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An Evaluation of the Effects of "Hand" Sanding and Plastic Media Blasting (PMB) Paint Removal Methods on Graphite/Epoxy Composite Materials

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NOTICE

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

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An abrasive blasting process using plastic beads has been used to strip paint from USAF aircraft surfaces and component parts. The mechanical effects of Plastic Media Blasting (PMB) were studied on quasi-isentropic and uni-directional graphite/epoxy substrates. Effects of "hand" sanding were also investigated. After one paint and strip cycle, the effects of PMB were found to be minimal; the mechanical properties varied within property limits of unstripped control samples. Using the primer as a flag to control stripping depth within the primer and resin rich "gel" coat is recommended to maintain mechanical properties.

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FOREWORD

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1 Wright Research and Development Center (WRDC) was formerly named Air Force Wright Aeronautical Laboratories (AFWAL) until January 1989.

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1.0 INTRODUCTION

Paint coatings are used on military aircraft for many reasons. They act as protective layers for the substrate material to which they are applied. Paint systems serve to protect aircraft from corrosion, erosion, environmental and thermal effects. Paints also serve as methods of visually camouflaging aircraft. For composite materials in particular, paints act as barriers protecting against environmental conditions, and ultraviolet radiation.

Paint removal is a necessary part of aircraft maintenance. For metal surfaces, paint removal is required in order to check and repair corrosion protection. For composites, paint removal is necessary in order to repair structures made of these materials. In many cases, paint is removed for purely cosmetic purposes or during a change in camouflage schemes.

In the past, paint removal was primarily accomplished using chemical stripping agents. This process resulted in health hazards, waste disposal problems, and incomplete stripping jobs which required "touch-ups" using power sanders. Since 1985, the U.S. Air Force has investigated and used the plastic media blasting (PMB) method as a way of removing paint from some of its aircraft. Some commercial firms have followed suit. The PMB process is currently being used to strip USAF F-4 fighter aircraft at the Ogden Air Logistics Center at Hill AFB, UT, and to strip A-10 and A-7 attack aircraft at the Sacramento Air Logistics Center at McClellan AFB, CA.

The skins of these aircraft, however, are mostly metal and newer aircraft (F-15, F-16, AV-8B, F/A-18) having substantially greater skin areas made from composite materials are beginning to be scheduled for maintenance including paint stripping. Methods for removing paint from composites have not advanced as quickly as those for removing paint from metals. Until 1989, the only method approved for removal of paint from composite materials in the USAF inventory was abrasive sanding. Methylene-chloride-based chemicals cannot be used because they can chemically attack the organic matrix of the composite and weaken the material.

In order to determine the effects of PMB on all aircraft materials, the Materials Laboratory conducted a study beginning in October 1984. This study resulted in the publication of AFWAL-TR-85-4138 Evaluation of the Effects of a Plastic Bead Paint Removal Process on Properties of Aircraft Structural Materials (Ref. 1). The study covered the effects of PMB on aluminum and also on graphite/epoxy composite materials. The study, however, failed to monitor and record the standoff distance and the angle at which the plastic media was blasted onto the surface being stripped. These two parameters have since been identified as being important to control during the PMB process. In addition, some of the paint removal from composites in the aforementioned study was performed using what are now recognized as extremely aggressive parameters which will inevitably lead to the erosion of material and degradation of mechanical properties.

Following the release of AFWAL-TR-85-4138, several manufacturers and users of PMB claimed to be able to successfully strip composites using PMB. They reported using less aggressive parameters and softer media. Their efforts rekindled interest within the Department of Defense for a better understanding of the use of PMB to strip composite materials. If a way could be found to safely use PMB to strip composite materials, it was reasoned, then the stripping operation of military aircraft could be streamlined because of the use of the same method on metal and composite surfaces, and health hazards and waste could be reduced. This report addresses these issues and concerns.

Research done for this report comes from three studies of plastic media blasting conducted by the Materials Laboratory (WRDC/MLSE) for the Warner-Robins Air Logistics Center (WR-ALC), for the Oklahoma City Air Logistic Center (OC-ALC), and as in-house work at WRDC/MLSE. Research on the use of "hand" sanding as a paint removal method was also conducted by WRDC/MLSE for WR-ALC and is included in this report.

"Hand" sanding and PMB can both cause severe damage to a composite laminate if used in an uncontrolled fashion. However, if PMB is used correctly, it is a safe method for removing paint from composite materials and has less potential for causing damage than does hand sanding. The correct use of PMB as a method of paint removal from composites means that PMB must be used to remove only the paint layer and not the primer layer. In other words, for safe removal of paint from composites with PMB, the primer layer beneath the paint layer being removed must serve as a "flag" or stopping point.

The goal of the studies documented in this report was to determine a safe way of using PMB on composite materials if one existed. It is by no means an all-inclusive report covering all types of PMB methods on all types of composite materials. Rather, it is intended to present the general effects of PMB on graphite/epoxy composite materials, to draw conclusions from the results of the tests performed in these studies, and to make recommendations regarding the future use of PMB on composite materials in the USAF inventory.

2.0 EXPERIMENTAL APPROACH

2.1 General

Three separate investigations of the effects of PMB were performed by WRDC/MLSE from October 1986 through March 1989. The objective of all of these test programs was three-fold. First, the programs were undertaken in order to understand the effects of PMB on graphite/epoxy composites by generating data, through mechanical and non-destructive testing, regarding their properties. A second objective of these programs was to determine if there existed "windows" of safe sets of PMB parameters which could be recommended for use on composites currently in use in the USAF. The final objective was to provide this information to Air Force Logistics Command and to the Systems Program Managers of the individual aircraft to allow these personnel to make a decision regarding the use of PMB on their specific weapons systems.

In addition, a small portion of one study examined the effects of "hand" sanding on graphite/epoxy panels.

In order to meet these objectives, stripping was performed in a laboratory setting at both Battelle-Columbus Laboratories in Columbus, OH, and at the Boeing Airplane Company in Wichita, KS, and under simulated depot conditions at Warner-Robins Air Logistics Center at Robins AFB, GA. Test panels were made of a graphite/epoxy substrate and were coated with an epoxy primer/polyurethane topcoat paint system in order to simulate composites currently in use on USAF aircraft. Laboratory tests used U.S. Plastics Polyextra™ (3.0 mohs hardness) and Polyplus™ (3.5 mohs hardness) media. The simulated depot conditions were used in the evaluation of hand-sanding techniques. Non-destructive evaluations (NDE) and mechanical tests were performed on the panels in their baseline and stripped configurations to obtain the desired engineering data.

The most important aspect of the approach taken during the PMB stripping tests was the use of the epoxy primer coat as a stopping point. Unless otherwise noted, the PMB operator used the epoxy primer coat as a visual cue to aim the blast nozzle away from an area which had already had its paint removed and to another area of a test panel which required stripping. This resulted in a mottled appearance of the remaining bright green primer, but it also minimized the amount of time which the PMB blast was aimed at one specific area of a test surface. This technique is described as "using the primer as a flag."

2.2 WR-ALC Program

WRDC/MLSE performed testing for WR-ALC to determine and to compare the effects of PMB and "hand" sanding as methods of paint removal from quasi-isotropic graphite/epoxy composite panels. "Hand" sanding is a misnomer here since the sanding was actually done with the use of power sanders. Panels were fabricated at University of Dayton Research Institute (UDRI), and primed and painted at WRDC/MLSA. The sanding operations were performed at WR-ALC by maintenance personnel. PMB stripping was accomplished using the USAF-owned PMB booth located at Battelle-Columbus Laboratories in Columbus, OH. Following stripping operations, the test panels were brought back to WRDC/MLSA where they underwent C-scan ultrasonic and X-ray non-destructive evaluation. Following NDE, the panels were cut into specimens which underwent tensile and interlaminar shear testing performed by WRDC/MLSE.

2.3 OC-ALC Program

WRDC/MLSE performed testing for OC-ALC to determine the effects of the softer (3.0 mohs hardness) media on quasi-isotropic graphite/epoxy composite panels. Panels were fabricated by UDRI, primed and painted at WRDC/MLSA, and sent to OC-ALC for PMB stripping. PMB stripping was performed by Boeing-Wichita under contract to OC-ALC. Following PMB stripping, the test panels were sent back to WRDC/MLSA for C-scan ultrasonic and X-ray evaluations. Following NDE, the panels were mechanically tested for tensile and interlaminar shear properties by WRDC/MLSE.

2.4 WRDC/MLSE In-House Program

In order to gain a more comprehensive view of PMB effects on graphite/epoxy composites, a program was started at WRDC/MLSE to investigate the effects of nine sets of PMB parameters on unidirectional graphite/epoxy composite panels. Unidirectional panels were chosen in order to allow the effects on the matrix material to be more easily distinguished from effect on the fibers. Panels were fabricated at UDRI, and primed and painted at WRDC/MLSA. The PMB stripping operations were performed using the USAF-owned PMB booth at Battelle-Columbus Laboratories in Columbus, OH. Following stripping, the panels were brought back to WRDC/MLSA for C-scan ultrasonic and X-ray evaluations. Following NDE, the panels were submitted to tensile, compressive, flexural and interlaminar shear tests at WRDC/MLSE.

3.0 TEST PROGRAM & PROCEDURES

3.1 Material

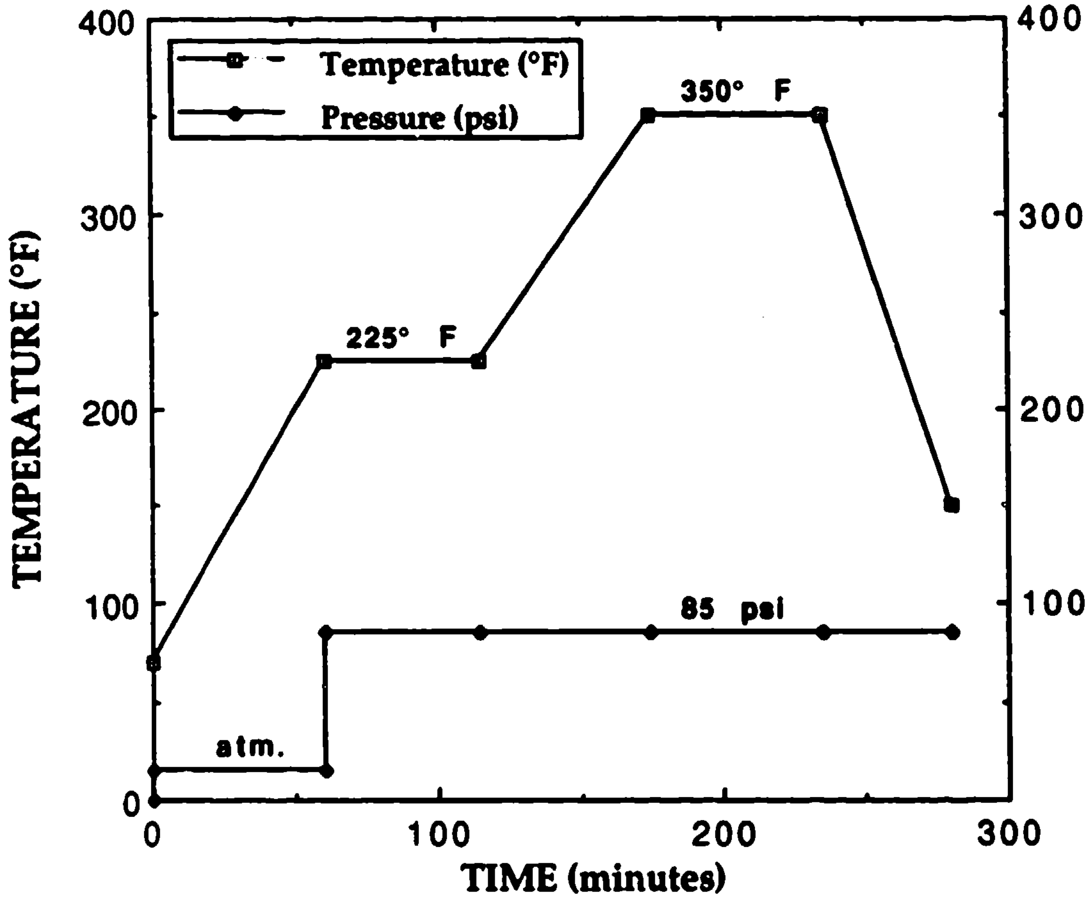
Hercules™ IM6/3501-6 graphite/epoxy prepreg system was used in the fabrication of all of the test panels used for all three of the test programs discussed in this report. All panel fabrication was performed at the University of Dayton Research Institute (UDRI) in Dayton, OH. All test panels consisted of 16 plies of the composite material.

Hand lay-up was used to construct the test panels. Test panels for the WR-ALC and OC-ALC programs were laid up in a quasi-isotropic configuration. Test panels for the WRDC/MLSE in-house program were laid up in a unidirectional configuration. All panels were fabricated with a protective teflon peel-ply film applied to the outside surfaces of the test panels. This peel-ply was removed prior to painting.

The cure cycle used by UDRI for this material is illustrated in Figure 1.

Final post-cure dimensions of the test panels were approximately 2 ft. by 2 ft. by 0.0825 inches (0.6094 m by 0.6094 m by 2.0955 mm).

Figure 1. Cure Cycle for IM6/3501-6 Graphite/Epoxy Composite Material



3.2 Painting

All test panels for all programs discussed in this report were primed and painted by WRDC/MLSA according to the following Materials Laboratory standard procedures and USAF T.O. 1-1-8, Application of Organic Coatings, Aerospace Equipment (Ref. 2).

Following panel fabrication, the protective peel ply film was removed from all areas of the test panels which were to be painted. For areas to be later sectioned into specimens for baseline (unstripped) mechanical tests, the teflon peel ply was left on the panels.

The panels were then sprayed with an epoxy/polyamide based primer (MIL-P-23377) to a dry film thickness of approximately 0.6 to 0.8 mils (0.0006 to 0.0008 in {0.0152 to 0.0203 mm}). The primer coat was allowed to dry at room temperature (approximately 75°F {23.9C}, 50%RH) for 3 to 4 hours. Following this, the primed panel was sprayed with two coats of polyurethane paint (MIL-C-83286, Federal Standard 595A, Color #34102, "Camouflage Olive Drab Green") to a dry film thickness of approximately 0.8 to 1.2 mils (0.0008 to 0.0012 in {0.0203 to 0.0305 mm}) per coat. The panels were allowed to dry at room temperature for one hour between coats of paint. This procedure resulted in a total primer-paint system dry film thickness of approximately 2.2 to 3.2 mils (0.0022 to 0.0032 in {0.0559 to 0.0813mm}

Following the application of the paint and primer, the paint system was cured for 168 hours at 75°F {23.9C} and 50%RH and then aged at 210°F {98.9C} for 96 hours.

3.3 Pre-Strip Non-Destructive Evaluation

All test panels were subjected to C-scan ultrasound and X-ray evaluations prior to being stripped. NDE of the panels was performed by WRDC/MLSA. Selected areas of the panels were also examined under a scanning electron microscope (SEM) also located in WRDC/MLSA.

3.4 Paint Removal Procedures

3.4.1 General

All three test programs discussed in this report required baseline data to be generated in order to allow the analysis of mechanical test results to compare stripped and unstripped specimens. For this baseline data, specimens were taken from areas of the test panels which were protected from the paint removal methods used.

3.4.2 "Using The Primer As A Flag"

With the exception of regions from some of the test panels for the OC-ALC program, all PMB paint stripping was done using the "primer as a flag" criteria. This criteria simply means that the PMB operator redirected the PMB blast away from an area when the epoxy primer (usually a bright yellow-green) showed through signalling that the paint had been removed. Due to the nature of PMB stripping, an enormous amount of control and training is necessary to leave a smooth layer of primer remaining following paint removal. Therefore, the surface of the panels stripped using the PMB method and the "primer as a flag" criteria usually have a mottled surface with the remaining primer being unevenly distributed on the stripped substrate (Figs. 2 and 3). By using the primer as a "flag," the amount of time for which a given surface area is exposed to the PMB blast is minimized. Therefore, this technique minimizes the possibility of degrading the mechanical properties of the composite by minimizing or preventing damage to the surface of the composite.

3.5 PMB Equipment

Test panels which were stripped with the PMB method were stripped in two locations, at Battelle-Columbus Laboratories in Columbus, OH, and at Boeing Military Aircraft Co. in Wichita, KS.

The equipment at Battelle, which was used for the majority of the tests, is owned by the US Air Force. The PMB cabinet is a FASTRIP™ 6060 unit manufactured by the Empire Abrasive Equipment Corporation in Langhorne, PA. It uses a 3/8 inch (9.525 mm) diameter nozzle (Fig. 4). Figures 5 through 7 show views of the system. Tests were conducted using a fixed nozzle and movable panel. The nozzle was held at a constant standoff distance and angle to the surface being stripped by attaching it to an aluminum frame. The tests panels were moved under the PMB blast while attached to a small table equipped with clamps to hold the panels and casters to allow it to roll easier (Figs. 8 and 9). New ("virgin") media was loaded into the PMB machine prior to the stripping of the panels , but this media was recycled through the system during the stripping process.

The equipment at Boeing-Wichita, which was used for the PMB stripping of the panels for the OC-ALC program, was the Zero PMD-III unit manufactured by Clemco Corp. This equipment used a 1/2 inch (12.7 mm) diameter nozzle. Unlike the equipment at Battelle, this unit was not a blast cabinet, but a temporary blast enclosure which was built around the unit for the stripping of the composite test panels. For the OC-ALC program, the panels were held fast and the nozzle was moved to pass the PMB blast over the surfaces of the panels. As with the procedures at Battelle, "virgin" media was used for these tests.

