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PAINT REMOVAL FROM COMPOSITES AND PROTECTIVE COATING DEVELOPMENT

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A three-phase program was undertaken to evaluate paint removal techinques and protective coatings for Air Force aircraft, with a focus on graphite-epoxy composite substrates. The first phase identified and evaluated 10 alternative depainting methods to offset chemical and plastic media blasting techniques. The second phase identified and evaluated protective coatings to guard against the effects of plastic media blasting on composites. The final phase conducted performance testing of protective coatings under multiple paint and strip cycles.

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Executive Summary

A three-phase program was undertaken to evaluate paint removal techniques and protective coatings for Air Force aircraft, with a focus on graphite-epoxy composite substrates. The first phase was the identification and evaluation of paint removal techniques as potential alternatives to chemical stripping and plastic media blasting. The second phase involved the identification and evaluation of potential coating systems for protecting aircraft from the various removal techniques. In the final phase, the performance of selected protective coating systems was evaluated in a four-cycle paint/depaint program utilizing selected removal methods.

The focus of the Phase I program was to identify methods which could effectively remove the aliphatic polyurethane topcoat (MIL-L-83286) from graphite-epoxy composites. It was desirable to terminate stripping within the epoxy-polyamide primer (MIL-P-23377) layer, thus using the primer as a flag.

After a thorough investigation and screening process for potential paint removal methods, nine methods were initially identified as the most promising. An in-depth industry and field/laboratory study was undertaken for each of these. Recently, two additional methods have been developed, and evaluations on these processes were initiated. Each removal technique was carefully screened for its ability to remove topcoat selectively without incurring damage to the composite, and to perform such removal at potentially reasonable rates. Techniques with satisfactory performance were subsequently evaluated using optical and scanning electron microscopy, and mechanical property testing such as four-point flexure and short beam shear.

The following is a summary of the 12 most promising paint removal methods:

1. **Waterjet Blasting** is the use of high-pressure water to erosively transform materials and surfaces. Advantages of waterjet systems are that no organic solvents are used, water can be recycled, it is inexpensive, and it is relatively safe to operate. Successful removal of coatings from metals was reported, while removal from composites was more difficult to accomplish. Waterjet systems also created the potential for corrosion, and water intrusion of peripheral components such as electronics. As a result of these negative factors, the process was determined to be unsuitable for Air Force aircraft.

2. **Thermal Stripping** is the use of heat to soften the topcoat in order to facilitate removal. Laboratory testing indicated that desirable softening of the topcoat occurred at a minimum temperature of 110°C (230°F). Because the advantage gained by such heating was minimal and the potential for damage to aircraft components (e.g., composite materials, plastics, fuels, etc.) that is due to localized heating, the process was determined to be unsuitable for Air Force aircraft.

3. **Alternative Solvents** to methylene chloride were investigated to identify materials which were safe and effective for removal of paint. Materials such as n-methyl pyrrolidine, ethyl 3-ethoxypropionate, ethylene carbonate, and several commercial "formulations" were evaluated. No material was identified that was a "safe" and effective paint stripper.

4. **Ultrasonic Paint Stripping** is the impartment of high-frequency sound energy, using a chisel-like tool, into the topcoat in an effort to facilitate removal. Testing indicated that in order to achieve acceptable removal rates, solvent pre-softening of the topcoat was required, which made the process undesirable.

5. **Cryogenic Paint Stripping** involves the application of liquid nitrogen (-320°F) onto a coated substrate in order to embrittle the coating (the polyurethane topcoat was found to embrittle at -5°C) and assist in its removal. One key advantage of such a process is the minimization of hazardous waste, as the cryogenic liquid quickly evaporates. Without significant differences in thermal expansion between the coating and the substrate, a complimentary removal technique is required. In our investigation, liquid nitrogen was fed onto the coated surface from the outside edge of a rotary sander - **cryogenic/abrasive paint stripping**. Overall, the cryogenic/abrasive system did not demonstrate a significant advantage over the non-cryogenic wet abrasive system to justify the added complexity and temperature extremes.

6. **Abrasive Paint Removal** is the use of abrasive-containing discs or pads in conjunction with a high-speed rotary sander. After extensive system evaluations, the optimized system was determined to contain the following components and operating parameters:

   - 3M 120 Grade Multicut disc
   - Dynabrade 800 rpm, wet/dry, pneumatic sander
   - 3M #57 Back-up pad
   - Water flow rate = 0.15 gallons/minute
   - Operating pressure = 90 psig

   The use of water allows for improved control over the level of stripping since the primer is used as a "flag" for the termination of stripping. Increased life of the sanding disc is also obtained. Using the above system, stripping rates of 1.0 ft^2/minute have been achieved using a 5" sanding disc. In evaluations on graphite-epoxy composite panels, the overall control of the system is very good, and no loss in mechanical properties was observed. This system shows strong capabilities for paint removal on smaller areas and for repair applications.

7. **Carbon Dioxide Pellet Blasting** is a blasting operation which uses a combination of thermal and kinetic effects to remove coatings. Waste production is minimal as the blasting media evaporates upon impinging the substrate. The most effective system identified for this application has been developed by Cold Jet, Inc. (Cincinnati, Ohio). The CO_2 pellets are 1.5 mm in diameter by 3 mm long, have a density of 75-97 lb/ft^3, and can be supercooled down to -110°F. Typical operating parameters are 225-275 psi, 2- to 6-inch standoff distance, a blasting angle of 60-80 degrees, and a maximum media flow rate of 700 lb/hr. The system has demonstrated very good results in removing paint from aluminum substrates, but has shown ineffective stripping control and rates on graphite-epoxy composites. This system is currently being carefully evaluated for large-scale use on aircraft.

8. **Sodium Bicarbonate Blasting** is a process being developed by Church and Dwight Co., Inc. and Schmidt Manufacturing, Inc. The Armex/Accustrip system uses the impingement of sodium bicarbonate to remove coatings. Optimized parameters for stripping topcoat from epoxy-graphite composites are:

    - Armex MPG (coarse) grade media
    - Blasting pressure = 60 psig
    - Flow rate = 2.5 - 3.0 lb/minute (dry -- no water)
    - Blasting angle = 60 - 70 degrees
    - Stand-off distance = 18 inches

    Using these parameters, stripping rates of 0.75 ft^2/min were achieved on 2-foot by 3-foot graphite-epoxy composite panels. The ability of the system to stop in the primer layer was good, and no loss in mechanical properties was observed. The Armex/Accustrip system is currently being carefully evaluated for large-scale use on aircraft.

9. **Excimer Laser Paint Stripping** utilizes pulsed lasers which operate in the ultraviolet spectrum. Excimer lasers are a new and rapidly developing technology which remove material by a process called ablation which minimizes heating. In a program performed in conjunction with Resonetics, the following operating parameters were found to be optimum using a 40-watt laser:

    - Wavelength = 248 nm (Krypton Fluoride)
    - Fluence level = 1.5 J/cm^2
    - Pulse rate = 150 Hz
    - Scan rate = 4.5 cm/second

    Results on graphite-epoxy composite panels indicated that the ability of the system to terminate stripping in the primer layer is outstanding, and no loss in mechanical properties was observed. With scale-up to a 250-watt laser (largest commercially available) operating at 300 Hz, stripping rates of about 0.1 ft^2/min could be achieved, a rate which is unacceptable. It is estimated that the technology to produce excimer lasers powerful enough to achieve desired stripping rates is about 10 years away.

10. **Envirostrip** is a new process being developed by Ogilvie Mills, Ltd. (Montreal, Quebec). The process uses modified wheat starch, which is biodegradable and non-toxic, in a blasting operation to remove coatings. Initial testing on graphite-epoxy composites indicates that appropriate blasting parameters are:

- Flow rate = 300 lb/hr
- Blasting pressure = 30 psig
- Blasting angle = 20 - 30 degrees
- Stand-off distance = 6 - 10 inches
- Nozzle size = 1/4-inch diameter

Using these conditions, the ability of the process to terminate stripping in the primer layer was very good, and stripping rates of 0.5 ft^2/min were achieved. Although mechanical property testing has not been performed at this time, initial results are very encouraging.

11. **Ice Blasting** utilizes 1- to 3-mm diameter "spheres" of ice which are projected onto the coated surface, melt on impact, and assist in washing the paint particles from the substrate. The process is being developed by Ixtal Blast Technology Corporation (Victoria, British Columbia). Typical blasting parameters are:

    - Flow rate = 400 lb/hr
    - Blasting pressure = 80 psig
    - Stand-off distance = 6 - 18 inches

    Ixtal asserts that optimum system performance occurs when the ice is supercooled to that temperature which allows it to be delivered to the painted surface at 32°F. Because of the newness of the process, no testing has been performed on the Ixtal ice blasting system.

Our conclusions from Phase I are that a number of paint removal methods exist which have demonstrated very promising results and should be evaluated in large-scale paint removal operations and in conjunction with the more effective protective coatings identified in Phase II of this project.

The objective of Phase II of this program was to identify and evaluate existing coatings systems for composite materials that would provide protection from potentially damaging paint removal methods. The first task was the identification and screening of protective coating candidates.

Initially, performance criteria were developed by which the candidate coatings would be judged. These included: the chemistry of each system, expected adhesion to plastics or composites, resistance to impact and solvents, potential resistance to paint removal procedures, and compatibility with procedures encountered at the air base. In addition, we examined other important variables such as: processing and application equipment requirements, level of skill required for application, application rates, applicability to large structures, cost, and toxicity.

The next step was to conduct an extensive literature survey of coating technologies that might satisfy the requirements. This included a review of general information on the environmental resistance properties of protective coatings with a focus on resin types likely to meet the requirements such as polyurethanes, epoxies, etc. We also reviewed patents and literature sources from industries with relevant technologies such as aviation and automotive. Finally, we reviewed military literatures through DTIC database and military combats. The most valuable result of this search was that it helped to identify the commercial sources of candidate coatings.

Following this effort, we conducted a company survey to identify promising commercially available coating systems and solicited both information and samples of coatings. A total of 24 companies were contacted, 12 of which provided one or more candidates. The companies contacted included large coating manufacturers such as Lord, DeSoto, Sherwin-Williams, and PPG, as well as raw material supplies such as Mobay and Freeman Chemical. Also included were companies with applicable in-house technologies such as Hughes Aircraft Co. and Hysol Aerospace Products.

From this survey, 20 promising coating and film laminate systems were identified for our screening program.

Initially, the twenty coatings were screened for basic coating performance on 4" x 12", 12-ply, graphite-epoxy composites. Fifteen of the coatings were applied according to manufacturers' specifications at 2- to 3-mil dry film thickness, and five of the systems were applied by the manufacturers on panels that were provided to them. These systems were evaluated for the following:

- Compatibility - (wetting, flow, etc.)
- Adhesion - ASTM 0335987 Tape Test Method
- Impact resistance - Gardner Light Duty Impact Tester
- Solvent/Chemical Resistance - Hydrocarbon Resistance Test, Mil-C-462686 (ME) Sec 3.6.9 and 4.3.2

At the conclusion of this screening, all of the systems except one performed well on these tests.

The next level of evaluations involved painting the coated composite substrates with a standard military topcoat and primer. Specifically the primer was MIL-P-23377, a yellow, two-component epoxy applied at 0.8-mil dry film thickness. The topcoat was MIL-C-83286, a green, two-component, polyurethane applied at 2.0 mil by film thickness. These test specimens were evaluated for the following:

- Compatibility of the paint systems to the coating
- Adhesion of the paint system to the coating
- Water resistance - Condensation Test ASTM-4585-87
- Adhesion after exposing to condensation

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The results of this testing determined that there was excellent compatibility and adhesion at the coating/paint system interface in all but one coating. Water-resistance testing was found to be very useful in distinguishing the relative performance of the remaining coatings.

All of the results to date were analyzed and ranked according to performance, ease-of-use, availability (experimental vs. commercial) and chemical makeup. Based on this analysis, eight candidate systems were selected to proceed to the paint removal testing. The results of water-resistance testing was critical in this selection.

The second task was the evaluation of selected coatings in paint removal methods. In this phase of the evaluation, the objective was to evaluate the eight coatings in two paint removal processes, PMB and Wet Abrasive. This work was carried out in a series of four depaint/repaint cycles over a period of 2 months. In these removal trials, the yellow primer was used as a "flag." Detailed evaluation of the test specimens, which consisted of composite/protective coating/paint system, occurred after the first and four cycles. Specifically the evaluation included:

- Protective Coating
  - Visual Observation
  - Adhesion to Substrate (composite)
  - Surface Roughness
  - Recoatability of Paint System

- Composite
  - Visual Observation
  - Mechanical Properties
  - Microscopy

Those coatings that performed well on adhesion, recoatability, and visual appearance were considered to pass this evaluation. Coatings which failed exhibited significant (> 30% surface area) loss of adhesion or delamination of the coating to the composite. During this testing, wide variations in the surface roughness of the panels were noted. Surface roughness measurements were taken on the panels after they were stripped, as well as after repainting. After the panels were exposed to four paint/paint removal cycles, they were repainted and tested for mechanical properties. In general, the wet abrasive method produced a smoother surface than the PMB methods. Also, the individual coating type did not significantly effect surface roughness compared to the removal technique used.

Finally, repainted samples of each specimen were tested for mechanical properties after the first and fourth removal cycles. The test measured flexural strength by ASTM D-790 with a 4-point bend, and the painted side in compression. Generally, the results showed that the paint removal process had no statistically significant effect on the flexural strength of the panels after four depaint/repaint cycles. However, by observing the failure mode, we noticed that the presence of the coating did have an effect in some cases on the strength of the composites after four removal cycles. The changes in flexural strength resulted from damage to the composite surface, the degree of surface roughness, and the ability of the protective coating to distribute stress concentrations when the surface of the panel is in compression. The changes in failure mode show a reduction in stress concentration at the side in compression.

Based on the results of this program, we believe that the presence of an intermediate layer between the composite and paint system can provide protection to the composite from multiple paint removal cycles when the paint removal process is plastic media blasting and wet abrasive paint removal. The coatings should be investigated further for their ability to provide protection against catastrophic situations, such as extended dwell times, contaminated media, and operator error.

Specifically, we found that the following coatings are effective for wet abrasive paint removal:

- Lord Chemglaze M1433 urethane
- DeSoto Koroflex 4086-176 urethane
- Hughes Aircraft HRG 3/A3
- 3M AF-32 Adhesive Film

The following coating was effective for PMB paint removal:

- Pratt & Lambert 482-300/120-900 epoxy

The following coatings were effective in both wet abrasive and PMB paint removal:

- Dexter Hysol SynSkin XHC9837 epoxy surfacing film
- Dexter Hysol Low Modulus Adhesive Film

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1.0 Introduction

The normal life cycle of U.S. Air Force aircraft includes visits to Logistics Centers for maintenance, repair, and refurbishment. A standard component of such visits is the removal of the primer and topcoat paints and subsequent repainting with fresh coatings. A number of technologies exist for the paint removal part of this process, and their relative benefits are fairly well understood for standard metal aircraft surfaces. However, in recent years there has been an increasing trend towards utilization of advanced composites in aircraft. This trend is expected to continue to grow, and the carbon, aramid, and boron fiber-reinforced organic matrix composites currently being used will undoubtedly be joined by other composite systems as important aircraft components in the near future. Unlike metals, the effect of paint removal on composite surfaces has not been extensively characterized except that it is known that composites are susceptible to possible damage by both chemical and mechanical techniques.

The current utilization of composites in aircraft includes critical items where loss of performance characteristics as a result of paint removal cannot be accepted. This small group of critical parts will soon be expanded to include a larger percentage of the total aircraft structure. As this occurs, and as aircraft containing these composite components reach the point where they are scheduled for maintenance, the Air Force must be able to ensure that paint removal can be carried out at the air base level without danger of introducing structural damage and in a manner that is clearly economical, efficient, and environmentally acceptable. The overall goal of the current program is to assist the Air Force in understanding the complex issues surrounding paint removal and repainting of composites on aircraft and identify effective systems and characterize their performance.

A major source of complexity in dealing with this issue arises from the fact that composites intended for different functions in the aircraft may have quite different physical and mechanical properties. As a result, a paint removal process that is non-damaging to one class of composites may have a detrimental effect on another class. This situation leads to the establishment of two major objectives for the program.

The first objective is to develop a thorough understanding of existing and new paint removal technologies that might have potential for depainting composite surfaces, as well as aluminum and other metal parts of the aircraft. This understanding must include determining the effect of each depainting method on a variety of composites, as well as defining the basic mechanism by which each method operates. For example, paint removal methods can be viewed broadly as being based on one or more of the following phenomena: mechanical abrasion, chemical dissolution, chemical decomposition, coating embrittlement, or reversal of adhesion.

The second objective arises from the fact that the preferred paint removal technology cannot be selected solely on the basis of its effect on composites. The realities of paint removal in the air base environment require that factors of cost, environmental effect, ease of use, reproducibility, and other considerations also be taken into account. Recognizing that these factors may require specification of a paint removal methodology that is not totally non-damaging to all types of composites, there is a need to carefully evaluate technology that could be used to produce composite surfaces free from the effects of paint removal. Thus, the second objective involves identification and evaluation of a variety of protective coatings systems that could serve this purpose by providing high durability and the ability to resist a number of paint removal and repainting cycles on a variety of composite surfaces. Coatings may also be required to protect against accidental mechanical damage and contact with chemicals.

While it is possible that a paint removal technology will be developed in this program that is broadly applicable to a variety of composites and has the other attributes necessary for implementation in the Air Force Logistics Centers, it is more likely that a combination of paint removal technology and protective coating technology will best serve the Air Force across the wide range of removal/repaint situations that must be addressed as aircraft of different types are returned for servicing and maintenance.

2.0 Approach to Paint Removal Techniques

Our investigation of potential paint removal techniques was focused on the removal of aliphatic polyurethane topcoat (MIL-C-83286) from graphite-epoxy composite panels (AS4/3501-6), with the termination of stripping in the epoxy-polyamide primer (MIL-P-23377) layer. The exact specification of this system is as follows:

- Topcoat - Aliphatic polyurethane (MIL-C-83286) applied by conventional spraying in two coats to a final dry film thickness of 2.0 ± 0.3 mils,
- Primer - Epoxy-polyamide primer (MIL-P-23377) applied by conventional spraying in one coat to a final dry film thickness of 0.6 to 0.9 mils,
- Composite - 16-ply, quasi-isotropic graphite-epoxy (AS4/3501-6) using a $[0°_2, 90°, \pm45°, 90°, \pm45°]_s$.

Some evaluations were also performed on aluminum (7075-T6, anodized clear) without the concern for the termination of stripping in the epoxy primer layer.

The identification of potential paint removal techniques was performed primarily using three methods -- an in-depth literature search and review, discussions with industry participants, and internal idea/concept generation meetings. Key requirements for potential paint removal methods were:

- Ability to remove topcoat at desired rate and level of control

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- Ability to remove topcoat at desired rate and level of control

- Appropriateness for use in large-scale aircraft paint removal operations
- Technology base
- Acceptability from environmental, health, and safety standpoints
- Years to commercialization.

Identified techniques were then subjected to a series of screening tests, as follows:

1) **Industry review** - Appropriate industry personnel were contacted and the processes were carefully examined for their appropriateness for this application.

2) **Preliminary laboratory evaluation** - Processes were screened for their ability to remove the topcoat from graphite-epoxy and aluminum test panels.

3) **In-depth laboratory/field evaluation** - Promising removal technologies were screened on large (1-foot by 3-foot) graphite epoxy test panels. Panels demonstrating desirable results were subsequently evaluated using mechanical property testing (4-point flexure and short beam shear), optical and SEM microscopy, and surface roughness testing.

2.1 Fabrication of Composite Panels

Panel Fabrication Dimensions:

Approximately 12"x36"x0.080", 16 plies of Magnamite Tape.

Material Used:

Magnamite AS4/3501-6 Graphite Prepreg Tape from Hercules Aerospace Products Group, Magna, Utah.

Fabrication Procedure:

Prepreg Tape plies were precut to size according to proper angle and fiber orientation specifications and stacked in [illegible]ermined sequence. Each ply was moved from the holding stack to the layup in the proper sequence and fiber orientation. Precut tape was placed on the base plate one layer/ply at a time, mating the surface of the plies and removing any wrinkles and trapped air, using a plastic hand squeegee. The protective cover was removed after mating the plies. The next ply was positioned, mated with the squeegee in the same manner and the protective cover removed. This process was repeated until the proper number of plies were stacked to complete the layup. A checkoff sheet was used to keep track of the ply number and orientation.

The 16 plies quasi-isotropic panels had the orientation $[0^\circ_2, 90^\circ, \pm 45^\circ, 90^\circ, \pm 45^\circ]_s$, while the 12-ply panels used for initial screening had the orientation $[0^\circ_2, 90^\circ_2, 0^\circ, 90^\circ]_s$.

The completed composite lay-up was then sandwiched between layers of bleeder cloth and placed in a vacuum bag. Vacuum was applied and pulled overnight at room temperature prior to autoclave curing. The vacuum was maintained at a minimum, of 25" of Hg throughout the cure cycle. The autoclave cure cycle, shown on Figure 2.1, took approximately 5 hours and 50 minutes to complete and consisted of the following temperature/pressure cycle:

Temperature: (start from 80°F)

Ramp temperature to 225°F at a rate of ~2.5°F/min. and hold at 225°F for 1 hour. Ramp to 350°F at ~2.1°F/min. and maintain 350°F for 2 hours. Start cool down ramp down to 100°F at ~5°F/min. and hold at 100°F.

Pressure: (start from 0 psi)

Ramp to 50 psi at a rate of ~1 psi/min., maintain at 50 psi while temperature cycle is at 225°F. Ramp to 85 psi at ~1 psi/min. and hold throughout 350°F cure cycle and cool down to 100°F. At this point pressure is dumped at ~5 psi/min. The cycle is then completed. The cure cycle is shown in Figure 2.1.

2.2 Paint Description and Application

Composite panels were water-washed, blown dry with air and air-dried overnight prior to application of the primer paint. This was done to remove any residue on the panels from the ultrasound test.

Deft (Mil-P-23377D) 02-Y-24 Epoxy-Polyamide Primer.

Component A was mixed on a paint shaker for 5 minutes to redisperse settled pigment. Component B was slowly added to component A, while hand mixing until a ratio of one-to-one by volume was achieved. The A/B components were mixed at low shear on a lab type paddle mixer for 5 minutes. The mix was then allowed to stand for 30 minutes prior to application. The viscosity without thinning was adequate for spraying, between 16 and 17 seconds on a #2 Zahn cup. The paint was strained through two layers of cheese-cloth while being added to the spray cup.

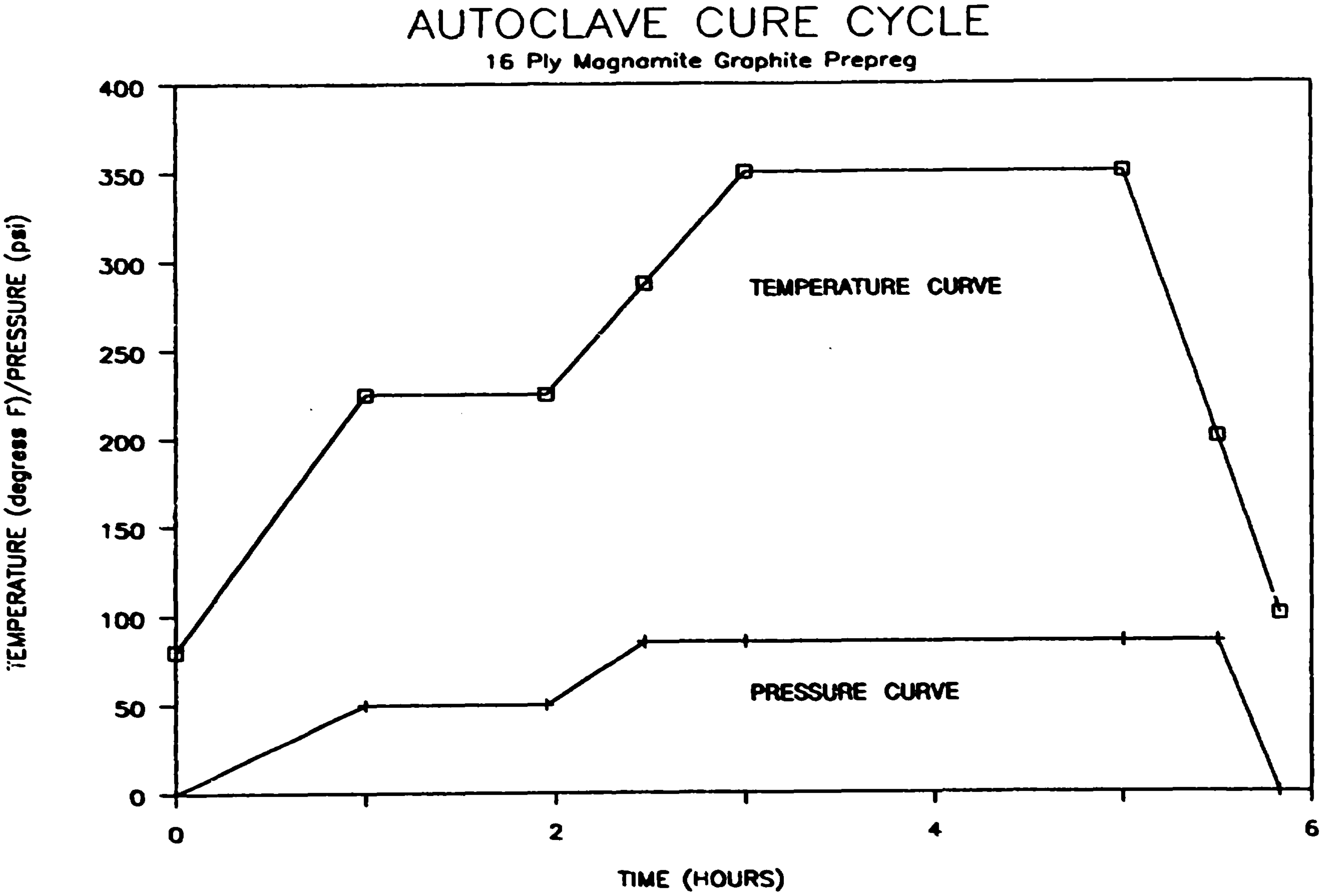

Figure 2.1 Autoclave Cure Cycle

Binks® conventional spray equipment with a pressure cup setup were used for application of the primer. A line pressure of 30 psi and cup pressure of 5 psi were used with a number 63 needle and nozzle combination. The primer was applied in single pass at a wet film thickness of approximately 2.5 mils having a dry film thickness between 0.6 and 0.7 mils. The primed panels were allowed to air dry for 2 hours before applying the topcoat.

Deft (Mil-C-83286B), 03-GN-74 Aliphatic Polyurethane Topcoat.
Component I was mixed on a paint shaker for 5 minutes to redisperse settled pigment. Component II was slowly added to component I while hand stirring until a ratio of one-to-one by volume was reached. The blend was mixed on a lab paddle mixer for 5 minutes. No induction period was required for this paint; however, we typically let it stand 20 minutes prior to application. The viscosity as mixed was approximately 17 seconds on the #2 Zahn cup and required no additional thinning.

Application was done using the same Binks equipment as the primer with the same setup and conditions. The topcoat was applied using two cross-coat passes allowing 15 minutes air dry between passes. The coating was applied to a total dry film thickness of 2.0 mils ±0.3 mils. Finish coated panels were air dried at 70°F and 50% RH for 7 days. A post-cure of 4 days at 212°F was done in addition to pre-age panels for testing.

2.3 Ultrasonic Testing of Composite Panels

All ultrasonic testing was done by Aerospace Testing Laboratory in Windsor, Connecticut. This subcontractor was chosen because of their broad knowledge of nondestructive inspection techniques, recognized quality, and willingness to work with us on a research-oriented project. They are approved by all major aircraft manufacturers and the Department of Defense.

The pulse-echo method of inspection was used with KB-6000 equipment. The probe had specifications of 10 Mhz, 1" focus, and 1/4" diameter. The final gain level selected was 25 dB. The threshold level was determined by cross-sectioning several panels where possible voids or delaminations were indicated. In essence, this was the calibration standard necessary with all ultrasound tests.

The submersion tanks originally used were filled with water which had been left to sit overnight to dissipate any air bubbles. This procedure was somewhat inconvenient because normally the tanks would have contained some Immunol 1228, a corrosion inhibitor for metals. Several mechanical and physical property tests were conducted on specimens exposed to 100% Immunol with no degradation. Based on these tests, subsequent submersion tanks contained 5% Immunol, which is standard practice at Aerospace Testing Lab.

The panels were placed on an aluminum disk and put into the immersion tank. As the disk rotated, the probe moved along the radius, and the plotter recorded the preset attenuation threshold. Panels with excessive void content and delaminations were not used in our studies.

2.4 Mechanical Testing of Composite Panels

To test for damage at the panel surface that is due to fiber breakage or matrix degradation, a flexure test was used. The flexure test is ideal for surface investigation because the outermost ply has the highest strain, and any surface damage will cause a greater decrease in flexural strength than that seen with pure tension or compression tests. Initially in our program, an investigation was conducted to determine whether the surface to be examined should be tested in tension or compression. Typically, a composite flexure specimen will fail in compression when the fibers, which are running lengthwise, break or buckle. We found this to be true for most of our trial tests. By putting the painted side of the specimen in compression, there will be a reduction in flexural strength if either the fiber or matrix is damaged and the specimen fails in compression. A tensile failure may still show a lower strength because of the loss of material on the compression side caused by the paint removal process.

The flexure tests followed ASTM D 790 procedures, Flexural Properties of Nonreinforced and Reinforced Plastics and Electrical Insulating Materials. ASTM D 790 is a three- or four-point bend test with a relatively long span causing the specimen to fail in flexure. The three-point method places the loading nose at the center of the specimen where the load peaks, making the influence of the nose on the failure an issue. To avoid the loading nose problem, we used the four-point bend method which has a region of constant highest load between the load noses. A span-to-depth ratio of 40 was used to ensure the proper failure mode. Initial tests with lower ratios resulted in some shear failures which are unacceptable. The specimen geometry was 1 inch (width) by 5 inches (length, zero direction) with a nominal thickness of 0.080 inches. The load span was 1.6 inches and the support span 3.2 inches. Both the load and support noses were 0.25 inches diameter stainless steel rods. The cross-head travel rate was set to produce a strain rate of 1% per minute on the outer fibers of the specimen.

Most of the panels were also tested for interlaminar shear strength using ASTM D 2344, Apparent Interlaminar Shear Strength Of Parallel Fiber Composites By Short Beam Method. This test is commonly used for quality control purposes and as a comparative test. It involves a three-point bend test with a very short span so that the specimen fails in shear as opposed to bending. The specimen geometry was 0.25 inches (width) by 1 inch (length, zero direction), with a nominal thickness of 0.080 inches. The support span was 0.70 inches. The load nose had a diameter of 0.25 inches, and the support noses were 0.25 inches. The cross-head travel rate was 0.05 inches per minute.

All specimens were measured before testing. Load versus deflection data was recorded for each test and after failure, the failure mode was recorded. All data and specimens were saved for further inspection if necessary.

2.5 Plastic Media Blasting of Test Panels

In the test program, plastic media blasting (PMB) was used on the control depainting process. The test panels were painted and depainted, using PMB four successive times. An Arthur D. Little engineer performed the actual depainting at an abrasive blasting equipment manufacturer, Empire Abrasive Equipment Corporation, in Langhorne, Pennsylvania. We performed the depainting in a FaStrip Pro-Finish blast cabinet, which is manufactured by Empire.

The plastic blast media used during testing was SolidStrip Type L, manufactured by E.I. duPont de Nemours and Company, Inc., in Wilmington, Delaware. This is a Type V media (acrylic - thermoplastic), as specified in the Naval Military Specification (MIL-P-85891[AS]). Type V media was chosen because of its combination of low abrasiveness and adequate paint removal rate. The media used had a hardness of approximately 3.5 MOH and a mesh size of 30 - 40 U.S. sieve size.

We performed the depainting according to Naval Specifications. To control the blasting parameters, the spray nozzle was placed in a stationary holding device. Specifically, the following blasting parameters were used:

– Blast Angles	70 degrees from the panel surface
– Standoff Distance	12 inches
– Blast Pressure	30 PSI at the nozzle
– Media Flow Rate	250 lbs/hr, using a 1/4-inch-diameter blast nozzle

Initially, the blast cabinet was thoroughly cleaned of all media and contaminants that may have been in the system. A weighed amount of media was then added. The nozzle was then set for the proper blast angle and standoff distance. Initial blasting (without test panels) was then performed to set the blast pressure. Blasting was then continued for approximately 20 minutes, so that the media could pass through the recycle system twice to remove any impurities that might be present in the media. At this point, blasting was stopped, and the recycle ports were opened to maximize media wasting. By maximizing wasting during the testing, we minimized the potential of paint chips and other impurities from entering the system and affecting test results.

The panels were then depainted. The test panel was placed on a horizontal surface and moved under the blast spray manually, using the primer-as-flag depainting method. In this technique, an area of the test panel was blasted until the green topcoat was removed, and the yellow primer was visible, at which time the spray was redirected to a new area. Depainting times and visual observations were recorded for each panel depainted. When the media in the system was depleted, more media was added and recycled for 20 minutes, as was done during startup. Depainting was continued until all the panels were depainted.

Figure 2.5-1 shows the PMB blast cabinet, and Figure 2.5-2 shows the cabinet interior.

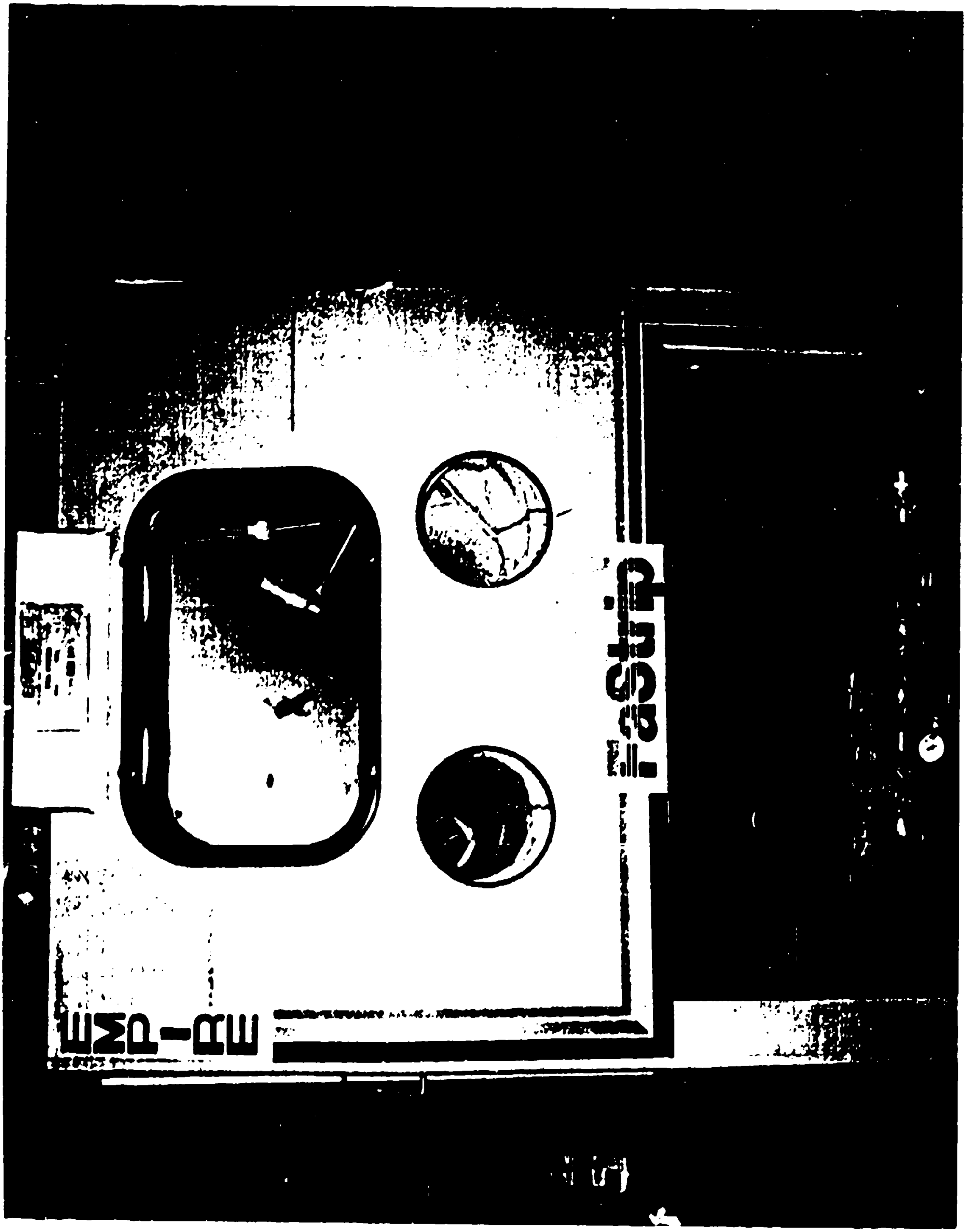

Figure 2.5-1 PMB Blast Cabinet Exterior

Figure 2.5-2 PMB Blast Cabinet Interior

3.0 Promising Paint Removal Technologies

3.1 Sodium Bicarbonate Blasting

Church and Dwight Company, Inc., (Princeton, New Jersey) and Schmidt Manufacturing, Inc., (Houston, Texas) have developed a blasting process which utilizes Armex (sodium bicarbonate) blasting media and Accustrip blasting equipment. The Armex/Accustrip system works in a similar manner to plastic media blasting (PMB) with the main difference being the substitution of a sodium bicarbonate and water blend for the plastic media. Potential advantages of the Armex/Accustrip system over PMB are minimal dust creation, minimal surface preparation, since the system removes oil and grease; the media is soluble in water, making it easier to separate hazardous waste; the process removes surface corrosion; it is nontoxic; and it is not a fire or explosion hazard. Currently, the major question concerning the system is whether or not the media will cause corrosion on metal substrates. The corrosion issue is being investigated by other sources, and this program focused on the ability of the system to remove paint and operate effectively in large-scale removal operations.

3.1.1 Initial Investigations

Three 12-ply epoxy-graphite composite test panels of alternating 0°/90° orientation were stripped by Church and Dwight using their Armex media and Accustrip II blasting equipment. The objective of this work was to determine initial feasibility of the process for stripping polyurethane topcoat (MIL-C-83286) from graphite/epoxy composite panels.

The following parameters were constant for each of the three composite panels:

Flow Rate - 2#/minute
Standoff - 12-16 inches
Angle - 70-80°
Nozzle Diameter - 5/16"
Media - Armex Fine Grade

The nozzle pressure was varied (20, 30, and 40 psig) for each of these panels.

The objective in stripping the topcoat from these panels was to terminate removal within the epoxy primer (MIL-P-23377) layer. Optimum stripping control was realized when all of the topcoat was removed, and no penetration through the primer and into the composite occurred.

The top three quarters of each of these panels were stripped to the epoxy primer or "flag" level to determine if the above stated objective was possible. The bottom quarter of these panels was stripped until all the topcoat and then all the primer was removed. This was done to 1) obtain an understanding of the removal of the epoxy primer and 2) study the effects the system has on the composite panel when stripping is performed beyond the desired end point.

Stripped panels were evaluated with both the naked eye and an optical microscope.

Results

Panel 1 -- This panel was stripped using a nozzle pressure of 20 psig. In the area stripped to the primer level, the removal appeared very effective overall. Essentially all of the topcoat was removed and minimal penetration (about 10%) to the composite occurred. The surface appears quite smooth and the process demonstrated effectiveness in using the yellow epoxy primer as a flag. In several isolated areas of the panel, penetration to the top surface of the first layer of fibers occurred. There appears to be some entrainment of the sodium bicarbonate particles in the primer, although a more powerful microscope will be required to verify this.

In the area stripped just through the epoxy primer, penetration occurred to the first layer of fibers over most of the area. Removal only to the gelcoat of the composite occurred in isolated areas. Approximately 95% of the primer was removed. This indicates that, at these operating conditions, the Armex/Accustrip system may be capable of effectively controlling primer removal with minimal damage to the fibers. However, further evaluation (mechanical property testing) is warranted to verify this result.

Panel 2 -- This panel was stripped using a nozzle pressure of 30 psig. Results were very similar to Panel 1 with a slight improvement in control.

Panel 3 -- This panel was stripped using a nozzle pressure of 40 psig. Results were very similar to Panel 2 with a slight improvement in control.

Church and Dwight believes that the increased stripping control with increased pressure is due to a shorter dwell time.

Church and Dwight also provided a video tape of these stripping operations. The basic process appears to assimilate plastic media blasting rather closely in that the process is very operator dependent, and paint is removed in a similar manner. The process appeared to be controllable (ability to stop at the epoxy primer). The removal rate of the primer was markedly faster than the urethane topcoat. Quite a bit of overspray (water and sodium bicarbonate) was observed.

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The following removal rates were calculated:

Panel	Pressure	To Primer	To Composite
1	20 psig	0.09 ft^2/min	0.05 ft^2/min
2	30 psig	0.13 ft^2/min	0.08 ft^2/min
3	40 psig	0.17 ft^2/min	0.06 ft^2/min

Based on these data, the removal rate increase was essentially proportional to the increase in nozzle pressure. These rates are low, but this can be expected in a "first-run" trial.

Conclusions

1. Initial feasibility of the Armex/Accustrip system for removing topcoat from epoxy-graphite composite panels was demonstrated.

2. The Armex/Accustrip system showed very good control capabilities for stopping within the "flag" or epoxy primer layer. Minimal penetration into the composite occurred.

3. Stripping rates were on the low side. Continued testing and optimization efforts are necessary to improve these rates.

4. Mechanical property testing needs to be performed to verify that no structural damage has occurred within the composite.

3.1.2 Initial Mechanical Property Testing

Sixteen-ply quasi-isotropic, epoxy graphite panels for mechanical property testing purposes were prepared and ultrasonically tested. They were subsequently stripped by Church and Dwight using a nozzle pressure of 40 PSIG, 12- to 16-inch standoff, 70- to 80-degree blast angle, and 2 lb/min flow rate with the fine grade medium. One panel was stripped to the epoxy primer or flag level, while the second panel was stripped until all the epoxy primer, along with the topcoat, was removed to simulate a worst-case situation.

Upon the return of these panels to Arthur D. Little, they were ultrasonically tested, recoated, and cured, as appropriate. Samples for mechanical property testing were then prepared. SEM examination was also performed on these test specimens.

Mechanical Property Testing

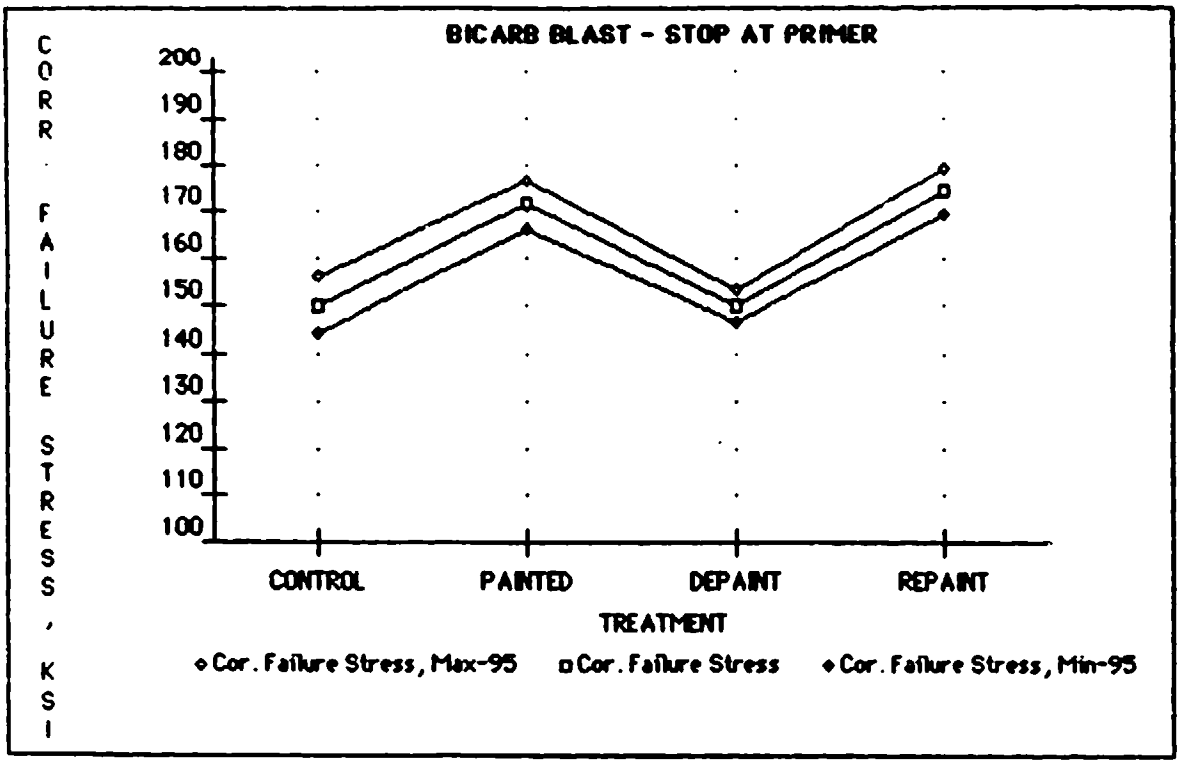
Flexure and Shear Test Results - Panels 60882-15-1 and -2

Results are presented in the attached tables of mechanical tests performed to evaluate the effects of paint removal methods. Four surface conditions were investigated for each of two panels. Note that the specimen lettering sequence is different from previous tests; however, the data is presented in the same order as before.

60882-15-1,2 -B uncoated panel (control)
-A primed and top-coated
-D -A and paint removed
-C -D and new primer and top coat

In all cases, the surface of interest was tested in compression. Figures 3.1.2-1 and 3.1.2-2 show the flexural and short beam shear data for these samples.

Neither process shows a statistically significant decrease in strength because of the single-paint removal process.



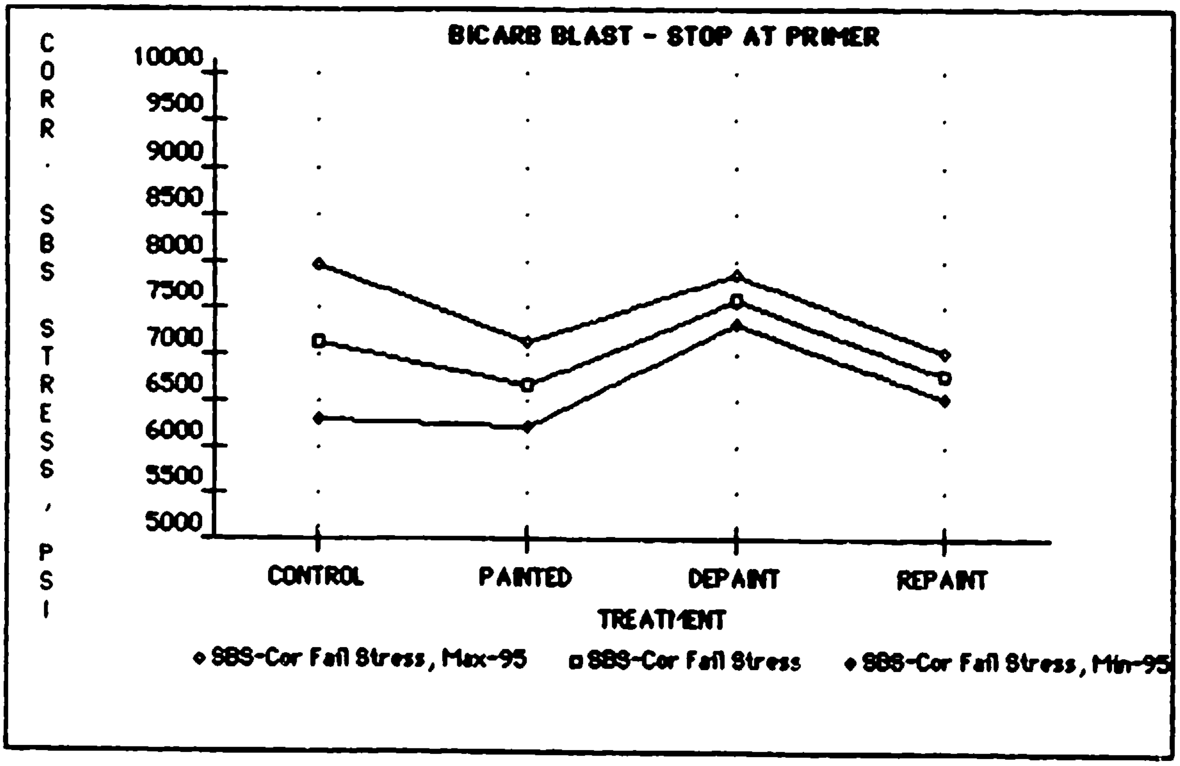
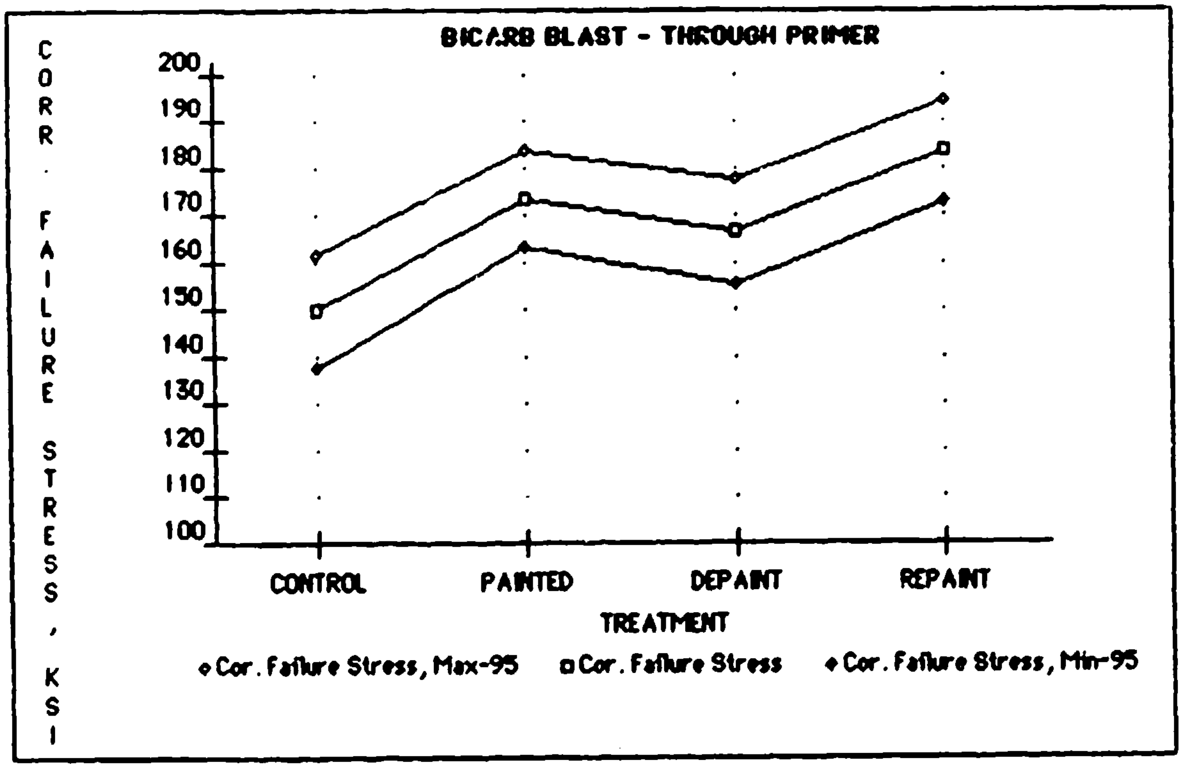


Figure 3.1.2-1 Bicarb Blast - Stop at Primer



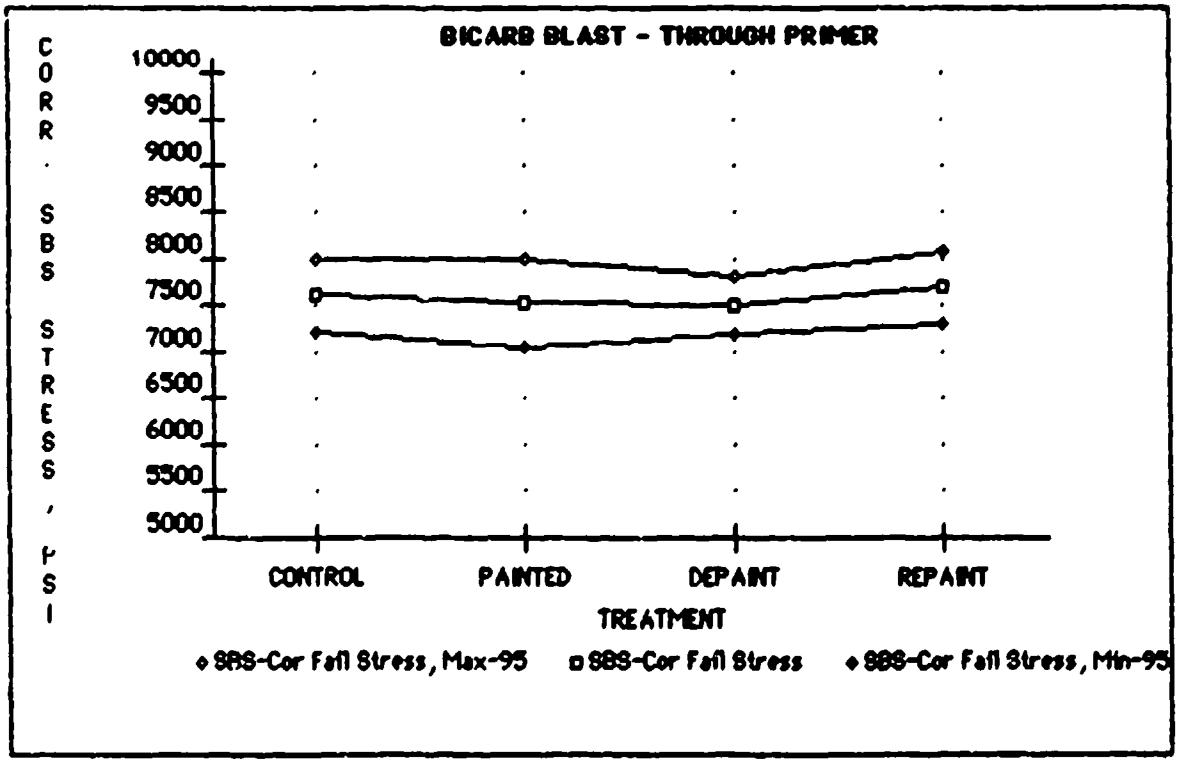


Figure 3.1.2-2 Bicarb Blast - Through Primer

Scanning electron microscopy (SEM) was used to evaluate the surface condition of each group within panel 60882-15-1 and -2. SEM was also used to evaluate panel 60882-13-2, which was stripped using a rotary sander. A description of the observations follows:

60882-15-1-B	Relatively resin rich with peel ply pattern visible.
60882-15-1-A	Bumpy but uniform and no large peaks or valley. Some areas flat and cracked.
60882-15-1-D	Rough with jagged appearance, uniform (stripped to primer)
60882-15-1-C	Similar to -A but rougher and some fiber particles.
60882-15-2-D	Fibers clearly visible (stripped to laminate). Minimal matrix damage, although significant removal. No fiber damage.
60882-15-2-C	Almost identical to 15-1-A but slightly rougher. No flat cracked areas.
60882-13-2-C	Very rough and nonuniform. Grooves visible. Minimal fiber damage.
60882-13-2-D	Identical to 15-2-C.

There is little correlation at this time of the surface condition and mechanical properties. Further investigation would be useful.

Overall, the results indicate that no damage occurred to the composite. As such, it appeared feasible to increase the pressure of the Armex/Accustrip system in order to increase the coating removal rate.

In an effort to increase stripping rates, discussions were held with Bill Spears of Church and Dwight Co., Inc. Because very minimal damage to the stripped panels was observed, it was agreed that an experiment using increased operating pressures should be performed. Other suggestions were to decrease the amount of water combined with the sodium bicarbonate, and to use a coarser grade media. We subsequently supplied Church and Dwight with 16 composite panels to use in this second parameter study.

In the first run, Church and Dwight focused on using increased pressures (up to 60 psi) with the fine-grade media in order to increase stripping rates. Bill Spears reported that progress was made, but stripping rates were still too low.

Next, Church and Dwight performed a parameter study using the coarse-grade ARMEX MPG blast medium. The testing was performed with and without the incorporation of water. Fixed parameters were a media flow rate of 2-lbs/minute, standoff distance of 18 inches, a #8 (1/2-inch) nozzle, and a primary blasting angle of 60 degrees, although lower angles were also used on occasion.

Significant improvements in stripping rates were achieved. Best results were obtained using dry blasting at 60 psig. Removal rates of about 0.70 ft^2/minute were achieved, which is four times the highest previous stripping rates of 0.17 ft^2/minute. The control of this system at these settings was good to very good. Removal to the primer occurred over about 75% of the panel. In areas where all the primer was removed, fibers were exposed but appear undamaged (optical microscope at 100X magnification).

In a subsequent discussion, Church and Dwight stated that using these parameters with the Armex/Accustrip system, the maximum stripping rates achievable on graphite-epoxy composites is about 1.0 ft^2/minute. He also requested additional composite panels. As such, we are preparing two 1-ft x 2.5-ft composite panels (which will be coated on both sides) for their use in the final optimization of the process.

In trial stripping of the two 1-foot by 2 1/2-foot graphite-epoxy composite panels, optimized conditions were found to be 60 psi blasting pressure, 2 pounds MPG media/minute (dry), 60° blast angle, and a standoff distance of 18 inches with the 1/2-inch nozzle.

Using these parameters, stripping rates of approximately 1 ft^2/minute were achieved. The control of the process was generally good, but varied somewhat from panel to panel. Penetration through the primer occurred in areas. Examination under an optical microscope showed that, in these areas, the resin rich layer was eroded and the first layer of fibers was exposed. Fiber damage appeared minimal.

The next panel stripped by Church and Dwight showed very good control with minimal penetration through the primer and a stripping rate of 1.02 ft^2/minute (Figure 3.1.2-3). A high-quality 16-ply quasi-isotropic test panel was also stripped for mechanical property evaluation, using the optimized parameters.

The flexural strength of this panel 4 is shown in Figure 3.1.2-4. No statistically significant reduction in strength was observed.

