (+1)	5.4	5.6 (+4)	4.8 (-11)	5.5
@ 260°F (% CHANGE)	7.4	6.7 (-9)	6.8 (-8)	4.8	5.4 (+13)	3.7 (-23)	4.9
HORIZONTAL SHEAR STRENGTH, KSI @ 73°F (% CHANGE)	11.7	11.3 (-3)	9.0 (-23)	9.4	10.2 (+9)	8.9 (-5)	10.1
@ 260°F (% CHANGE)	8.9	4.8 (-46)	4.3 (-52)	6.9	7.2 (+4)	6.1 (-12)	7.0
THICKNESS RANGE, IN.	0.099-0.102	0.099-0.103	0.102-0.103	0.104-0.117	0.109-0.112	0.111-0.116	0.102-0.115

*RESULTS OBTAINED IN PHASE I OF THE PROGRAM (REF. 1); REPORTED HERE FOR COMPARISON.

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	5052 PERFORATED FOIL-PAINTED			2024 SOLID FOIL-PAINTED*			5056 COCURED PERFORATED FOIL-NO PAINT*		
KING	CONTROL	HUMIDITY	SPIKING	CONTROL	HUMIDITY	SPIKING	CONTROL	HUMIDITY	SPIKING
	85	86	40	91	88	26	90	90	39
.03 (.84)	-0.06	0.70	0.40 (1.25)	0.17	0.16	-0.09 (0.26)	0.01	0.46	0.49 (0.51)
.4 (3)	135.2	136.8 (+1)	129.1 (-5)	130.8	151.0 (+15)	132.8 (+2)	185.8	184.7 (-1)	152.7 (-15)
.2 (16)	111.2	109.2 (-2)	107.9 (-3)	120.2	136.1 (+13)	136.1 (+13)	175.3	173.1 (-1)	130.1 (-26)
.8 (11)	5.5	5.3 (-4)	5.1 (-7)	6.1	6.8 (+11)	6.5 (+7)	8.8	8.4 (-4)	7.1 (-19)
.7 (23)	4.8	4.9 (+2)	4.8 (-0-)	5.7	6.2 (+9)	6.2 (+9)	7.1	8.0 (+13)	7.2 (+1)
.9 (6)	10.1	10.0 (-1)	8.9 (-12)	10.0	10.4 (+4)	10.7 (+7)	10.6	11.2 (+6)	11.8 (+11)
.1 (12)	7.0	6.1 (-13)	5.8 (-17)	7.9	8.1 (+3)	8.4 (+6)	9.2	8.6 (-7)	7.6 (-17)
-0.116	0.102-0.115	0.109-0.117	0.099-0.109	0.114-0.116	0.110-0.112	0.113-0.115	0.112-0.115	0.112-0.115	0.113-0.119

Figure 4-25 Results of Mechanical Property Tests

Section 5

SERVICEABILITY EVALUATION

5.1 APPROACH

This phase of the program was directed towards determining the resistance of selected coating systems to aircraft service environments. Secondary bonded perforated foil, repaired perforated foil, and pressed-powder bonded panels were prepared and cut into subpanel sizes as shown in Figure 4-5.

5.2 STUDY AREAS

The following technical efforts were involved in determining coating serviceability in aircraft environments:

- Coating Selection and Panel Preparation
- Machining Evaluation
- Paint Stripper Protection
- Shielding Effectiveness
- Lightning Strike Protection.

5.3 COATING SELECTION AND PANEL PREPARATION

5.3.1 Coating Selection

One foil coating and one pressed-powder bond coating were selected for serviceability evaluation based on the results of the process screening tests (Section 4) and data generated under the previous Phase I programs. The perforated foil coating was selected based on the good protection provided during the humidity/thermal spiking tests (see Figure 4-25) and the results of the Phase I serviceability tests with solid foil-coated graphite/epoxy laminates. The fiber-type pressed-powder coating was selected based on coating uniformity and polishability.

5.3.2 Panel Preparation

Graphite/epoxy serviceability panels were prepared, cut into subpanels, coated with perforated foil and pressed-powder (fiber), and painted prior to testing. The

18-ply, AS-3501-6 graphite/epoxy panels (Ref. Figure 4-5) were laid up and cured in accordance with the established procedure (see Section 3). Ultrasonic scanning showed that all panels were satisfactory. The major panels were sectioned into the subpanel sizes shown in Figure 4-5. The subpanels were coated with perforated foil and pressed-powder coatings in accordance with previously established procedures (see Section 4). The coated test panels were painted with standard Navy finish (MIL-P-23377 epoxy polyamide primer and MIL-C-81773 polyurethane topcoat).

5.4 MACHINING EVALUATION

5.4.1 Procedure

Drilling, countersinking, and radial sawing characteristics were evaluated with respect to hole quality and cut quality for various machining conditions. Holes were drilled and countersunk in graphite/epoxy laminates with solid carbide drill/countersinks (Figure 5-1) using a 21,000-rpm and a 5,500-rpm Gardner-Denver positive air-feed portable drill mounted on a stationary stand (Figure 5-2). Radial sawing tests were conducted with a Rockwell table saw using diamond-coated or diamond-sintered saw blades (Figure 5-3).

5.4.2 Results

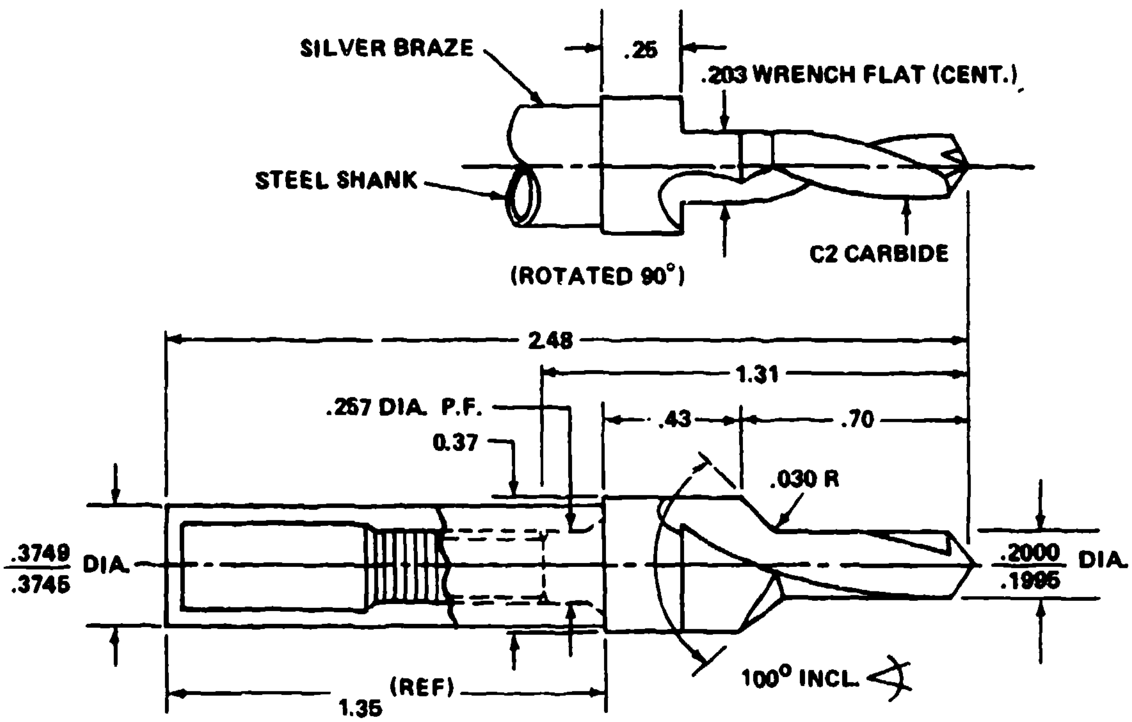
5.4.2.1 Drilling and Countersinking

Initial drilling/countersinking tests on pressed-powder bond coated, graphite/epoxy panels showed that backup material was needed to prevent breakout of the outer laminate plies when the peel-ply was removed. Good holes without breakout were generated using masonite as a backup. Although slight burrs developed on the entry side of the drilled holes, they can be easily removed by a simple deburring operation. The quality of the drilled/countersunk holes was excellent, with no burrs on the entry side. Test results are presented in Figures 5-4 and 5-5.

The quality of drilled and drilled/countersunk holes in graphite/epoxy panels coated with perforated aluminum on both sides was excellent. Slight burrs developed on the entry and exit sides of the drilled holes, and on the exit side only of drilled/countersunk holes. Test results are presented in Figures 5-4 and 5-5.