Figure 2. Mottled Appearance of PMB Stripped Panel Showing Incomplete Primer Removal

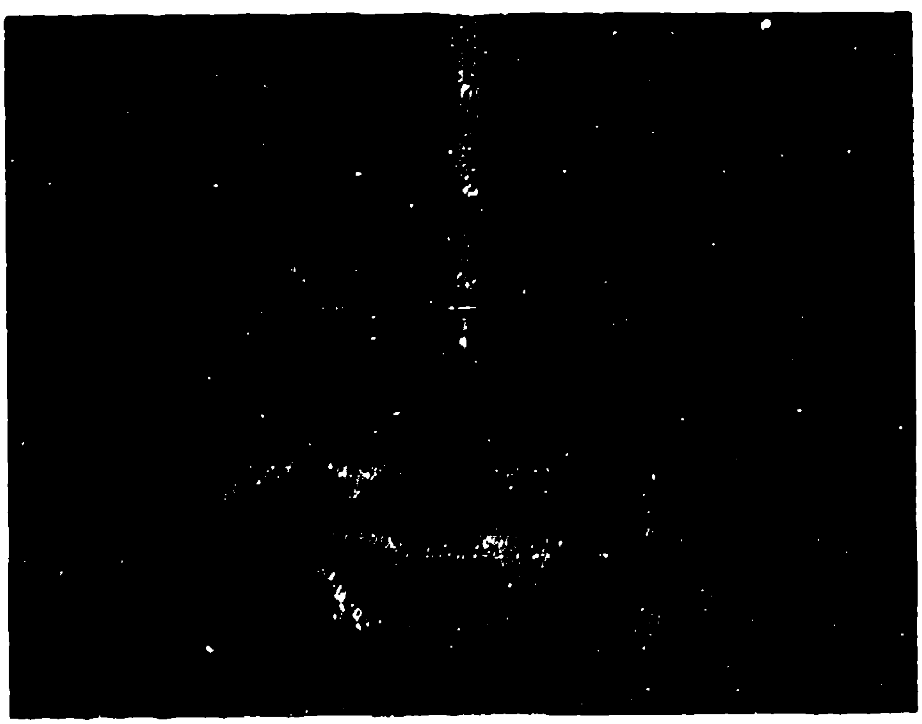


Figure 3. Mottled Appearance of PMB Stripped Panel Showing Incomplete Primer Removal

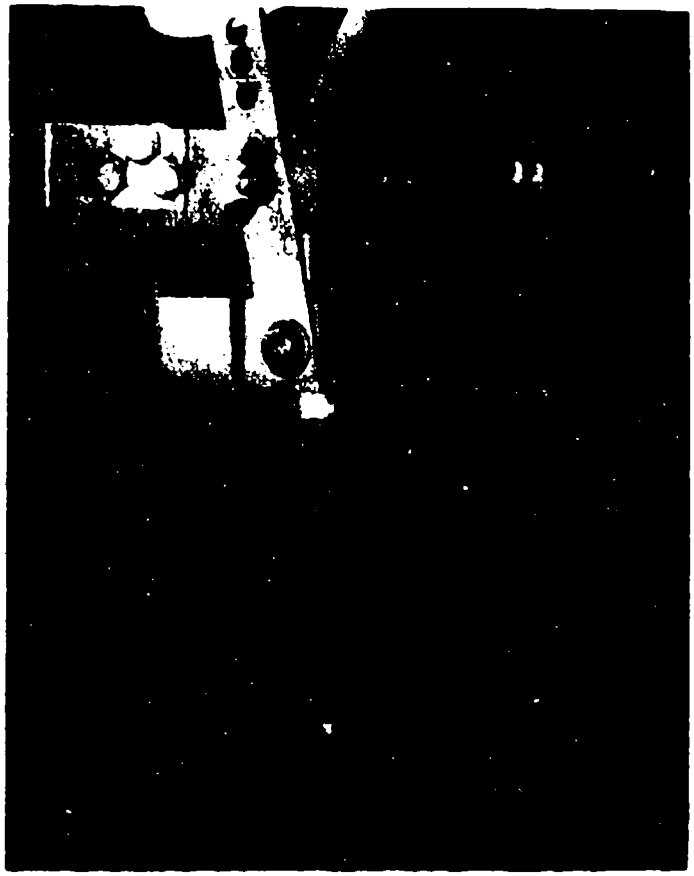


Figure 4. **PMB Blast Nozzle in PMB Cabinet Located at Battelle-Columbus Labs**

Figure 5. **PMB Blast Cabinet Located at Battelle-Columbus Labs**

Figure 6. Looking Inside PMB Blast Cabinet

Figure 7. PMB Blast Cabinet Located at Battelle-Columbus Labs In Operation

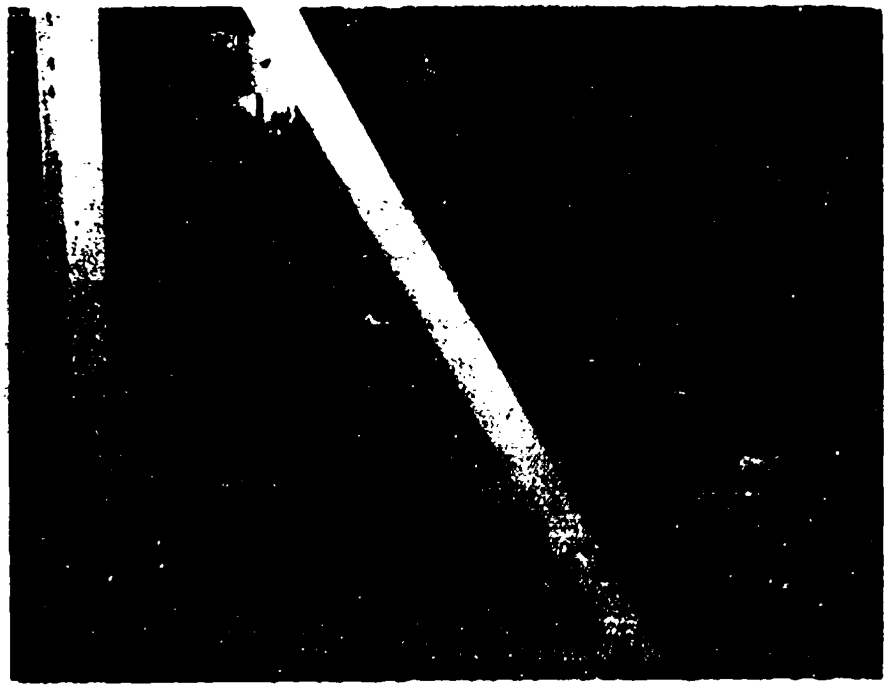


Figure 8. **Panel and Nozzle Holding Fixtures Inside PMB Cabinet**

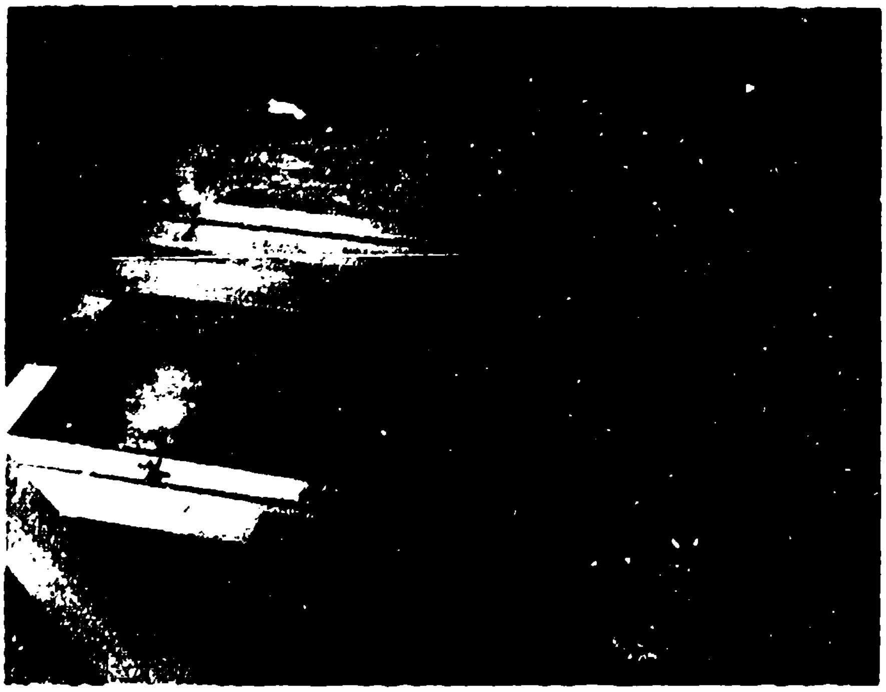


Figure 9. **Panel Holding Fixture Inside PMB Cabinet**

3.6 Test Programs Conducted by WRDC/MLSE

3.6.1 WR-ALC Program

Panels for the test program conducted for WR-ALC by WRDC/MLSE were stripped using two methods. Some were stripped using "hand" sanding, the others were stripped using PMB.

The panels intended for "hand" sanding were sent to WR-ALC/MMEMM where they were taken to the paint shop. Personnel in the paint shop were instructed that the test panels were made of graphite/epoxy composite and were told to remove the paint from them in the same manner as they would remove paint from a composite aircraft part. (WR-ALC is the primary depot for the F-15 which has a graphite/epoxy speed brake and boron/epoxy panels and skins on the empennage.) The maintenance personnel used "jitterbug" sanders and sandpaper. Of the three test panels, one was stripped using 60 grit sandpaper, another using 120 grit, and a third using 180 grit (See Table 1).

The PMB stripping for this program was performed by WRDC/MLSE at Battelle-Columbus Laboratories. Four 1ft. by 1ft. by 16 ply {0.3048 m by 0.3048 m by 16 ply} quasi-isotropic graphite/epoxy panels were stripped using four different combinations of PMB parameters. (See Table 1).

Table 1. **Stripping Parameters for WR-ALC Program**

Panel #	Pressure (psi) {bar}	Standoff (in) {m}	Angle (deg)	Grit (if sanded)
29-16-I	60 {4.14}	12 {0.3048}	60	
29-16-II	60 {4.14}	12 {0.3048}	90	
29-16-III	60 {4.14}	12 {0.3048}	45	
29-16-IV	60 {4.14}	12 {0.3048}	30	
30-16				180
35-16				120
36-16				60

The media used was 30/40 U.S. sieve size (0.015 to 0.023 in {0.381 to 0.5842 mm}) U.S. Plastics Polyextra™ (3.0 mohs hardness). The media flow rate was 250-300 lbs/hour {114 to 136 kg/hour}. The nozzle pressure was 60 psi {4.138 bar} and the standoff distance was 12 inches {0.3048 m}. Angles of incidence used were 30°, 45°, 60°, or 90° measured from the horizontal. The "primer as a flag" criteria was used in stripping all of the test panels for this program.

3.6.2 OC-ALC Program

The test panels stripped for the OC-ALC program underwent PMB at Boeing-Wichita. Two 2 ft. by 2 ft. by 16 ply {0.6096 m by 0.6096 m by 16 ply} quasi-isotropic graphite/epoxy panels were stripped using five different sets of PMB parameters (See Table 2). The media used was 30/40 U.S. sieve size (0.015 to 0.023 in {0.381 to 0.5842 mm}) U.S. Plastics Polyextra™ (3.0 mohs hardness). The media flow rate was 400 lbs/hour {182 kg/hour}. Nozzle pressures used were 50, 60, or 70 psi {3.45, 4.14, or 4.83 bar}.The standoff distance was held between 12 an 18 inches {0.3048 and 0.4572 m}, and the angle of incidence was held constant at 70° measured from the horizontal. The "primer as a flag" criteria was used in stripping three of the five panels used in this test program (See Table 2).

Table 2. PMB Parameters for OC-ALC Program

Panel #	Pressure (psi) {bar}	Standoff (in) {m}	Angle (deg)	"Primer as Flag"?
33-16-1	60 {4.14}	12 to 18 {.305 to .457}	70	NO
34-16-2A	70 {4.83}	12 to 18 {.305 to .457}	70	NO
34-16-2B	70 {4.83}	12 to 18 {.305 to .457}	70	YES
34-16-3	50 {3.45}	12 to 18 {.305 to .457}	70	YES
33-16-4	60 {4.14}	12 to 18 {.305 to .457}	70	YES

3.6.3 WRDC/MLSE In-House Program

Nine 2 ft. by 2 ft. by 16 ply {0.6096 m by 0.6096 m by 16 ply} unidirectional graphite/epoxy composite panels were PMB stripped by WRDC/MLSE at Battelle-Columbus for this program. Nine separate sets of parameters were used (See Table 3). The media types used were 30/40 U.S. sieve size (0.015 to 0.023 in {0.381 to 0.5842 mm}) U.S. Plastics Polyextra™ (3.0 mohs hardness) and Polyplus™ (3.5 mohs hardness). The media flow rate was 250 to 300 lbs/hour {114 to 136 kg/hour}. Nozzle pressures used were 30, 40, or 60 psi {2.07, 2.76, or 4.14 bar}. Standoff distances used were 12 or 18 inches {0.3048 or 0.4572 m}. Angles of incidence used were 90° or 45° measured from the horizontal. The "primer as a flag" criteria was used in stripping all test panels for this program.

Table 3. PMB Parameters for WRDC/MLSE In-House Program

Panel #	Media (mohs)	Pressure (psi) {bar}	Standoff (in) {m}	Angle (deg)
1	3.0	40 {2.76}	12 {.305}	90
2	3.5	30 {2.07}	12 {.305}	90
3	3.0	60 {4.14}	18 {.457}	90
5	3.0	60 {4.14}	12 {.305}	90
6	3.5	40 {2.76}	12 {.305}	45
7	3.5	40 {2.76}	12 {.305}	90
8	3.5	30 {2.07}	12 {.305}	45
9	3.5	60 {4.14}	18 {.457}	90
11	3.5	40 {2.76}	18 {.457}	90

3.7 Post-Strip Non-Destructive Evaluation

Following paint removal, all panels were again subjected to NDE by WRDC/MLSA. This included, as in the pre-strip evaluations, C-scan ultrasound, X-ray, and selected SEM examinations.

3.8 Mechanical Test Procedures

All mechanical testing was performed by WRDC/MLSE at the Materials Laboratory at room temperature. Test machines used were the Instron TTCM and the Instron 1125 test machines (Figs. 10 and 11). Tensile tests conformed to ASTM Standard Test Procedure D3039-76. An MTS Biaxial Strain Gage was used to take strain measurements on the tensile test specimens. Flexural tests conformed to ASTM Standard Test Procedure D790-84a. Interlaminar shear tests were also performed using ASTM Standard Test Procedure D790-84a except that the span-to-depth ration was changed to 32:1 according to procedures used by WRDC/MLSE for conducting these types of tests (Ref. 3). Flexural and interlaminar shear tests were performed with the stripped side of the specimens in tension according to procedures used by WRDC/MLSE. Compression tests were performed using ASTM Standard Test Procedure D3410-75. ASTM test procedures for tensile and compression tests can be found in Reference 4, and those for flexural and interlaminar shear tests can be found in References 3 and 5. Table 4 shows which mechanical tests were performed for each of the three programs discussed in this report. Figures 10 through 16 show the set-ups for the individual tests.

