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(2)

USAF
PRAM PROGRAM
FINAL REPORT

28 FEBRUARY 1987

SACRAMENTO AIR LOGISTICS CENTER (AFLC)
McCLELLAN AIR FORCE BASE, CALIFORNIA 95652

PRAM PROJECT

FLASHLAMP DEPAINTING SYSTEM

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ATTACHMENTS

INTRODUCTION

Objective: The objective of this PRAM project was to develop a depainting process that eliminates the use of chemicals to depaint aircraft. Additional goals were to replace cost and prevent the generation of large volumes of hazardous waste. The new process must be able to remove paint from aircraft efficiently, economically, safely, and without any damage to the aircraft surfaces. The PRAM project is envisioned as having three phases; a laboratory development phase 1 (current phase), a production validation phase 2 (procure a mechanical movable model), and phase 3, a fully robotized system to optimize and maximize production output. (mgm)

Historical Background: The Xenon arc lamp (flashlamp) depaint system was originally conceived about 1975 by Dr John Asmus while cleaning art objects with a laser in Florence, Italy. The laser was pulsed or excited by Xenon arc lamps. Dr Asmus decided to bypass the laser and use the Xenon arc lamps directly on the coating. Utilizing aluminum foil as a focusing reflector, Dr Asmus removed the coating successfully. By using the Xenon arc lamps directly on the coating the efficiency ratio of the total power input to output was increased from 10% to 50%. Thus, the modification of a pulsed laser depainting technique gave rise to flashlamp depainting.

The laser cost in 1975 was $250.00 per square foot to clean art objects. The first flashlamp was used in 1975 to remove paint from Parisian theater seats at a cost of $30.00 per square foot. In 1978 the flashlamp was used to strip nine layers of paint from the California State Capitol Building during a renovation program. The effort successfully stripped the paint down to the dome ceiling design, exposing its original colors.

A 9-inch Xenon arc flashlamp was manufactured and delivered to SM-ALC, McClellan AFB in October 1985. It is the largest manufactured to date.

EXECUTIVE SUMMARY

Potential Application: Recent changes in environmental law necessitates that the DOD find alternative ways of removing paint from aircraft and related equipment. The increased cost to dispose of the hazardous waste of chemical depainting makes it economically unsound for continued use.

Laboratory data has shown that the flashlamp effectively removes paint from both metallic and composite aircraft components. Initial data also indicates that the flashlamp is both safe and cost effective. The process will enhance the environmental posture of the ALC when compared to the existing chemical depainting method. The process essentially generates no hazardous waste material.

Problem: To get from the laboratory process development phase to the production validation phase several problems must be solved. These problems are: (1) procure a flashlamp with a mechanical movable quick disconnect head and (2) procure specially designed heads for corners and various other geometries.

Cost to Date: The feasibility study and the procurement of the first scaled up model of the flashlamp cost $155,226. The anticipated 5-year savings is $1,661,824 (Atch 1, Economic Summary).

LESSONS LEARNED

The flashlamp has the capability and adaptability for field use. It was demonstrated that the system can be modified and manipulated with a semi-automated device which is a positive step towards robotizing the system. On 10 April 1986, the Physical Sciences Laboratory was requested by the Reliability Engineering Branch (MMEA) to remove the paint from the aft part of the underside of the outboard engine pod of a C-130 aircraft using the flashlamp. The depainted surface section was to be inspected by NDI to check for corrosion and fatigue cracks. The flashlamp (FL) was forklifted onto a truck and transported to Bldg 1071 where the 41st RWRW C-130 aircraft were located.

The NDI Manager wanted to remove enough paint from the C-130 outboard engine pod to reveal the rivits. This was determined to be adequate to perform the required NDI evaluation in that area. The FL removed the coating to the metal surface on the C-130 (A/C #238) with some difficulty. This was due to a special polysulfide primer applied in September 1985 (special chemical depaint systems also found it difficult to remove). The second C-130 (A/C #213) was easier to remove because it had the conventional epoxy primer undercoat instead of the polysulfide undercoat primer (Atch 2).

TECHNICAL INVESTIGATION

1. **Abstract:** A research and development PRAM program using the Xenon flashlamp was initiated to develop a new approach to depainting aircraft and related equipment. The FL coating removal system is an entirely new technical approach. The system generates little or no residue with no foreign matter incursion into the aircraft. The system needs no preparation such as masking prior to depainting. The FL depainted surfaces are ready for paint application after a simple water washing and solvent wipe. Test data has shown that the FL can selectively remove surface coatings without damage to composites or metals. This will give systems managers the option of stripping to the primer or base material.

2. **The Xenon Flashlamp:**

a. The prototype, Model 903, configuration consists of a power source, umbilical cords, and two heads with their respective housings. The flashlamp operating mechanism is the same as the one used in the camera strobelight flash attachment of modern photography. The "flashlamp" is several thousand times more intense. When an electronic current is discharged through certain gases, the gas molecules absorb energy and become excited. These excited molecules in turn release their energy through photon emission (light). The wavelength or color of the emitted light can be determined, to various degrees, by controlling the gas composition, gas pressure, and the discharge voltage. Therefore, it may be possible to tailor a wavelength that will couple with a specific paint molecule and facilitate the removal of certain difficult-to-remove coatings.

b. When energy is applied to surfaces by conventional methods, e.g., flame, radiant heaters, etc., heating becomes generalized and the entire piece is elevated in temperature. This is a very impractical method for removal of surface coatings, especially those on the surface of aircraft or missiles. However, concentrated light energy applied over a short pulsed time (microseconds) will heat thin layers of coatings rapidly. The coating will absorb light and carbonize without going through the melt phase. This carbonization is so rapid that metal, composite, and fiberglass substrate temperatures are not affected by the intense heat of the lamp. Laboratory tests show that the rise in temperature of the flashlamp substrates (30°-50°F) are cooler than when exposed to direct sunlight on a hot day.

c. The lamp head or housing is an important component of the system. The primary factor is the configuration of the reflecting surfaces. The reflector concentrates the maximum amount of light energy onto the surface. The optimum operational parameters for the reflector were determined by computer design. Contamination of the reflector surface and the lamp water jacket will lower the efficiency of the reflected light; therefore, compressed air and vacuum systems are incorporated in the head design to control debris and to help cool the lamp.

d. Training of the FL operation is minimal. All that would be required is to start and stop the power source. At present, the operation of the FL requires two persons. The next generation FL will have all start and stop operations located at the operator's position giving the operator complete control.

3. **Test Specimens:**

a. An F-111 aircraft wing was used as a test article for the metallic evaluation. The wing was originally painted with epoxy primer (MIL-P-23377) and an acrylic topcoat (MIL-L-81352). The thickness of the paint system ranged from (3) mils to (5) mils. The coating on the F-111 wing is estimated to be a minimum of four years old.

b. The composite test articles were fabricated by AFWAL/MLSE and consisted of three plies (.025-inch) of graphite/epoxy with an outer layer of fiberglass as a peel ply. The peel ply had been removed and the twelve test specimens painted with an epoxy primer and a polyurethane topcoat. The polyurethane topcoat and primer were 2.0 mils and .7 mils respectively. The size of the test panels was 12" x 12" x .025".

4. **Test Results:**

a. F-111 Wing: Paint was stripped from an F-111 aircraft wing. The paint was removed down to the primer in some locations and to the metal in others. The flashlamp has the ability to selectively strip 1 mil of paint at a time. The amount of paint stripped is a function of the power output. A setting of eighty percent of the total available power output appears to give optimum stripping results. This power setting allows you to strip the topcoat to the primer 1 mil at a time. This feature is extremely important in stripping the F-111 aircraft. The system managers want to remove only the topcoat and leave the primer. This approach will preclude the use of acidic alodine to repaint. Acidic alodine will induce stress corrosion cracking in D6AC high-strength steel found in critical locations on the F-111. The flashlamp is an ideal stripping process for the F-111 aircraft when compared to chemical depainting. It does not require the use of methylene chloride base depaint. Studies have shown that methylene chloride base depaints in the presence of moisture can induce stress corrosion in high-strength steel.

b. Advanced Composite Test Panels: The flashlamp will remove paint from composites without damaging the substrate. The topcoat can be removed down to the primer or the gel coat. Examination with a scanning electron microscope (SEM) indicated no damage to the composite laminate.

(1) Twelve graphite/epoxy test panels from AFWAL/MLSE were primed per MIL-C-233770 and painted per MIL-C-83286B. These panels were aged at 120°F for seven days prior to shipment to McClellan for flashlamp depainting. The twelve panels were depainted using the flashlamp set-up and conditions given in Atchs 3 and 4 respectively. The power output settings of the flashlamp range from 75-100%, with the total pulse counts varying from 34 to 311 to strip the paint from the graphite/epoxy composite panels. The temperature measured by an infrared thermometer during the stripping operation increased from 30°-50°F (Atch 5).

(2) Three panels (1, 5, and 12) were given 121, 311, and 128 pulses respectively (Atch 4). In order to avoid any miscommunication, we would like to emphasize that specimens 1, 5, and 12 were purposely given excessive pulses to see what kind of damage would be done to the composite structure. The resulting damage is shown in Atch 6 (Figs 1-4, 11-14, 31-34, 37 and 38). Laboratory data has clearly shown that damage to composite panels can be easily averted by monitoring the sound feedback during flashlamp depainting. The sound diminishes as the paint is removed. The bottom line is, sound from the flashlamp can be used to control the stripping process to avoid damage to the substrate.

(3) Test results of fractographic analysis from both AFWAL/MLSE and SM-ALC/MAQC (Atchs 6 and 7) clearly show that paint can be removed from composite panels without damage (Atch 6, Figs 5-10, 15-22, 25 and 26, and Atch 7, all Figs). In addition, the data also show the high degree of control of the flashlamp in terms of where you want to stop; at the primer, the gel coat, or the composite material. This gives the IM/SM a variety of depainting options. The AFWAL/MLSE report concludes that "there was no evidence of any damage to the specimens in the through thickness direction when cross sections were examined." Therefore, from a damage assessment point of view, the flashlamp offers an alternative method of removing paint from composite aircraft components.

5. **Work that Needs to be Done:**

a. Production Validation: A mechanical manipulated head should be procured to optimize the flashlamp depainting process. The improved system should contain a quick disconnect head(s) and special snap-on head(s) for corners and various other geometries found on a typical aircraft. The improved system should be installed in a production environment and used initially to strip aircraft components such as rudders, leading edges, overwing fairings, etc., to validate the production paint removal rate. The improved system will also establish operational cost, parts replacement cost and production down-time. This data would be used to optimize the flashlamp depainting process in a production environment and make a decision about the future of robotizing the process.

b. Structural Damage Evaluation: A joint program between SM-ALC/MAQC and AFWAL/MLSE should be set up to evaluate the effect on the structural components of selected aircraft. The manual flashlamp at SM-ALC/MAQC could be used to strip paint from a wide variety of test panels prepared by AFWAL/MLSE for aircraft component evaluation. The study should at least determine the effect of the flashlamp depainting process on mechanical properties of both metallic and composite components, the effect on fatigue life, and corrosion induction. This joint evaluation program could be done concurrently with the recommended procurement of a mechanical manipulated flashlamp and the performance of a production validation study. These studies would provide the necessary information needed by item/system managers to make decisions about the use of the flashlamp depainting process in lieu of chemical depainting or other alternatives.

c. Shortcomings:

(1) Manual FDS:

Today's Flashlamp is cumbersome and awkward to handle manually. The cumbersome problem should be solved with a mechanical or semi-automatic manipulator as mentioned in Para 5.a.

(2) Reliability of FDS:

Up to this point the FDS power source hasn't had problems. However, the lamps and the power source have not been subjected to a continuous production mode. The reliability of the FDS process has not been validated. The reliability of the FDS will be determined with a production validation study after retrofitting with a semi-automatic or a robotic system.

(3) Soot Removal:

The removal of the soot that is generated when using the FDS process may be a problem. The redesign of the existing vacumn cleaning system, integrated in the head of the FDS, should remove the residue.

(4) Risk Assessment:

The risks involved in proceeding with the FDS program are minimal compared to potential returns on investment if the FDS is successful (see Atch 8).

6. **Conclusion:**

a. The flashlamp will strip paint from both metallic and composite structures without damage to the substrate.

b. The flashlamp can selectively strip to the primer and stop.

c. The rise in temperature of the components during flashlamp depainting ranges from 30°-50°F.

d. Specially designed heads must be fabricated to remove paint from corners and recessed areas.

7. **Recommendations:**

a. We find the flashlamp a potential candidate to replace chemical depainting.

b. In order to maximize the flashlamp production capabilities, further development should be performed by qualified R & D facilities such as:

(1) Western Research.

(2) Maxwell Laboratories.

(3) South Western Research.

(4) Northrop Aircraft.