On June 22, 1989 at the "BOSS" Technical Interchange in San Antonio, a demonstration of the Armex/Accustrip system was performed at Kelly Air Force Base. A scrap (all-metal) tail piece was stripped. Stripping was performed at 50 to

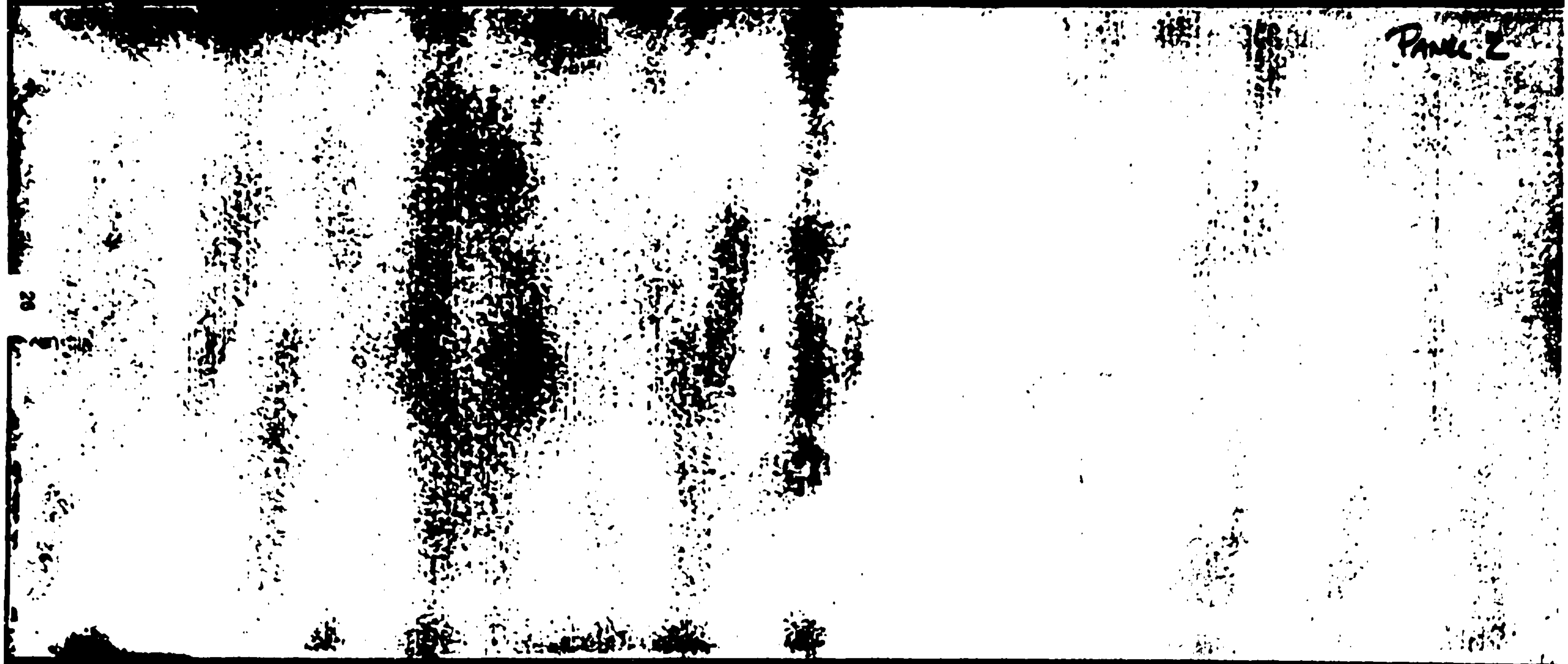


Figure 3.1.2-3 Bicarb Stripping

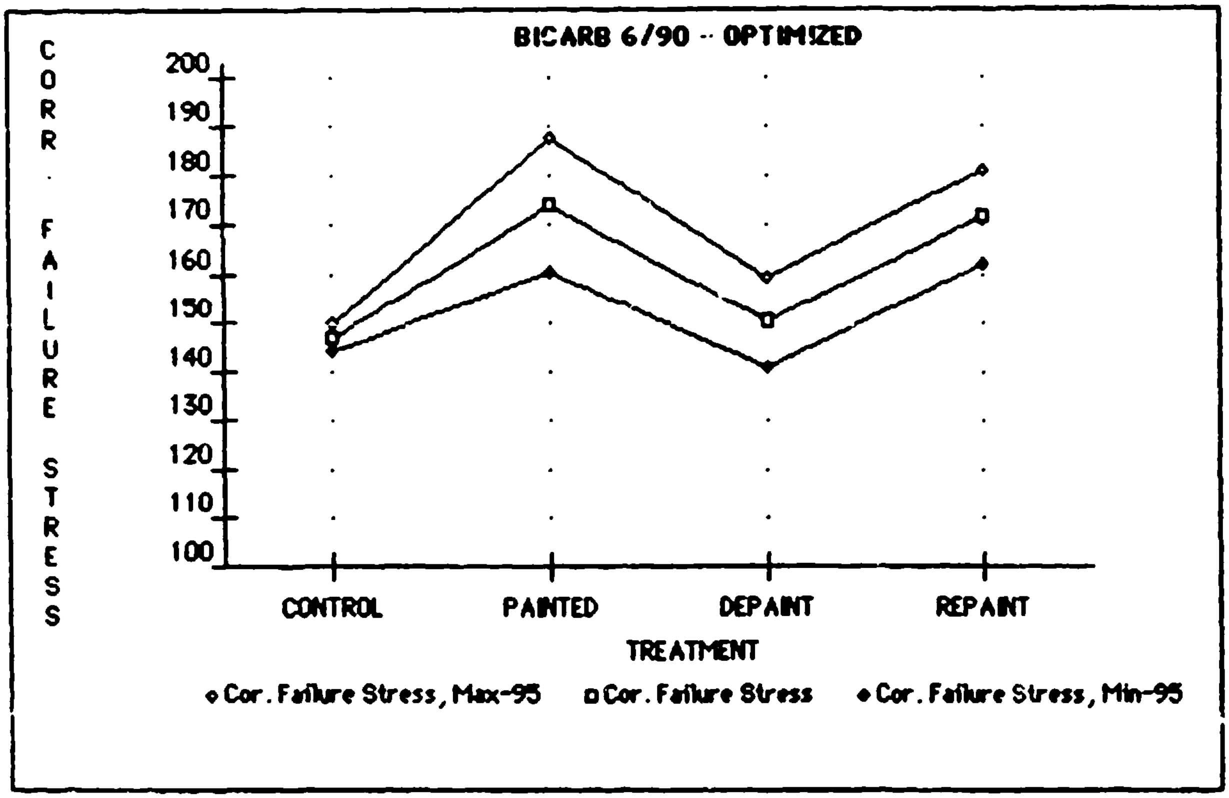


Figure 3.1.2-4 Bicarb 6/90 - Optimized

60 psig. The system removed topcoat and primer quite effectively (roughly 0.5 ft^2/minute). In areas where a decal was present, removal slowed significantly. Two metal (aluminum) surfaces--one soft, one harder--were encountered. The softer surface was roughened noticeably. The harder surface was left quite smooth. Removal around rivets appeared effective. The stripping process was loud (ear plugs required). A large overspray mist was created. Significant amounts of water and sodium bicarbonate were left on the ground surrounding the tail piece. Overall, the process appeared to work quite well.

Also at the conference, an environmental task group uncovered no significant environment or health hazards. The clear need in the environmental area for bicarbonate blasting revolves around the water-treatment system. The technology is available to contain the heavy metal particulates. Soluble heavy metal compounds should be extremely low, and dissolved sodium bicarbonate can actually be a benefit to the water treatment systems.

Conclusions

The results of our laboratory evaluation show that no statistically significant reduction in flexural or interlaminar strength after one complete cycle. The resulting surface is rather rough; however, typically 250 microinches RMS.

3.2 Carbon Dioxide Pellet Blasting

Until recently, carbon dioxide pellet blasting systems have been used primarily as a cleaning process. It is very effective in removing many types of surface contaminants including: grease, tars, dirt, asphalts, and various chemical residue. In this approach, liquified carbon dioxide is allowed to flash into snow-type crystals. The "snow" is then compressed and extruded to the pellet size desired. These pellets are then blasted onto the surface to be cleaned, and upon impact the pellets vaporize, leaving only the removed surface contaminants as waste. There are several theorized removal mechanisms; 1) purely impact/abrasion, 2) purely by embrittlement, and 3) a combination of impact and embrittlement.

Initially, the following companies were contacted regarding potential removal of the paint, using the carbon dioxide pellet blasting system:

- Del Crane Corporation (Milford, Ohio)
- Airco Industrial Gases (Murray Hill, New Jersey)
- Liquid Carbonic Inc. (Chicago, Illinois)
- Lockheed Aeronautical Systems Company (Burbank, California)
- Alpheus Cleaning Technology Corporation (Rancho Kugamunga, California)

The general consensus of these companies was that the system was not aggressive enough to effectively remove polyurethane coatings. The system has removed paint in some instance, but these tended to be inherently brittle or weakly bonded coating systems. A potential use for the system in paint removal operations would be as a surface preparation device for the composite material prior to coating, or for the epoxy primer after completion of a paint removal operation.

Personnel at military facilities who have had experience with CO_2 pellet blasting systems were also contacted. Overall, the feeling was that the polyurethane topcoat was too flexible, abrasion-resistant, and impact-absorbing for the CO_2 pellet blasting system.

Finally, Cold Jet, Inc., of Cincinnati, Ohio, was contacted regarding the CO_2 pellet blasting system which they were developing. The system was reportedly able to remove the urethane topcoat from metals and composites without causing any damage to these substrates. Cold Jet explained that the mechanism for material removal is totally nonimpact, as the carbon dioxide pellets sublime prior to reaching the substrate. It is the heat-transfer phenomena which results in material removal. Because the atmosphere which reaches the substrate surface is so much colder than the substrate, it pulls large amounts of heat from the substrate surface layers. This creates a condition where the immediate top surface layer is much colder than the layer immediately below it. As such, the chemical and physical bonds between these layers relax, and the removal of the top layer is facilitated. This phenomena is known as fracking.

Cold Jet has completed an initial trial involving the removal of topcoat from aluminum panels. Larry Jones, Director of Sales and Engineering for Cold Jet, reports that they were able to remove the paint, but the operator misunderstood the stopping point and penetrated through the primer in much of the removal area. As such, Mr. Jones has requested a second set of panels to repeat the experiment. Coated aluminum and composite panels were subsequently sent to Cold Jet.

Larry Jones also stated that the final report evaluating their systems ability to strip Boeing specification paint from aluminum has been completed. The report will be released to us pending an explanatory meeting with Cold Jet and Liquid Carbonics, who sponsored the work. Arrangements for this meeting are being made.

The use of various blasting pressures and mass flow rates with this system is to provide the necessary amount of heat transfer between the sublimed carbon dioxide "atmosphere" and the top layer of material, so that fracking occurs. Cold Jet adds that removal tends to occur layer by layer, as opposed to break-up within a layer (i.e., the entire polyurethane topcoat layer should be removed from the epoxy primer layer all at once). The major advantage that the Cold Jet system has over other carbon dioxide pellet blasting systems is that the pellets are super-cooled to -110°F. Other systems function at the freezing point temperature of the CO_2 pellets (-40°F) and do not provide the heat transfer that the Cold Jet system achieves.

On October 19, 1989 a meeting was held at Cold Jet, Inc., to discuss and demonstrate the Cold Jet carbon dioxide pellet blasting system. Key points made by Cold Jet during the discussion were:

- The Cold Jet system has three primary applications - cleaning, paint stripping/surface preparation, and as a material-processing tool.

- The Cold Jet system is superior in many aspects to other carbon dioxide pellet blasting systems, because of their rectilinear nozzles, which minimize leading and trailing edges and maximize blasting efficiency, the 700-lb/hr maximum capacity, and super-cooled (-110°F) pellets for increased efficiency. In addition, the Cold Jet systems are capable of converting about 52% of the liquid carbon dioxide to pellets in a given cycle (with recycle, essentially 100% can be converted), while other systems typically convert only 40% per pass.

- The Cold Jet System operates at a noise level below 130 dB; however, the Air Force requires less than 85 dB. The Alpheus system operates above 130 dB.

- The carbon dioxide pellets produced by the Cold Jet system are 1.5mm in diameter and 3mm in length. Three densities of pellets are available - low-density = 75-85 lb/ft^3, medium-density = 85-92 lb/ft^3, and high-density = 92-97 lb/ft^3. The density of the pellets is varied with a machine adjustment.

- No part deformation (warping) has been observed as a result of the significant thermal cooling that the parts receive from the CO_2 pellets.

- Thicker coatings are often removed faster (than thinner coatings) as a result of the fracking mechanism. The paint residue from the stripping process is comprised of varying size particles, but can be typically described as fine and dust-like.

- Standoff distances and blasting angles are not as critical as with PMB.

- Hose lengths up to 300 feet have been used with minimal temperature losses.

- A range of Cold Jet systems is available dependent upon the application. The cost of the smallest Cold Jet system is $144,000. A liquid CO_2 (300 psi, 0°F) source and a propellant source are also needed. These typically cost about $40,000. Operational costs are $12 to $60/hr.

- No breathing problems have been observed (oxygen displacement), although ventilation is recommended in smaller areas of operation.

- The system removes material by a combination of thermal and kinetic effects. The degree to which each is effected can be varied depending on the application.

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- No breathing problems have been observed (oxygen displacement), although ventilation is recommended in smaller areas of operation.

- The system removes material by a combination of thermal and kinetic effects. The degree to which each is effected can be varied depending on the application.

- Good paint removal results have been achieved on composites. However, some composites are not compatible with the Cold Jet system. For example, when removing paint from radomes, some damage to the radomes has been observed.

- The bond strength of materials applied to surfaces which were previously stripped with the Cold Jet system have been reported to be 108% to 110% higher than the original bonds. This indicates that the system is an effective surface-preparation device.

- At present, no Cold Jet systems are being used by the military.

- An effective carbon dioxide pellet blasting system for paint removal from aircraft will require robotic operation, and a suitable feedback vision system.

A demonstration of the Cold Jet system was performed. There were two main components to the system: the carbon dioxide pellet "generator and supplier," and the robotically controlled delivery system. The delivery system manipulated the nozzle in the x-y-z directions. Key control parameters for the delivery system were distance and angle from the substrate, traversing speed and scan rate, mass flow rate, and pressure at the nozzle.

The first item stripped was a 2-foot by 2-foot aluminum panel with a coating that was identified as being an epoxy, although the coating was fairly soft. The Cold Jet system was able to effectively remove the coating at a fairly good rate. Minimal surface damage to the aluminum was observed.

Next, we attempted to strip an epoxy-graphite panel with the standard epoxy primer and urethane topcoat. Initially, the Cold Jet system was run at "low pressure and mass flow rate" to insure that the panel was not damaged. This resulted in no noticeable removal of topcoat. Over several additional trial runs, the settings were increased and the distance between the nozzle and the panel was reduced to facilitate removal. However, topcoat removal was ineffective. At this point, it was decided that operating conditions for effective removal would have to be further studied at a later time.

Coated aluminum test panels were provided to Cold Jet, Inc., so that a parameter study could be performed. The result of this study was the successful removal of the topcoat and primer. Examination of the panels and the videotape revealed the following:

1) The Process - The system used in this trial was a Cold Jet Model 65 Pelletizer. The pellets were delivered through a 1.5-inch-wide rectangular nozzle which was controlled by a robotic arm. The following operating parameters were used:

Pressure at nozzle - approx. 225 psi
Standoff distance - 2 inches
Nozzle angle - 80 degrees
Traversing speed - 0.75 to 1.25 feet per minute

The removal in a given area was achieved with a single pass of the nozzle. Panels were taped onto a horizontal table during the removal process.

2) Composite panel - An area of approximately 3 inches by 10 inches on this composite panel was stripped. The nozzle traversed the panel at a speed of about 1.25 ft/minute. The width of each pass was approximately 1.5 inches, providing a removal rate of about 0.16 ft^2/minute. Although the large majority of paint was removed, the ability of the system to stop within primer layer was not demonstrated. In fact, in the areas where the paint was removed, penetration was often to the first

or second layer of fibers. The level of penetration was very variable. That is, penetration was most often to the second layer of fibers, somewhat less often to the first layer of fibers, and occasionally to the gelcoat or topcoat (no penetration). Penetration to the epoxy primer layer was very limited. Material removal tends to occur in layers (i.e. either complete or no removal occurs within a given layer - topcoat, primer, gelcoat, and composite ply).

It appears that the operating conditions were too severe for the composite panel. In addition, it appeared that it would be helpful to perform this paint removal operation using more than one pass with the nozzle. Unfortunately, the removal rates were also on the low side. Therefore, reduction of operating parameters to improve the control of the level of penetration would most likely decrease the removal rates. Overall, the Cold Jet system did not demonstrate the ability to remove paint from graphite-epoxy composites with the required control and speed.

3) Aluminum Panel - An area of approximately 1.5 inches by 11 inches was stripped with one pass of the blasting nozzle (80 seconds). This provided a traversing speed of 0.75 ft/minute, and a removal rate of about 0.1 ft^2/minute. Complete removal of the topcoat and primer occurs over essentially the entire removal area, which is acceptable with aluminum substrates. Very small pieces of primer and sometimes topcoat remained sporadically over the removal surface. The surface of the aluminum did not appear to be damaged. Overall, the Cold Jet system demonstrated the ability to remove the topcoat and primer without damaging the substrate, but did not remove the paint with the required rates.

Our analysis was subsequently discussed with Cold Jet, and we decided that an additional trial should be performed to optimize the operating parameters, particularly with epoxy-graphite composites. Feed rate, blasting pressure and rate of traversing are the key parameters to be optimized. Cold Jet reported that their work with composite materials supplied by Boeing required a fairly extensive parameter study to arrive at the proper operating conditions, and that upon completion of the work, excellent results were achieved.

In regard to the low stripping rates, Cold Jet indicated that the use of a wider (up-to-4-inches) nozzle and the optimization of blasting parameters should improve the rates.

Subsequently, Cold Jet Inc. performed a parameter study on two 1-foot by 2 1/2-foot graphite-epoxy composite panels which had been coated on both sides. Cold Jet determined that the best parameters for stripping these panels were 200 psig air pressure, 90° blast angle, and approximately a 2-inch standoff distance. A hand-held, 25-inch by 180-inch nozzle was used.

Using these parameters, a square-foot area of the panel was stripped in approximately 3 minutes, producing a stripping rate of 0.33 ft^2/minute. The process was completely unable to terminate stripping in the primer layer. Damage to the resin-rich layer of the composite was significant, although the "weave-pattern" was still visible in areas (Figure 3.2-1). Penetration to the fibers occurred in many areas, and in a few areas delamination of plies was evident. The use of these operating parameters reduced the damage to the composite (compared to earlier trials), but the control of this process on graphite-epoxy composites is still very questionable and appears unsuitable. In addition, the surface was quite rough, typically 2.0 microinches RMS.

Conclusions

The Cold Jet CO_2 pellet blasting system has been able to successfully remove the topcoat and primer from aluminum panels. However, the system has not been able to successfully remove coatings from graphite-epoxy composites. At this point, it does

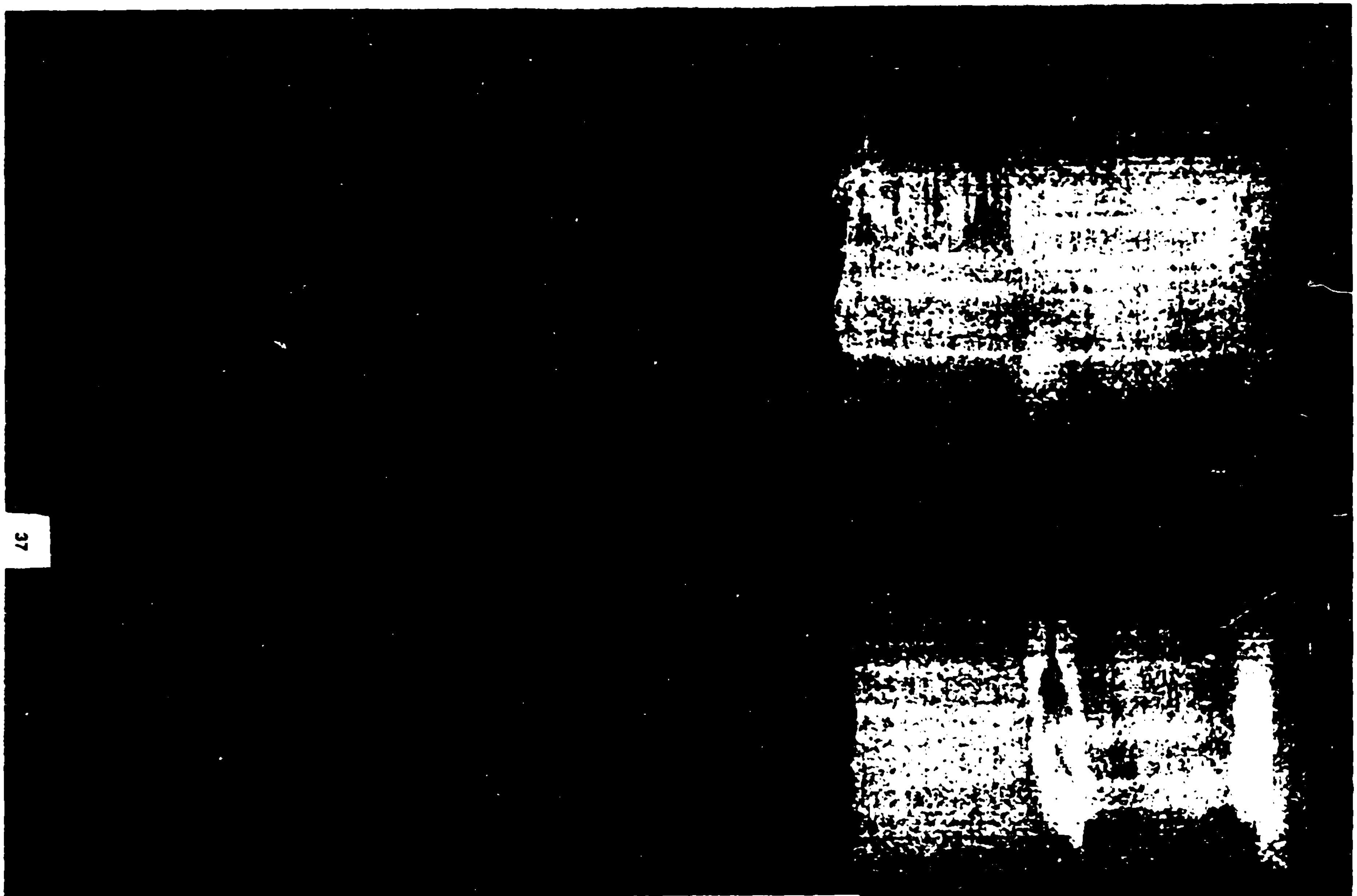

Figure 3.2-1 Carbon Dioxide Pellet Blasting

not appear feasible to use this system on epoxy-graphite composite components on aircraft.

3.3 Excimer Laser Paint Stripping

The use of excimer lasers to strip painted surfaces is an innovative approach to laser paint removal. Numerous reports in the literature describe previous studies of laser paint stripping, especially with infrared lasers based on CO_2 and Nd: YAG[1-11]. Excimer lasers are pulsed lasers which operate in the ultraviolet region of the spectrum (400 - 200 nm). As a result, they are capable of removing coatings with a minimal amount of heating and a high degree of precision. The mechanisms by which excimer lasers remove coatings is known as ablation. Ablation is the high level of absorption of UV energy by very thin layers (0.1 to 0.5 μm) of organic materials and the subsequent decomposition and ejection of these layers from the bulk material. Because this is not primarily a thermal mechanism, local temperature increases and charring is minimized. Excimer lasers typically operate at peak power levels of about 250 watts, although more powerful laser systems are being developed. The wavelength of the light beam emitted by the excimer laser is determined by the type of gas that the system is using. Typical wavelengths are F_2 (157 nm), ArF (193 nm), KrCl (222 nm), KrF (248 nm), XeCl (308 nm), and XeF (351 nm). Material removal efficiency is greatly affected by the wavelength, pulse rate, and fluence level of the laser. Fluence level is the amount of energy per unit area which is delivered by each pulse of the laser to the removal surface. Each material surface possesses its own optimum fluence level at which it decomposes and ejects (ablates) from the surface. We believe that operation just slightly above the fluence level of a material will provide optimum results (i.e., effective material removal with minimal surface heating).

The major drawback to excimer lasers, at this time, is their relatively low removal rates. Because a relatively small volume of material is removed with each pulse, many pulses are required to remove significant amounts of material; and thus, rates are low. However, this problem could be solved by the ongoing development of more powerful lasers.

3.3.1 Industry Survey

The objective of this industry survey was to acquire information on excimer lasers and their potential effectiveness in stripping aircraft coatings from composite materials. Key representatives of industrial excimer laser manufacturers and testing facilities were contacted and interviewed. These included representatives from Lambda Physik, Inc.; Questek, Inc.; Lumonics, Inc.; XMR, Inc.; Oak Ridge National Laboratories; General Electric; AVCO Research Laboratories; and Cymer. Main topics in these conversations were the feasibility of using excimer lasers to strip coated composite panels, existing equipment and facility capabilities, and recommended approaches to a test program. Overall, a general agreement of views was found. Key points made were:

1. Excimer lasers are capable of removing paint from aircraft with the precision required. That is, the polyurethane topcoat can be completely removed, and penetration by the laser would terminate within the epoxy layer. The "waffle pattern" on the surface of the composite may create a problem; however, leveling of the surface prior to the primer and topcoat application would alleviate this problem.

2. The ablation mechanism by which excimer lasers remove material would create minimal heating and charring. As a result, stress effects that are due to heating of the composite panel should be negligible.

3. Removal rates with existing excimer laser equipment would be on the low side. The desired 1 ft^2/minute would be very difficult to achieve. Estimated removal

rates were typically below 0.5 ft^2/minute using a 100-watt excimer laser. Once operating parameters are optimized, the rates can only be improved by using either a more powerful laser and/or a higher pulse rate.

4. Excimer laser equipment is comparable in price to CO_2 laser equipment. Currently, the maintenance of excimer lasers is significantly more expensive. The gases used with excimer lasers are expensive and need recharging at times (Lambda Physik estimates a recharge is required every 5×10^8 pulses with their 60-watt laser). This typically costs about $10,000 per recharge.

5. Initial testing of excimer lasers on coated composite panels should be performed in an applications laboratory in a two-phase program. First, the excimer laser operating parameters (power level, energy density, wavelength, pulse rate, etc.) would be optimized for stripping of the polyurethane topcoat. Once this was accomplished, actual stripping rates could be determined. Next, coatings could be routinely removed from composite panel for mechanical property testing and other evaluations.

6. Manipulation of the beam to provide uniform paint removal should be easily accomplished on a small panel in a laboratory environment. The large size and irregular shape of an aircraft would be much more difficult to strip uniformly.

7. The excimer laser system required to strip an aircraft would have to be robotically controlled. Because a very large excimer laser would be required to achieve the desired stripping rates, it would not be very mobile. As a result, the beam delivery system would be the manipulated component of the system. This could be accomplished by the use of robotically controlled beam tubes containing a series of mirrors and lenses.

8. Other factors of concern with excimer lasers, as well as the other types of lasers, are toxicity and disposal of byproducts, operator safety, and the sensitivity of the equipment.

9. Implementation of an excimer laser system to remove paint from aircraft is long-range, as much testing needs to be done, and equipment (excimer laser of required power and robotics) needs to be developed.

3.3.2 Initial Composite Panel Paint Stripping Trials

Questek

A coated composite panel was provided to Questek for preliminary excimer laser paint removal. Prior to the stripping trials, the following key points were made:

1. With excimer lasers, the substrate is of little importance, as far as its effect on material removal, because material is removed layer by layer.

2. Removal rate of most organic materials is approximately the same. Therefore, uniform layers of material will be removed no matter if the layer is urethane topcoat, epoxy primer, epoxy matrix resin, or a combination of these. However, the pigment volume content (PVC) of the paint may affect ablation rate.

3. Excimer laser power is currently more difficult to scale-up than a CO_2 laser. Presently, the power cap is around 150 watts. Questek believes it is unlikely that excimer lasers will be produced with power in excess of 1 KW.

4. The UV absorption characteristics of the coated composite panel need to be considered as part of a systematic evaluation.

5. Excimer lasers are commonly used for pumping dye lasers, research, medical (ophthalmology) applications, material processing, and as marking devices.

Initial paint removal trials were undertaken in Questek's applications lab. The excimer laser used was a Questek 2000. It has a maximum power output of about 75 watts. However, it operates continuously at 50 watts.

This laser has six gas sources which operate at different wavelengths: F_2 (157 nm), ArF (193 nm), KrCl (222 nm), KrF (248 nm), XeCl (308 nm), and XeF (351 nm). Each gas type has a different supply life (e.g., KrF ≈ 2-3 days, XeCl ≈ 1 week) before a recharge is necessary.

The excimer laser works by mask imaging--that is, the beam is projected through an opening, the geometry and size of which determines the geometry and size of the footprint. The beam first passes through a focusing lens, then the mask, then two more focusing lenses, and finally onto the panel. A secondary beam of visible light from a neon-argon laser is used to align the optics and focus the beam.

The laser itself, its power source, and all other subsystems are contained in a housing approximately 2 feet tall by 3 feet wide by 5 feet long. Once the beam leaves the housing, it travels through a series of lenses which are appropriately positioned on an optical bench. The optical bench is mounted on an "air" table which minimizes vibration.

The panel was placed in a holder on a programmable x-y stage. The panel was then properly positioned in front of the laser by operation of the stage. The mask imager was adjusted to deliver a footprint of 0.1 inch by 0.2 inch -- the maximum footprint attainable with this set-up was 0.2 by 0.4 inch. Mask size was about 1/4 inch by 1/2 inch. A krypton fluoride laser operating at 248 nm was used in this trial.

Test 1

The first test was performed at 1 pulse per second, so that removal could be closely monitored. Each pulse created a microexplosion at the surface of the composite and a blue plasma, and small amounts of smoke were generated.

The laser was allowed to fire 10 pulses, and then an observation of the material was made through an optical microscope. It was obvious that topcoat was being removed in a very exact manner (rectangular shape and very sharp edges).

The laser was then allowed to run until the yellow primer first became evident (about 70 pulses). At this point, the removal process was viewed through the microscope. With each pulse, more and more primer became visible. The process was stopped after about 100 pulses, and the surface was about 95% free of any topcoat. Only very small dots of topcoat remained, primarily in the "valleys" of the composite's waffle-pattern. (See Figure 3.3.2-1)

The excimer laser removes all types of organic material with essentially the same amount of depth of penetration. If there is topcoat below a peak in the composite material (waffle pattern), the part of the peak higher than the topcoat will be removed if all the topcoat is removed--that is, the excimer laser penetrates layer by layer with minimal material differentiation.

At greater than 60 repetitions, a dark ring of soot became visible around the outside of the rectangle of removed material. This soot could be easily removed with a light scrape. Similar soot deposits have been reported previously.[1-2]

Each laser pulse had a power of about 400 mJ/pulse as it left the equipment. It was estimated that about 70 mJ reach the surface of the panel, because of the masking and reflection at the lenses.

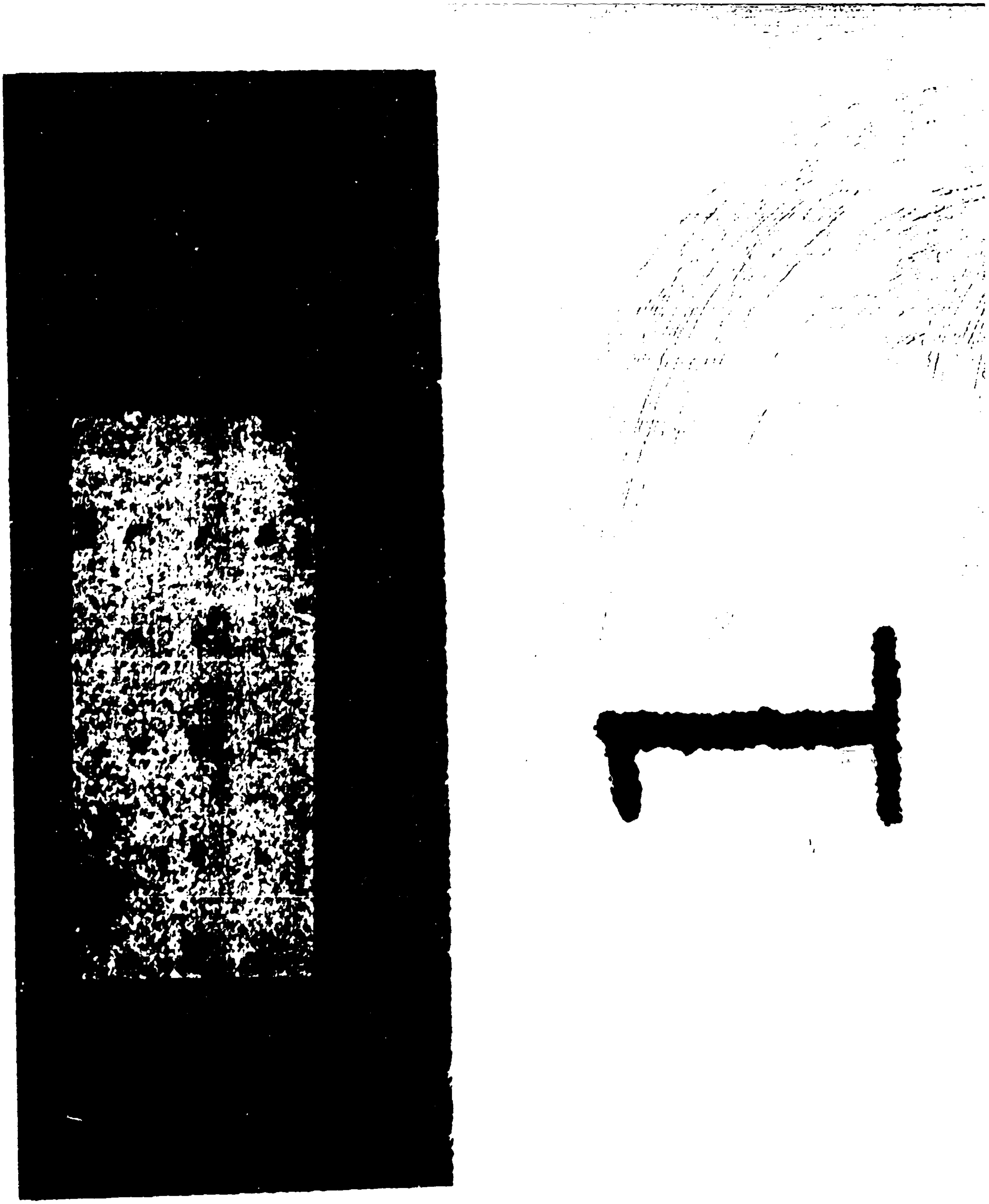

Figure 3.3.2-1 Questek - Test 1

Test 2

The pulse rate was 20 Hz, and the entire exposure was approximately 5 seconds. Results were essentially the same as Test 1.

Test 3

The pulse rate was 50 Hz, and the exposure time was about 2 seconds. Results were essentially the same as Test 1.

Test 4

The removal performed on this area was to demonstrate what would happen if the laser was held slightly too long in one position. It was accomplished by using a pulse rate of 50 Hz and exposure time of about 3 seconds. Epoxy-graphite composite material was clearly visible in about 50% of the exposed area. Depth of penetration appeared constant along the surface of this area. (See Figure 3.3.2-2)

Test 5

This test was done with the intention of going well past the epoxy layer and into the composite material. It was accomplished at 50 Hz with a 4- to 5-second exposure. Material removal appeared uniform, and penetration was into the first layer of fibers. (See Figure 3.3.2-3)

Figure 3.3.2-4 shows all five test areas.

Power Level and Removal Rate

A pulse rate of 100 Hz would require about 7 watts. Therefore, with a 70 W laser, about 10 times this amount could be done every second. The size of the rectangle is approximately 0.1 inch by 0.2 inch. It was also estimated that with all parameters (wavelength, image size, optics, etc.) optimized, it would be possible to double the removal rate. This would provide a removal rate of about 0.17 ft^2/minute.

Figure 3.3.2-2 Questck - Test 4

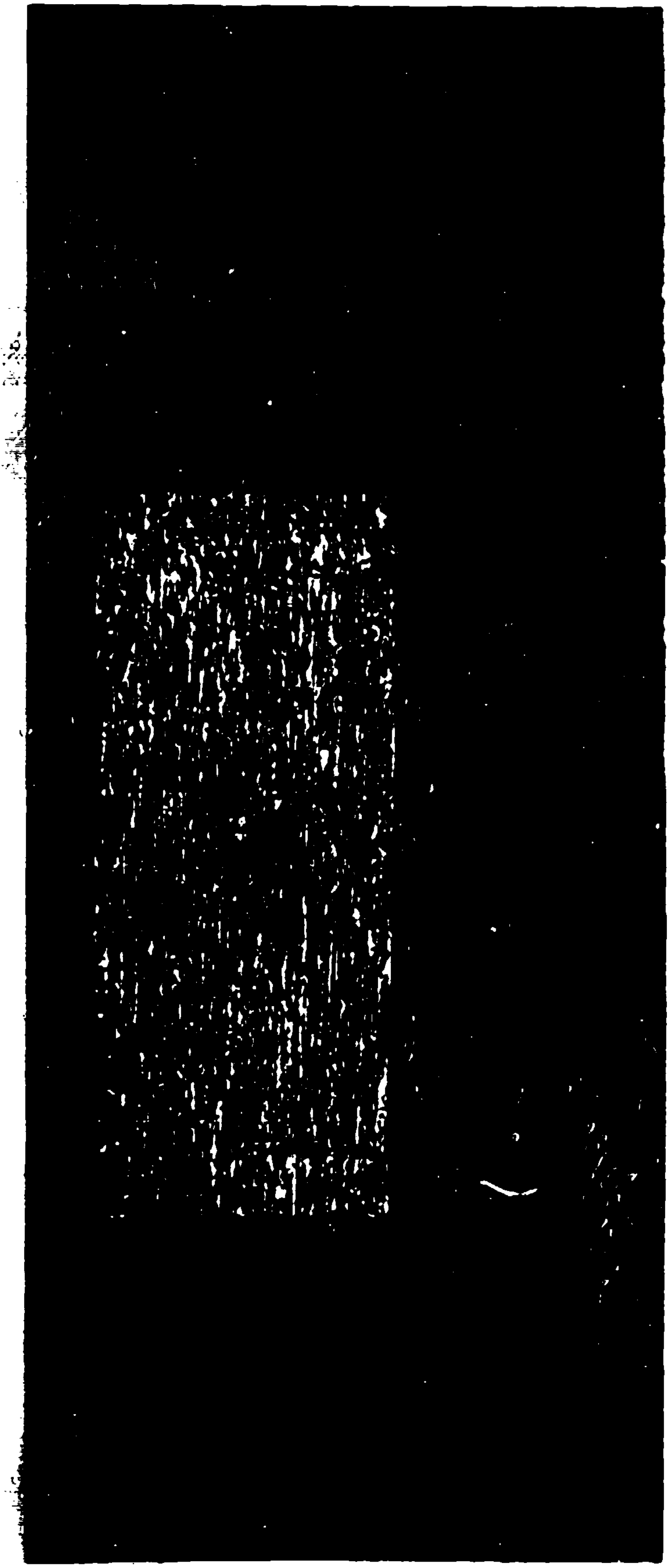

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Figure 3.3.2-3 Questek - Test 5

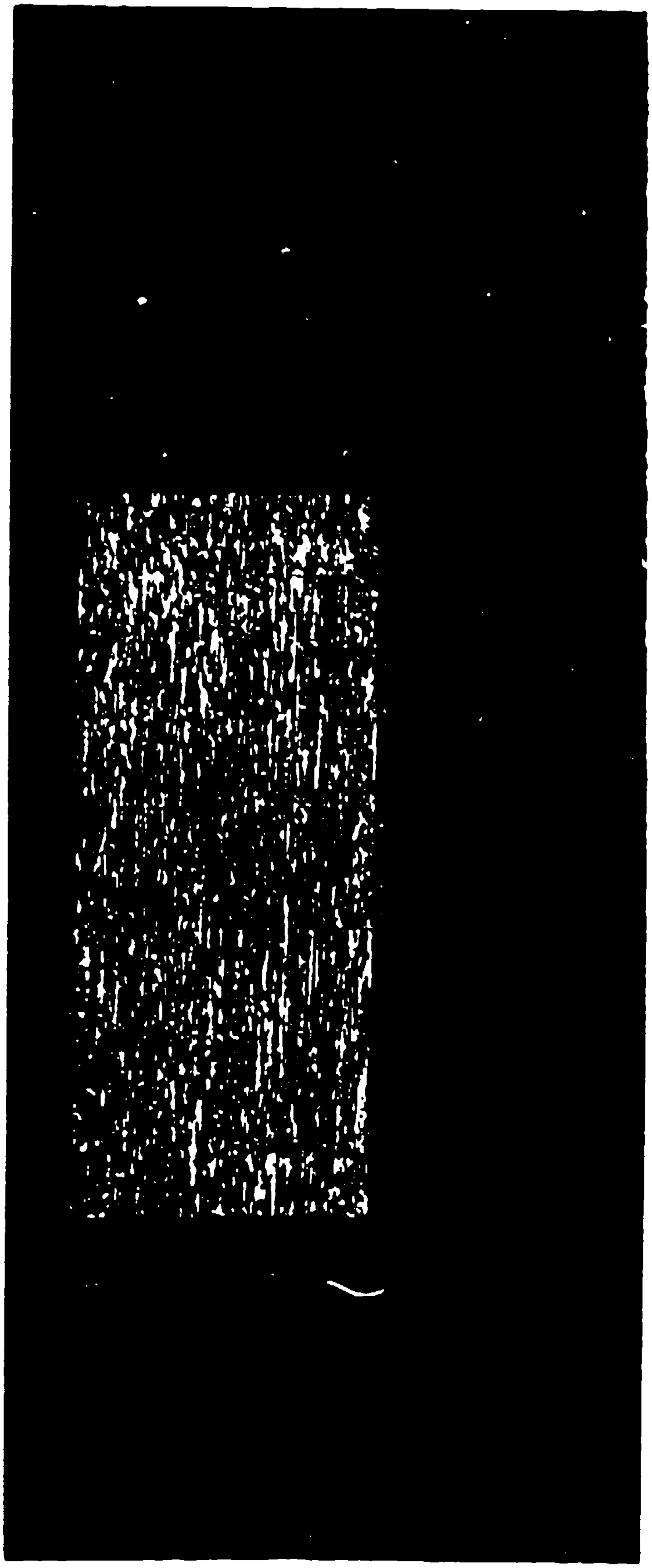

Figure 3.3.2-3 Questek - Test 5

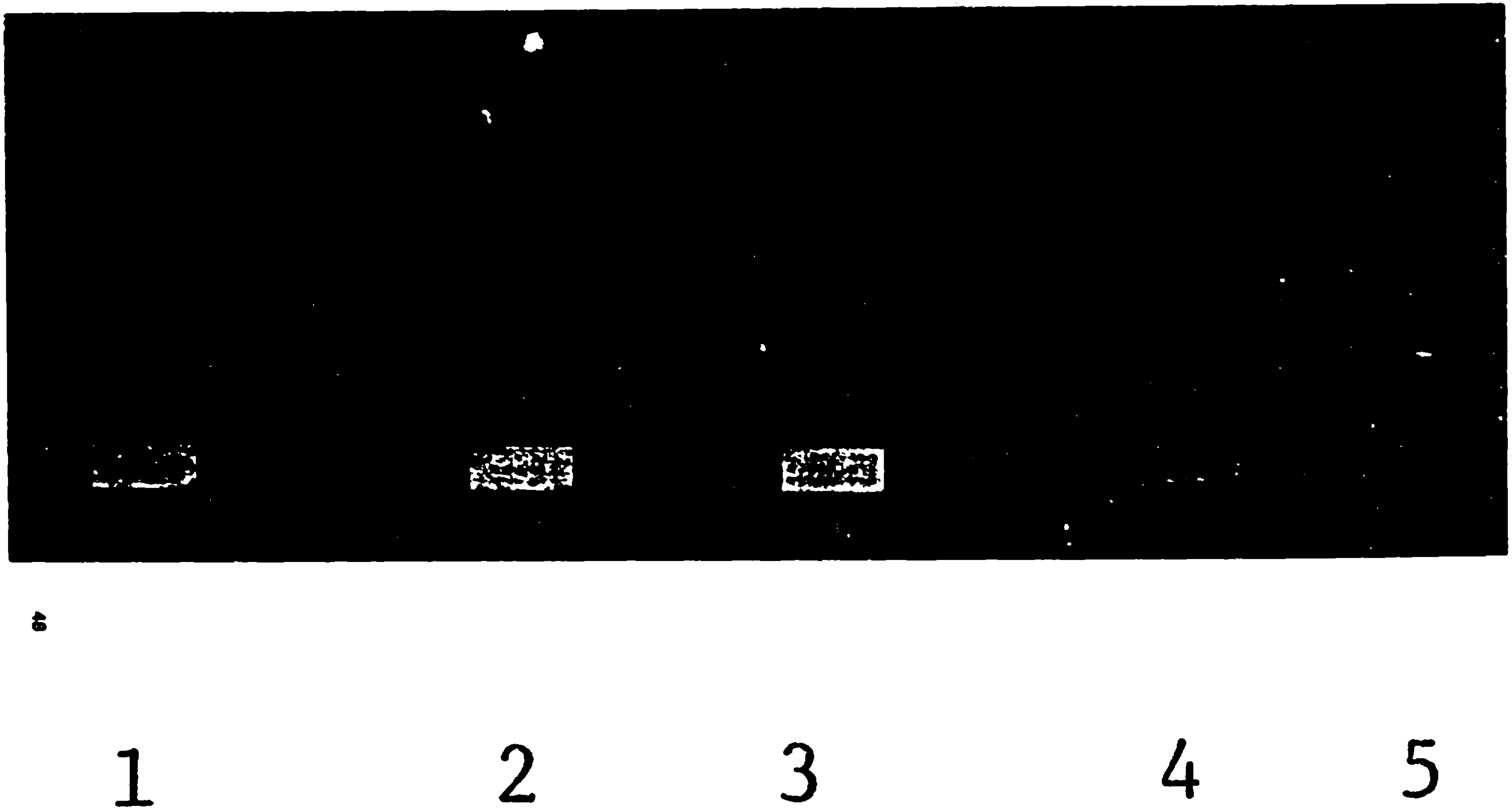

Figure 3.3.2-4 Questek - Tests 1-5

Questek observed that at this time, excimer lasers may not be feasible for stripping an entire airplane but may be very useful for specific "hard-to-strip" or "delicate" areas and parts. Waste products should be similar to those from paint removal operations using a CO_2 laser.

Safety

Eye protection is needed at all times. Skin should be protected when working with an excimer laser for long periods of time (more than 1 or 2 hours). "Sunburns" can result from indirect exposure. A quick direct exposure would probably be harmless. However, if human tissue were held in front of the beam, it would be removed at about the same rate as the topcoat.

Overall, the precision of the excimer laser was exceptional. No method, observed to date, has possessed the control and precision of an excimer laser. Removal rates are on the low side. Leveling of the composite surface prior to primer and topcoat application would provide excimer lasers the capability to terminate stripping without penetrating into the composite.

Lumonics

Lumonics performed paint removal trials using their Index 200 excimer laser - Model 200-K. The gas used was krypton fluoride (248 nm), power was 50 watts, energy per pulse was 250 mJ, pulse repetition rate was 200 pulses/second, and footprint size was 2 mm by 6 mm.

The panel was mounted in the MPS 100 machining center. The panel was continuously moved in the MPS 100 according to a computer program which is capable of exposing areas of the panel to a specified number of pulses. (Overlap of footprints does occur.)

The beam size is 8 mm by 25 mm; for this work the beam was "imaged" down to 2 mm by 6 mm. Two passes across the panel with each pulse setting were made.

Observations of Stripped Panel

The desired number of pulses is between 50 and 70 pulses. At 50 pulses, the bulk of the topcoat was removed. After 50 pulses, a singeing phenomena began to occur in the epoxy primer layer and became increasingly evident as the number of pulses was increased. The singeing effect was best visualized in an area of the panel which was exposed to 100 pulses. In this area, we were able to scrape off the singed material and expose the yellow epoxy primer. Removal tends to be at a maximum in the center of stripes, with material removal at edges to a somewhat lesser degree. Slight penetration into the composite material has occurred after 50 pulses. The amount of exposed composite material increases (rather slowly) with an increasing number of pulses.

In regards to the panel, Lumonics found it "easy" to work with. They said there are essentially three ways to improve rates:

1. Decrease the topcoat thickness
2. Increase the laser power
3. Use more than one laser (in parallel).

Lumonics believed the nonuniformity in coating removal is due to unevenness in the coating thickness. They felt that the beam was very uniform and was not the problem source.

Lumonics also felt that the removal rate of the urethane and epoxy may be somewhat different, which was why the epoxy layer is singeing. That is, at this fluence level, the excimer laser was unable to ablate the epoxy primer with the same effectiveness as the urethane topcoat. They felt the excimer laser was operating fairly close to optimum.

Actual removal rate: 0.03 ft^2/minute.

Oak Ridge National Laboratories

The Oak Ridge National Laboratories (ORNL) which is operated by Martin Marietta Energy Systems, Inc., performed stripping operations over a 6" x 6" area of a coated composite panel. Their Questek Model 2000 excimer laser was used at a wavelength of 248 nm (krypton fluoride) and an initial energy level of 300 mJ. The beam profile, which was originally 3/4" x 1/2", was reduced to a footprint size of 3/4" x 0.01" upon focusing through a 4-inch focal length cylindrical lens. After several trial runs to adjust laser energy and the desired number of pulses, it was established that 30 pulses were required to strip to the level of the epoxy primer. The pulse rate used was 30 Hz.

The panel was moved manually in front of the beam. As a result, the stripping process took considerably longer than if the panel was automatically and continually manipulated. The calculated removal rate was 0.003 ft^2/minute, while the actual was about half of this amount. This was due to the hand manipulation of the panel and the time required to adjust for drift in the laser power.

Overall, the level of penetration through the topcoat and into the primer appears appropriate. The main problem was inability to accurately overlap the footprints because of the hand manipulation of the panel. Areas of unremoved topcoat were visible in many areas of the panel. We believe that much of this unremoved topcoat could be eliminated with an exacting panel manipulator. Several dark areas are also apparent where the stripping process has gone too far and penetrated into the composite panel. These areas were very obvious to the naked eye and were also probably caused as a result of inaccurate movement of the panel. The Lumonics panel also noticed, to a minor degree, singeing in the epoxy layer. This singeing effect seems to be a result of ineffective removal of primer. That is, the fluence level being used works well with the urethane topcoat, but is less effective in the epoxy primer. This phenomenon may make the termination of stripping in the epoxy layer easier to accomplish.

ORNL reports that the laser produced a luminous plume which was bright yellow-white while removing topcoat. If the laser repetition rate was slowed and the observer viewed the plasma through a slit to attenuate the intensity, the plasma changed color to a reddish-pink when the laser penetrated into the primer. This may provide one basis for a feedback control mechanism. ORNL estimates that 0.07 mils of paint was removed per pulse. Thus, if this same level were maintained in the 0.6- to 0.9-mil primer layer, as few as 10 extra laser shots could cause penetration through the primer. This points to the need for good process control or perhaps a thicker primer.

Finally, ORNL points out that their calculated removal rate can be easily improved by operating at a higher energy level and repetition rate. For example, if a 400-mJ laser operated at 600 Hz (lasers capable of these settings are available), the stripping rate would be improved to 0.21 ft^2/minute, all other factors being equal.

XMR, Inc.

XMR is a manufacturer of high-power excimer lasers. They currently have a 150-watt (300-mJ/pulse, 500-Hz) laser commercially available, and development of a 250-watt (800-mJ/pulse, 300-Hz) laser was finalized in late 1989. XMR was recently acquired by Amoco Technology Company. As such, they have gained access to the laboratories at the Amoco Laser Company in Naperville, Illinois. At these laboratories, optimized parameters for the processing of specific materials with excimer lasers are determined and the behavior of these materials characterized.

XMR is also involved in a joint venture with Siemens to develop high-performance excimer lasers. Because XMR has developed high pulse rate lasers with somewhat lower power/pulse and Siemens has developed high power/pulse lasers with lower pulse rates, we hope that a combined effort will result in high pulse rate, high power/pulse lasers.

XMR felt that excimer lasers offer strong potential for our application, especially with the current direction toward more powerful excimer laser systems.

XMR has performed various paint removal trials on a coated composite panel. Using their Model 5100, 150-watt excimer laser at a wavelength of 308 nm (XeCl) and a pulse rate of 300 Hz. The beam was projected to the sample using a 3-mirror beam delivery system. The panel was manipulated horizontally at a speed of 5 inches per second on an x-y table. Initial testing was performed to determine the fluence level at which acceptable ablation occurred. Poor ablation occurred at fluence levels of 0.04, 0.31, and 0.57 Joules/cm^2, while good ablation occurred at 0.75 Joules/cm^2. This setting was used for subsequent trial work. It required approximately 80 pulses to penetrate through the urethane topcoat and terminate within the epoxy layer.

Once these workable parameters were determined, XMR initiated stripping efforts over larger areas of the panel. Initially, 80 passes over one horizontal strip (approximately 1/4" wide by 6" in length) were made, and then the panel was manipulated vertically to the next strip. This tended to leave lines of unremoved topcoat at the top and bottom of each strip. Therefore, XMR decided to slowly (0.009 inches/pass) move the panel vertically with each pass. Results were excellent. The ability of this system to stop within the epoxy layer was outstanding

(Figure 3.3.2-5). Some areas did exist where removal of topcoat was incomplete. XMR explains that this was more than likely the result of a deviation in the original coating thickness of the polyurethane topcoat (depth of penetration by the excimer laser is very uniform). Very minimal (only at the very peaks of the waffle pattern) penetration into the gel coat of the composite occurred. It was also suggested that a vision system should further improve control. Estimated trial stripping rates were quite good at 0.30 ft^2/minute. However, XMR feels there is room for considerable improvement for the following reasons:

1. Laser settings were not optimum, but were effective enough to demonstrate initial feasibility.

2. Increased pulse rates of 500 Hz or more could be used.

3. The development of more powerful lasers, which is the general direction of the excimer laser industry, would significantly improve this rate.

A final experiment was conducted on the back or uncoated side of the composite panel. Here, XMR removed a single strip of composite material using 10 pulses of penetration. Observations under a microscope showed that penetration through the gel coat and into the fibers had occurred. This indicates that at this fluence level, the excimer laser ablates the composite's matrix resin readily.

Overall, XMR concluded that excimer laser ablation of paint from an epoxy-graphite composite material appeared to work well. The termination of stripping, in areas of the panel which were stripped at a fluence level of 0.75 Joules/cm^2, was able to be accomplished without penetration into the fibers. This was verified by inspection using a microscope at 50X magnification. Based upon these preliminary steps, the

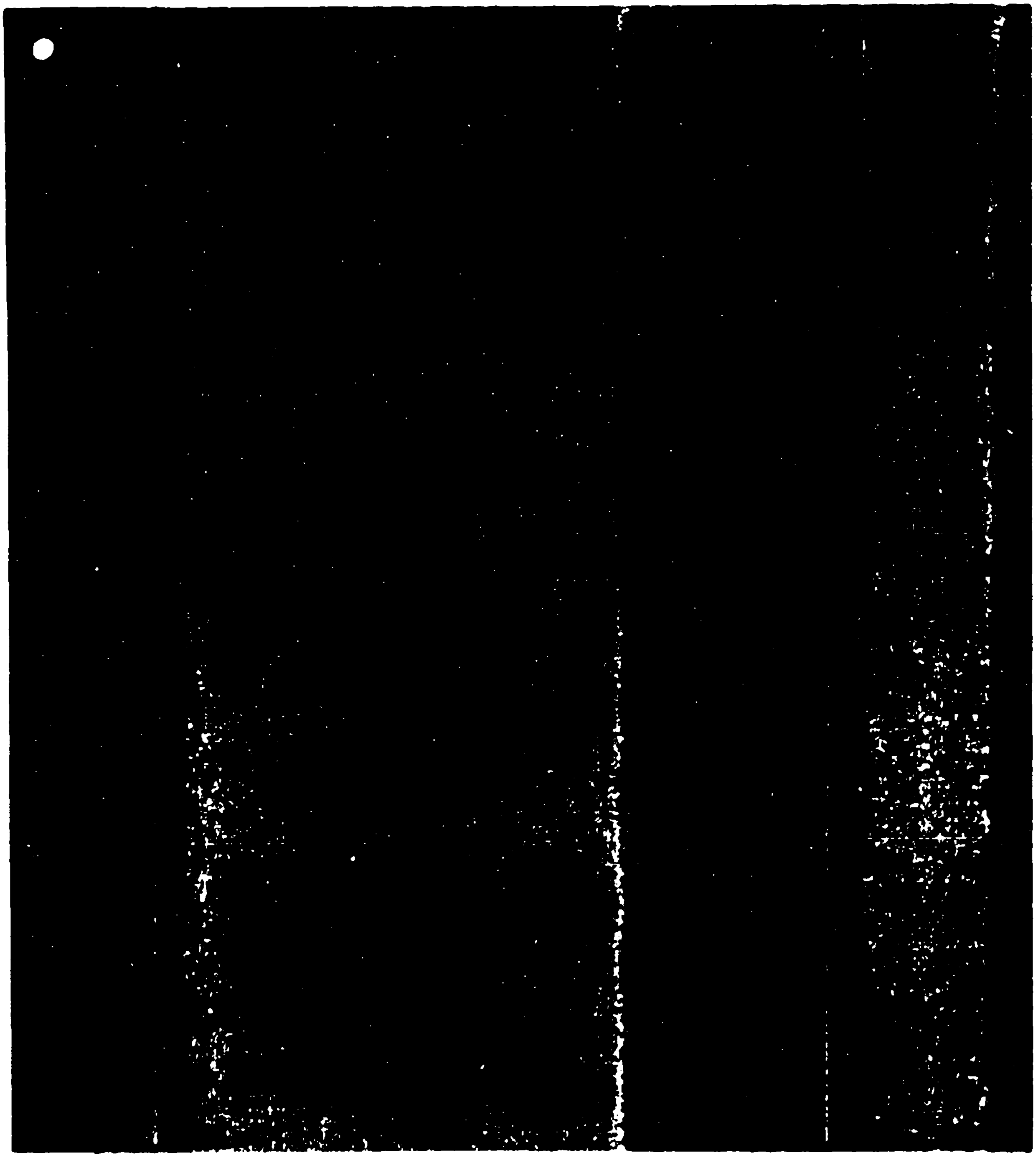

Figure 3.3.2-5 XMR Laser Stripping Area 11

process appeared feasible. Figure 3.3.2-6 shows the various testing trials performed on graphite-epoxy panel.

Avco Research Laboratories

A meeting was held with representatives of the Avco Research Laboratory (Everett, Massachusetts). Avco presented their views on an excimer laser paint stripping system. The key points were:

- Cost is a significant factor, as the equipment (laser, delivery system, robotics, vision system, etc.), the work to integrate this equipment, and the overall research effort will be expensive.
- Lasers are capable of performing the desired level of paint stripping. The major task required is to assemble the appropriate system. Functionally, the key component of this system will be the development of a suitable work head with vision sensor.
- The absorption depth of an excimer laser pulse is lower than that of a CO_2 laser. Therefore, the fluence level of each pulse will be lower. However, the overall energy required to remove the topcoat will be the same.
- In scanning the surface of a paint removal surface, the overlap of footprints will be a crucial factor.
- In terms of cost, the robotics for the excimer laser paint stripper will be the most expensive, followed by the laser, and then the vision sensor. The least expensive portion of the program will be the integration of these components.

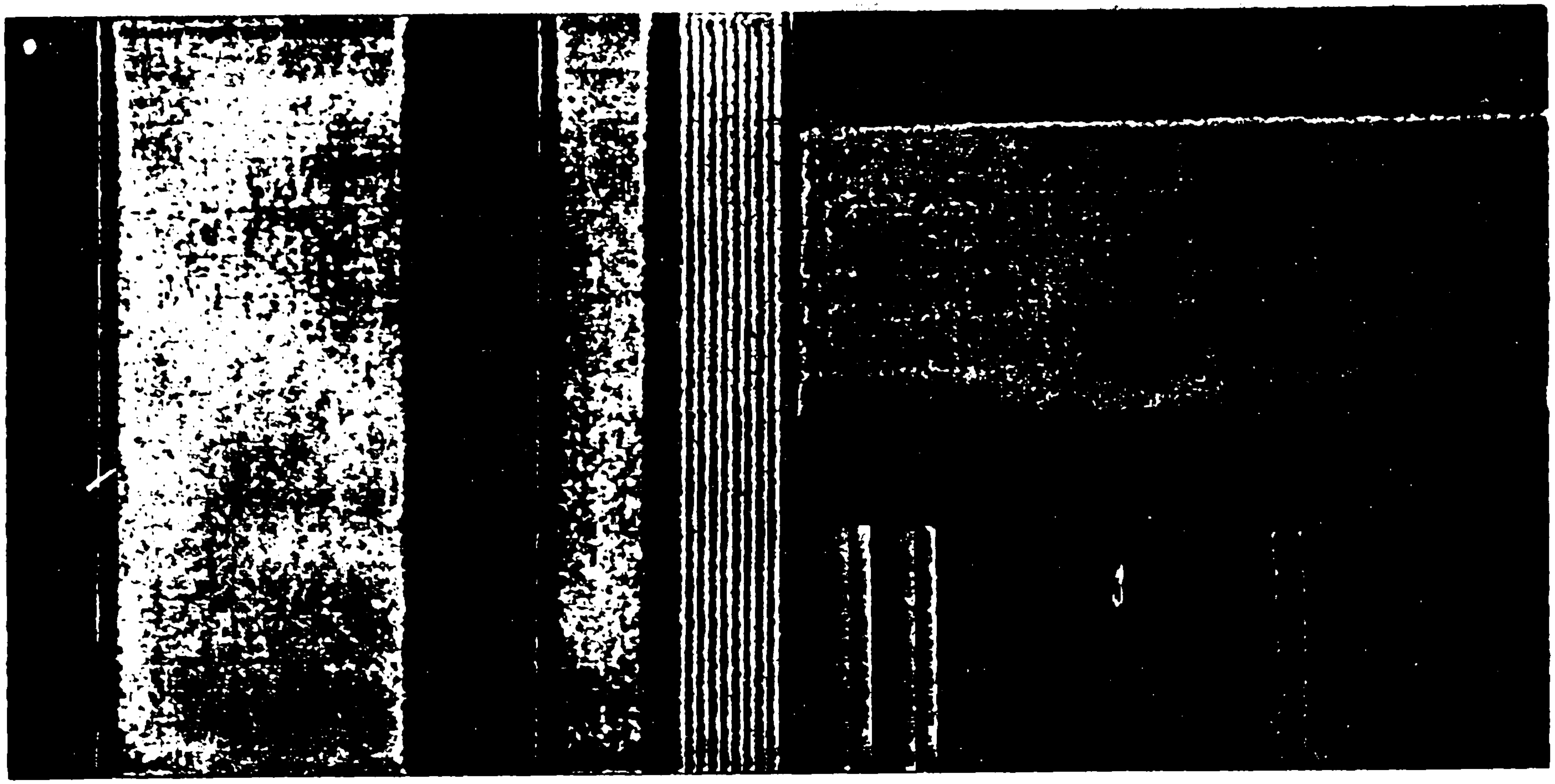

Figure 3.3.2-6 XMR Stripping Areas 1 + 2

- An evaluation of the byproducts of the stripped materials should be performed, so that they can be handled properly.