Figure 10.
Instron Model TTCM with Compression Fixture

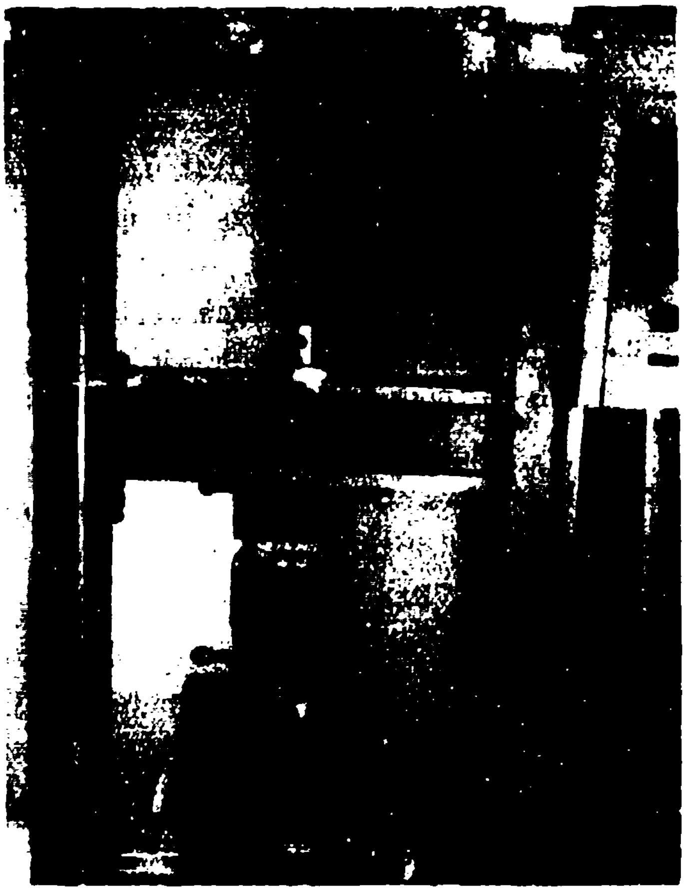


Figure 11.
Instron Model 1125 with Tension Fixture

Table 4. Mechanical Tests Performed

Test Type (lay-up type, direction of test)	WR-ALC	OC-ALC	WRDC/MLSE
HAND SANDING			
Tensile Strength (quasi-isotropic)	X		
Tensile Modulus (quasi-isotropic)	X		
Interlaminar Shear Strength (quasi-isotropic)	X		
PMB			
Tensile Strength (quasi-isotropic)	X	X	
Tensile Strength (unidirectional, parallel)			X
Tensile Strength (unidirectional, perpendicular)			X
Tensile Modulus (quasi-isotropic)	X	X	
Tensile Modulus (unidirectional, parallel)			X
Tensile Modulus (unidirectional, perpendicular)			X
Interlaminar Shear Strength (quasi-isotropic)		X	
Interlaminar Shear Strength (unidirectional)			X
Flexural Shear Strength (unidirectional)			X
Compression Strength (unidirectional, parallel)			X

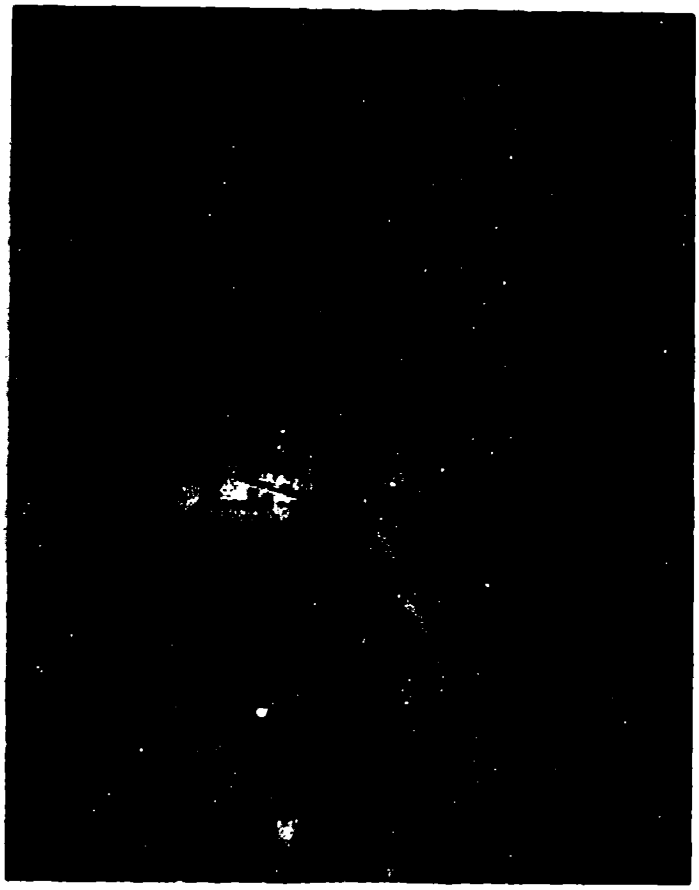


Figure 12. **Tensile Test Fixture with Biaxial Strain Gage**

Figure 13. **Compression Test Fixture**

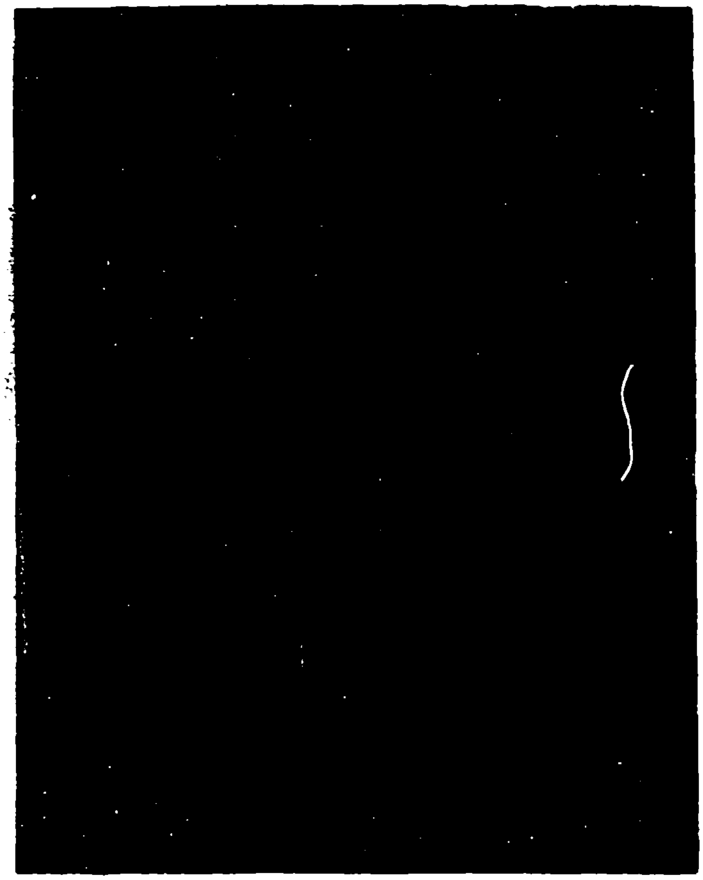


Figure 14. Flexural/Interlaminar Shear Test Set-Up

Figure 15. Flexural/Interlaminar Shear Test Fixture

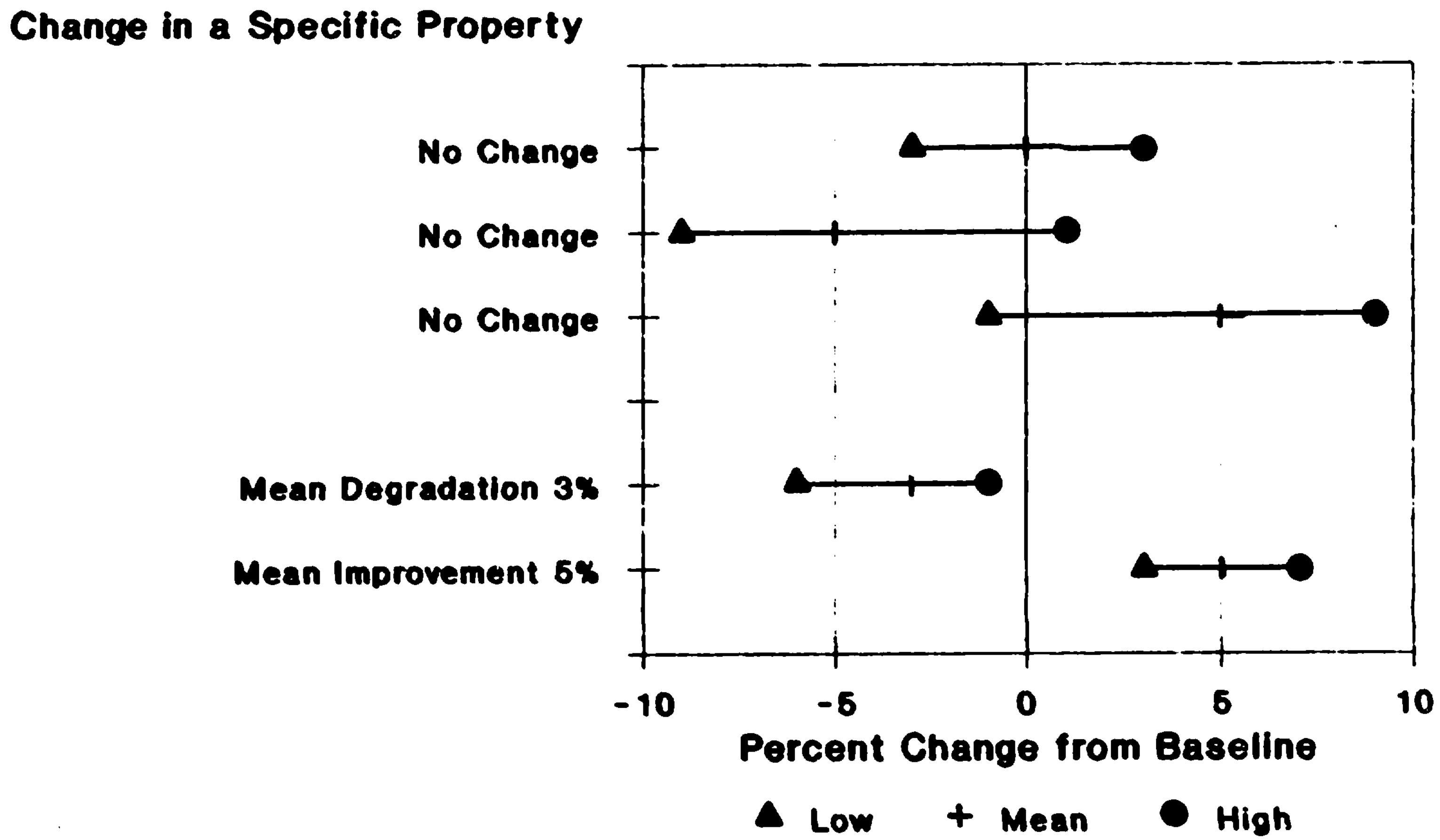
Figure 16. **Rear of Flexural/Interlaminar Shear test Fixture Showing Dial Gage and Deflectometer used in Measuring Specimen Deflections**

3.9 Data Reduction and Analysis

Following the completion of the mechanical testing, the results were tabulated and analyzed. This was done by comparing the average values of the stripped specimens with those of the baseline (unstripped) specimens and by using the statistical "T" test to determine the significance of any variances between these two sets of values (Ref. 5).

The "T" test was used to find the 95% confidence interval for each set of data generated from each panel. This test allows one to say with 95% confidence that the value of a given mechanical property for a given specimen subject to a given stripping procedure will fall between the high and low values of the interval. The "T" test was used to determine the amount of variance between the mechanical properties of a baseline (unstripped) sample and those of a stripped sample. In the following diagram (called a "variation analysis chart"), if the "zero percent change from baseline" line passes through the confidence interval for a given specimen's mechanical property values, then there is no statistical change between the baseline value for that property and the stripped value for that property. In other words, the stripping procedure did not statistically affect that mechanical property. If, however, the "zero percent change from baseline" line does not pass through the confidence interval, then one can say that there is a statistical change in that mechanical property of the stripped specimen as compared to the unstripped (baseline) specimen (See Fig. 17).

How to Read Variation Analysis Charts
What Constitutes a "Change"?



- BASED ON 95% CONFIDENCE INTERVAL
- Derived from the "T" test

Figure 17.

3.10 Variation Analysis Charts

Two types of variation analysis charts are shown in the following section covering test results. The first type shows the variation in one specific mechanical property (i.e. "WR-ALC Tensile Strength Variation"). Values shown on these charts represent the variation between the mechanical property values for a specific stripped panel as compared with the average baseline value for all of the panels used in the program. For example, if panels A, B, and C were all used in a program, one chart which may be generated would show the variation between the tensile strength of the stripped portion of panel A with the average baseline tensile strength obtained from averaging the baseline tensile strengths of the unstripped portions of panels A, B, and C.

The second type of variation analysis chart shows a summary of all of the variations of mechanical properties discovered in the particular program (i.e. "Variations shown by WR-ALC Program"). There is one of these summary charts for each program. This second type shows the variation between the average of all of the mechanical property values for one given type of test of all of the stripped panels in the program with the average baseline value for all of the panels used in the program. Back to our example; this would mean that the summary chart would include a plot of the variation of the average of the tensile strengths of the stripped portions of panels A, B, and C with the average baseline tensile strength value for the unstripped portions of panels A, B, and C.

The rationale behind the first type of variation analysis chart is that an increased pool of baseline data will increase the accuracy of the correlation of the mechanical property values of the baseline data arrived at through testing with the inherent mechanical properties of the material. Therefore, the first type of variation analysis chart attempts to give as true a comparison as possible between the mechanical properties of stripped panels arrived at through testing with the mechanical properties inherent to the baseline material. The rationale behind the second type of variation analysis chart is based on the fact that any single portion of an aircraft surface will "see" several sets of PMB parameters during its strip cycle due to the changing position of the blast nozzle and operator. Therefore, any specific mechanical property of the surface material will be affected in several ways by these parameters. The second type of variation analysis chart is an attempt to present the average effect of several sets of PMB parameters on a stripped surface.

4.0 TEST RESULTS

All results reported in this section are results of tests performed on panels after one strip cycle (i.e. a single time subjection to the PMB or hand sanding paint removal process).

4 1 Non-Destructive Evaluation

4.1.1 Ultrasonic C-Scan and X-ray Inspection

All test panels were subjected to ultrasonic C-scan and X-ray analysis before and after being stripped. According to these tests, no panels were found to have been internally affected by the sanding or PMB processes. No voids, delaminations, or internal areas of fiber breakage in the panels were indicated by these NDE methods.

4.1.2 Scanning Electron Microscopy

Some of the test panels were examined using the Scanning Electron Microscope (SEM). SEM analysis showed in greater detail the texture of the surface of the stripped and unstripped panels and allowed comparisons to be drawn between panels subjected to hand sanding, to PMB, and to no paint removal. Unstripped sections of test panels had a definitive "peel-ply pattern" on their surface resulting from the resin-rich outer surface (often termed the"gel-coat") of the panels being molded against the woven release cloth during curing. The pattern evident on the baseline panels, therefore, does not show fibers, but is an imprint of the weave pattern of the peel-ply release cloth (Fig. 18). SEM photos of the surfaces stripped using sandpaper in the WR-ALC Program show a total lack of "gel-coat" and exposure and severe damage to the fiber layers near the surface of the sanded panels (Figs. 19 and 20). Similarly, SEM photos of sections of test panels which were stripped down to the bare composite surface using PMB and not following the "primer as a flag" technique, also show extreme erosion of the surface layers and extensive fiber damage (Figs. 21 and 22). Photos of the surfaces of sections of test panels stripped with PMB using the "primer as a flag" technique appear mottled since much of the primer remains in a semi-removed condition (Figs. 23 - 25). If examined closely, Figure 23 shows that in some areas the primer has been removed down to the bare composite and the peel-ply weave pattern is exposed in these regions.

Figure 18. **Surface of Unpainted/Unstripped Graphite/Epoxy Panel (Mag. X150)**

Figure 19. **Surface of Graphite/Epoxy Panel Stripped with 60 Grit Sandpaper (Mag. X100)**

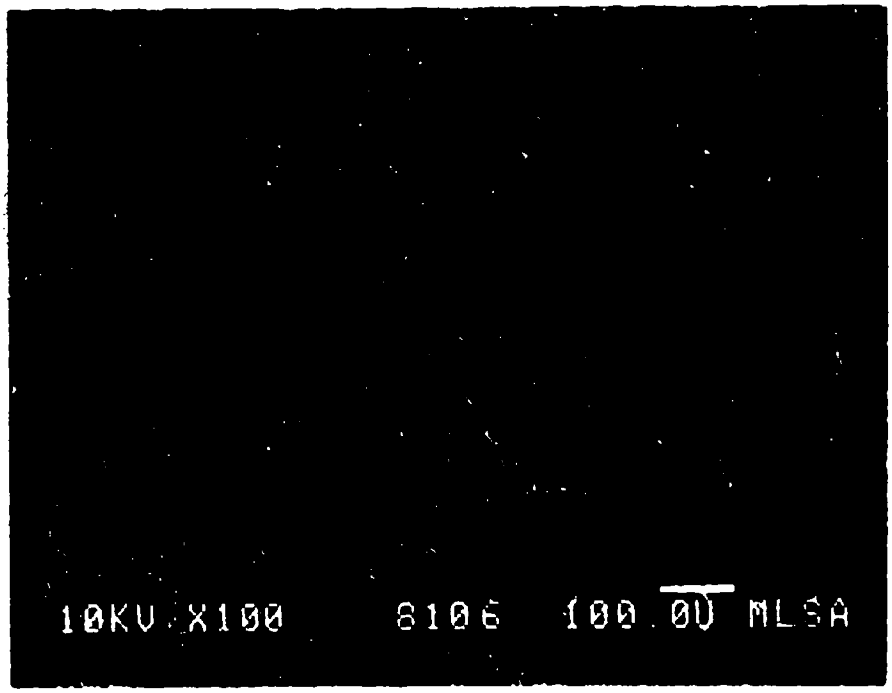


Figure 20. **Surface of Graphite/Epoxy Panel Stripped with 120 Grit Sandpaper (Mag. X100)**