NOTE:

FOR USE ON GRAPHITE/EPOXY



GEOMETRIC FEATURES

a) HELIX ANGLE 20° ± 1°
b) WEB AT POINT .050 ± .005 IN.
c) WEB TAPER .032 IN./IN.
d) C'SINK RELIEF = 4° ± 1°
e) MARGIN WIDTH .015 $^{+.010}_{-.005}$ IN.
f) DRILL POINT 135° ± 3°
g) NOTCH RAKE ANGLE 0° AXIAL ± 2°
h) POINT GEOMETRY PER GAC MFG. STD CD 2700-D11 EXCEPT POINT IS MODIFIED TO 135°
i) DRILL BACK TAPER $\frac{.0005}{.0010}$ IN/IN
j) INDENT. NO. CSZ114105
CSZ114 104 SAME AS ABOVE EXCEPT DRILL DIA'S $\frac{.1910}{.1905}$

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Figure 5-1 Solid Carbide Combination Drill/Countersink Cutting Tool

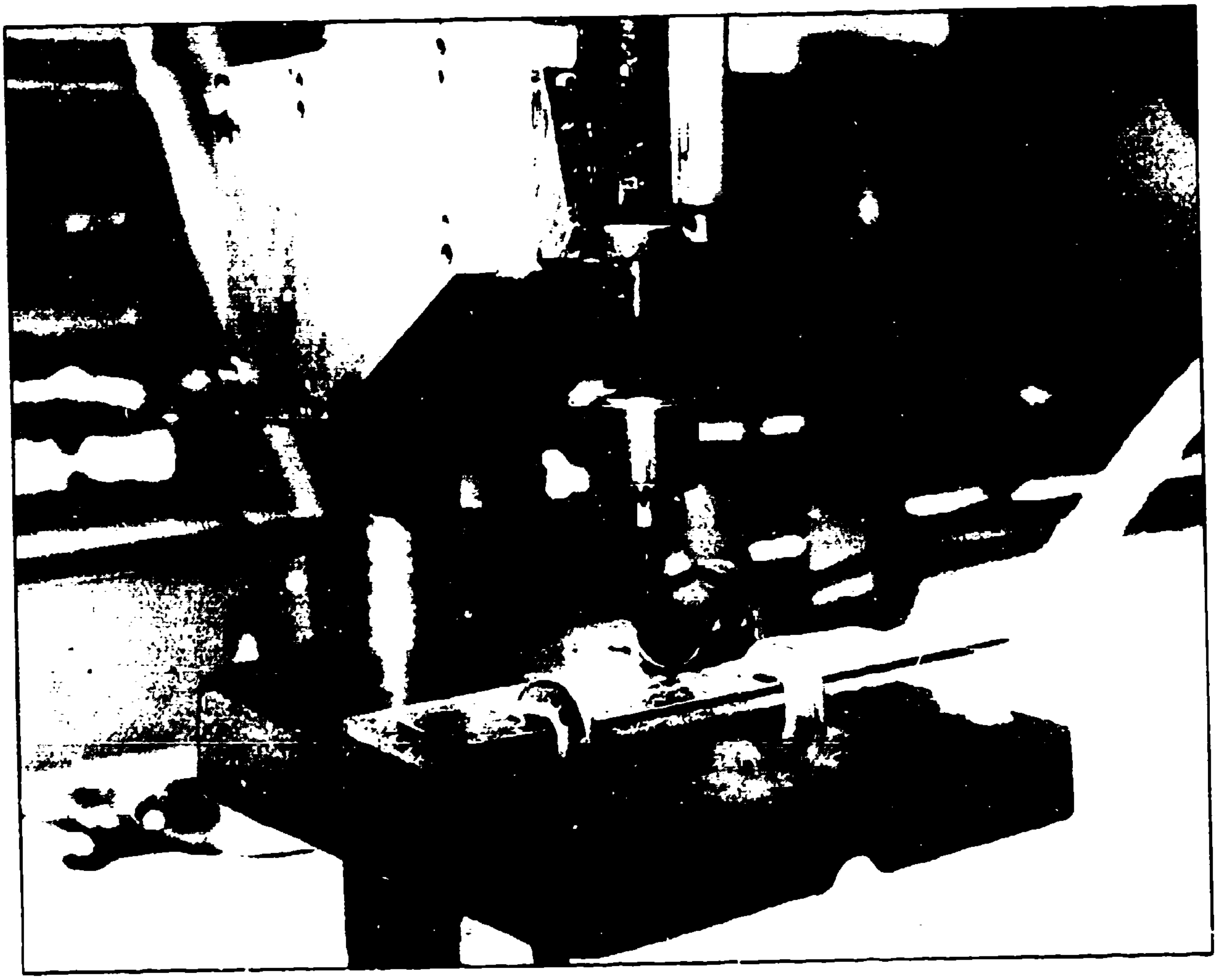

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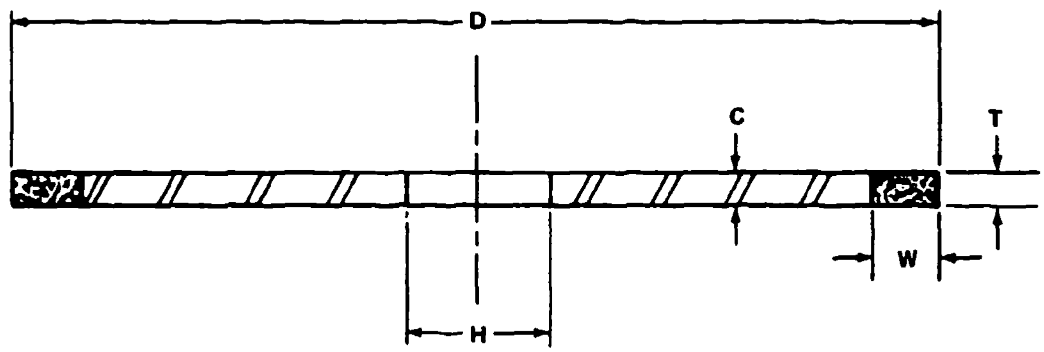
Figure 5-2 Gardner-Denver Air-Feed Drilling Setup



D	T	H	W	GRIT		C
8	3/32	5/8	1/16	60	PLATED	1/16
8	0.50	5/8	3/16	60/80	SINTERED	0.40

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Figure 5-3 Configurations of Diamond Radial Saw Blades

PANEL NO.	TYPE OF ALUMINUM COATING	PANEL THICK, IN.	DRILL (0.190-IN.) NO.	SPEED, RPM	FEED, IPR	BACKUP	RESULTS (NO COOLANT USED)			
							DRILLED HOLES			C
							HOLE NO.	BURR (ON TOP)	BREAKOUT	BURR (ON TOP)
A-8	PRESSED POWDER (ONE SIDE)	0.135	1	21,000	0.001	YES	1-5	SLIGHT	NONE	–
						NO	6-7	SLIGHT	NONE	–
						NO	8-10	SLIGHT	YES (NO PEEL PLY)	–
						YES	11-15	SLIGHT	NONE (NO PEEL PLY)	–
						YES	16-20	–	–	NON
						YES	21-29	–	–	NON
						YES	30-44	–	–	NON
B-8	PERFORATED FOIL (BOTH SIDES)	0.118	2	21,000	0.001	YES	1-10	SLIGHT	SLIGHT	–
						YES	11-16	SLIGHT	SLIGHT	–
						NO	12-32	SLIGHT	SLIGHT	–
						NO	33-48	–	–	SLIG
A-9	PRESSED POWDER (ONE SIDE)	0.135	3	5,500	0.001	NO	1-3	SLIGHT	YES (NO PEEL PLY)	–
						YES	4-16	SLIGHT	NONE (NO PEEL PLY)	–
						YES	17-32	–	–	NON
						YES	33-48	–	–	NON
B-9	PERFORATED FOIL (BOTH SIDES)	0.118	4	5,500	0.001	NO	1-17	SLIGHT	SLIGHT	–
						NO	18-50	–	–	SLIG