- Aluminum will absorb varying amounts (20% - 40%) of the excimer laser energy, depending on the wavelength of light used. An evaluation of the excimer laser's effect on aluminum should be performed.

Finally, Lambda Physik of Germany is currently building a 500-watt, 1.6-Joule, 300-Hz excimer laser for use in a large European project. This is very encouraging news, as a laser of this size would greatly increase stripping rates. (The largest currently available commercial excimer laser is in the vicinity of 250 watts.) If stripping rate is a linear relationship with laser power, Lambda Physik's original estimate of 0.32 ft^2/minute with a 100 watt, 200 Hz laser would be improved to 2.4 ft^2/minute. Martin Marietta maintains that the removal rate is proportional to the square of laser energy and their results could be improved to 1.5 ft^2/minute with this 1.6-Joule laser working optimally. Using these estimates with two lasers working in parallel, excimer laser paint removal could be accomplished at 3 to 5 ft^2/minute.

3.3.3 Conclusions from Initial Trials

1. The ability of excimer lasers to perform paint stripping with the desired amount of control is superior to any other removal system observed to date. These lasers are very capable of removing a very high percentage of topcoat with very minimal penetration through the epoxy primer. Any penetration through the epoxy primer is confined to the very outermost surface of the gelcoat of the epoxy-graphite composite - no damage to fibers has been observed.

2. Stripping rates, at this time, are very low, but higher rates may be obtainable.

3. The ablation mechanism, by which excimer lasers remove material, creates minimal heating. As a result, stress effects on the composite that are due to heating are minimized.

4. The excimer laser operating parameters (fluence level, wavelength, pulse rate, etc.) need to be optimized for removal of polyurethane topcoat.

5. Mechanical property testing needs to be performed to verify that no structural damage is occurring to the composite. This will involve topcoat stripping over the majority of the surface area of 6" x 12" composite panels.

6. Excimer lasers remove material very uniformly, layer by layer. Therefore, a significant irregularity in the coating thickness or substrate surface can create a stripping problem. The "waffle" pattern of the composite surface is one such irregularity. However, the 0.6- to 0.9-mil epoxy primer layer serves as a buffer to minimize penetration into the gelcoat of the composite. Leveling of the composite surface prior to primer and topcoat applications should further minimize this problem.

   Utilization of a vision system is a potential solution to the nonuniform coating thickness problem (because of nonuniform coating application, variation in the number of coats of paint, etc.). Since the epoxy primer and the urethane topcoat are typically significantly different in color, this could be used as the visual indicator to terminate stripping. Another potential visual indicator is the change in color of the luminous plume produced during excimer laser stripping. Martin Marietta reported that the plume is yellow-white when removing topcoat and becomes a reddish-pink upon reaching the epoxy primer. This change in color could be due to the different pigments in the primer and topcoat.

7. Equipment cost of excimer lasers are comparable in price to (CO_2 laser equipment. However the maintenance costs are significantly higher.

8. The excimer laser system required to strip an aircraft would be large and require robotic manipulation. Only limited movement of the laser would be possible. The primary manipulation of the beam would be done with a mirror and lens system. The contour of the aircraft would create some stripping challenges.

9. Other items of concern with excimer lasers, as well as with other types of lasers, are toxicity and disposal of by-products, operator safety, and equipment sensitivity.

10. Implementation of an excimer laser system to strip aircraft is long-term.

11. Overall, the desired level of control in stripping urethane topcoat from a composite panel has been demonstrated using excimer lasers. Although stripping rates are currently low, significant progress is being made to develop excimer laser which would provide reasonable stripping rates, within the next several years. Excimer lasers appear to offer great potential for use in a paint stripping system for aircraft.

3.3.4 Resonetics Program

As a result of the promising results in the initial study, it was determined that a more in-depth investigation should be performed to determine actual, achievable stripping rates, the effect of the laser on each of the individual components of the system, and the effect of the laser on mechanical properties of the graphite-epoxy composite. The first step in this process was to identify the proper organization to undertake this study.

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3.3.4 Resonetics Program

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A meeting at Lambda Physik (Acton, Massachusetts) to discuss this work indicated that Resonetics (Nashua, New Hampshire), an excimer laser job shop, was an appropriate source. Interestingly, representatives at Lambda Physik also stated that the ablation of graphite with the excimer laser should occur much more slowly and require higher fluences than the polymeric materials.

Resonetics is an excimer laser job shop which typically performs feasibility testing and high-volume material processing operations. They possess two excimer lasers to perform this work. In addition, Resonetics also designs and builds excimer laser systems for specific applications. Using purchased lasers, they customize and improve the operating efficiency of the excimer laser for a particular application. This includes the incorporation of the beam delivery system, optics, gas recovery system, and waste recovery system. Resonetics frequently utilizes their CAD/CAM system to develop such systems.

The staff at Resonetics was very knowledgeable about the entire excimer laser industry, and had prior experience in laser paint removal with carbon dioxide "T" lasers. They fully believed that excimer lasers can provide the degree of control necessary to strip paint from composites and that the yellow primer will serve as a very effective flag for the termination of stripping. For the stripping of composite panels, a very uniform beam should be used, scanning effects should be watched closely, and material heating monitored. At frequencies higher than 30 Hz, heating could result if scanning is not done properly (heat must dissipate). If necessary, air cooling can be easily incorporated to minimize heating. He felt that the excimer laser powerful enough to strip aircraft at the desired rate was 5 to 10 years from commercialization.

The following points were also added:

- The fluence level used to effectively strip the urethane topcoat probably will not be powerful enough to do significant damage to the graphite fibers.

- Leveling the composite surface prior to coating will help minimize penetration into the composite.

- In regard to potential protective coating systems, epoxy and urethane coatings filled with various pigments should be evaluated, as color is a key factor in the degree to which a material accepts light. As a result, material removal rates may differ drastically.

The following three-step program was to be undertaken by Resonetics:

1. Using coated composite panels, determine the effective stripping parameters for removal of the polyurethane topcoat. Of primary importance was the optimization of the fluence level.

2. Using the parameters identified in Step 1, strip three 6"x12" composite panels to the primer level, strip one 6"x12" composite panel using double the number of pulses to effectively remove the topcoat and terminate stripping at the primer level, and strip one 6"x12" composite panel using triple the number of pulses to effectively remove the topcoat and terminate stripping at the primer level. These panels were subsequently used in mechanical property evaluations.

3. Using specially prepared samples, determine the optimum fluence levels for each of the individual components of the system -- epoxy primer, epoxy matrix resin, and graphite fibers. Subsequently, expose each of these individual components using the optimum fluence level for the polyurethane topcoat.

In the first step of the Resonetics program, key excimer laser stripping parameters - fluence level, pulse rate, optical configuration, and removal rates - were determined. A 75W laser was used in this evaluation. By varying the fluence level and carefully measuring the amount of topcoat being removed, the optimum fluence level was found to be 1.5J/cm^2 (See Figure 3.3.4-1). It took approximately 150 pulses to remove the topcoat at 300 pulses per second. The removal was performed through a 300-mm cylindrical lens and a removal rate of 0.007 square feet per minute was calculated.

Step 2 of this program involved the stripping of five 6-inch x 12-inch composite panels for mechanical property evaluation. The panels were stripped using a 75-watt, KrF (248-nm) excimer laser at a fluence level of 1.5 J/cm^2 and a pulse rate of 150 Hz. A 100-mm cylindrical lens was used to scan the panels at a rate of 4.5 cm/second. The entire surface of the panels were stripped to the following levels: (Figure 3.3.4.2).

Panel 1 - Control

Panel 2 - This is a 12-ply, 0-90 panel which was stripped to demonstrate that the proper parameters were being utilized. The panel was stripped to the epoxy primer layer (complete topcoat removal) using 150 pulses for a given area (Figure 3.3.4-3).

Panel 3 - This is a 16-ply, 0-90-45 panel for mechanical property evaluation. The panel was stripped to the epoxy primer layer (complete topcoat removal) using 150 pulses for a given area.

Panel 4 - This is a 16-ply, 0-90-45 panel for mechanical property evaluation. The panel was stripped to the epoxy primer layer (complete topcoat removal) using 150 pulses for a given area.

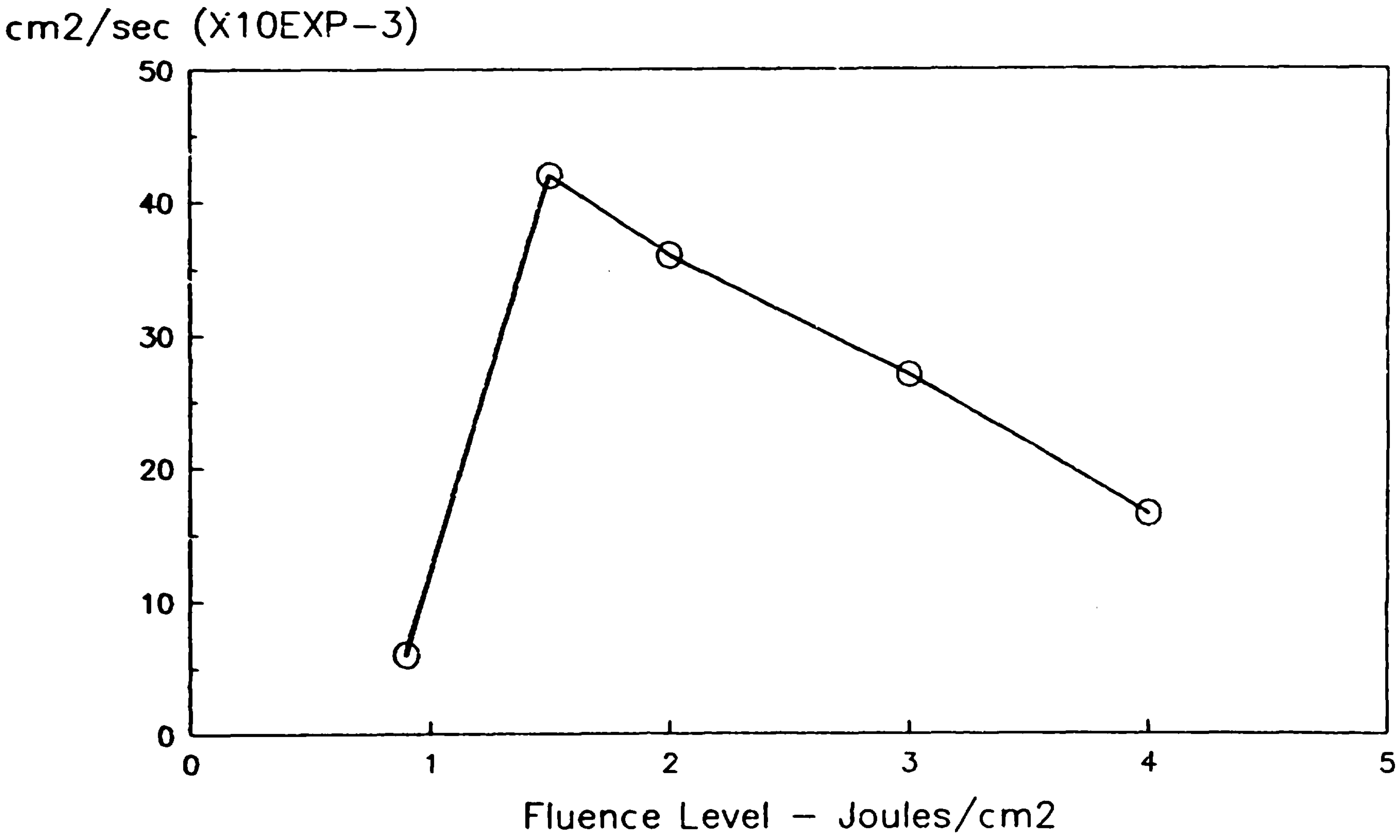


Figure 3.3.4-1 Fluence Level vs. Removal Rate of Polyurethane Topcoat

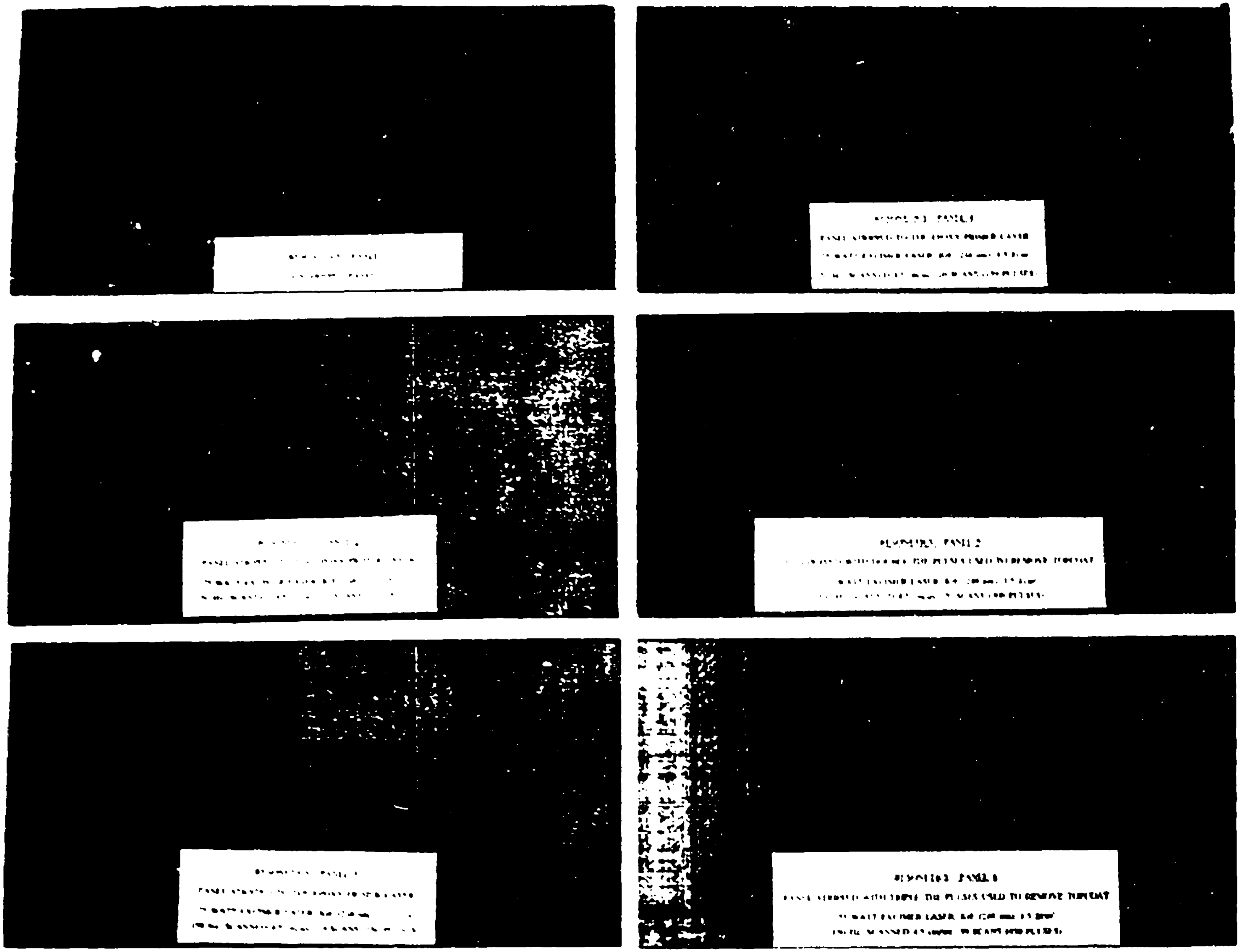


Figure 3.3.4-2 Resonetics - Panels 1-6

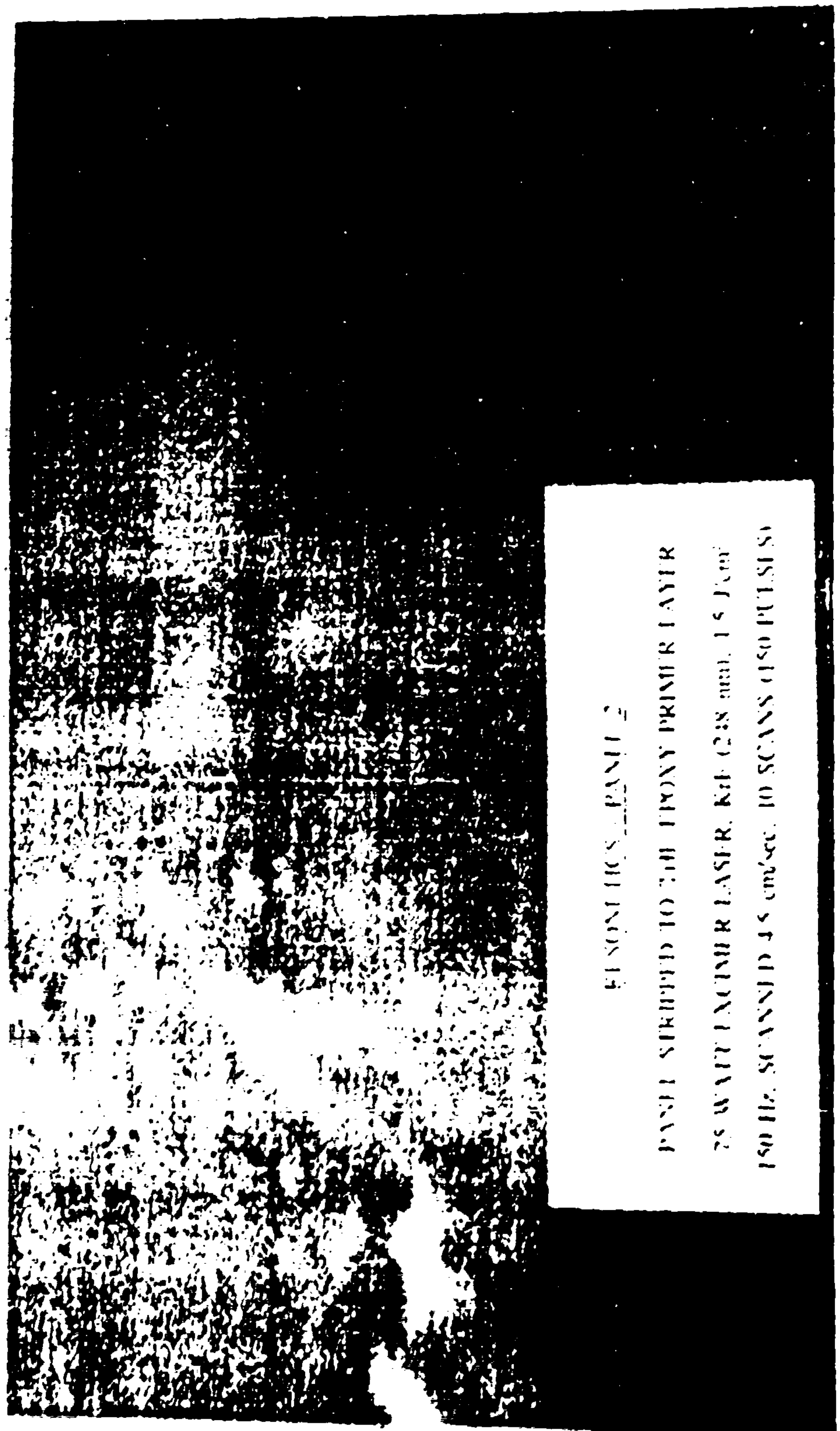


Figure 3.3.4-3 Resonetic - Panel 2

Panel 5 - This is a 16-ply, 0-90-45 panel for mechanical property evaluation. The panel was stripped using 300 pulses for a given area or double the number of pulses to completely remove the topcoat. This exposure failed to completely remove the epoxy primer over the majority of the panel surface. Penetration through the epoxy primer did occur over approximately 20% of the panel. However, no fiber penetration was observed at this exposure level (Figure 3.3.4-4).

Panel 6 - This is a 16-ply, 0-90-45 panel for mechanical property evaluation. The panel was stripped using 450 pulses for a given area or triple the number of pulses to completely remove the topcoat. This exposure resulted in complete removal of the epoxy primer over approximately 95% of the panel surface. The majority of epoxy gelcoat was removed at least down to the first layer of fibers, and fibers were also exposed over the majority of the panel surface. Under an optical microscope, there does not appear to be any damage to the fibers (Figure 3.3.4-5).

Overall, the Resonetics work on this panel stripping was outstanding. The ability of the excimer laser to strip the panels to exactly the desired level has been demonstrated. In this operation, it appeared that the epoxy primer was removed at a lower rate than the urethane topcoat, the epoxy gelcoat was removed at a faster rate than the epoxy primer, and the graphite fibers were removed at the slowest rate of all the components. The step 3 work of this program should provide more definitive results about the individual components.

Mechanical Property testing results for a panel stripped with single pulses and the panel stripped with triple pulses are shown in Figure 3.3.4-6. The results show no statistically significant reduction in flexural or shear strength as a result of the stripping.

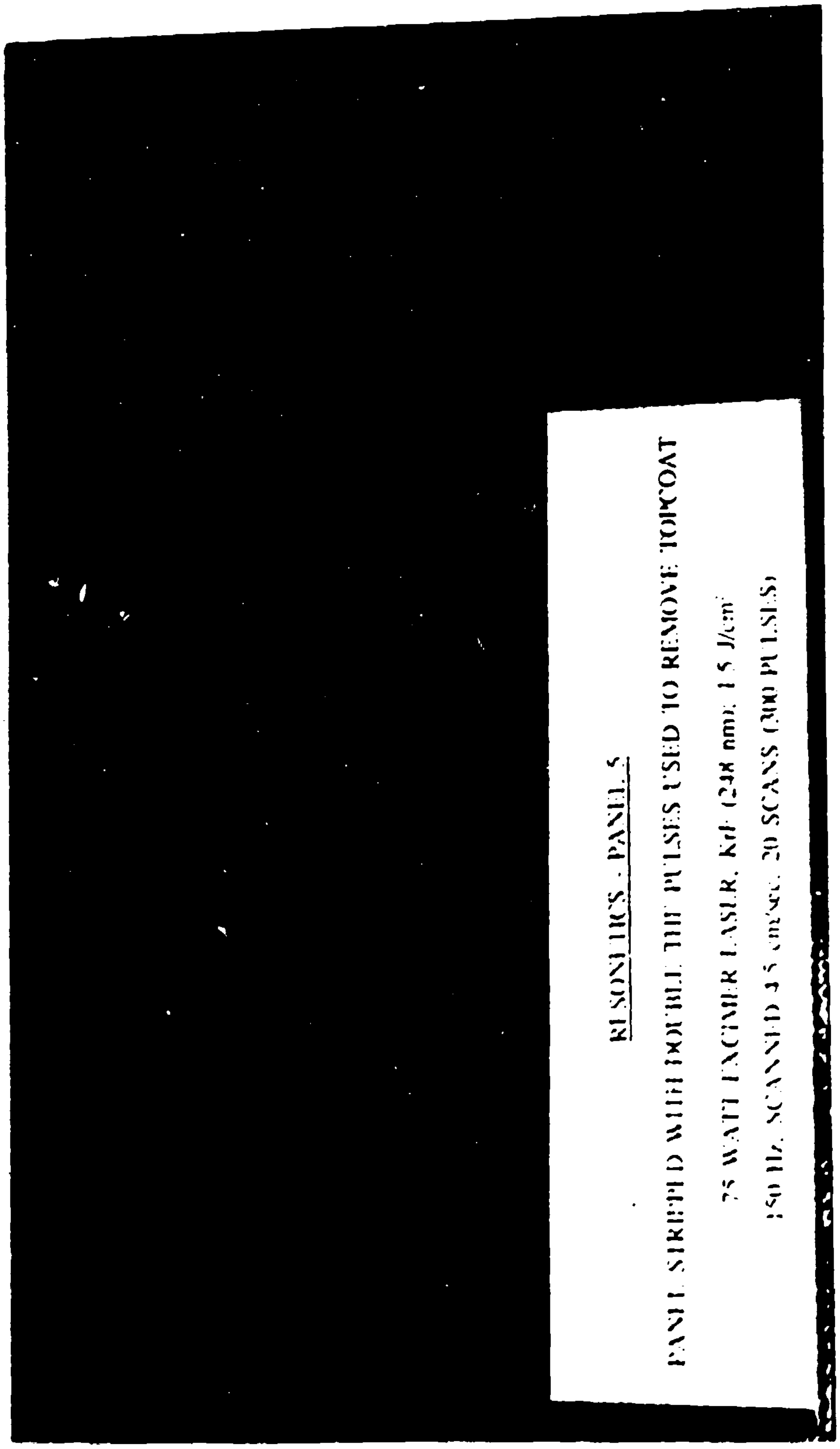


Figure 3.3.4-4 Resonetics - Panel 5

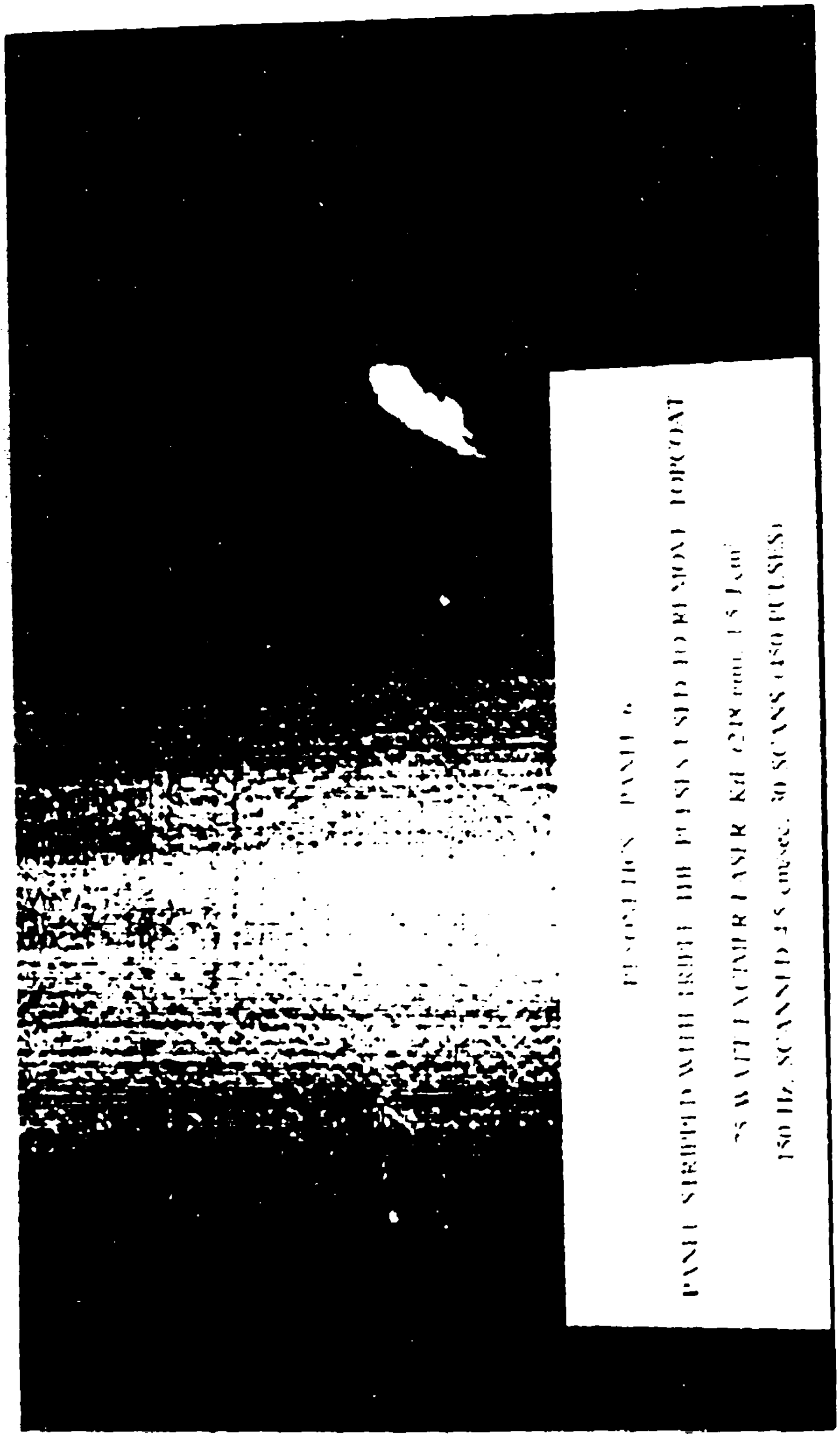
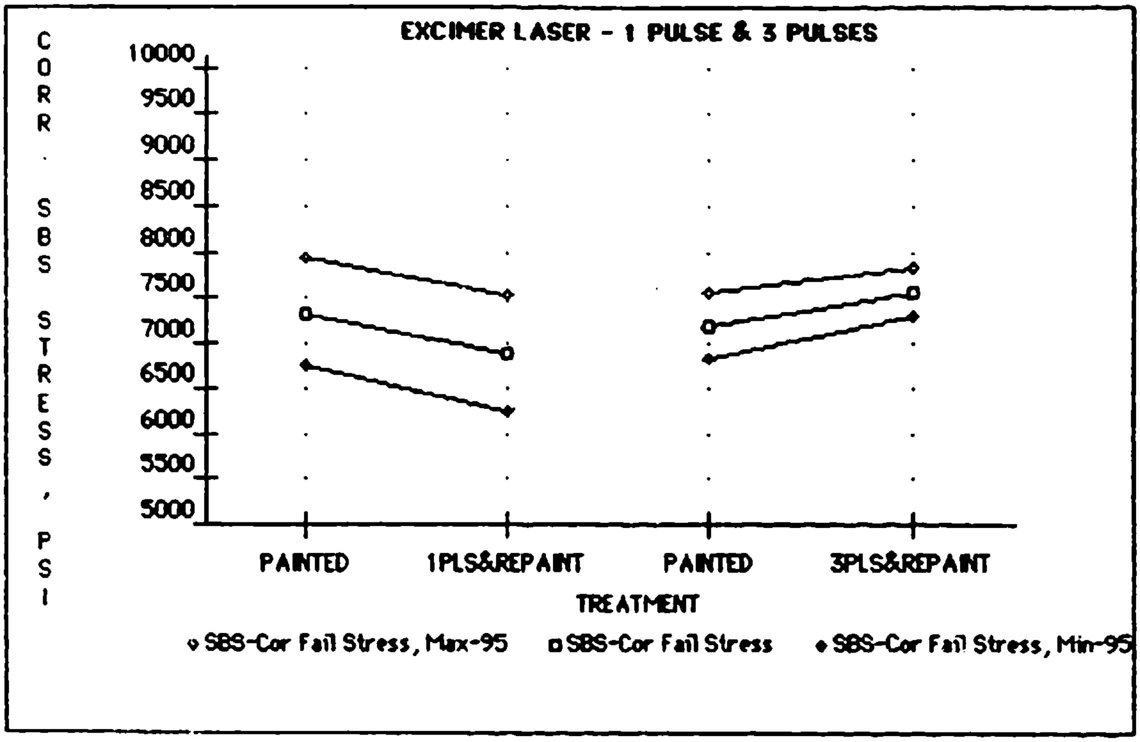


Figure 3.3.4-5 Resonetics - Panel 6



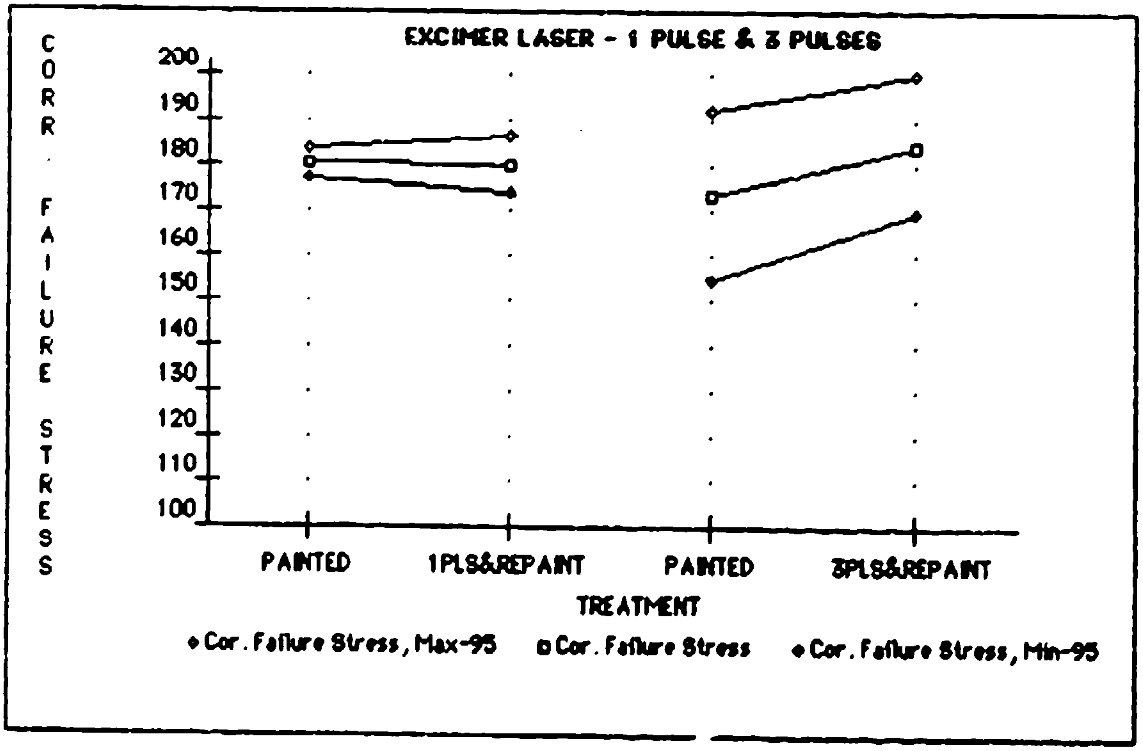


Figure 3.3.4-6 Excimer Laser - 1 Pulse & 3 Pulses

Several preparatory steps were required for the execution of Step 3 of the Resonetics program, as the individual components of the composite panel system had to be isolated so that the effect of the excimer laser on each component could be studied. First, special arrangements were made with Hercules, Inc. (Magna, Utah) to receive a sample of their epoxy matrix resin (i.e., no carbon fibers) which is used in the composite prepreg. Next, carefully prepared samples of the epoxy primer (4 mils) on a smooth casting of the epoxy matrix resin, films of epoxy matrix resin (32 mils), and uncoated and coated (topcoat and primer) composite panels were fabricated. A plan for processing each of these parts was developed (see Table 3.3.4-1). The primary objectives of the plan are to identify the optimum fluence level of each component and then determine the removal rate of each component at its optimum fluence level and at 1.5 J/cm^2 (optimum fluence level for the urethane topcoat). Once the individual components have been evaluated, several trials with a standard composite panel which has been primed and top-coated will be run to determine the number of pulses necessary to penetrate each layer of the system. These trials will be run using the optimum fluence level for the urethane topcoat, 1.5 J/cm^2.

Step 3 of the Resonetics program was performed using a 75W krypton-fluoride (248 nm) excimer laser. Optimum fluence levels were determined using the specially prepared samples of each individual component. Optimum fluence levels were determined by measuring the amount of material removed at varying fluence levels. The results of the fluence level study are presented in Table 3.3.4-2. The results of this study indicate that the epoxy primer and epoxy matrix resin ablate slightly more easily than the urethane topcoat, but of a similar magnitude. The graphite fibers are more difficult to ablate than the polyurethane topcoat.

The effect of the optimum fluence level of the polyurethane topcoat (1.5 J/cm^2) on the individual components of the coated epoxy-graphite panel system were also

Table 3.3.4-1

Resonetics

Step 3 Work

1) Epoxy Primer on Epoxy Matrix Resin

Determine a) optimum fluence level for removal and b) number of pulses to completely penetrate the epoxy primer at the optimum fluence level and at 1.5 J/cm^2 (optimum fluence level for urethane topcoat removal). Primer thickness is 0.004 inches.

2) Film of Epoxy Matrix Resin

Determine a) optimum fluence level for removal, and b) number of pulses to completely penetrate the epoxy matrix resin at the optimum fluence level and at 1.5 J/cm^2. Use material in the unmarked areas; thickness is 0.032 inches.

3) Uncoated Composite Panel

Determine (a) optimum fluence level for removal, and (b) number of pulses to completely penetrate the epoxy matrix resin and the first layer of fibers at the optimum fluence level and at 1.5 J/cm^2. There is an epoxy matrix resin-rich layer at the surface of the panel. However, once the "waffle pattern" has been removed, graphite fibers will become exposed. The optimum fluence level and stripping rates will most likely change at this point.

4) Coated Composite Panel

Using a fluence level of 1.5 J/cm^2, determine the following:

a) Point (number of pulses) at which primer first becomes evident,
b) Point at which topcoat is completely removed,
c) Point at which composite (waffle pattern) first becomes evident,
d) Point at which primer is completely removed,
e) Point at which graphite fibers first become evident,
f) Point at which "waffle pattern" is completely removed,
g) Point at which second layer of fibers (direction will change) becomes evident, and
h) Point at which first layer of fibers is completely removed.

Note: f) may occur before e).

Table 3.3.4-2

Material Removal at Varying Fluence Levels for the Individual Components of the System

	Fluence Level (J/cm2)				
	0.5	**0.6**	**0.9**	**1.5**	**1.96**
Component	**Material Removed (mm^3/second)**				
Polyurethane Topcoat	0.0	0.0	0.04	**0.27**	0.23
Epoxy Primer	0.0	0.43	**0.63**	0.55	0.49
Epoxy Matrix Resin	**0.64**	0.59	0.57	0.46	0.40
Graphite Fibers	0.0	0.0	0.01	0.04	0.10

Note: Number in bold print indicates optimum fluence level.

evaluated on a coated epoxy-graphite panel or a combined system. This was done by quantifying the number of pulses required to penetrate each layer of the system. The results are presented in Table 3.3.4-3. These results seem to indicate that the urethane topcoat is easier to ablate than the epoxy primer and matrix resin. However, the results may be somewhat misleading because the layers of material are not flat because of the waffle-pattern on the surface of the composite panel. At any rate the "buffer" period to terminate stripping before doing any damage to the composite panel is more than adequate. This conclusion is further verified by the high level of control achieved in the stripping of composite panels in Step 2 of this program. Finally, this work verifies that the graphite fibers are much more difficult to ablate at this fluence level than any of the other components.

The ability of the excimer laser to control the level of paint removal is outstanding; however, the stripping rates (0.05 ft^2/minute with a 150 watt laser) are not sufficient to warrant its use for stripping entire aircraft. In combination with the primary stripping method, excimer lasers may be useful for stripping areas of the aircraft which are particularly delicate or difficult to access. The surface that resulted from the laser paint stripping was extremely smooth, typically 115 microinches RMS.

Protective Coating Systems

An investigation into potential protective coatings specifically for excimer laser stripped composite panels was initiated. We believe that these protective coating systems will require significantly different properties from those used for other stripping methods. For example, it is likely that the color and amount of pigment used will significantly affect the rate at which the coating will be removed. This is because of the varying abilities of these pigments to accept light. As such, we inquired of Deft Inc., asking that firm to provide pigment volume contents (PVC) and evaluated on a coated epoxy-graphite panel or a combined system. This was done by quantifying the number of pulses required to penetrate each layer of the system. The results are presented in Table 3.3.4-3. These results seem to indicate that the urethane topcoat is easier to ablate than the epoxy primer and matrix resin. However, the results may be somewhat misleading because the layers of material are not flat because of the waffle-pattern on the surface of the composite panel. At any rate the "buffer" period to terminate stripping before doing any damage to the composite panel is more than adequate. This conclusion is further verified by the high level of control achieved in the stripping of composite panels in Step 2 of this program. Finally, this work verifies that the graphite fibers are much more difficult to ablate at this fluence level than any of the other components.

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Table 3.3.4-3

Number of Pulses Required to Penetrate Each Layer of a Coated Epoxy-Graphite Composite Panel System

LEVEL	NUMBER OF PULSES
Primer becomes evident	85
Waffle pattern becomes evident	150
Topcoat completely removed	125
Graphite fibers become evident	220
Primer completely removed	270
Waffle pattern complete removed	280
Second layer of fibers becomes evident	2000
First layer of fibers completely removed	2200

pigment-to-binder ratios (P/B) for various MIL-P-23377 and MIL-C-83286 materials. The following information was obtained:

Specification	Color	PVC	P/B
MIL-P-23377	yellow	0.280	0.392
MIL-C-83286	green	0.177	0.215
MIL-C-83286	red	0.152	0.180
MIL-C-83286	black	0.146	0.170
MIL-C-83286	white	0.186	0.228
MIL-C-83286	gray	0.192	0.238
MIL-C-83286	blue	0.192	0.238
MIL-C-83286	brown	0.191	0.235

Conclusions

Results of graphite-epoxy composite panels indicated that the ability of the system to terminate stripping in the primer layer is outstanding, and no loss in mechanical properties was observed. With scale-up to a 250-watt laser (largest commercially available) operating at 300 Hz, stripping rates of about 0.1 ft^2/min could be achieved, which is unacceptable. We estimate that the technology to produce excimer lasers powerful enough to achieve desired stripping rates is about 10 years away.

3.4 Abrasive Paint Removal

This method is perhaps the oldest of paint removal techniques. It is well developed and understood. The technique utilizes high-speed passes of abrasive materials to erode coated surfaces. The polyurethane topcoat, epoxy primer, and epoxy-graphite system is a particularly difficult one for abrasives for several reasons. First, the urethane topcoat is much more abrasion-resistant than the epoxy primer. Second, the epoxy primer layer is very thin, making penetration through it rather easy. Third, the surface of the composite panel is not smooth, but instead possesses the "waffle" pattern of the bleeder cloth used during fabrication. As a result of this, removal of polyurethane film, which lies below a high point in the composite, will be very difficult.

Two abrasive types were the focus of this investigation, coated abrasives and surface preparation pads. Coated abrasives consist of abrasive grain (aluminum oxide, silicon carbide, garnet, etc.), a flexible or semirigid backing (paper, cloth, plastic film, etc.), and an adhesive to bond and anchor the grains to the backing. Surface conditioning pads are comprised of abrasive grains (aluminum oxide, silicon carbide), a non-woven synthetic fiber, and an adhesive to bond and anchor the abrasive grain and non-woven fiber. Other key aspects of abrasive paint removal were the selection of sanding equipment and the utilization of effective sanding techniques.

3M of St. Paul, Minnesota has been involved in work with the polyurethane/paint/ composite system using both coated abrasives and surface preparation pads. On the coated abrasive side, 3M's main concern was the rough composite surface. Smoothing of the surface through better composite surface finishing or application of a primer which would completely level the surface would greatly simplify the problem. Repriming after a paint removal operation will lead to a smoother surface--that is, the first removal operation will be the most difficult. Because identification of the primer layer is almost entirely visual, 3M recommends a primer which is significantly different in color from the topcoat. Coated abrasives systems recommended include the Stikit Gold system and the Multicut system. The Stikit Gold system is an aluminum oxide abrasive, paper-backed resin over glue bond system. The 150-320 grade range was recommended. The Multicut system is a newly developed system described as being three-dimensional. It is comprised of a multi-mineral configuration, which works by sacrificing the coating on abrasive grains allowing new grains to be introduced. A Multicut system utilizing aluminum oxide abrasive and cloth backing was recommended for initial work.

The equipment suggested was a random orbital sander with vacuum pickup to aid in the removal of debris. Random orbital sanders are less aggressive than right angle sanders, thus providing more control over the paint removal operation, although removal rates will be lower. 3M indicated that dry sanding should provide the best finish, although wet sanding may be somewhat faster and provide a cooling effect. 3M has performed limited testing on the polyurethane/epoxy/composite systems using the Stikit Gold system and a random orbital sander. Results indicated that complete removal of the topcoat will be difficult, mainly because of the "waffle" pattern on the composite.

3M recommended that the Scotchbrite system in the medium and very-fine grade be used. Scotchbrite is made up of aluminum oxide abrasive and nylon nonwoven fibers. Initial abrading should be performed with the medium grade, and the very-fine grade should be used when nearing the primer. Scotchbrite pads are a much milder and more forgiving system than coated abrasives, and therefore, a right-angle sander operating at 3-600 rpm was recommended. Initial work should be performed dry, although water injection may reduce heating effects and help remove debris from the pad, yet may slow removal rates somewhat because of reduced friction. The main concern with Scotchbrite pads is the removal rate. Preliminary work utilizing a water-injected orbital grinder developed by Gates-Lear provided effective removal with damage to the composite, but removal rates were extremely slow.

Norton Company of Worcester, Massachusetts recommended that their No. F91 Adalox system be used at 180, 240, 320, and 400 grit. The No-Fil Adalox system is comprised of aluminum oxide abrasive which is open-coated and glue-bonded on F-weight paperbacking. A special surface coating treatment is applied to the disc to resist loading. Norton also recommended that their coated abrasive be used on a random orbital sander with vacuum pickup. Surface preparation pads designated were medium and fine-grade Bear-Tex discs. These discs feature a reinforced nonwoven nylon web backing, which is impregnated with aluminum oxide abrasive grain. These discs were recommended to be used on a right-angle sander.

Carborundum Abrasives Company of Niagara Falls, New York identified two products from their Dry Lube line. The first uses aluminum oxide abrasive grains, while the second uses silicon carbide abrasive grains. Both types were bonded to D-weight paper with 180, 240, and 320 grits recommended. Carborundum also suggested that these discs should be used on a random orbital sander.

3.4.1 Equipment Selection

Abrasive Materials

Two types of abrasive materials, coated abrasive discs and surface conditioning pads, were evaluated. Coated abrasive discs and surface conditioning pads were supplied by 3M and Norton Company according to their best judgment for this particular application. Coated abrasive discs were pressure-sensitive adhesive-backed, while surface conditioning pads utilized a "Velcro" type system to attach them to backup pads. Discs and pads were 5 inches in diameter. The following pads and discs were evaluated.

Coated Abrasives:

Norton No-Fil Adalox (180, 240, 320, and 400 grade)
3M Stikit Gold (100, 180, 240, and 320 grade)
3M Three-M-ite Resin Bond Cloth or Multicut (120 and 180 grade)

Surface Conditioning Pads:

Norton Beartex Discs (medium and fine grades)
3M Scotchbrite Discs (coarse, medium and very fine grade)

Sanders

Several types of sanders were required for this work. First, a milder sander (random orbital or lower-speed right angle) was needed for coated abrasives, while a more aggressive sander (high-speed right angle) was required for surface conditioning pads. In addition, sanders for wet, dry, and cryogenic (see Section 3) removal were also required. As a result of these needs, the following four sanders were procured based on their speed, power, and adaptability:

- 0.3 HP, random orbital sander (Aro)
- 1.8 HP, 6000 RPM, right angle sander (Dynabrade)
- 0.5 HP, 3000 RPM, right angle wet/dry sander (Dynabrade)
- 0.5 HP, 800 RPM, right angle wet/dry sander (Dynabrade)

Backup Pads

A variety of backup pads from Ferro Industries and 3M were selected for use with both coated abrasive discs and surface conditioning pads. The primary differences in the pads were the thickness and stiffness of the foam used.

Coated Abrasive Backup Pads

Ferro 60655V	1/2 inch of hard, somewhat flexible foam
Ferro 60615V	3/8 inch of hard, inflexible foam
Ferro 855L	3/4 inch of soft, flexible foam topped with 1/4 inch of hard, inflexible foam
Ferro 805L	1 inch of soft, flexible foam

Surface Conditioning Backup Pads

3M No. 14	1/2 inch of firm, flexible foam
3M No. 82	1/2 inch of firm, flexible foam with an angled outer edge
3M No. 57	1-1/4 inches of firm, flexible foam
Ferro GP 35	3/4 inch of firm, flexible foam
Ferro GP 915U	1/8 inch of hard, inflexible foam

3.4.2 Screening Tests

Initial screening tests were performed on 4" x 12" aluminum "Q" panels coated with Mil-P-23377 epoxy primer (0.6 - 0.9 mils) and Mil-C-83286 polyurethane topcoat (2.0 ± 0.3 mils). Testing was performed using various combinations of abrasive materials and sanders in order to obtain an understanding of which systems had the most potential. All work was performed using 5-inch diameter abrasive discs and pads (8-inch discs are also available). Systems were evaluated based upon topcoat removal rates and control. Control is defined as the ability of an abrasive system to <u>stop within the epoxy primer layer</u> (i.e., maximum topcoat removal and minimal penetration to the substrate). Test results are presented in Tables 3.4.2-1 and 3.4.2-2.

This testing provided the following conclusions:

Table 3.4.2-1

Results of Abrasive Removal Using Surface Conditioning Pads on Coated Aluminum Panels

Grade	Sander	Test Time (seconds)	Area of Topcoat Removed (inch^2)	Control
Medium[1]	Orbital	60	0	Good
	6000 RPM	30	18	Poor
	3000 RPM	30	7	Fair to Good
	3000 RPM (wet)	30	9	Fair to Good
Fine[2]	Orbital	-	-	-
	6000 RPM	-	-	-
	3000 RPM	30	2	Good
	3000 RPM (wet)	30	2	Good
Very Fine[3]	Orbital	-	-	-
	6000 RPM	90	12	Fair
	3000 RPM	120	0	-
	3000 RPM (wet)	30	0	-

---

[1] Scotchbrite and Beartex discs

[2] Beartex discs

[3] Scotchbrite discs

the primer layer was good, and no loss in mechanical properties was observed. The Armex/Accustrip system is currently being carefully evaluated for large-scale use on aircraft.

9. **Excimer Laser Paint Stripping** utilizes pulsed lasers which operate in the ultraviolet spectrum. Excimer lasers are a new and rapidly developing technology which remove material by a process called ablation which minimizes heating. In a program performed in conjunction with Resonetics, the following operating parameters were found to be optimum using a 40-watt laser:

   - Wavelength = 248 nm (Krypton Fluoride)
   - Fluence level = 1.5 J/cm^2
   - Pulse rate = 150 Hz
   - Scan rate = 4.5 cm/second

   Results on graphite-epoxy composite panels indicated that the ability of the system to terminate stripping in the primer layer is outstanding, and no loss in mechanical properties was observed. With scale-up to a 250-watt laser (largest commercially available) operating at 300 Hz, stripping rates of about 0.1 ft^2/min could be achieved, a rate which is unacceptable. It is estimated that the technology to produce excimer lasers powerful enough to achieve desired stripping rates is about 10 years away.

10. **Envirostrip** is a new process being developed by Ogilvie Mills, Ltd. (Montreal, Quebec). The process uses modified wheat starch, which is biodegradable and non-toxic, in a blasting operation to remove coatings. Initial testing on graphite-epoxy composites indicates that appropriate blasting parameters are:

TABLE 3.4.2-2

Results of Abrasive Removal Using Coated Abrasives on Coated Aluminum Panels

Grade	Sander	Test Time (seconds)	Area of Topcoat Removed (inch^2)	Control
100[1]	Orbital	30	3	Good
	6000 RPM	-	-	-
	3000 RPM	15	4	Good
	3000 RPM (wet)	30	39	Good
180[2]	Orbital	45	9	Good
	6000 RPM	-	-	-
	3000 RPM	30	20	Good
	3000 RPM (wet)	20	13	Very Good
240[3]	Orbital	-	-	-
	6000 RPM	15	16	Fair
	3000 RPM	25	4	Fair
	3000 RPM (wet)	30	5	Very Good
320[3]	Orbital	-	-	-
	6000 RPM	15	11	Fair
	3000 RPM	45	5	Good
	3000 RPM (wet)	60	1	Good
400[2]	Orbital	-	-	-
	6000 RPM	30	2	Good
	3000 RPM	-	-	-
	3000 RPM (wet)	-	-	-

---

[1] Stikit Gold disks

[2] No-Fil Adalox discs

[3] Stikit and No-Fil Adalox discs

1. The Dynabrade 3000 RPM sander, dry or wet, provided the best results. Stripping rates were similar for both wet and dry operation, while control was somewhat better with wet operation. The random orbital sander provided good control but very low stripping rates. The 6000-RPM sander provided high stripping rates with essentially no control.

2. Both coated abrasive discs and surface conditioning pads showed potential when used with the 3000-RPM (wet or dry) sander.

3. A two-phase system would be required for successful removal. The "first cut" should be made with a more aggressive (coarser grade) material to achieve maximum removal rates. Once the epoxy primer becomes visible, a milder (finer grade) material should be used to improve control Products qualifying as "first cut" materials were Stikit Gold - 100 or 180 grade, No-Fil Adalox - 180 grade, Beartex - medium grade, and Scotchbrite - medium grade. Products qualifying as "second cut" materials were Stikit Gold - 240 or 320 grade, No-Fil Adalox - 240 or 320 grade, Beartex - fine grade, and Scotchbrite - very fine grade.

The next step was to evaluate these abrasive systems on coated composite panels. Testing was performed in a similar manner to the coated aluminum panel work, except in many cases a "two-cut" system was employed. Generally, results were similar to those obtained on aluminum panels. The following observations and conclusions were made:

1. The "waffle" pattern on the surface of composite panels is an obstacle to effective paint removal by abrasive means. The "waffle" pattern is an arrangement of high and low points in the gel coat of the composite, which was created by contact with the porous teflon release film in the fabrication process (layup). As a result, paint is being removed from a nonlevel surface (variation in

height is approximately 1 mil). This creates difficulty in removal, especially where topcoat exists below high points of the gel coat. With all topcoat removed, the best results showed some penetration into the gel coat in about 25% of the surface.

2. A "two-cut" system with the 3000 RPM (wet or dry) sander and either the coated abrasives or surface conditioning pads provided the best results. The best performing abrasive materials were the same as with coated aluminum panels.

3. The 6000-RPM sander is too aggressive with any abrasive material. The 3000-RPM sander appears to be slightly too aggressive when used with coated abrasives. The random orbital sander was only effective as a "second-cut" tool with finer grade coated abrasives. As a result of these observations, the 6000-RPM sander was returned to Dynabrade and replaced with a 0.5-HP, 800-RPM, right-angle wet/dry sander (Dynabrade).

4. Clogging was observed in surface conditioning pads in dry sanding operations.

5. Coated abrasive discs tended to wear rather quickly.

At this point, a test program was performed to evaluate the 800-RPM wet/dry sander and the various backup pads. As before, initial work was performed on coated aluminum panels. Test results are presented in Tables 3.4.2-3 and 3.4.2-4. These results indicated that the following four systems should be evaluated on composite panels:

Table 3.4.2-3

Sanding of Aluminum Panels Using 800 RPM Sander with Coated Abrasives

(A) Dry Sanding

Disc	Backup Pad	Area of Topcoat Removed (in.^{2})	Area Removed to Aluminum (in.^{2})	Sanding Control	Damage to Disc	Sanding Time (sec.)
Stikit Gold 100	805L	12.5	2.5	fair	very little	20
Stikit Gold 180	805L	11.2	0	very good	very little	20
Stikit Gold 180	60655V	5.6	0	good	very little	20
Stikit Gold 180	60615V	12.7	0.25	tendency to hop	very little	20
Stikit Gold 180	855L	8.1	0	very good	very little	20
Stikit Gold 180	805L	9.3	0	very good	very little	20
No-Fil Adalox 180	805L	2.2	0	good	very good	20
Stikit Gold 240	805L	2.6	0	very good	very little	20

Table 3.4.2-3 (Continued)

Sanding of Aluminum Panels Using 800 RPM Sander with Coated Abrasives

(B) Wet Sander (Water Flow Rate = 0.1 Gallons/Minute)

Disc	Backup Pad	Area of Topcoat Removed (in.^{2})	Area Removed to Aluminum (in.^{2})	Sanding Control	Damage to Disc	Sanding Time (sec.)
Stikit Gold 320	805L	0	0	good	very little	20
No-Fil Adalox 320	805L	<1	0	good	very little	20
Stikit Gold 100	805L	8.7	0	very good	very little	20
Stikit Gold 180	805L	2.5	0	good	50% of abrasive removed	20
No-Fil Adalox 180	805L	7.5	0	very good	80% of abrasive removed	20
Stikit Gold 240	805L	9.0	1	fair	very little	20
Stikit Gold 320	805L	1.0	0	good	very little	20
No-Fil Adalox 320	805L	0	0	good	75% of abrasive removed	20

Table 3.4.2-4

Sanding of Aluminum Panels Using 800 RPM Sander with Surface Conditioning Pads

(A) Dry Sanding

Disc	Backup Pad	Area of Topcoat Removed (in.^{2})	Area Removed to Aluminum (in.^{2})	Sanding Control	Damage to Disc	Sanding Time (sec.)
Scotchbrite Coarse	GP915V	8.2	0.25	good	considerable clogging	20
Scotchbrite Coarse	GP35	2.2	0	good	considerable clogging	20
Scotchbrite Medium	GP915V	1.0	0	poor	considerable clogging	20
Scotchbrite Medium	GP35	0	0	good	considerable clogging	20
Beartex Medium	GP35	3	1	poor	considerable clogging	20
Beartex Fine	GP35	0	0	good	considerable clogging	20
Scotchbrite Very Fine	GP35	0	0	good	some clogging	20

Table 3.4.2-4 (Continued)

Sanding of Aluminum Panels Using 800 RPM Sander with Surface Conditioning Pads

(B) Wet Sanding (Water Flow Rate = 0.2 Gallons/Minute)

Disc	Backup Pad	Area of Topcoat Removed (in.^{2})	Area Removed to Aluminum (in.^{2})	Sanding Control	Damage to Disc	Sanding Time (sec.)
Scotchbrite Coarse	GP35	15	1.5	fair	none	20
Scotchbrite Medium	GP35	8	1	fair	none	20
Beartex Medium	GP35	22	1	fair	very little	20
Beartex Fine	GP35	7.5	1	fair	very little	20
Scotchbrite Very Fine	GP35	0	0	good	none	20

Coated Abrasives with 800-RPM Dry Sander

First Cut - Stikit Gold 180 grade with 805/L backup pad
Second Cut - Stikit Gold 320 grade with 805/L backup pad

Coated Abrasives with 800-RPM Wet Sander

First Cut - Stikit Gold 100 grade with 805/L backup pad
Second Cut - Stikit Gold 320 grade with 805/L backup pad

Surface Conditioning Pads with 3000-RPM Dry Sander

First Cut - Scotchbrite coarse grade with GP 915U backup pad
Second Cut - Scotchbrite very fine grade with GP 35 backup pad

Surface Conditioning Pads with 3000-RPM Wet Sander

First Cut - Beartex medium grade with GP 35 backup pad
Second Cut - Scotchbrite very fine grade with GP 35 backup pad

In addition, the softer, more flexible backup pads (Ferro 805L and GP 35) provided better control and increased contact area, mainly because of their ability to conform to the surface of the substrate.