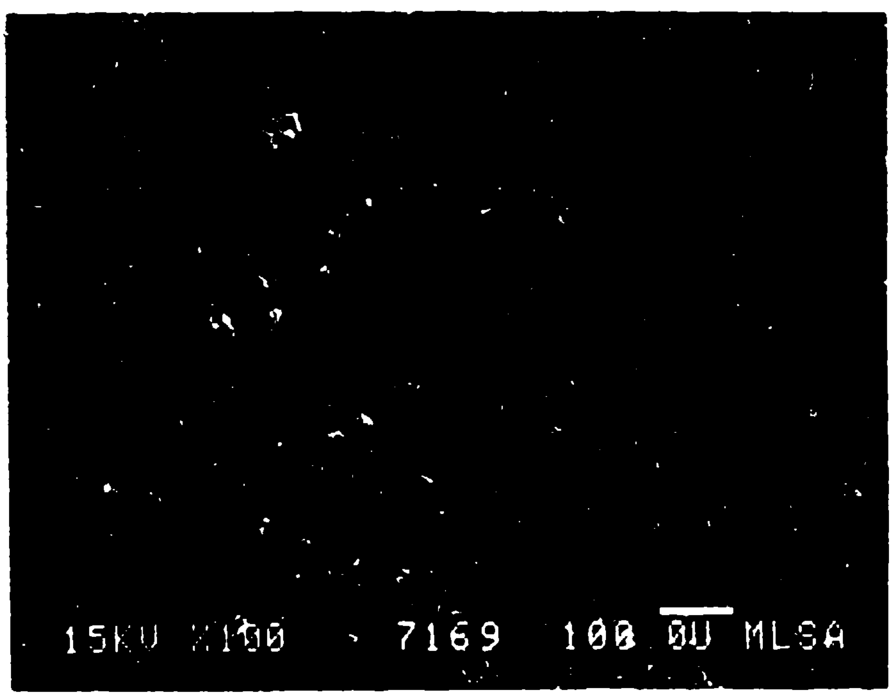


Figure 21. **Surface of Graphite/Epoxy Panel Stripped with PMB <u>WITHOUT</u> Using the "Primer as a Flag" Criteria (Mag. X100)**

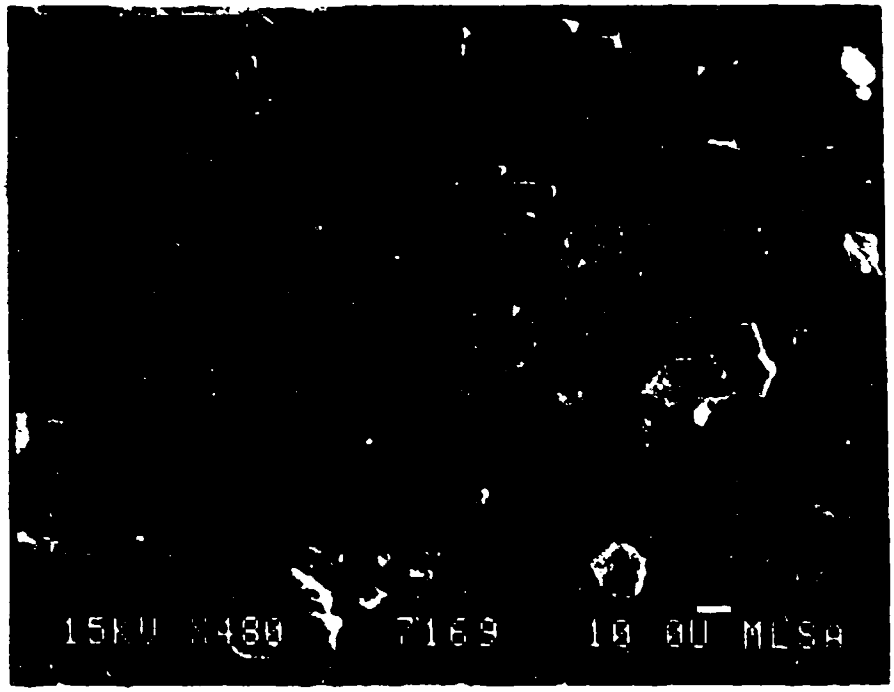


Figure 22. **Surface of Graphite/Epoxy Panel Stripped with PMB <u>WITHOUT</u> Using the "Primer as a Flag" Criteria (Mag. X480)**

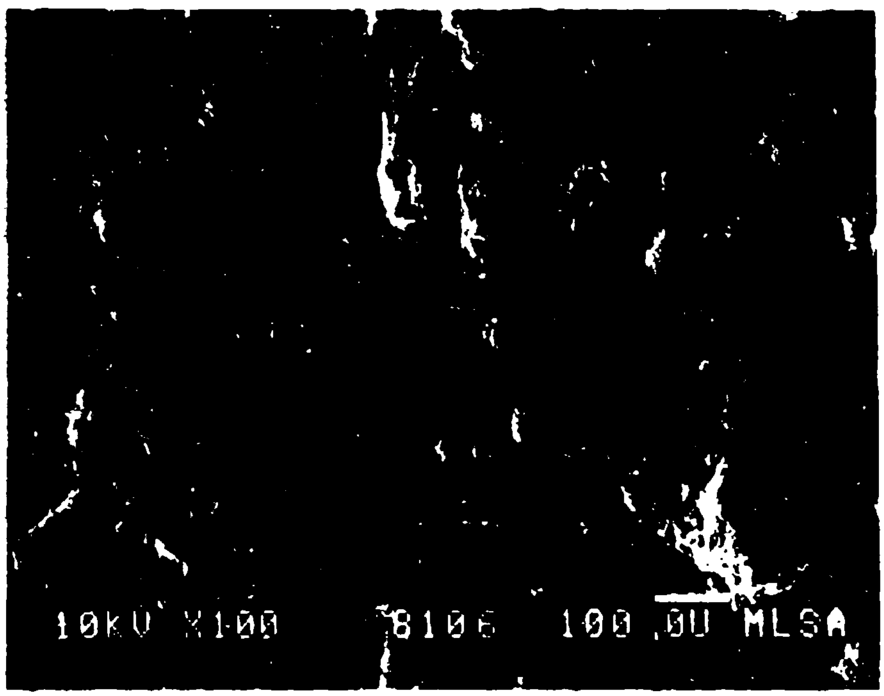


Figure 23. **Surface of Graphite/Epoxy Panel Stripped with PMB Using the "Primer as a Flag" Criteria [Note Appearance of Peel-Ply Pattern] (Mag. X100)**

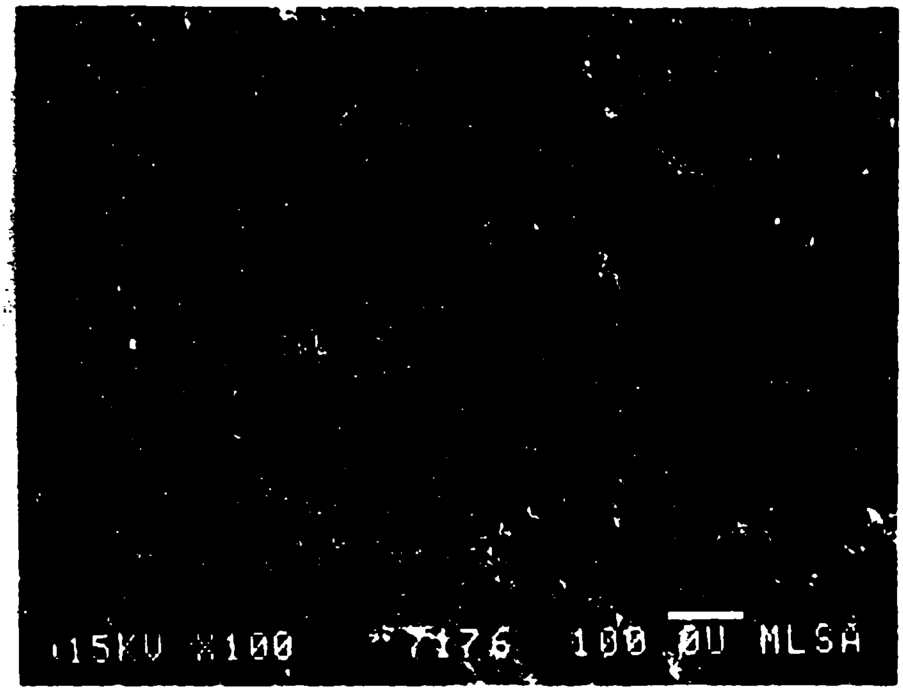


Figure 24. **Surface of Graphite/Epoxy Panel Stripped with PMB Using the "Primer as a Flag" Criteria (Mag. X100)**

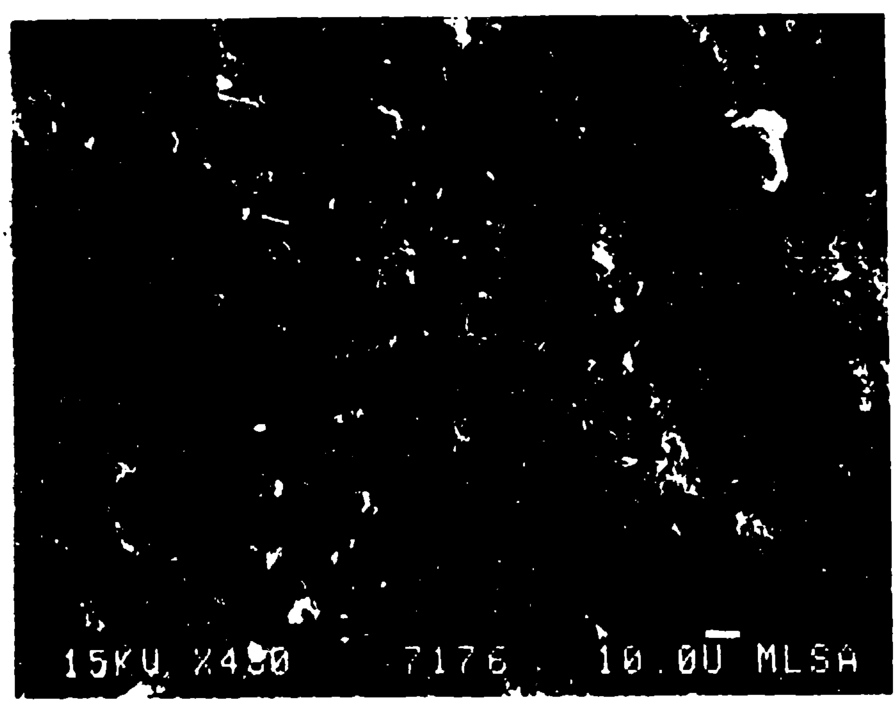


Figure 25. **Surface of Graphite/Epoxy Panel Stripped with PMB Using the "Primer as a Flag" Criteria (Mag. X480)**

4.2 Mechanical Test Results

4.2.1 WR-ALC Program

4.2.1.1 Tensile Strength (Fig. 26)

Testing showed a slight mean degradation (3.4% loss) of the tensile strength of the stripped section of the panel subjected to PMB under 60 psi (4.14 bar), at a distance of 12 inches (0.3048 m) and angle of 30 degrees. A 13.6% mean loss of tensile strength was experienced by the test panel section sanded with 60 grit sandpaper, and an 8% loss by the panel section sanded with 120 grit. Average tensile strength values showed no mean statistical loss in tensile strength for the material stripped with PMB and a 10.7% mean statistical loss of tensile strength for the material stripped by "hand" sanding.

4.2.1.2 Tensile Modulus (Fig. 27)

Results showed scatter in all of the tensile modulus tests conducted for the WR-ALC Program. Sections of panels stripped with the PMB method which showed mean statistical losses in tensile modulus values experienced losses between 6.1% and 4.1%. The panel section which was hand sanded with 60 grit sandpaper experienced a mean loss in tensile modulus of 7.3% On the average, panel sections stripped with PMB showed a 3.9% mean statistical loss in tensile modulus,and sanded panel sections experienced no statistical loss.

4.2.1.3 Interlaminar Shear Strength(Fig. 28)

Interlaminar shear tests were performed only on panels subjected to "hand" sanding. A 9.1% statistical increase in the interlaminar shear (ILS) value of the panels sanded with 120 grit paper was discovered. Overall, these panels experienced a 5.7% statistical gain in their mean ILS values.

4.2.2 OC-ALC Program

4.2.2.1 Tensile Strength (Fig. 29)

Panel sections stripped with PMB at Boeing-Wichita for OC-ALC showed no statistical degradation in tensile strength properties. No distinction with respect to tensile strength can be made between panel sections from this program which were stripped using the "primer as a flag" technique and those which were not. On the average, a mean statistical improvement of 7.8% was seen in the tensile strengths of the panels examined under this program.

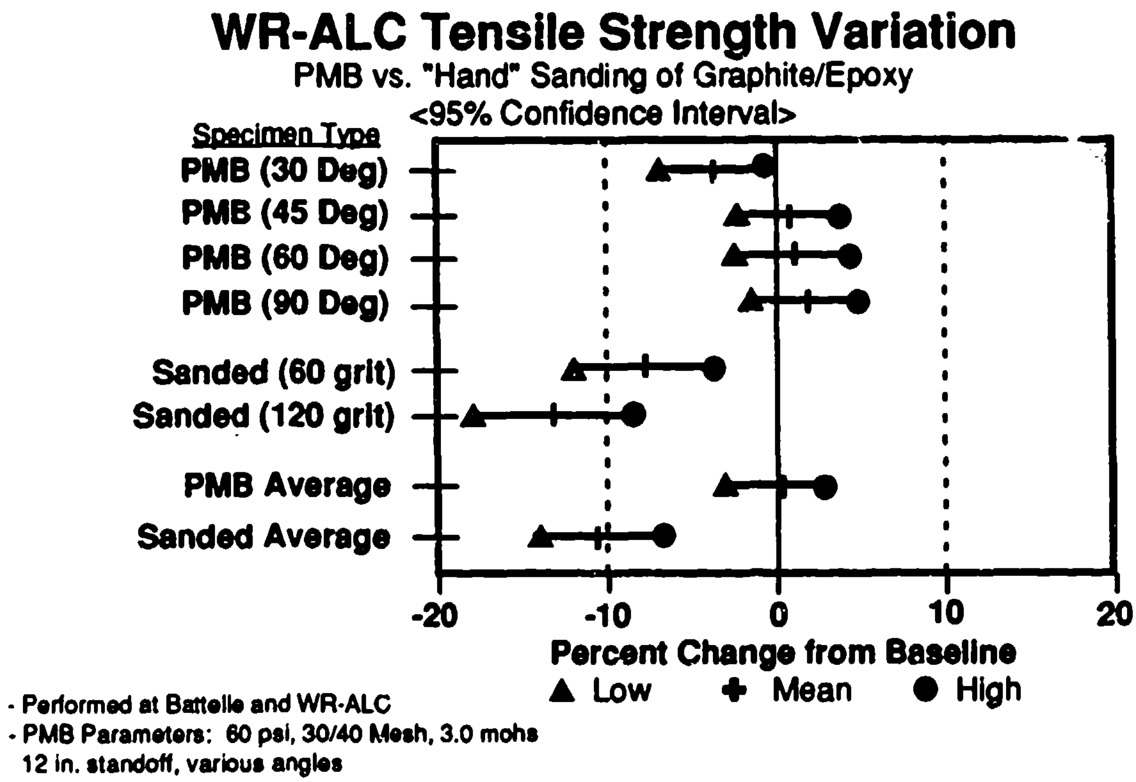


Figure 26.

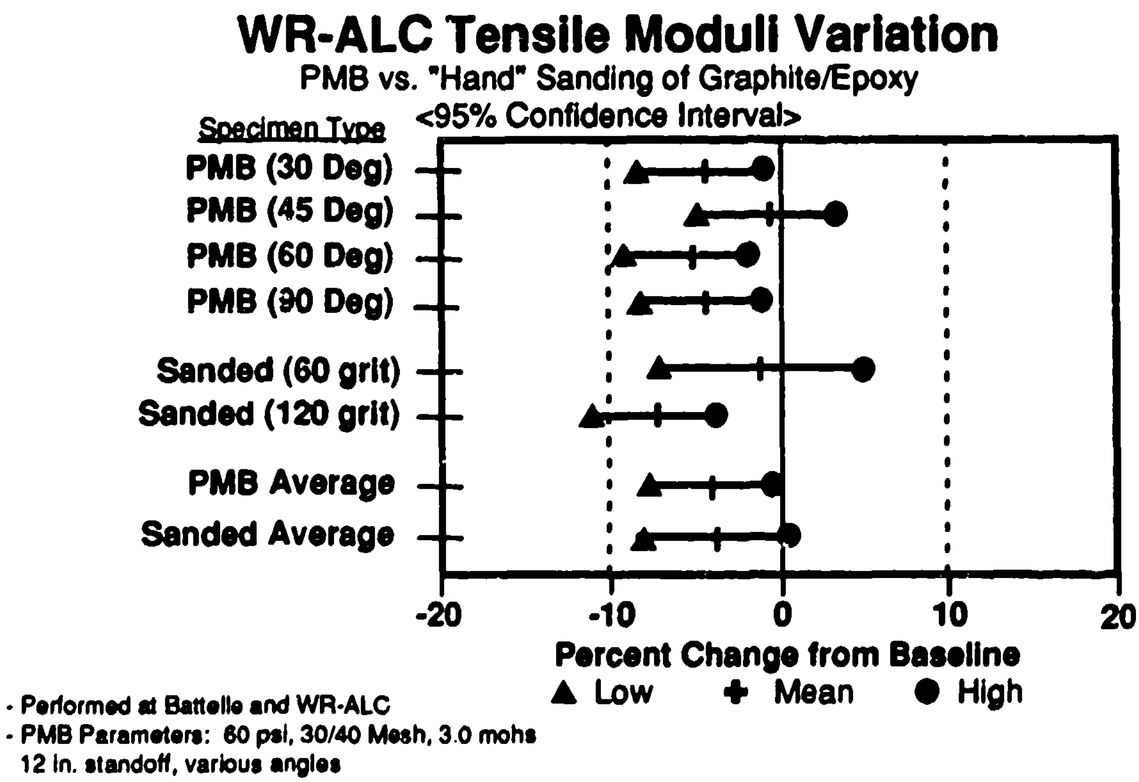


Figure 27.