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Figure 5-4 Sum

BACKUP	RESULTS (NO COOLANT USED)					COMMENTS	
	DRILLED HOLES			COUNTERSINKS			
	HOLE NO.	BURR (ON TOP)	BREAKOUT	BURR (ON TOP)	BREAKOUT	TOOL WEAR	HOLE AND C' SINK ACCEPTANCE
YES	1-5	SLIGHT	NONE	–	–	NONE	YES – WITH DEBURRING OPERATION
NO	6-7	SLIGHT	NONE	–	–	NONE	YES – WITH DEBURRING OPERATION
NO	8-10	SLIGHT	YES (NO PEEL PLY)	–	–	NONE	NO
YES	11-15	SLIGHT	NONE (NO PEEL PLY)	–	–	NONE	YES – WITH DEBURRING OPERATION
YES	16-20	–	–	NONE	NONE	NONE	YES
YES	21-29	–	–	NONE	NONE	NONE	YES
YES	30-44	–	–	NONE	NONE	START OF DRILL WEAR LAND	YES
YES	1-10	SLIGHT	SLIGHT	–	–	NONE	YES – WITH DEBURRING OPERATION
YES	11-16	SLIGHT	SLIGHT	–	–	NONE	YES – WITH DEBURRING OPERATION
NO	12-32	SLIGHT	SLIGHT	–	–	NONE	YES – WITH DEBURRING OPERATION
NO	33-48	–	–	SLIGHT	SLIGHT	NONE	YES – WITH DEBURRING OPERATION
NO	1-3	SLIGHT	YES (NO PEEL PLY)	–	–	NONE	YES – WITH DEBURRING OPERATION
YES	4-16	SLIGHT	NONE (NO PEEL PLY)	–	–	NONE	YES – WITH DEBURRING OPERATION
YES	17-32	–	–	NONE	NONE	NONE	YES
YES	33-48	–	–	NONE	NONE	NONE	YES
NO	1-17	SLIGHT	SLIGHT	–	–	NONE	YES – WITH DEBURRING OPERATION
NO	18-50	–	–	SLIGHT	SLIGHT	NONE	YES – WITH DEBURRING OPERATION

Figure 5-4 Summary of Drilling/Countersinking Tests on Coated Graphite/Epoxy Laminates

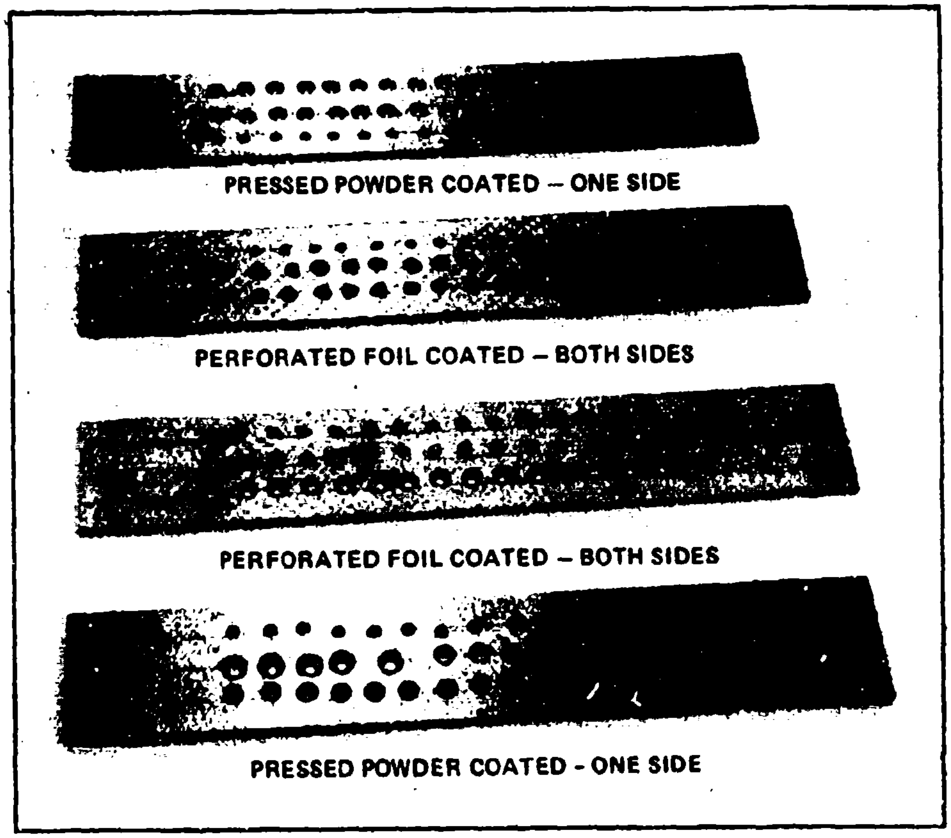

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Figure 5-5 Drilling and Countersinking Evaluation Test Specimens

Since the quality of drilled holes and countersinks is equivalent whether produced at 21,000 or 5500 rpm, the higher speed is preferred because of the shorter drilling time (about 3 sec per hole versus 11 sec per hole).

Resharpened drill/countersinks were used for each test. No significant tool wear occurred during these tests, which involved generation of about 50 holes for each of the four coating systems evaluated. Drill No. 1, however, did show the start of a wear land.

5.4.2.2 Radial Sawing

Radial sawing tests were conducted with both plated-diamond and sintered-diamond blades (Figure 5-6). A feed rate range of 25-43 in./min gave the best cuts (see Figure 5-4). Faster feed rates produced a large burr on the aluminum foil coatings. These burrs can be easily removed, however, by a simple deburring operation. Cross-sectional views of radially cut graphite/epoxy panels coated with pressed aluminum powder and perforated aluminum foil are shown in Figures 5-7 and 5-8, respectively.

TYPE OF ALUMINUM COATING	PANEL NO.	PANEL THICK, (IN.)	FEED RATE, IPM	TYPE OF DIAMOND SAW*	CUT QUALITY
PRESSED – POWDER (ONE SIDE)	A-1	0.135	26.8	SINTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)
	A-2	0.135	38.7	PLATED	UNIFORM CUT – LIGHT BURRS ON COATING AND CO
	A-3	0.135	50.0	PLATED	UNIFORM CUT – MEDIUM BURR ON COATING SLIGHT BURR ON COMPOSITE
	A-4	0.135	57.0	SINTERED	UNIFORM CUT – MEDIUM BURR ON COATING SLIGHT BURR ON COMPOSITE
	A-5	0.135	25.5	SINTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)
	A-6	0.135	15.0	SINTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)
	A-7	0.135	24.0	SINTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)
	A-8	0.135	27.9	SINTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)
	A-9	0.135	34.3	SINTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)
	A-10	0.135	30.0	SINTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)
	A-11	0.135	27.0	SINTERED	UNIFORM CUT – HEAVY BURR ON COATING
PERFORATED FOIL (BOTH SIDES)	B-1	0.118	33.3	SINTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)
	B-2	0.118	40.0	PLATED	SL. ROUGH CUT – LIGHT BURR ON BOTH SIDES
	B-3	0.118	70.0	PLATED	UNIFORM CUT – HEAVY BURR ON BOTH SIDES
	B-4	0.118	60.0	SINTERED	UNIFORM CUT – MEDIUM BURR ON BOTH SIDES
	B-5	0.118	24.5	SINTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)
	B-6	0.118	40.0	SINTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)
	B-7	0.118	35.1	SINTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)
	B-8	0.118	37.5	SINTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)
	B-9	0.118	42.9	SINTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)
	B-10	0.118	40.0	SINTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)

CUTTING CONDITIONS:

- CUTTING SPEED–7000 SFM
- COOLANT-HANGSTERFERS HE-2 (20:1)
- PANELS CUT WITH COATING SIDE DOWN
- RADIAL SAW BLADE
  8-IN. DIAMETER
  SINTERED (60-80 GRIT)
  PLATED (60 GRIT)