APPROVAL AND COORDINATION

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7 Atch
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2. Flashlamp Selective Paint Stripping
3. Flashlamp Set-Up
4. Flashlamp Depainting Conditions
5. Temperature Reading
6. AFWAL/MLSE Report
7. Selective Removal of Paint via Flashlamp
8. Estimated Potentials

cc: AFWAL/MLSE (T. Reinhart)

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ECONOMIC SUMMARY

PRAM COST (PC)	Procurement of mechanically manipulated Flashlamp	**$500,000.00**
	Flashlamp development - expended monies	**$155,226.00**
PRESENT METHOD	F-4 A/C depaint hours (chemical)	
	57 F-4s x 300 man-hours x $40.65	**$695,115.00**
	5-year cost (5 x $695,115.00)	**$3,475,575.00**
PROPOSED METHOD	F-4 A/C depaint hours (Flashlamp)	
	57 F-4s x 100 man-hours x $40.65	**$231,705.00**
	5-year cost (5 x $231,705.00)	**$1,158,525.00**

GROSS SAVINGS (5 YEARS IN MAN-HOURS)

$3,475,575.00 - $1,158,525.00 **$2,317,050.00**

NET SAVINGS (5 YEARS)

$2,317,050.00 - $655,226.00 (PC) **$1,661,824.00**

NOTE

The flashlamp experimental removal rate is 3 sq ft per minute. This experimental removal rate is based upon stripping twelve (12) composite panels (12" x 12" x .025"[7]/12" x 12" x 0.275"[4]) from AFWAL/MLSE and the top skin of a damaged F-111 aircraft wing. The estimated surface of a typical fighter aircraft is 3500 sq ft.

Figure 1

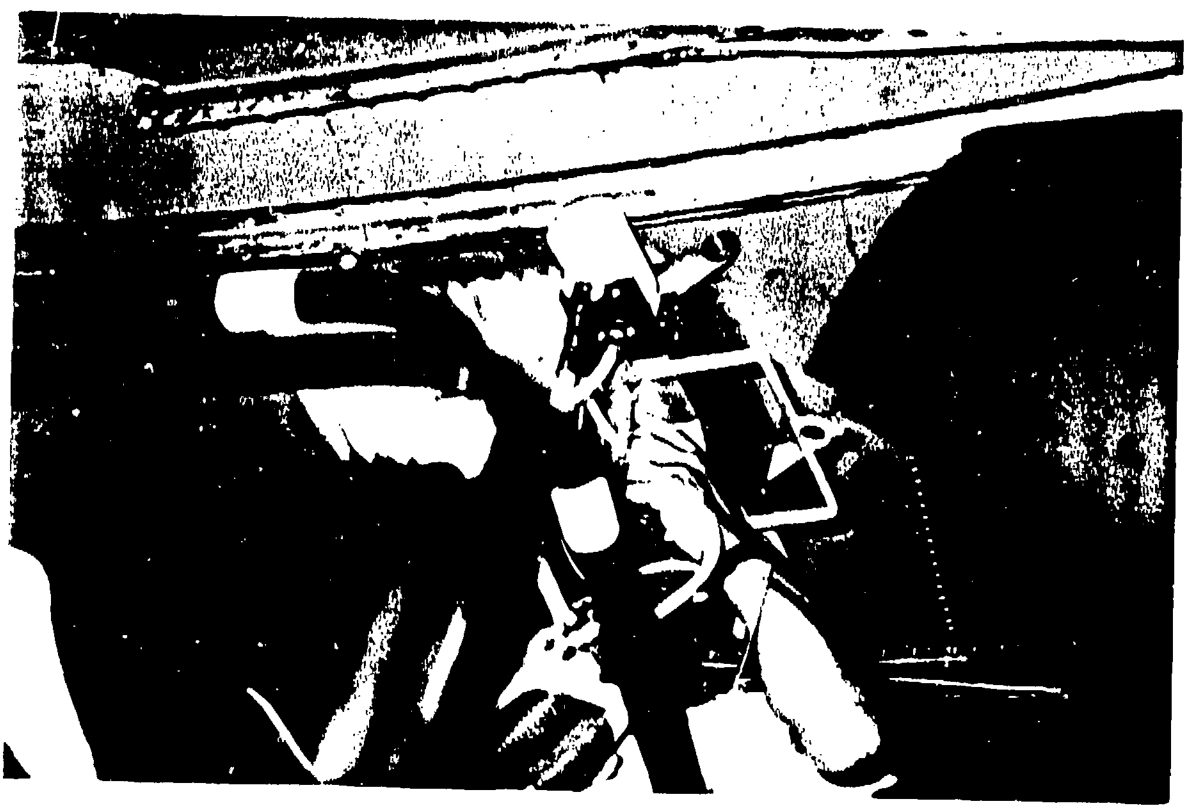

Figure 2

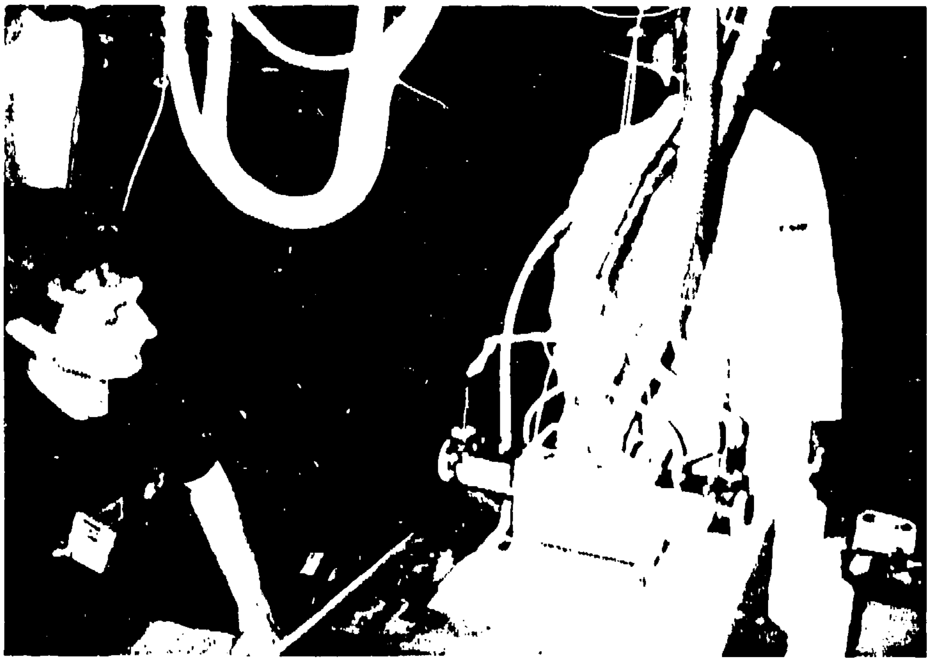

Figure 1
Laboratory Flashlamp Set-Up.

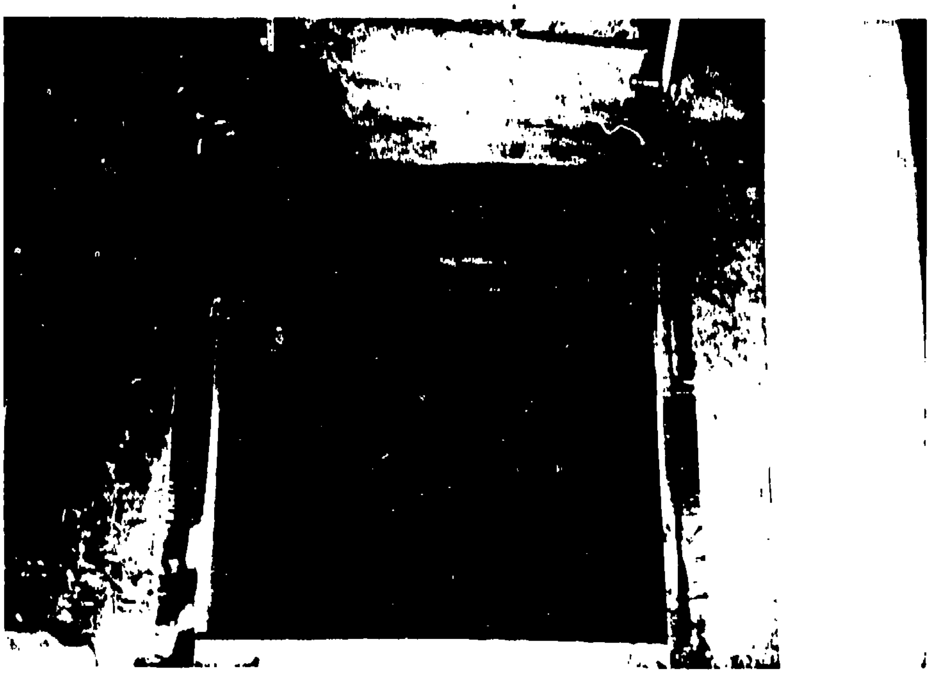

Figure 2
Flashlamp Depainted E/G Panel (Residue Removed).

FIG. 1
Temperature reading immediatly after flash blast.

FIG. 2
Temperature check prior to residue removal.

FLASHLAMP DEPAINTING CONDITIONS

Specimen	# of Passes	% of Total Available Power	% of Pulses	Cleaned After Each Pulse
#1	4	75	121*	No
#2	2	85	91	No
#3	2	100	54	No
#4	2	100	96	Yes
#5	5	100	311*	Yes
#6	1	100	43	No
#7	1	85	36	No
#8	1	100	34	No
#9	1	80	43	No
#10	2	80	62	Yes
#11	2	100	88	Yes
#12	4	100	128*	Yes

* Panels 1, 5, and 12 were shot with an excess number of pulses to simulate an overkill situation in a production environment.

SYSTEMS SUPPORT DIVISION
AFWAL/MLS MATERIALS LABORATORY
WRIGHT PATTERSON AIR FORCE BASE, OHIO

EVALUATION REPORT

FLASH LAMP PAINT REMOVAL STUDY

REPORT NR: AFWAL/MLS 86-77 DATE: 9 September 1986

PROJECT NR: 24180420 TYPE EVAL: MATERIALS CHARACTERIZATION

SUBMITTED BY: AFWAL/MLSE (R. Urzi)
SMALC/MAQCB (M. Morante)
MCCLELLAN AFB, CA 95652

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I. BACKGROUND: Several graphite/epoxy panels were primed per MIL-P-23377D, painted per MIL-C-83286B, cured for seven days and then aged for 96 hours at 210°F. The panels were then sent to McClellan AFB for removal of the paint using flash lamps. Scanning electron microscopic studies were performed on the twelve different sections which were tested under various conditions. The test conditions and results of this study are presented below.

II. FACTUAL DATA:

1. TEST CONDITIONS:

a. SPECIMEN #1: Panel #10 - 75% intensity
1st Pass - Brown coating exposed (19 pulses)
2nd Pass - 90 Degrees to First pass (25 pulses)
3rd Pass - 140°F (37 pulses)
4th Pass - Sound decreased (40 pulses)

b. SPECIMEN #2: Panel #10 - 85% intensity
1st Pass (46 pulses) - 170°F
2nd Pass (45 pulses) - 175°F

c. SPECIMEN #3: Panel #11
1st Pass (54 pulses) - 200°F
2 Passes - No clean/100% intensity

d. SPECIMEN #4: Panel #11
1st Pass - (45 pulses) - 190°F
2nd Pass - (51 pulses) - 190°F

e. SPECIMEN #5:
NO INFORMATION

f. SPECIMEN #6: Panel #3
1 Pass (43 pulses) - 170°F
1 Pass - 100% intensity

g. SPECIMEN #7: Panel #3
1st Pass (36 pulses) - 160°F
1 Pass - 85% intensity

h. SPECIMEN #8: THICK PANEL
1 Pass (34 pulses) - 100% intensity

i. SPECIMEN #9: THICK PANEL
1 Pass (43 pulses) - 80% intensity

j. SPECIMEN #10: THICK PANEL
1st Pass (45 pulses) - 190°F
1 Pass - 80% intensity
Clean
1 Pass - 80% intensity

k. SPECIMEN #11: THICK PANEL
1 Pass - 100% intensity
Clean
1 Pass - 100% intensity

l. SPECIMEN #12: THICK PANEL
4 Passes (128 pulses total)
Clean after passes

2. FRACTOGRAPHIC DATA:

a. Many of the surfaces examined were similar in appearance and a number of the specimens had almost identical surface features - both visually and when viewed through the scanning electron microscope. Those specimens which exhibited surface features which were nearly identical will be grouped together and those specimens having somewhat unique features will be discussed separately. The specimens will be discussed in order of the least to the most paint removed from the composite. Specimens numbered 1 through 7 were obtained from thin panels (approximately 0.025 in.) in which the flash lamp moved parallel to the 0 degree surface ply orientation whereas specimens numbered 8 through 12 were taken from thick panels (approximately 0.275 in.) in which the surface ply was 45 degrees to the movement of the flash lamp. It was noted that the surface of the panels were generally a combination of colors - green (indicative of the primer and/or paint); brown (thought to be due to a chemical change in the primer and/or paint system due to the flash lamp process); and black (indicative of the total removal of the paint from the composite).

b. SPECIMENS #3 AND #7

On these specimens, a thick, evenly distributed layer of the paint/primer system still covered most of the composite surface. There was no resulting damage to the composite. See Figures 1, 2, 3 and 4.

c. SPECIMENS #2, #4, #6, #8 AND #10

On these specimens a thin layer of the paint/primer system still covered most of the composite surface and no composite material was visible. However, the coating was relatively thin and found mainly in the crevices of the matrix rich layer formed by the peel ply. See Figures 5, 6, 7, 8, 9, 10, 11, 12, 13, and 14.

d. SPECIMEN #9

On this specimen, a thin layer of the paint/primer system still covered most of the composite surface, but in some areas the 45 degree surface ply was visible. See Figure 15. In the areas in which the coating was generally removed, there was some damage to the surface ply in the form of broken fibers, fiber/matrix debonding and possible matrix degradation on the surface. See Figures 17 and 18. In the remaining areas where the coating was thin, the coating was generally confined to the matrix rich region formed from the peel ply. See Figure 16.

e. SPECIMENS #1, 11, and 12

On these specimens, the paint/primer system was generally removed and the surface of the composite was visible. The surface plys were exposed and there was some surface damage in the form of broken fibers, matrix cracking, fiber/matrix debonding and the loss (and possible degradation) of the resin in the top few fiber layers. See Figures 19 to 22, 23 to 26 and 27 to 30.

f. SPECIMEN #5

On this specimen, the paint/primer system was totally removed and the composite surface was visible. There was considerable damage to the surface in the form of broken fibers, fiber/matrix debonding with subsequent fiber pullout and loss of matrix between the fibers. See Figures 31 to 34.