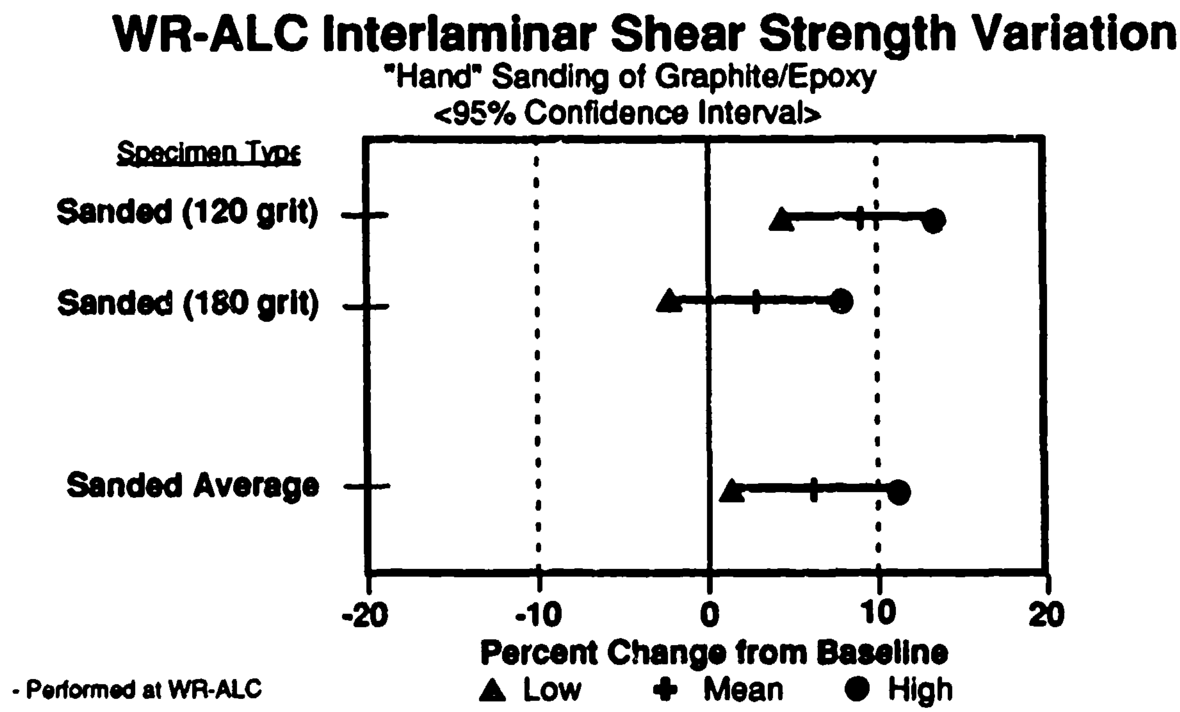


Figure 28.

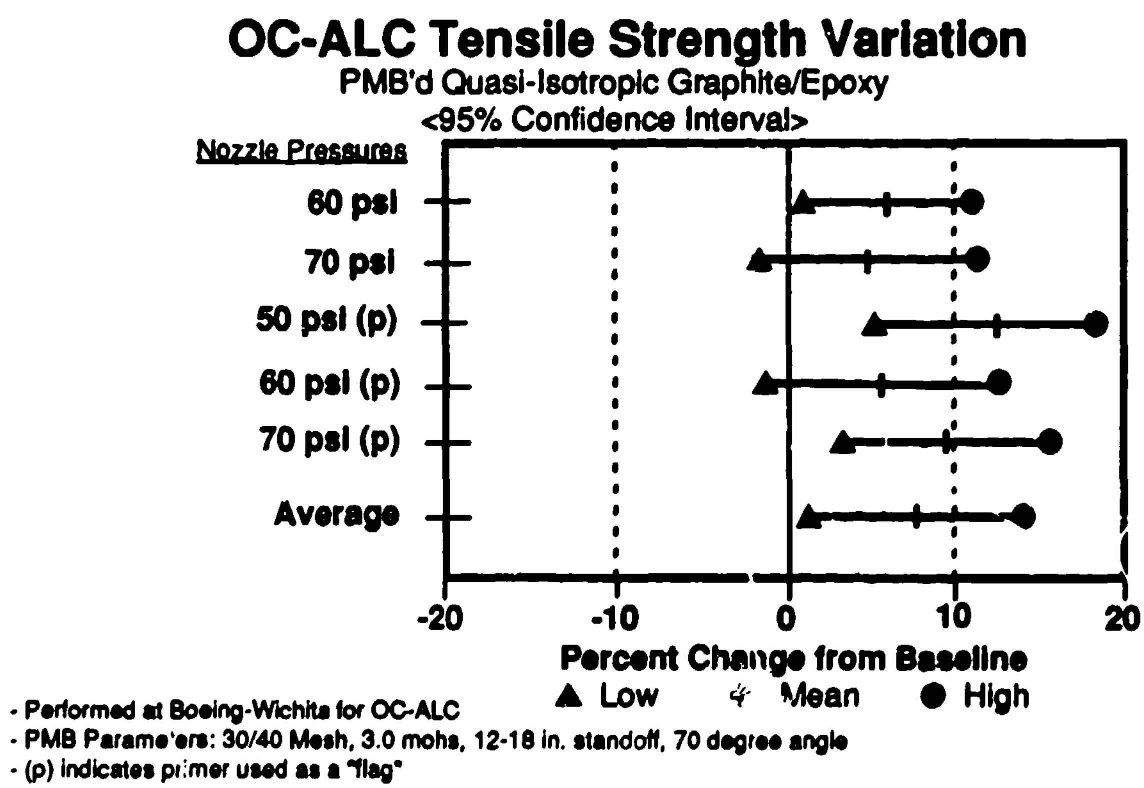


Figure 29.

4.2.2.2 Tensile Modulus (Fig. 30)

Similarly, no degradation in the tensile modulus values of the PMB-stripped panels was found for the OC-ALC Program. All stripped panel sections exhibited increased tensile modulus values. Statistical mean improvements in the tensile modulus values ranged from 22.5% to 10.7% with the average statistical mean improvement for the tensile modulus of the panels stripped under the OC-ALC program being 17.5%. No distinction with respect to tensile modulus can be made between panel sections from this program which were stripped using the "primer as a flag" technique and those which were not.

4.2.2.3 Interlaminar Shear Strength (Fig. 31)

With two exceptions, all stripped panel sections in the OC-ALC Program exhibited slightly higher mean ILS strengths than the baseline value. The panel stripped at stripped at 60 psi (4.14 bar), at 12 inches standoff (0.3048 m) and at an angle of 30 degrees using the "primer as a flag" technique experienced a mean statistical loss of 5.9% A similar panel which did not use the "primer as a flag" technique experienced a mean statistical loss of 5.8%. On the average, however, no statistical variation in interlaminar shear strength was exhibited by this group of panels.

4.2.3 WRDC/MLSE In-House Program

For ease of reference, please refer to Table 3 for the exact PMB parameters which correspond to the panel numbers used in the WRDC/MLSE program.

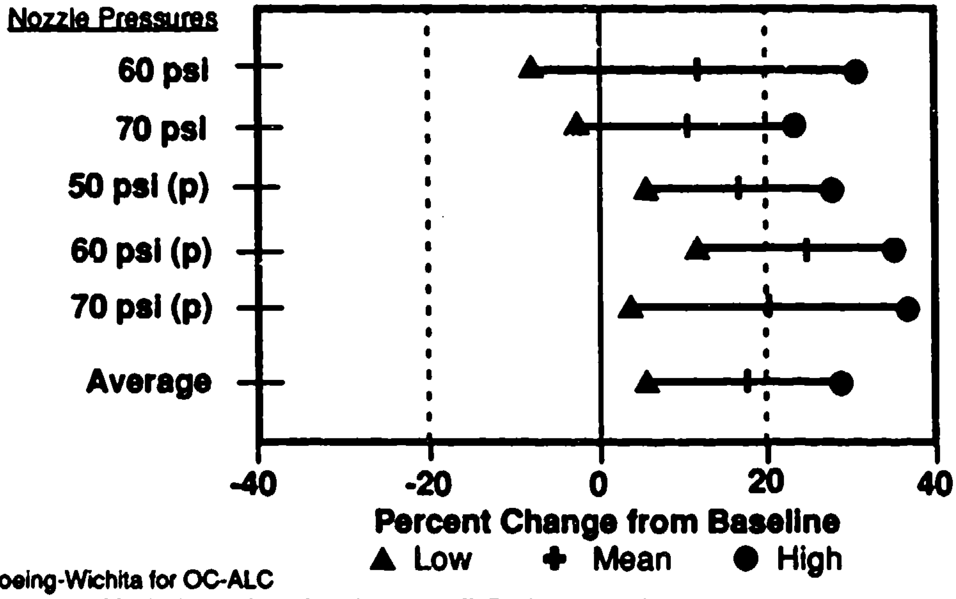
4.2.3.1 Tensile Strength Parallel to Fibers (Fig. 32)

Stripped and baseline sections of unidirectional panels were subjected to tensile testing parallel to the axis of the fibers. This test primarily tested the fibers in the graphite/epoxy specimens. On the average, these tests showed no statistical change from baseline values. However, the stripped section of Panel 11 exhibited a 18.6% mean statistical loss.

OC-ALC Tensile Moduli Variation

PMB'd Quasi-Isotropic Graphite/Epoxy

<95% Confidence Interval>



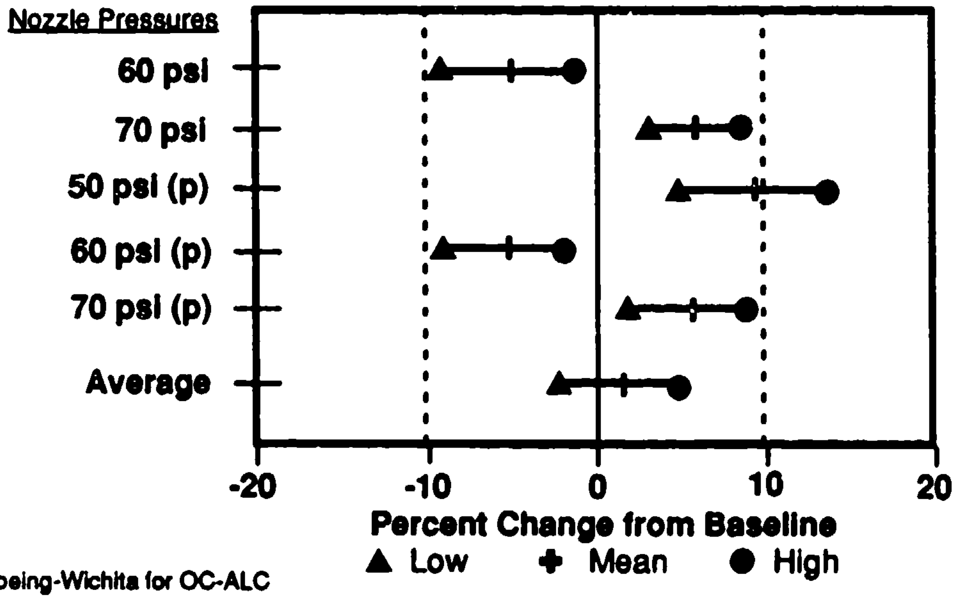
- Performed at Boeing-Wichita for OC-ALC
- PMB Parameters: 30/40 Mesh, 3.0 mohs, 12-18 in. standoff, 70 degree angle
- (p) indicates primer used as a "flag"

Figure 30.

OC-ALC Interlaminar Shear Strength Variation

PMB'd Quasi-Isotropic Graphite/Epoxy

<95% Confidence Interval>



- Performed at Boeing-Wichita for OC-ALC
- PMB Parameters: 30/40 Mesh, 3.0 mohs, 12-18 in. standoff, 70 degree angle
- (p) indicates primer used as a "flag"

Figure 31.

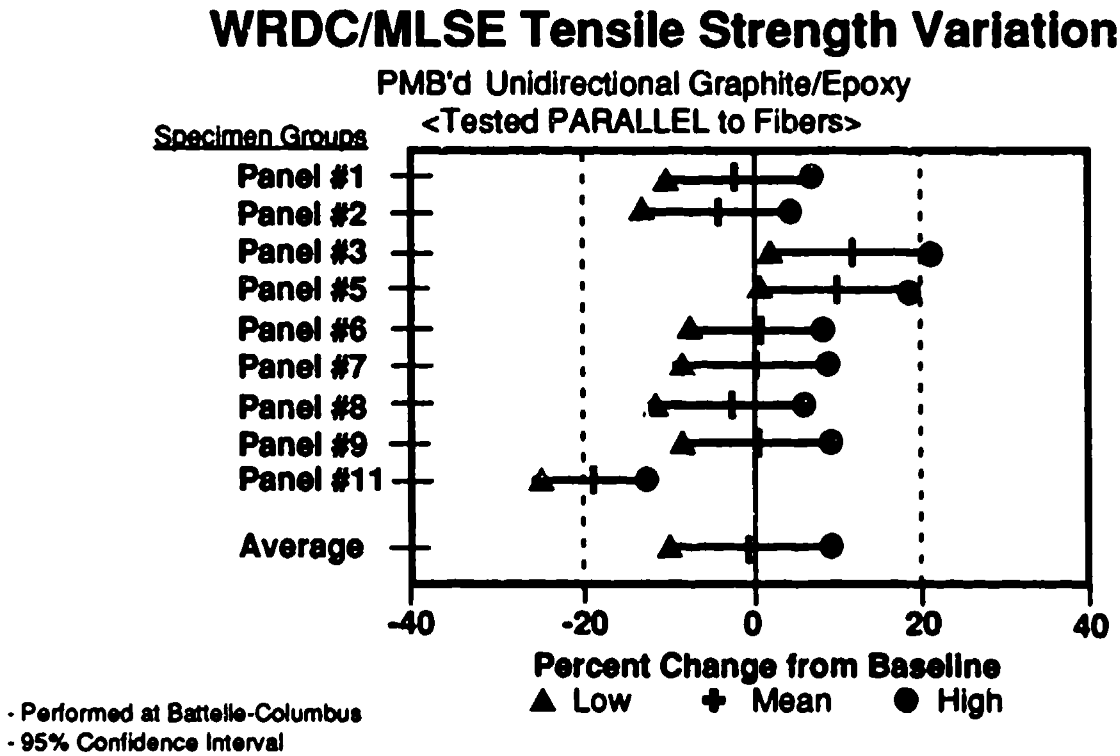


Figure 32.

4.2.3.2 **Tensile Strength Perpendicular to Fibers** (Fig. 33)

In tensile tests conducted on stripped and baseline sections of unidirectional panels with the loading axis perpendicular to the axis of the fibers, no statistical variation was shown in the perpendicular tensile strength. This test primarily tested the matrix of the graphite/epoxy specimens, and a great deal of scatter was present in the test data.

4.2.3.3 **Tensile Modulus Parallel to Fibers** (Fig. 34)

On the average, no statistical variation was noted between the tensile modulus values of the stripped and baseline sections of the panels in the WRDC/MLSE program. However, the stripped section of Panel 7 experienced a 9.1% mean loss in parallel tensile modulus, the stripped section of Panel 9 exhibited an 11.3% mean loss, and the stripped section of Panel 11 exhibited an 23.9% mean loss.

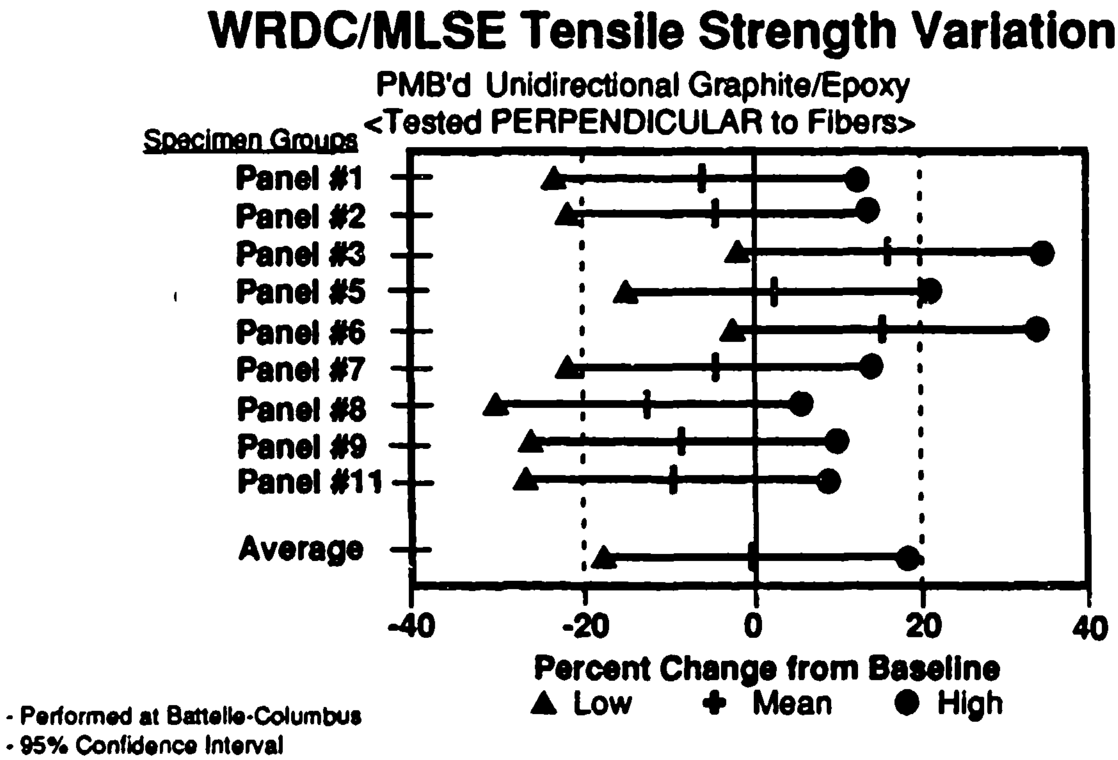


Figure 33.