These systems were subsequently used as a guide for the testing on coated composite panels. In this testing, the first-cut system was used until a considerable amount (40-50% of the surface area) of the primer was visible. Results indicated that the best systems were the same as those determined on coated aluminum panels, with the exception being that the 800-RPM sander should also be used with surface conditioning pads. These systems were rated as follows:

Coated Abrasives with 800-RPM Wet Sander

First Cut - Stikit Gold 100 grade with 805L backup pad
Second Cut - Stikit Gold 320 grade with 805L backup pad

This system worked very effectively. A 6" x 12" panel was completely stripped in 60 seconds using a 5-inch disc. The control of this system was very good, as it effectively removed about 95% of the top coat with minimal (10-15%) composite penetration. Any penetration into the composite surface was completely limited to the very outermost surface of the gel coat. We believe that the current stripping rate of 0.5 ft^2/minute would be improved considerably in field application for the following reasons:

1. An 8-inch-(or greater) diameter disc would be substituted for the 5-inch-diameter disc, providing 60% or more additional sanding surface.

2. Sanding large-surface-area objects drastically improves the workers' freedom of movement. The sanding of a 6-inch wide panel with a 5-inch-diameter disc is quite difficult, because of the movement and vision constraints. The alleviating of vision constraints should also improve control.

The water flow rate used was 0.4 gallons per minute. Wet sanding is advantageous, as it provides better control, eliminates dust emissions, and reduces clogging of sanding discs. However, it also creates waste, is quite messy and tends to affect the adhesive bond of the sanding disc to the backup pads. Water can be filtered and recycled to minimize waste, but despite this face, the amount of water used should be kept to the absolute minimum amount required to provide the necessary control.

Two other minor concerns became apparent. First, coated abrasive discs tended to wear slightly faster with wet sanding than with dry sanding. Second, the softer, urethane-foam backup pads tended to tear on the outer edge with extended use.

Coated Abrasives with 800-RPM Dry Sander

First Cut - Stikit Gold 180 grade with 805L backup pad
Second Cut - Stikit Gold 320 grade with 805L backup pad

This system was also very effective. Its stripping rates were comparable to the wet sanding system. However, the control was somewhat less. That is, in order to remove the same amount of top coat, slightly more of the composite surface was penetrated. Again, only the outermost surface of the gel coat is penetrated. This system did produce dust, but a vacuum system would help minimize this problem. In addition, use of the dry system would alleviate some of the problems associated with wet sanding. This is a very good alternative system to the wet sanding system.

Surface Conditioning Pads with 800-RPM Wet Sander

First Cut - Beartex medium grade pad with GP 35 backup pad
Second Cut - Scotchbrite very fine grade pad with GP 35 backup pad

This system was only fairly effective. Stripping rates were almost half of the coated abrasive systems. In addition, control was somewhat less. Efforts to use the 3000 RPM sander resulted in improved rates, but with additional and unacceptable loss of control, as significant areas of the composite gel coat were being exposed. Overall, this system is inferior to wet- or dry-coated abrasive sanding.

Surface Conditioning Pads with 800-RPM Dry Sander

First Cut - Beartex medium grade with GP 35 backup pad
Second Cut - Scotchbrite very fine grade with GP 35 backup pad

This system was comparable to the surface conditioning pads with 800-RPM wet sander, with still somewhat less control. This system is definitely inferior to the coated abrasive systems.

3.4.3 Fine Tuning of the System

The final step in this effort was to address disadvantages of the wet/dry system with coated abrasives, in an effort to improve these systems. First, experiments were run to determine the minimum water flow rate for wet sanding, which would provide the desired control without clogging of the abrasive discs and also minimize waste. Here, the water flow rate was able to be reduced from 0.4 gallons per minute to 0.15 gallons per minute.

Next, two problems associated with the coated abrasive systems were discussed with 3M. These were the fairly quick wearing of the coated abrasive discs when used with wet sanding and the intermittent loss of adhesion of pressure-sensitive adhesive-backed coated abrasive discs to the backup pad during wet operations. As a result, 3M provided two alternative systems. The first was a 261 Stikit resin bond polyester film-backed disc. This product with the plastic backing was designed for better wear and adhesion during wet operation than the Stikit Gold discs which had a paper backing. The second product was a 259F Three-M-ite resin bonded cloth or Multicut system. The Multicut system is a so-called three-dimensional system which slowly and continually exposes new abrasive grains as a specially designed sacrificial coating is penetrated. In addition, the Multicut system attaches to the backup pad by a "hook-and-loop" (Velcro-type) system which eliminates the pressure-sensitive adhesive altogether and hopefully the adhesion problem.

Testing of the 261 Stikit resin bond polyester film-backed disc showed no apparent adhesion problems to the backup pad and considerable improvement in disc wear. Dry stripping rates were comparable to Stikit Gold products, while control was considerably less. Wet stripping rates were considerably slower than Stikit Gold products, while control was somewhat less. In conclusion, the 261 Stikit resin bond polyester film-backed disc provided solutions to the problems being addressed, but was inferior to the Stikit Gold in removal rates and control. Results are presented in Table 3.4.3-1.

Dramatic improvements were realized with the 259F Three-M-ite resin bond cloth (Multicut system) discs. First, very minimal wear and clogging were observed, and the "hook-and-loop" method for attaching these discs to the backup pad worked without any problems. More importantly, stripping rates were doubled (1 ft^2/min with a 5-inch disc) along with an improvement in control, especially with wet operation. In fact, the Multicut system was so easy to control that paint removal was effectively accomplished in one cut. This provides a further rate increase, as changeover to a "second-cut" system could now be eliminated. In conclusion, the performance of the Multicut system was outstanding and without comparison to any other system tested to date. Results are presented in Table 3.4.3-1.

Finally, the problem of degradation of the softer backup pads which provided the desired control was also discussed with 3M. In an attempt to solve this problem, 3M provided three alternative backup pads (Nos. 14, 57, and 82). These pads utilized a cast foam which was somewhat firmer for improved durability, yet still flexible for the desired control. Laboratory testing determined that the No. 57 disc provided very good control with very little sign of wear as of this time.

Rating of the best systems is provided in Table 3.4.3-2.

Mechanical property testing has produced very favorable results. Flexural and shear tests have been performed on various carefully abraded samples, as well as samples

Table 3.4.3-1

Multicut and Plastic Film-backed Stikit Results

A. 120 Grade, 259F Three-M-ite Resin Bond Cloth (Multicut System)

Sander	Wet/ Dry	Flow Rate (GPM)	Time to sand 6" x 12" Panel (sec.)	Control
3000 RPM	Dry	-	35	Fair
800 RPM	Dry	-	35	Very Good
3000 RPM	Wet	0.15	25	Good
800 RPM	Wet	0.15	30	Very Good

B. 100 Grade, 261 Stikit Resin Bond Polyester Film-backed Discs

Sander	Wet/ Dry	Flow Rate (GPM)	Second Cut System	Time to sand 6" x 12" Panel (sec.)	Control
3000 RPM	Dry	-	-	28	Poor
3000 RPM	Dry	-	Stikit Gold	1-18	Poor
			320 Grade	2-27	
800 RPM	Dry	-	Stikit Gold	1-25	Good
			320 Grade	2-32	
3000 RPM	Wet	0.15	-	50	Fair
800 RPM	Wet	0.15	-	>90	Good

Table 3.4.3-2

Rating of Abrasive Systems

Disc	Sander	Time to Sand 6" x 12" Panel (sec)	Control
Multicut 120	800 RPM-Wet	30	Excellent
Multicut 120	800 RPM-Dry	35	V.Good
1-Stikit Gold 100	800 RPM-Wet	30	Good
2-Stikit Gold 320	800 RPM-Wet	30	
1-Stikit Gold 180	800 RPM-Dry	30	Good
2-Stikit Gold 320	800 RPM-Dry	30	
1-Beartex Medium	800 RPM-Wet	40	Fair
2-Scotchbrite Very Fine	800 RPM-Wet	35	
1-Scotchbrite Medium	800 RPM-Dry	40	Fair
2-Scotchbrite Very Fine	800 RPM-Dry	35	

Backup pad used with Multicut 120 was 3M No. 57.

Backup pad used with Stikit systems was Ferro 805L.

Backup pad used with Beartex and Scotchbrite systems was Ferro GP 35.

that have been abraded well past the desired endpoint (within the epoxy). As shown in Figures 3.4.3-1 and 3.4.3-2, test results indicated that no statistically significant loss of properties has occurred. In addition, the surface roughness is quite low, typically 140 microinches RMS for wet abrasive and 180 microinches RMS for dry abrasive.

3.4.4 Conclusions

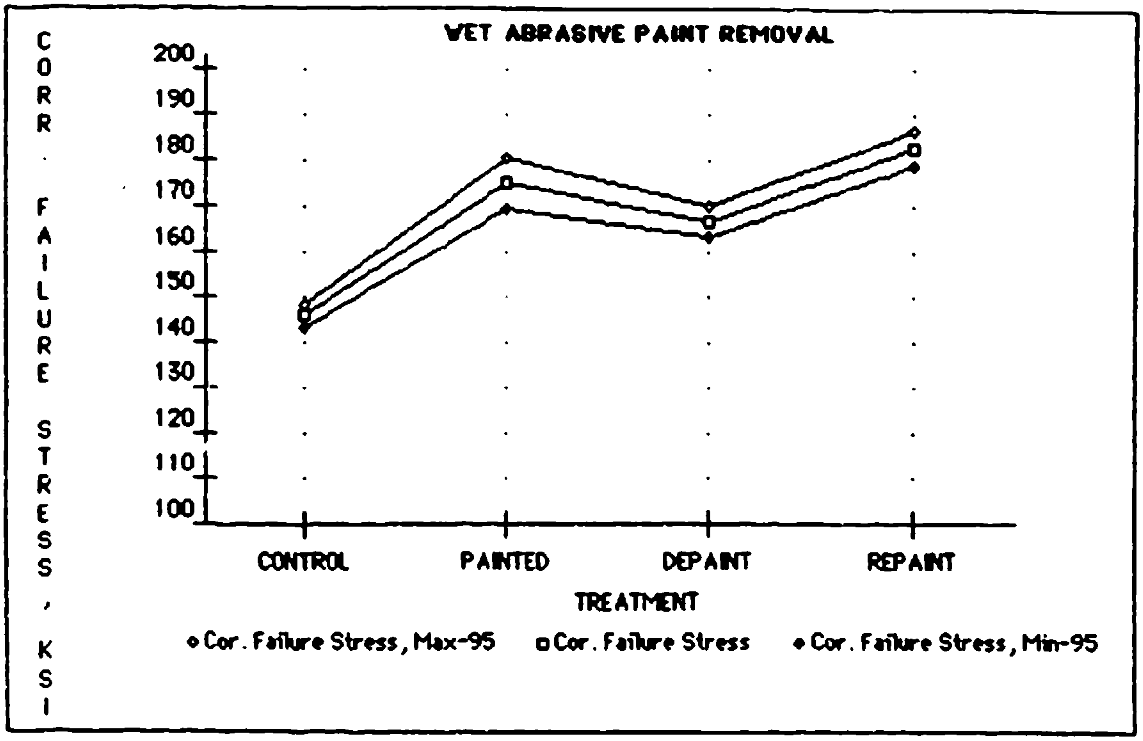
1. Abrasive paint removal on composites is a very feasible approach to depainting.

2. The 3M Multicut (120 grade) system with 800-RPM wet (0.15 gallons of water per minute) sander and 3M backup pad No. 57 is the best system evaluated to date (See Figure 3.4.3-3). Using a 5-inch disc on a 6" x 12" panel, stripping rates of 1 ft²/minute have been achieved with excellent control (See Figure 3.4.3-4). In addition, the Multicut discs have shown good durability, minimal clogging, and no adhesion problems to the backup pad.

3. The 3M Multicut (120 grade) system with 800-RPM dry sander and 3M backup pad No. 57 is nearly as effective as the wet system. Stripping rates and control are slightly less.

4. Generally, wet sanding eliminates dust, reduces clogging, provides somewhat better control than dry sanding, but is messy and creates a wastewater handling situation. Recycling and filtering is a potential solution to the wastewater problem. At the very least, minimal amounts of water should be used

5. The achieved laboratory stripping rate of 1 ft²/minute should be substantially improved in field use for several reasons. First, a disc of at least 8-inch diameter can replace the current 5-inch diameter disc. This will provide at least



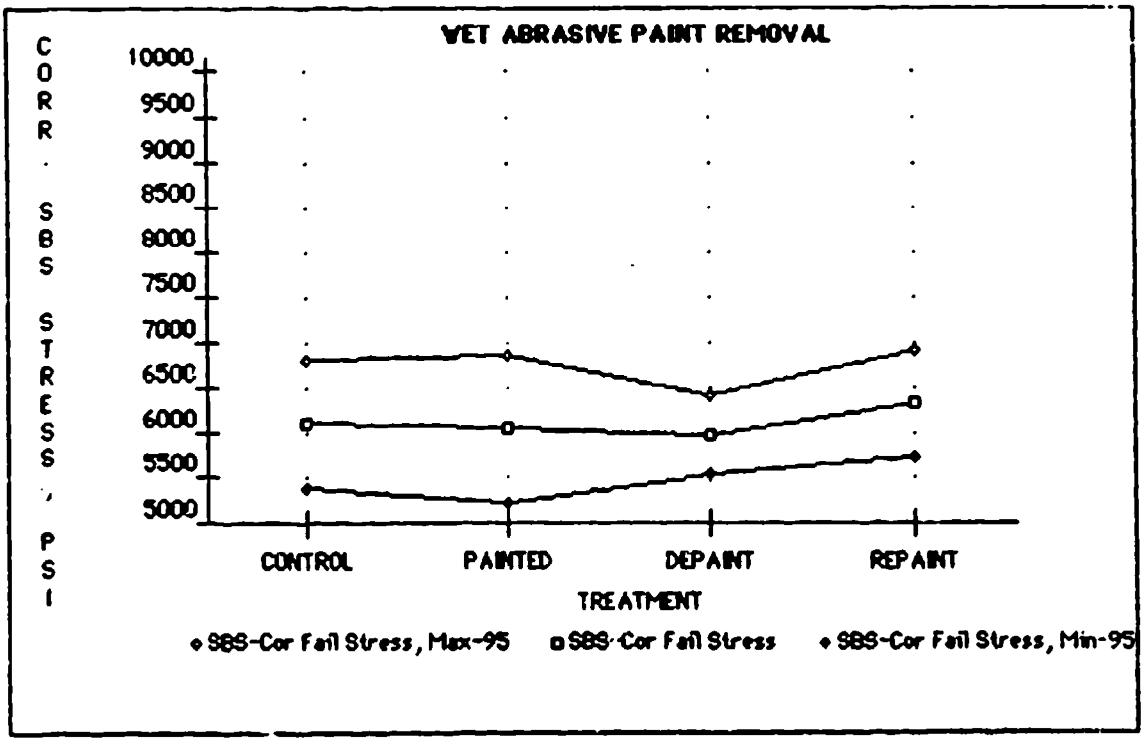
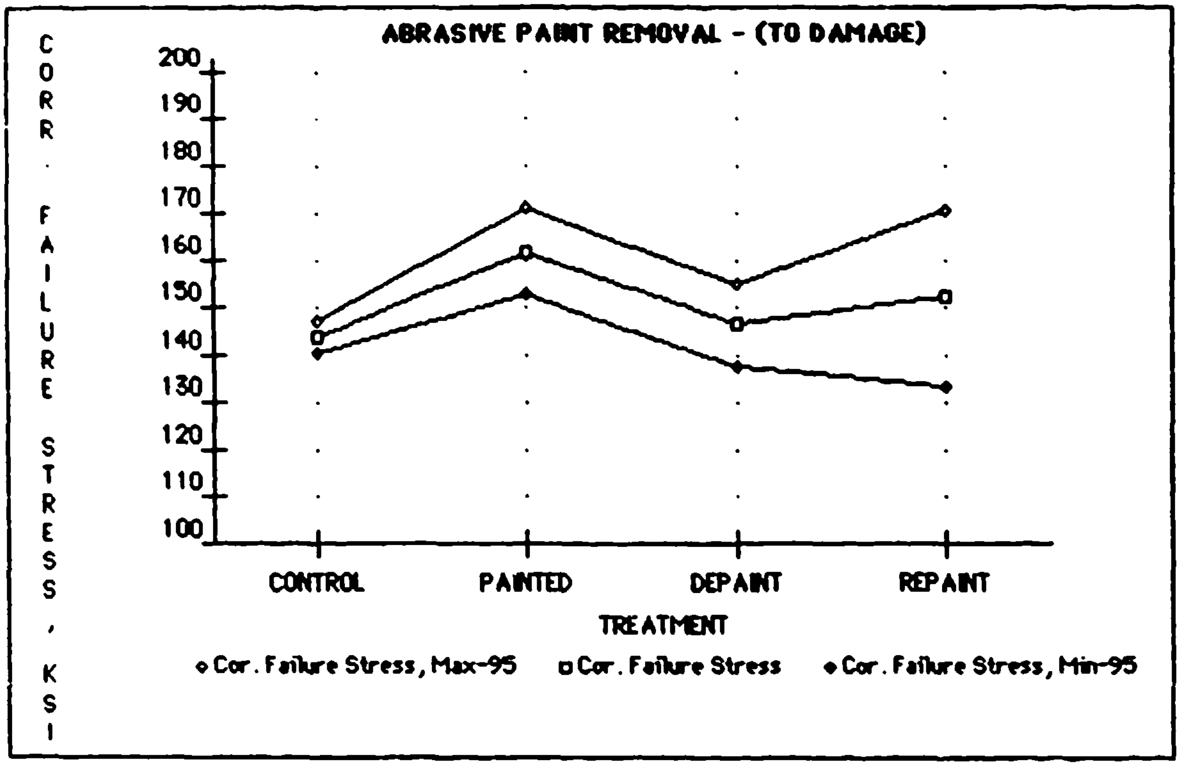


Figure 3.4.3-1 Wet Abrasive Paint Removal



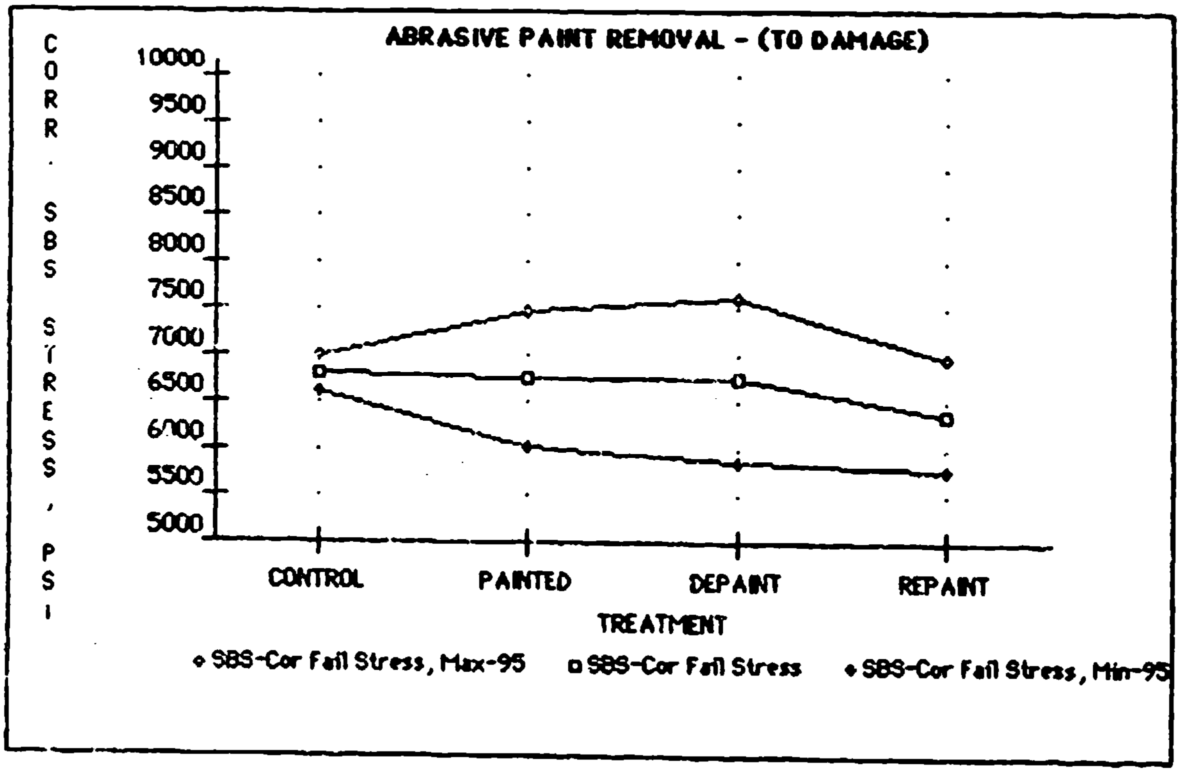


Figure 3.4.3-2 Abrasive Paint Removal - (To Damage)

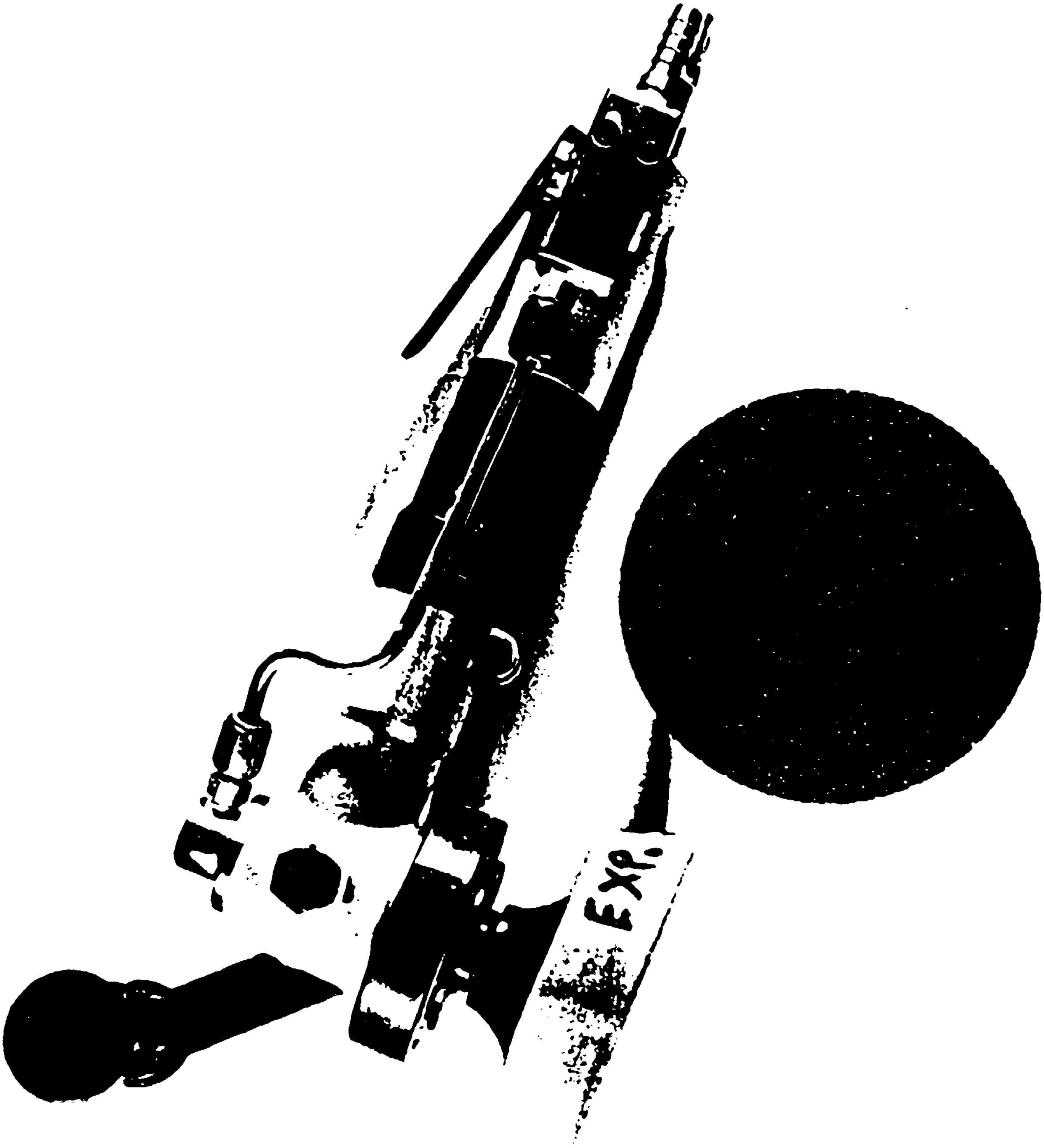


Figure 3.4.3-3 Dynabrade Sander and
3M Multicut Pad

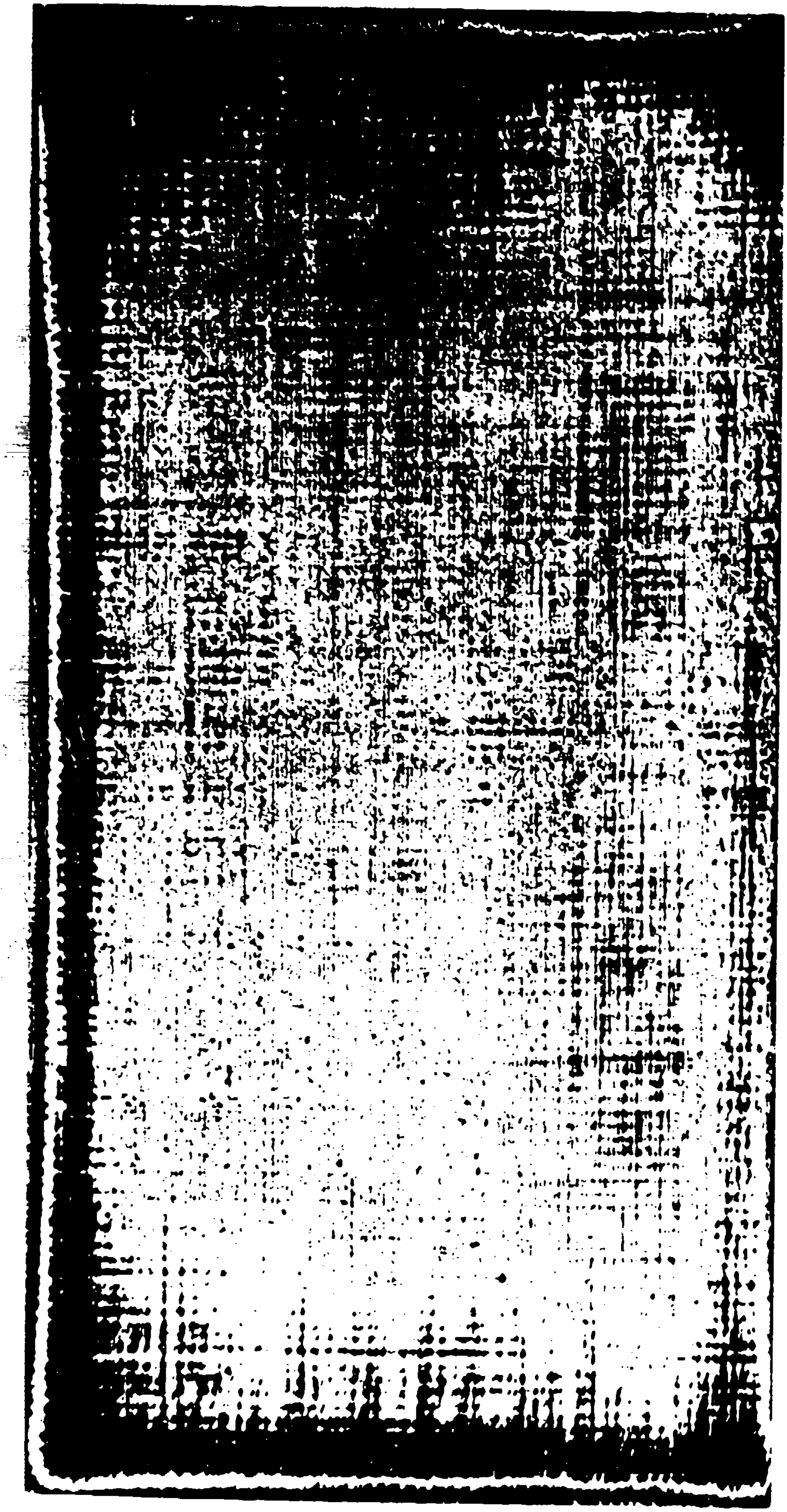


Figure 3.4.3-4 Wet Abrasive Stripped Panel

2 1/2 times the surface area. Secondly, a variable speed 2000-RPM wet/dry sander is currently being developed which would allow for improved speed control. That is, higher speeds could be used for initial stripping, and then lower speeds could be used upon nearing or reaching the epoxy primer with very minimal change over time. This should allow for improved rates and control. In addition, paint removal on a 6" x 12" panel with a 5-inch diameter abrasive disc is difficult because of movement and vision constraints. Abrasive removal on large surface areas will alleviate movement and vision constraints, which should improve rates as well as control. A disadvantage is that this method is labor intensive and operators may not be able to sustain these rates for extended periods of time.

6. Initial mechanical property testing shows no loss in properties provided the primer is not severely penetrated.

7. Levelling (elimination of the "waffle" pattern) of the composite surface prior to application of the primer and topcoat should minimize penetration through the epoxy primer.

8. Further testing should be performed on larger surfaces and contoured surfaces.

Dynabrade's new variable speed (0-2000 rpm), wet/dry sander was evaluated. The system was tested using 120-grade Multicut discs and the 3M No. 57 backup pad. Results were disappointing, as the variable speed sander did not possess the power that both the 800- and 2000-rpm sanders had. As such, stripping rates were much lower. Our conclusions are that the performance of the variable speed sander was inferior to the "single" speed sanders and did not warrant any further consideration.

3.5 Wheat Starch Blasting

Ogilvie Mills, Inc., has introduced a wheat starch blasting process for paint removal. The process utilizes a nonpetroleum amylaceous polymer which is biodegradable and nontoxic. The raw material is purified (99.98%) wheat starch with all organic ingredients such as the oils removed. Ogilvie Mills reports that the media has been engineered to perform to exacting specifications and does not damage aluminum. The media has a hardness of 85 Shore D or 2.8 Mohs, does not clump together at high relative humidity (but will clump in liquid water), and costs between $2.10 and $2.50 per pound. The media is delivered to the substrate in a similar manner as in plastic media blasting. Equipment to separate hazardous and nonhazardous waste is in the prototype development stage. A small, portable blasting unit is available for demonstration purposes.

Testing

Initial stripping trials, using the Envirostrip process, were performed on two coated aluminum panels and a coated composite panel. On the first aluminum panel, stripping was performed to the primer level. Stripping was able to be terminated in the primer layer over the majority of the panel. Blasting parameters used were 35-psig blasting pressure, 20- to 40-degree blast angle, 6- to 10-inch standoff, and 250-lb/hr media flow rate. Overall, the control was very good, as only small amounts of topcoat remained, and virtually no penetration to the aluminum was observed. The process left the primer surface slightly rough.

The second panel was stripped to the aluminum. Blasting parameters were the same except the pressure was increased to 50 psig and the angle was 50 to 70 degrees. The process was very effective, as virtually all of the coatings (topcoat and primer) were removed, and the aluminum surface appeared undamaged. The panel was slightly curved as a result of the removal process.

The graphite-epoxy composite panel was stripped to the primer layer. The blasting parameters used were 30 psig blasting pressure, 20- to 40-degree blasting angle, 6- to 10-inch standoff, and 250-lb/hr media flow rate. The control of the process was fairly good, as stripping was able to be terminated in the primer layer over the majority of the panel. However, there was some penetration through the primer and small amounts of unremoved topcoat. No fiber damage was obvious. Ogilvie Mills suggests that the process should be able to remove all of the topcoat and primer without damaging the composite and produce higher overall stripping rates in the process. Stripping rates were not able to be calculated in these initial trials.

Next, Ogilvie Mills performed trial stripping on a 2.5-foot by 1-foot graphite-epoxy composite panel. The panel was sectioned into quarters and the following stripping operations were performed:

Section 1 - This portion of the panel was used for practicing both selective (termination at the primer layer) and complete paint removal. Removal in this area indicated that the Envirostrip process has reasonably good control for stripping to both of these levels. Also in this section, an area was exposed to a 30-second dwell. Damage in this area was very limited, as penetration was generally only to the surface of the first layer of fibers or less, although one small spot of fiber delamination was evident.

Section 2 - This area was stripped to the primer level. The control of the system was very good. Over the large majority of the panel, stripping was terminated in the primer layer. Essentially no penetration through the primer layer occurred. Remnants of the polyurethane topcoat were visible over about 5% of this section. A nozzle pressure of 35 psig, a blast angle of 30 degrees, a standoff distance of 7 inches, and a media flow rate of 900 lb/hr were used. The stripping rate was estimated to be 0.5 ft^2/minute.

Section 3 - Topcoat and primer were completely stripped. Over the majority of the area, stripping was terminated at the surface of the composite without any obvious signs of damage to the matrix resin or the fibers. However, delamination of the first and second composite plies was produced in areas. Ogilvie Mills feels that a small amount of glass bead contamination may have caused the delamination. A nozzle pressure of 45 psig, a blast angle of 70 degrees, a standoff distance of 7 inches, and a media flow rate of 900 lb/hr were used. The stripping rate was estimated to be 0.75 ft^2/minute.

Section 4 - Topcoat and primer left intact -- unstripped area.

The results of this trial are shown in Figure 3.5-1.

Finally, on the uncoated side of the panel, a 30-second dwell time was also evaluated. In this area, no delamination and minimal damage to the gelcoat was observed. Overall, the results of this series of testing were very promising.

In an effort to evaluate the capabilities of with noncontaminated media, a third series of stripping trials was undertaken. These trials were performed on a 2.5-foot by 1-foot graphite-epoxy composite panel which had been coated on both sides. The primary objective in stripping this panel was to eliminate the delamination in the fiber layers of the composite, as had occurred during nonselective stripping in the previous trial. Media for this trial was carefully chosen and handled to prevent any contamination.

Figure 3.5-1 Wheat Starch Blasting - Various Conditions

Using the same blasting parameters as in the previous trial, approximately one fourth of one side of the test panel was stripped to the composite surface. Delamination of the first ply was observed, albeit to a much lesser degree than the previous trial. Ogilvie concluded that the process did not allow for complete removal of the topcoat and primer on this type of graphite-epoxy composite (Ogilvie claims to have had good success on other graphite-epoxy composites).

With this result, the remaining 7/8 of the panel was then stripped, using the primer layer as a "flag" with very good results. The process was able to terminate stripping in the primer layer very effectively, and at a stripping rate of 0.5 ft^2/minute (Figure 3.5-2).

Because of the time constraints of this program, mechanical property evaluations of composite panels stripped by the Envirostrip system were not able to be performed. The surface generated, however, is very smooth, typically 115 microinches RMS.

Conclusions

The Envirostrip system has performed well in these trial stripping operations and appears to be a promising process for large-scale aircraft paint removal operations. The control of the system is very good, and stripping rates are reasonable. Mechanical property testing on panels stripped with the Envirostrip process should be performed.

3.6 Ice Blasting

Ixtal Corporation (Victoria, B.C.) is developing an ice blasting system for paint removal applications. The system was originally conceived to overcome a shortcoming of CO_2 pellet blasting -- namely the inability to use the process in closed areas because of ventilation problems. Ixtal believes the system has shown great promise, and are especially encouraged by the nonabrasive nature of this technique

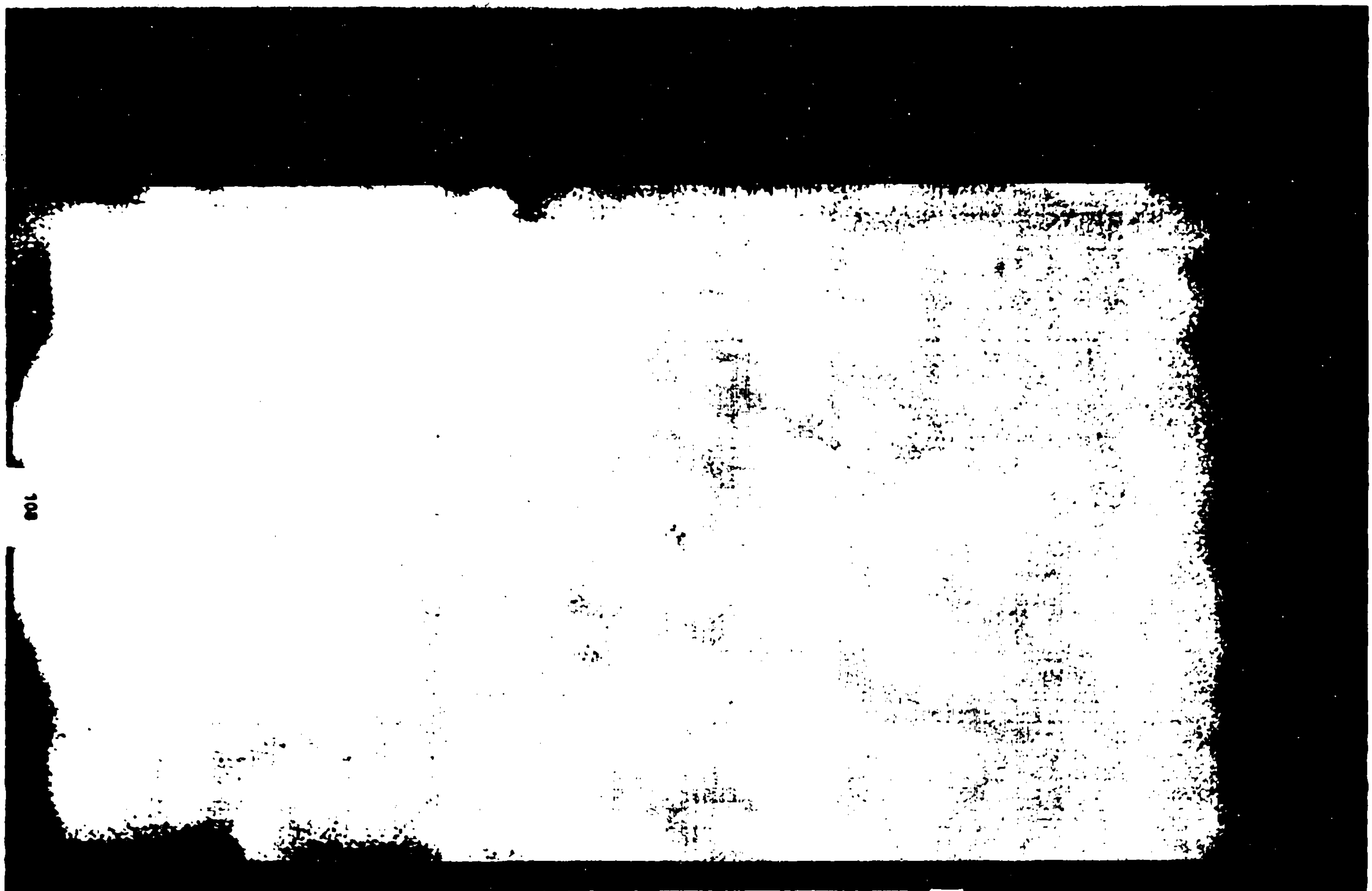


Figure 3.5-2 Wheat Starch Blasting Optimized

(plexiglass can be blasted without scratching). Their work is 50% funded by the Canadian National Defense, and they are currently finalizing the commercialization of the process with General Electric.

The system operates in a similar manner as other blasting operations (i.e., PMB, sodium bicarbonate, CO_2 pellets, etc). Typical blasting parameters are 80 psig blasting pressure, 6- to 18-inch standoff distance, 45 gallons of water per hour (for the production of ice), and a water temperature at the substrate surface of 32°F. Exact setting of the operating parameters for a given application is critical for the successful removal of coatings. The system is currently operated by hand, but may be redesigned for robotic integration. The ice "spheres" (1-3 mm in diameter) melt on impact and subsequently aid in washing the removed paint particles from the substrate. A key objective in the optimization of the ice blasting process is to deliver the ice to the substrate surface without having melted the ice and with minimal super-cooling (to minimize energy costs). Reportedly, this is a strong point of their system, as they have successfully transported 32°F ice through 150 feet of hose.

Ixtal claims that the ice blasting process has successfully removed numerous coatings from a variety of metal and composite substrates, including the standard Air Force epoxy primer and urethane topcoat from graphite-epoxy composites. The removal has been performed with no alteration of the composite surface, that is, the "waffle" pattern has been left intact. The removal mechanism is described as fracture, and not abrasion. The blend of 1- to 3-mm ice spheres impacts the coated surface. The larger ice spheres (3 mm) initiate cracking, and subsequently the smaller spheres (1mm) propagate the cracking and disbond the coating. The coatings tend to disbond layer by layer. Ixtal theorizes that disbonding occurs between the layers of weakest attraction. With a coated graphite-epoxy panel, disbonding tends to occur at the epoxy primer/graphite-epoxy composite interface, perhaps because of surface oxidation and contamination from the atmospheric exposure of the composite surface prior to priming. In contrast, the urethane topcoat is typically applied to the epoxy primer within a few hours after application of the primer, limiting surface problems. As a result, stronger bonds form at the primer/topcoat interface.

Because of the novelty of the development, factors such as waste separation and corrosion have not been thoroughly investigated. Ixtal believes that flash-corrosion will occur, but that it will be possible to treat the water to minimize this problem.

Trial stripping of test panels was unable to be performed because of some equipment problems and the time constraints of this program.

Conclusions

The qualities of the system which have been reported regarding the Ixtal ice blasting process appear desirable. Paint removal on aluminum and graphite-epoxy test panels should be evaluated. With successful results in this trial, more extensive testing -- large composite panels, along with mechanical property testing, should also be performed.

3.7 Summary of Results from Key Paint Removal Methods

The paint removal rates and the resulting surface roughness varied substantially among the methods investigated. Table 3.7-1 summarizes these results, as well as qualitative observations on the potential effect of the paint removal process on the composite substrate.

Table 3.7-1

Summary of Results from Key Paint Removal Methods

METHOD	REMOVAL RATE	SURFACE ROUGHNESS	EFFECT ON COMPOSITES
Plastic Media	1-2	270	Damage possible
Dry Abrasive	1	180	Minimal damage observed
Wet Abrasive	1	140	Minimal damage observed
Carbon Dioxide Pellets	≤0.5	210	Severe damage observed
Sodium Bicarbonate	0.75	250	Minimal damage observed
Excimer Laser	0.1	115	No damage observed
Wheat Starch	≥0.5	115	Potentially minimal
	(ft^2/min)	(microinches)	

4.0 Other Paint Removal Technologies

4.1 Cryogenic/Cryogenic Abrasive

Cryogenic paint removal involves the application of a cryogenic liquid nitrogen (-320°F) onto a coated substrate for the purpose of embrittling the coating and facilitating the removal process. A complimentary mechanical process, such as PMB or sanding, is often required to complete the removal process. There are two mechanisms for removal. First, the paint is frozen and embrittled, allowing impact or abrasion operations to work more effectively. Second, there is thermal contraction of the coating which is a maximum at the surface and decreases with coating depth due to the temperature gradient. If a surface coating with a significantly different thermal expansion from the substrate is present, debonding can occur as a result of the stresses incurred during contraction. With the urethane topcoat/epoxy primer/graphite-epoxy composite system, the advantage is gained by embrittlement, not differing thermal expansions. However, with metal substrates, both removal mechanisms provide contributions. The embrittlement temperature of the urethane topcoat has been determined to be around 30°F (this is significantly higher than the -100° to -200°F which the surface is estimated to reach in the spray application of liquid nitrogen). At temperatures above 0°C (32°F), the urethane topcoat possesses an elastomeric, abrasion-resistant nature. However, at temperatures below 0°C, the urethane topcoat embrittles and becomes less abrasion-resistant. The effect is to alter the nature of the polyurethane topcoat such that removal by a secondary means is facilitated. Another advantage of the system is the minimal waste generated. Upon warming, the liquid nitrogen evaporates, leaving behind only the removed coating and any debris from a complimentary removal method.

Liquid nitrogen was first used as a paint removal method on the Statue of Liberty restoration project during 1984 through 1986. The Linde Division of Union Carbide Corporation was responsible for development of the cryogenic system used on the

Statue of Liberty. The process worked very effectively on the Statue of Liberty for several reasons:

1. Surface coatings were very thick, as up to seven layers of various paints, including vinyls and old lead-based paint, were present;
2. Effective embrittlement; and
3. The difference in thermal expansion coefficients between the paint and the copper skin.

The coatings, in many cases, were easily removed by brushing after exposure to liquid nitrogen. Union Carbide is no longer involved with cryogenic paint removal.

Air Products and Chemicals, Inc., Industrial Gas Division of Allentown, Pennsylvania has a proprietary process for the cryogenic removal of coatings which also involves media blasting. Panels painted with the polyurethane and epoxy primer were submitted to Air Products for a preliminary screening. Results indicated that their system is not aggressive enough to remove the paint at an acceptable rate.

Wisconsin Alumni Research Foundation (WARF) of Madison, Wisconsin has been issued a patent concerning the "Removal of Built-up Layers of Organic Coatings." The process utilizes the application of an unspecified liquified inert gas onto the coated substrate. This is followed by an abrasion or impact method to complete removal.

AGA Gas of Cleveland, Ohio and Lintech of Warsaw, Wisconsin utilize a dipping process for paint removal. Parts, typically small and metallic, are dipped in a tank of liquid nitrogen. The surface coating is embrittled at -320°F, and upon removal from the tank, any unremoved paint is dislodged by a second method such as brushing, chipping or blasting. Obviously, the dipping process is not feasible for coating removal on aircraft. However, many of the same effects can be achieved in a spray-applied cryogenic removal operation.

Laboratory Testing

Preliminary experiments were conducted, comparing removal rates by hand sanding on aluminum panels which had no cooling, and those which had been 1) cooled with dry ice and 2) cooled with a stream of liquid nitrogen. The dry ice exposure increased removal rate by about three times, while the liquid nitrogen exposure produced an unmeasured but definite increase in rate. A second benefit of these cryogenic applications is the substantially reduced heating effects of the sanding operation. Because of the potential advantage of such a system, it was decided to more thoroughly investigate the concept of a cryogenic abrasive paint removal system.

Cryogenic abrasive paint removal is a two-phase removal process. First, a cryogenic liquid is applied locally to the surface from which the paint is to be removed. Immediately after this, an abrasive system, similar to that described in Section 3D, is passed over the surface to mechanically remove the paint. The first step in our evaluation of the cryogenic abrasive system was to identify appropriate equipment and develop it for this application. The focus of this work was on the cryogenic aspects of this system. That is, much of the abrasive aspects (i.e., sanders, backup pads, abrasive discs and pads, etc.) had been developed in the abrasive removal program (Section 3D) and applied reasonably well in this program. The details of this work are presented.

Equipment

The first step in cryogenic abrasive removal was the identification, modification, and development of appropriate equipment. With an emphasis on obtaining equipment which was as portable and nonrestrictive as possible, equipment for the delivery of liquid nitrogen (-320°F) to the sander was developed in coordination with WESCO (Welders Supply Company) of Billerica, Massachusetts. The liquid nitrogen delivery system was comprised of their standard NL230 liquid nitrogen tank and a flexible, 1/2-inch I.D. stainless steel supply line which was insulated with urethane foam pipe insulation. The pipe insulation was a temporary insulator for our trial laboratory experiments. Standard insulated flexible liquid nitrogen lines exist at a significantly higher cost. In addition, WESCO also supplied clothing (i.e., gloves and aprons) to protect operators from the cryogenic materials and splashes created by the sanders. Our initial plan was to deliver the liquid nitrogen through the water inlet line of a Dynabrade 3000-RPM wet/dry sander, with the only modification being the necessary insulation of various portions of the sander. The water inlet line delivers the liquid through the shaft of the sander and subsequently the center of the abrasive disc. This approach was generally not successful for the following reasons:

1. In order to provide liquid nitrogen (as opposed to gaseous nitrogen) from the sander, the liquid nitrogen had to be run through the sander for 15 to 20 minutes to provide adequate cooling of the sander.

2. The internal gears, bearings, and other moving parts froze, greatly reducing rotational speed and power of the sander.

3. Leaks occurred internally because of contraction differences of various parts.

4. Stiffening and embrittlement of backup pads and surface conditioning pads occurred. In addition, the pressure sensitive adhesive used to hold the coated

abrasive discs to the backup pad completely lost tack when chilled, causing the discs to fall off.

As a result, modifications were made to segregate the liquid nitrogen line from the sander. This was achieved by attaching a well insulated parallel line to the sander. The feed line was split near the shaft of the sander and directed along each side of the outside edge of the abrasive disc, terminating about 1/2 inch above the substrate surface. This provided distribution of coolant on both sides of the sanding disc to accommodate the back and forth direction of sander travel. These modifications allowed for better control of the liquid nitrogen delivery to the removal surface and also eliminated the need for any "chill-down" time for the sander. In addition, none of the working parts of the sander were affected by this design.

However, stiffening of the backup pads still existed, although to a much lesser degree. Testing was performed to identify the backup pad, which would provide the best level of softness and flexibility. Durometer readings for backup pads at room temperature and after liquid nitrogen exposure are presented in Table 4.1-1. Paint removal trials with these backup pads indicated that, as in abrasive removal, the softer, more flexible backup pads provided the most control. A second phenomenon which commonly occurred with the backup pads used in cryogenic abrasive removal was stress cracking of the plastic plate to which the foam was bonded. The 3M No. 57 backup pad was the only tested pad which did not stress crack. Fortunately, it was also the softest pad and provided good control with the cryogenic system. As a result, the backup pad of choice for cryogenic abrasive paint removal was the 3M No. 57 pad.

Screening Tests

All testing was performed on 6" x 12", 12-ply, 0/90 coated composite panels.

Table 4.1-1

Shore D Durometer Readings
Room Temperature vs. Liquid Nitrogen Temperature

Backup Pad No.	Type Pad	Room Temp. Shore D	Liquid Nitrogen Shore D	Adverse Effects
Ferro - GP 915U	S.C.P.[1]	20	55	Stress cracks
Ferro - GP 35	S.C.P.[1]	14	60	Stress cracks
3M - No. 57	S.C.P.[1]	10	40	None
Ferro - 2	C.A.D.[2]	10	45	Stress cracks
Ferro - 3	C.A.D.[2]	17	80	Stress cracks
Ferro - 60655V	C.A.D.[2]	15	85	Stress cracks
Ferro - 805L	C.A.D.[2]	8	50	Stress cracks
Ferro - 885L	C.A.D.[2]	10	55	Stress cracks

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[1] S.C.P. = surface conditioning pad.
[2] C.A.D. = coated abrasive disc.

NOTE: 3M - No. 57 was the only backup pad that did not stress crack upon chilling at liquid nitrogen temperatures.

Initial testing of the cryogenic abrasive paint removal system utilized the modified 3000-RPM wet/dry sander, the 3M No. 57 backup pad and various surface conditioning pads. (Surface conditioning pads attached to backup pads with a "Velcro" type system. Coated abrasive discs could not be used at this time because of a loss in adhesion of the pressure-sensitive adhesive with cooling.) Best results with surface-conditioning pads were realized with the following:

- First cut, Beartex (Norton) medium grade with 3M No. 57 backup pad, and

- Second cut, Scotchbrite (3M) very fine grade with 3M No. 57 backup pad.

The cryogenic system removed an approximate 40 in^2 of topcoat in 32 seconds. In comparison, the identical wet sanding system removed approximately 33 in^2 of topcoat in 30 seconds. The cryogenic system showed an increase in stripping rate over the wet system, however, control with the cryogenic system was somewhat less.

At this point, the performance of a less cold cryogenic source was investigated. Since a temperature of -10°C would effectively embrittle the urethane topcoat, use of liquid nitrogen at -320°F appeared to be extreme. It was also possible that such low temperatures would produce undesirable stresses within the composite panel. As a result, a chilled nitrogen gas system was developed, using a heat exchanger consisting of a coil of tubing immersed in a liquid nitrogen bath. Dry nitrogen gas flowed through the immersion coil and subsequently lead to the sander through an insulated, flexible, stainless-steel line. The external delivery system at the sander was not changed. Initial testing of the system showed that chilled nitrogen gas is capable of exiting the sander at -70°C. Composite panel surface temperatures of between -20°C and -30°C were measured during testing.

A new abrasive disc, 3M - 259F Three-M-ite resin bond cloth or the Multicut system, was introduced at this time. This product, with its "hook-and-loop" attaching system, enabled coated abrasive discs to be successfully tested with the cryogenic system. Dramatic improvements over the surface conditioning pad systems were observed for both stripping rates and control. This system was evaluated on both the 3000 RPM and the 800 RPM sander. Testing indicated that both sanders provided equally good levels of control, with the 3000 RPM sander producing higher stripping rates. For these reasons, subsequent testing was performed with the 3000-RPM sander.

Using the 120 grade Multicut system with the 3000-RPM sander and 3M No. 57 backup pad, a direct comparison of the chilled nitrogen gas, the liquid nitrogen, and the conventional wet sanding systems was performed. These tests indicated that the chilled nitrogen gas provided higher stripping rates than the liquid nitrogen system. However, conventional wet sanding provided the best stripping rates. This phenomenon was not seen prior to the use of the Multicut system, and results may differ with larger, more realistic-sized panels. Control was good with all three systems. The results are summarized in Table 4.1-2.

In an effort to more evenly disperse the chilled nitrogen gas onto the composite panel, a manifold nozzle system was installed on the Dynabrade 3000-RPM wet sander. The manifold nozzle consists of two 1/4-inch copper tubes, each 2-1/2 inches long. The tubes were curved to follow the outer circumference of the abrasive disc, and situated on either side of the abrasive disc. Each tube has a series of small holes along the bottom to direct the chilled nitrogen gas downward onto the composite surface.

Initial testing of this system indicated that the dispersion of chilled nitrogen gas needed to be increased further (i.e., manifolds positioned further away from the disc,

Table 4.1-2

Cryogenic Abrasive Removal Rate Comparisons

Abrasive Removal Method	Approx. Surface Temperature (°C)	Sanding Time (Sec)	Area of Topcoat Removed (In^2)	Sanding Control	Damage to Disc
Liquid Nitrogen	-140	22	36	Good	None
Conventional, Wet	10*	12	47	Good	None
Refrigerated Nitrogen (Fanned tube nozzles)	-20	16	36	Good	None
Refrigerated Nitrogen (Manifold system)	-10	20	30	Good	None

All methods used Dynabrade 3000-RPM sander with 3M No.57 backup pad and 120 grade Multicut disc.

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*Cold tap water temperature.

longer tubes, more holes, etc.). Further modifications were made to the manifold nozzles on the cryogenic sander, distributing chilled nitrogen gas more uniformly to the paint removal surface. This was accomplished by increasing the number of outlet holes and directing the spray down and outward away from the sanding disc. The result of these changes created a very broad spray pattern, cooling a much greater area. Our conclusions of the manifold nozzle system are:

- The system has been optimized. Chill down of the painted surface is more uniform and covers a broader area.
- Trials showed no change in removal rate for the manifold nozzle system over the fanned tube nozzle.
- No gain in sanding control was noticed.
- The manifold addition made the sander more awkward (e.g., it would be difficult to maneuver in tight corners).

The results of this system compared to other abrasive removal methods are summarized in Table 4.1-2.

For the purposes of this program, the cryogenic abrasive system has been optimized. The preferred system is the Dynabrade 3000-RPM sander outfitted with the fanned tube nozzles, 3M 120 grade Multicut disc, and 3M No. 57 back-up pad. Chilled nitrogen gas is dispersed at a temperature between -50° and -70°C, cooling the paint removal surface to approximately -20°C concurrent to the sanding operation. Unfortunately, the performance of this system on graphite-epoxy composites was slightly inferior to that of the optimized wet abrasive system. The flexural and shear strength measurements show no statistically significant decrease as a result of this process (Figure 4.1-1).

Conclusions

1. Overall, the cryogenic abrasive system did not demonstrate better performance on graphite-epoxy composites than the wet abrasive system. As such, the added complexity of the cryogenic system is not warranted for this application.

2. The chilled nitrogen gas system with the 120 grade Multicut disc, 3000-RPM sander, and 3M No. 57 backup pad provided the most effective stripping rates and control.

3. The chilled nitrogen system (-70°C) was more effective than the liquid nitrogen system (-320°F).

4. Test results of abrasive discs and pads parallel those found with abrasive paint removal. That is, the relative ratings, based on stripping rates and control, of the discs and pads were essentially the same.

5. The softer, more flexible backup pads provided the highest level of control.

6. The 3000-RPM sander provided higher stripping rates with similar control in comparison to the 800-RPM sander.

7. Condensing gases on the surface of the composite panel creates some vision problems. A low dew point environment is desirable.

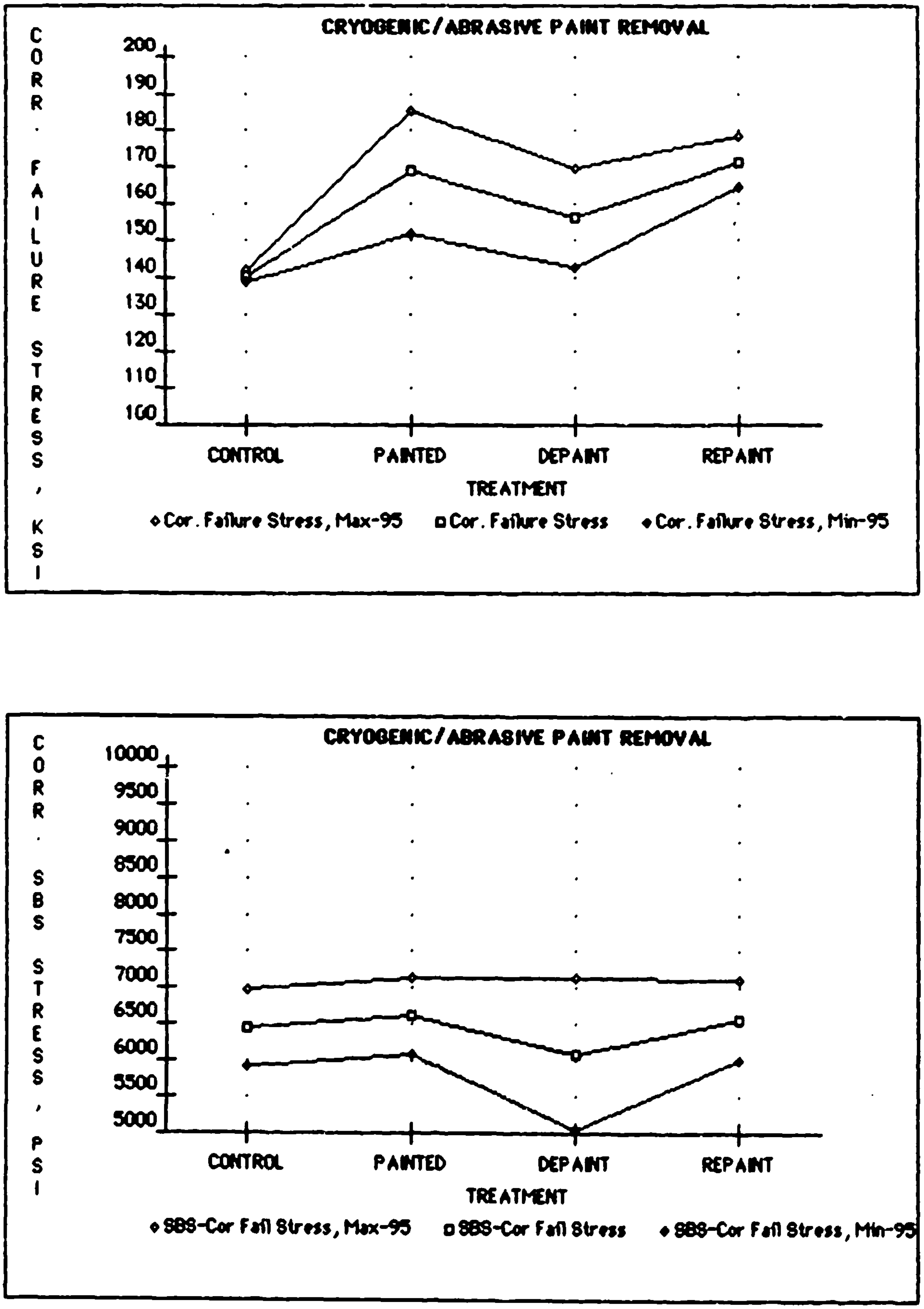


Figure 4.1-1 Cryogenic/Abrasive Paint Removal

8. Paint removal on larger surface areas should provide improved results because of more even cooling of the coated surface, less movement and vision constraints, and the ability to use a larger abrasive disc.