3. CROSS-SECTION EXAMINATIONS:

Examinations were conducted on all of the cross-sections taken from the thick and the thin panels in this study. The results indicated that, except for specimen #5, there was no significant damage to the composite through the thickness due to the flash lamp paint removal process on any of the sections examined. Figures 35 and 36, which were taken from specimen #9, are representative of most of the specimens. Damage to specimen #5 consisted of fiber/matrix debonding and loss of matrix between the fibers up to about 4 to 6 fiber diameters in depth. See Figures 37 and 38.

III. CONCLUSIONS:

1. Examination of the surfaces of the test specimens revealed that the different test conditions (ie., flash lamp settings) did not have a large influence on paint removal from the composite.

2. There were some differences in the amount of paint removed from the surfaces, but because the test conditions varied considerably, it was difficult to determine the exact causes responsible. Generally, most of the paint was removed when there were at least two passes at 100% intensity or four passes at other percentage intensities.

3. Cleaning of the surface between passes as was done on specimens #10, #11 and #12 may help in the paint removal process.

4. There was no evidence of any damage to the specimens (except on specimen #5) in the through the thickness direction when cross-sections were examined.

5. The reason for the damage to specimen #5 is unknown as the test conditions were not available.

6. There was some damage to the surface layers of the composite when, in addition to the paint, the matrix rich surface layer is removed. This damage was in the form of fiber breakage, matrix cracking, fiber/matrix debonding and loss to matrix between the fibers.

IV. RECOMMENDATIONS:

If, when all aspects of this paint removal method are considered including, time, cost, availability, etc., it is determined that this paint removal method has potential, then it would be advisable to conduct mechanical tests on the flash lamp paint removed specimens similar to those conducted under the plastic bead paint removal program.

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PUBLICATION REVIEW

This report has been reviewed and approved.

Thomas D. Cooper

THOMAS D. COOPER, Chief
Materials Integrity Branch
System Support Division
Materials Laboratory

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SELECTIVE REMOVAL OF PAINT VIA FLASHLAMP

The ability of the flashlamp system to selectively remove layers of paint off a composite laminate without any apparent damage to the laminate is demonstrated in this series of photo micrographs. These photo micrographs are of cross sections of painted epoxy/graphite laminates in various stages of depainting by the flashlamp system. Results of chemical analysis done with the Scanning Electron Microscope are listed under each photo micrograph. Major constituents are indicated with asterisks.

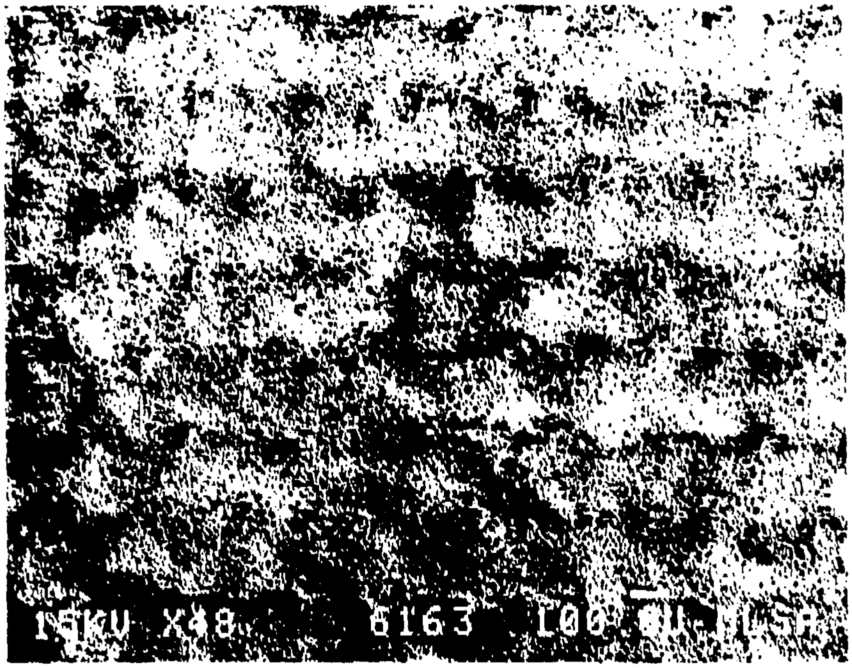

Figure 1.
Low magnification photomicrograph of the surface of specimen #3. (48x)

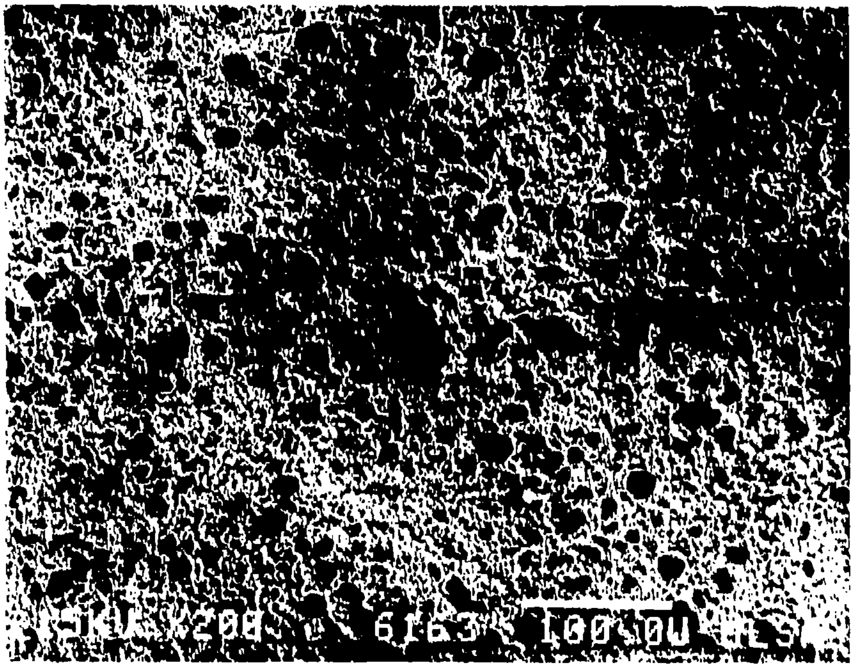

Figure 2.
Higher magnification of the surface of specimen #3. (200x)

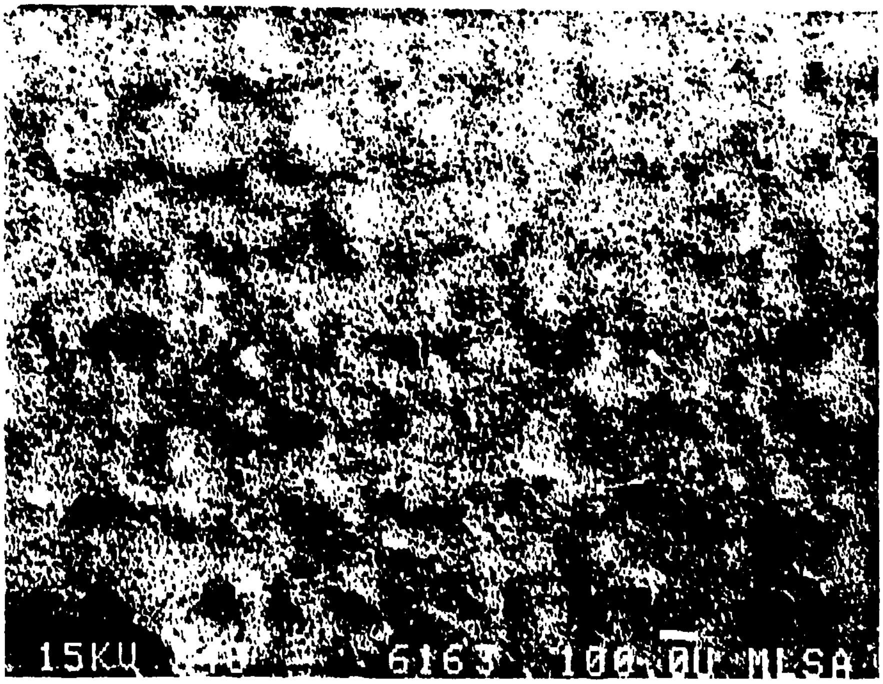

Figure 3.
Low magnification photomicrograph of the surface of specimen #7. (48x)

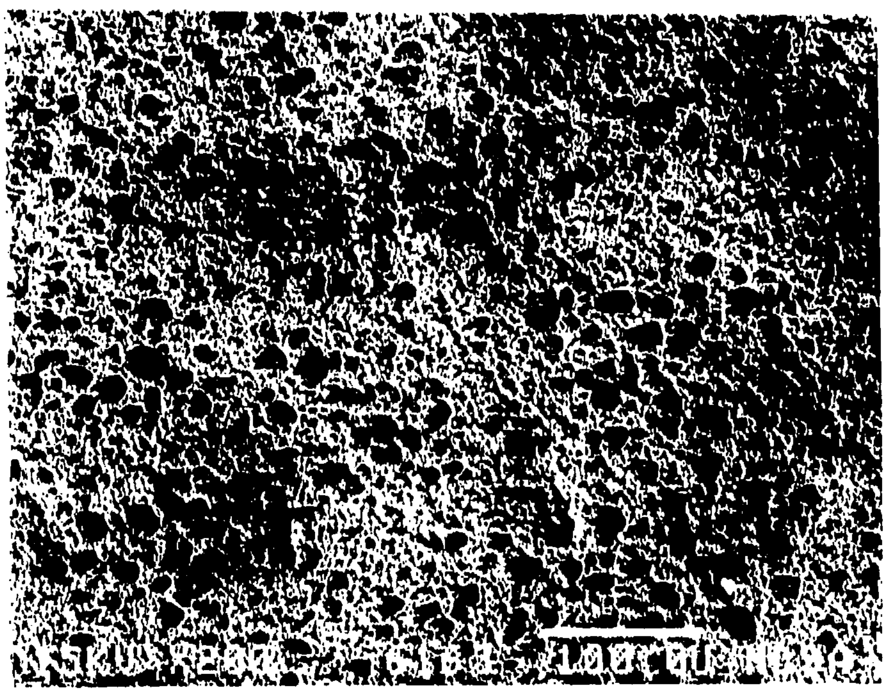

Figure 4.
Higher magnification of the surface of specimen #7. (200x)

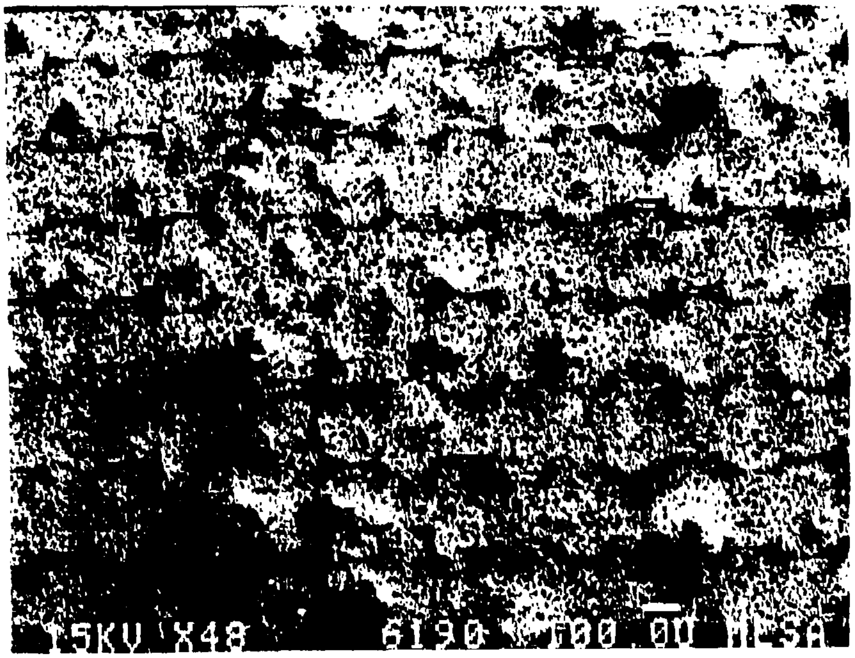

Figure 5.
Low magnification photomicrograph of the surface of specimen #2. (48x)