*PRECONDITIO

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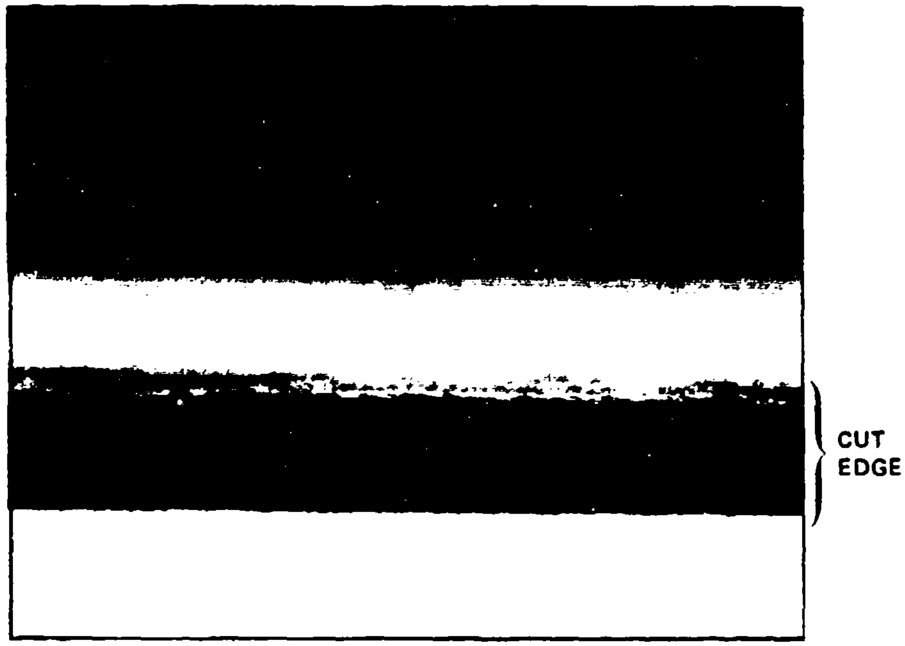
Figure 5-6

ʼPE OF AMOND SAW*	CUT QUALITY	GENERAL COMMENTS
INTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)	FEED RATE RANGE USED GAVE UNIFORM CUTS ON THE COMPOSITE MATERIAL BUT PRODUCED BURRS ON THE ALUMINUM COATING. FASTER FEED RATES PRODUCED LARGER BURRS ON THE ALUMINUM COATING
'LATED	UNIFORM CUT – LIGHT BURRS ON COATING AND COMPOSITE	
'LATED	UNIFORM CUT – MEDIUM BURR ON COATING SLIGHT BURR ON COMPOSITE	
INTERED	UNIFORM CUT – MEDIUM BURR ON COATING SLIGHT BURR ON COMPOSITE	
INTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)	
INTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)	
INTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)	
INTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)	
INTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)	
INTERED	UNIFORM CUT – LIGHT BURR ON COATING (BEST)	
INTERED	UNIFORM CUT – HEAVY BURR ON COATING	
INTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)	FEED RATE RANGE USED GAVE UNIFORM CUTS ON THE COMPOSITE MATERIAL BUT PRODUCED BURRS ON BOTH SIDES OF THE ALUMINUM COATING. FASTER FEED RATES PRODUCED LARGER BURRS ON THE ALUMINUM COATING
LATED	SL. ROUGH CUT – LIGHT BURR ON BOTH SIDES	
LATED	UNIFORM CUT – HEAVY BURR ON BOTH SIDES	
INTERED	UNIFORM CUT – MEDIUM BURR ON BOTH SIDES	
INTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)	
INTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)	
INTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)	
INTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)	
INTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)	
INTERED	UNIFORM CUT – LIGHT BURR ON BOTH SIDES (BEST)	

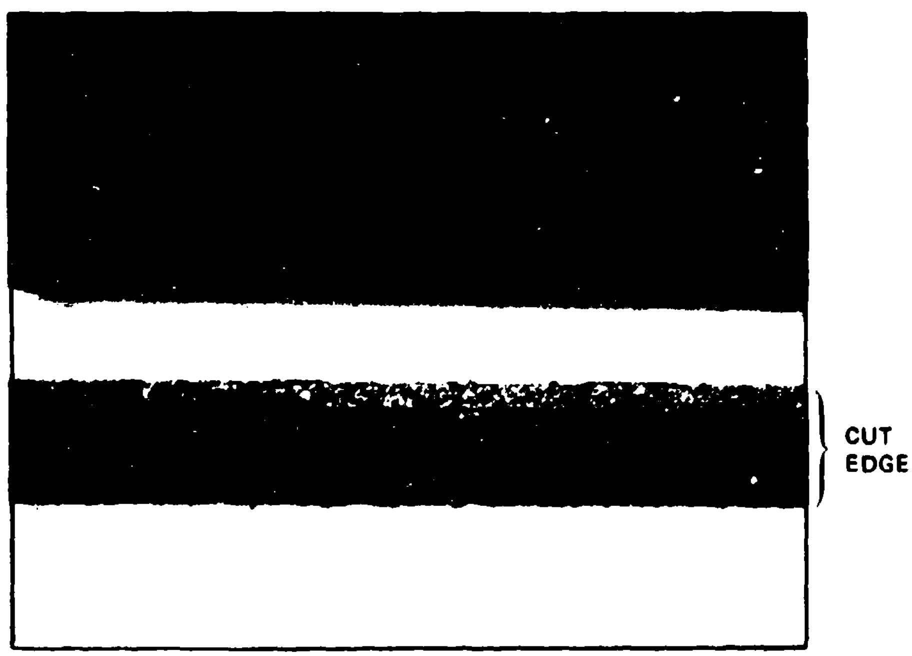
• RADIAL SAW BLADE
8-IN. DIAMETER
SINTERED (60-80 GRIT)
PLATED (60 GRIT)

*PRECONDITIONED BLADES

Figure 5-8 Summary of Radial Sawing Tests on Coated Graphite/Epoxy Laminates



A. SINTERED-DIAMOND BLADE



B. PLATED-DIAMOND BLADE

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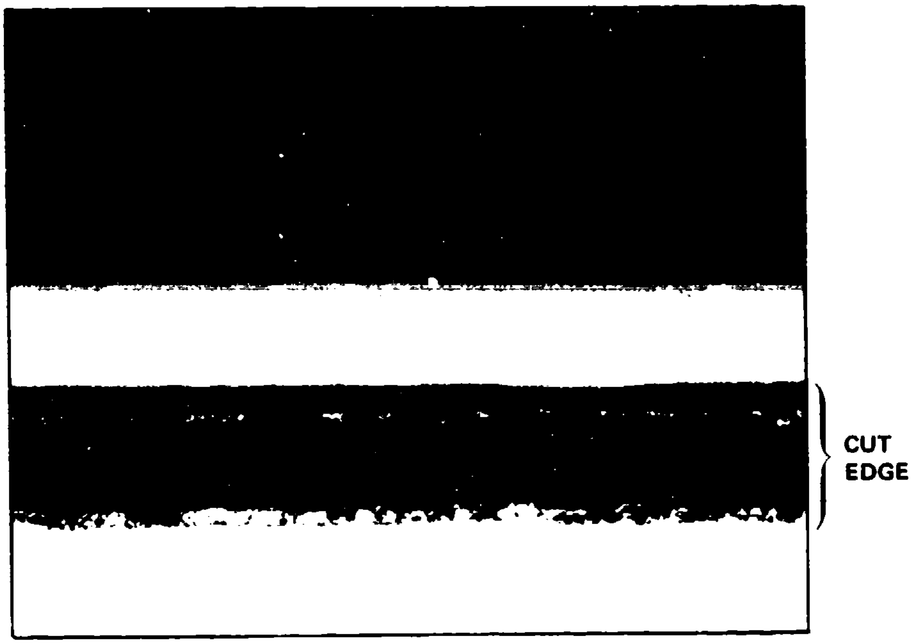
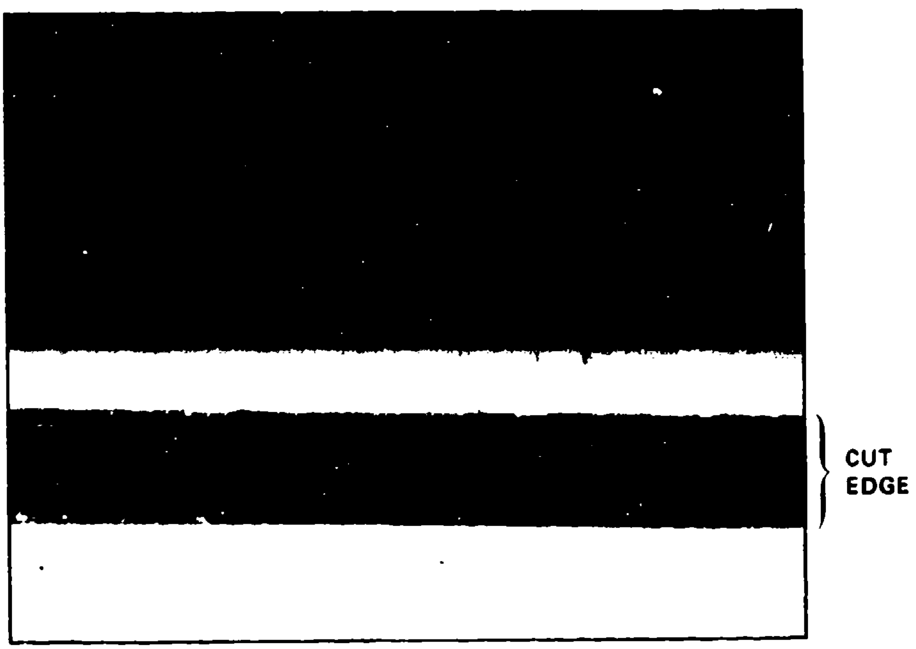
Figure 5-7 Pressed-Powder Bond Coated Graphite/Epoxy Laminates Cut With a Radial Table Saw