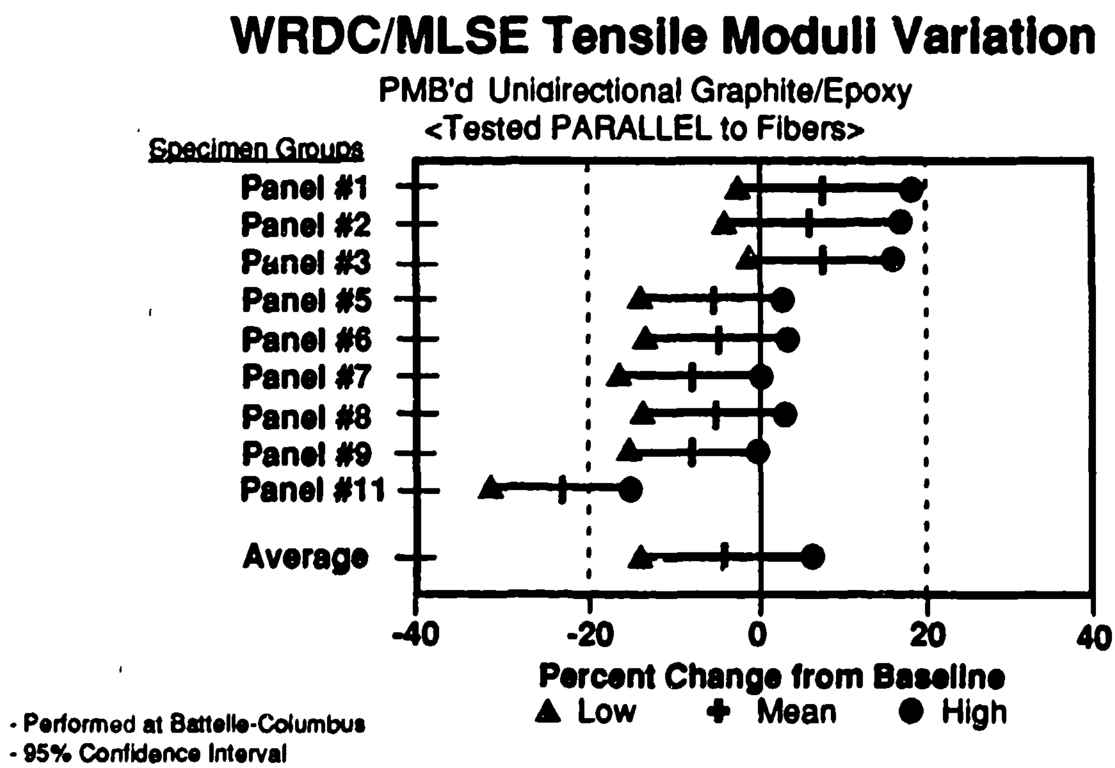


Figure 34.

4.2.3.4 Tensile Modulus Perpendicular to Fibers (Fig. 35)

There was a great amount of scatter in this set of tests, but, on the average, there was no statistical variation between the perpendicular tensile moduli of the stripped section of the panels and the unstripped baseline sections.

4.2.3.5 Interlaminar Shear Strength (Fig. 36)

On the average, the ILS values for the stripped sections of the panels in the WRDC/MLSE Program showed a 2.9% statistical degradation when compared with the baseline ILS values. Degradations as high as 6.4% were noted.

4.2.3.6 Flexural Shear Strength (Fig. 37)

On the average, the flexural shear strengths of the stripped sections of the panels in the WRDC/MLSE Program showed no statistical variation from baseline flexural shear values. However, the stripped section of Panel 9 experienced a 5.9% mean loss in flexural shear strength. Panels 3 and 6 were not tested.

4.2.3.7 Compression Strength Parallel to Fibers (Fig. 38)

Four panels exhibited mean degradations in parallel compression strength. The stripped section of Panel 3 experienced a 11.5% mean loss, the stripped section of Panel 6 exhibited a 11.3% mean loss, the stripped section of Panel 7 showed an 6.6% mean loss, and the stripped section of Panel 8 showed a 15.1% loss. On the average, though, there was no statistical variation between the stripped and baseline sections of the panels in the WRDC/MLSE program with respect to parallel compression strength.

4.3 Summary

Summarizing variation analysis charts can be found in Figures 39-42.

4.3.1 Non-Destructive Evaluation and Scanning Electron Microscopy

NDE and SEM analysis showed no damage to specimens stripped using the"primer as a flag" technique. Sections of panels stripped with sandpaper and those stripped with PMB without the use of the "primer as a flag" technique showed severe damage to the surface consisting of partial or total gel coat erosion and fiber damage.

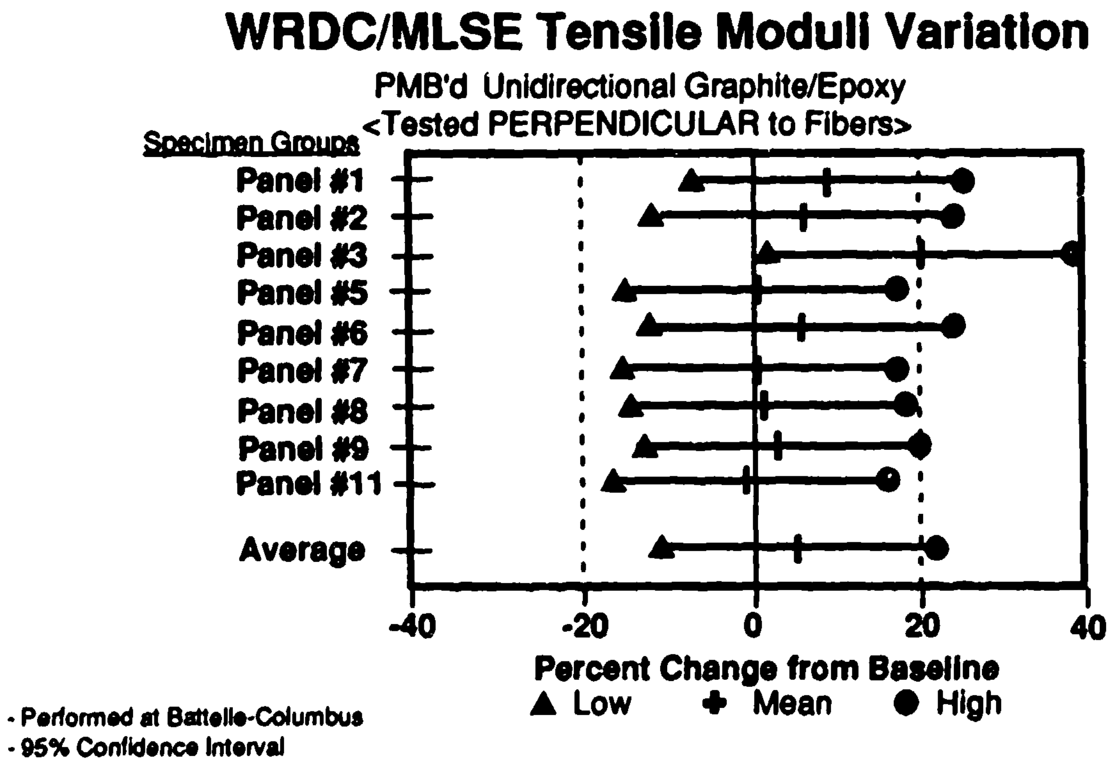


Figure 35.

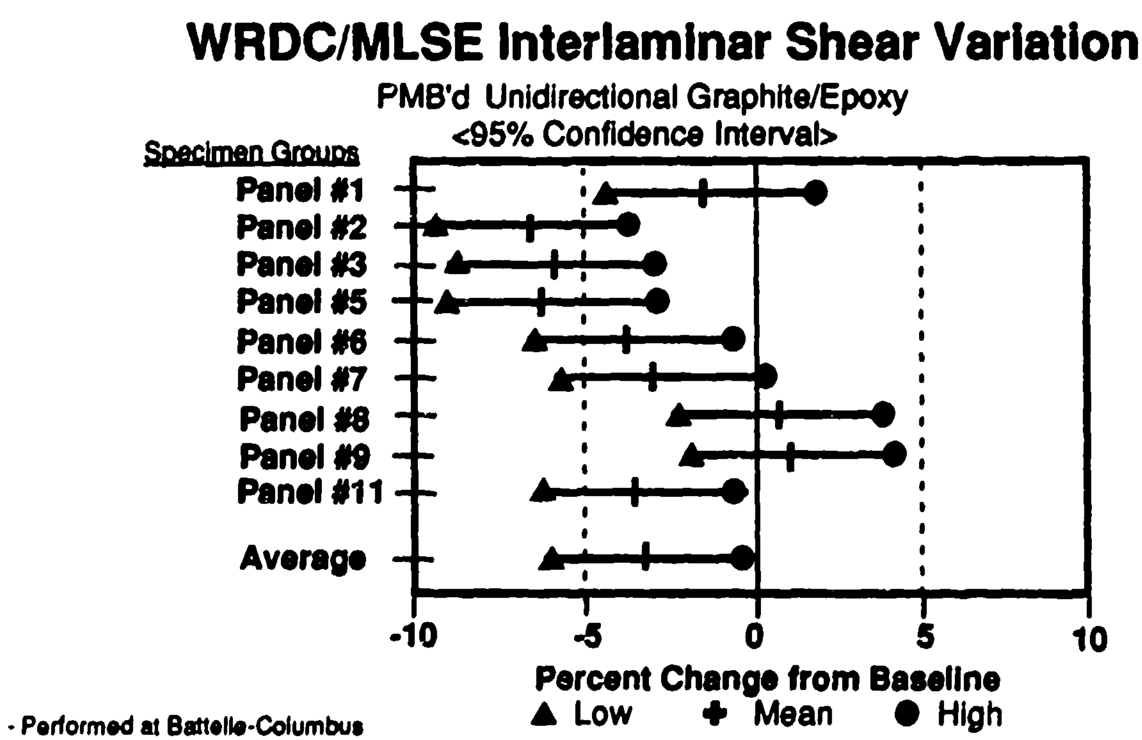


Figure 36.

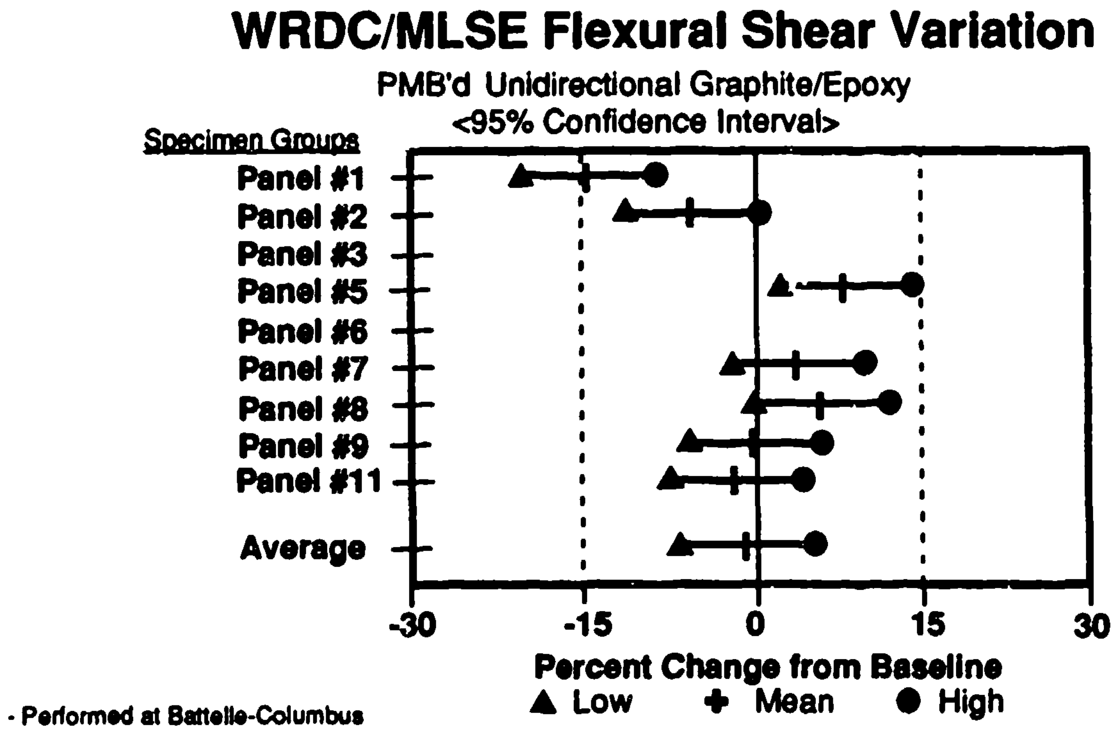


Figure 37.

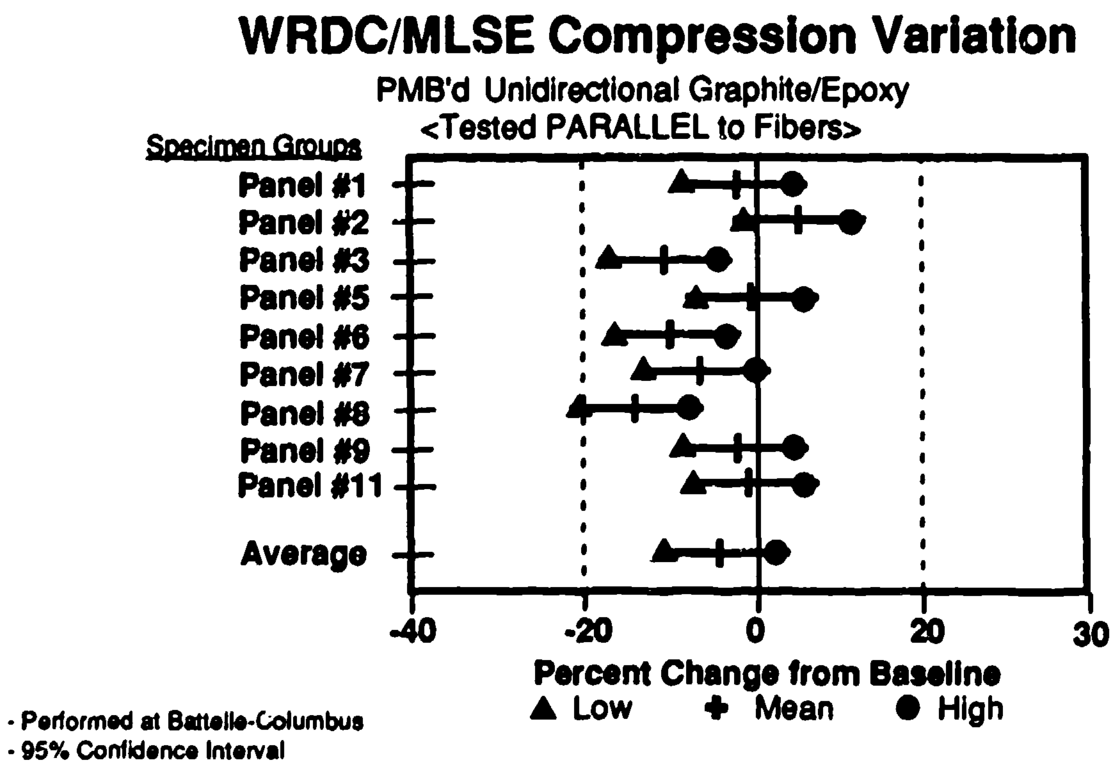


Figure 38.

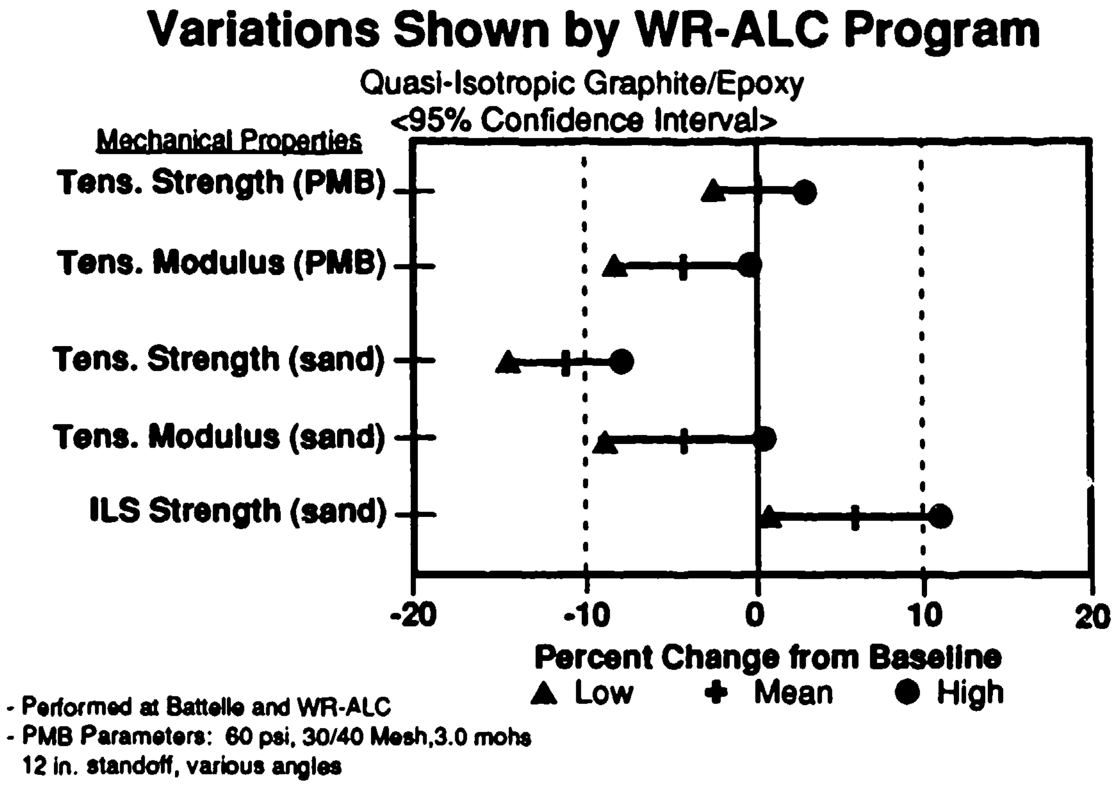


Figure 39.