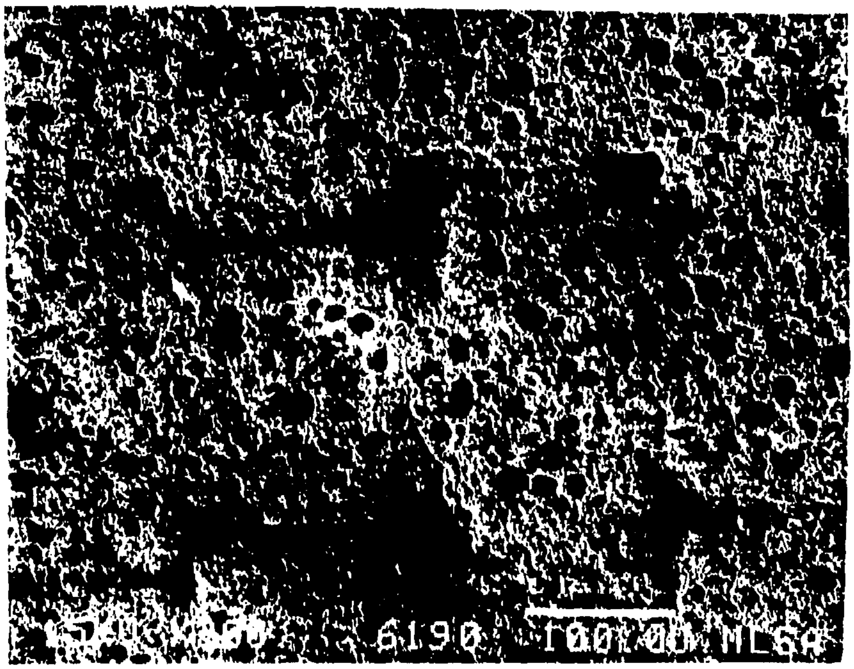

Figure 6.
Higher magnification of the surface of specimen #2. (200x)

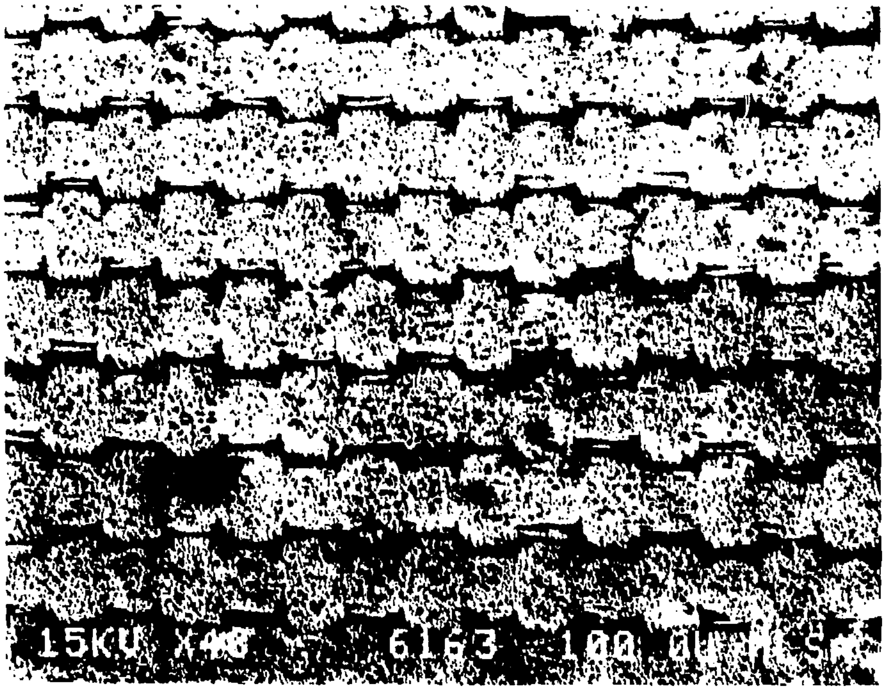

Figure 7.
Low magnification photomicrograph of the surface of specimen #4. (48x)

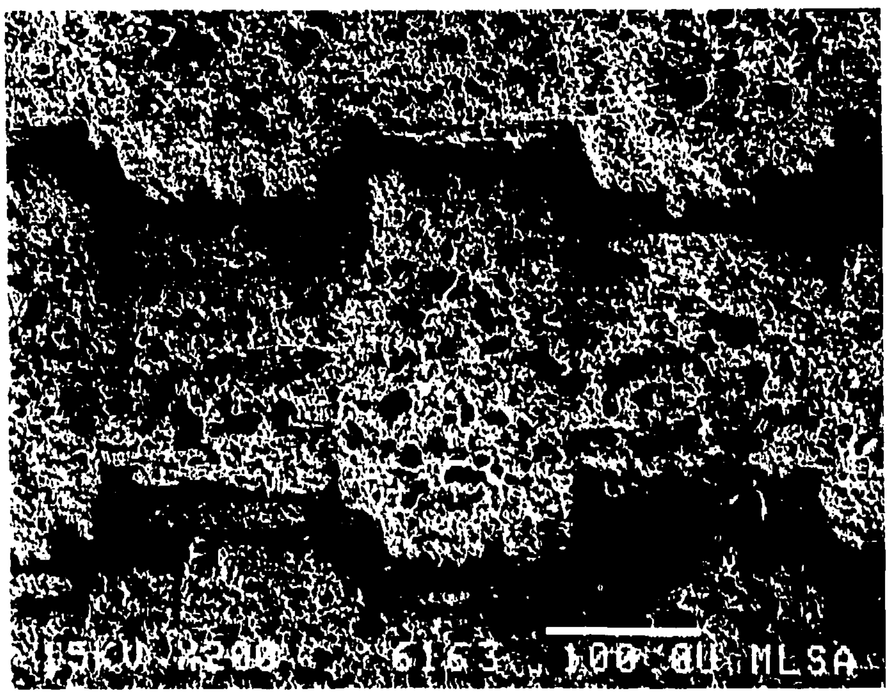

Figure 8.
Higher magnification of the surface of specimen #4. (200x)

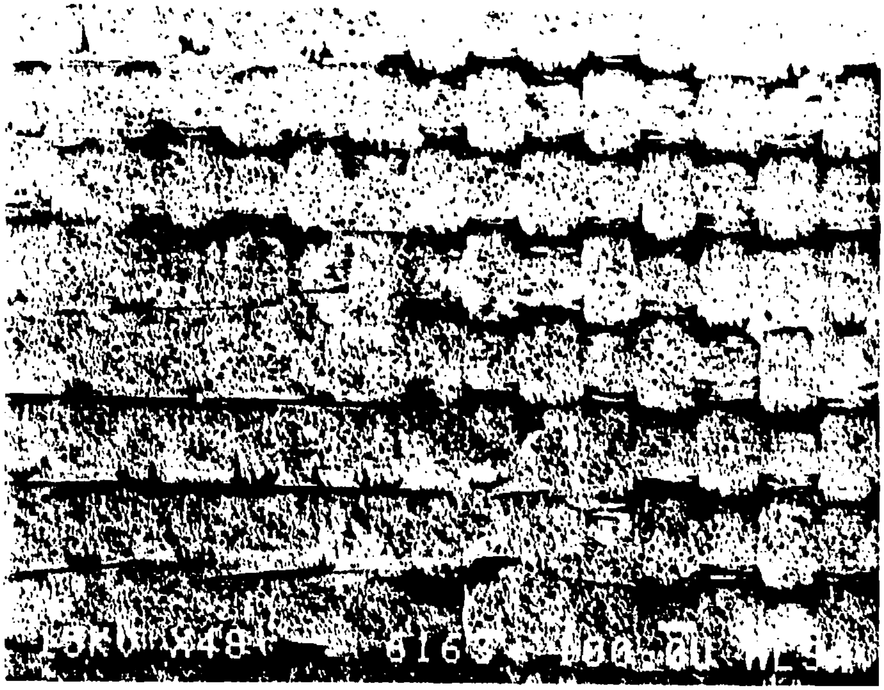

Figure 9.
Low magnification photomicrograph of the surface of specimen #6. (48x)

Figure 10.
Higher magnification of the surface of specimen #6. (200x)

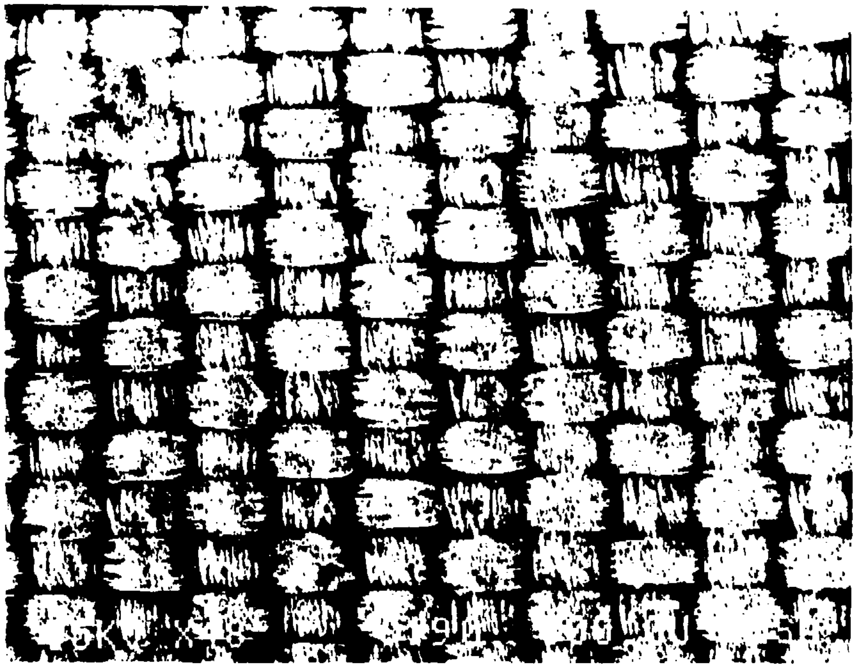

Figure 11.
Low magnification photomicrograph of the surface of specimen #8. (48x)

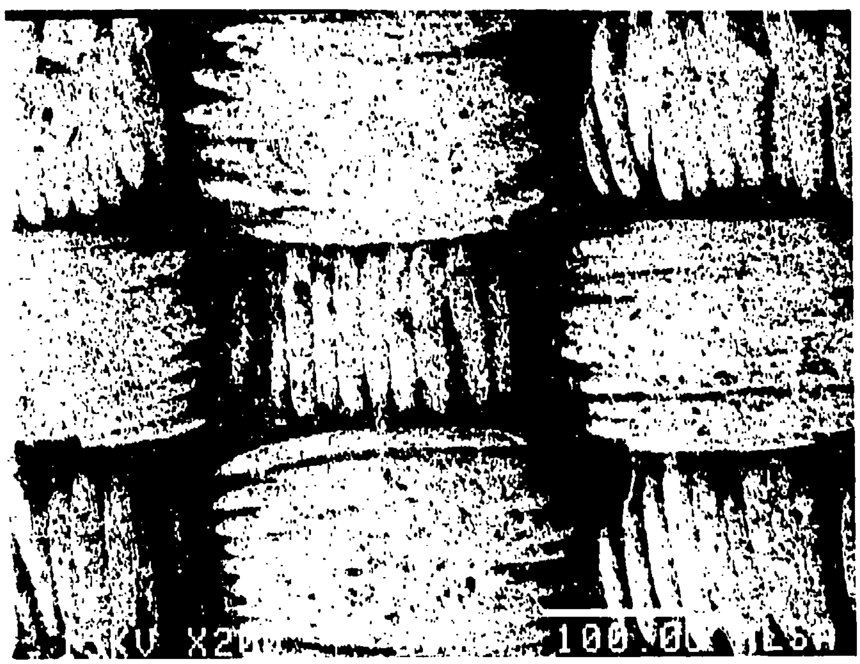

Figure 12.
Higher magnification of the surface of specimen #8. (200x)