4.2 Waterjet Blasting

Waterjet technology utilizes high-pressure water to erosively transform materials and surfaces. Systems are available which are capable of cutting or drilling numerous materials such as concrete, rubber, various plastics, printed circuit boards, particle board, and even cardboard. Waterjets are also successfully used as cleaning equipment for removal of materials such as rust, corrosion, rubber, and some paints. Overall, these systems are well developed for cutting applications and work effectively when cleaning is performed on durable materials. The concept of using waterjets as precision removal instruments on more delicate substrates is relatively new, and with relatively few exceptions, has not been extensively investigated. The main advantages of waterjets include: no organic solvents, water can be recycled which minimizes waste, and relatively safety and inexpensive operation.

Tracor Hydronautics of Laurel, Maryland, has done considerable work specific to precision coating removal by waterjet. In 1982 they reported on "Self-Resonating Pulsed Waterjets for Aircraft Coating Removal: Feasibility Study" for the Office of Naval Research. Coatings were removed using a Servojet. This is a pulsed, self-resonating, high-pressure waterjet which is disrupted into a discrete train of well-organized slugs through passive acoustic, self-excitation of the jet. This produces the following effects: a larger initial impact stress, because of the water-hammer effect; larger outflow velocities, which aid the material removal processes; an increased area of impact; and short-duration, cyclic loadings, which serve to more efficiently interact with naturally occurring material flaws and enhance debonding of surface adherents. Using a 0.10-inch Servojet nozzle and operating at pressures of about 5,000 psi, the system was able to remove the MIL-C-83286 polyurethane topcoat from aluminum and graphite/epoxy panels. Results on aluminum panels were reported to be very positive, while results on composites were found to be inconclusive due to large discrepancies in paint and material properties. "Removal of Paint from Aircraft Surfaces using Servojet Self-Resonating Pulsed Waterjets: A Status Report" of November 1987 reports on the optimization of parameters for the Servojet for stripping Pratt and Lambert's "Jet Glo" polyurethane topcoat and MIL-Spec-724-222 yellow epoxy primer from aluminum and graphite-epoxy panels. Parameters that were varied were nozzle size and configuration, standoff distance, nozzle pressure drop, flow rate through the nozzle, and traversing rate of the nozzle. Optimum operating for removal of the topcoat only was found using the following parameters:

Nozzle size and type	0.081 in. round
Pressure drop, Δp, psi	7,500
Flow rate, Q, gpm	11.0
Hydraulic power, P, hp	47.9
Traversing rate, v, in./s	1.0
Standoff distance, X, in.	3.0
Cleaned path width, w., in.	0.87
Paint stripping rate, A, ft^2/hr.	21.8
Area cleaning effectiveness, ft^2/hp-hr.	0.45

Hydronautics found that some surface attack occurred on the composite panels and that these preliminary results indicated that the Servojet nozzles could be used for coating removal on graphite/epoxy composites.

ADMAC of Kent, Washington, possesses a line of waterjet equipment which is typically used in heavy-duty industrial cutting and cleaning operations. These waterjet systems typically operate at pressures up to 35,000 psi. They can operate as either high-pressure/low-volume or low-pressure/high-volume systems. ADMAC has achieved success in some paint removal operations from metals, but to date their limited testing on composites has been unsuccessful. ADMAC has also done work with carbon dioxide pellet blasting.

Other companies such as NLB Corporation of Wixom, Michigan; Hammelmann Corporation of Dayton, Ohio; and Wakatsuki Technology International of San Rafael, California, have had limited success with various paint removal operations but have not attempted precision coating removal on composite materials.

Conclusions

Because of potential for corrosion, water intrusion, and high blasting pressures, as well as a lack of demonstrated performance on composite materials, it was jointly decided that waterjet blasting is not an appropriate paint removal technique for military aircraft.

4.3 Thermal Stripping

This technique utilizes heat to soften the coating and facilitate removal. A complimentary mechanical operation, such as scraping, abrading, or blasting, is required to perform the physical coating removal. Heating must be performed at levels low enough to prevent any damage to the underlying composite materials.

Air Product and Chemicals has a proprietary process for paint removal, involving thermal decomposition by gases at precisely controlled temperatures from 190-260°C. Coated panels were submitted to Air Products for a screening evaluation. Results indicated that their process does not facilitate the removal of the urethane topcoat. The only transformation observed was a substantial darkening of the coating.

Brisk Heat Corporation of Columbus, Ohio manufactures a line of electrically powered heated tapes and blankets. These products are capable of being heated up to temperatures of 1200°F. Heated tapes are available in widths up to 3 inches and lengths up to 12 feet. The blankets are relatively expensive, and would likely warrant multiple use. Heated blankets are available in sizes up to 24 feet by 24 feet. The military currently uses these blankets for curing operations with certain composite fabrications.

Testing

A 7075-T6 aluminum panel coated with epoxy primer and polyurethane topcoat was placed in an oven. The panel was exposed to increasing temperatures from 50°C (122°F) up to 180°C (365°F). The softening of the coating was evaluated after every 10°C increase in temperature by forcing the pointed tip of a spatula into the coating. Significant softening occurred at approximately 110°C (230°F). At this point, it became much easier to penetrate the topcoat and to remove a significantly higher amount of topcoat than primer. Further increases in temperature produced insignificant increases in the softening of the topcoat.

Finally, the panel was cycled six times between room temperature and 180°C (356°F) to observe the effect of multiple heatings. The test determined that heat cycling at these temperatures produced no facilitation of coating removal. The coating was just as difficult to remove at room temperature or 180°C after one cycle as it was after six cycles.

Conclusions

The primary composite used on aircraft is the 350°F epoxy/graphite system with heat distortion temperature in the rage of 370° to 400°F. Thermal techniques can readily exceed this temperature in localized areas. Other materials (fuels, plastics, etc.) are also present on military aircraft which could be damaged by a thermal removal process. In addition, no significant advantage in coating removal was observed. As a result, thermally assisted paint removal from composites on military aircraft was determined to be inappropriate.

4.4 Alternative Solvents

Solvents remove paint as a result of chemical transformation and/or swelling of the polymer binder system. In paint removal applications, solvents, typically methylene chloride, are applied by spraying or brushing, and allowed to soak into the coating. Mechanical methods, such as scraping, are commonly used to remove the loosened paint. This tends to be a very messy and labor-intensive operation. Another key consideration concerning paint removal with solvents is volatiles emitted. Regulations limiting emission amounts of volatile organics have become increasingly stringent. In addition, solvents often possess various types of health hazards. Finally, disposal of paint containing solvents produces several problems, since they must be treated as hazardous waste.

In a previous study of alternative solvents, the Naval Air Development Center of Warminster, Pennsylvania investigated the use of Type I phenolic and Type II non-phenolic versions of MIL-R-81294 (see Table 4.4-1 for compositions) in stripping MIL-C-83286 polyurethane topcoat and MIL-P-23377 epoxy primer on graphite-epoxy composites.

Table 4.4-1

MIL-R-81294 Paint Remover Compositions

	(Weight Percent) Type I Phenolic	Type II Non-Phenolic
Methylene Chloride	71	75
Phenol	20	0
Water	4	2
Other Solvents	0	10
Additives	5	13

Results of this study indicated that MIL-R-81294 causes a statistically significant decrease in the physical properties of composite materials under simulated rework conditions. This deleterious effect was concentrated at the composite surface directly exposed to the paint stripper. The conclusion was that graphite-epoxy composite structure should not be exposed to MIL-R-81294 paint stripper.

In this program, we conducted an investigation of solvent alternatives to methylene chloride. Four commercial solvents were identified which were considered to have removal potential and to be relatively safe. These were Kodak Ektapro EEP (ethyl 3-ethoxypropionate), Fine Organics FO 2115A, N-methyl pyrrolidone, and ethylene carbonate.

The ability of each of these solvents to remove topcoat and/or primer was compared to methylene chloride using coated aluminum panels. Solvents were applied at room temperature to a small area of the test panels. At regular intervals, the degree of penetration into the coatings was checked. The following results were obtained:

1. Methylene Chloride was found to be very aggressive. Removal of topcoat and primer to bare metal was achieved in several minutes. After about one hour, most areas of the coating blistered and completely disbonded from the aluminum.

2. Kodak Ektapro EEP (ethyl 3-ethoxypropionate) was mildly aggressive. Penetration through the urethane topcoat occurred in about one and one-half hours, while penetration through the epoxy primer occurred after two hours.

3. Fine Organics, FO 2115A was moderately aggressive. Penetration through the urethane topcoat occurred in one hour, while penetration through the epoxy primer occurred in about two hours.

4. N-methyl pyrrolidone was moderately aggressive. Penetration through the urethane topcoat occurred in 45 minutes, while penetration through the epoxy primer occurred in one hour.

5. Ethylene Carbonate is a solid at room temperature and melts at about 95°F, which presents certain advantages as well as disadvantages. In order to liquify the ethylene carbonate, the test panel was placed in an oven at 117°F. Upon melting, the ethylene carbonate was moderately aggressive, as the urethane topcoat was penetrated in about one hour, while penetration through the epoxy primer occurred in about one and one-half hours. In an attempt to take advantage of ethylene carbonate's solid nature at room temperature and contain its solvent release, the ethylene carbonate was covered with various solvent-resistant tapes (vinyl, ultra-high molecular weight polyethylene, nylon, and polyethylene). The samples were placed in an oven at 117°F for two hours. Upon their removal, the following observations were made:

1. The ethylene carbonate tended to move to the outer perimeter of the area under the tape, leaving a void in the center portion.

2. The topcoat and primer were easily removed when scraped immediately after removal from the oven, but became more difficult after the ethylene carbonate had resolidified.

3. No damage or softening was observed to any of the tape backings, although the vinyl and nylon did develop small leaks because of an ineffective bond to the coated panel.

The low-level heating which was required by the ethylene carbonate could be accomplished on aircraft using heated tapes and blankets. These heating devices are available through Brisk Heat Corporation of Columbus, Ohio.

Conclusions

No solvent system was as aggressive as methylene chloride. Distinct differences in penetration times for the urethane topcoat and epoxy primer were observed. However, selective removal of the topcoat would require careful monitoring of the exposure time and exacting knowledge of the underlying coating(s). Ethylene carbonate showed potential as a material which could be contained to prevent volatile emissions and removed as a solid waste, but not without additional processing steps -- covering and heating. No solvent has been identified which would overcome the messiness of the operation or the disposal problem. Overall, alternative solvent systems are not a viable paint removal option.

4.5 Ultrasonic Paint Stripping

Everything that makes a sound vibrates, and everything that vibrates makes a sound; however, not all sounds are audible. Ultrasound literally means sound beyond the audible spectrum. 18,000 Hz is approximately the limit of human hearing, as such ultrasonics refers to sound above 18,000 Hz.

Ultrasonics came of age after World War II with the introduction of ultrasonic flaw detection equipment; ultrasonic cleaning and degreasing followed, and, with broad industrial acceptance, many new applications for ultrasonic energy were found. The ultrasonic welding of rigid thermoplastic emerged in the mid-1960's.

The essential components required to apply ultrasonic energy are the power supply, converter, booster horn, horn, and assembly stand. The power supply, or ultrasonic generator, supplies high-frequency electrical energy to the converter, a component that changes electrical energy into mechanical vibratory energy. Attached to the converter is an amplitude-modifying device, or booster horn, which can either increase or decrease the amplitude of vibration supplied to the horn, the tool that transmits the ultrasonic energy to the part.

The weld power generated in plastic depends primarily on the velocity of the ultrasonic horn contacting the part. This velocity is an alternating current in electric machinery. Horn-face velocity is proportional to the product of horn-face displacement amplitude and operating frequency. For a constant frequency of operation, horn-face velocity varies directly with face-displacement amplitude.

The mechanical vibratory power delivered to the part is a product of horn velocity and the reaction force to the horn movement produced by the part. Within limits, this reaction force is related to the clamping pressure applied to the part and is also a function of the weld area and the material welded. While the mechanical power flow into the workpiece is determined by the force-velocity product alone, for optimum results each ultrasonic application also requires a specific force-velocity ratio or a selection of horn velocity amplitude best suited for the job. The energy required to accomplish a weld is the product of the average power dissipated in the joint and the weld time.

At ultrasonic frequencies, considerable amounts of power are imparted to the load without the application of large displacements or forces. One kilowatt of power supplied to an ultrasonic horn vibrating 20,000 times per second through a distance of 0.005 inch (0.127mm) requires a load reaction force of 56.3 pounds (250 N). This is equivalent to about 9,000 pounds (40 kN) of force exerted though a distance of 1 inch in 1 second. The use of ultrasonics enables high energy to be imparted to a plastic part at force levels that will not stress, crack, or produce residual deflection of the material.

The approach of using ultrasonic energy to remove paint form a composite substrate was explored by S.R. Taylor and Associates under contract to the U.S. Air Force (1986). The objective was to demonstrate the technical feasibility of the development of a hand-held ultrasonic tool for removing paint without altering the properties of the composites. In addition, the feasibility of using alternative solvents in combination with ultrasonic activation was evaluated. Two types of portable wave guide arrangements were devised with relative motions parallel and at right angles to the surface coating. The chemicals used for pretreatment included common acids and bases and solvents, such as toluene, acetone, and isopropanol. The waveguides operated as frequencies from 17.5 kHz to 25 kHz.

Results from the study are summarized briefly below:

- Ultrasonic paint removal is effective in the frequency range of 17.5 to 50 kHz.

- The rate of ultrasonic paint removal is directly dependent on the ultrasonic power input and energy density at the wave guide tip.

- Aqueous acids and bases affect the paint in a manner that appears to increase the rate of mechanical scraping.

- The rate of ultrasonic and mechanical paint removal is also dependent on the chemical reagent type, concentration, and contact time.

- The mechanical properties of the laminate are not measurably affected by the ultrasonic paint removal process.

The purpose of the study was not to optimize paint removal rates; however, rates in general were in the range of 2 to 10 square feet per hour (0.03-0.17 ft^2/min).

The hand-held ultrasonic devices were assembled by S.R. Taylor and Associates, Bartlesville, Oklahoma. Another manufacturer of stationary ultrasonic equipment, as well as some portable equipment, is Branson Sonic Power Company, Danbury, Connecticut. The primary emphasis at Branson is the ultrasonic welding of plastics.

Some of the advantages and disadvantages of ultrasonic paint removal from composites are listed below:

Advantages

- Appears to have little or no effect on composite properties
- Reasonably lightweight and portable
- Readily adapted to curved surfaces

Disadvantages

- The need for chemical stripping agents to soften the coatings
- Slow paint removal rates
- Moderate level of operator skill required

- Long cumbersome waveguides required
- Combustible stripping agents present flammability hazards
- Waste disposal of chemical stripping agents

Conclusions

The physical properties of the MIL-83286 urethane topcoat make it very resistant to mechanical devices such as the ultrasonic horn. We expect that chemical stripping agents would be required in conjunction with ultrasonic tools in order to provide an acceptably efficient paint removal rate. The method does not appear to provide a substantial improvement over the existing chemical stripping approaches currently used at Air Force logistics centers.

5.0 Identification and Evaluation of Protective Coatings

The objective of Phase II of the program was to identify and evaluate coating systems for composite substrates that would provide protection from potentially damaging paint removal methods such as media blasting and abrasives. This section of the report will cover results of the following four activities relating to the selection and evaluation of the candidate protective coatings.

1. Development of Performance Criteria
2. Literature Search
3. Company Survey
4. Laboratory Screening

Results of the paint/paint removal testing will be discussed in the following section.

5.1 Development of Performance Criteria

At the outset of this phase of the program, performance criteria for potentially successful protective coatings were developed. These criteria were based on three main considerations. They are discussed separately as follows:

Results of the Investigation of Paint Removal Techniques - This earlier phase of the program indicated that it was unlikely that a single coating would provide the optimum protection from different removal techniques. This is due to the theory that the coatings response to the paint removal method would be substantially different, depending on the chemical and physical nature of the coating. For example, blasting types of removal such as PMB and Carbon Dioxide Blasting resulted in rough-surface profiles of the composite, while abrasive methods resulted in much smoother surfaces. Based on this information, the composites may be protected from blasting techniques by using elastomeric coatings (Tg < 0°C), which have energy-absorbing and abrasion-resistant properties. On the other hand, hard, durable, filled coatings were predicted to protect composites from abrasive or sanding techniques. Table 5.1 summarizes these observations for some of the more promising removal methods.

Minimum Performance of a Successful Protective Coating - Although the most important performance criteria of the coating was its ability to protect the substrate from the effects of paint removal, there were several other minimum requirements that had to be met. The Air Force agreed that the coating would be applied between the composite and the primer surface, in order to act as an armor for the composite. A basic requirement, therefore, was the compatibility (wetability) of the coating with the surface of the graphite/epoxy composite. This required the coating to exhibit excellent adhesion to the composite substrate and to act as a suitable substrate for the epoxy polyamide primer paints.

Common requirements of aircraft coatings were also considered. The coating was expected to offer impact resistance that may result from maintenance, dropped tools, etc. Also, it must have the solvent and chemical resistance to standard aircraft fluids and fuels. Finally, good weathering properties, particularly moisture resistance, was a minimum performance requirement.

Other Requirements of the Protective Coating - The performance of the coating was critical to its success; however, several other factors were used in developing the selection criteria. The processing and maximum application requirements of the candidate coatings were considered, as well as the level of skill required for application. The applicability to large structures and maximum application rates were noted. Other important factors included toxicity, cost, and availability (i.e., experimental vs. commercially available).

Table 5.1

Potential Effectiveness of Protective Coating Systems

Paint Removal Method	Resulting Surface of Composites	Potential Coating System
Plastic Media	Rough	Elastomeric
Abrasion	Smooth	Hard, Tough
Excimer Laser	Smooth	Filled
Carbon Dioxide Pellets	Very Rough	Elastomeric
Sodium Bicarbonate	Slightly Rough	Elastomeric

During this period, the study was not restricted only to conventional coating systems. Free-standing films such as film adhesives and composite-surfacing films would be screened for use if it was determined that they could meet the specifications.

5.2 Literature Search

In the next task, we conducted an extensive literature search of protective coating technologies that might satisfy the desired requirements. This survey focused on three major topics. The first was a review of general information on the resistance properties of protective coatings, with a focus on resin types likely to meet the requirements such as polyurethanes, epoxies, etc. The second portion of the search examined patents and literature sources from industries with relevant technologies such as aerospace, aviation, and automotive. Finally, various related topics in the military literature were reviewed, using the DTIC information database.

This review provided useful background information on relevant technologies. Probably the most valuable result of this search was that it helped to identify the commercial sources of candidate coatings. A list of some of the most salient literature is shown below.

5.3 Company Survey

The object of this survey is to identify promising commercial coatings technologies that could meet all or some of the requirements of a successful protective coating. To perform this survey, we relied on both industry contacts of Arthur D. Little staff members and companies identified in the literature search. During this task, we were successful in establishing continuing relationships with companies interested in participating in the iterative process of testing and improving the coatings.

The primary goal of the contact was both to solicit technical and product information and to obtain samples of candidate coatings. A total of 24 companies were contacted, 12 of which provided one or more candidates. The companies contacted included large coating manufacturers such as Lord, Desoto, and PPG, as well as raw material suppliers such as Mobay and Freeman Chemical. Also included were companies with applicable in-house technologies such as Hughes Aircraft Co., Hysol Aerospace Products, and 3M. From this survey, a total of 20 promising coating and film lamination systems were identified for our screening program. The companies surveyed are listed in Table 5.3.

5.3.1 Description of Protective Coatings

General Information

An attempt was made to apply each protective coating or film laminate using a reproducible, standardized method. Typically, a Binks conventional spray setup equipped with a pressure cup was used to apply the wet coating solutions. Spray conditions included a line pressure of 25 to 30 psi, a cup pressure of 5 to 10 psi, and a number 63 needle and nozzle combination. The target dry film thickness of each coating was 1-4 mils; therefore, the wet film applied was determined by the total solids of each candidate coating. The specific mixing and application specifications were used as guidelines and is included in the individual product information sheets. (See Appendix C.)

Once applied, all coatings were allowed to dry at 70°F temperature, 50% RH for 7 days. At this point, the primer and topcoat were applied, if called for in that phase of testing.

The following section describes pertinent information for the individual candidate protective coatings and films used in the screening program.

Table 5.3

Companies Surveyed

- Airbus Industries
- Akzo
- Coatings for Industry
- Crown Metro
- Deft, Inc.
- DeSoto
- DuPont
- Essex Specialty Products, Inc.
- Fiber Resins Corp.
- Freeman Chemical
- GE
- Grow Group, Inc.
- H.B. Fuller
- Hughes Aircraft Co.
- Hysol Aerospace Products
- ICI
- Lord
- 3M
- Mobay
- Norton Company
- Ohio Sealer
- PPG Industries
- Pratt & Lambert
- Sherwin Williams

Coating No. 2 (U2A)

Product: Chemglaze M1433

Supplier: Lord Corporation

Coatings and Laminating Adhesives
2000 West Grandview Blvd.
P.O. Box 10038
Erie PA 16514-0038
814-868-3611

Description: Chemglaze M1433 is an aromatic, elastomeric polyurethane which is used as a rain-erosion coating for radomes, leading edges and antennae. It was selected as an example of an energy absorbing coating that may help protect the composite from PMB removal. The supplier claims that it is tough, flexible over a wide temperature range, and has excellent resistance to wear, abrasion and impact. M1433 is a two-package coating with a 2-hour pot life when mixed. It is provided in premeasured kits.

Product Information: Total Solids - 58% by weight (mixed)

Viscosity - 200-600 cps (mixed)

Drying time - 2-3 hours (77°F and 50% RH)

Application: Part A was redispersed on a paint shaker prior to adding Part B. Part B was added to Part A while mixing, until a ratio of 3 to 1 by volume was reached. Once thoroughly mixed, the coating could be applied without an induction period. The coating was applied by conventional spray following the standard setup and procedures. Two cross-coat passes were made, allowing approximately 5 minutes between passes. Total wet film thickness was 4 mils; dry film thickness was approximately 2 mils.

Coating No. 3 (U1C)

Product: Koroflex 4086-176

Supplier: Desoto Aerospace Coatings Inc.

Description: The Koroflex primers are clear, one-component, aromatic moisture-cure urethanes. They were selected for their reported flexibility and good adhesion to several aircraft substrates including aluminum, Kevlar composites and rubber. These products have been tested by the U.S. Air Force and Navy in previous programs.

Product Information: Total Solids - 43.9% by weight

Viscosity - NA

Drying time - 7 days at RT and 50% RH

Application: One-component moisture-cure urethane, hand-stirred prior to application. Applied using conventional spray method in 2 cross-coat passes of approximately 2 mils each. Dry-film thickness was 1.4 mils.

Coating No. 4 (U1Y)

Product: Koroflex 823x439

Supplier: Desoto Aerospace Coatings Inc.

Description: This is a pigmented (yellow) version of Coating No. 3. It was selected for screening because it presented an opportunity to compare the protective effect of a filled and unfilled version of one candidate. It was theorized that the filled coating may withstand abrasive (or laser), while the unfilled version would remain more flexible and withstand blasting-type removal.

Product Information: Total Solids - NA

Viscosity -NA

Drying Time - NA

Application: One-component moisture-cure urethane, mixed on paint shaker 5 minutes prior to application. Applied using conventional spray equipment and method in 2 cross-coat passes, totaling 4 mils wet for an approximate 1.6 mil dry-film thickness.

Coating No. 5 (EPX)

Product: HRG 3/A3

Supplier: Hughes Aircraft Co.
Electro Optical & Data Systems Group
2000 East El Segundo Boulevard
P.O. Box 902
El Segundo, CA 90244
213-616-1375

Description: HRG-/A3 was the third coating sample received from Hughes Aircraft Co. that is based on a family of compliant, modified-epoxy resins. These materials are reported to exhibit low viscosities, glass transition temperatures, and outgassing temperatures. They are toughened epoxy systems with good thermal stability, repairability and abrasion, and moisture resistance. Hughes also reported earlier attempts at using an nonoptimized HRG-31A as an intermediate layer between an epoxy/graphite composite and a primer/polyurethane topcoat. This specimen was subjected to PMB and showed promising protective properties.

Product Information: NA

Application: Coating was applied by manufacturer.

Coating No. 6 (EPA)

Product: 482-300/120-900

Supplier: Pratt & Lambert
Industrial Coatings Division
Box 2153,
Wichita, KS 67201
1-800-835-2854

Description: The 482-300/120-900 is a two-component, epoxy-based primer/filler for aviation composite applications. It is a blue-tinted, pigmented product that is reported to be useful when high-fill characteristics are desired. The actual chemical makeup is proprietary information and like several of the commercially available materials, is unknown. Although it was not specifically investigated in this study, it was selected for its sanding characteristics, which may allow it to be an "erodible" coating in abrasive removal techniques. Also, it was reported by the supplier to have generally good physical properties other than filling/leveling.

Product Information: Total Solids - 38.5 +/-1.0% (mixed)
Viscosity - NA
Drying Time - 4-6 hours at 50% RH

Application: Mixed by volume, one-part 482-300 to one-part 120-900 on paint shaker for 10 minutes. Mixture allowed to stand 25 minutes for induction period prior to spray application by conventional spray method. Applied using 2 cross-coat passes each at 1.8 mils wet; total dry-film thickness was 1 mil.

Coating No. 7 (FHM)

Product: Syn Skin XHC 9837

Supplier: Dexter Corporation
Hysol Aerospace Products
2850 Willow Pass Road
P.O. Box 312
Pittsburg, California 94565-0031
415-687-4201

Description: Syn Skin XHC 9837 is a high-modulus, epoxy-based, composite-surfacing film that is reported to provide aerodynamic smoothness and protection with a resistant, paintable surface. It appears to offer less finishing steps and maximizes leveling properties. Its makeup is proprietary, and it was selected for evaluation, even though it was difficult to predict how it would withstand the basic screening tests.

Product Information: Film Thickness - 5-6 mils
Weight - 0.040 psf

Application: Surfacing films were applied to the composite panels as the last layer of the laminate in the layup procedure. The film was vacuum-bagged and cured along with the composite, using the standard composite cure cycle in the autoclave, (2 hours at 350° F and 85 psi).

Coating No. 8 (FLM)

Product: Low Modulus Adhesive Film

Supplier: Dexter Corporation
Hysol Aerospace Products
2850 Willow Pass Road
P.O. Box 312
Pittsburg, California 94565-0031
415-687-4201

Description: EA 9628 is a modified-epoxy film adhesive designed for structural bonds requiring toughness. It is designed for aerospace applications and was selected as an example of a film that might provide sufficient protective properties.

Product Information: Film Thickness - 7-8.0 mils
Weight - 0.060 lbs/sq ft.

Application: Films were applied to completely cured composite panels in sheet form. Panel and film were vacuum-bagged and cured, using the autoclave 1-hour at 250°F and 100-psi cure cycle.

Coating No. 9 (FNP)

Product: AF-32 Adhesive Film

Supplier: 3M
Aerospace Materials Department
3211 East Chestnut Expressway
Springfield, MO 65802
1-800-235-2376

Description: This film was selected on the request of Ted Reinhart to act as a "control" to other materials. He was familiar with it as a high-performance, thermosetting film adhesive designed for metal-to-metal bonding. It is reported to have exceptionally high peel strengths, good aging properties and flexibility.

Product Information: Film Thickness - 9.0 Mils

Weight - 0.060 lbs/sq ft.

Application: Films were applied to completely cured composite panels in sheet form. Panel and film were vacuum-bagged and cured, using the following autoclave cure cycle: Ramp to 350°F at 10-12° per minute, while applying pressure at a rate of 5 psi per minute, hold pressure at 100 psi and temperature at 350°F for 2 hours. Cool to 200°F before releasing pressure.

Coating No. 10

Product: DuPont Imron 824S/817M

Supplier: E.I. duPont de Nemours & Company
Wilmington, Delaware 19898

Description: DuPont provided a primer/topcoat system for the test program. The primer was 8245 Colar®, based on proprietary epoxy/polyamide chemistry. The recommended coating for the primer was Imron® 824S, a product from their polyurethane enamel line of coatings. These are not formulated for particular military specifications but are reported to provide a good balance of coating properties for aircraft applications.

Product Information: NA

Application: Colar epoxy primer mixed 2 parts 824S to 1 part 826S, mixed on paint shaker for 5 minutes. Urethane enamel, mixed 3 parts 817U to 1 part 192S on low-shear mixer until uniform. Both coatings were applied by conventional spray method each at 2 mils wet. Total protective coating thickness (primer and enamel) was approximately 2 mils dry.

Coating No. 11

Product: Mobay 471425

Supplier: Mobay Corporation
Coatings Division
Mobay Road
Pittsburg, PA 15205-9741
412-777-2000

Description: The coating was formulated by Mobay's staff and is a two-component aliphatic polyurethane based on Mobay's Desmodur Desmophen resins.

Product Information: NA

Application: Coating was applied by the manufacturer, using conventional spray equipment, and applied in 2 passes with 10 minutes flash-off between coats. A total dry-film thickness of 2.5 mils was achieved.

Coating No. 12

Product: Bladder coating 4086-168

Supplier: Desoto Aerospace Coatings Inc.

Description: This product is a two-component, amine-cured polyurethane coating designed to be a sprayable fuel bladder coating. It was recommended because of its reported excellent flexibility and chemical/solvent resistance properties.

Product Information: Total Solids - 59.9% by weight, 53% by volume

Viscosity - NA

Drying Time - 14 days at RT and 50% RH

Application: Two component urethane, blend one-part urethane base 4086-168 to 1 part activator 4086-175A. Mixed on a low-shear mixer until uniform ~5 minutes. Applied using conventional spray method in 2 cross-coat passes. Wet film thickness 4 mils, approximately 2 mils dry.

Coating No. 13

Product: Lumiflon

Supplier ICI Americas Inc.
Wilmington , Delaware 19897
302-575-3000

Description: ICI provided the program with a two-component, black air dry coating based on their Lumiflon 200 Resin. These resins are based on fluropolymers and were selected for their reported weatherability, and chemical resistance.

Product Information: Total Solids - 43.6% (mixed)

Viscosity - NA

Drying Time - air dry

Application: Mix 32 parts A with 2 parts B on low-shear mixer until uniform, thinned with xylene to 40% solids. Applied using conventional spray method and equipment in 1 fan coat pattern at 3 mils wet, dry film thickness approximately 1.2 mils.

Coating No. 14

Product: Deft 44-BK-6

Supplier: Deft., Inc.
17451 Von Karman Avenue
Irvine, California 92714
714-474-0400

Description: Coating 44-BK-6 is a water-reducible, catalyzed epoxy, corrosion-inhibiting primer designed to meet California's strict VOC requirements. It was reported to exhibit excellent adhesion to fiberglass and metal substrates, chemical and solvent resistance, and offer a proper surface for polyurethane topcoats. It was attractive for this program because, if successful, it would make an environmentally friendly coating.

Product Information: Total Solids - 76.2% by weight, 60.0% by volume
Viscosity - NA
Drying Time - 6 hours at 73+/-2°F with good air circulation

Application: Mixed component I with component II at a 3-to-1 ratio on a low-shear mixer. Added 6 parts distilled water and mixed on paint shaker for 10 minutes. Final solids were 30% by volume. Applied using conventional spray equipment and method in 2 cross-coat passes totaling 3.5 mils wet. Dry film thickness was 1.1 mils.

Coating No. 15

Product: Deft 02-Y-38

Supplier: Deft., Inc.

17451 Von Karman Avenue
Irvine, California 92714
714-474-0400

Description: Deft 02-Y-38 is a two-component, high-solids, flexible primer based on epoxy/polyamide chemistry. It was chosen for its reported flexibility, which was theorized to help in withstanding blasting removal. It has a pot life of 4 hours.

Product Information: Total Solids - 68.3% by weight

Viscosity - 30" - 35" #2 Zahn Cup

Drying Time - Air Dry

Application: Two-component primer mixed 1 to 1 by volume on low-shear mixer until uniform. Applied using conventional spray method in 2 cross-coat passes. Wet film thickness 3 mils, dry film 1.2 mils.

Coating No. 16

Product: Freeman 62-E

Supplier: Freeman Chemical Corporation

217 Freeman Drive
P.O. Box 996
Port Washington, WI 53074-0996
414-284-5541

Description: Freeman, who is a supplier of intermediate materials for coating formulations, provided us with a peroxide curable coating based on urethane/acrylate chemistry. They felt that this coating may meet the requirements of the screening program.

Product Information: Total Solids - 80% by weight(?)

Viscosity - NA

Drying Time - 1 hour at 100°C.

Application: Urethane coating applied by manufacturer.

Coating No. 17

Product: Freeman 66-F

Supplier: Freeman Chemical Corporation
217 Freeman Drive
P.O. Box 996
Port Washington, WI 53074-0996
414-284-5541

Description: This coating formulation was based on epoxy/acrylate chemistry and was also peroxide-cured.

Product Information: Total Solids - 80% by weight(?)

Viscosity - NA

Drying Time - 1 hour at 10°C.

Application: Epoxy coating applied by manufacturer.

Coating No. 18

Product: Hughes HRG-3/A2

Supplier: Hughes Aircraft Co.
Electro Optical & Data Systems Group
2000 East El Segundo Boulevard
P.O. Box 902

El Segundo, CA 90244
213-616-1375

Description: This coating was an earlier version of coating No.5.

Product Information: NA

Application: Coating applied by manufacturer.

Coating No. 19

Product: Fuller FR-7020

Supplier: H.B. Fuller Company
1200 Wolters Boulevard
Vadnais Heights, MN 55110
612-481-3300

Description: This product was actually not a coating, but a resin system used in an epoxy patch kit for composites. The literature shows that it had some interesting properties in an earlier program. However, it was too thick to apply by spray and attempts to improve its application properties (with the help of the supplier) were unsuccessful.

Product Information: NA

Application: Mixed 100 parts A with 58 parts B on low-shear mixer until uniform. Applied to panels by draw-down blade 3 mils wet. Blend was too thick to spray and could not be thinned.

Coating No. 20

Product: Fuller SN-3012

Supplier: H.B. Fuller Company
1200 Wolters Boulevard
Vadnais Heights, MN 55110
612-481-3300

Description: This is a proprietary, experimental coating recommended for the program by the supplier. It is a two-component, polyurethane-based product that was reported to have excellent impact resistance. Unfortunately, it had relatively poor application properties when applied with air-assisted spray equipment. It may perform better with airless spray equipment; however, the supplier provided the coating too late in the program to investigate this option.

Product Information: NA

Application: Mixed 100 parts A with 59 parts B on low-shear mixer until uniform. Thinned with xylene until sprayable with convention spray equipment. System is generally coated, using airless spray with a mixing nozzle. The coating formed fisheyes and overall did not coat well using our method. Dry film thickness was approximately 1.5 mils.

5.4 Laboratory Screening Procedures

The overall objective of this task was to screen the 20 candidate coating systems for basic-performance properties and to select the most promising systems for evaluation in four paint/paint removal cycles. Initially, the coatings were applied according to manufacturers' specifications at 2.0 - 3.0 dry film thickness and were allowed to air dry for a minimum of 7 days. In the preliminary screening, five of the coatings/films were applied by the manufacturers onto substrates provided to them by Arthur D. Little. In this stage of the testing, the candidates were applied to two different test substrates: (1) 4"x 12", 12 ply, graphite/epoxy composite panels and (2) .032" x 4" x 12", 70-75-TG anodized, clear aluminum panels. These 40 test panels were evaluated for the following:

1. *Compatibility* - This was a subjective assessment of the wetting and flow characteristics of the wet and dry film properties of the candidate coatings. This evaluation was made by experienced coating specialists each time the coating was applied.

2. *Adhesion* - Adhesion was measured by the ASTM D3359 - 87 Tape Test Method. In this test, a grid of crosscuts is made into the dried coating with a sharp instrument for this purpose. A pressure-sensitive tape (No. 250 tape provided by 3M), is applied evenly by hand over the crosscuts and then removed within 90 seconds (+/- 30 seconds). Adhesion was evaluated by comparison of the flaked area with standard descriptions and illustrations. The classification scale is 0B to 5B, with 5B exhibiting the best adhesion (See ASTM D3359 -87 for specific details).

3. *Impact Resistance* - Impact resistance was measured on a Gardner Light Duty Impact Tester with an extended graduated guide tube capable of subjecting test specimens to an impact force of up to 50 inch-pounds. The impactor was a 2-pound steel cylinder with a 0.50-inch diameter round-nosed end. A 0.56-inch diameter hole in the base allows for the deformation of the panel. All coated test panels were allowed to condition prior to testing for 24 hours in an environment of 72°F at 50% RH.

The panels were subjected to a series of impacts at various heights to determine the maximum impact force the coating could withstand for both forward and reverse impact. (Note: Although reverse impact may be unlikely in an aircraft application, the measurement was made to further characterize the ability of the coating to withstand impact. Generally, reverse impact is a more severe test for a coating system.) A new undamaged area of the panel was used for each impact. Failure was characterized by cracking or chipping of the coating.

4. Solvent/Chemical Resistance - Solvent Resistance was measured by using the Hydrocarbon Resistance Test MIL-C46268C (ME) Sections 3.6.9 and 4.3.20. This test measures the effect of a hydrocarbon fluid (TT-S-735, Type III as defined in ASTM 01308-54) on coatings which may result in alterations in the surface of the coating. The actual composition of the coating was as follows:

Component	% By Weight
Iso-octane	70.0
Toluene	30.0
	100.0

The test required that the coated panels be air dried for 168 hours (1 week) and then immersed for 168 hours at 23°C in the hydrocarbon fluid. At the end of that period, the panels were removed and examined according to the MIL specification, which requires that immediately after removal, the coating should show no blistering or wrinkling. Two hours after removal, there was to be no excessive softening, whitening or dulling. After 24 hours, the immersed panel should be almost indistinguishable with regard to hardness, adhesion, and general appearance from a control panel prepared at the same time but not immersed. Any coatings exhibiting any significant deviance from these definitions were given a " Fail" rating.

5. *Surface Roughness* - Surface roughness of coated panels was measured on a Mitutoyo Surftest model 211 set at a 0.03-inch stroke. The instrument was calibrated using a 116-micro-inch precision reference standard; readings were recorded to the nearest micro-inch. The average surface roughness and standard deviation were reported on a minimum of 5 readings from 5 different areas within the panel. The reference standard was checked after each panel to confirm that accurate meetings were obtained.

The screening program was required to confirm the minimum, basic coating performance of the candidate systems. As expected, the majority of the samples (19 of 20 systems) performed quite well on these tests Although this testing did not adequately distinguish relative performance amongst the candidates, it was very useful in allowing us to become familiar with the differences in the application properties of the coatings. Since the test panels were already prepared and minimum effort was required, it was decided to test all of the coatings in the next evaluation to maximize the information gained by this screening program.

In the next phase of the screening program, the coated composite and aluminum substrates were painted with the standard MIL-P-233770 epoxy primer and MIL-C-82386 polyurethane topcoat. Again, the compatibility and adhesion of the paint system to the protective coating was evaluated. (See above section for description of methods.) In all but one case, both properties were excellent.

6. Water Resistance - The next step was to test the weathering properties of the painted and coated test panels by subjecting them to the Controlled Condensation Test ASTM-4585, which is designed to measure moisture resistance. This method measures water resistance of the coatings by using condensation produced by exposing one surface of a coated specimen to a heated, saturated mixture of air and water vapor. The reverse side of the panel is exposed to the cooling effect of the room temperature air. These tests were performed in a Cleveland Condensing Type Humidity Cabinet at the following conditions:

- Exposure temperature (vapor/air) 130 +/- 5°F
- Pan water temperature 70 +/- 5°F
- Room temperature 70 +/- 2°F
- Inclination of test panels = 15°
- Panel positions were rotated weekly

Prior to placement in the chamber, two X-cuts, one with light pressure and one with heavy pressure, were made in each panel.

Weekly, the test panels were removed from the chamber and dried by gentle blotting. They were evaluated according to the following schedule:

- Weekly visual and microscopic observation
- 3 week (500 hours) - Adhesion test of X-cuts
- 6 week (1000 hours) - Adhesion test of X-cuts
- 12 week (2000 hours) - Visual observation and final rating

The results indicate that the water resistance testing was very useful in distinguishing the relative performance of the candidate coatings.

5.5 Screening Results

The results of all of the screening tests were analyzed and ranked according to performance, ease of use, availability (i.e., commercial vs experimental), and chemical makeup. This ranking identified three groups of coating systems:

1. High-priority - Coatings that were evaluated in the four paint/paint removal testing are shown in Table 5.5-1. This high-priority group included a control, three urethane-based coatings, two epoxy coatings, two epoxy films, and a nitrile phenolic film. The results of the evaluations on these are shown in Tables 5.5-2 to 5.5-4.

2. Medium-priority - Promising coatings that with some adjustment may be screened on a future program are shown in Table 5.5-5. The results of these evaluations on these are shown in Tables 5.5-6 to 5.5-8.

3. Low-priority - No further work is recommended on coatings shown in Table 5.5-9. The results of these evaluations are shown in Tables 5.5-10 to 5.5-12.

The selection of these eight systems in the high-priority category for evaluation in paint/paint removal testing completed this phase of the screening program.

Table 5.5-1

High Priority Coatings - Selected for Paint/Paint Removal Evaluation

Coating Number	Designation	Company	Product	Description
1	CTL	-	-	Control - no protective coating
2	U2A	Lord Industrial Coatings	Chemglaze M1433	Two component, aromatic urethane, elastomeric rain erosion coating
3	U1C	Desoto Aerospace Coatings	Koroflex 4086-176	One component, moisture cure, elastomeric, clear polyurethane primer
4	U1Y	Desoto Aerospace Coatings	Koroflex 823X439	Pigmented (yellow) version of 4086-176
5	EPX	Hughes Aircraft	HRG 3/A3	Improved proprietary epoxy coating; experimental product
6	EPA	Pratt & Lambert	482-300/120-900	Two component epoxy primer; surface leveler for aviation composites
7	FHM	Dexter Hysol	SynSkin XHC 9837	High modulus, composite surfacing film (commercial)
8	FLM	Dexter Hysol	Low Modulus Adhesive Film	Tough, modified epoxy film adhesive for structural bonding
9	FNP	3M	AF-32 Adhesive Film	Thermosetting film adhesive based on nitrile phenolic chemistry

Table 5.5-2

High Priority Coatings - Water Resistance (Composite Panels)

		500 Hour Exposure		1000 Hour Exposure		2000 Hour Exposure	
Coating No.	Designation	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut
1	CTL	[illegible]	NC	B-8-F	NC	B-8-F	Nc
2	U2A	NC	NC	B-8-F	NC	B-4-F	Slt Delam
3	U1C	NC	Slt Delam	NC	Slt Delam	B-4-F	Slt Delam
[illegible]	[illegible]	NC	Slt Delam	NC	Slt Delam	NC	Slt Delam
5	EPX	B-3-F	NC	B-3-M	NC	B-2-MD	NC
6	EPA	NC	NC	NC	NC	B-8-F	NC
7	FHM	B-4-F	NC	B-3-F	NC	B-7-F	NC
8	FLM	B-8-F	NC	B-4-F	NC	B-7-F	NC
9	FNP	NC	NC	B-8-F	NC	B-6-F	NC

NC = No Change
B = Blisters

Blister size:
0 = Very Large Blisters
9 = Very Small Blisters

Blister frequency:
D = Dense
MD = Medium Dense
M = Medium
F = Few

Cross X Cut:
NC = No Change
Slt = Slight
Delam = Delamination

Table 5.5-3

High Priority Coatings - Water Resistance (Aluminum Panels)

	500 Hour Exposure		1000 Hour Exposure		2000 Hour Exposure	
Coating No.	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut
1	B-4-F	Slt Delam	B-4-F	Slt Delam	B-4-F	Slt Delam
2	NC	NC	NC	NC	NC	NC
3	B-6-MD	Slt Delam	B-4-MD	Slt Delam	B-4-MD	Slt Delam
4	B-6-M	Slt Delam	B-6-M	Slt Delam	B-6-M	Slt Delam
5	B-6-M	NC	B-4-D	NC	B-3-D	NC
6	B-3-MD	Slt Delam	B-4-D	NC	B-4-D	Slt Delam
9	B-4-MD	NC	B-4-D	NC	B-3-D	NC

NC = No Change
B = Blisters

Blister size:
0 = Very Large Blisters
9 = Very Small Blisters

Blister frequency:
D = Dense
MD = Medium Dense
M = Medium
F = Few

Cross X Cut:
NC = No Change
Slt = Slight
Delam = Delamination

Table 5.5-4

High Priority Coatings - Results of Screening

							Impact Resistance, Inch/Lbs					
		Physical Appearance			Adhesion		Al		Comp		H-C Resistance	
Coating No.	Designation	Gloss	Color	Surface Roughness	Al	Comp	Fwd	Rev	Fwd	Rev	Al	Comp
1	CTL	-	-	-	-	-	-	-	-	-	-	-
2	U2A	Gloss	Gray-Green	35±12	5B	5B	36	37	31	31	Pass	Pass
3	U1C	Gloss	Clear	38±13	5B	5B	38	33	24	33	Pass	Pass
4	U1Y	Flat	Yellow	136±20	5B	5B	41	38	38	36	Pass	Pass
5	EPX	Gloss	Amber	8±2	5B	5B	50+	50+	26	14	Fail	Pass
6	EPA	Flat	Blue	199±36	5B	5B	34	4	16	10	Pass	Pass
7	FHM	Flat	Opaque	241±11	5B	5B	-	-	46	30	-	Pass
8	FLM	Flat	Opaque	179±33	5B	5B	-	-	48	46	-	Pass
9	FNP	Flat	Dark Brown	179±33	5B	5B	50+	50+	34	32	Pass	Pass

Table 5.5-5

Medium Priority Coatings - Potential for Future Evaluation

Coating Number	Company	Product	Description
10	DuPont	8245/817M	Aviation coating; epoxy primer with polyurethane enamel topcoat
11	Mobay	471425	Two component, polyurethane primer
12	Desoto Aerospace Coatings	Bladder Coating 4086-168	Two component, amino cure polyurethane

Table 5.5-6

Medium Priority Coatings - Water Resistance (Composite Substrates)

Coating No.	500 Hour Exposure		1000 Hour Exposure		2000 Hour Exposure	
	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut
10	NC	Slt Delam	B-4-F	Slt Delam	B-4-F	Slt Delam
11	B-6-MD	Slt Delam	B-3-D	Slt Delam	B-3-D	Delam
12	NC	NC	B-4-F	NC	B-4-F	NC

NC = No Change
B = Blisters

Blister size:
0 = Very Large Blisters
9 = Very Small Blisters

Blister frequency:
D = Dense
MD = Medium Dense
M = Medium
F = Few

Cross X Cut:
NC = No Change
Slt = Slight
Delam = Delamination

Table 5.5-7

Medium Priority Coatings - Water Resistance (Aluminum Panels)

	500 Hour Exposure		1000 Hour Exposure		2000 Hour Exposure	
Coating No.	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut
10	B-8-MD	Slt Delam	B-6-D	Slt Delam	B-2-D	Delam
11	B-6-MD	Slt Delam	B-4-D	Slt Delam	B-4-D	Delam
12	B-6-MD	NC	B-4-M	NC	B-4-M	NC

NC = No Change
B = Blisters

Blister size:
0 = Very Large Blisters
9 = Very Small Blisters

Blister frequency:
D = Dense
MD = Medium Dense
M = Medium
F = Few

Cross X Cut:
NC = No Change
Slt = Slight
Delam = Delamination

Table 5.5-8

Medium Priority Coatings - Results of Screening

	Physical Appearance			Adhesion		Impact Resistance, Inch/Lbs				H-C Resistance	
						Al		Comp			
Coating No.	Gloss	Color	Surface Roughness	Al	Comp	Fwd	Rev	Fwd	Rev	Al	Comp
10	Gloss	White	23±8	5B	5B	39	27	30	13	Pass	Pass
11	Gloss	Gray	13±62	5B	5B	39	39	20	16	Pass	Pass
12	Gloss	Clear	28±4*	5B	5B	50+	50+	26	26	Pass	Pass

*some fisheyes

Table 5.5-9

Low Priority Coatings - No Further Work Recommended

Coating Number	Company	Product	Description
13	ICI	Lumiflon	High performance fluoropolymer resin
14	Deft	44-BK-6	Water reducible, abrasion resistant, epoxy primer
15	Deft	02-Y-38	Highly flexible, high solids, epoxy-polyamide
16	Freeman Chemical	62-E	Urethane/acrylate-based coating
17	Freeman Chemical	62-F	Epoxy/acrylate-based coating
18	Hughes Aircraft	HRG-3/A2	Proprietary epoxy-based coating (experimental)
19	H.B. Fuller	FR-7020	Two component epoxy product used as a patch kit for composites
20	H.B. Fuller	SN-3012	Two component polyurethane protective coating

Table 5.5-10

Low Priority Coatings - Water Resistance (Composite Substrates)

	500 Hour Exposure		1000 Hour Exposure		2000 Hour Exposure	
Coating No.	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut
13	B-3-F	Delam	B-3-MD	Delam	-*	_*
14	NC	Slt Delam	NC	Slt Delam	-*	-*
15	B-3-MD	Delam	B-3-D	Delam	-*	-*
16	B-2-MD	NC	B-2-D	NC	-*	-*
17	B-2-MD	Slt Delam	B-2-D	Slt Delam	-*	-*
18	NC	Slt Delam	B-4-F	Slt Delam	B-2-MD	Slt Delam
19	B-8-F	NC	B-8-F	NC	-*	-*

NC = No Change
B = Blisters

Blister size:
0 = Very Large Blisters
9 = Very Small Blisters

Blister frequency:
D = Dense
MD = Medium Dense
M = Medium
F = Few

Cross X Cut:
NC = No Change
Slt = Slight
Delam = Delamination

*Test stopped after 1000 hours of exposure

Table 5.5-11

Low Priority Coatings - Water Resistance (Aluminum Panels)

	500 Hour Exposure		1000 Hour Exposure		2000 Hour Exposure	
Coating No.	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut	Coating Surface	Cross X Cut
14	NC	Delam	B-3-MD	Delam	-*	-*
15	B-4-MD	Delam	B-6-D	Delam	-*	-*
16	B-2-MD	Delam	B-2-MD	Delam	-*	-*
17	B-2-D	Delam	B-2-D	Delam	-*	-*
18	NC	NC	B-2-D	NC	B-2-D	NC
19	B-8-D	Slt Delam	B-3-D	Slt Delam	-*	-*

NC = No Change
B = Blisters

Blister size:
0 = Very Large Blisters
9 = Very Small Blisters

Blister frequency:
D = Dense
MD = Medium Dense
M = Medium
F = Few

Cross X Cut:
NC = No Change
Slt = Slight
Delam = Delamination

*Test stopped after 1000 hours exposure

Table 5.5-12

Low Priority Coatings - Results of Screening

	Physical Appearance			Adhesion		Impact Resistance, Inch/Lbs				H-C Resistance	
						Al		Comp			
Coating No.	Gloss	Color	Surface Roughness	Al	Comp	Fwd	Rev	Fwd	Rev	Al	Comp
13	Gloss	Black	84±23*	5B	5B	34	10	25	26	Fail	Pass
14	Flat	Black	145±9	5B	4B-5B	34	35	19	12	Fail	Fail
15	Flat	Yellow	22±4	5B	5B	44	43	4	4	Pass	Pass
16	Gloss	Clear	32±26**	5B	4B-5B	40	32	17	18	Pass	Pass
17	Gloss	Clear	117±38**	5B	5B	31	30	6	6	Pass	Pass
18	Gloss	Amber	11±6	5B	5B	42	42	24	12	-	Pass
19	Semigloss	Gray	72±12	5B	5B	41	3	13	32	Pass	Pass
20	Gloss	Beige	45±24	5B	5B	39	39	34	13	Pass	Pass

* several fisheyes
** flow lines

5.6 Paint Stripping Procedures

Two paint stripping procedures, plastic media blasting, and wet abrasive paint removal, were selected for evaluation of the eight protective coatings listed in Table 5.5-1. Plastic media was selected as a control, since it is currently used for depainting the aluminum surfaces of many Air Force aircraft. In addition, it is a good model for other media impacting processes, such as bicarbonate blasting, wheat starch blasting, and ice or dry ice blasting. Any coating which shows promise in preventing damage from the PMB blasting should also be useful for these other techniques. The other technique selected, wet abrasive paint removal, involves a different type of physical motion, namely an in-plane shear and shaving action, which is expected to affect the paint, coating, and composite differently than PMB.

Each panel was initially coated with the protective coating, painted with the standard primer and topcoat, and subjected to four depaint/repaint cycles. In the paint removal process, the yellow primer was used as the "flag" to signal a stop to the stripping process. Once stripped, the panels were examined microscopically for defects and microcracks. No microcracking was observed, however. Typical photomicrographs are shown in Appendix A. The surface roughness of the panels was monitored throughout the process, using an RMS gauge. When repainting the panels, a very thin coat of primer was used to reprime the panel in order to obtain the adhesion needed for the polyurethane topcoat. Mechanical properties were measured on a painted but unstripped section of the panel and again on other sections of the same panel after the first and fourth depaint/repaint cycles. Samples from intermediate cycles have been retained but have not been tested for mechanical properties as a matter of efficiency.

5.7 Visual and Surface Roughness Results

All of the coating systems resisted the mechanical effects of wet abrasive paint removal; however, three of the coatings were damaged by the mechanical action of the PMB process. As shown in Table 5.7-1, urethane coatings U2A and U1C failed to maintain adhesion to the composite substrate after the first PMB cycle. As a result, these systems would not be suitable when PMB is the paint removal process. In addition, film coating FHM lost adhesion after the fourth PMB cycle. This film coating requires special vacuum and autoclave curing, and it is possible that this processing was not optimum for the current substrate.

As shown in Section 3, the roughness of the surface of the composite depends dramatically on the paint removal process. During this phase of the project, we observed that the roughness also depends on the coating and the paint present. When some of the coatings are applied, the surface roughness can be decreased substantially. However, when the paint stripping process is applied, the surface tends to approach a final roughness value that is typical of the particular. Surface roughness data is summarized in Table 5.7-2 for the processes and coatings studied in this phase. Before repainting, wet abrasive panels approach a roughness of about 140 microinches, and PMB panels approach a roughness of about 300 microinches. When the panels are painted, the wet abrasive panel has a final roughness of about 60 microinches, and the PMB panel is about 90 microinches. Even very smooth coating such as EPX, which had an initial smoothness of about 8 microinches, attains a final roughness that is characteristic of the stripping process used. Figures 5.7-1 and 5.7-2 display the surface of the panel as a function of the process used, the number of cycles, and the protective coating used. The differences are important, since the surface roughness can effect the panel aerodynamically and could have implications for long-term fatigue crack growth.