A. SINTERED-DIAMOND BLADE



B. PLATED-DIAMOND BLADE

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Figure 5-8 Perforated Aluminum Foil-Coated Graphite/Epoxy Laminates Cut With a Radial Table Saw

5.5 MIL-R-81294 PAINT STRIPPER PROTECTION

5.5.1 Background

Analysis of data generated under the previous Phase I program (Ref. 1) showed that MIL-R-81294 paint stripper reduced the 260°F flexural strength by 18% but had almost no effect on horizontal shear strength on uncoated graphite/epoxy laminates. Apparently, solid foil coatings prevented the degradation in flexural strength caused by paint stripper attack on the graphite/epoxy laminates.

5.5.2 Test Procedure

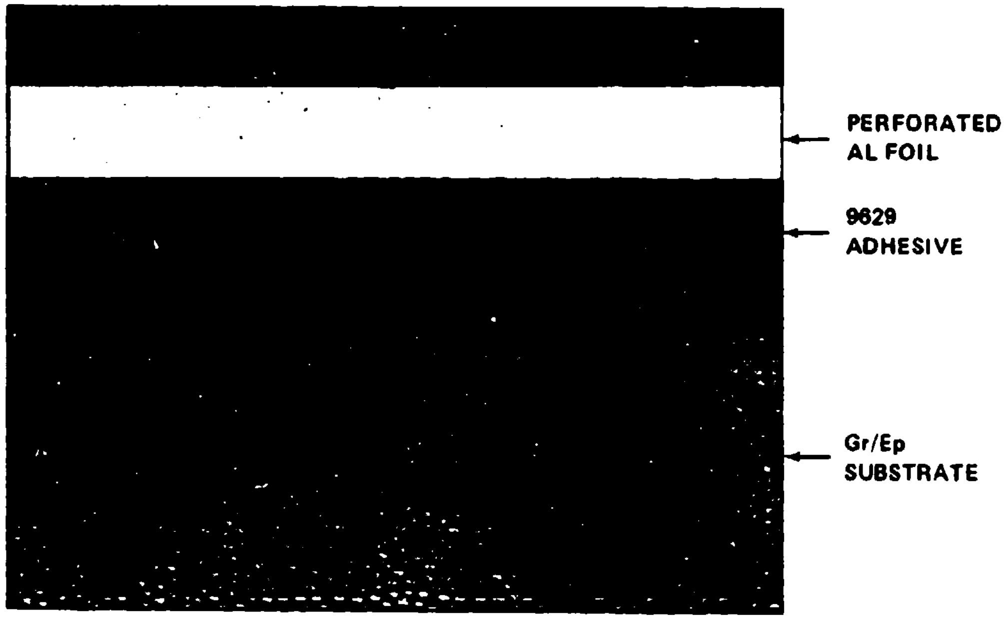
The effectiveness of the perforated aluminum foil coating in preventing attack on the graphite/epoxy substrates by MIL-R-81294 phenolic paint stripper was determined by microscopic examination. A 12 x 12-in., AS/3501-6 graphite/epoxy laminate was coated with perforated aluminum foil and cut into two 8 x 12-in. subpanels. One subpanel was painted with the standard Navy finish (MIL-P-23377 epoxy polyamide primer and MIL-C-81773 polyurethane topcoat). This coating was then stripped from the subpanel using MIL-R-81294 phenolic paint stripper. Sections were cut from the stripped subpanel and the other unpainted foil-coated subpanel, mounted, and examined microscopically at a magnification of 200X.

5.5.3 Test Results

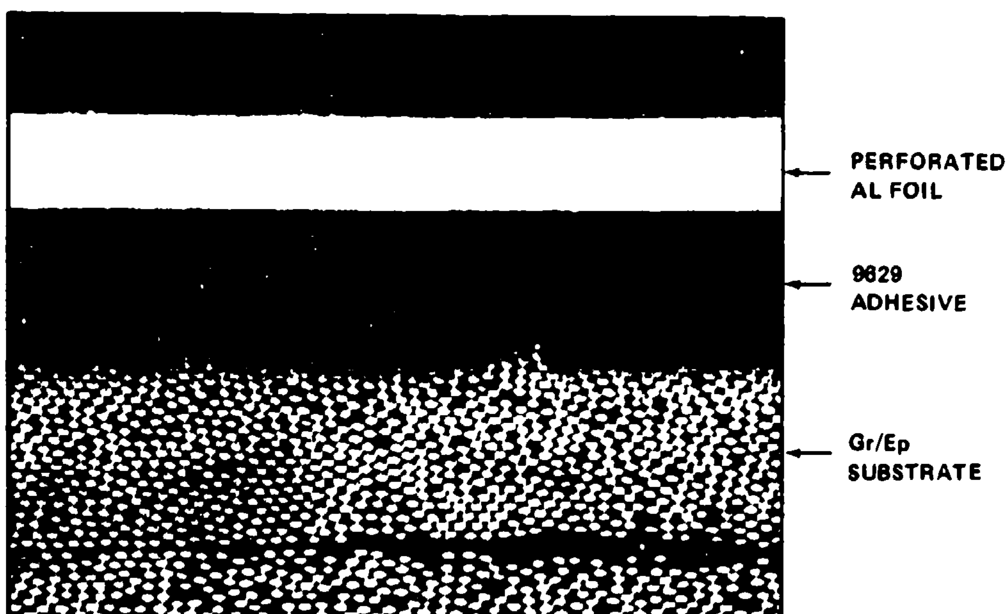
Microscopic examination of the stripped and unstripped subpanel sections (Figure 5-9) showed that the graphite/epoxy substrates had not been attacked. Possible effects of paint strippers on graphite/epoxy laminates are being studied by Grumman under Contract No. N00019-80-C-0059, "Application and Testing of Metallic Coatings on Graphite/Epoxy Composites."

5.6 SHIELDING EFFECTIVENESS

Shielding effectiveness is a measure of the ability of a material to control the passage of radiated electromagnetic energy. This characteristic is an important factor in designing electrical and electronic equipment to be protected from the interference effects of other electronic devices and to eliminate interference propagation. The EMI shielding effectiveness of perforated foil-coated (both sides), perforated foil-coated (both sides) and repaired, and pressed-powder-coated (one side) graphite/epoxy panels was determined for low-impedance (H), high-impedance (E) and plane-wave fields.



A. UNPAINTED (CONTROL)



B. PAINTED AND STRIPPED

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Figure 5-9 Photomicrographs of Unpainted, and Painted and Stripped Aluminum Foil-Coated Graphite/Epoxy Laminates (200X Mag)

At most frequencies, the shielding effectiveness of both types of perforated foil-coated panels was better than that of the uncoated panels for H, E, and plane-wave fields. High frequencies (10K MHz) reduced the shielding effectiveness in all three fields. Although the pressed-powder coating provided an overall increase in shielding effectiveness, the degree of improvement varied with the type of fields and the frequency range (Figures 5-10 and 5-11). These tests demonstrated that perforated-foil coatings can improve the shielding effectiveness of graphite/epoxy laminates. The repair made to the perforated-foil coating did not significantly alter the shielding effectiveness of the panel. The conclusions drawn from these tests are considered generally valid, even though only one sample of each type of coating was evaluated. These tests should be duplicated, however, before specific shielding effectiveness values are applied.

5.7 LIGHTNING STRIKE PROTECTION

Three 12 x 12-in. graphite/epoxy panels coated with the optimized metallic systems were prepared -- perforated foil-coated, perforated foil-coated and repaired, and pressed-powder coated. These panels were sent to NAVAIR to determine the effectiveness of the protective coating systems against lightning strikes.