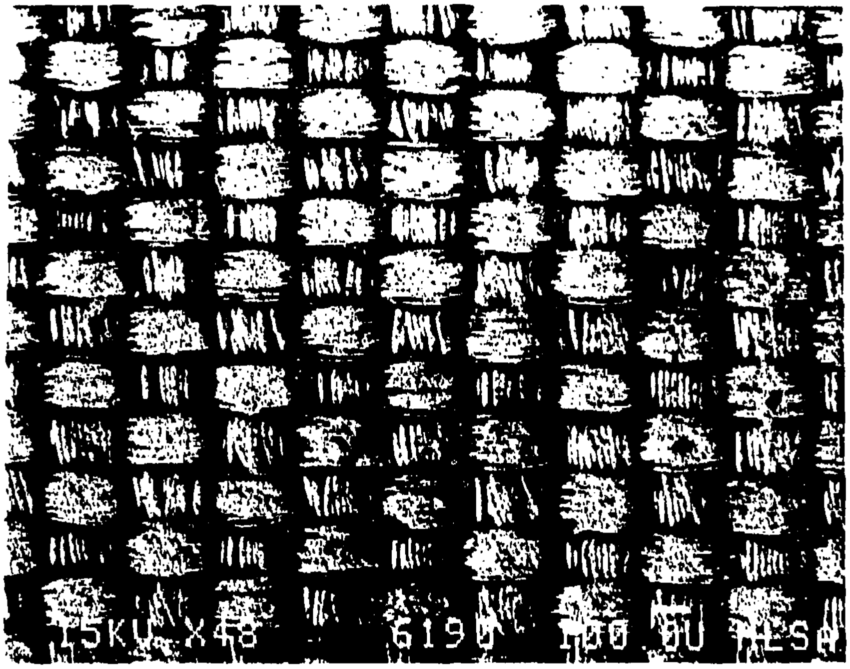

Figure 13.
Low magnification photomicrograph of the surface of specimen #10. (48x)

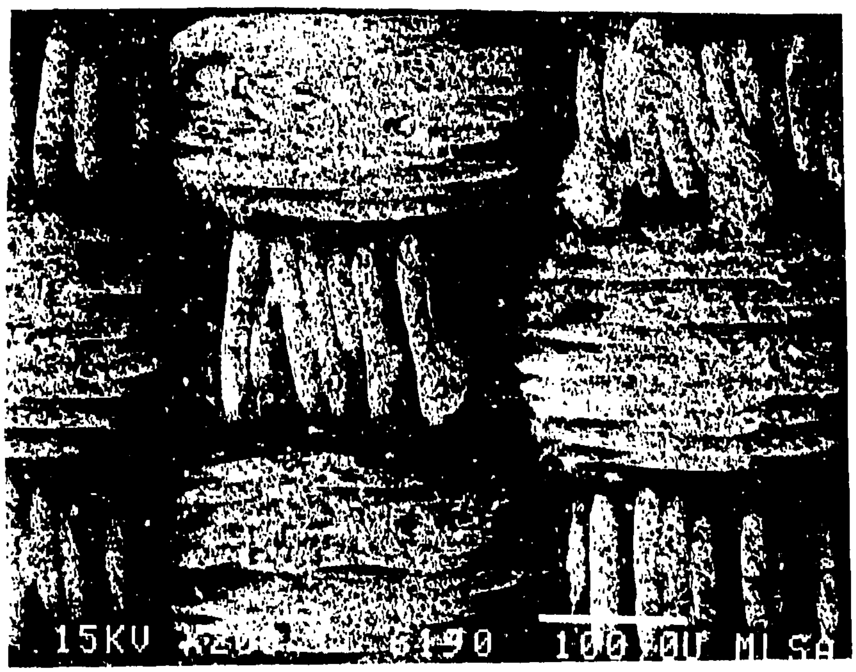

Figure 14.
Higher magnification of the surface of specimen #10. (200x)

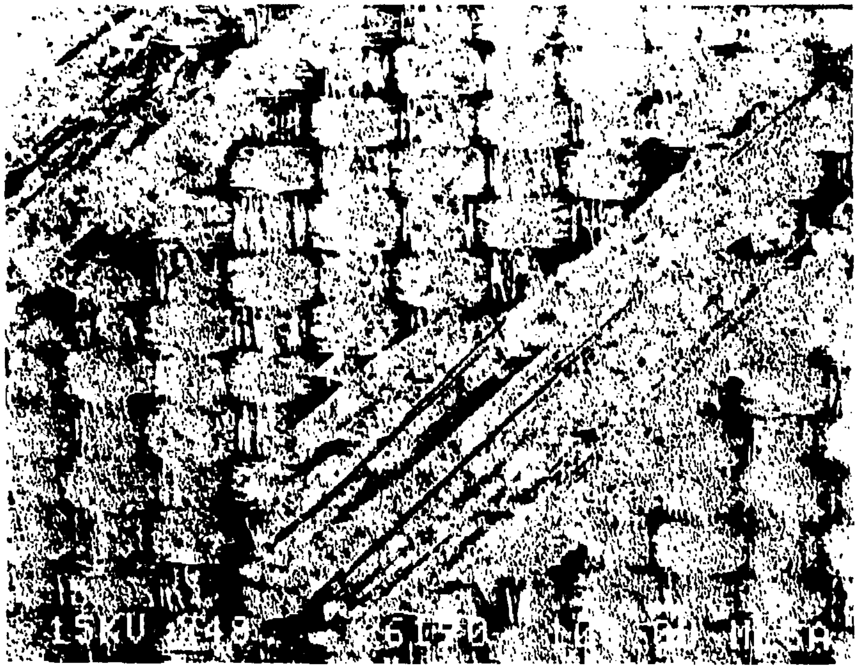

Figure 15.
Low magnification photomicrograph of the surface of specimen #9. (48x)

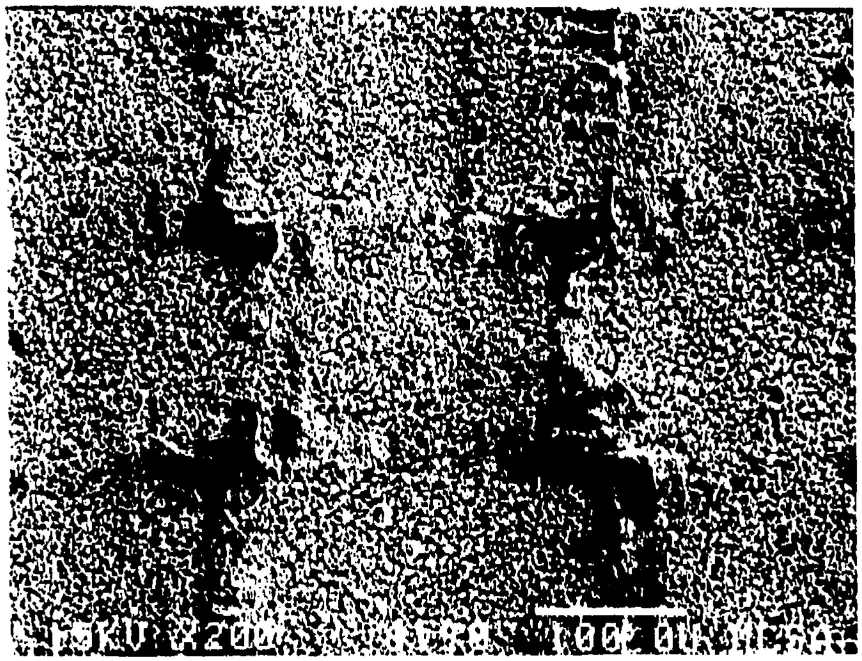

Figure 16.
Higher magnification of the surface of specimen #9. (200x)

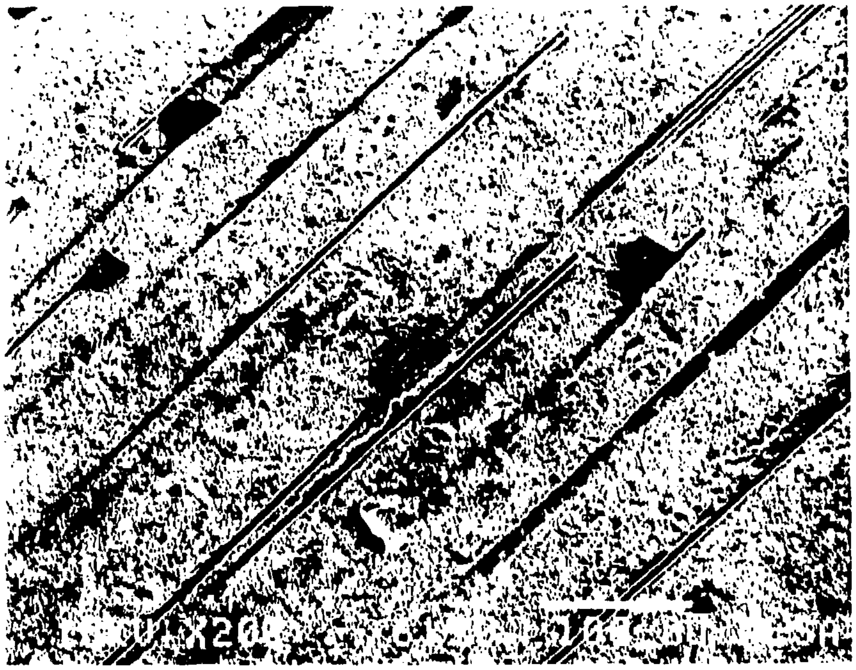

Figure 17.
Photomicrograph of surface of specimen #9 showing matrix morphology and 45 degree fibers. (200x)

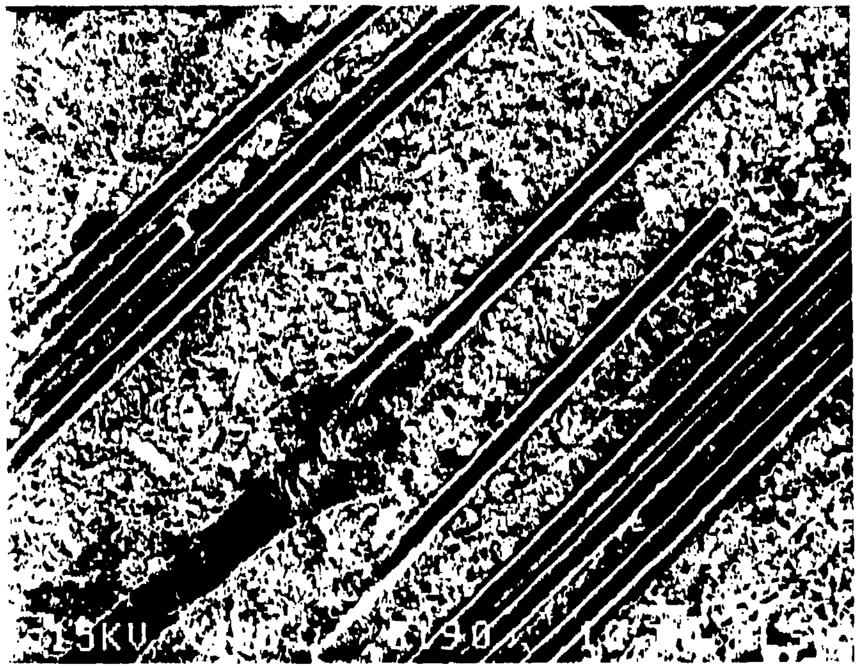

Figure 18.
Higher magnification of the surface of specimen #9 showing bare and broken 45 degree fibers. (480x)

Figure 19.
Low magnification photomicrograph of the surface of specimen #1. (48x)

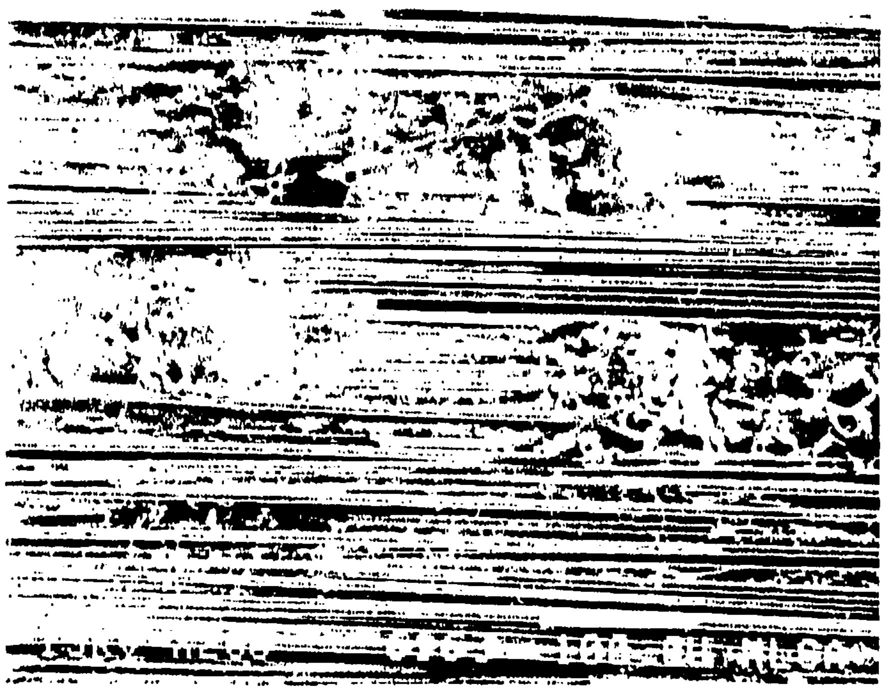

Figure 20.
Higher magnification of the surface of specimen #1. (200x)