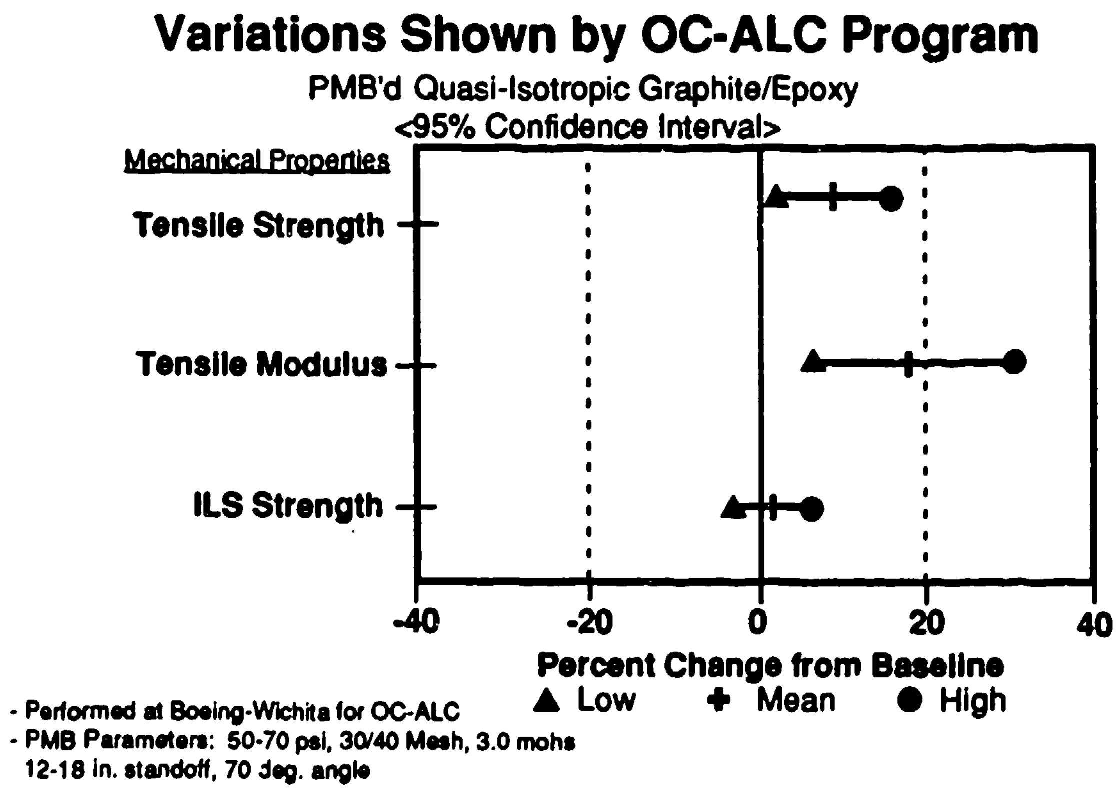
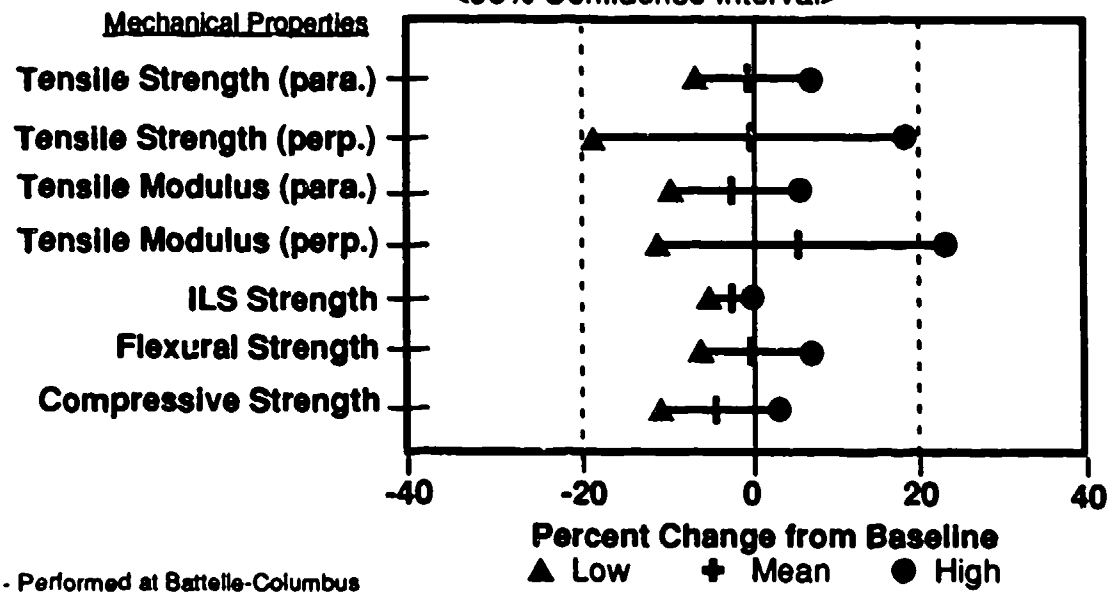


Figure 40.

Variations Shown by WRDC/MLSE Program

PMB'd Unidirectional Graphite/Epoxy

<95% Confidence Interval>

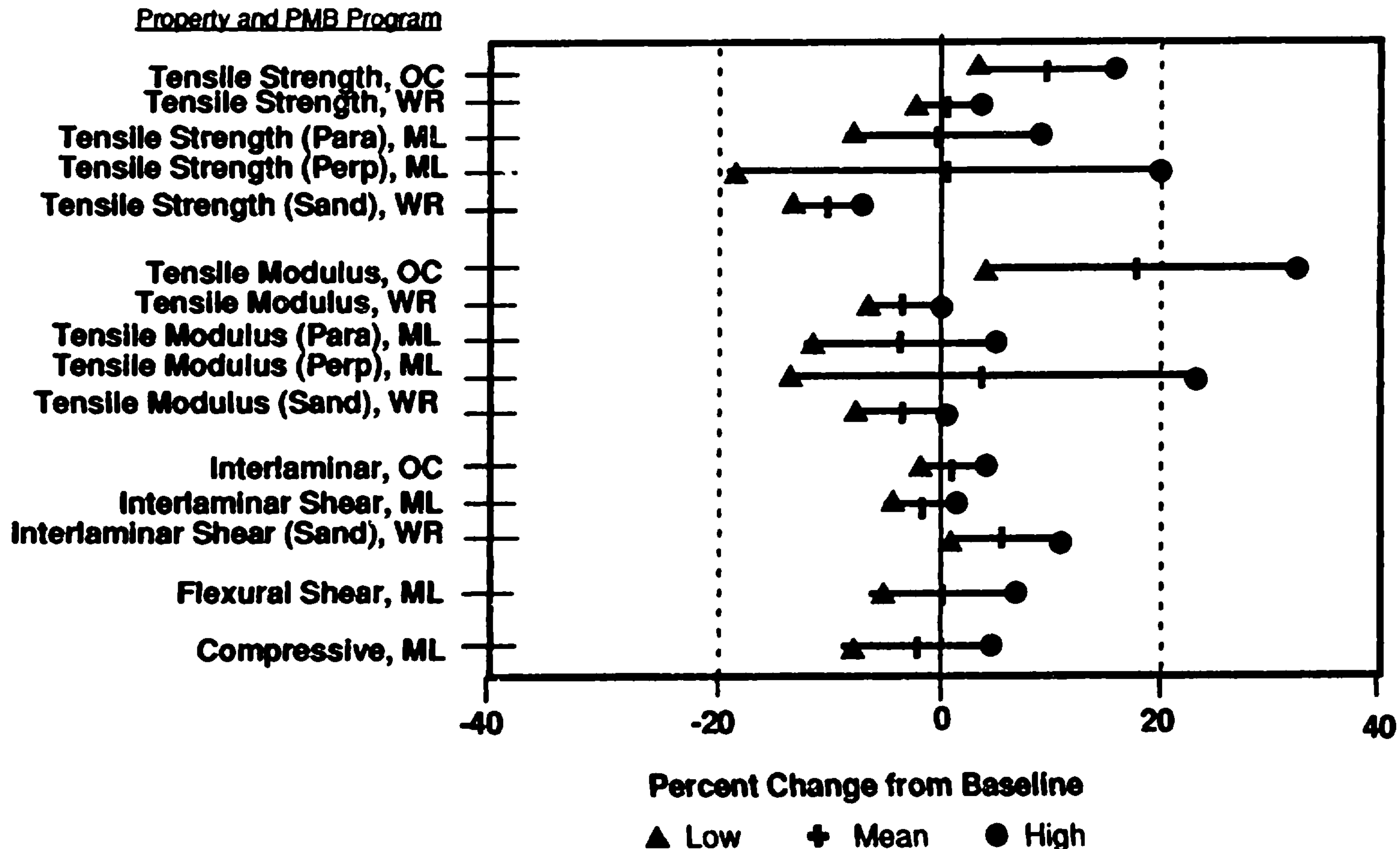


- Performed at Battelle-Columbus
- PMB Parameters: 40-60 psi, 30/40 Mesh, 3.0 & 3.5 mohs, 12-18 in. standoff, 45-90 deg. angle

Figure 41.

Variations of Mechanical Properties of PMB'd Graphite/Epoxy Composites

<95% Confidence Interval>



-WR and OC Programs: Quasi-Isotropic Panels
- ML Program: Unidirectional Panels

Figure 42

4.3.2 Mechanical Testing

Only three sets of data exhibited statistical mean degradations of the mechanical properties of material in the stripped condition. The hand-sanded WR-ALC samples experienced an average loss of 10.7% in tensile strengths , and the WR-ALC samples subjected to PMB showed an average loss of 3.9% in tensile moduli values. Also, the panels stripped at WRDC/MLSE showed an average loss of 2.9% in their ILS strengths. With the exception of these three groups of samples, all other tests showed no statistical mean degradation in any of the mechanical properties tested.

Scatter in the data was present in all of the tests. However, scatter was most prevalent in those tests evaluating the matrix material (i.e. those tests conducted perpendicular to the fiber direction on unidirectional panels and compression tests) and those evaluating tensile moduli.

Tables containing the data generated by the mechanical tests and the subsequent reduction of that data through statistical analysis may be found in the appendices at the end of this report.

5.0 CONCLUSIONS

1. Based on the available test results, properly controlled plastic media blasting is a less damaging method of paint removal for graphite/epoxy composites than is "hand" sanding.

2. The overall effect of the PMB paint removal methods investigated in this report on the mechanical and physical properties of graphite/epoxy composites is negligible if carried out using the "primer as a flag" criteria.

3. No internal damage to the graphite/epoxy test panels was caused by either the "hand" sanding or the PMB methods. However, considerable surface erosion and surface fiber damage was caused by the "hand" sanding methods investigated and can be caused by PMB if the "primer as a flag" criteria is not used. Such surface damage inevitably results in the loss of mechanical properties of stripped composite materials.

4. Although tests were not conducted specifically to compare composite panels stripped using the "primer as a flag" criteria and those not using such a criteria, using the "primer as a flag" will significantly reduce the potential for causing surface damage and subsequent degradation to the mechanical properties of composites during PMB stripping operations.

5. No direct relationships were discovered between the amount of mechanical property degradation and specific PMB parameter combinations or between mechanical property degradation and specific PMB media used in the stripping operations.

6. Higher mechanical property values were seen in several stripped specimens. This may be due to the stripping method relieving residual surface stresses or smoothing out stress concentrations.

7. Results generated and conclusions reached by this research concerning the effect of "hand" sanding and plastic media blasting on graphite/epoxy composites should be applicable to the effects of "hand" sanding and PMB on other types of composites.

6.0 RECOMMENDATIONS

6.1 Paint Removal From Composites

Based on the results of the NDE and SEM analyses and on the mechanical tests which the stripped and baseline panels were subjected to, two recommendations can be made:

1) Hand sanding should not be the method of choice for paint removal from composite materials. In some situations such as composite repair, hand sanding made be the only method available or the only way possible to remove paint from a composite surface. However, when PMB is available, it should be used instead of hand sanding. Hand sanding has too great a potential for damaging the surface which is being stripped. It is also time consuming, labor intensive, and difficult to control in a manner which would allow the stripping of only the paint layer while leaving the primer relatively intact.

2) Conversely, PMB should be considered as the method of choice for paint removal from composites with the following important provision: **The primer coat must be used as a "flag" or stopping point!** Failure to control the PMB process well enough to do this will result in a high potential for the erosion of the outer resin-rich layer, for fiber damage, and for opening the composite material up to moisture intrusion. Although a smooth, uniform primer layer is very difficult to attain after stripping, every attempt should be made to use the primer as a signal ("flag") that the paint has been removed and that it is time for the PMB stream to be aimed at another section of the area being stripped. This recommendation is absolutely the most important piece of information in this report.

3) Based on the results of the testing and on the judgement of those performing the PMB paint stripping for this program, the following "window" of PMB parameters is recommended for use on composite materials:

a) For use with 30/40 U.S. sieve size (0.015 to 0.023 in (0.381 to 0.5842 mm)), 3.0 mohs hardness media (Polyextra™) - use a 30 to 60 psi (2.07 to 4.14 bar) nozzle pressure, a 12 to 24 inch (0.3048 to 0.6096 m) standoff distance, and a 45 to 90 degree angle of incidence as measured from the horizontal. Media flow rates should be at least 250 lbs/hour (114 kg/hour).

b) For use with 30/40 U.S. sieve size (0.015 to 0.023 in (0.381 to 0.5842 mm)), 3.5 mohs hardness media (Polyplus™) - use a 25 to 40 psi (1.725 to 2.76 bar) nozzle pressure, a 12 to 24 inch (0.3048 to 0.6096 m) standoff distance, and a 45 to 90 degree angle of incidence as measured from the horizontal. Media flow rates should be at least 250 lbs/hour (114 kg/hour).

c) For use with any media, the "primer as a flag" criteria should be applied in a manner so as to leave as much of the primer coat remaining as possible.

d) Great care should also be taken to minimize the time which the PMB contacts any single section of an area being stripped. Minimizing the exposure time will minimize the chance that the "primer as a flag" criterion is successfully followed.

6.2 Further Research, Investigation, and Action

With respect to this report and the information contained in it, several recommendations can be made regarding its use and expansion:

1) Further tests should be conducted to examine the effects of multiple strip cycles on composite materials. WRDC/MLSE and other organizations are currently doing some of this work.

2) As new media and new substrates are proposed for use, preliminary tests including NDE, SEM analysis, and mechanical testing should be carried out to determine the behavior of the new materials under PMB conditions.

3) Investigations to discover the reasons behind the scatter in the matri-dominated properties of composites and behind the increased ILS strengths of many of the stripped materials would be valuable.

4) Further investigations of PMB to determine, in a more analytical fashion, the effects of the separate parameters (i.e. pressure, standoff distance, angle of incidence, flow rate, etc.) would also be helpful in better understanding the process.

5) Research into protective coatings for composite materials that would allow the safe use of aggressive paint removal methods must be continued.

6) Further research into other, less hazardous and less toxic paint removal methods is necessary.

7) Information in this report has been used to update T.O. 1-1-8, Application of Organic Coatings, Aerospace Equipment, in order to reflect the new recommended paint removal procedures for advanced composites.

8) The sharing of information regarding the use of PMB on composites should continue and increase so that repetition of mistakes can be avoided.

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2. T.O. 1-1-8, Application of Organic Coatings, Aerospace Equipment. 27 March 1986.

3. Browning, C.E.; Abrams, F.; and Whitney, J.M. "A Four-Point Shear Test for Graphite/Epoxy Composites." Composite Materials: Quality Assurance and Processing, ASTM STP 797. American Society for Testing and Materials. 1982.

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APPENDIX

APPENDIX (Cont.)