5.8 Mechanical Property Results

The methods for measuring the mechanical properties of the treated panels has been described earlier in Section 2. In this phase of the program, we determined that the most useful property to measure would be flexural strength, since earlier we

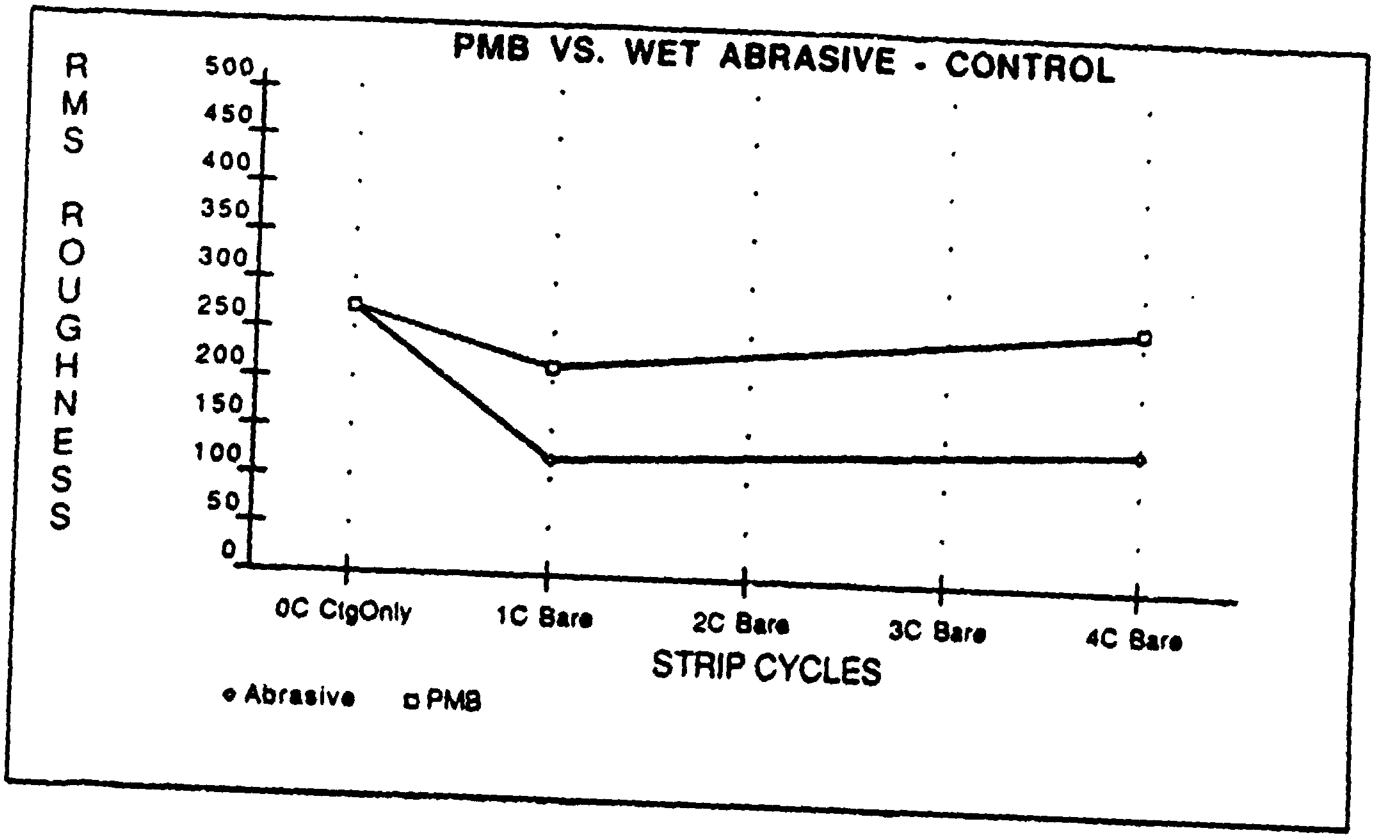
Table 5.7-1
Effects of Paint Removal Process--Visual Inspection

Coating No.	Designation	Wet Abrasive 1st Cycle	Wet Abrasive 4th Cycle	PMB 1st Cycle	PMB 4th Cycle
1	CT2	---	---	---	---
2	U2A	Pass	Pass	Fail	Fail
3	U1C	Pass	Pass	Fail	Fail
4	U1Y	Pass	Pass	Pass	Pass
5	EPX	Pass	Pass	Pass	Pass
6	EPA	Pass	Pass	Pass	Pass
7	FHM	Pass	Pass	Pass	Fail
8	FLM	Pass	Pass	Pass	Pass
9	FNP	Pass	Pass	Pass	Pass

Table 5.7-2

Surface Roughness

TEST	ADL			PAINT		BEFORE REPAINTING		AFTER REPAINTING		
PANEL	REPORT	COATING NAME	DESIG-	REMOVAL	ROUGH(X)	ROUGH(4)	ROUGH(7)	ROUGH(2)	ROUGH(3)	ROUGH(8)
NO.	NO.	& DATA	NATION	PROCESS	0C CtgOnly	1C Bare	4C Bare	0C Ptd	1C Ptd	4C Ptd
7A	1	Control	CTL	Abrasive	271	119	141	62	61	62
5A	2	Lord Chemglaze	U2A	Abrasive	55	80	133	68	61	60
2A	3	Desoto, Clear	U1C	Abrasive	38	94	129	63	51	48
3A	4	Desoto, Yellow	U1Y	Abrasive	136	100	115	57	57	51
4AC	5	HughesHRG3/A3	EPX	Abrasive	8	90	142	65	57	55
6A	6	Pratt&Lambert	EPA	Abrasive	199	94	141	66	69	75
9A	7	Hysol Synskin	FHM	Abrasive	241	81	81	70	52	58
10A	8	Hysol Film	FLM	Adhesive	179	109	128	58	55	55
8A	9	3M Film	FNP	Abrasive	215	93	140	84	58	69
7B	1	Control	CTL	PMB	271	213	266	74	90	89
5B	2	Lord Chemglaze	U2A	PMB	55	324	439	68	64	140
2B	3	Desoto, Clear	U1C	PMB	38	322	306	64	106	109
3B	4	Desoto,Yellow	U1Y	PMB	136	274	282	109	87	90
4B	5	HughesHRG3/A3	EPX	PMB	8	272	259	55	78	90
6B	6	Pratt&Lambert	EPA	PMB	199	232	261	75	73	96
9B	7	Hysol Synskin	FHM	PMB	241	298	286	85	68	85
10B	8	Hysol Film	FLM	PMB	179	243	297	73	87	75
8B	9	3M Film	FNP	PMB	215	272	227	75	78	82



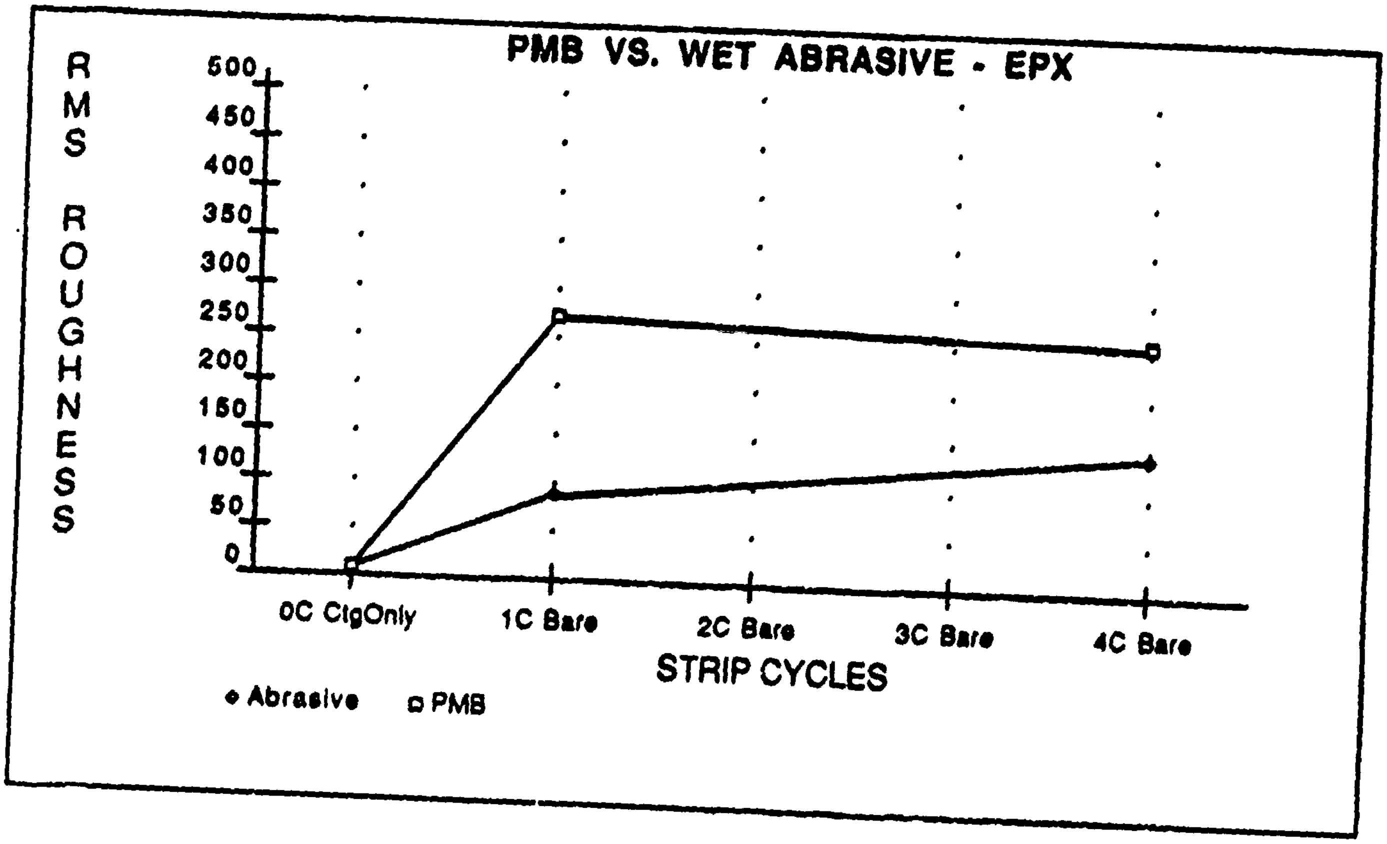
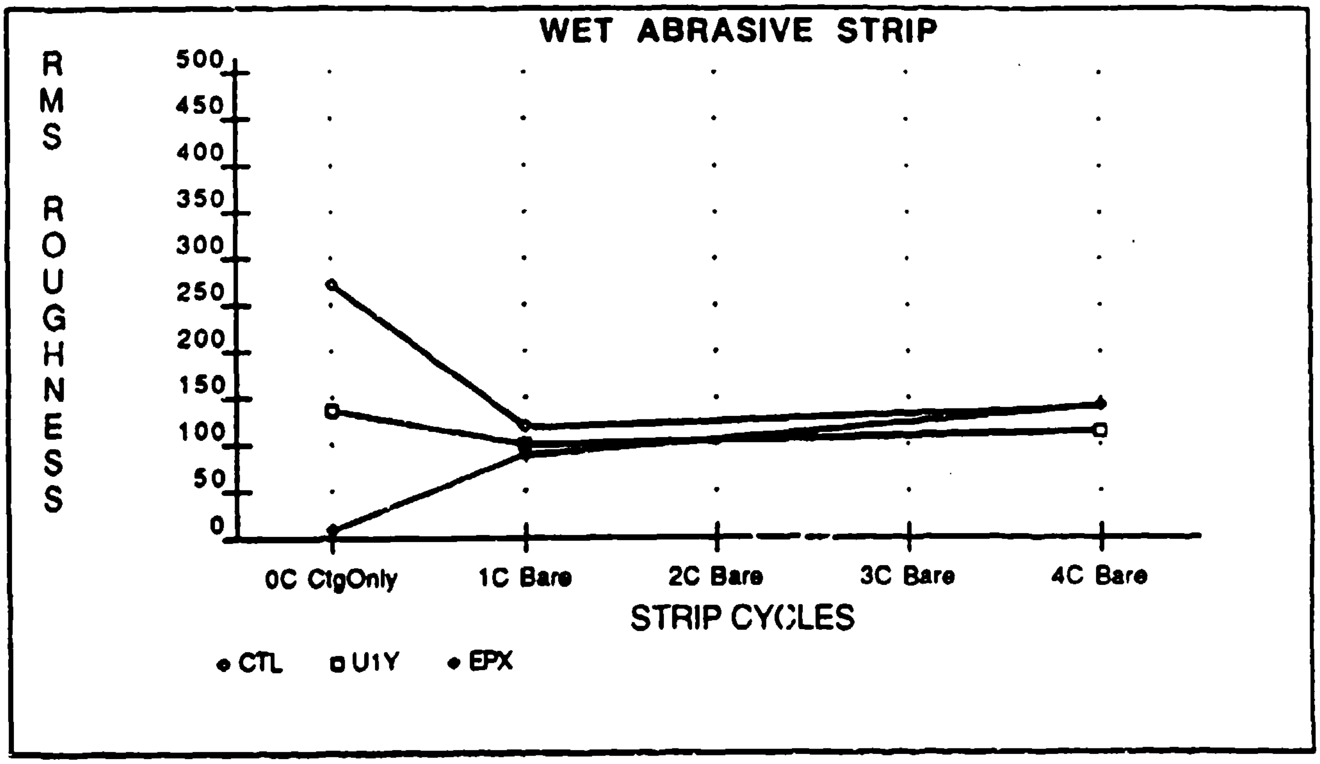


Figure 5.7-1 PMB vs. Wet Abrasive Roughness



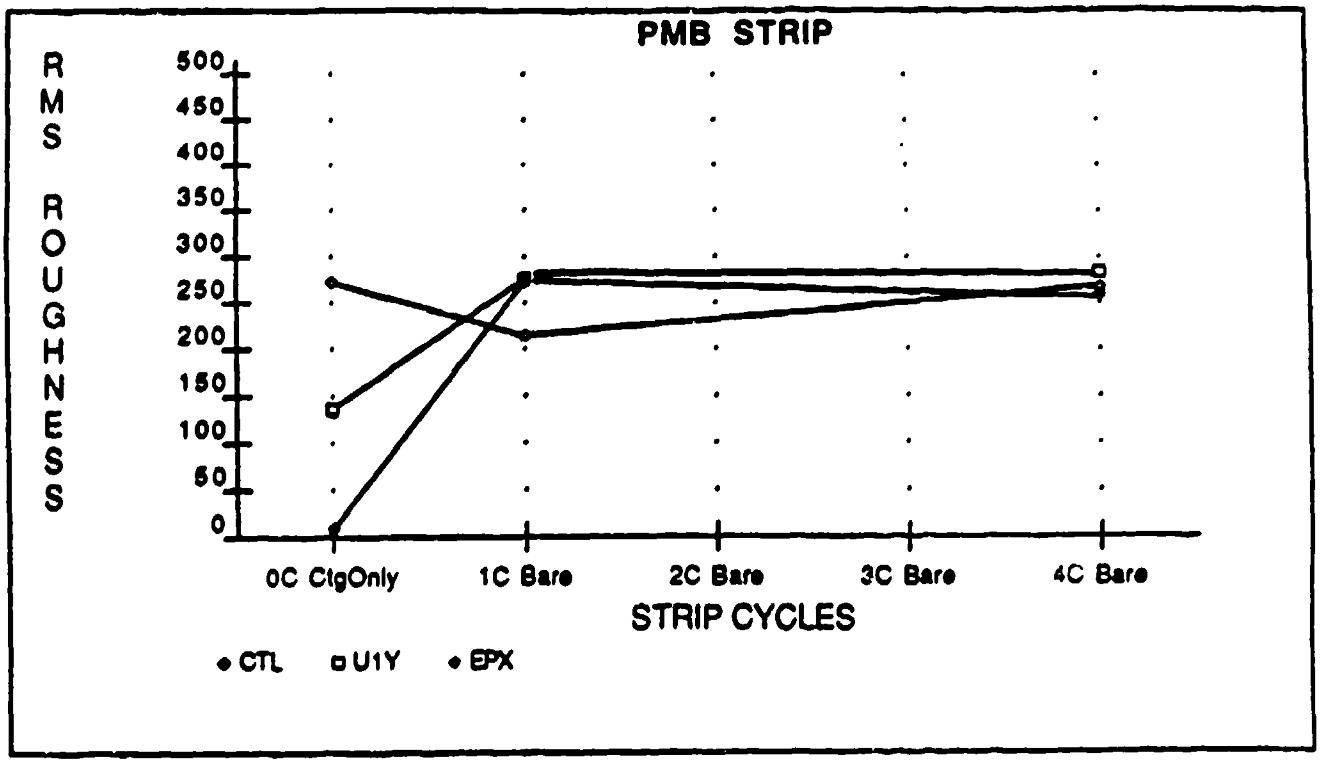


Figure 5.7-2 Roughness of CTL vs. U1Y and EPX

determined that this measurement was more sensitive to changes in the composite than was the short beam shear strength (interlaminar shear strength). The direct measurement from the testing machine gave a breaking load, which was then used to calculate flexural strength. As a given panel was processed through the coating, painting, and stripping processes, the thickness of the panel changed. This change in thickness affected the flexural strength values obtained and made analysis difficult. As a result, we found it convenient to "correct" the value of the flexural strength obtained to a constant thickness equivalent to the initial thickness value. In addition, we found that comparing various panels to one another was better carried out if the strength data was normalized to the same initial strength. The original raw data obtained during the tests are displayed in Appendix B. The corrected and normalized flexural strength data are shown in Tables 5.8-1 and 5.8-2. Measurements of flexural strength were made before treatment and after the first and fourth depaint/paint cycle. Samples from the second and third depaint/paint cycles have been retained, but the data indicated that these measurements were not necessary to reach our conclusions. Also reported in Tables 5.8-1 and 5.8-2 are the maximum and minimum values which establish the 95% confidence intervals according to the "Student's t Distribution."

Although the data is difficult to interpret numerically, it is readily analyzed graphically. Figures 5.8-1 to 5.8-9 contain the plots of the corrected and normalized failure stress as a function of the number of depaint/repaint recycles. The graphs show that the vast majority of the panels, including the PMB and wet abrasive controls, show no statistically significant loss in flexural strength as a result of the four depaint/repaint cycles. Only coating EPA using wet abrasives showed a statistically significant loss in mechanical properties. We believe an important contributor to this stability in mechanical properties is the excellent control possible in stopping at the primer. This may not always be possible in the real world,

Table 5.8-1

Mechanical Properties - Wet Abrasive Stripping

TEST PANEL NO.	ADL REPORT NO.	COATING NAME & DATA	DESIG-NATION	PAINT REMOVAL PROCESS	COR. FAIL STRESS(2) 0 CYC	COR. FAIL STRESS(3) 1 CYC	COR. FAIL STRESS(8) 4 CYC	NORM/COR FAIL STR(2) 0 CYC	NORM/COR FAIL STR(3) 1 CYC	NORM/COR FAIL STR(8) 4 CYC
7A	1	Control	CTL-MEAN	Abrasive	191.4	203.5	198.7	100.0	106.3	103.8
		stdev			15.4	8.6	8.1			
		t-factor (95%)			19.1	10.7	10.0	10.0	5.3	5.1
		max-95	CTL-MAX		210.5	214.2	208.7	110.0	111.6	108.9
		min-95	CTL-MIN		172.3	192.8	188.7	90.0	101.0	98.8
5A	2	Lord Chemglaze	U2A	Abrasive	187.7	192.8	192.0	100.0	102.7	102.3
		stdev			4.0	6.0	8.5			
		t-factor (95%)			6.3	9.6	10.6	3.4	5.0	5.5
		max-95	U2A-MAX		194.0	202.4	202.6	103.4	107.7	107.8
		min-95	U2A-MIN		181.4	183.2	181.4	96.6	97.7	96.8
2A	3	Desoto, Clear	U1C	Abrasive	185.8	196.2	194.0	100.0	105.6	104.4
		stdev			4.2	6.7	10.0			
		t-factor (95%)			5.2	8.3	12.4	2.8	4.2	6.4
		max-95	U1C-MAX		191.0	204.5	206.4	102.8	109.8	110.8
		min-95	U1C-MIN		180.6	187.9	181.6	97.2	101.4	98.0
3A	4	Desoto, Yellow	U1Y	Abrasive	198.4	202.6	198.8	100.0	102.1	100.2
		stdev			1.6	4.3	9.9			
		t-factor (95%)			2.0	5.3	12.2	1.0	2.6	6.2
		max-95	U1Y-MAX		200.4	207.9	211.0	101.0	104.7	106.4
		min-95	U1Y-MIN		196.4	197.3	186.6	99.0	99.5	94.0
4AC	5	HughesHRG3/A3	EPX-MEAN	Abrasive	162.0	176.3	177.4	100.0	108.8	109.5
		stdev			12.6	14.6	10.3			
		t-factor(95%)			15.6	18.2	12.8	9.7	10.3	7.2
		max-95	EPX-MAX		177.6	194.5	190.2	109.7	119.1	116.7
		min-95	EPX-MIN		146.4	158.1	164.6	90.3	98.5	102.3

Table 5.8-1

Mechanical Properties - Wet Abrasive Stripping
(Continued)

TEST	ADL			PAINT	COR. FAIL	COR. FAIL	COR. FAIL	NORM/COR	NORM/COR	NORM/COR
PANEL	REPORT	COATING NAME	DESIG-	REMOVAL	STRESS(2)	STRESS(3)	STRESS(8)	FAIL STR(2)	FAIL STR(3)	FAIL STR(8)
NO.	NO.	& DATA	NATION	PROCESS	0 CYC	1 CYC	4 CYC	0 CYC	1 CYC	4 CYC
6A	6	Pratt&Lambert	EPA	Abrasive	201.5	204.6	188.9	100.0	101.5	93.7
		stdev			10.5	3.4	6.6			
		t-factor(95%)			13.0	4.2	8.2	6.5	2.0	4.4
		max-95	EPA-MAX		214.5	208.8	197.1	106.5	103.6	98.1
		min-95	EPA-MIN		188.5	200.4	180.7	93.5	99.5	89.4
9A	7	Hysol Synskin	FHM	Abrasive	213.6	209.7	214.7	100.0	98.2	100.5
		stdev			3.4	5.8	10.3			
		t-factor(95%)			4.2	7.2	12.8	2.0	3.5	6.0
		max-95	FHM-MAX		217.8	216.9	227.5	102.0	101.6	106.5
		min-95	FHM-MIN		209.4	202.5	201.9	98.0	94.7	94.6
10A	8	Hysol Film	FLM	Adhesive	209.6	202.9	208.8	100.0	96.8	99.6
		stdev			3.8	4.9	10.8			
		t-factor(95%)			4.7	6.1	13.4	2.2	3.0	6.4
		max-95	FLM-MAX		214.3	209.0	222.2	102.2	99.8	106.1
		min-95	FLM-MIN		204.9	196.8	195.4	97.8	93.8	93.2
8A	9	3M Film	FNP	Abrasive	202.4	193.0	195.0	100.0	95.4	96.3
		stdev			3.7	5.2	5.8			
		t-factor(95%)			4.6	6.5	7.2	2.3	3.4	3.7
		max-95	FNP-MAX		207.0	199.5	202.2	102.3	98.7	100.1
		min-95	FNP-MIN		197.8	186.5	187.8	97.7	92.0	92.6

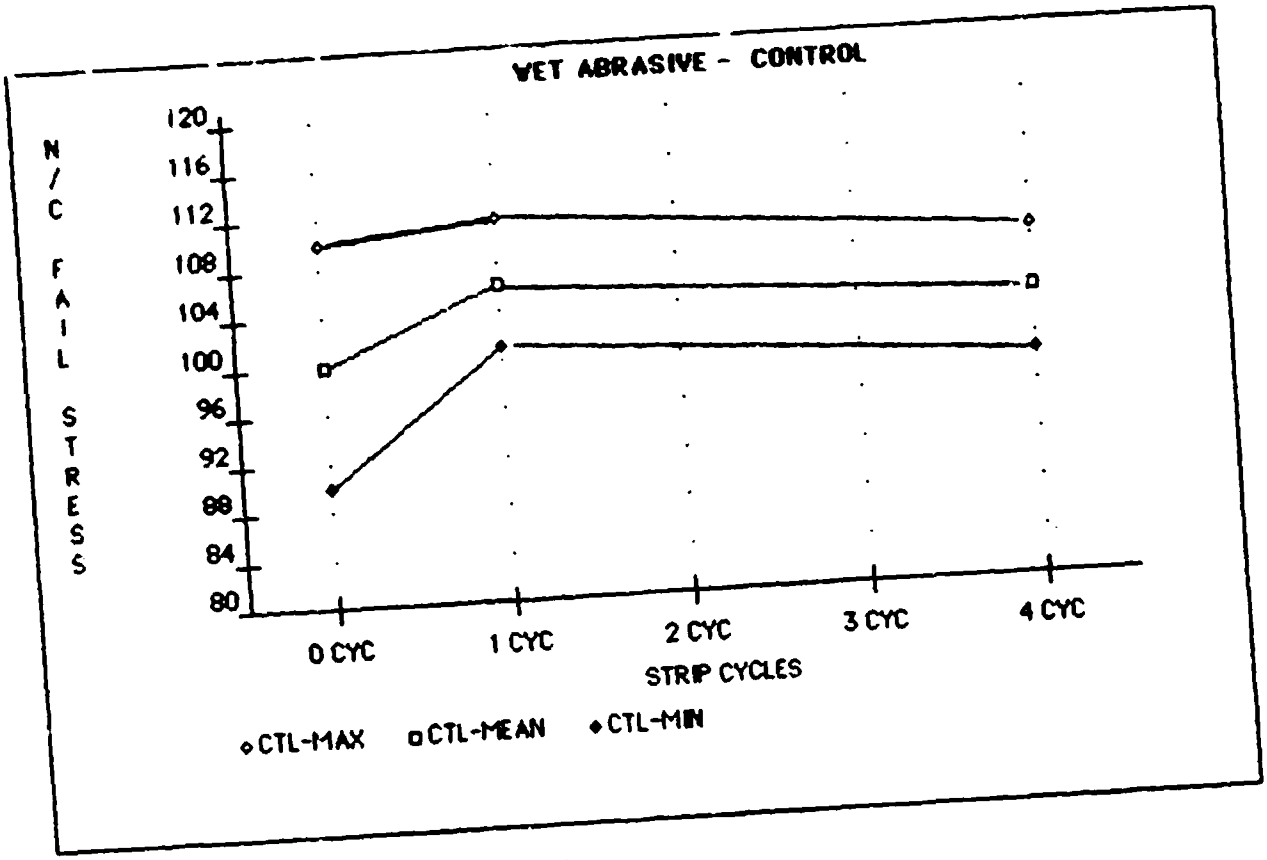
Table 5.8-2
Mechanical Properties - PMB Stripping

TEST	ADL			PAINT		COR. FAIL	COR. FAIL	COR. FAIL		NORM/COR	NORM/COR	NORM/COR
PANEL	REPORT	COATING NAME	DESIG-	REMOVAL		STRESS(2)	STRESS(3)	STRESS(8)		FAIL STR(2)	FAIL STR(3)	FAIL STR(8)
NO.	NO.	& DATA	NATION	PROCESS		0 CYC	1 CYC	4 CYC		0 CYC	1 CYC	4 CYC
7B	1	Control	CTL-MEAN	PMB		209.4	216.5	211.6		100.0	103.4	101.1
		stdev				5.5	11.9	3.9				
		t-factor(95%)				6.9	14.8	4.8		3.3	6.8	2.3
		max-95	CTL-MAX			216.3	231.3	216.4		103.3	110.2	103.3
		min-95	CTL-MIN			202.5	201.7	206.8		96.7	96.5	98.8
5B	2	Lord Chemglaze	U2A	PMB		182.5	178.9	181.9		100.0	98.0	99.7
		stdev				10.0	8.6	4.3				
		t-factor(95%)				12.4	10.6	5.4		6.8	5.9	3.0
		max-95	U2A-MAX			194.9	189.5	187.3		106.8	104.0	102.6
		min-95	U2A-MIN			170.1	168.3	176.5		93.2	92.1	96.7
2B	3	Desoto, Clear	U1C	PMB		186.9	199.4	200.2		100.0	106.7	107.1
		stdev				13.9	5.4	11.6				
		t-factor(95%)				17.2	6.7	14.4		9.2	3.4	7.2
		max-95	U1C-MAX			204.1	206.1	214.6		109.2	110.1	114.3
		min-95	U1C-MIN			169.7	192.7	185.8		90.8	103.3	99.9
3B	4	Desoto,Yellow	U1Y	PMB		202.0	212.8	194.5		100.0	105.3	96.3
		stdev				4.1	5.7	14.6				
		t-factor(95%)				5.1	7.0	18.1		2.5	3.3	9.3
		max-95	U1Y-MAX			207.1	219.8	212.6		102.5	108.6	105.6
		min-95	U1Y-MIN			196.9	205.8	176.4		97.5	102.0	87.0
4B	5	HughesHRG3/A3	EPX-MEAN	PMB		196.9	210.7	207.7		100.0	107.0	105.5
		stdev				9.6	6.6	3.7				
		t-factor(95%)				11.9	8.1	4.6		6.1	3.9	2.2
		max-95	EPX-MAX			208.8	218.8	212.3		106.1	110.9	107.7
		min-95	EPX-MIN			185.0	202.6	203.1		93.9	103.1	103.3

Table 5.8-2

Mechanical Proprties - PMB Stripping
(Continued)

TEST PANEL NO.	ADL REPORT NO.	COATING NAME & DATA	DESIG-NATION	PAINT REMOVAL PROCESS	COR. FAIL STRESS(2) 0 CYC	COR. FAIL STRESS(3) 1 CYC	COR. FAIL STRESS(8) 4 CYC	NORM/COR FAIL STR(2) 0 CYC	NORM/COR FAIL STR(3) 1 CYC	NORM/COR FAIL STR(8) 4 CYC
6B	6	Pratt&Lambert	EPA	PMB	199.2	198.1	200.1	100.0	99.4	100.5
		stdev			18.1	8.0	6.5			
		t-factor(95%)			22.5	9.9	8.1	11.3	5.0	4.0
		max-95	EPA-MAX		221.7	208.0	208.2	111.3	104.4	104.5
		min-95	EPA-MIN		176.7	188.2	192.0	88.7	94.5	96.4
9B	7	Hysol Synskin	FHM	PMB	207.3	210.1	217.5	100.0	101.4	104.9
		stdev			6.6	5.3	6.0			
		t-factor(95%)			8.2	6.6	7.4	4.0	3.2	3.4
		max-95	FHM-MAX		215.5	216.7	224.9	104.0	104.5	108.3
		min-95	FHM-MIN		199.1	203.5	210.1	96.0	98.2	101.5
10B	8	Hysol Film	FLM	PMB	211.2	208.1	207.8	100.0	98.5	98.4
		stdev			4.7	3.9	7.6			
		t-factor(95%)			5.9	4.8	9.4	2.8	2.3	4.5
		max-95	FLM-MAX		217.1	212.9	217.2	102.8	100.9	102.9
		min-95	FLM-MIN		205.3	203.3	198.4	97.2	96.2	93.9
8B	9	3M Film	FNP	PMB	190.2	194.1	174.4	100.0	102.1	91.7
		stdev			7.5	10.8	8.3			
		t-factor(95%)			9.3	13.4	10.2	4.9	6.9	5.9
		max-95	FNP-MAX		199.5	207.5	184.6	104.9	109.0	97.6
		min-95	FNP-MIN		180.9	180.7	164.2	95.1	95.1	85.8



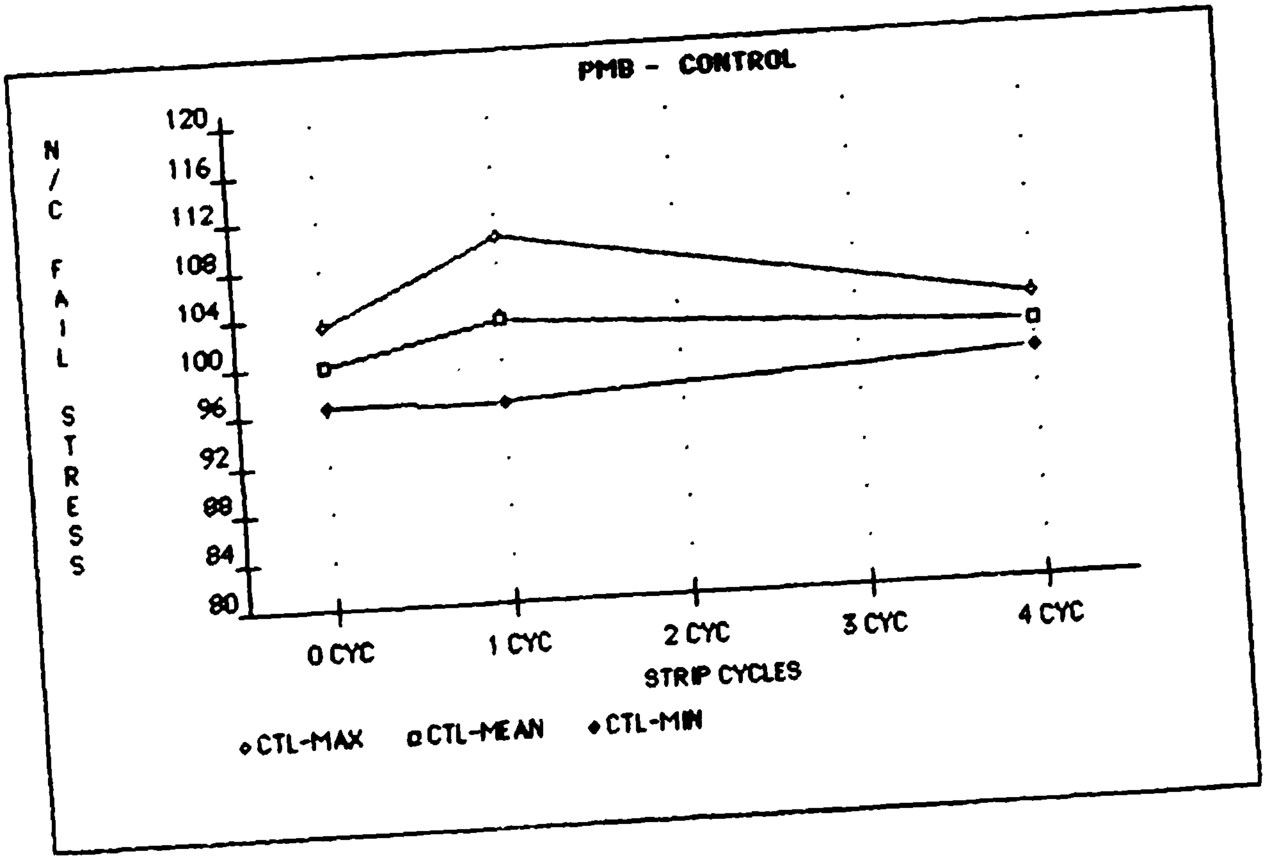
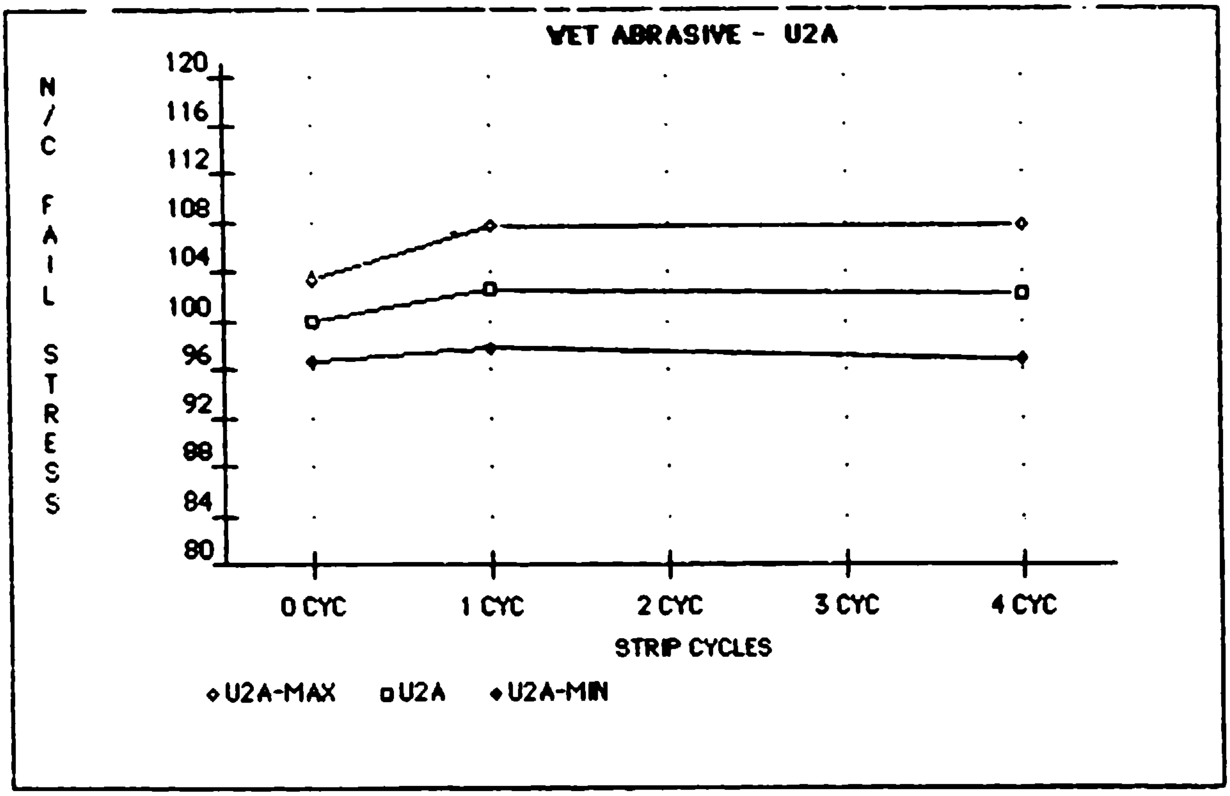


Figure 5.8-1 Failure Stress - Control



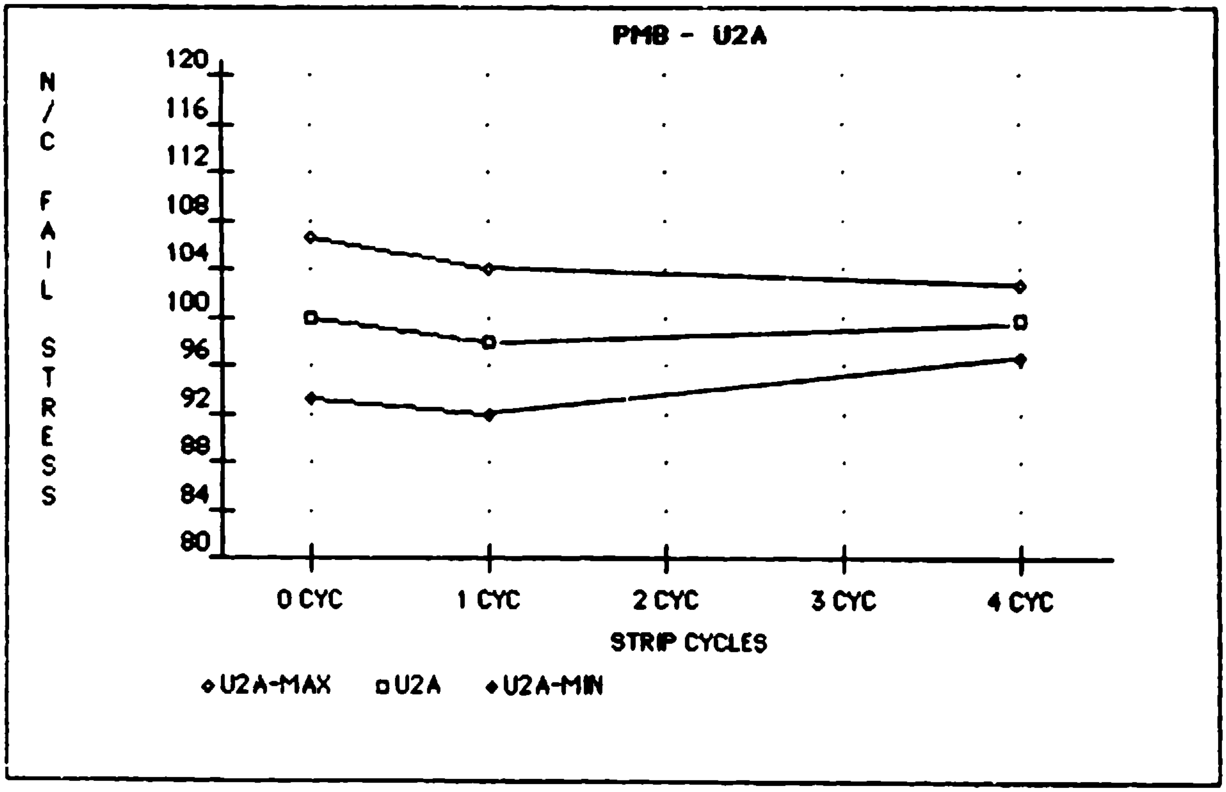


Figure 5.8-2 Failure Stress - U2A

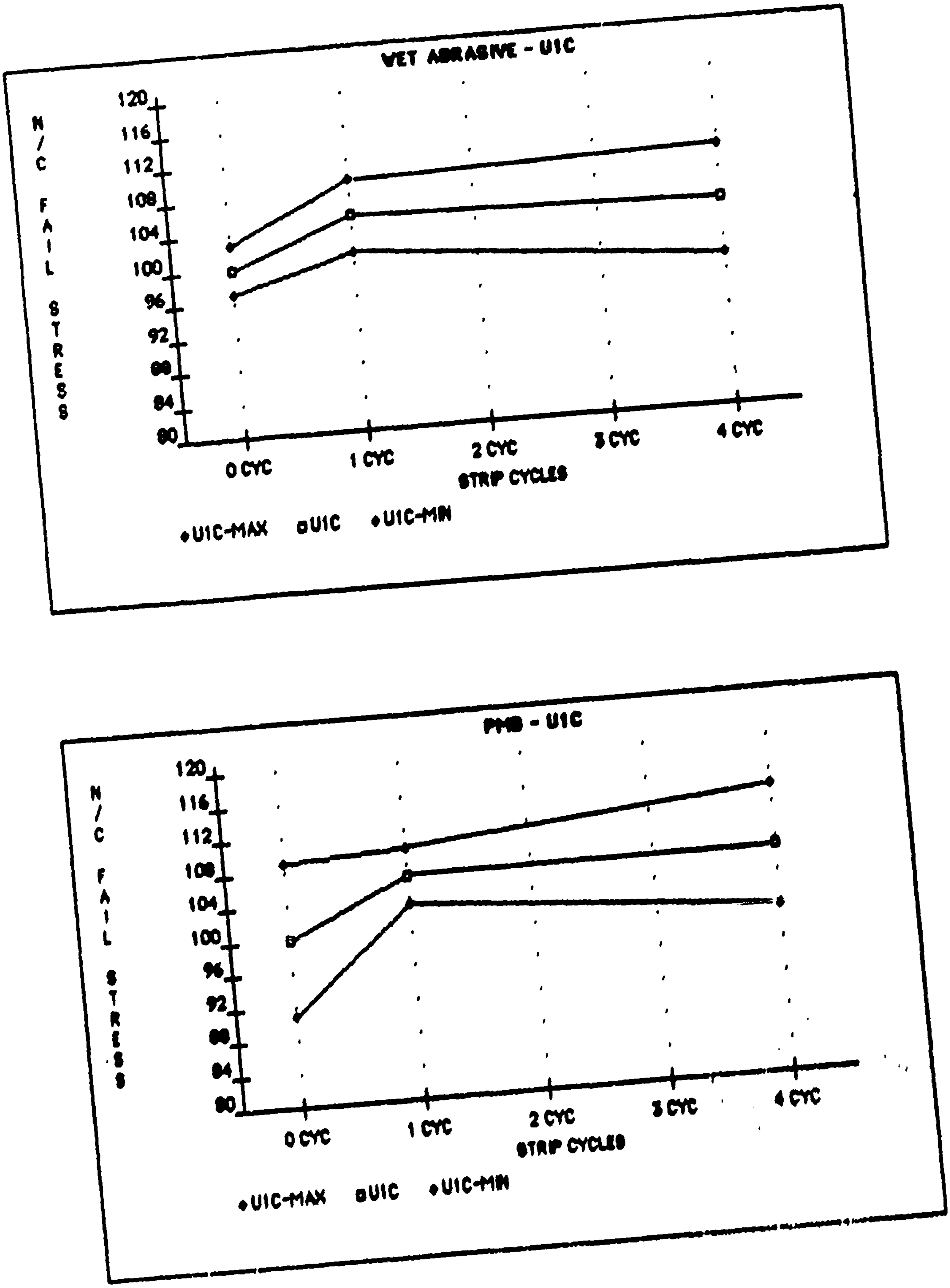
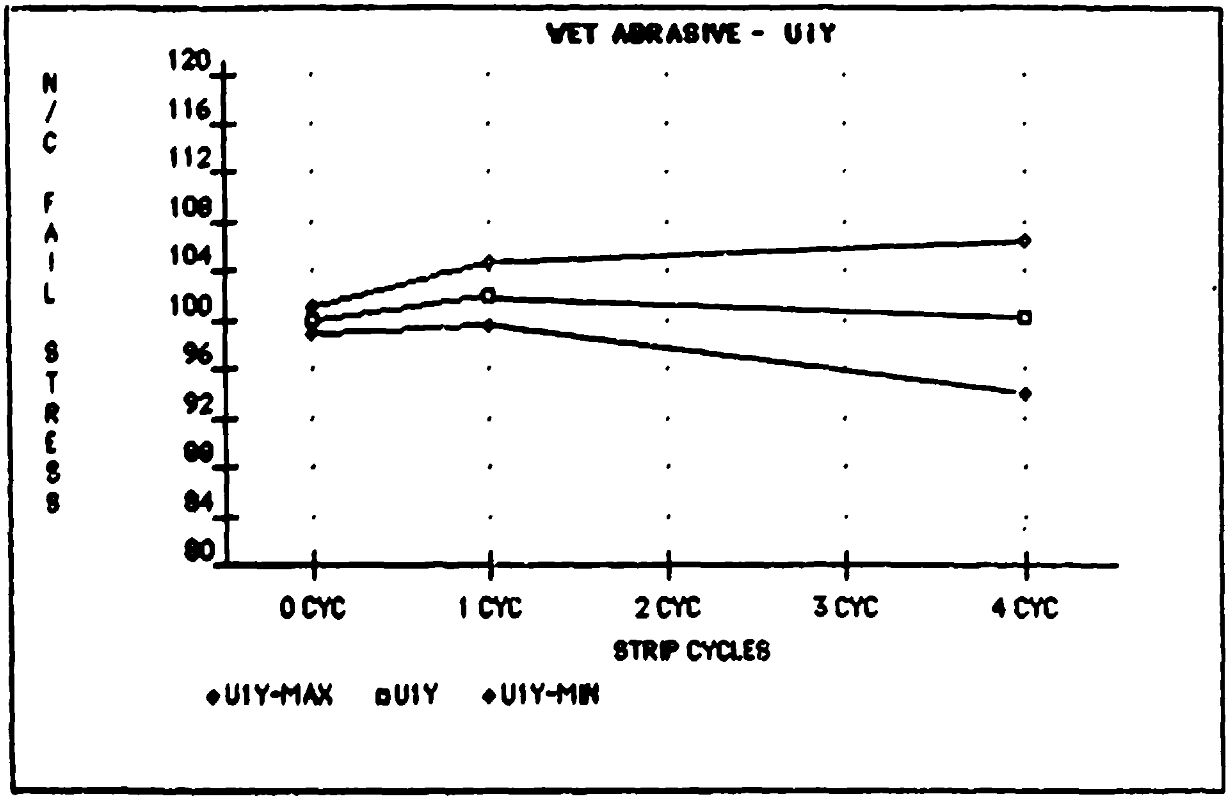


Figure 5.8-3 Failure Stress - U1C



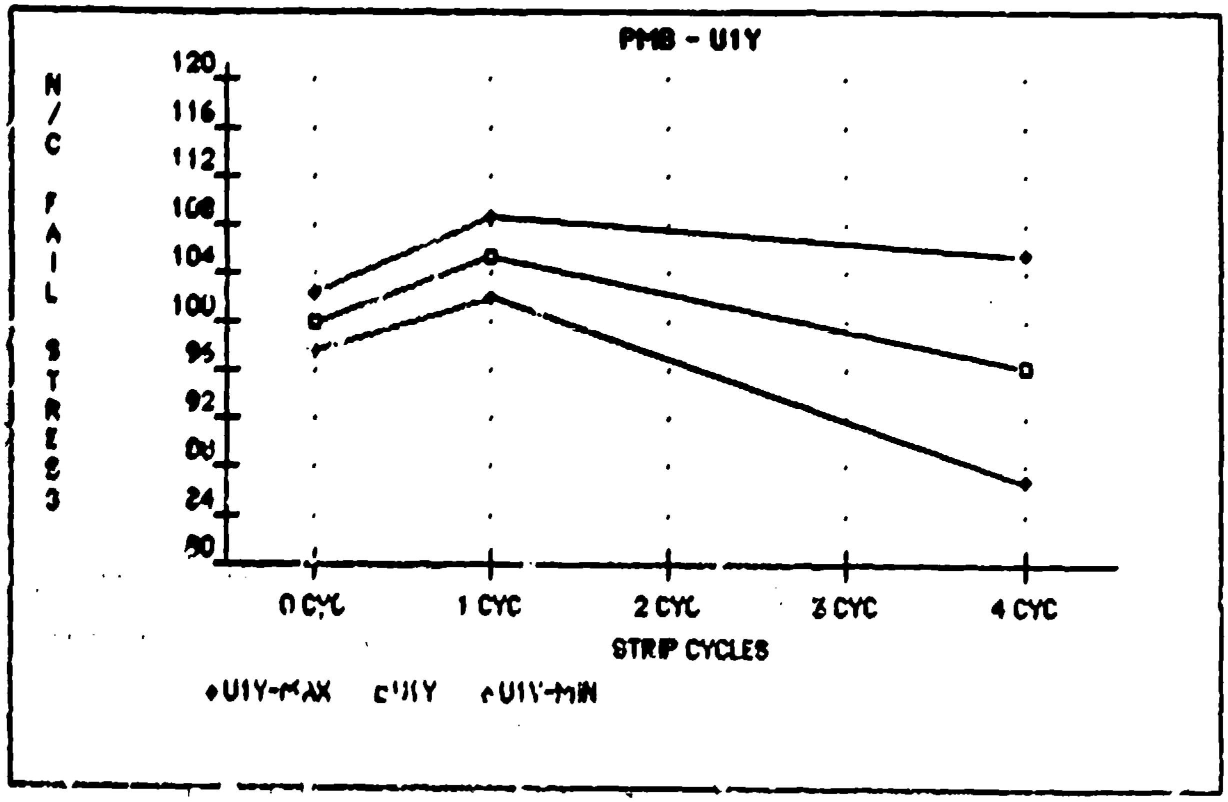
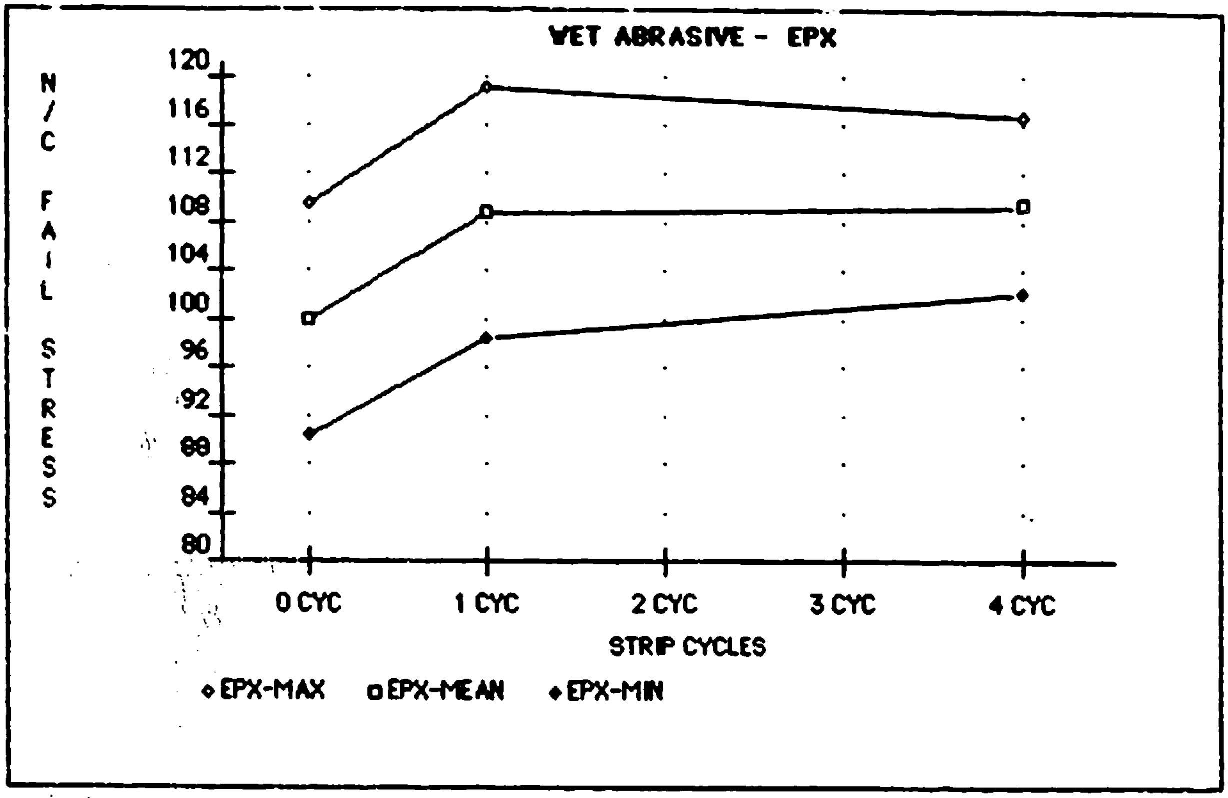


Figure 5.5-4 Failure Stress - U1Y



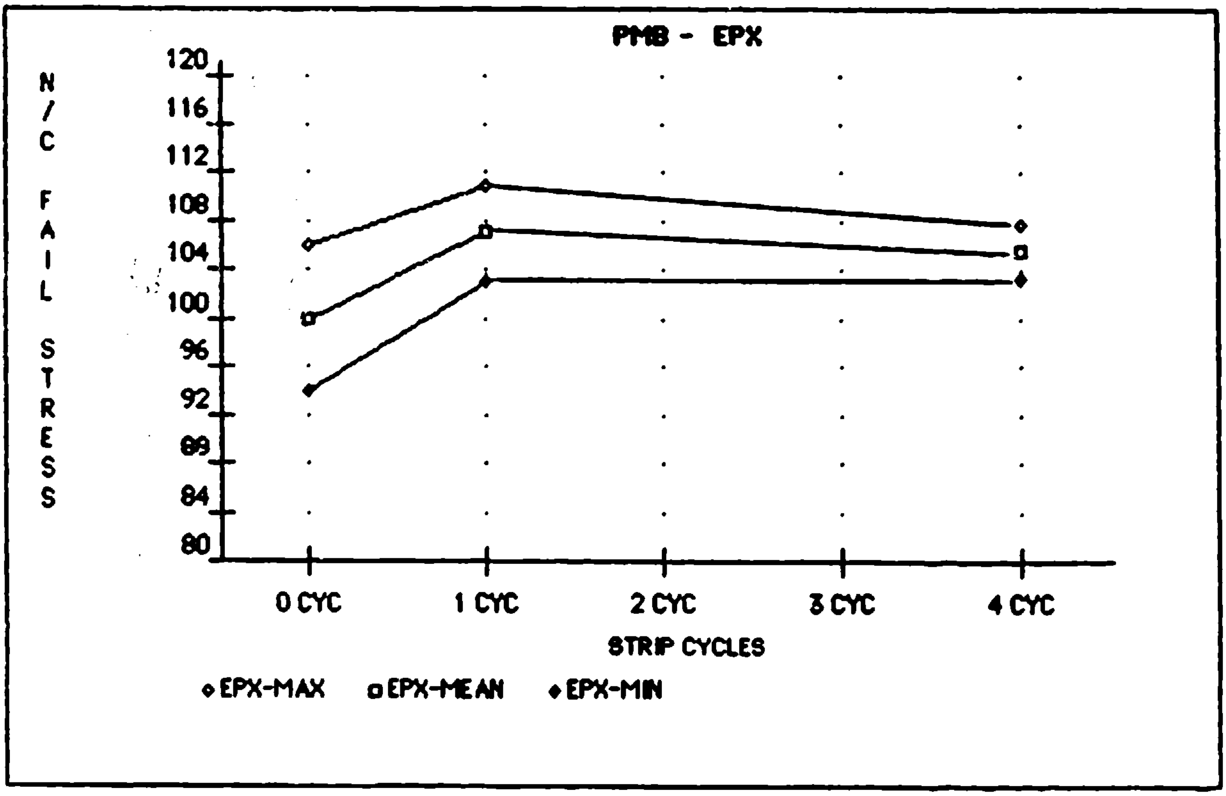
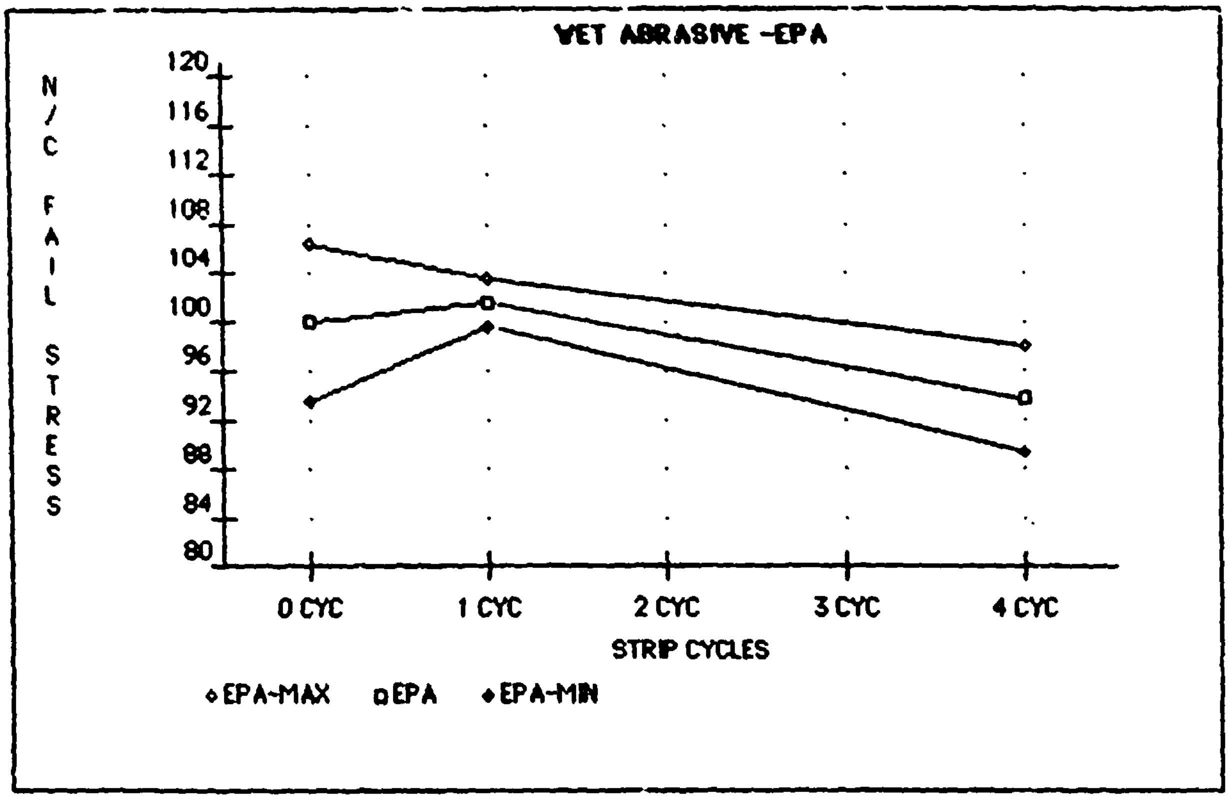


Figure 5.8-5 Failure Stress - EPX



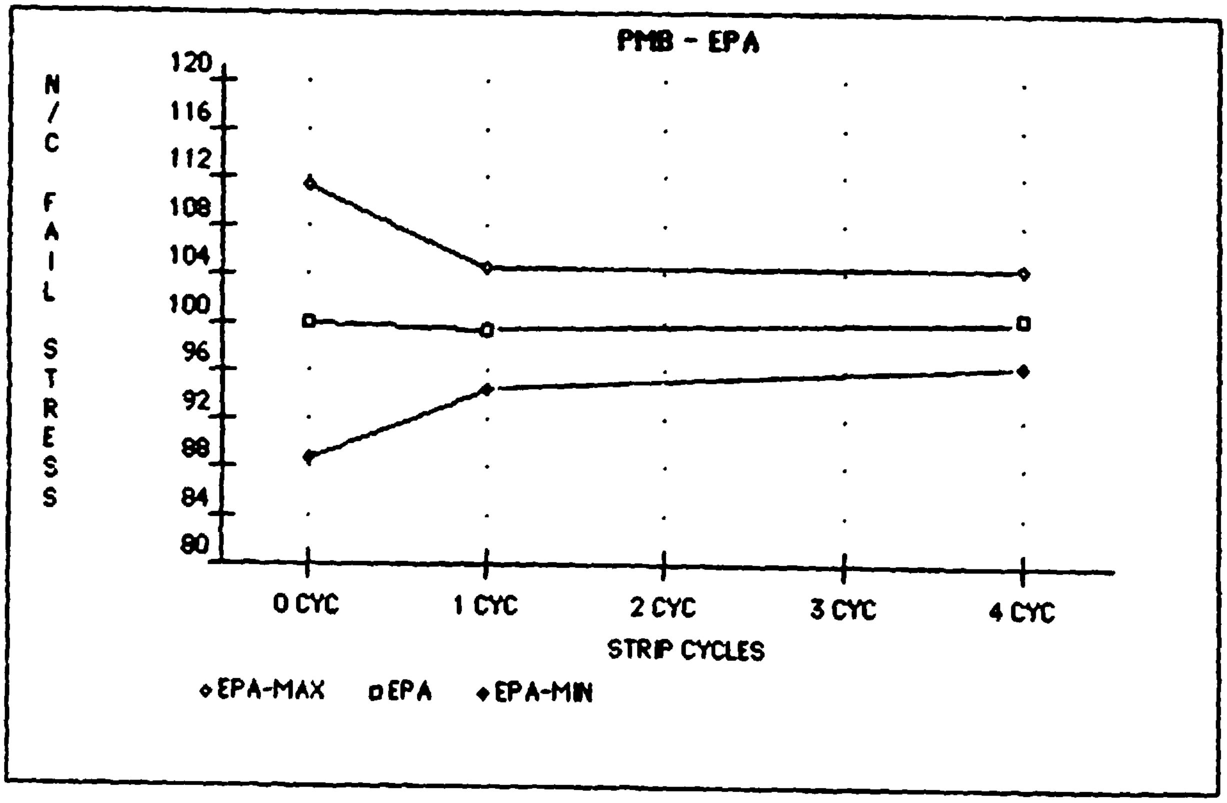
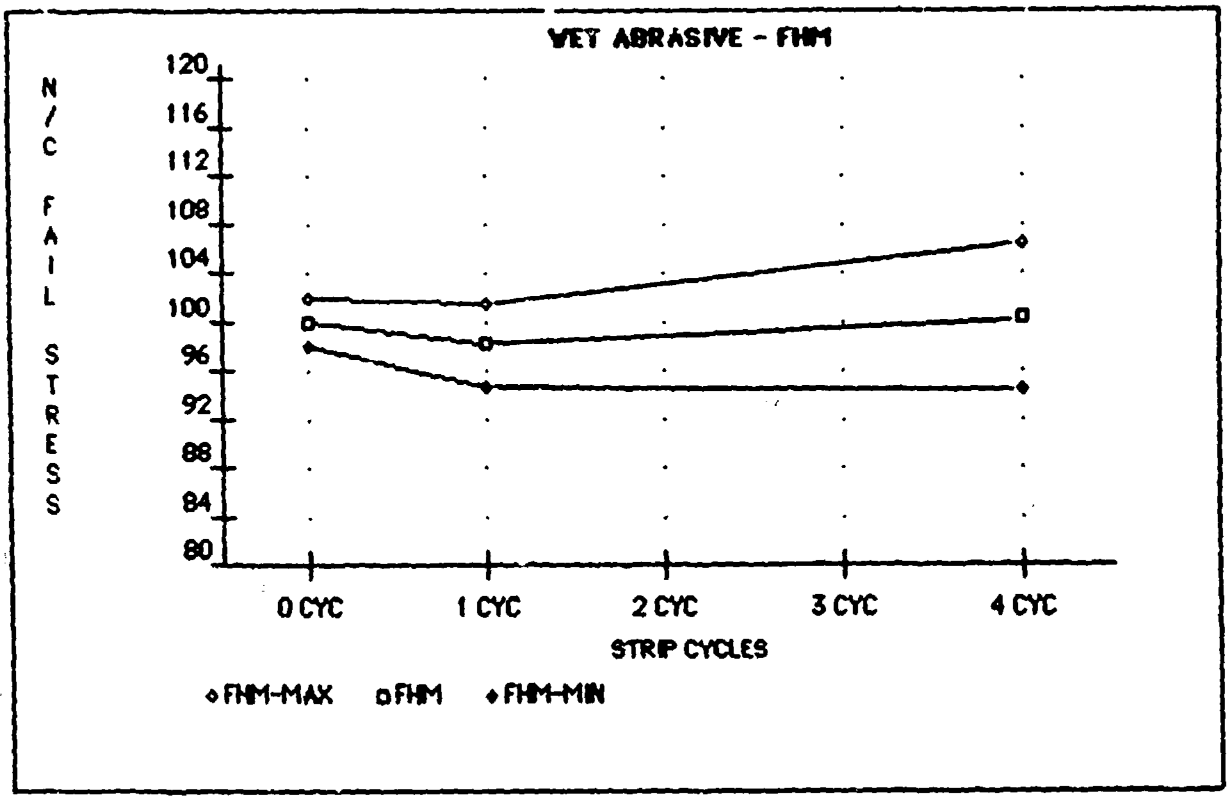