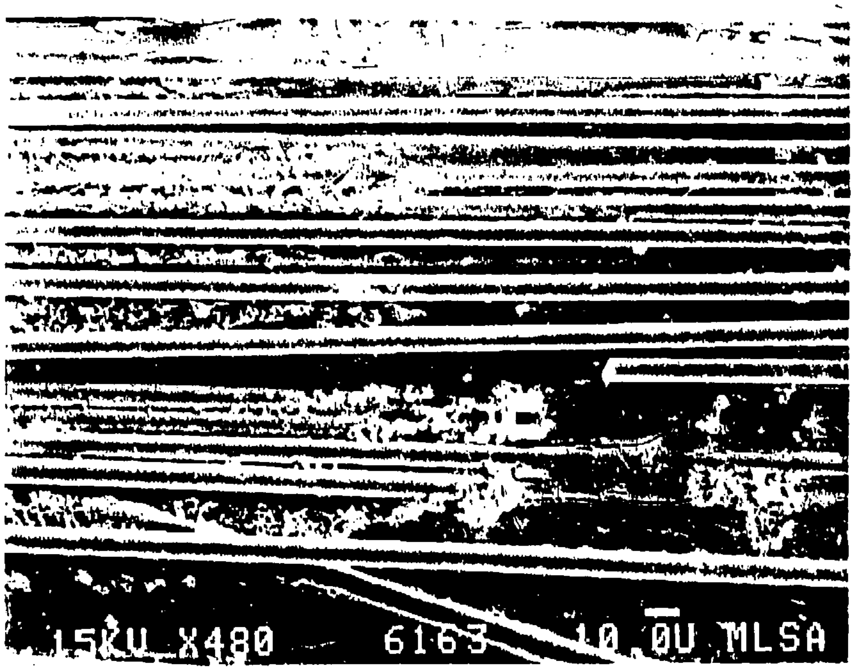

Figure 21.
Further magnification of the surface of specimen #1 showing bare and broken fibers and matrix cracking. (480x)

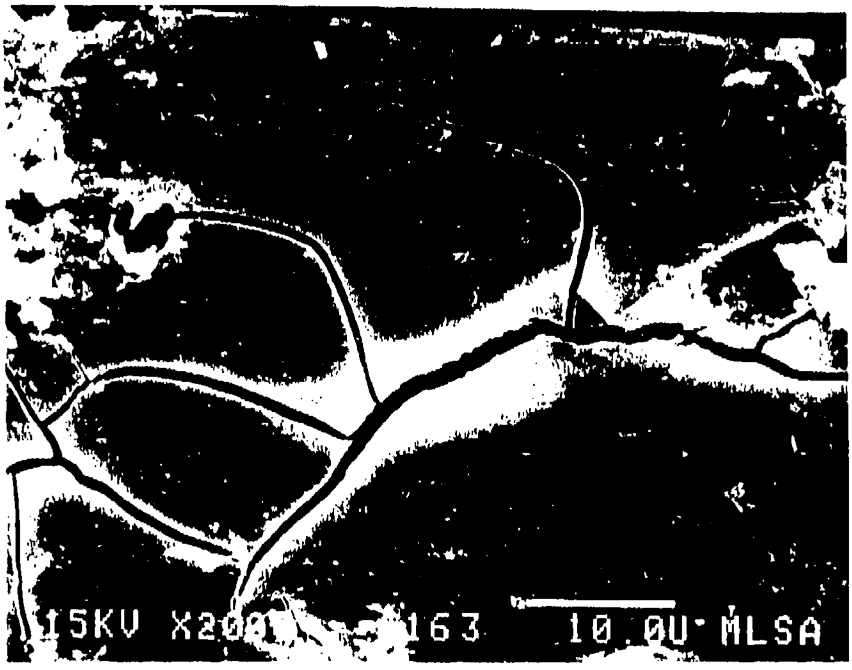

Figure 22.
Higher magnification of matrix cracking found in specimen #1. (2000x)

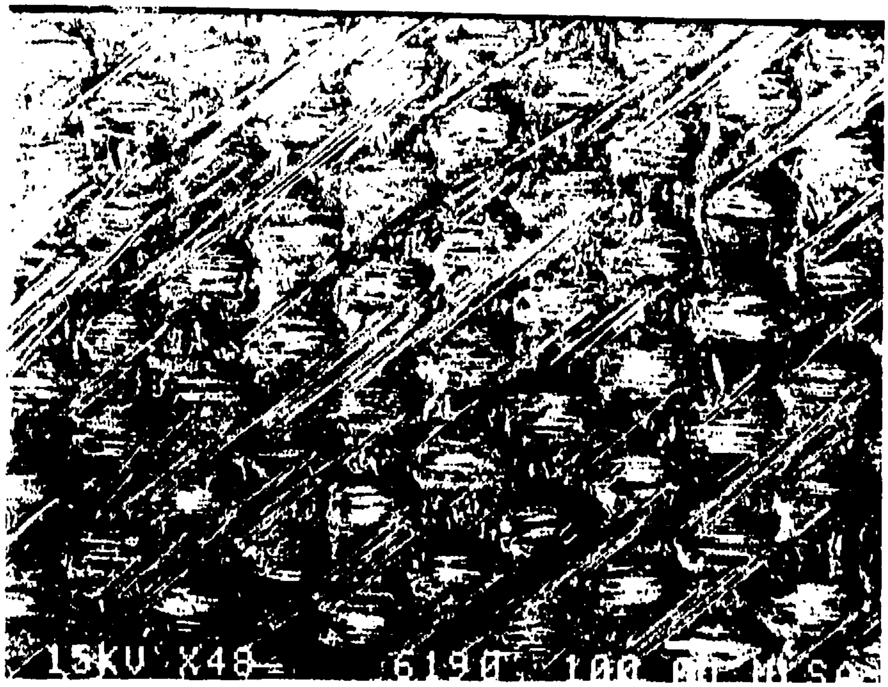

Figure 23.
Low magnification photomicrograph of the surface of specimen #11. (48x)

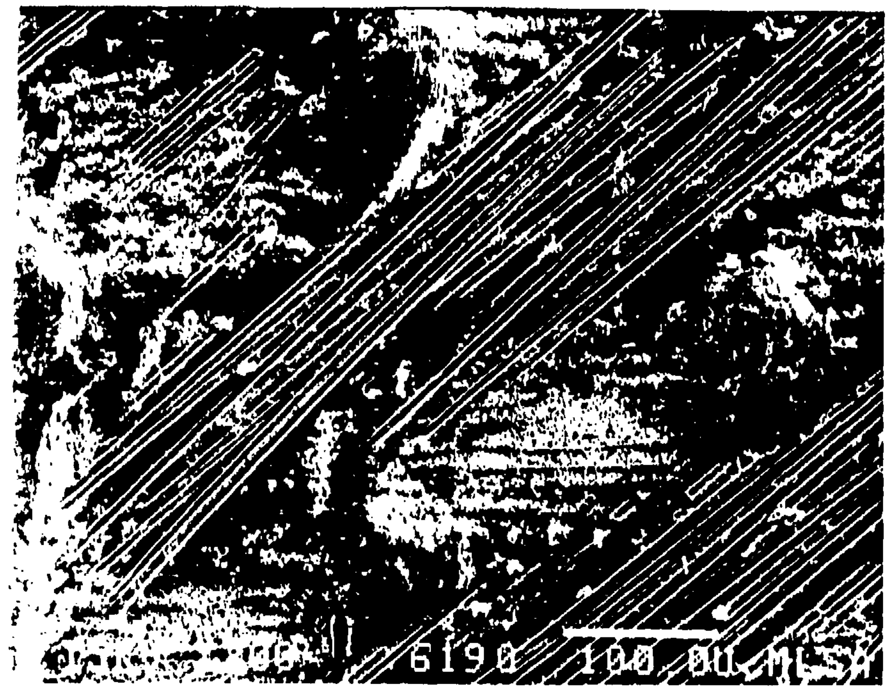

Figure 24.
Higher magnification of the surface of specimen #11. (200x)

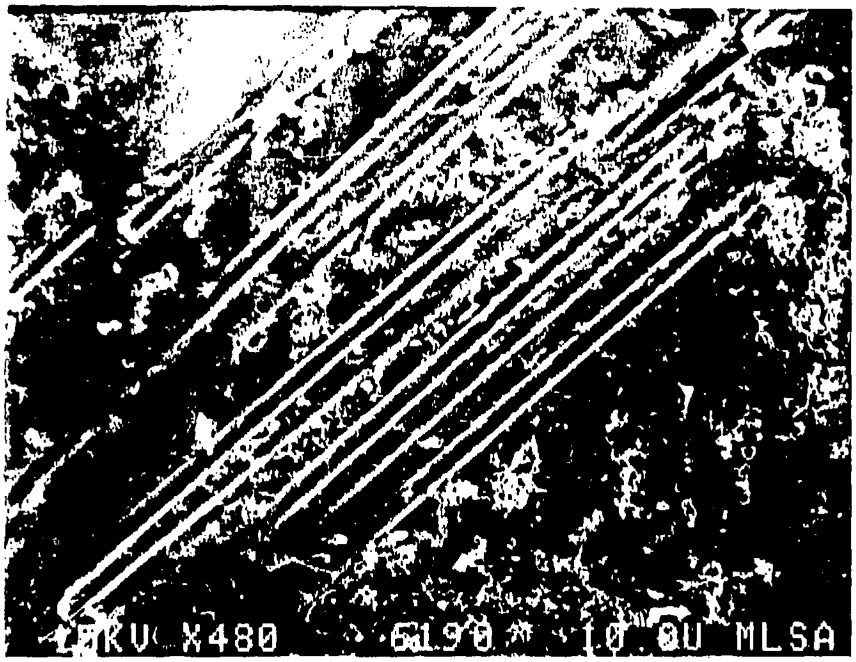

Figure 25.
Further magnification of the surface of specimen #11 showing bare 45 degree surface fibers. (480x)

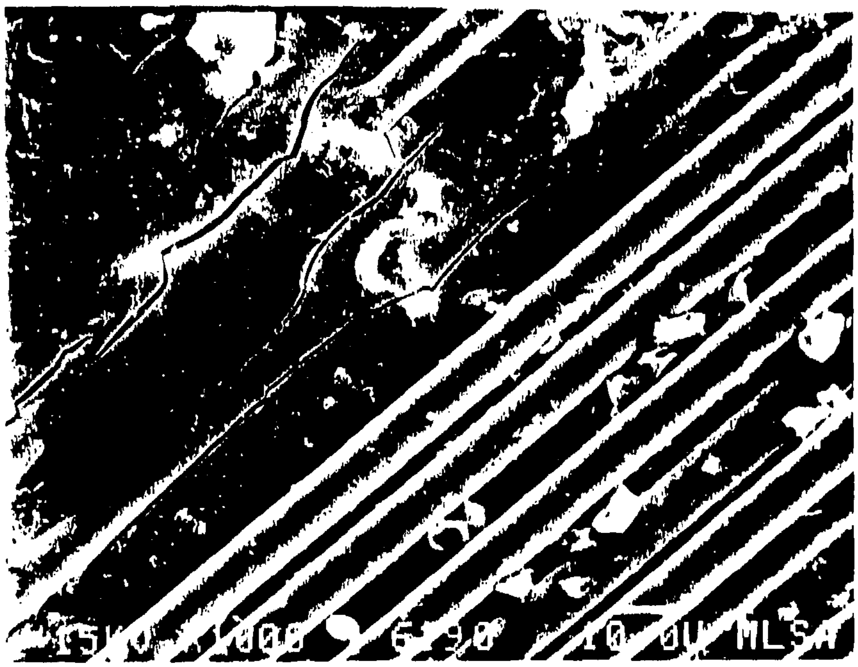

Figure 26.
Higher magnification of the surface of specimen #11 showing loss of matrix and broken matrix pieces between fibers, bare fibers and matrix cracking. (1000x)