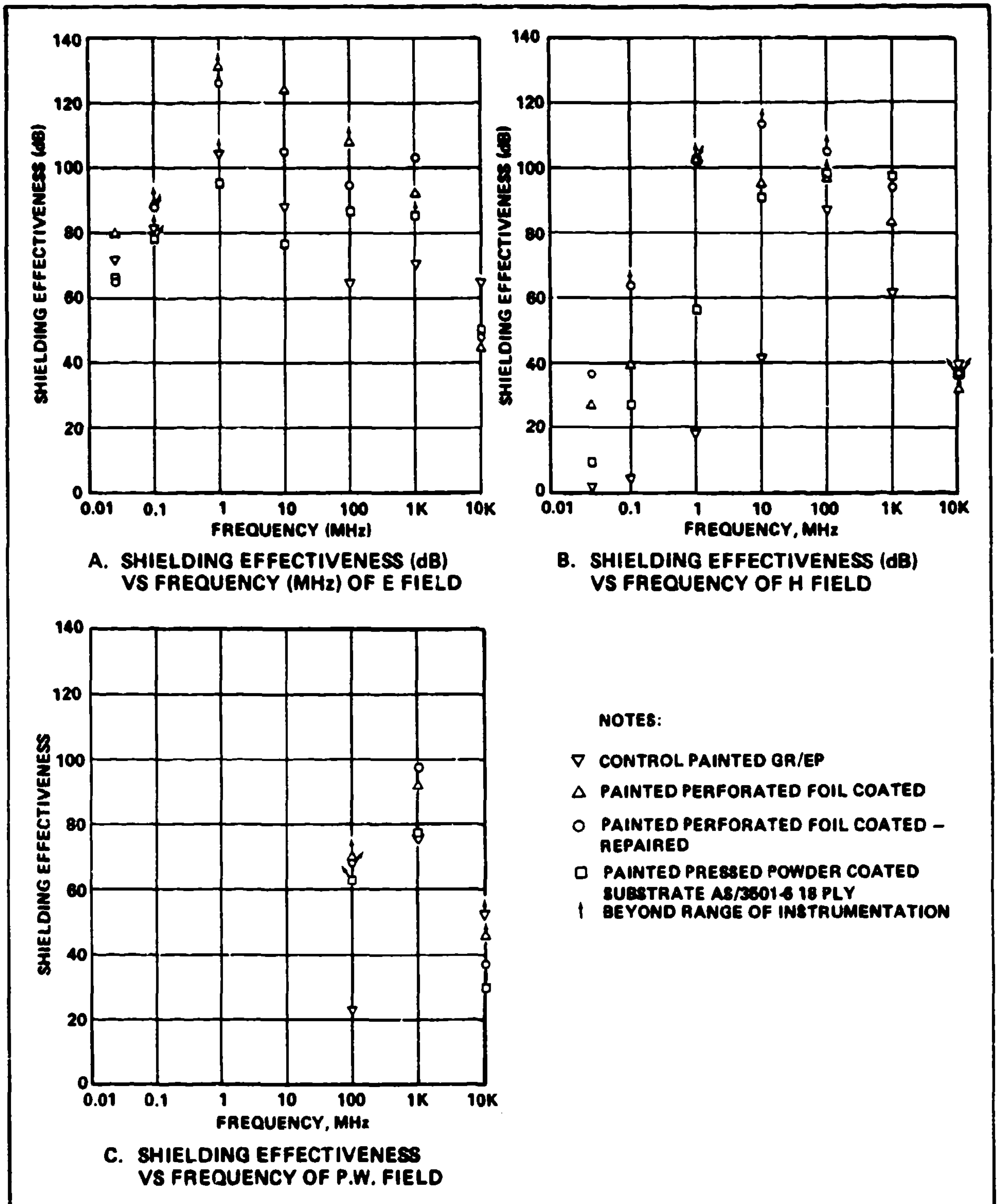

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Figure 5-10 EMI Shielding Effectiveness of Perforated Foil, Perforated Foil-Repaired, and Pressed-Powder Coated Graphite/Epoxy

FIELD	FREQUENCY, MHz	SHIELDING EFFECTIVENESS, dB			
		CONTROL-PAINTED Gr/Ep	PAINTED PERFORATED FOIL-COATED	PAINTED, PERFORATED FOIL COATED-REPAIRED	PAINTED PRESSED-POWDER COATED
E	0.014	>1	80	65	66
	0.1	81	>89	>88	>78
	1	103	>131	>126	95
	10	87	124	105	76
	100	64	>108	94	86
	1,000	69	92	103	85
	10,000	64	45	48	50
H	0.014	1	27	36	9
	0.1	3	39	> 63	26
	1	18	>102	>102	56
	10	41	95	>113	90
	100	86	97	>104	>98
	1,000	61	83	94	87
	10,000	39	>33	>37	>37
PLANE WAVE	100	22	>69	>67	>64
	1,000	76	92	97	77
	10,000	> 52	>45	37	29

R80-1922-038P

Figure 5-11 Shielding Effectiveness of 18-Ply AS-3501-6 Graphite/Epoxy Test Specimens in E, H, and Plane-Wave Fields

Section 6

REFERENCES

1. Staebler, Christian J., Jr., and Simpers, Bonnie F., "Metallic Coatings for Graphite/Epoxy Composites," Final Report, Contract No. N00019-77-C-0250 (Naval Air System Command), May 1979

2. NAVAIR 01-F-14AAA-3-2, "Repair Instructions, Boron-Epoxy Structure, Inspection, Damage Limitations, and Recommended Repairs," 1 December 1977

APPENDIX A

TEST PROCEDURES

A.1 ENVIRONMENTAL CONDITIONING

Environmental conditioning of test panels was performed using a Hotpack humidity chamber. The chamber was held at the conditions of 140°F (±3°F) and 98% RH (+1, -3%) for the duration of the test. Minor variations in the humidity level in the chamber were reflected in the moisture pickup of all the specimens under exposure during certain periods. Because exposure of various specimens was started at different time intervals, however, direct comparison of these trends on the moisture pickup curves could not be made. The overall humidity level also remained relatively constant (see Figures 4-23 and 4-24).

Thermal spiking of the test specimens was performed in a circulating-air oven held at a constant temperature of 260°F.

A.2 CORROSION (SULFUR DIOXIDE AND NORMAL)

Two types of corrosion tests were used to characterize the corrosion resistance of the coating systems under evaluation: 5% salt spray and sulfur dioxide (SO_2) salt spray. Two 3x6-in. specimens from each protection system were scribed and exposed to each corrosive environment, as specified in ASTM Test Method No. D1654. Periodically during exposure, one of the specimens from each protection system was removed and a section cut perpendicularly to the scribe line. The specimens were cleaned and dried following their removal from the exposure chamber. Care was taken in cleaning the specimen before returning it to the exposure chamber to prevent any machining residues from entering the chambers. The sections removed were examined under low-power magnification for evidence of corrosion, blistering, and loss of adhesion. The 5% salt spray test was performed as specified in ASTM Test Method No. B117. The SO_2 salt spray test, which imposes greater severity than the standard salt spray environment, was designed to produce better simulation of the aircraft carrier environment. A 5% salt (NaCl) solution saturated with SO_2 (pH 2.0) was used in a spray chamber (Figure A-1) designed for periodic introduction of SO_2 to the spray tower. The salt spray was operated continuously for 23 hr at 97°F with SO_2 introduced into the chamber during the first and nineteenth hours of exposure. At the end of 23 hr of exposure, the chamber was purged of all fog for one hour, completing one cycle.