Statistical Analysis of PMB'd and "Hand" Sanded Graphite/Epoxy

Key:

# tests = number of specimens in sample group
Mean = mean value of sample group; given in units of sample group (ksi or Msi)
Std. Dev. = standard deviation of a sample group
Delta = difference between sample group mean value and average baseline value
% Loss/Gain = % difference between mean sample group value and average baseline value

% Variance Range = upper (+ %) and lower (- %) bounds of 95% confidence variation range

<P> = denotes OC-ALC panels which were stripped using "primer as a flag"
NOTE: All WR-ALC and WRDC/MLSE panels were stripped using the "primer as a flag" except for "hand" sanded panels.

APPENDIX (Cont.)

Statistical Analysis of PMB'd and "Hand" Sanded Graphite/Epoxy

Sample Group	# tests (n)	Mean (units)	Std. Dev.	Delta (units)	% Loss/Gain	% Variance Range - %	+ %
OC-ALC SPECIMENS							
TENSILE STRENGTH (ksi)							
Baseline (Avg)	8	98.540	5.460				
Stripped (Avg)	28	106.192	5.860	7.652	7.765	1.717	13.814
60 psi (Group 1)	8	104.240	4.680	5.700	5.784	0.727	10.842
70 psi (Group 2A)	8	103.520	7.070	4.980	5.054	-1.228	11.336
50 psi (P) (Group 3)	8	110.700	7.520	12.160	12.340	5.805	18.875
60 psi (P) (Group 4)	8	104.700	7.580	6.160	6.251	-0.318	12.821
70 psi (P) (Group 2B)	4	107.800	2.450	9.260	9.397	3.598	15.196
TENSILE MODULUS (Msi)							
Baseline (Avg)	8	7.771	1.258				
Stripped (Avg)	28	9.131	0.527	1.360	17.501	4.410	30.592
60 psi (Group 1)	8	9.226	0.437	1.455	18.723	6.848	30.599
70 psi (Group 2A)	8	8.604	0.604	0.833	10.719	-1.725	23.163
50 psi (P) (Group 3)	8	9.021	0.454	1.250	16.085	4.159	28.012
60 psi (P) (Group 4)	8	9.518	0.494	1.747	22.481	10.429	34.533
70 psi (P) (Group 2B)	4	9.286	0.648	1.515	19.496	2.340	36.651
ILS STRENGTH (ksi)							
Baseline (Avg)	8	5.178	0.141				
Stripped (Avg)	30	5.248	0.207	0.070	1.352	-2.098	4.801
60 psi (Group 1)	10	4.879	0.243	-0.299	-5.774	-9.445	-2.104
70 psi (Group 2A)	8	5.444	0.118	0.266	5.137	2.687	7.587
50 psi (P) (Group 3)	8	5.605	0.258	0.427	8.246	4.318	12.175
60 psi (P) (Group 4)	8	4.870	0.226	-0.308	-5.948	-9.506	-2.390
70 psi (P) (Group 2B)	4	5.442	0.191	0.264	5.098	1.458	8.739

APPENDIX (Cont.)

Statistical Analysis of PMB'd and "Hand" Sanded Graphite/Epoxy

Sample Group	# tests (n)	Mean (units)	Std. Dev.	Delta (units)	% Loss/Gain	% Variance Range - %	% Variance Range + %
WR-ALC SPECIMENS							
TENSILE STRENGTH (ksi)							
Baseline (Avg)	16	105.410	2.300				
PMB Stripped (Avg)	16	105.468	4.078	0.058	0.055	-2.947	3.057
30 deg (Section IV)	4	101.830	3.450	-3.580	-3.396	-6.213	-0.579
45 deg (Section III)	4	106.060	3.450	0.650	0.617	-2.200	3.434
60 deg (Section I)	4	106.510	5.660	1.100	1.044	-2.435	4.522
90 deg (Section II)	4	107.470	3.750	2.060	1.954	-0.941	4.850
Sanded (Avg)	21	94.100	7.690	-11.310	-10.730	-14.507	-6.952
120 Grit (Panel #35)	11	97.080	7.140	-8.330	-7.902	-11.438	-4.367
60 Grit (Panel #36)	10	91.120	8.240	-14.290	-13.557	-17.577	-9.536
TENSILE MODULUS (Msi)							
Baseline (Avg)	16	9.090	0.280				
PMB Stripped (Avg)	16	8.740	0.143	-0.350	-3.850	-7.249	-0.452
30 deg (Section IV)	4	8.720	0.070	-0.370	-4.070	-7.394	-0.747
45 deg (Section III)	4	9.050	0.190	-0.040	-0.440	-3.891	3.011
60 deg (Section I)	4	8.540	0.110	-0.550	-6.051	-9.404	-2.697
90 deg (Section II)	4	8.650	0.200	-0.440	-4.840	-8.307	-1.373
Sanded (Avg)	21	8.700	0.750	-0.390	-4.290	-8.760	0.179
120 Grit (Panel #35)	11	8.980	1.010	-0.110	-1.210	-6.907	4.487
60 Grit (Panel #36)	10	8.420	0.490	-0.670	-7.371	-10.612	-4.130
ILS STRENGTH (ksi)							
Baseline (Avg)	32	5.052	0.126				
Sanded (Avg)	31	5.342	0.666	0.290	5.730	1.043	10.418
Sanded 120 Grit (#35)	15	5.513	0.580	0.461	9.125	4.998	1[illegible].253
Sanded 180 Grit (#37)	16	5.170	0.752	0.118	2.336	-2.911	7.5[illegible]

APPENDIX (Cont.)

Statistical Analysis of PMB'd and "Hand" Sanded Graphite/Epoxy

Sample Group	# tests (n)	Mean (units)	Std. Dev.	Delta (units)	% Loss/Gain	% Variance Range - %	+ %
WRDC/MLSE IN-HOUSE SPECIMENS							
TENSILE (Parallel) STRENGTH (ksi)							
Baseline (Avg)	36	241.920	26.292				
Baseline (Panel 1)	4	207.258	28.810				
Baseline (Panel 2)	4	217.118	18.368				
Baseline (Panel 3)	4	255.787	15.168				
Baseline (Panel 5)	4	229.006	16.477				
Baseline (Panel 6)	4	263.337	7.456				
Baseline (Panel 7)	4	253.970	7.288				
Baseline (Panel 8)	4	270.403	12.468				
Baseline (Panel 9)	4	222.471	21.265				
Baseline (Panel 11)	4	257.928	7.650				
Stripped (Avg)	59	241.020	15.291	-0.900	-0.372	-9.065	8.321
Stripped (Panel 1)	6	239.376	16.882	-2.544	-1.052	-10.093	7.990
Stripped (Panel 2)	6	235.533	18.819	-6.387	-2.640	-11.742	6.462
Stripped (Panel 3)	5	267.577	7.039	25.657	10.606	0.935	20.276
Stripped (Panel 5)	7	263.063	12.957	21.143	8.740	0.442	17.037
Stripped (Panel 6)	7	244.336	18.636	2.416	0.999	-7.474	9.471
Stripped (Panel 7)	7	242.257	20.484	0.337	0.139	-8.403	8.682
Stripped (Panel 8)	7	237.243	13.314	-4.677	-1.933	-10.240	6.373
Stripped (Panel 9)	7	242.904	6.927	0.984	0.407	-7.771	8.585
Stripped (Panel 11)	7	196.889	22.562	-45.031	-18.614	-27.242	-9.986
TENSILE (Perpendicular) STRENGTH (ksi)							
Baseline (Avg)	35	7.410	1.813				
Baseline (Panel 1)	4	6.872	0.911				
Baseline (Panel 2)	3	5.876	1.203				
Baseline (Panel 3)	4	7.371	1.004				
Baseline (Panel 5)	4	7.689	0.654				
Baseline (Panel 6)	4	8.242	0.961				
Baseline (Panel 7)	4	9.236	0.576				
Baseline (Panel 8)	4	8.328	0.825				
Baseline (Panel 9)	4	6.806	1.349				
Baseline (Panel 11)	4	6.273	0.391				
Stripped (Avg)	56	7.402	0.790	-0.008	-0.109	-18.738	18.519
Stripped (Panel 1)	7	7.005	1.053	-0.405	-5.466	-24.308	13.377
Stripped (Panel 2)	7	7.132	0.573	-0.278	-3.752	-22.218	14.715
Stripped (Panel 3)	7	8.765	0.785	1.355	18.286	-0.320	36.892
Stripped (Panel 5)	7	7.641	0.772	0.231	3.117	-15.479	21.714
Stripped (Panel 6)	7	8.708	0.982	1.298	17.517	-1.257	36.290
Stripped (Panel 7)	7	7.109	0.833	-0.301	-4.062	-22.706	14.581
Stripped (Panel 8)	7	6.429	0.945	-0.981	-13.239	-31.978	5.501
Stripped (Panel 9)	7	6.924	0.806	-0.486	-6.559	-25.181	12.064
Stripped (Panel 11)	7	6.904	0.358	-0.506	-6.829	-25.197	11.540

APPENDIX (Cont.)

Statistical Analysis of PMB'd and "Hand" Sanded Graphite/Epoxy

Sample Group	# tests (n)	Mean (units)	Std. Dev.	Delta (units)	% Loss/Gain	% Variance Range - %	+ %
TENSILE (Parallel) MODULUS (Msi)							
Baseline (Avg)	36	22.875	2.360				
Baseline (Panel 1)	4	25.052	5.105				
Baseline (Panel 2)	4	23.445	1.434				
Baseline (Panel 3)	4	24.435	0.978				
Baseline (Panel 5)	4	22.329	1.261				
Baseline (Panel 6)	4	22.799	1.044				
Baseline (Panel 7)	4	22.962	2.586				
Baseline (Panel 8)	4	22.803	1.129				
Baseline (Panel 9)	4	22.010	0.713				
Baseline (Panel 11)	4	20.044	1.133				
Stripped (Avg)	59	21.978	1.503	-0.897	-3.920	-12.219	4.379
Stripped (Panel 1)	6	24.859	2.717	1.984	8.673	-0.423	17.769
Stripped (Panel 2)	6	24.222	1.889	1.347	5.889	-2.826	14.603
Stripped (Panel 3)	5	24.479	1.781	1.604	7.012	-2.423	16.447
Stripped (Panel 5)	7	21.479	0.596	-1.396	-6.103	-13.862	1.657
Stripped (Panel 6)	7	21.708	1.707	-1.167	-5.102	-13.158	2.955
Stripped (Panel 7)	7	20.796	1.655	-2.079	-9.089	-17.125	-1.052
Stripped (Panel 8)	7	21.809	0.916	-1.066	-4.660	-12.477	3.157
Stripped (Panel 9)	7	21.045	0.707	-1.830	-8.000	-15.777	-0.223
Stripped (Panel 11)	7	17.407	1.556	-5.468	-23.904	-31.904	-15.904
TENSILE (Perpendicular) MODULUS (Msi)							
Baseline (Avg)	33	4.691	1.0640				
Baseline (Panel 1)	4	4.3190	1.2250				
Baseline (Panel 2)	3	4.9150	0.1340				
Baseline (Panel 3)	3	5.2650	0.5330				
Baseline (Panel 5)	3	4.6640	0.0630				
Baseline (Panel 6)	4	4.6300	0.0430				
Baseline (Panel 7)	4	4.7160	0.0800				
Baseline (Panel 8)	4	4.6250	0.0530				
Baseline (Panel 9)	4	4.5650	0.3610				
Baseline (Panel 11)	4	4.5170	0.1100				
Stripped (Avg)	61	4.921	0.310	0.230	4.912	-12.735	22.559
Stripped (Panel 1)	7	5.0780	0.1300	0.3870	8.2498	-8.7501	25.2497
Stripped (Panel 2)	6	4.9570	0.1350	0.2660	5.6704	-12.7014	24.0422
Stripped (Panel 3)	7	5.6420	1.5170	0.9510	20.2729	0.3221	40.2236
Stripped (Panel 5)	7	4.7130	0.1498	0.0220	0.4690	-16.5387	17.4767
Stripped (Panel 6)	6	4.9420	0.3130	0.2510	5.3507	-13.1217	23.8230
Stripped (Panel 7)	7	4.7270	0.1700	0.0360	0.7674	-16.2493	17.7842
Stripped (Panel 8)	7	4.7560	0.1600	0.0650	1.3856	-15.6265	18.3977
Stripped (Panel 9)	7	4.8080	0.1570	0.1170	2.4941	-14.5166	19.5049
Stripped (Panel 11)	7	4.6700	0.0580	-0.0210	-0.4477	-17.4286	16.5332

APPENDIX (Cont.)

Statistical Analysis of PMB'd and "Hand" Sanded Graphite/Epoxy

Sample Group	# tests (n)	Mean (units)	Std. Dev.	Delta (units)	% Loss/Gain	% Variance Range - %	% Variance Range + %
ILS STRENGTH (ksi)							
Baseline (Avg)	36	10.254	0.313				
Baseline (Panel 1)	4	10.113	0.195				
Baseline (Panel 2)	4	9.711	0.126				
Baseline (Panel 3)	4	10.274	0.216				
Baseline (Panel 5)	4	10.232	0.379				
Baseline (Panel 6)	4	10.001	0.316				
Baseline (Panel 7)	4	10.536	0.452				
Baseline (Panel 8)	4	10.770	0.458				
Baseline (Panel 9)	4	10.594	0.357				
Baseline (Panel 11)	4	10.053	0.217				
Stripped (Avg)	61	9.953	0.416	-0.301	-2.939	-5.605	-0.272
Stripped (Panel 1)	7	10.091	0.751	-0.163	-1.590	-4.808	1.629
Stripped (Panel 2)	6	9.596	0.360	-0.658	-6.417	-9.108	-3.726
Stripped (Panel 3)	7	9.683	0.490	-0.571	-5.569	-8.290	-2.847
Stripped (Panel 5)	6	9.623	0.268	-0.631	-6.154	-8.748	-3.560
Stripped (Panel 6)	7	9.879	0.259	-0.375	-3.657	-6.071	-1.243
Stripped (Panel 7)	7	9.994	0.432	-0.260	-2.536	-5.166	0.094
Stripped (Panel 8)	7	10.364	0.344	0.110	1.073	-1.436	3.581
Stripped (Panel 9)	7	10.410	0.403	0.156	1.521	-1.066	4.109
Stripped (Panel 11)	7	9.934	0.436	-0.320	-3.121	-5.757	-0.485
FLEXURAL STRENGTH (ksi)							
Baseline (Avg)	28	5.411	0.484				
Baseline (Panel 1)	4	4.727	0.212				
Baseline (Panel 2)	4	4.867	0.206				
Baseline (Panel 3)	0						
Baseline (Panel 5)	4	5.612	0.223				
Baseline (Panel 6)	0						
Baseline (Panel 7)	4	5.562	0.400				
Baseline (Panel 8)	4	5.581	0.261				
Baseline (Panel 9)	4	5.758	0.246				
Baseline (Panel 11)	4	5.766	0.463				
Stripped (Avg)	54	5.382	0.162	-0.029	-0.541	-7.333	6.250
Stripped (Panel 1)	7	4.623	0.179	-0.788	-14.563	-21.365	-7.761
Stripped (Panel 2)	7	5.103	0.084	-0.308	-5.692	-12.416	1.032
Stripped (Panel 3)	5	5.925	0.636	0.514			
Stripped (Panel 5)	7	5.861	0.107	0.450	8.316	1.579	15.054
Stripped (Panel 6)	7	5.876	0.594	0.465			
Stripped (Panel 7)	7	5.617	0.135	0.206	3.807	-2.952	10.566
Stripped (Panel 8)	7	5.752	0.214	0.341	6.302	-0.543	13.147
Stripped (Panel 9)	7	5.418	0.206	0.007	0.129	-6.705	6.964
Stripped (Panel 11)	7	5.298	0.208	-0.113	-2.088	-8.926	4.749

Statistical Analysis of PMB'd and "Hand" Sanded Graphite/Epoxy

Sample Group	# tests (n)	Mean (units)	Std. Dev.	Delta (units)	% Loss/Gain	% Variance Range - %	+ %
COMPRESSIVE STRENGTH (ksi)							
Baseline (Avg)	36	170.350	13.640				
Baseline (Panel 1)	4	185.760	17.500				
Baseline (Panel 2)	4	188.160	14.380				
Baseline (Panel 3)	4	172.000	17.080				
Baseline (Panel 5)	4	174.780	16.810				
Baseline (Panel 6)	4	143.560	8.790				
Baseline (Panel 7)	4	167.840	13.390				
Baseline (Panel 8)	4	162.220	6.600				
Baseline (Panel 9)	4	183.490	10.320				
Baseline (Panel 11)	4	170.740	5.890				
Stripped (Avg)	60	161.949	11.082	-8.401	-4.932	-11.480	1.616
Stripped (Panel 1)	6	166.820	7.180	-3.530	-2.072	-8.672	4.528
Stripped (Panel 2)	6	178.670	10.770	8.320	4.884	-1.871	11.640
Stripped (Panel 3)	7	150.800	25.870	-19.550	-11.476	-19.092	-3.861
Stripped (Panel 5)	6	169.790	16.540	-0.560	-0.329	-7.450	6.792
Stripped (Panel 6)	7	151.070	7.420	-19.280	-11.318	-17.458	-5.178
Stripped (Panel 7)	7	159.040	11.140	-11.310	-6.639	-12.962	-0.316
Stripped (Panel 8)	7	144.660	5.550	-25.690	-15.081	-21.155	-9.007
Stripped (Panel 9)	7	168.040	8.820	-2.310	-1.356	-7.557	4.845
Stripped (Panel 11)	7	168.650	6.450	-1.700	-0.998	-7.101	5.105

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