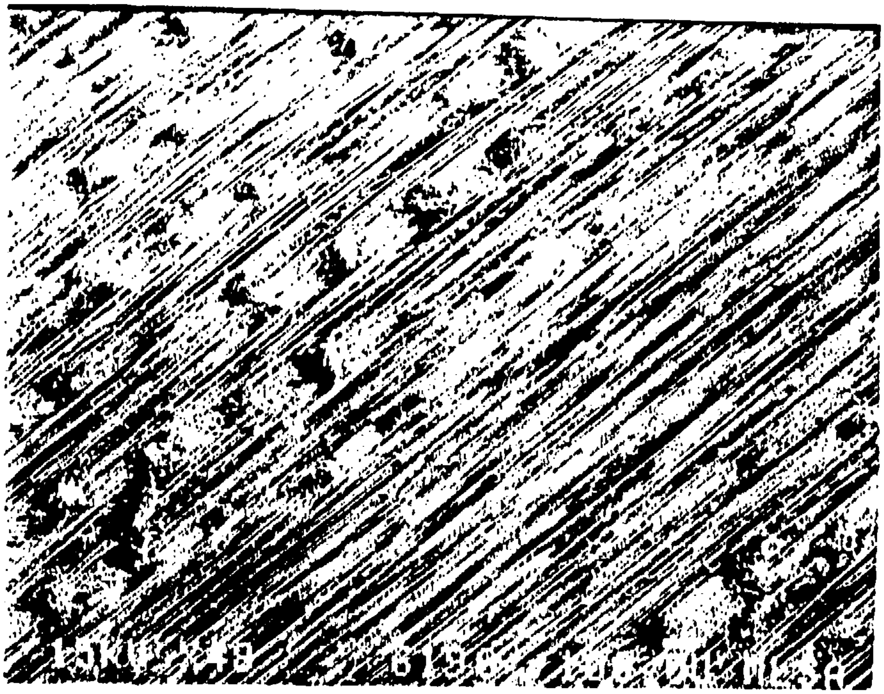

Figure 27.
Low magnification photomicrograph of the surface of specimen #12. (48x)

Figure 28.
Further magnification of the surface of specimen #12. (200x)

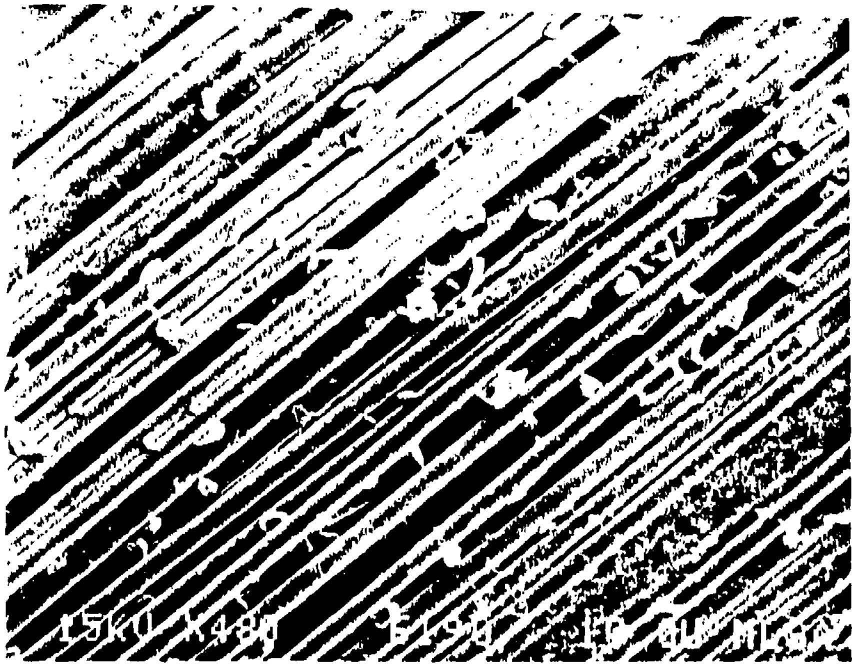

Figure 29.
Further magnification of the surface of specimen #12 showing bare fibers and missing and broken bits of matrix between fibers. (480x)

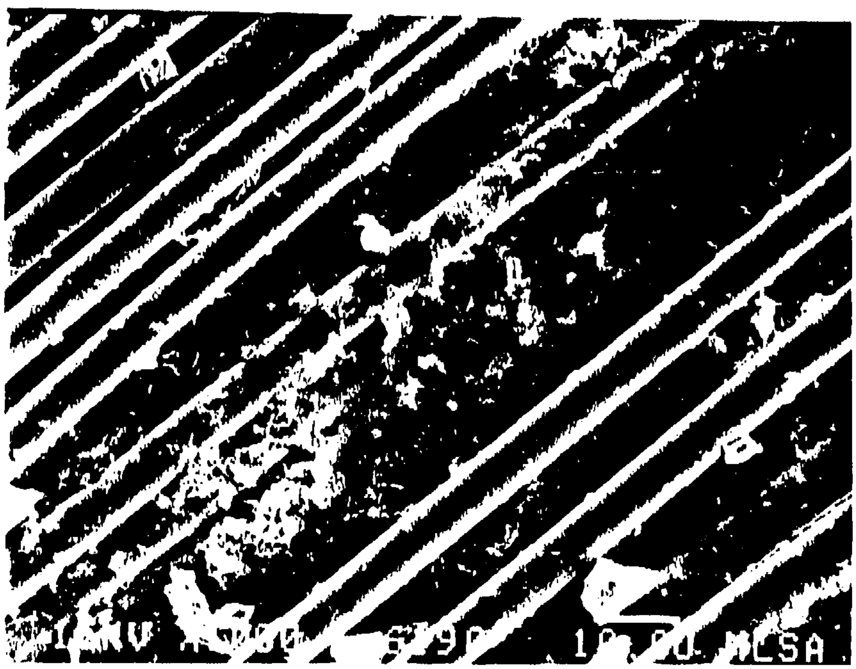

Figure 30.
Further magnification of the surface of specimen #12 showing matrix morphology, bare fibers and missing and broken bits of matrix between fibers. (1000x)

Figure 31.
Low magnification photomicrograph of the surface of specimen #5. (48x)

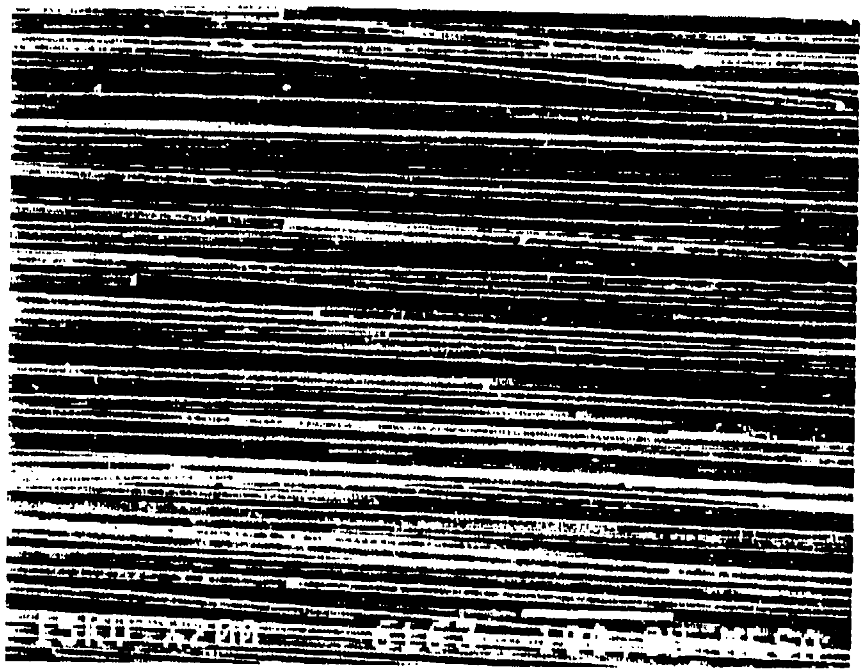

Figure 32.
Higher magnification of the surface of specimen #5. (200x)

Figure 33.
Further magnification of the surface of specimen #5 showing loss of matrix and bare fibers. (480x)

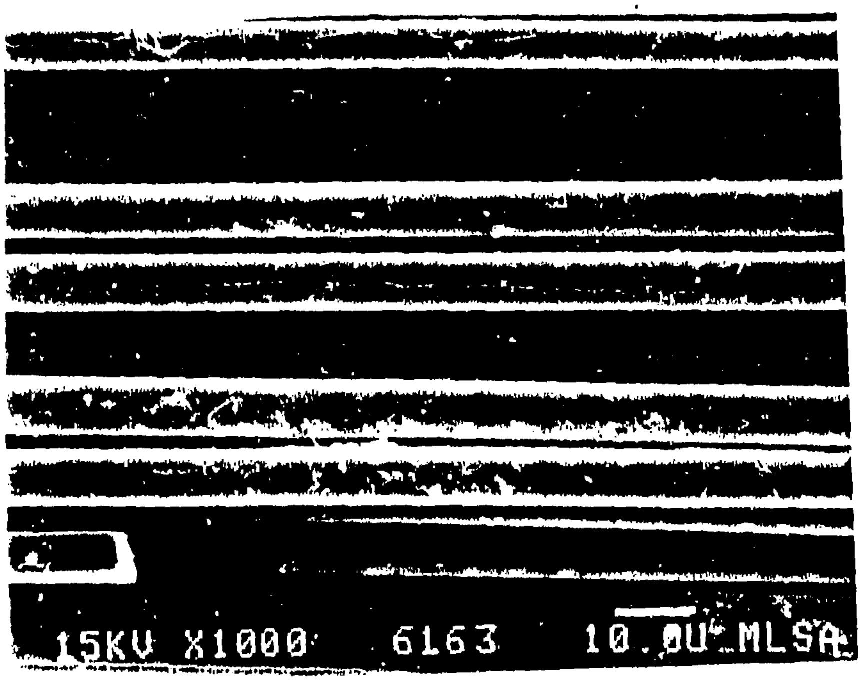

Figure 34.
Further magnification of the surface of specimen #5. (1000x)

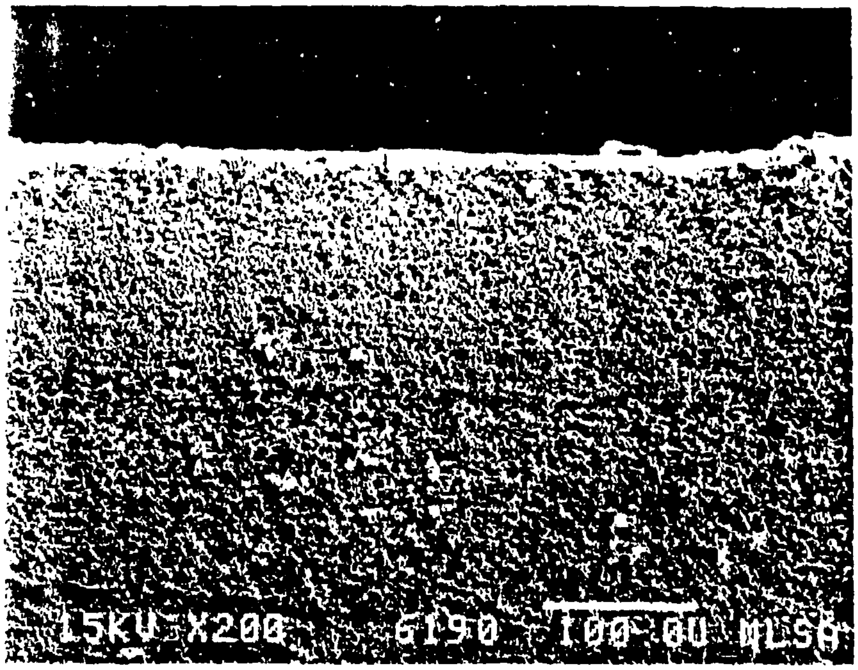

Figure 35.
Cross-section photomicrograph of specimen #9 showing no material degradation through the thickness of the sample. (200x)

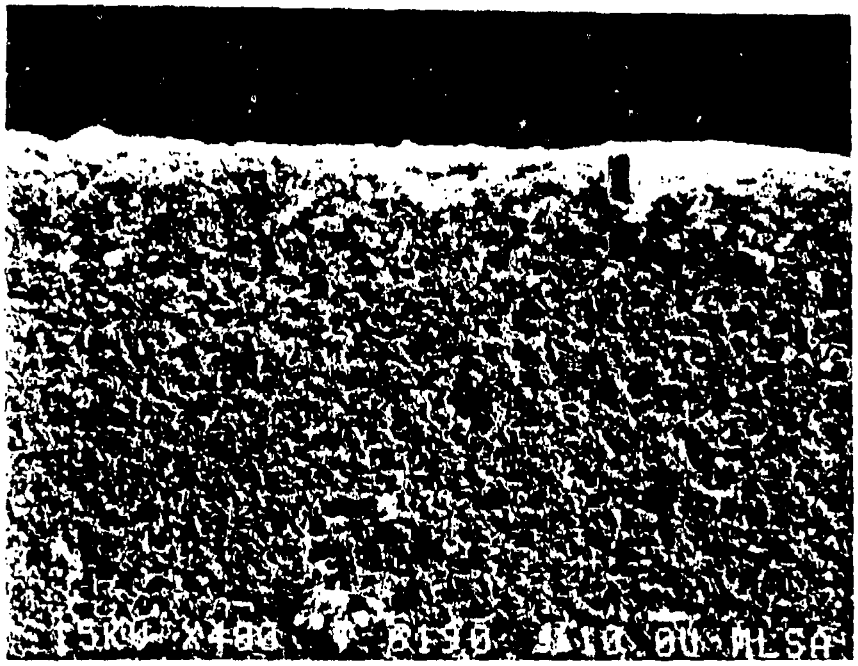

Figure 36.
Further magnification of the cross-section of specimen #9. (480x)