A.3 FLEXURAL AND HORIZONTAL SHEAR STRENGTHS

Uniform cross-section rectangular bar flexure and horizontal shear specimens were tested as simple beams at span-to-depth ratios of 32-to-1 and 5-to-1, respectively,

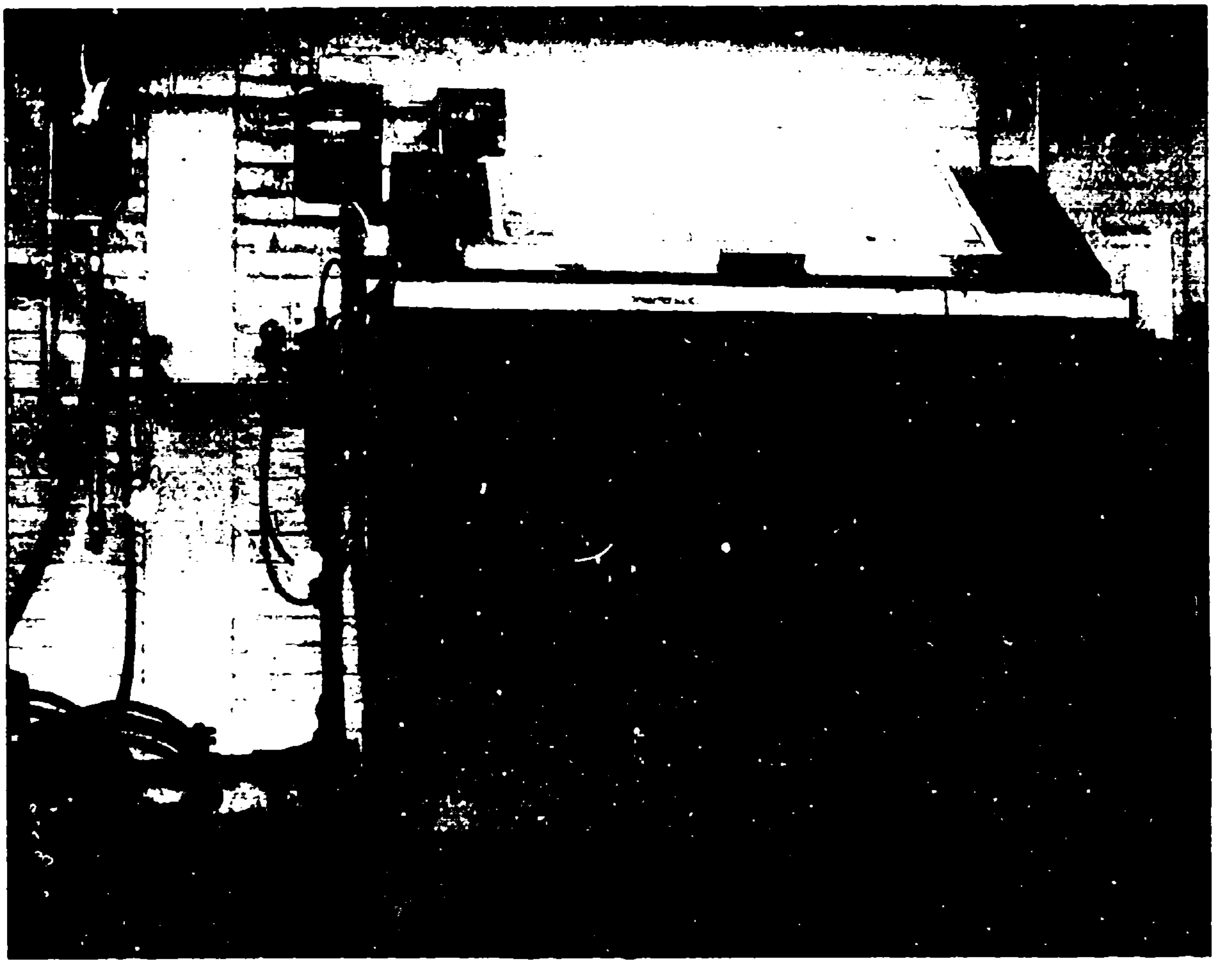

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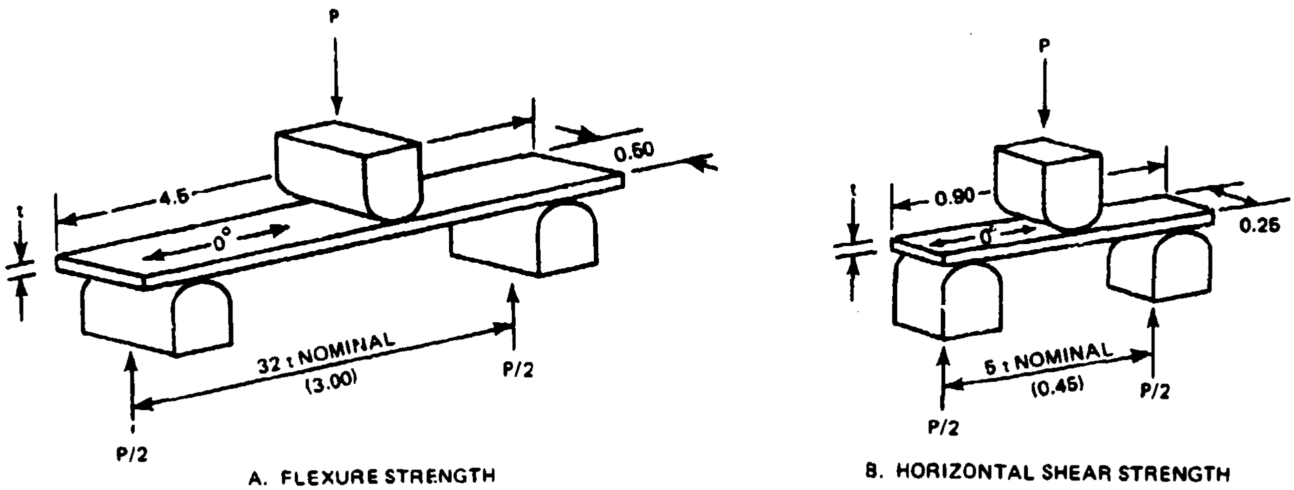
Figure A-1 Sulfur Dioxide-Salt Spray Chamber

under single-point, center-loading (Figure A-2). The procedures followed were essentially those of ASTM D-790 and D-2344, respectively. The test load was applied at a constant cross-head rate of 0.05 in./min. Center deflection was autographically recorded concurrent with load application. Flexural moduli were established from load-center deflection relationships.

The 260°F elevated-test temperature was provided by large-volume circulating air chambers that mated with the universal testing machines. Specimen temperature readings were obtained by thermocouples attached to each specimen. High-temperature LVDT deflectometers were used to measure flexural deflection. Semi annual instrument calibration is performed on this equipment according to the procedures of ASTM E-83.



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0166-056B

Figure A-2 Specimen/Test Configurations

The uncondi' . control specimens were soaked at the 260°F test temperature for 30 min prior to loading. To maintain the moisture level in the specimen for the duration of the test, the conditioned specimens were soaked at 260°F for only 2 min prior to being loaded. Grumman's experience has repeatedly demonstrated that for static tests, such as those performed under this study, the magnitude of the diffusion coefficient and the long duration required to desorb a significant amount of water in epoxy matrices are such that the moisture condition can be maintained by performing the test in ambient air without active moisture control. For example, 16-ply IITRI-type compression specimens of AS/3501-5A graphite/epoxy retained 91% of their preconditioning moisture after 5 to 7 min at 260°F.

A.4 EMI SHIELDING EFFECTIVENESS

Shielding effectiveness was measured using Grumman's shielding effectiveness facility (Figure A-3). This facility was designed so that shielding effectiveness measurements for low-impedance (H), high-impedance (E), and plane-wave fields above 100 MHz can be obtained from one fixture. A two-pair antenna system was employed in this facility. Of the four compartments in the test fixture, one pair was used to obtain a reference without a sample mounted in the aperture. The sample was mounted in the aperture of the other pair of compartments. Both pairs of compartments were identically constructed. The measurement of shielding effectiveness (Figure A-4) was made by first taking a reference reading in the two compartments with the naked aperture and then taking a measurement in the other two compartments with the sample mounted in the aperture. The difference in decibels