Figure 5.8-6 Failure Stress - EPA



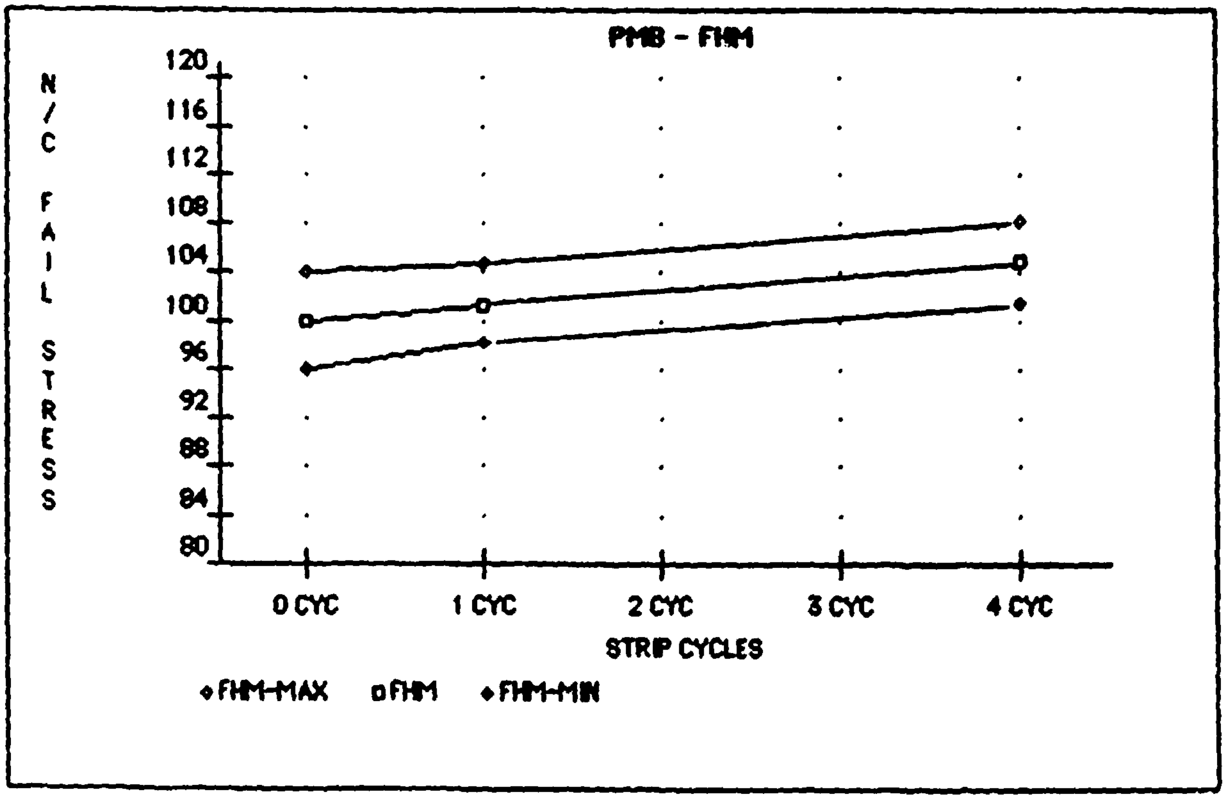
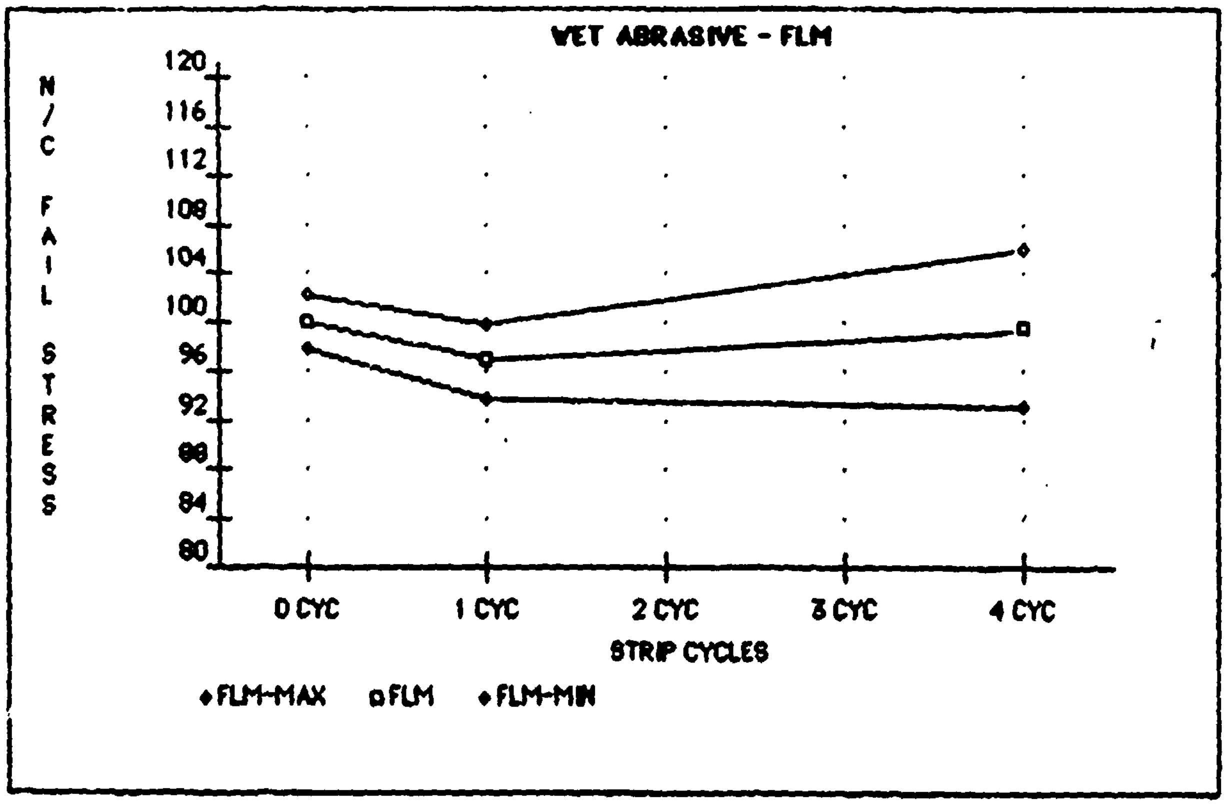


Figure 5.8-7 Failure Stress - FHM



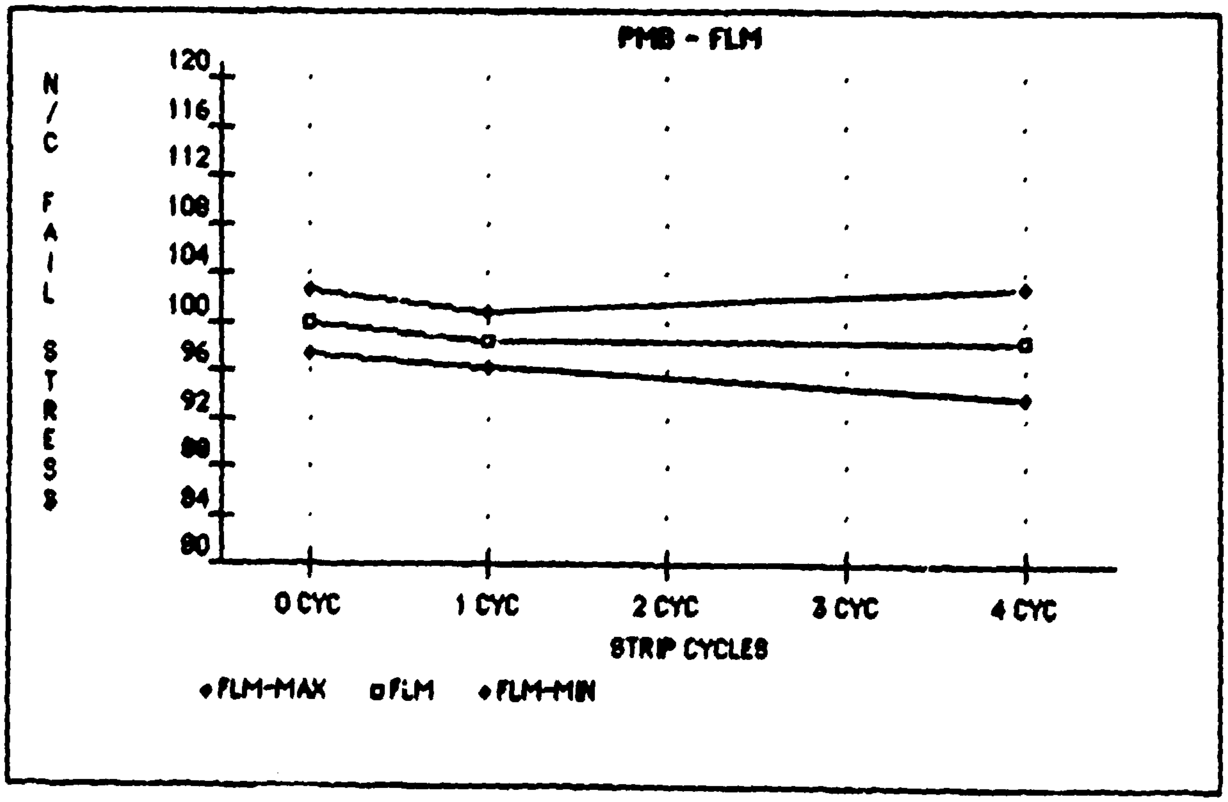
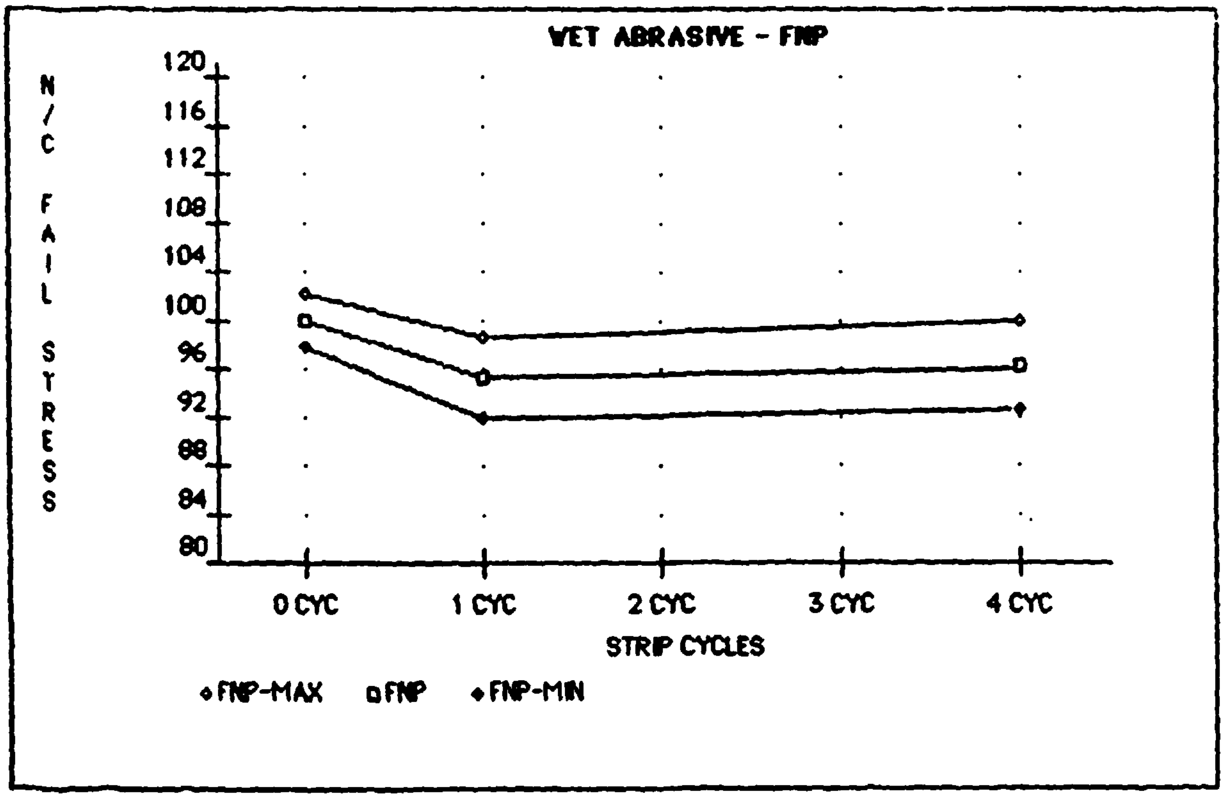


Figure 5.8-8 Failure Stress - FLM



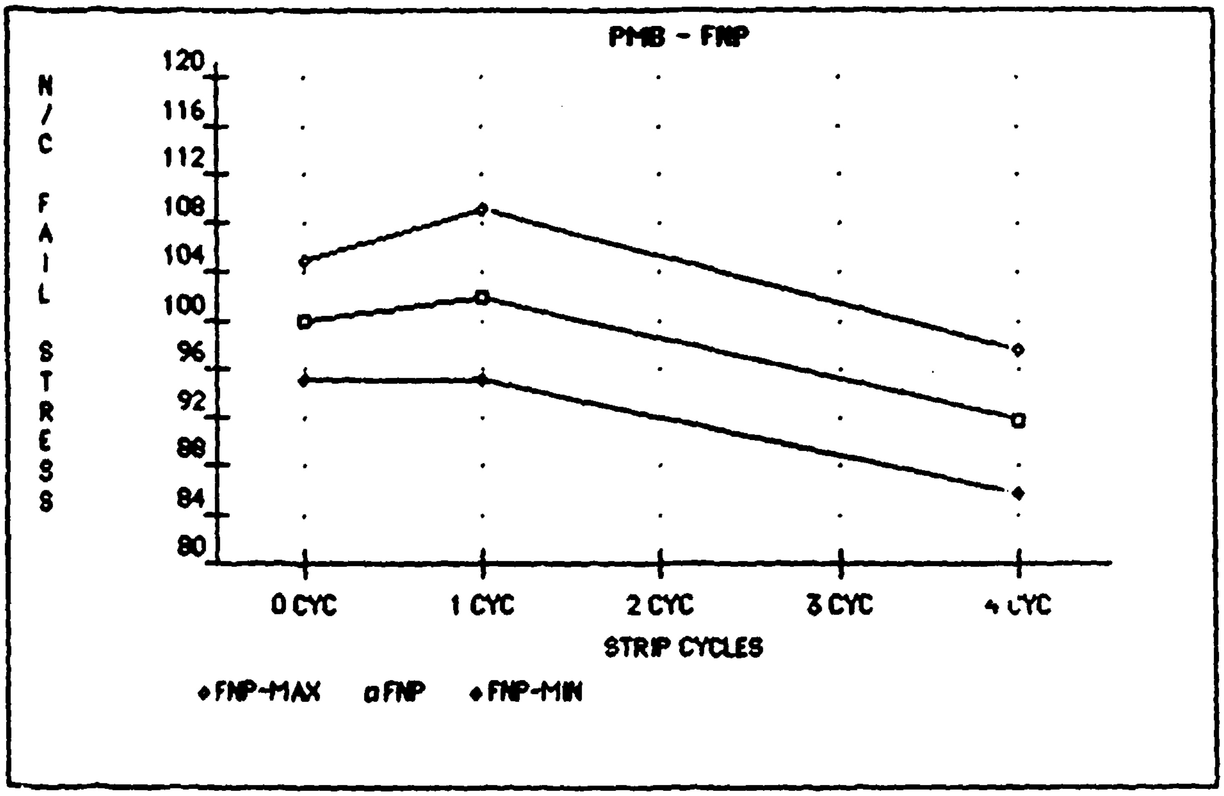


Figure 5.8-9 Failure Stress - FNP

however; it is in these instances that the protective coating is most likely to be important.

We have observed that both the paint removal process and the nature of the protective coating had an effect on the failure mode in the flexure test. In this test, the treated side is in compression and painted panels without a protect coating routinely fail at the compression side. After one or more depainting treatments, the side in tension more frequently fails, indicating a reduction of the stress concentration at the compression side. In addition, certain coatings such as FHM and FLM cause the initial failures to also shift to the tension side of the specimen. Evidently these coatings also are capable of reducing stress concentrations at the surface in compression without the benefit of the paint removal process. These observations point out the potential utility of the protective coating, even though the change in flexural strength is not statistically significant. The observations on the various failure modes observed for each system are summarized in Table 5.8-3 and 5.8-4.

Even though the flexural strengths of the panels are generally not reduced according to statistical significance, the systems generally show trends toward lower strength through the four cycles. These trends can only be verified through many more cycles, which is currently not feasible. However, we can observe the trend and make some careful comparisons. In Tables 5.8-5 and 5.8-6, we compare the statistical conclusions, the trend in flexural strength, and the trend in failure mode to reach an overall ranking of the potential effectiveness of the coating system on maintaining mechanical properties overall. Table 5.8-7 summarizes the potential that the coatings have to protect the mechanical properties of composites stripped by PMB and wet abrasive paint removal.

The potential ability for preserving mechanical properties is not the only consideration in determining the overall viability of the coating, however. It is also

Table 5.8-3
Failure Modes in Flexure Testing (Abrasive)
C = Comparison; S = Shear; T = Comparison

TEST PANEL NO.	ADL REPORT NO.	COATING NAME & DATA	DESIG-NATION	PAINT REMOVAL PROCESS	FAILURE MODE 0 CYC	FAILURE MODE 1 CYC	FAILURE MODE 4 CYC
7A	1	Control	CTL	Abrasive	C,C,C	T,T,T	T,T,T/S
					C/T,C/S	C/T,S	C,C/S
5A	2	Lord Chemglaze	U2A	Abrasive	C,C	C,C,C	T,T,T
					C/S,C/S	T,T	C,C
					T		
2A	3	Desoto, Clear	U1C	Abrasive	T,T,T	T,T,T,T	T,T
					C,C	C	S,S
							C/S
3A	4	Desoto, Yellow	U1Y	Abrasive	C,C,C,C	T,T,T,T,T	T,T,T
					T		C,C
4AC	5	HughesHRG3/A3	EPX	Abrasive	C,C,C,C,C	C,C,C,C,C	T,T,T
							T/S
							C
6A	6	Pratt&Lambert	EPA	Abrasive	T,T,T	T,T	S,S
					C	T/S,T/S	T,T/S
					S	S	C/S
9A	7	Hysol Synskin	FHM	Abrasive	T,T,T,T,T	T,T,T,T,T	T/S,T/S,T/S
							T,T
10A	8	Hysol Film	FLM	Adhesive	T,T,T,T,T	T,T,T,T	T/S,T/S,T/S
						T/S	T,T
8A	9	3M Film	FNP	Abrasive	T,T	C/S,C/S	T/S,T/S
					T/S,T/S	S,S	T
					C	T/S	C
							S

Table 5.8-4
Failure Modes in Flexure Testing(PMB)
C = Comparison; S = Shear; T = Comparison

TEST PANEL NO.	ADL REPORT NO.	COATING NAME & DATA	DESIG-NATION	PAINT REMOVAL PROCESS	FAILURE MODE 0 CYC	FAILURE MODE 1 CYC	FAILURE MODE 4 CYC
7B	1	Control	CTL	PMB	C,C,C,C,C	T,T,T	T,T,T
						T/C,T/C	T/S
							S
5B	2	Lord Chemglaze	U2A	PMB	C/S,C/S,	C/S,C/S,C/S	S,S,S,S
					C/S,C/S	C	T/S
					S	T	
2B	3	Desoto, Clear	U1C	PMB	C,C,C	T,T,T	T,T,T
					T,T	C,C	S
							C
3B	4	Desoto,Yellow	U1Y	PMB	T,T,T,T	T,T,T,T,T	S,S
					C		T/C/S
							C
4B	5	HughesHRG3/A3	EPX	PMB	C,C	T,T,T,T	T,T,T,T
					C/T	S	T/S
					T,T		
6B	6	Pratt&Lambert	EPA	PMB	C,C,C	S,S,S	T/S,T/S,T/S
					S	T	T
					T	C	S
9B	7	Hysol Synskin	FHM	PMB	T,T,T,T	T/S,T/S,T/S	T/S,T/S,
					S	T,T	T/S,T/S
							T
10B	8	Hysol Film	FLM	PMB	T,T,T,T,T	T,T,T,T,T	T/S,T/S,
							T/S,T/S
							T
8B	9	3M Film	FNP	PMB	C/S,C/S,C/S	C/S,C/S,	C,C,C
					T/S	C/S,C/S	T/S
					S	S	S

Table 5.8-5
Wet Abrasive--Trends

Panel No.	ADL Report No.	Name	Designation	Effect on Mech. Properties Statistical (95% C.I.)	Trend (1-4)	Failure Trend	Rating
7A	1	Control	CTL	None	-0.83%/cycle	C → T	0
5A	2	Lord Chemglaze	U2A	None	-0.13	C → T	+
2A	3	DeSoto, Clear	U1C	None	-0.34	T → T	+
3A	4	DeSoto, Yellow	U1Y	None	-0.63	C → T	0
4AC	5	Hughes HRG3/A3	EPX	None	0.00	C → T	+
6A	6	Pratt & Lambert	EPA	Decrease	-2.60	T → T	-
9A	7	Hysol SynSkin	FHM	None	0.00	T → T	+
10A	8	Hysol Film	FLM	None	0.00	T → T	+
8A	9	3M Film	FNP	None	0.00	T → T	+

C = Compression   T = Tension

Table 5.8-6
PMB Strip--Trends

Panel No.	ADL Report No.	Name	Designation	Effect on Mech. Properties Statistical (95% C.I.)	Trend (1-4)	Failure Trend	Rating
7B	1	Control	CTL	None	-0.77%/cycle	C → T	0
5B	2	Lord Chemglaze	U2A	None	-0.00	C → S	+
2B	3	DeSoto, Clear	U1C	None	-0.00	C → T	+
3B	4	DeSoto, Yellow	U1Y	None	-3.00	T → S	-
4B	5	Hughes HRG3/A3	EPX	None	-0.50	C → T	0
6B	6	Pratt & Lambert	EPA	None	-0.00	C → T	+
9B	7	Hysol SynSkin	FHM	None	+1.27	T → T/S	+
10B	8	Hysol Film	FLM	None	0.00	T → T/S	+
8B	9	3M Film	FNP	None	-3.47	C → C	-

C = Compression T = Tension S = Shear

Table 5.8-7
Summary of Coatings Effect on Mechanical Properties

Panel No.	ADL Report No.	Name	Designation	Promising for Wet Abrasive	Promising for PMB Strip
7A,B	1	Control	CTL	—	—
5A,B	2	Lord Chemglaze	U2A	Yes	Yes
2A,B	3	DeSoto, Clear	U1	Yes	Yes
3A,B	4	DeSoto, Yellow	U1Y	No effect	No
4A,B	5	Hughes HRG3/A3	EPX	Yes	No effect
6A,B	6	Pratt & Lambert	EPA	No	Yes
9A,B	7	Hysol SynSkin	FHM	Yes	Yes
10A,B	8	Hysol Film	FLM	Yes	Yes
8A,B	9	3M Film	FNP	Yes	No

necessary to consider the weatherability of the coating under the conditions that might occur and the overall durability of the coating to the specific paint removal process. Table 5.8-8 summarizes each of these considerations for the coatings when PMB and wet abrasive are the paint removal processes. Considering each of these effects, we were able to establish the overall performance listed in the last column and Table 5.8-7. The analysis shows that coatings such as U2A, U1C, EPX, and FNP offer the most potential protection from PMB, while EPA is better suited for PMB. Only coatings FHM and FLM show potential for both PMB and wet abrasive paint removal. These conclusions are summarized in Table 5.8-9.

Overall, the results of this phase of the program show that PMB and wet abrasive paint removal can be carried out with little or no damage to composite substrates when the primer is used as the "flag." When this type of "controlled" situation is not possible, such as with field repair or the result of operator or mechanical error, protective coatings identified in this work would provide an effective means of protecting the composite. To investigate this further, we recommend evaluating selective coatings identified in this work, for their ability to prevent damage in catastrophic situations such as when a PMB robot might stall at a given position or when an operator might become distracted. Some of these coatings have the potential to provide substantial protection to the composite under these circumstances.

Table 5.8-8
Summary of Protective Coating Performance

Designation	Weathering	Effect of Paint Removal PMB	 Wet Abrasive	Effect on Mechanical Properties of Composites PMB	 Wet Abrasive	Overall Performance Summary PMB	 Wet Abrasive
CTL	Good	Good	Good	Fair	Fair	Fair	Fair
U2A	Fair	Poor	Good	Good	Good	Poor	Good
U1C	Fair	Poor	Good	Good	Good	Poor	Good
U1Y	Excellent	Good	Good	Poor	Fair	Poor	Fair
EPX	Fair	Good	Good	Fair	Good	Fair	Good
EPA	Good	Good	Good	Good	Poor	Good	Poor
FBM	Fair	Good	Good	Good	Good	Good	Good
FLM	Fair	Good	Good	Good	Good	Good	Good
FNP	Fair	Good	Good	Poor	Good	Poor	Good

Table 5.8-9
Potentially Suitable Coatings

Name	Designation	Potential Protection Provided For:
Lord Chemglaze	U2A	Wet Abrasive
DeSoto, Clear	U1C	Wet Abrasive
Hughes HRG3/A3	EPX	Wet Abrasive
Pratt & Lambert	EPA	PMB
Hysoil SynSkin	FHM	PMB and Wet Abrasive
Hysol Film	FLM	PMB and Wet Abrasive
3M Film	FNP	Wet Abrasive

6.0 References

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APPENDIX A

PHOTOGRAPHS USING THE SCANNING ELECTRON MICROSCOPE

APPENDIX A

PHOTOGRAPHS USING THE

SCANNING ELECTRON MICROSCOPE

1. 60882-13-2D - Re-topcoated panel which had been previously stripped to the epoxy primer layer using optimized wet-abrasive system. (126X)

2. 60882-15-1D - Panel stripped to the epoxy primer layer using sodium bicarbonate blasting technique at 40 psig with water incorporation. (124X)

3. 60882-13-2C - Panel stripped to the epoxy primer layer using optimized wet-abrasive system. (128X)

4. 1X - Excimer laser panel stripped by Resonetics using the optimum number of pulses necessary to remove the topcoat. (200X)

5. 3X - Excimer laser panel stripped by Resonetics using triple the number of pulses necessary to remove the topcoat. (244X)

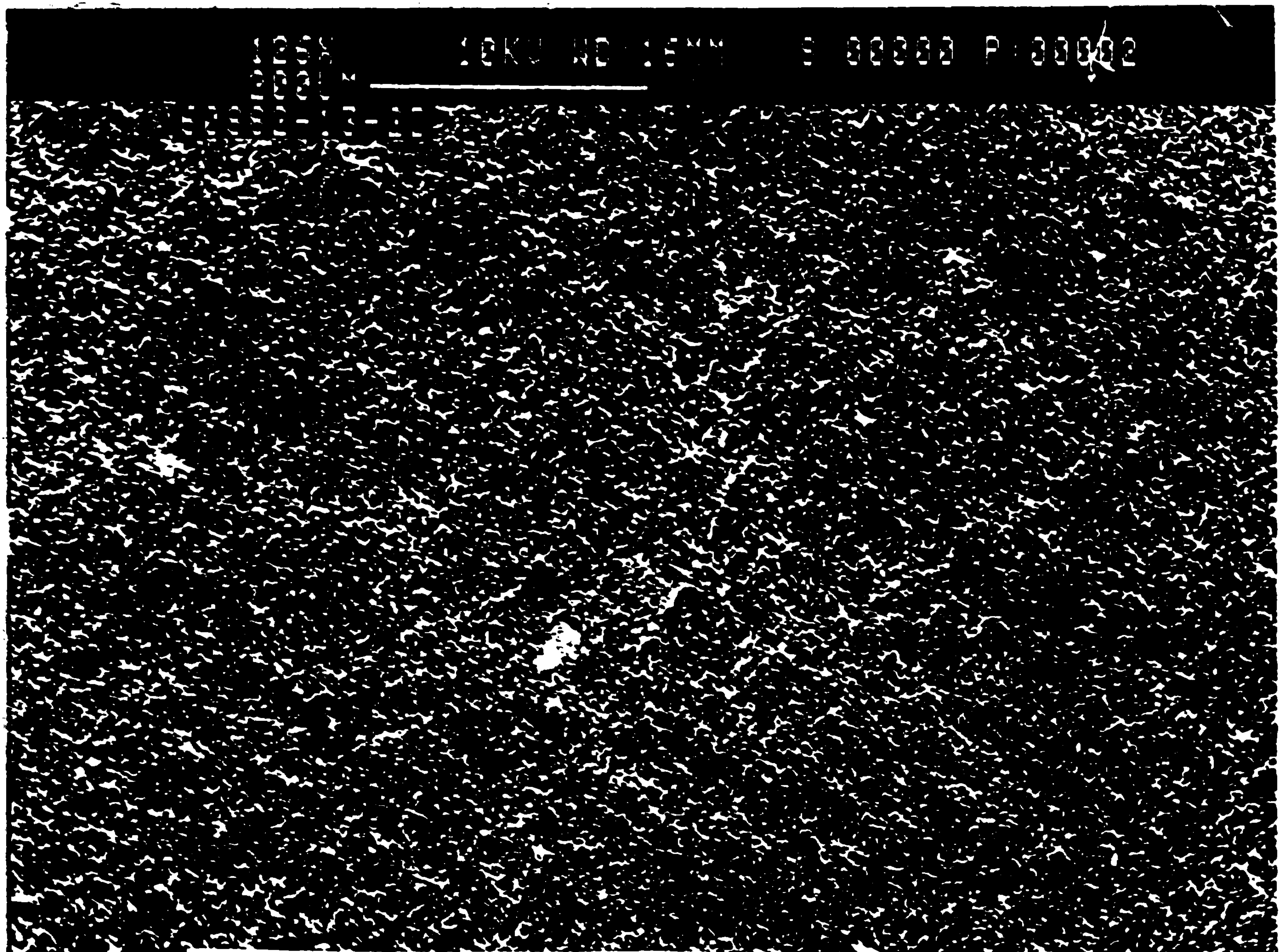
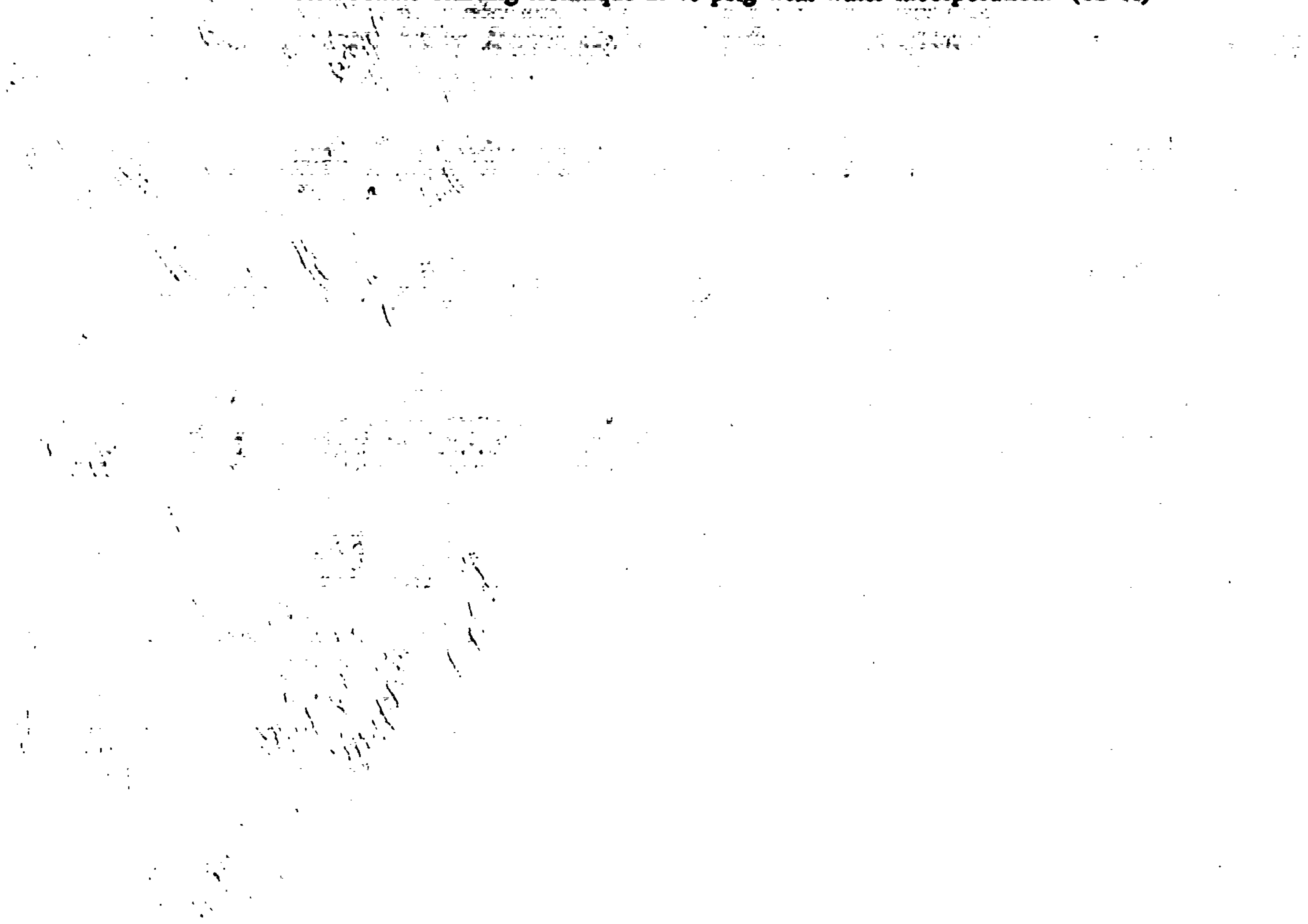


Figure A-1 60882-13-2D - Re-topcoated panel which had been previously stripped to the epoxy primer layer using optimized wet-abrasive system. (126X)

PHOTOGRAPH USING THE

SCANNING ELECTRON MICROSCOPE

2. 60882-15-1D - Panel stripped to the epoxy primer layer using sodium bicarbonate blasting technique at 40 psig with water incorporation. (124X)



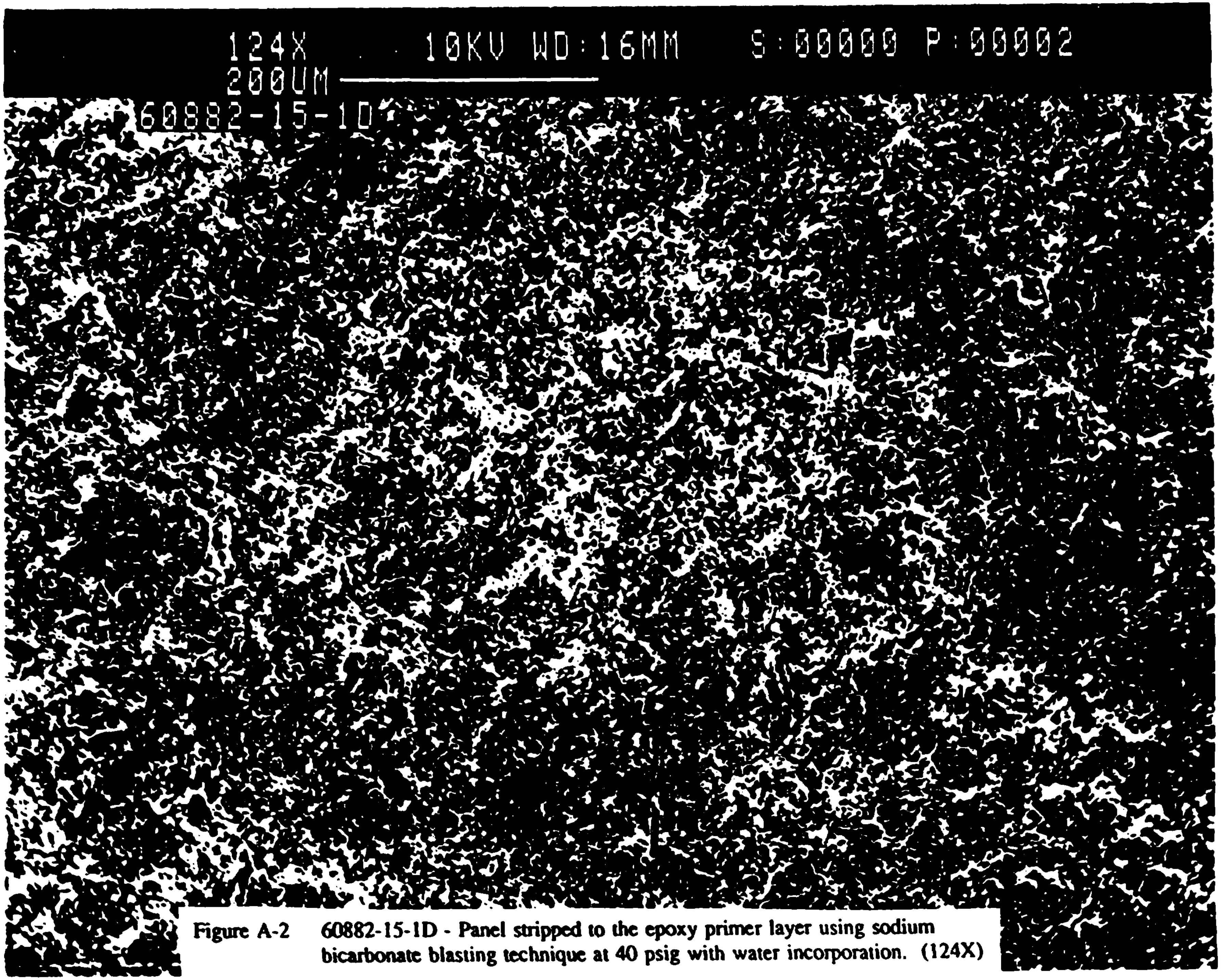


Figure A-2 60882-15-1D - Panel stripped to the epoxy primer layer using sodium bicarbonate blasting technique at 40 psig with water incorporation. (124X)

PHOTOGRAPH USING THE SCANNING ELECTRON MICROSCOPE

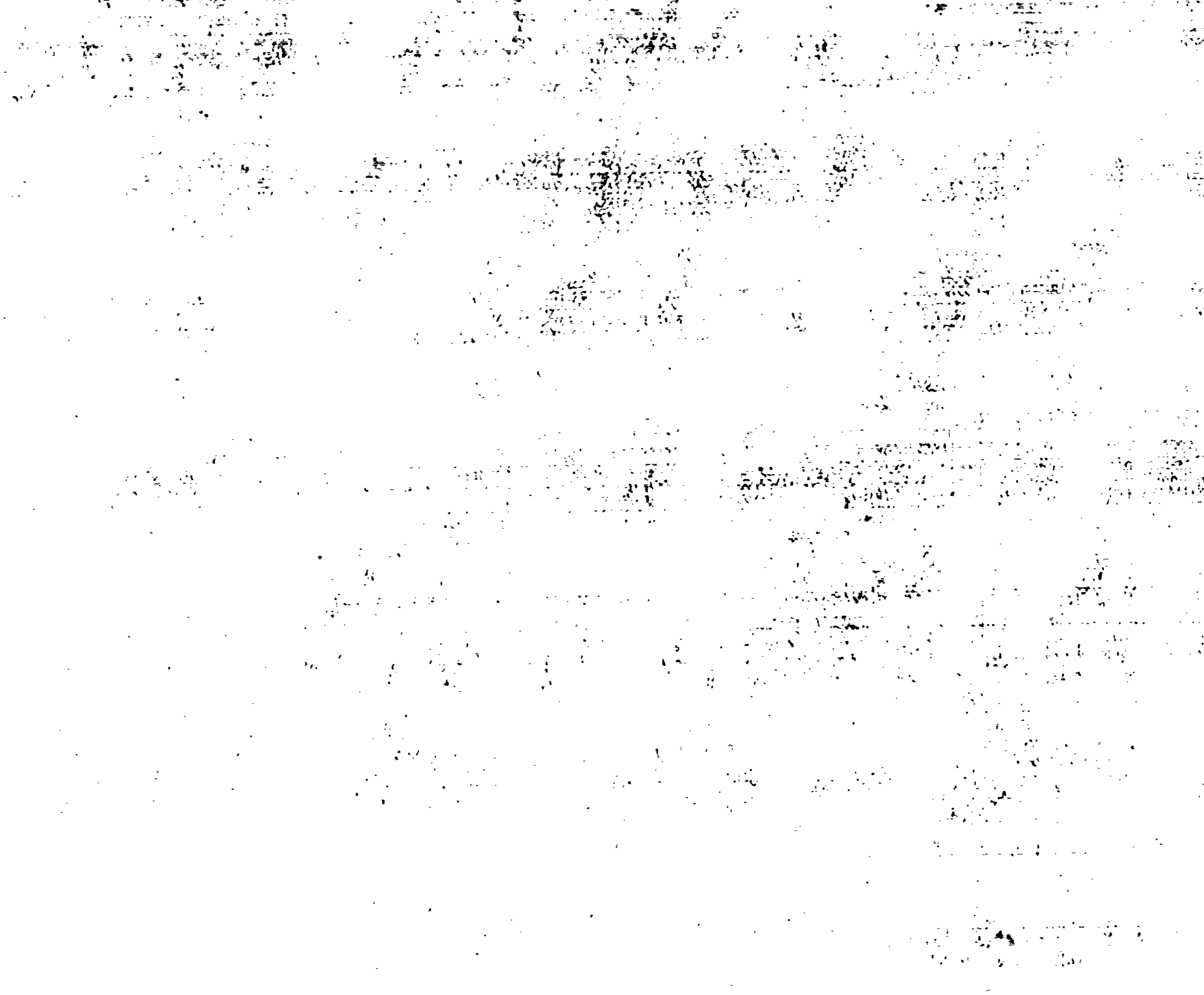
3. 60882-13-2C - Panel stripped to the epoxy primer layer using optimized wet-abrasive system. (128X)

Figure A-3 60882-13-2C - Panel stripped to the epoxy primer layer using optimized wet-abrasive system. (128X)

PHOTOGRAPH USING THE

SCANNING ELECTRON MICROSCOPE

4. 1X - Excimer laser panel stripped by Resonetics using the optimum number of pulses necessary to remove the topcoat. (200X)



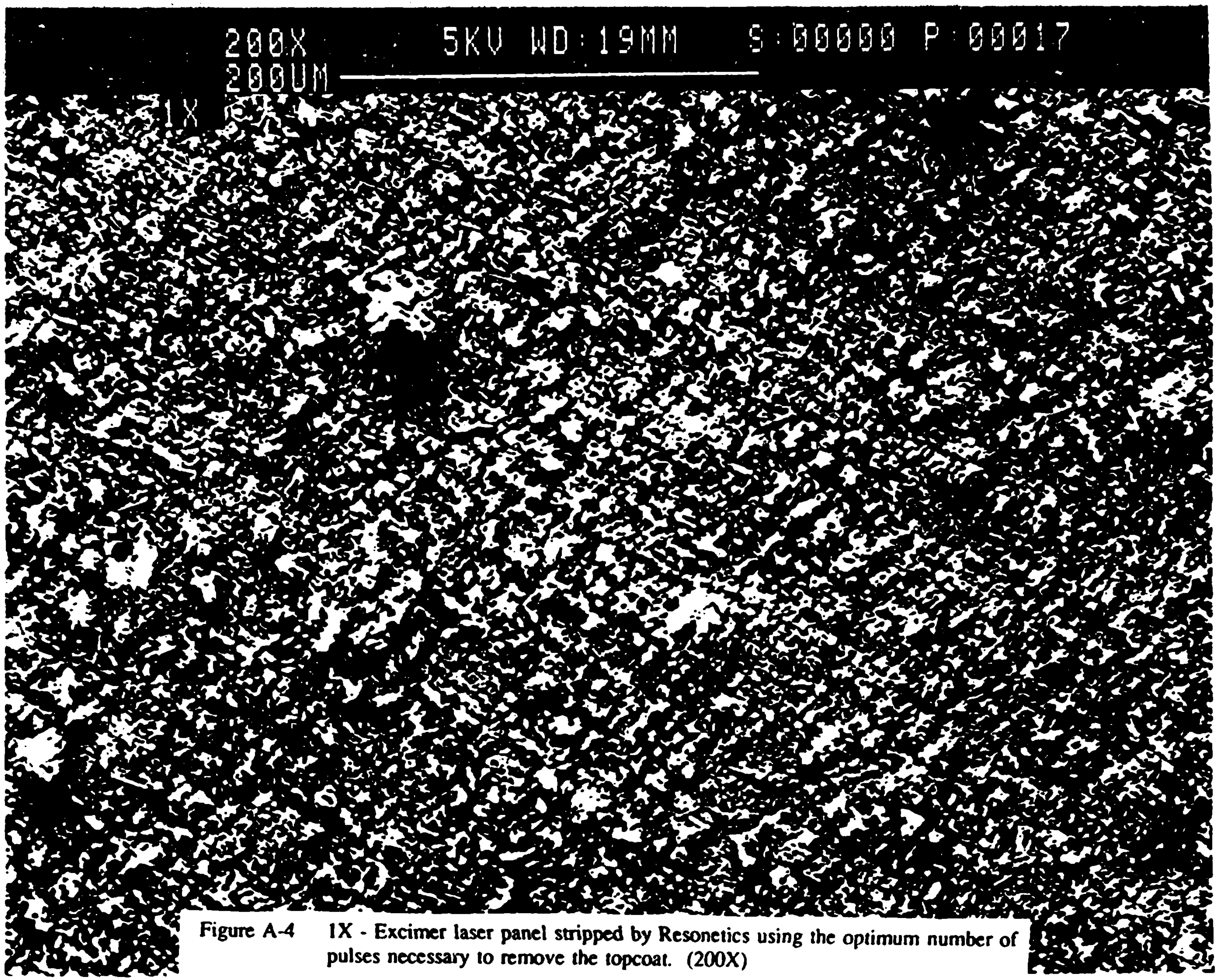


Figure A-4 1X - Excimer laser panel stripped by Resonetics using the optimum number of pulses necessary to remove the topcoat. (200X)

PHOTOGRAPH USING THE

SCANNING ELECTRON MICROSCOPE

5. 3X - Excimer laser panel stripped by Resonetics using triple the number of pulses necessary to remove the topcoat. (244X)

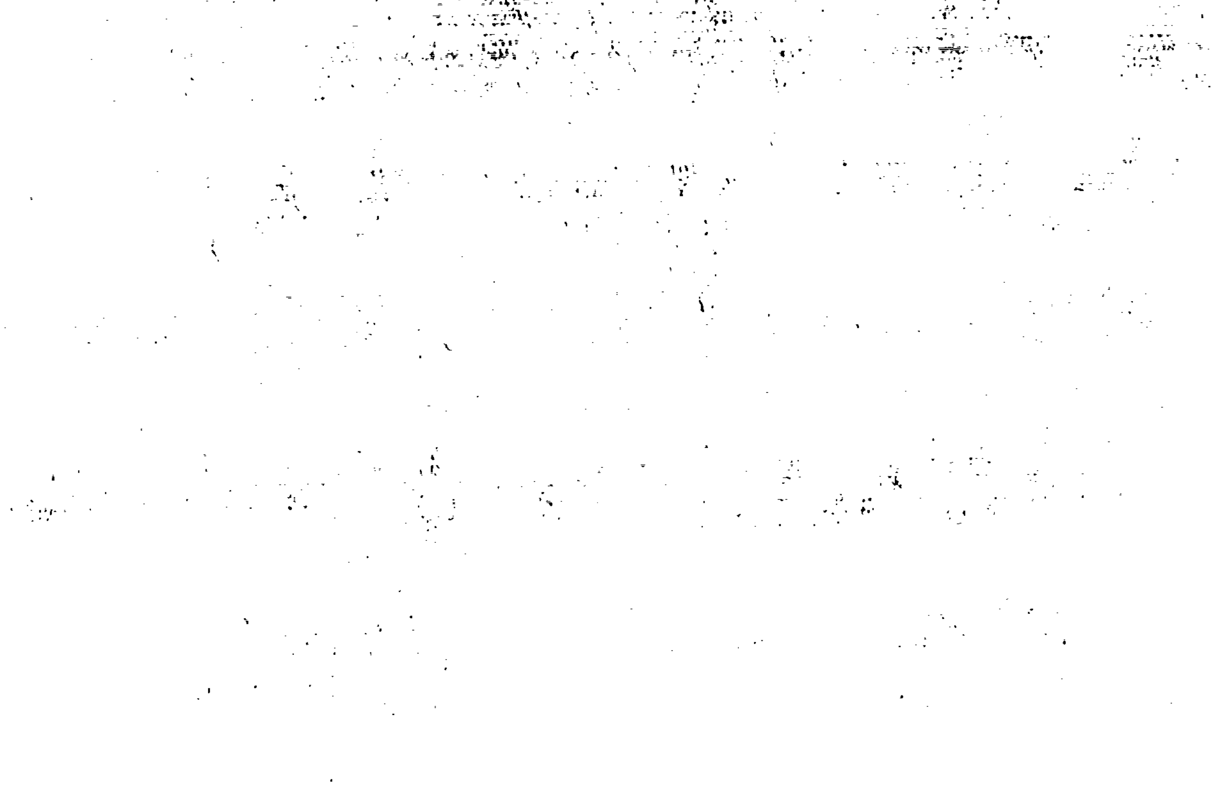


Figure A-5 3X - Excimer laser panel stripped by Resonetics using triple the number of pulses necessary to remove the topcoat. (244X)

APPENDIX B

MECHANICAL PROPERTY TESTING

TEST SELECTION

Evaluate
- Fiber damage at surface
- Matrix damage, especially at surface
- Interlaminar weakening

o Flexure
- Fiber damage in tension or compression
- Matrix damage in compression

ASTM D 790, Method II, Procedure A

o ILS
- Interlaminar weakening

ASTM D 2344

TEST FIXTURE

- Meet ASTM specifications
- Adjustable support and load spans
- Self aligning about in-plane axes of specimen
- Changeable support and loading noses
- Minimize specimen to fixture friction during tests

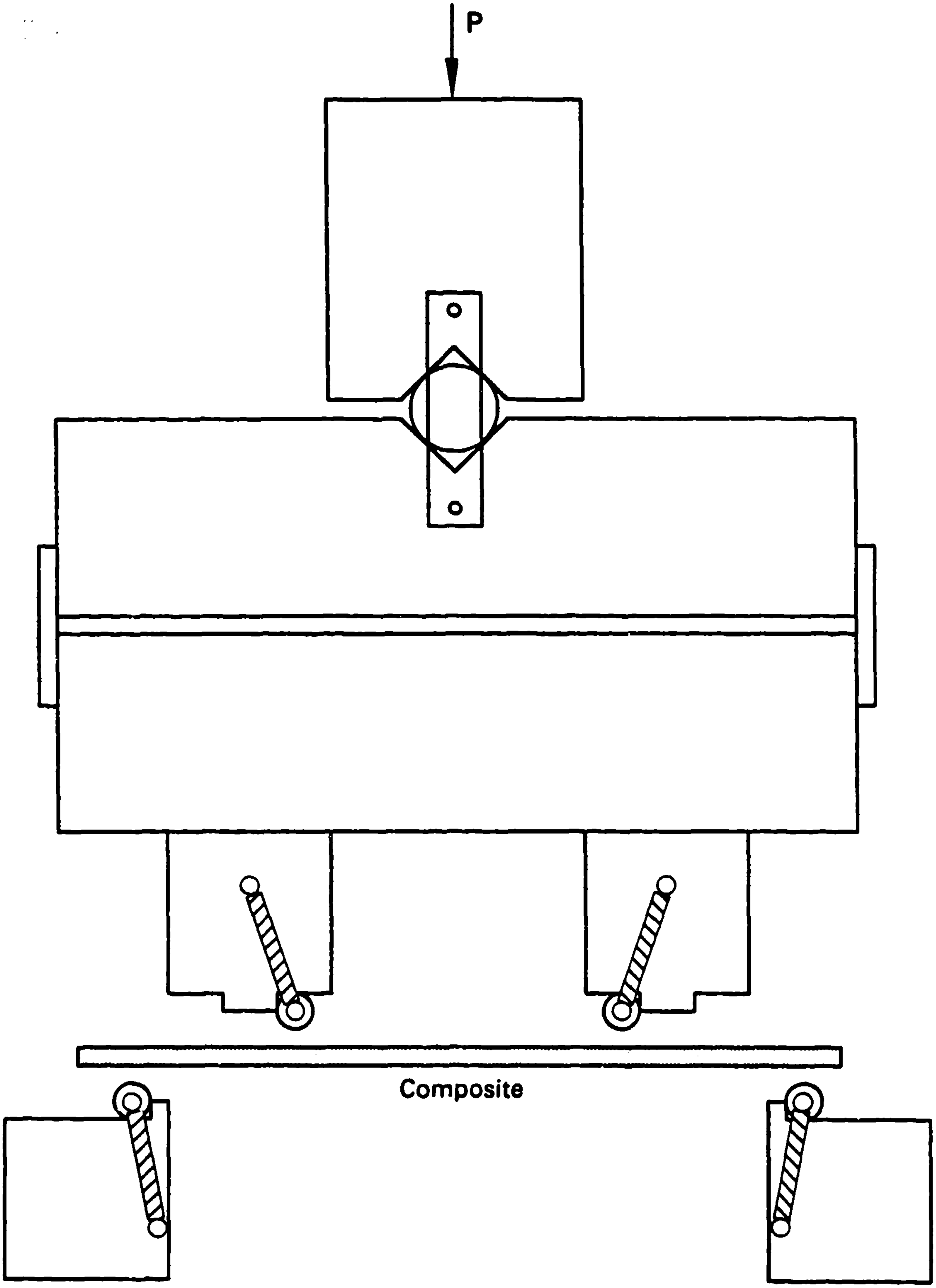


Figure B-1: Four Point Bend Fixture

ULTRASONIC TESTING

- Insure integrity of panels
- Evaluate damage caused by paint removal
- Have hardcopy record of test (C-scan)

Figure B-2
Ultrasonic Testing of Panel 22882-7-1B

Flexure and Shear Test Results
Test 23882-7, Panels 1 and 2
Abrasive Paint Removal

Initial mechanical tests to evaluate the effects of abrasion and testing configuration on graphite/epoxy laminates has been completed. The laminate layup was [0/0/90/+45/-45/90/+45/-45]s. Two panels were cut in half and one of the halves of each panel was abraded using a circular sander. The panels were then cut into flexure and shear specimens. In all cases the abraded or control surface was opposite the labeled surface. Care was taken to make sure that comparable specimens were symmetrical about the panel cut line since this was shown by the ultrasonic tests to also be a line of symmetry with regard to voids.

The results of the flexure tests are shown in Table B-1. All flexure specimens failed in compression as expected. A span to depth ratio of 40 was used to insure the proper failure mode. Earlier tests showed that a ratio of only 30 allowed some shear failures which is unacceptable. The crosshead deflection (cross. defl.) is the deflection at the 1/4 span of the specimen. The center deflection can be calculated and is 1.375 times the measured deflection. The reference load (ref. load) is used only to calculate the bending stiffness. The data is very consistent within each category, tension or compression and abraded or not. The strength and stiffness of the abraded specimens appears to increase, however this is partly due to the decrease in specimen depth. Table B-2 shows the average strength and stiffness for each category normalized to the initial average depth of 0.0798 inches. All the normalized average strength values for each category are within a narrow range of plus or minus 5 percent of the total average excluding the abraded specimens in compression which are higher by 20 percent. The normalized bending stiffness is very consistent for all categories.

Two conclusions can be made from the above discussion. First, testing specimens with the abraded or control surface in compression is desirable since it places the surface in question in the failure location. Secondly, the abrading process increased the strength of the material at the surface but not the stiffness. The increase in strength may have been caused by several mechanisms; relieving of residual stresses by plastic flow, change in matrix chemistry, or elimination of surface defects which initiate failure. The consistency of the stiffness data indicates that no fiber damage was caused during sanding. Examination of the specimens shows that the bleed cloth pattern is still visible indicating that only the resin rich surface was affected.

The results of the shear tests are shown in Table B-3. There seems to be no appreciable difference in the average failure stress of specimens from the same panel half tested with the control or abraded surface in either tension or compression. The average stress of the abraded specimens is 8 percent higher than the control group even when normalized by a constant thickness. This difference is not large when compared to the scatter in data, however may still be significant. It was not expected that a difference would occur since shear failure is not greatly affected by surface conditions. Examination of the failure mode and location showed shear failure in all specimens at relatively consistent ply location.

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	*
F1A-1	0.8256	0.0792	270	0.2510	165	121.5	11.0	T
F1A-2	0.9989	0.0797	355	0.2707	205	130.0	11.1	T
F1A-3	0.9975	0.0803	375	0.2854	215	135.2	11.4	C
F1A-4	0.9964	0.0807	380	0.2854	210	135.8	11.0	C
F1A-5	0.9925	0.0798	370	0.2879	205	135.8	11.2	C
F1B-1	0.9979	0.0785	430	0.3396	210	161.3	11.9	C
F1B-2	0.9976	0.0783	440	0.3494	215	165.7	12.3	C
F1B-3	0.9973	0.0773	440	0.3691	205	169.8	12.2	C
F1B-4	0.9996	0.0765	355	0.2904	195	140.9	12.0	T
F1B-5	0.9958	0.0761	345	0.2805	195	139.1	12.2	T
F2A-1	0.9900	0.0792	350	0.2657	205	131.1	11.4	T
F2A-2	0.9959	0.0794	340	0.2559	205	126.1	11.3	T
F2A-3	0.9961	0.0794	360	0.2805	200	133.1	11.0	C
F2A-4	0.9978	0.0803	355	0.2756	200	128.1	10.6	C
F2A-5	0.9977	0.0800	375	0.2757	210	136.4	11.3	C
F2B-1	0.9899	0.0768	365	0.2904	200	145.1	12.2	C
F2B-2	0.9957	0.0771	440	0.3691	210	171.0	12.6	C
F2B-3	0.9976	0.0764	430	0.3445	200	170.4	12.3	C
F2B-4	0.9930	0.0768	355	0.2805	200	140.9	12.2	T
F2B-5	0.9973	0.0749	310	0.2559	195	129.2	12.8	T

* T - control or abraded surface in tension
C - control or abraded surface in compression

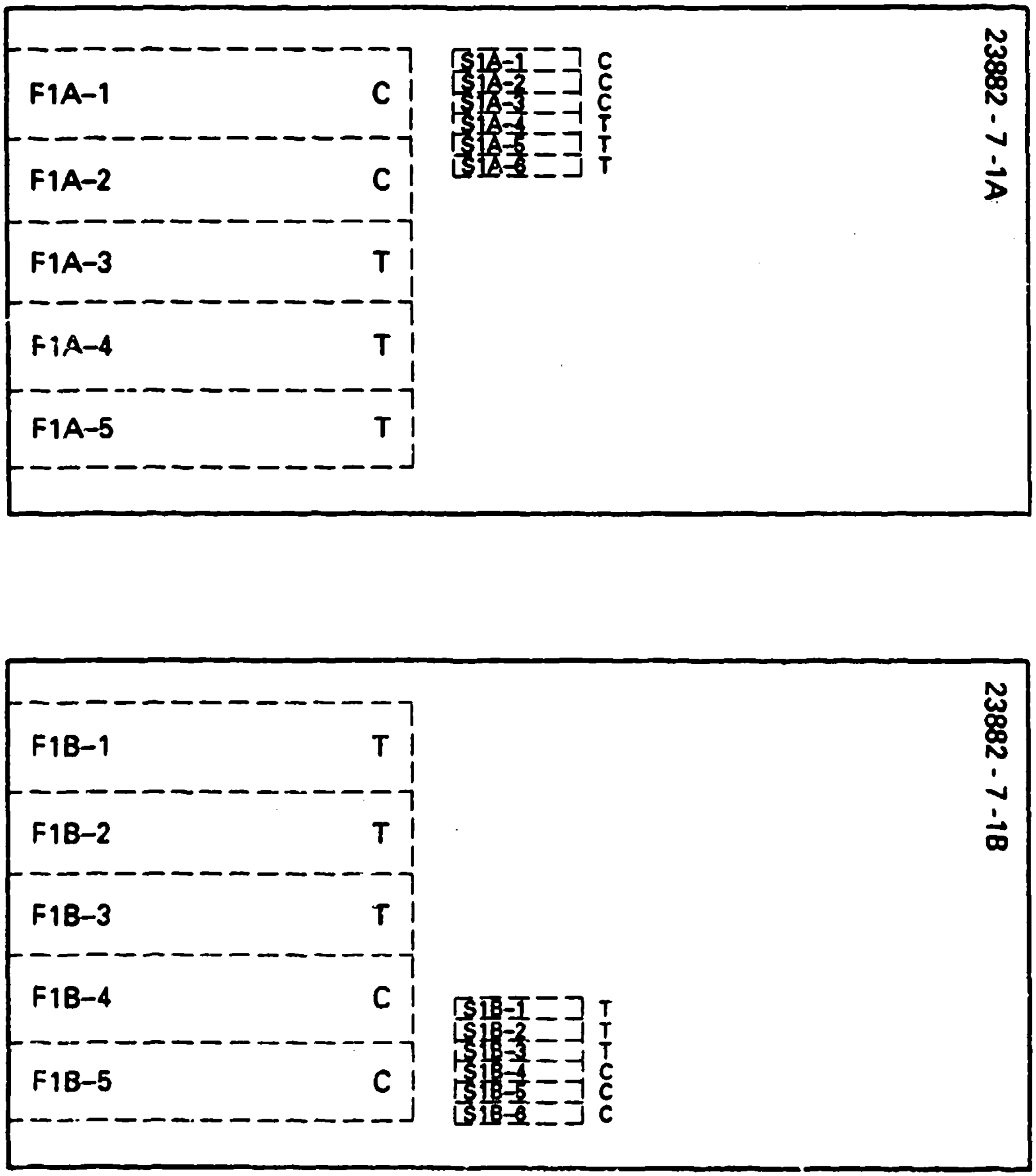
note: Panels 1B and 2B were abraded.