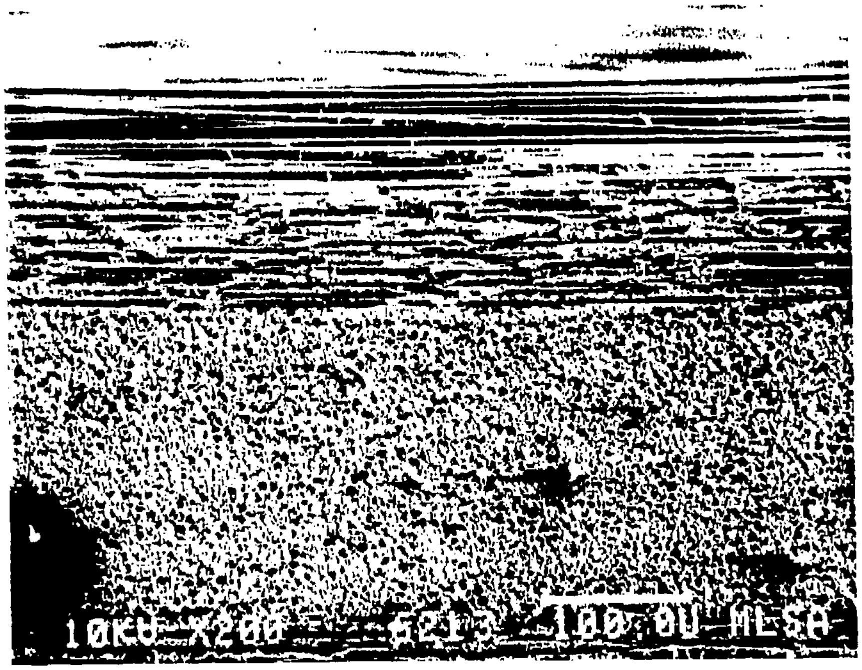

Figure 37.
Cross-section photomicrograph of specimen #5 showing some loss of matrix material down in the first few fibers layers. (200x)

Figure 38.
Further magnification of the cross-section of specimen #5. (480x)

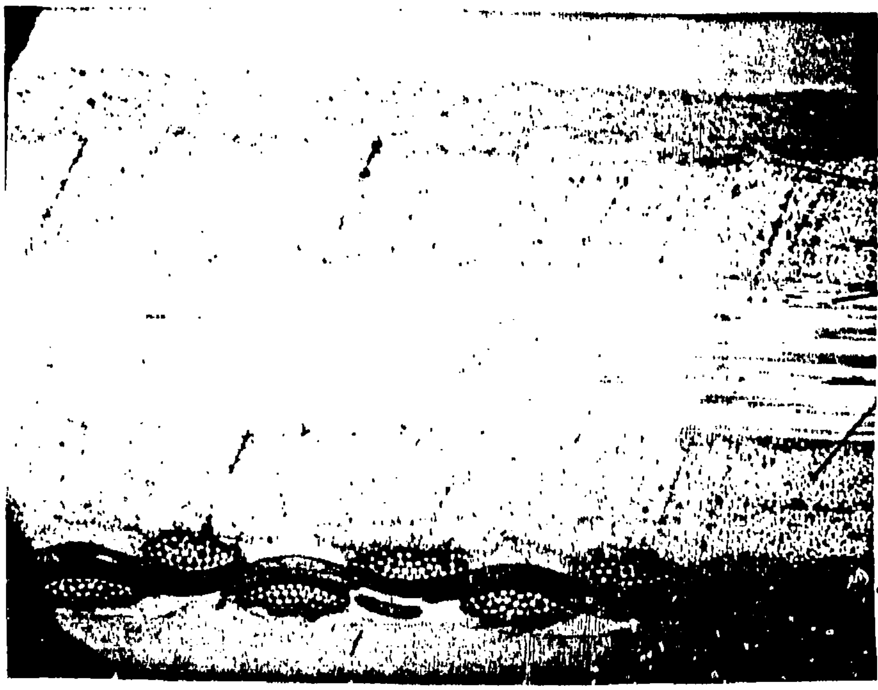

Figure 1. Laminate before paint removal. MAG. 100X
Chemical Analysis: Si*, S, Fe*, Cl, Ba*

Figure 1 is a photo cross section view of an epoxy/graphite laminate before any paint is removed. The polyurethane top coat and epoxy primer (MIL-P-23377) subcoat are 2.0 mils and 0.7 mils respectively. Between the primer and resin layer is an impression of a peel ply cloth. The other side of the laminate is covered with a glass cloth.

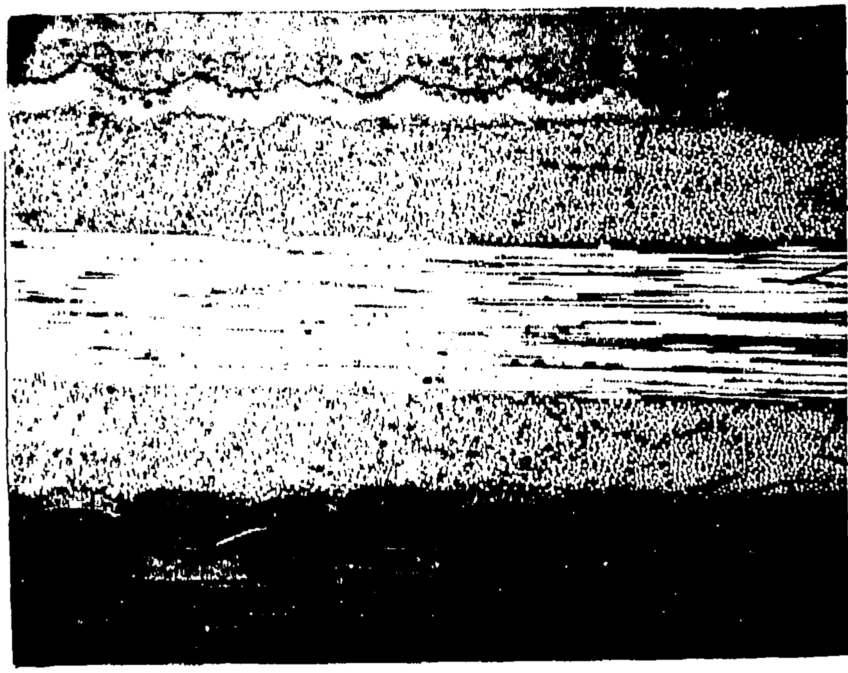

Figure 2. Laminate after paint removal. MAG. 100X
Chemical Analysis: Si*, Fe*, Al, Si, Cr

Figure 2 is a photograph taken after approximately 1.0 mils of the polyurethane was removed. None of the remaining paint layers appear damaged as a result of heat. This photograph shows a sharper image of the peel ply impression.

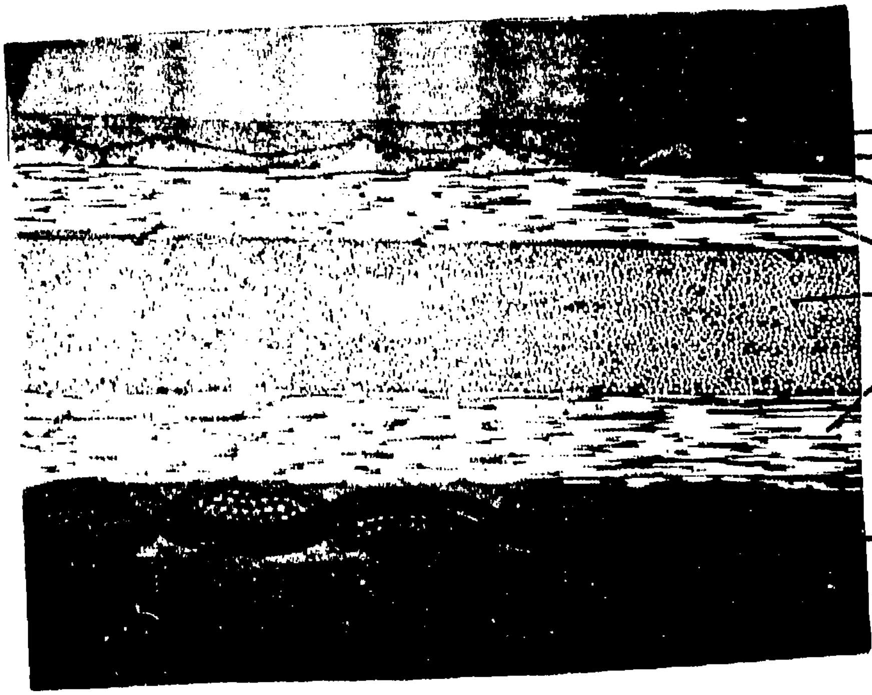

Figure 3. Laminate after paint removal. MAG. 100X
Chemical Analysis: Si*, S, Fe*, Cl, Ba

Figure 3 is a different side view of the laminate shown in Figure 2. Note how the primer contours the impression left by the peel ply.

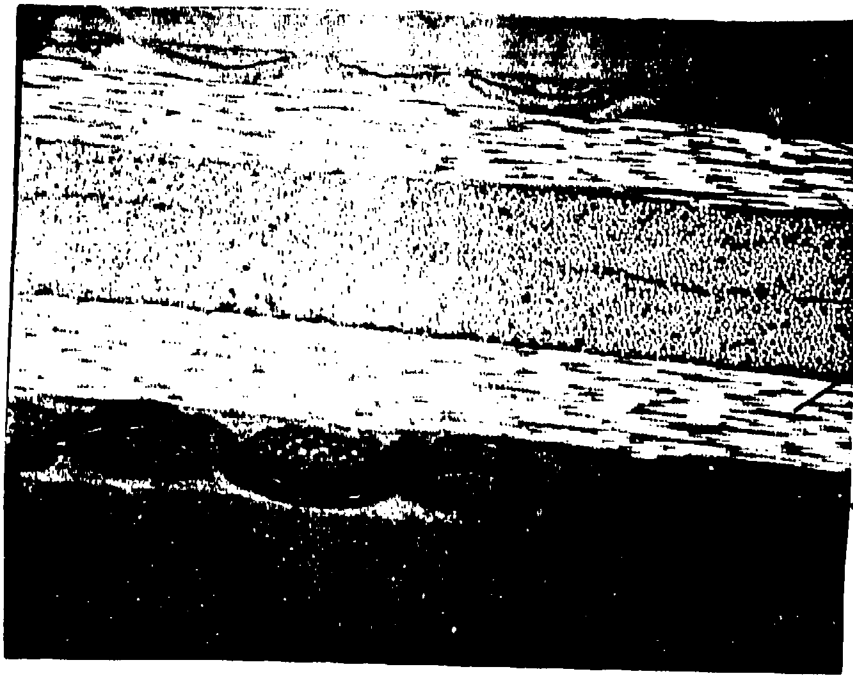

Figure 4. Laminate after most of the top coat is removed. MAG. 100X
Chemical Analysis: Fe*, Si*, Ba, S, Cl

Figure 4 is a photograph taken after most of the polyurethane topcoat was removed. The primer and resin layer appear to be left intact by the flashlamp system. In addition, no signs of delamination are evident in any of the photographs.

ESTIMATED POTENTIAL FOR SUCCESS

PROGRAM ELEMENT	CURRENT PROGRAM	FULLY FUNDED R&D PROGRAM		
	1 YEAR (PRAM)	2 YR	5 YR	10 YR
"FRONT END" (FLASHLAMP)	.1	.2	.5	.9
AUTOMATION OF PROCESS	.2	.5	.8	1.0
ENVIRONMENTAL SOLUTIONS	.5	.6	.8	.9
SCHEDULE COMPLIANCE	.8	.8	.8	.8
JOINT PROBABILITY OF SUCCESS	.008	.048	.256	.648
ESTIMATED NET BENEFIT	$25 M	$25 M	$25 M	$25 M
DOLLAR PROBABILITY (PROBABILITY X BENEFIT)	$200,000	$1.2 M	$6.4	$16.2
ESTIMATED INVESTMENT	$650,000	$1.3 M	$6.0	$12.0
BENEFITS/INVESTMENT	.31	.92	1.06	1.35

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- ASSIGNED PROBABILITIES, COSTS, AND BENEFITS ARE ALL ESTIMATED
- FLASHLAMP BECOMES AN ACCEPTABLE RISK CANDIDATE WITH APPROXIMATELY 2-5 YEARS R&D
- FLASHLAMP HAS ECONOMIC ADVANTAGE (BASED ON THESE DATA) PRIOR TO THE 10TH YEAR OF R&D
- CURRENT PRAM FOLLOW-ON PROGRAM FUNDING ($650K) IS INSUFFICIENT
- SIGNIFICANT FUNDING LEVEL INCREASES AND MORE TIME ARE REQUIRED FOR A REASONABLE CHANCE OF PROGRAM SUCCESS. EFFORT OF THIS SCOPE AND MAGNITUDE BELONG TO AN R&D AGENCY.
- SM-ALC/MA SHOULD NOT BE RESPONSIBLE FOR DIRECTING THIS R&D ACTIVITY