A. OVERALL VIEW

B. TEST CHAMBER

R80-1922-041P

Figure A-3 EMI Shielding Effectiveness Testing Facility

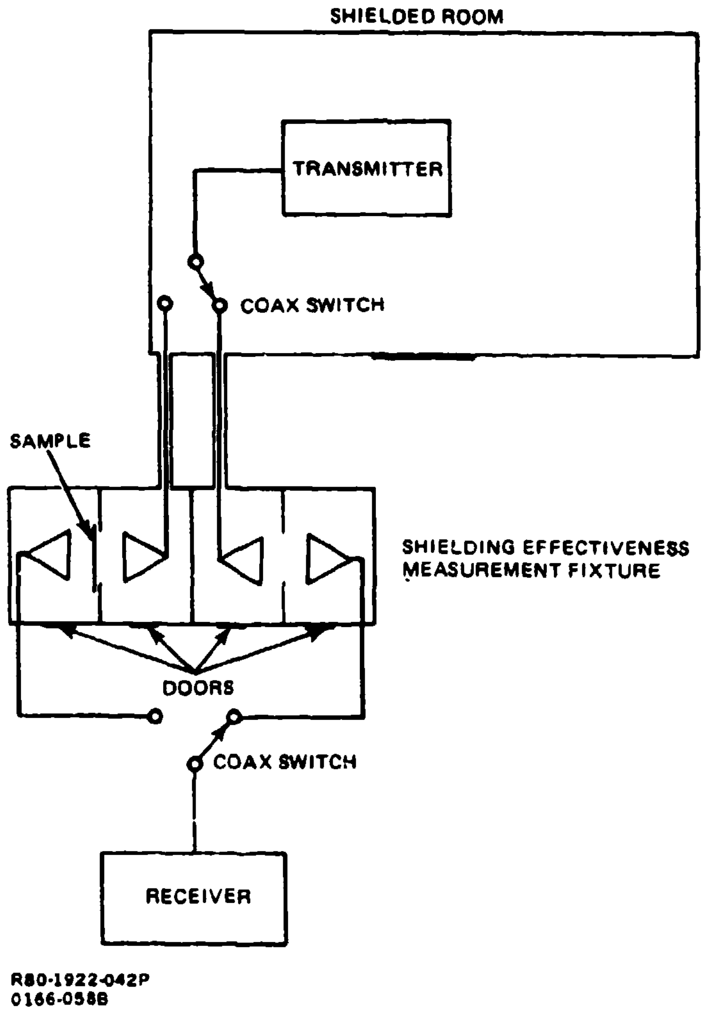

Figure A-4 Shielding Effectiveness Measurement Setup

(dB) of the two readings was the shielding effectiveness of the material under test. Each pair of transmitting antennas and receiving antennas was checked for equivalency to ensure that conditions were the same in each pair of compartments.

Measurements of the near-field E and H shielding effectiveness were made using the equipment listed in Figure A-5. The distance from the transmitting antenna to the sample shield was less than $\lambda/2\pi$ in. to ensure true electric and magnetic near fields. The same transmitting and receiving equipment was used for plane waves; however, the distances between the transmitting antenna and the sample was greater than $\lambda/2\pi$ in. for electrically small antenna and $2D^2/\lambda$ in. for larger antennas, where D was the largest dimension of the transmitting element.

TYPE OF FIELD	ANTENNA		DISTANCE FROM TRANSMITTING ANTENNA TO SAMPLE	FREQUENCY RANGE MHz
	RECEIVING	TRANSMITTING		
E-ELECTRIC (HIGH IMPEDANCE)	VR 105 36" ROD	36" ROD	3"	0.014-0.15
	VA 105 36" ROD	36" ROD	3"	0.15-10
	3" ROD	3" ROD	3"	100
	1" ROD	1" ROD	1"	1K
	1/8" ROD	1/8" ROD	1/8"	10K
H-MAGNETIC (LOW IMPEDANCE)	1 TURN 3" LOOP	1 TURN 3" LOOP	3"	0.014-100
	1 TURN 1" LOOP	1 TURN 1" LOOP	1"	1K
	1 TURN 1/8" LOOP	1 TURN 1/8" LOOP	1/8" LOOP	10K
PLANE WAVE (377 Ω)	3" ROD	3" ROD	32"	100
	1" ROD	1" ROD	12"	1K
R80-1922-043P 0166-059B	1/8" ROD	POLORAD CA-Y	12"	10K

Figure A-5 Shielding Effectiveness Measurement Equipment

A two-part electrical checkout of the system was performed prior to testing. Antenna equivalency was verified by comparing the field strength of two antennas in a particular field type (E, H, or plane). Antennas that agree within 2 dB are considered to be equivalent. The enclosure was checked for RF leaks by making a shielding effectiveness measurement of a 0.125-in.-thick aluminum panel. If there are no leaks, only the internal noise of the receiver is observed when the shielding of the 0.125 in.-thick aluminum panel is measured.

To ensure that only the electromagnetic shielding characteristics of the candidate protection systems were measured, the following precautions were taken:

- The candidate protective systems on each 15 x 15-in. graphite/epoxy sample were peripherally framed by a 1-1/2-in.-wide electrically continuous coating intimately contacting the graphite fibers around the edge and on both sides of each sample (Figure A-6)
- All apertures, both external and internal, were hardened by installing a 1/4-in. x 3/16-in. RF metal gasket, Type 20-40118 (Tecknit Corporation), at a distance of 1/2 in. from the edge of the opening in a rigid recessed groove. The external doors were fabricated by the Universal Shielding Corporation and were of the UQ 904 type, which electrically seal the enclosure against RF leakage
- The 15 x 15-in. graphite/epoxy sample was installed in the enclosure system in such a manner that the electrically continuous picture frame firmly con-

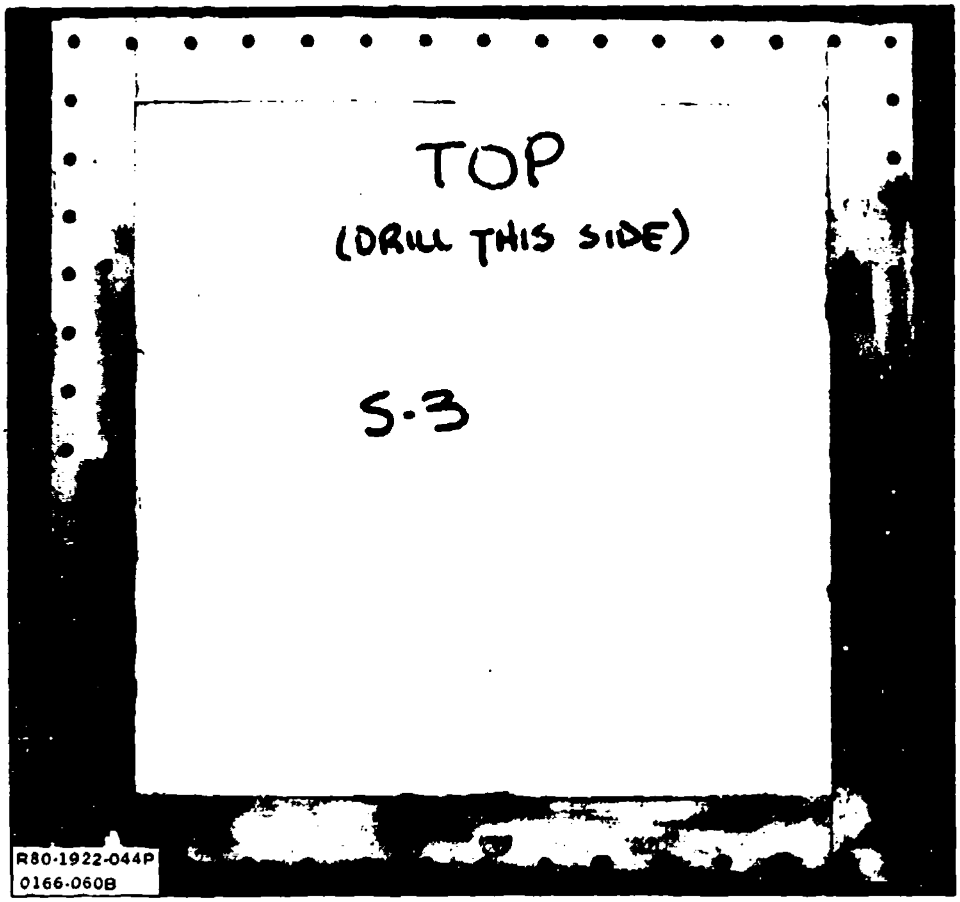

Figure A-8 EMI Test Panel with Edge Treatment

tacted the RF gasket around the 12 x 12-in. aperture. To accomplish this, a metal frame or pressure plate was installed over the sample and bolted to the mount; this provided an even distribution of pressure upon the samples mounted against the RF gasket and apertures of the two enclosure systems.

Together, these precautions guarded against RF leakage while providing intimate electrical continuity between the graphite/epoxy samples and the shielding effectiveness measurement fixture. The edge treatment used to frame the specimens peripherally with an electrically continuous coating was applied to each of the 15 x 15-in. shielding effectiveness specimens. All edges were chamfered 3t x t/2 (where "t" is the panel thickness) on both sides, creating a knife edge which effectively exposed six-times the original fiber end cross-sectional area. A thin, continuous layer of silver-filled conductive epoxy was applied in a 1.5-in.-wide strip on both sides around the periphery. The epoxy was covered with a layer of 0.010-in.-thick aluminum foil and the system cured for 2 hr at 140°F.

APPENDIX

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