Table B-1
Test 23882-7, Raw Flexure Data

specimen number		*	failure stress d=actual	 d=normal.	bending stiff. d=actual	 d=normal.
			(ksi)		(msi)	
F1A	control	T	125.8	125.8	11.1	11.1
F1A	control	C	135.6	135.6	11.2	11.2
F1B	abraded	T	140.0	127.8	12.1	11.0
F1B	abraded	C	165.6	158.3	12.1	11.0
F2A	control	T	128.6	128.6	11.4	11.4
F2A	control	C	132.5	132.5	11.0	11.0
F2B	abraded	T	135.1	122.2	12.5	10.8
F2B	abraded	C	162.2	150.0	12.4	11.1

* T - control or abraded surface in tension
C - control or abraded surface in compression

Table B-2
Test 23882-7, Normalized Flexure Data



C = Label side tested in compression

T = Label side tested in tension

Figure B-3: Test Specimen Layout for 23882 - 7

specimen number	width (in.)	depth (in.)	failure load (lbs.)	failure stress (psi)	*	average stress (psi) d-actual	d-normal.
S1A-1	0.2493	0.0798	169	6371	T		
S1A-2	0.2502	0.0787	153	5828	T	6043	5975
S1A-3	0.2455	0.0783	152	5931	T		
S1A-4	0.2493	0.0786	174	6660	C		
S1A-5	0.2486	0.0789	158	6041	C	6373	6301
S1A-6	0.2491	0.0793	169	6417	C		
S1B-1	0.2507	0.0794	167	6292	C		
S1B-2	0.2473	0.0795	176	6714	C	6528	6512
S1B-3	0.2426	0.0799	170	6578	C		
S1B-4	0.2482	0.0796	184	6985	T		
S1B-5	0.2438	0.0793	177	6866	T	6850	6807
S1B-6	0.2455	0.0789	173	6699	T		
S2A-1	0.2498	0.0756	148	5878	T		
S2A-2	0.2488	0.0779	167	6462	T	6240	6060
S2A-3	0.2452	0.0791	165	6380	T		
S2A-4	0.2474	0.0793	175	6690	C		
S2A-5	0.2469	0.0798	162	6167	C	6288	6272
S2A-6	0.2475	0.0797	158	6007	C		
S2B-1	0.2499	0.0800	190	7128	C		
S2B-2	0.2426	0.0790	168	6574	C	6877	6825
S2B-3	0.2438	0.0786	177	6928	C		
S2B-4	0.2487	0.0784	180	6924	T		
S2B-5	0.2452	0.0781	167	6540	T	6580	6440
S2B-6	0.2427	0.0778	158	6276	T		

* T - control or abraded surface in tension
C - control or abraded surface in compression

Table B-3
Test 23882-7, Shear Data

TEST RESULTS - 23882-7
tension vs. compression

- o All flexure specimens failed in compression
- o All ILS specimens failed in shear
- o Significant increase in strength of flexure specimens with abraded surface in compression
  - relief of residual stresses
  - change in matrix chemistry
  - elimination of surface defects which initiate failure
  - elimination of surface defects allowing less specimen to fixture friction
- o Slight increase in strength of abraded ILS specimens

FLEXURE - TENSION VS. COMPRESSION

o Concluded that best to test surface of interest in compression

  - Most flexure specimens fail in compression
  - Damaged fibers in compression will cause early failure
  - Damaged matrix will allow fibers in compression to buckle
  - Damaged matrix will not affect fibers in tension

Flexure and Shear Test Results
Test 60882-10
Abrasive Paint Removal (to Damage)

Results are presented in the attached tables of mechanical tests performed to evaluate the effects of specimen surface conditions. Four surface conditions were investigated, all from the same panel:

60882-10-2	-A	uncoated panel
	-B	primed and top coated
	-C	-B and abraded
	-D	-C with new primer and top coat

In all cases the surface of interest was tested in compression. Table B-4 shows the flexure data. Table B-5 summarizes the flexure data for the actual thickness and a normalized thickness which is the average thickness of the control group, F2A. The normalization allows the comparison of total load bearing and stiffness capability. The normalized values will be used in the following discussion. As observed in earlier tests, the abraded specimens, F2C and F2D, were stronger than the control group, but only by a small amount. Also, the painted surface caused an increase in strength as can be seen by comparing F2A to F2B and F2C to F2D. The failure mode in some of the painted specimens was tension which was not seen in unpainted specimens in this or previous tests. The specimens which had identical surfaces, F2B and F2D, exhibited the expected results of the abraded specimens having a lower strength. The stiffness results were very consistent showing both abraded groups, F2C and F2D, to be less stiff than the unabraded groups, F2A and F2B. There was no significant affect of the paint.

Interlaminar shear test results are shown in Table B-6. Overall, the normalized strengths are fairly uniform as would be expected since shear strength should not be affected by the surface conditions.

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
F2A-1	0.9951	0.0786	385	0.2953	205	145.2	11.6	C
F2A-2	0.9954	0.0803	390	0.3002	210	140.9	11.2	C
F2A-3	0.9955	0.0801	400	0.3002	210	145.2	11.3	C
F2A-4	0.9930	0.0793	390	0.3223	200	144.3	11.1	C
F2B-1	0.9936	0.0807	405	0.3150	205	144.6	10.8	C
F2B-2	0.9965	0.0820	455	0.3691	210	155.7	10.5	T
F2B-3	0.9989	0.0821	455	0.4134	205	154.1	10.2	T
F2B-4	0.9960	0.0823	465	0.4035	210	157.6	10.4	T
F2C-1	0.9972	0.0761	380	0.3543	185	151.7	11.6	C
F2C-2	0.9944	0.0763	410	0.4035	185	162.3	11.5	C
F2C-3	0.9955	0.0783	430	0.3740	200	162.0	11.5	C
F2C-4	0.9966	0.0763	390	0.3666	190	154.7	11.8	C
F2D-1	0.9974	0.0818	420	0.3888	195	144.0	9.8	T
F2D-2	0.9963	0.0829	455	0.4232	200	151.5	9.7	T
F2D-3	0.9964	0.0806	385	0.3716	185	136.5	9.7	C
F2D-4	0.9964	0.0778	250	0.2461	155	96.8	9.1	C

* T = tension failure
C = compression failure

Table B-4
Test 60882-10, Raw Flexure Data

specimen number		*	failure stress d-actual (ksi)	failure stress d-normal. (ksi)	bending stiff. d-actual (msi)	bending stiff. d-normal. (msi)
F2A	control	C	143.9	143.7	11.3	11.3
F2B	A painted	C	153.0	161.7	10.5	11.4
F2C	B abraded	C	157.7	146.4	11.6	10.4
F2D	C painted	C	144.0	152.2	9.7	10.5

* T - surface of interest in tension
C - surface of interest in compression

Table B-5
Test 60882-10, Normalized Flexure Data

specimen number	width (in.)	depth (in.)	failure load (lbs.)	failure stress (psi)	*	average stress (psi)	
						d=actual	d=normal.
S2A-1	0.2510	0.0774	178	6872	C	6976	6806
S2A-2	0.2512	0.0776	184	7079	C		
S2A-3	0.2500	0.0774	173	6707	C		
S2A-4	0.2517	0.0778	183	7010	C		
S2A-5	0.2494	0.0780	187	7210	C		
S2A-6	0.2531	0.0777	183	6980	C		
S2B-1	0.2527	0.0823	190	6857	C	6406	6748
S2B-2	0.2521	0.0809	191	7024	C		
S2B-3	0.2505	0.0968	183	5661	C		
S2B-4	0.2509	0.0816	148	5425	C		
S2B-5	0.2481	0.0818	188	6953	C		
S2B-6	0.2498	0.0816	177	6517	C		
S2C-1	0.2475	0.0749	138	5584	C	7187	6743
S2C-2	0.2517	0.0748	175	6977	C		
S2C-3	0.2502	0.0753	193	7690	C		
S2C-4	0.2508	0.0742	187	7537	C		
S2C-5	0.2502	0.0750	195	7794	C		
S2C-6	0.2513	0.0741	187	7538	C		
S2D-1	0.2506	0.0777	176	6783	C	6480	6373
S2D-2	0.2494	0.0777	167	6465	C		
S2D-3	0.2514	0.0792	189	7125	C		
S2D-4	0.2486	0.0776	155	6030	C		
S2D-5	0.2502	0.0792	182	6888	C		
S2D-6	0.2519	0.0784	147	5586	C		

* T = control or abraded surface in tension
C = control or abraded surface in compression

Table B-6
Test 60882-10, Shear Data

Flexure and Shear Test Results
Tests 60882-13-2 and -3
Wet Abrasive Paint Removal

Results are presented in the attached tables of mechanical tests performed to evaluate the effects of specimen surface conditions. Four surface conditions were investigated for each of two panels:

60882-13	-A	uncoated panel
	-B	primed and top coated
	-C	-B and paint removed
	-D	-C and new primer and top coat

In all cases the surface of interest was tested in compression. Table B-7 and B-8 show the flexure data for panels 60882-13-2 and -3, respectively. Table B-9 and B-10 summarize the flexure data for the actual thickness and a normalized thickness which is the average thickness of the control group, -A. The normalized data are useful in comparing the strength and stiffness results to the control group and will be used in the following discussion. As observed in previous tests, the abraded specimens, -C and -D, were stronger than the control group. Also, the painted surface caused an apparent increase in strength and in most cases stiffness as can be seen by comparing -A to -B and -C to -D. The failure mode in most of the painted specimens was tension whereas the unpainted specimens failed primarily in compression. For panel 60882-13-2, the specimens with painted surfaces, -B and -D, had very near the same strength indicating that no degradation occurred during paint removal. Unexpectedly, for panel 60882-13-3, there was an increase in strength of the -D specimens. This may be due to a 0.002 average increase in thickness of the -D specimens over the -B specimens if the increase was not due solely to the painting process. The strength and stiffness of panel 60882-13-3 specimens was higher than the comparable specimens in panel 60882-13-2 in all cases. This indicates that the manufacturing process is not consistent. As a whole, the results are consistent with previous tests with a few exceptions.

Interlaminar shear test results are shown in Table B-11 and B-12. Overall, the normalized strengths are fairly uniform as would be expected since shear strength should not be affected by the surface conditions. The strength of panel 60882-13-2 specimens was higher than the comparable specimens in panel 60882-13-3 in all cases. This is opposite the flexure data but not inconsistent since flexure and shear results are not related. However, the difference again indicates some processing inconsistencies.

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
F2A-1	1.0041	0.0758	350	0.3100	180	140.6	11.3	C
F2A-2	1.0039	0.0759	350	0.3150	180	140.2	11.3	C
F2A-3	0.9951	0.0760	345	0.3051	180	139.2	11.3	C
F2A-4	1.0035	0.0755	350	0.3100	180	142.0	11.5	C
F2B-1	1.0044	0.0790	435	0.4429	185	158.0	10.3	T
F2B-2	1.0036	0.0804	445	0.4380	195	156.1	10.3	T
F2B-3	1.0045	0.0801	380	0.3248	195	136.3	10.4	C
F2B-4	1.0040	0.0797	440	0.4380	190	157.3	10.3	T
F2C-1	1.0044	0.0746	380	0.3445	180	157.2	11.9	C
F2C-2	1.0042	0.0749	410	0.4331	180	166.4	11.7	C/T
F2C-3	1.0033	0.0741	410	0.3888	180	171.3	12.1	C
F2C-4	0.9958	0.0745	365	0.3445	175	152.8	11.7	C
F2D-1	1.0030	0.0794	445	0.4921	175	159.2	9.6	T
F2D-2	1.0010	0.0787	435	0.4872	180	158.9	10.1	T
F2D-3	0.9945	0.0800	420	0.4478	180	150.1	9.7	T
F2D-4	0.9995	0.0799	430	0.4528	180	153.2	9.7	T

* T = tension failure
C = compression failure

Table B-7
Test 60882-13-2, Raw Flexure Data

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
F3A-1	1.0023	0.0749	350	0.3199	185	144.1	12.1	C
F3A-2	1.0021	0.0740	350	0.3346	175	147.7	11.9	C
F3A-3	1.0034	0.0749	355	0.3199	185	146.0	12.0	C
F3A-4	1.0008	0.0753	360	0.3346	175	146.8	11.3	C
F3B-1	1.0015	0.0785	435	0.4675	185	160.3	10.5	T
F3B-2	0.9943	0.0793	415	0.3986	185	152.1	10.3	T
F3B-3	0.9989	0.0792	435	0.4528	185	158.1	10.2	T
F3B-4	1.0016	0.0787	425	0.4281	190	156.5	10.7	T
F3C-1	1.0023	0.0753	395	0.3839	180	160.0	11.6	C
F3C-2	1.0019	0.0754	410	0.4429	180	164.3	11.5	C
F3C-3	1.0034	0.0759	415	0.3986	185	164.7	11.6	C
F3C-4	1.0012	0.0759	410	0.4232	180	162.8	11.3	C
F3D-1	0.9975	0.0797	445	0.4823	185	159.1	10.1	T
F3D-2	0.9885	0.0806	445	0.4380	185	157.7	9.8	T
F3D-3	1.0005	0.0812	445	0.4232	195	153.7	10.0	T
F3D-4	1.0005	0.0812	450	0.4380	190	155.2	9.7	T

* T = tension failure
C = compression failure

Table B-8
Test 60882-13-3, Raw Flexure Data

specimen number		*	failure stress d-actual (ksi)	d-normal.	bending stiff. d-actual (msi)	d-normal.
F2A	control	C	140.5	140.4	11.4	11.3
F2B	A painted	C	151.9	168.7	10.3	12.0
F2C	B removed	C	161.9	156.3	11.9	11.3
F2D	C painted	C	155.4	171.3	9.8	11.3

* T - surface of interest in tension
C - surface of interest in compression

Table B-9
Test 60882-13-2, Normalized Flexure Data

specimen number		*	failure stress d-actual (ksi)	failure stress d-normal. (ksi)	bending stiff. d-actual (msi)	bending stiff. d-normal. (msi)
F3A	control	C	146.2	146.0	11.8	11.8
F3B	A painted	C	156.8	174.8	10.4	12.2
F3C	B removed	C	163.0	166.5	11.5	11.9
F3D	C painted	C	156.4	182.7	9.9	12.5

* T - surface of interest in tension
C - surface of interest in compression

Table B-10
Test 60882-13-3, Normalized Flexure Data

specimen number	width (in.)	depth (in.)	failure load (lbs.)	failure stress (psi)	*	average stress d-actual (psi)	d-normal.
S2A-1	0.2463	0.0747	169	6895	C		
S2A-2	0.2510	0.0748	175	6997	C		
S2A-3	0.2458	0.0742	171	7032	C	6541	6441
S2A-4	0.2519	0.0745	147	5875	C		
S2A-5	0.2482	0.0746	154	6242	C		
S2A-6	0.2507	0.0752	156	6207	C		
S2B-1	0.2534	0.0770	172	6613	C		
S2B-2	0.2505	0.0762	172	6763	C		
S2B-3	0.2447	0.0760	137	5530	C	6493	6622
S2B-4	0.2526	0.0773	180	6915	C		
S2B-5	0.2496	0.0786	176	6728	C		
S2B-6	0.2509	0.0788	169	6412	C		
S2C-1	0.2522	0.0719	110	4550	C		
S2C-2	0.2508	0.0747	156	6246	C		
S2C-3	0.2521	0.0733	167	6784	C	6270	6095
S2C-4	0.2431	0.0730	138	5833	C		
S2C-5	0.2497	0.0743	174	7039	C		
S2C-6	0.2497	0.0750	179	7169	C		
S2D-1	0.2568	0.0795	185	6796	C		
S2D-2	0.2559	0.0784	187	6991	C		
S2D-3	0.2580	0.0776	168	6293	C	6291	6553
S2D-4	0.2553	0.0796	159	5868	C		
S2D-5	0.2563	0.0797	168	6168	C		
S2D-6	0.2549	0.0789	151	5631	C		

* T - control or abraded surface in tension
C - control or abraded surface in compression

Table B-11
Test 60882-13-2, Shear Data

specimen number	width (in.)	depth (in.)	failure load (lbs.)	failure stress (psi)	*	average stress d-actual (psi)	average stress d-normal. (psi)
S3A-1	0.2514	0.0751	156	6202	C		
S3A-2	0.2522	0.0751	123	4875	C		
S3A-3	0.2499	0.0744	152	6137	C	6101	6098
S3A-4	0.2476	0.0749	171	6917	C		
S3A-5	0.2521	0.0745	150	5994	C		
S3A-6	0.2523	0.0748	163	6483	C		
S3B-1	0.2519	0.0775	177	6806	C		
S3B-2	0.2527	0.0782	142	5389	C		
S3B-3	0.2462	0.0766	153	6085	C	5808	6044
S3B-4	0.2521	0.0786	163	6173	C		
S3B-5	0.2501	0.0781	153	5880	C		
S3B-6	0.2485	0.0782	117	4516	C		
S3C-1	0.2505	0.0762	138	5423	C		
S3C-2	0.2512	0.0752	145	5757	C		
S3C-3	0.2452	0.0752	159	6472	C	5877	5976
S3C-4	0.2514	0.0769	141	5471	C		
S3C-5	0.2512	0.0768	160	6224	C		
S3C-6	0.2431	0.0762	146	5912	C		
S3D-1	0.2562	0.0814	167	6006	C		
S3D-2	0.2558	0.0812	182	6572	C		
S3D-3	0.2554	0.0812	158	5714	C	5818	6328
S3D-4	0.2547	0.0812	155	5621	C		
S3D-5	0.2560	0.0816	170	6104	C		
S3D-6	0.2556	0.0816	136	4890	C		

* T = control or abraded surface in tension
C = control or abraded surface in compression

Table B-12
Test 60882-13-3, Shear Data

Flexure and Shear Test Results
Tests 60882-15-1 and -2
Bicarbonate Blast

Results are presented in the attached tables of mechanical tests performed to evaluate the effects of paint removal methods. Four surface conditions were investigated for each of two panels. Note that the specimen lettering sequence is different from previous tests, however the data is presented in the same order as before.

60882-15	-B	uncoated panel (control)
	-A	primed and top coated
	-D	-A and paint removed
	-C	-D and new primer and top coat

In all cases the surface of interest was tested in compression. Tables B-13 and B-14 show the flexure data for panels 60882-15-1 and -2, respectively. Tables B-15 and B-16 summarize the flexure data for the actual thickness and a normalized thickness which is the average thickness of the control group. The normalized data are useful in comparing the strength and stiffness values to the control group. The data generally follows previous observations. A shear mode of failure was observed for two painted specimens from panel 60882-15-2.

Scanning electron microscopy (SEM) was used to evaluate the surface condition of each group within panel 60882-15-1 and -2. SEM was also used to evaluate panel 60882-13-2 which was stripped using a rotary sander. A description of the observations follows:

60882-15-1	-B	Relatively resin rich with peel ply pattern visible.
	-A	Bumpy but uniform and no large peaks or valleys. Some areas flat and cracked.
	-D	Rough with jagged appearance, uniform. (stripped to primer)
	-C	Similar to -A but rougher and some fiber particles.
60882-15-2	-D	Fibers clearly visible (stripped to laminate). Minimal matrix damage although significant removal. No fiber damage.
	-C	Almost identical to 15-1-A but slightly rougher. No flat cracked areas.
60882-13-2	-C	Very rough and non-uniform. Grooves visible. Minimal fiber damage.
	-D	Identical to 15-2-C.

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
F1B-1	1.0030	0.0762	370	0.3150	190	147.1	11.7	C
F1B-2	0.9930	0.0766	380	0.3150	195	151.0	12.0	C
F1B-3	0.9985	0.0773	380	0.3199	195	147.3	11.6	C
F1B-4	1.0030	0.0763	390	0.3051	205	154.8	12.6	C
F1A-1	1.0034	0.0790	445	0.4281	190	162.1	10.5	T/C
F1A-2	1.0017	0.0803	445	0.3740	200	158.1	10.6	T/C
F1A-3	1.0010	0.0789	430	0.5315	190	155.4	10.6	T
F1A-4	1.0023	0.0793	450	0.4823	190	161.7	10.4	C
F1D-1	1.0035	0.0747	390	0.3543	185	160.7	12.1	C
F1D-2	0.9958	0.0746	380	0.3100	190	159.0	12.6	C
F1D-3	0.9990	0.0744	385	0.3248	190	161.2	12.7	C
F1D-4	0.9963	0.0737	365	0.2953	195	156.7	13.4	C
F1C-1	1.0006	0.0790	460	0.4675	190	167.2	10.6	T
F1C-2	0.9940	0.0799	450	0.4724	185	160.8	10.0	T
F1C-3	1.0007	0.0781	450	0.4724	185	167.4	10.6	T
F1C-4	0.9977	0.0775	440	0.4872	185	166.5	10.9	T

* T - tension failure
C - compression failure

Table B-13
Test 60882-15-1, Raw Flexure Data

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
F2B-1	1.0052	0.0736	375	0.3297	185	159.4	12.7	C
F2B-2	1.0040	0.0736	350	0.3051	185	149.4	12.7	C
F2B-3	1.0058	0.0751	345	0.2904	185	141.3	11.9	C
F2B-4	1.0010	0.0738	350	0.3100	180	148.9	12.3	C
F2A-1	1.0042	0.0765	430	0.4183	185	167.4	11.3	C
F2A-2	1.0035	0.0760	430	0.4577	180	169.0	11.2	C/S
F2A-3	1.0038	0.0764	410	0.3494	185	161.4	11.3	C
F2A-4	1.0009	0.0761	390	0.3691	185	154.8	11.5	C
F2D-1	0.9979	0.0731	410	0.3789	190	177.0	13.4	C
F2D-2	testing problem							
F2D-3	1.0035	0.0733	400	0.3642	180	171.1	12.5	C
F2D-4	1.0035	0.0721	380	0.3543	180	168.3	13.1	C
F2C-1	1.0031	0.0778	455	0.4626	195	170.4	11.3	T
F2C-2	1.0033	0.0767	425	0.3986	185	165.1	11.2	C/S
F2C-3	1.0010	0.0767	465	0.4577	195	179.8	11.8	T
F2C-4	1.0026	0.0761	420	0.4331	180	165.2	11.2	T

* T - tension failure
C - compression failure
S - shear failure

Table B-14
Test 60882-15-2, Raw Flexure Data

specimen number		*	failure stress d-actual	d-normal.	bending stiff. d-actual	d-normal.
			(ksi)		(msi)	
F1B	control	C	150.1	150.1	12.0	12.0
F1A	B painted	C	159.3	171.4	10.5	11.7
F1D	A removed	C	159.4	150.0	12.7	11.6
F1C	D painted	C	165.5	174.6	10.5	11.4

* T - surface of interest in tension
C - surface of interest in compression

Table B-15
Test 60882-15-1, Normalized Flexure Data

specimen number		*	failure stress d-actual (ksi)	failure stress d-normal.	bending stiff. d-actual (msi)	bending stiff. d-normal.
F2B	control	C	149.7	149.8	12.4	12.4
F2A	B painted	C	163.1	173.5	11.3	12.4
F2D	A removed	C	172.1	166.7	13.0	12.4
F2C	D painted	C	170.1	183.7	11.4	12.8

* T - surface of interest in tension
C - surface of interest in compression

Table B-16
Test 60882-15-2, Normalized Flexure Data

specimen number	width (in.)	depth (in.)	failure load (lbs.)	failure stress (psi)	*	average stress d-actual (psi)	d-normal.
S1B-1	0.2314	0.0766	165	6982	C		
S1B-2	0.2305	0.0761	139	5943	C		
S1B-3	0.2313	0.0755	156	6700	C	7148	7145
S1B-4	0.2303	0.0770	172	7275	C		
S1B-5	0.2303	0.0775	190	7984	C		
S1B-6	0.2321	0.0767	190	8005	C		
S1A-1	0.2299	0.0776	160	6726	C		
S1A-2	0.2308	0.0775	156	6541	C		
S1A-3	0.2310	0.0786	176	7270	C	6548	6675
S1A-4	0.2300	0.0782	157	6547	C		
S1A-5	0.2317	0.0782	150	6209	C		
S1A-6	0.2314	0.0784	145	5994	C		
S1D-1	0.2307	0.0759	178	7624	C		
S1D-2	0.2298	0.0767	178	7574	C		
S1D-3	0.2295	0.0759	177	7621	C	7642	7597
S1D-4	0.2293	0.0763	183	7845	C		
S1D-5	0.2299	0.0764	186	7942	C		
S1D-6	0.2297	0.0757	168	7246	C		
S1C-1	0.2294	0.0795	147	6045	C		
S1C-2	0.2310	0.0797	168	6844	C		
S1C-3	0.2302	0.0805	153	6192	C	6564	6777
S1C-4	0.2300	0.0780	138	5769	C		
S1C-5	0.2316	0.0778	164	6826	C		
S1C-6	0.2316	0.0790	188	7706	C		

* T - control or abraded surface in tension
C - control or abraded surface in compression

Table B-17
Test 60882-15-1, Shear Data

specimen number	width (in.)	depth (in.)	failure load (lbs.)	failure stress (psi)	*	average stress d=actual (psi)	d=normal.
S2B-1	0.2368	0.0753	172	7235	C		
S2B-2	0.2364	0.0749	185	7836	C		
S2B-3	0.2368	0.0745	184	7822	C	7493	7611
S2B-4	0.2360	0.0755	174	7324	C		
S2B-5	0.2367	0.0755	166	6967	C		
S2B-6	0.2370	0.0753	185	7775	C		
S2A-1	0.2460	0.0786	183	7098	C		
S2A-2	0.2473	0.0781	195	7572	C		
S2A-3	0.2452	0.0774	177	6995	C	7112	7519
S2A-4	0.2371	0.0788	158	6343	C		
S2A-5	0.2363	0.0782	175	7103	C		
S2A-6	0.2356	0.0783	186	7562	C		
S2D-1	0.2368	0.0743	169	7204	C		
S2D-2	0.2370	0.0744	187	7954	C		
S2D-3	0.2365	0.0738	177	7606	C	7491	7491
S2D-4	0.2370	0.0739	168	7194	C		
S2D-5	0.2353	0.0740	176	7581	C		
S2D-6	0.2367	0.0736	172	7405	C		
S2C-1	0.2363	0.0776	177	7240	C		
S2C-2	0.2382	0.0788	185	7392	C		
S2C-3	0.2372	0.0797	185	7339	C	7271	7708
S2C-4	0.2366	0.0775	181	7403	C		
S2C-5	0.2371	0.0787	191	7677	C		
S2C-6	0.2357	0.0784	162	6575	C		

* T = control or abraded surface in tension
C = control or abraded surface in compression

Table B-18
Test 60882-15-2, Shear Data

Flexure and Shear Test Results
Tests 60882-15-7 and -9
Excimer Laser Paint Removal

Results are presented in the attached tables of mechanical tests performed to evaluate the effects of paint removal methods. Four surface conditions were to be investigated for each of two panels, however, configuration "C" was painted and thus was not available for testing.

60882-15-	-A	uncoated panel (control)
	-B	primed and top coated
	-C	-B and paint removed
	-D	-C and new primer and top coat

In all cases the surface of interest was tested in compression. Tables B-19 and B-20 show the flexure data for panels 60882-15-7 and -9, respectively. Tables B-21 and B-22 summarize the flexure data for the actual thickness and a normalized thickness which is the average thickness of the control group. The normalized data are useful in comparing the strength and stiffness values to the control group. The data generally follows previous observations.

The material that was suppose to be configuration "C" has been sent to Aerospace Testing Laboratory for use in checking their ultrasonic inspection setup for future tests.

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
F7A-1	1.0000	0.0785	380	0.3125	200	142.7	11.3	C
F7A-2	1.0000	0.0790	385	0.3051	205	142.8	11.4	C
F7A-3	1.0001	0.0785	380	0.3002	205	142.9	11.6	C
F7A-4	1.0001	0.0795	390	0.3076	205	142.8	11.2	C
F7B-1	1.0035	0.0810	475	0.4577	205	163.7	10.5	T
F7B-2	1.0035	0.0810	480	0.3986	210	166.7	10.8	C/S
F7B-3	0.9995	0.0805	480	0.4257	205	168.9	10.8	C
F7B-4	1.0035	0.0798	470	0.4380	200	167.5	10.8	T
F7C-1	no test	0.0000	0	0.0000	0	ERR	ERR	
F7C-2	no test	0.0000	0	0.0000	0	ERR	ERR	
F7C-3	no test	0.0000	0	0.0000	0	ERR	ERR	
F7C-4	no test	0.0000	0	0.0000	0	ERR	ERR	
F7D-1	1.0025	0.0837	485	0.4724	210	156.1	9.8	T
F7D-2	1.0000	0.0830	495	0.4478	210	163.1	10.1	C/S
F7D-3	1.0025	0.0823	470	0.4232	200	157.6	9.8	T/C
F7D-4	1.0000	0.0818	450	0.3839	195	154.0	9.8	T

* T - tension failure
C - compression failure
S - shear failure

Table B-19
Test 60882-15-7, Raw Flexure Data

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
F9A-1	0.9995	0.0765	375	0.3100	190	148.5	11.7	C
F9A-2	0.9895	0.0765	375	0.3150	190	149.9	11.8	C
F9A-3	0.9905	0.0765	365	0.3002	195	146.0	12.1	C
F9A-4	0.9980	0.0768	360	0.2904	195	142.0	11.8	C
F9B-1	0.9985	0.0788	475	0.4478	200	174.4	11.2	C/S
F9B-2	1.0015	0.0788	420	0.3494	195	155.6	10.9	C
F9B-3	1.0000	0.0797	450	0.4183	200	161.7	10.8	C
F9B-4	1.0010	0.0800	405	0.3292	200	145.9	10.7	C
F9C-1	no test	0.0000	0	0.0000	0	ERR	ERR	
F9C-2	no test	0.0000	0	0.0000	0	ERR	ERR	
F9C-3	no test	0.0000	0	0.0000	0	ERR	ERR	
F9C-4	no test	0.0000	0	0.0000	0	ERR	ERR	
F9D-1	0.9990	0.0812	460	0.4158	200	159.3	10.3	T/C
F9D-2	1.0010	0.0815	430	0.3765	195	148.2	9.9	C
F9D-3	0.9900	0.0817	495	0.4528	205	170.0	10.4	C/S
F9D-4	1.0000	0.0810	480	0.4528	200	166.1	10.3	T

* T - tension failure
C - compression failure
S - shear failure

Table B-20
Test 60882-15-9, Raw Flexure Data

specimen number		*	failure stress (ksi) d-actual	failure stress (ksi) d-normal. 0.0775	bending stiff. (msi) d-actual	bending stiff. (msi) d-normal. 0.0775
F9A	control	C	142.8	148.0	11.4	12.0
F9B	A painted	C	166.7	180.6	10.7	12.0
F9C	B removed	C	no test	0.0	0.0	0.0
F9D	C painted	C	157.7	180.2	9.9	12.0

* T = surface of interest in tension
C = surface of interest in compression

Table B-21
Test 60882-15-7, Normalized Flexure Data

specimen number		*	failure stress (ksi) d-actual	failure stress (ksi) d-normal. 0.0761	bending stiff. (msi) d-actual	bending stiff. (msi) d-normal. 0.0761
F9A	control	C	146.6	148.5	11.9	12.1
F9B	A painted	C	159.4	173.4	10.9	12.4
F9C	B removed	C	no test	0.0	0.0	0.0
F9D	C painted	C	160.9	184.6	10.2	12.5

* T - surface of interest in tension
C - surface of interest in compression

Table B-22
Test 60882-15-9, Normalized Flexure Data

specimen number	width	depth	failure load	failure stress	*	average stress (psi)	
	(in.)	(in.)	(lbs.)	(psi)		d-actual	d-normal. 0.0775
S7A-1	0.2460	0.0765	190	7572	C	7250	7156
S7A-2	0.2465	0.0765	188	7477	C		
S7A-3	0.2460	0.0760	183	7341	C		
S7A-4	0.2465	0.0770	180	7113	C		
S7A-5	0.2430	0.0765	176	7101	C		
S7A-6	0.2460	0.0765	173	6895	C		
S7B-1	0.2460	0.0790	173	6676	C	7262	7340
S7B-2	0.2450	0.0785	175	6824	C		
S7B-3	0.2460	0.0775	190	7474	C		
S7B-4	0.2455	0.0790	180	6961	C		
S7B-5	0.2460	0.0785	191	7418	C		
S7B-6	0.2450	0.0775	208	8216	C		
S7C-1	no test	0.0000	0	ERR	C	ERR	ERR
S7C-2	no test	0.0000	0	ERR	C		
S7C-3	no test	0.0000	0	ERR	C		
S7C-4	no test	0.0000	0	ERR	C		
S7C-5	no test	0.0000	0	ERR	C		
S7C-6	no test	0.0000	0	ERR	C		
S7D-1	0.2445	0.0820	157	5873	C	6490	6881
S7D-2	0.2465	0.0820	173	6419	C		
S7D-3	0.2445	0.0820	163	6098	C		
S7D-4	0.2420	0.0825	202	7588	C		
S7D-5	0.2440	0.0830	182	6740	C		
S7D-6	0.2440	0.0815	165	6223	C		

* T = control or abraded surface in tension
C = control or abraded surface in compression

Table B-23
Test 60882-15-7, Shear Data

specimen number	width (in.)	depth (in.)	failure load (lbs.)	failure stress (psi)	*	average stress (psi) d=actual	d=normal. 0.0761
S9A-1	0.2215	0.0760	164	7307	C		
S9A-2	0.2195	0.0770	160	7100	C		
S9A-3	0.2175	0.0750	140	6437	C	6916	6884
S9A-4	0.2205	0.0765	152	6758	C		
S9A-5	0.2195	0.0750	152	6925	C		
S9A-6	0.2210	0.0750	154	6968	C		
S9B-1	0.2205	0.0780	153	6672	C		
S9B-2	0.2160	0.0785	156	6900	C		
S9B-3	0.2185	0.0790	159	6908	C	6980	7192
S9B-4	0.2200	0.0785	176	7643	C		
S9B-5	0.2205	0.0780	155	6759	C		
S9B-6	0.2185	0.0785	160	6996	C		
S9C-1	no test	0.0000	0	ERR	C		
S9C-2	no test	0.0000	0	ERR	C		
S9C-3	no test	0.0000	0	ERR	C	ERR	ERR
S9C-4	no test	0.0000	0	ERR	C		
S9C-5	no test	0.0000	0	ERR	C		
S9C-6	no test	0.0000	0	ERR	C		
S9D-1	0.2175	0.0820	164	6897	C		
S9D-2	0.2185	0.0815	169	7118	C		
S9D-3	0.2180	0.0810	160	6796	C	7108	7565
S9D-4	0.2205	0.0810	178	7475	C		
S9D-5	0.2205	0.0805	167	7056	C		
S9D-6	0.2220	0.0800	173	7306	C		

* T - control or abraded surface in tension
C - control or abraded surface in compression

Table B-24
Test 60882-15-9, Shear Data

Flexure and Shear Test Results
Tests 60882-1617
Optimized Biocarbonate Blasting

1617A =	Uncoated
1617B =	Coated
1617C =	Stripped
1617D =	Recoated

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
1617A-1	0.9980	0.0805	405	0.2804	225	145.3	11.9	C
1617A-2	0.9965	0.0802	410	0.2854	225	148.4	12.0	C
1617A-3	0.9945	0.0800	410	0.2903	223	149.3	12.0	C
1617A-4	0.9960	0.0790	395	0.2854	220	147.5	12.3	C
1617B-1	0.9980	0.0810	490	0.3937	220	171.2	11.4	T/C
1617B-2	0.9975	0.0815	495	0.3937	225	170.9	11.4	T/C
1617B-3	0.9990	0.0815	505	0.3592	230	174.8	11.7	C
1617B-4	0.9890	0.0815	445	0.3494	233	155.8	11.9	C
1617C-1	0.9960	0.0820	435	0.3002	228	150.3	11.4	C
1617C-2	0.9965	0.0825	425	0.2953	230	145.0	11.3	C
1617C-3	0.9985	0.0815	390	0.2805	218	136.4	11.1	C
1617C-4	0.9980	0.0810	405	0.2903	218	143.3	11.3	C
1617D-1	0.9930	0.0825	455	0.3445	215	154.8	10.6	C
1617D-2	0.9955	0.0840	460	0.3248	225	150.9	10.5	C
1617D-3	0.9950	0.0845	510	0.3494	240	164.8	11.0	C
1617D-4	0.9975	0.0835	475	0.3642	215	156.6	10.2	C

* T - tension failure
C - compression failure
S - shear failure

Table B-25
Test 60882-1617, Raw Flexure Data

specimen number	*	failure stress (ksi)		bending stiff. (msi)	
		d-actual	d-normal. 0.08	d-actual	d-normal. 0.08
1617A	C	147.6	147.3	12.0	12.0
1617B	C	168.2	174.1	11.6	12.2
1617C	C	143.8	150.3	11.3	12.0
1617D	C	156.8	171.7	10.5	12.0

* T - surface of interest in tension
C - surface of interest in compression

Table B-26
Test 60882-1617, Normalized Flexure Data

Key for Protective Coated Panels

Coated Panel No.	Composite Panel No.	Coating Name	Panel End Use
2A	25-4	Desoto, Clear	Abrasive
2B	25-3	Desoto, Clear	PMB
2C	21-4A	Desoto, Clear	Extra Testing
3A	21-3	Desoto, Yellow	Abrasive
3B	26-1	Desoto, Yellow	PMB
3C	21-4B	Desoto, Yellow	Extra Testing
4A	21-1	Hughes HRG3/A3	Abrasive
4B	21-2	Hughes HRG3/A3	PMB
4C	20-3	Hughes HRG3/A3	Extra Testing
5A	22-1	Lord, Chemglaze	Abrasive
5B	26-8	Lord, Chemglaze	PMB
5C	24-5A	Lord, Chemglaze	Extra Testing
5D	26-4	Lord, Chemglaze	Extra
6A	24-8	Pratt & Lambert	Abrasive
6B	24-10	Pratt & Lambert	PMB
6C	24-5B	Pratt & Lambert	Extra Testing
7A	22-2	Control, No PC	Abrasive
7B	20-1	Control, No PC	PMB
7C	25-1B	Control, No PC	Extra Testing
8A	26-3	3M Adh. Film	Abrasive
8B	26-5	3M Adh. Film	PMB
8C	22-3	3M Adh. Film	Extra Testing
9A	27-5	Hysol, Synskin	Abrasive
9B	27-6	Hysol, Synskin	PMB
9C	27-4	Hysol, Synskin	Extra Testing
9D	27-3	Hysol, Synskin	Extra Panel
10A	27-1	Hysol Adh. Film	Abrasive
10B	27-7	Hysol Adh. Film	PMB
10C	27-2	Hysol Adh. Film	Extra Testing

Figure B-4
Panels with Protective Coating for Evaluation Against Paint Removal Methods

[1] Primer Topcoat Unstripped Test as is - Mechanical Property Testing 0,%	[2] Protective Coating Primer Topcoat Unstripped Test as is - Mechanical Property Testing 0,1
[3] Protective Coating Primer Topcoat Strip Once Reprime & Topcoat - for Mechanical Property Testing 1,2	[4] Protective Coating Primer Topcoat Strip Once Do <u>not</u> recoat - for coating tests 1,1
[5] Protective Coating Primer Topcoat Strip Twice Reprime & Topcoat - for Mechanical Property Testing 2,3	[6] Protective Coating Primer Topcoat Strip Three Times Reprime & Topcoat - for Mechanical Property Testing 3,4
[7] Protective Coating Primer Topcoat Strip Four Times Do <u>not</u> recoat - for coating tests 4,4	[8] Protective Coating Primer Topcoat Strip Four Times Reprime & Topcoat - for coating tests 4,5
[9] Protective Coating Primer Topcoat for coating tests 0.1	

*Number in lower right hand corner indicates the number of paint removal cycles, and the number of times painted.

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
2A2-1	0.9980	0.0879	495	0.3691	225	146.7	9.1	T
2A2-2	0.9900	0.0884	525	0.3691	240	155.1	9.6	C
2A2-3	1.0010	0.0878	523	0.3937	225	154.4	9.1	C
2A2-4	0.9950	0.0888	535	0.3937	230	155.3	9.1	T
2A2-5	0.9975	0.0885	507	0.3986	228	147.7	9.0	T
2A3-1	0.9870	0.0894	510	0.3863	230	147.3	8.9	C
2A3-2	1.0020	0.0898	560	0.4527	240	156.4	9.1	T
2A3-3	1.0010	0.0898	540	0.3814	240	152.5	9.1	T
2A3-4	1.0000	0.0893	580	0.4035	250	165.3	9.6	T
2A3-5	1.0010	0.0891	550	0.3814	245	157.8	9.5	T
2B2-1	0.9985	0.0876	560	0.3789	255	166.9	10.4	T
2B2-2	1.0015	0.0896	560	0.3543	260	159.4	9.9	C
2B2-3	0.9990	0.0880	505	0.3199	255	150.2	10.3	C
2B2-4	1.0025	0.0883	540	0.3838	245	157.6	9.7	T
2B2-5	1.0030	0.0877	435	0.2805	240	130.5	9.7	C
2B3-1	0.9985	0.0905	560	0.3765	250	156.1	9.3	T
2B3-2	1.0005	0.0905	550	0.3543	250	153.5	9.3	C
2B3-3	1.0015	0.0912	575	0.3888	245	157.1	8.8	T
2B3-4	1.0030	0.0907	520	0.3297	255	144.6	9.4	C
2B3-5	1.0010	0.0911	575	0.3691	260	157.9	9.4	T

* T - tension failure
C - compression failure
S - shear failure

Table B-27
Raw Flexure Data, Tests 2A2, 2A3, 2B2, 2B3

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
3A2-1	1.0000	0.0928	560	0.3715	255	148.2	8.8	C
3A2-2	1.0015	0.0922	565	0.3740	260	151.2	9.1	T
3A2-3	0.9975	0.0918	555	0.3691	255	150.6	9.1	C
3A2-4	0.9995	0.0912	540	0.3691	245	148.2	8.9	C
3A2-5	1.0005	0.0906	545	0.3691	240	151.5	8.9	C
3A3-1	0.9990	0.0911	545	0.3838	240	149.7	8.7	T
3A3-2	1.0010	0.0934	610	0.3838	265	158.8	8.9	T
3A3-3	1.0015	0.0923	570	0.3838	255	152.0	8.9	T
3A3-4	1.0010	0.0913	550	0.3789	250	150.2	9.0	T
3A3-5	1.0020	0.0925	555	0.3642	260	147.7	9.0	T
3B2-1	0.9980	0.0924	560	0.3789	255	149.6	8.9	T
3B2-2	1.0025	0.0931	550	0.3434	250	144.8	8.5	T
3B2-3	1.0020	0.0927	585	0.3642	275	155.0	9.5	T
3B2-4	1.0000	0.0931	550	0.3346	260	145.3	8.8	C
3B2-5	0.9940	0.0936	565	0.3691	260	147.8	8.8	T
3B3-1	0.9960	0.0935	585	0.3740	270	153.0	9.1	T
3B3-2	1.0010	0.0936	610	0.4060	265	157.6	8.9	T
3B3-3	1.0035	0.0936	555	0.3814	245	143.6	8.2	T
3B3-4	1.0005	0.0[illegible]	610	0.3642	270	157.3	8.9	T
3B3-5	0.9960	0.0951	610	0.4011	265	153.4	8.5	T

* T - tension failure
C - compression failure
S - shear failure

Table B-28
Raw Flexure Data, Tests 3A2, 3A3, 3B2, 3B3

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
2A8-1	0.9970	0.0930	510	0.3494	245	135.2	8.4	C/S
2A8-2	0.9975	0.0912	485	0.3297	250	134.1	9.1	S
2A8-3	0.9955	0.0923	565	0.3838	255	151.6	8.9	T
2A8-4	0.9950	0.0908	560	0.3937	265	155.3	9.8	T
2A8-5	0.9955	0.0910	545	0.3789	255	150.7	9.3	S
2B8-1	0.9885	0.0967	490	0.3248	245	121.4	7.5	S
2B8-2	0.9970	0.0933	560	0.3789	248	146.8	8.4	C
2B8-3	0.9965	0.0933	575	0.3937	270	150.5	9.2	T
2B8-4	0.9975	0.0928	550	0.4035	248	145.2	8.5	T
2B8-5	0.9975	0.0928	545	0.3642	255	144.7	8.8	T
3A8-1	0.9835	0.0933	480	0.3149	243	128.8	8.3	C
3A8-2	0.9975	0.0923	570	0.4035	260	152.2	9.1	C
3A8-3	0.9970	0.0923	530	0.3691	250	142.3	8.8	T
3A8-4	0.9975	0.0920	540	0.3888	258	145.5	9.1	T
3A8-5	0.9980	0.0925	575	0.3789	263	153.3	9.1	T
3B8-1	0.9980	0.0983	515	0.3051	275	122.5	8.0	S
3B8-2	0.9945	0.0958	600	0.4035	263	148.8	8.3	S
3B8-3	0.9955	0.0957	570	0.3740	260	142.2	8.2	T
3B8-4	0.9970	0.0962	450	0.2707	255	112.6	7.9	C
3B8-5	0.9955	0.0962	535	0.3445	253	132.6	7.8	T/C/S

* T - tension failure
C - compression failure
S - shear failure

Note: All -1 specimens have an exposed edge

Table B-29
Raw Flexure Data, Tests 2A8, 2B8, 3A8, 3B8

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
4A2-1	1.0000	0.0898	480	0.3740	210	135.8	8.0	C
4A2-2	1.0005	0.0877	370	0.2436	220	111.8	8.9	C
4A2-3	0.9985	0.0879	445	0.3076	225	133.0	9.1	C
4A2-4	1.0005	0.0862	395	0.2854	200	122.9	8.6	C
4A2-5	1.0010	0.0863	345	0.2556	200	107.5	8.5	C
4A3-1	0.9980	0.0894	410	0.2707	225	119.0	8.7	C
4A3-2	1.0010	0.0890	535	0.3715	230	154.1	8.9	C
4A3-3	1.0010	0.0890	540	0.3937	225	155.1	8.7	C
4A3-4	1.0010	0.0887	490	0.3715	220	142.1	8.6	C
4A3-5	0.9990	0.0888	480	0.3838	215	138.9	8.4	C
4B2-1	0.9880	0.0934	550	0.3740	245	145.3	8.4	C
4B2-2	1.0005	0.0924	570	0.3642	255	152.3	8.9	C/T
4B2-3	1.0015	0.0917	555	0.3838	240	150.0	8.5	T
4B2-4	1.0010	0.0924	585	0.3863	265	155.7	9.2	T
4B2-5	1.0025	0.0916	480	0.3199	245	131.1	8.7	C
4B3-1	1.0000	0.0943	525	0.3445	250	134.9	8.2	S
4B3-2	1.0010	0.0957	610	0.3912	270	150.9	8.4	T
4B3-3	1.0005	0.0962	605	0.4035	255	147.9	7.9	T
4B3-4	1.0020	0.0960	595	0.3813	260	146.3	8.0	T
4B3-5	1.0015	0.0958	610	0.3888	270	150.6	8.4	T

* T = tension failure
C = compression failure
S = shear failure

Table B-30
Raw Flexure Data, Tests 4A2, 4A3, 4B2, 4B3

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
5A2-1	0.9950	0.0886	565	0.3592	260	165.5	10.3	C/S
5A2-2	1.0015	0.0884	535	0.3346	250	157.0	9.9	C
5A2-3	0.9980	0.0882	550	0.3592	245	162.1	9.8	C
5A2-4	1.0015	0.0883	540	0.3789	245	157.8	9.8	T
5A2-5	1.0020	0.0889	415	0.2411	240	121.8	9.4	C/S
5A3-1	0.9975	0.0888	555	0.3838	245	160.9	9.6	C
5A3-2	1.0020	0.0894	535	0.3543	250	152.9	9.6	C
5A3-3	1.0015	0.0895	565	0.3765	250	160.7	9.6	T
5A3-4	1.0015	0.0898	595	0.3937	255	167.7	9.6	T
5A3-5	1.0005	0.0889	435	0.2707	240	127.4	9.4	C
5B2-1	1.0015	0.0892	535	0.3494	255	154.1	9.9	C/S
5B2-2	1.0015	0.0887	530	0.3199	265	154.7	10.4	C/S
5B2-3	1.0020	0.0883	485	0.2854	260	143.5	10.3	C/S
5B2-4	1.0020	0.0891	520	0.3297	260	150.1	10.1	S
5B2-5	1.0000	0.0902	460	0.2780	245	130.7	9.2	C/S
5B3-1	0.9990	0.0920	470	0.2756	265	128.4	9.3	C
5B3-2	1.0013	0.0917	460	0.2854	265	126.1	9.4	C/S
5B3-3	1.0010	0.0927	490	0.2903	260	131.3	8.9	C/S
5B3-4	1.0020	0.0919	545	0.3445	265	147.4	9.4	C/S
5B3-5	1.0015	0.0923	510	0.3002	270	137.6	9.4	T

* T - tension failure
C - compression failure
S - shear failure

Table B-31
Raw Flexure Data, Tests 5A2, 5A3, 5B2, 5B3

TABLE 2

Wright Patterson - Flexure Specimens, Panel 4A8,4B8,5A8,5B8

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
4A8-1	0.9935	0.0913	420	0.3100	213	116.7	7.7	C
4A8-2	0.9990	0.0897	465	0.3838	203	131.8	7.7	T
4A8-3	0.9920	0.0903	515	0.4330	220	144.1	8.3	T
4A8-4	0.9950	0.0908	500	0.3986	223	138.5	8.2	T
4A8-5	0.9955	0.0918	495	0.3740	223	134.5	7.9	T/S
4B8-1	0.9905	0.0972	565	0.3838	250	137.0	7.5	T
4B8-2	0.9935	0.0955	580	0.3937	250	145.2	7.9	T/S
4B8-3	0.9955	0.0958	580	0.3888	263	144.0	8.2	T
4B8-4	0.9835	0.0963	575	0.4232	255	142.3	8.0	T
4B8-5	0.9925	0.0943	570	0.4035	250	146.4	8.2	T
5A8-1	0.9920	0.0900	525	0.3937	225	148.7	8.5	C
5A8-2	0.9940	0.0915	485	0.3100	250	134.1	9.0	C
5A8-3	0.9945	0.0895	535	0.4035	233	152.7	9.0	T
5A8-4	0.9970	0.0910	565	0.4281	240	154.9	8.8	T
5A8-5	0.9960	0.0905	550	0.3937	235	153.4	8.7	T
5B8-1	0.9905	0.0945	530	0.3642	243	136.6	8.0	T/C
5B8-2	0.9945	0.0937	510	0.3297	250	133.8	8.4	S
5B8-3	0.9945	0.0945	515	0.3149	263	133.1	8.6	S
5B8-4	0.9935	0.0938	475	0.2953	245	125.1	8.2	S
5B8-5	0.9950	0.0942	505	0.3445	250	130.7	8.2	S

* T = tension failure
C = compression failure
S = shear failure

Note: All -1 specimens have an exposed edge

Table B-32
Raw Flexure Data, Tests 4A8, 4B8, 5A8, 5B8

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
6A2-1	0.9990	0.0970	565	0.3814	260	136.4	7.8	S
6A2-2	1.0005	0.0907	590	0.3691	275	163.6	10.1	T
6A2-3	0.9890	0.0901	560	0.3568	270	159.5	10.2	T
6A2-4	0.9915	0.0892	540	0.3445	260	156.9	10.1	C
6A2-5	0.9970	0.0897	540	0.3838	245	153.4	9.3	T
6A3-1	0.9950	0.0903	550	0.3937	250	154.2	9.4	T
6A3-2	1.0005	0.0907	585	0.3986	255	161.5	9.4	T/S
6A3-3	1.0015	0.0918	590	0.3888	260	159.0	9.2	T/S
6A3-4	1.0025	0.0906	580	0.4035	255	160.1	9.4	T
6A3-5	1.0015	0.0905	555	0.3691	255	154.4	9.4	S
6B2-1	1.0030	0.0891	545	0.3912	240	155.9	9.3	T
6B2-2	1.0030	0.0915	610	0.3519	290	166.0	10.3	C/S
6B2-3	1.0030	0.0900	620	0.3838	280	174.0	10.5	C
6B2-4	1.0025	0.0889	570	0.3715	260	164.3	10.1	C/S
6B2-5	1.0030	0.0890	435	0.2559	260	127.1	10.1	S
6B3-1	0.9985	0.0916	520	0.3100	265	142.7	9.5	S
6B3-2	1.0050	0.0933	540	0.3248	265	141.7	8.9	S
6B3-3	1.0015	0.0919	590	0.3789	265	159.0	9.4	T
6B3-4	1.0030	0.0933	585	0.3642	265	152.9	8.9	S
6B3-5	0.8160	0.0919	425	0.3248	210	141.6	9.1	C

* T - tension failure
C - compression failure
S - shear failure

Table B-33
Raw Flexure Data, Tests 6A2, 6A3, 6B2, 6B3

TABLE 6

Wright Patterson - Flexure Specimens, Panel 7A2,7A3,7B2,7B3

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
7A2-1	0.9980	0.0866	445	0.2682	250	137.8	10.6	C
7A2-2	1.0040	0.0853	535	0.3297	255	168.5	11.2	C
7A2-3	1.0040	0.0861	550	0.3543	255	169.4	10.9	C
7A2-4	1.0045	0.0854	565	0.3765	250	176.4	11.0	T/C
7A2-5	1.0025	0.0871	570	0.3494	270	171.9	11.2	C/S
7A3-1	0.9975	0.0868	550	0.3913	240	166.9	10.1	T/C
7A3-2	1.0000	0.0877	545	0.4158	240	161.0	9.8	T
7A3-3	1.0005	0.0876	540	0.3814	250	160.5	10.2	T
7A3-4	1.0005	0.0881	570	0.3592	275	168.0	11.0	S
7A3-5	0.6560	0.0893	420	0.4281	230	181.9	13.5	T
7B2-1	0.9880	0.0885	580	0.3666	265	171.3	10.6	C/S
7B2-2	1.0030	0.0881	590	0.3617	270	173.4	10.8	C/S
7B2-3	1.0015	0.0885	555	0.3125	275	162.9	10.9	C/S
7B2-4	1.0040	0.0879	605	0.3715	280	178.2	11.3	C/S
7B2-5	0.9940	0.0882	580	0.3862	270	171.0	10.9	C/S
7B3-1	0.9875	0.0905	565	0.3789	265	159.2	9.9	T
7B3-2	0.9995	0.0912	605	0.3765	275	165.9	10.0	T/C
7B3-3	1.0005	0.0912	580	0.3617	275	159.2	9.9	T
7B3-4	1.0015	0.0908	585	0.3469	275	162.2	10.1	T/C/S
7B3-5	0.8415	0.0906	570	0.3986	225	187.6	9.9	T

* T - tension failure
C - compression failure
S - shear failure

Table B-34
Raw Flexure Data, Tests 7A2, 7A3, 7B2, 7B3

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
6A8-1	0.9950	0.0945	520	0.3691	240	133.3	7.8	T
6A8-2	0.9980	0.0930	490	0.3149	250	130.4	8.5	S
6A8-3	0.9955	0.0923	520	0.3395	250	140.4	8.8	S
6A8-4	0.9955	0.0923	535	0.3543	260	144.1	9.1	T/S
6A8-5	0.9995	0.0928	550	0.3789	255	145.5	8.8	C/S
6B8-1	0.9860	0.0965	545	0.3888	240	134.6	7.4	T
6B8-2	0.9940	0.0927	550	0.3937	245	146.3	8.5	T/S
6B8-3	0.9885	0.0927	560	0.3838	250	150.0	8.7	T/S
6B8-4	0.9950	0.0922	560	0.3740	250	150.9	8.8	S
6B8-5	0.9935	0.0927	550	0.4084	235	146.0	8.1	T/S
7A8-1	0.9950	0.0920	545	0.3592	250	147.8	8.9	C
7A8-2	0.9990	0.0895	525	0.3838	230	149.5	8.8	T
7A8-3	0.9945	0.0885	555	0.3937	240	162.3	9.6	T
7A8-4	0.9960	0.0882	560	0.3691	258	165.2	10.4	T/S
7A8-5	0.9955	0.0898	570	0.3691	260	162.1	9.9	C/S
7B8-1	0.9910	0.0913	615	0.4035	265	169.0	9.6	T/S
7B8-2	0.9920	0.0910	595	0.3986	275	164.6	10.1	T
7B8-3	0.9955	0.0905	600	0.4134	263	166.9	9.8	T
7B8-4	0.9910	0.0913	580	0.4330	260	158.8	9.5	T
7B8-5	0.9960	0.0902	580	0.3888	263	163.0	9.9	S

* T - tension failure
C - compression failure
S - shear failure

Note: All -1 specimens have an exposed edge

Table B-35
Raw Flexure Data, Tests 6A8, 6B8, 7A8, 7B8

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
8A2-1	0.9995	0.0955	570	0.3937	260	141.8	8.2	T/S
8A2-2	1.0005	0.0957	560	0.3789	245	138.9	7.7	T/S
8A2-3	0.9970	0.0949	545	0.3642	245	138.3	7.9	C
8A2-4	1.0025	0.0958	555	0.3592	255	137.5	7.9	T
8A2-5	1.0000	0.0959	595	0.4035	255	146.5	7.9	T
8A3-1	0.9935	0.0930	530	0.3322	255	141.3	8.8	C/S
8A3-2	1.0015	0.0954	550	0.3494	255	137.7	8.0	C/S
8A3-3	1.0002	0.0961	535	0.3051	275	133.0	8.5	S
8A3-4	0.9950	0.0949	545	0.3784	250	138.3	8.1	T/S
8A3-5	1.0002	0.0960	515	0.3297	250	127.9	7.8	S
8B2-1	0.9955	0.0946	510	0.3248	260	131.2	8.5	C/S
8B2-2	0.9995	0.0963	510	0.2854	270	126.7	8.3	C/S
8B2-3	0.9995	0.0951	570	0.3642	250	143.7	8.0	S
8B2-4	1.0020	0.0951	550	0.3592	245	138.4	7.8	T/S
8B2-5	0.9970	0.0948	495	0.3149	250	126.8	8.1	C/S
8B3-1	0.9940	0.0979	560	0.3100	250	134.8	7.4	C/S
8B3-2	0.9990	0.0970	550	0.3297	255	133.9	7.7	S
8B3-3	1.0000	0.0962	450	0.2559	255	112.5	7.9	C/S
8B3-4	1.0030	0.0970	560	0.3248	255	135.8	7.6	C/S
8B3-5	0.9990	0.0960	565	0.3543	245	139.9	7.6	C/S

* T - tension failure
C - compression failure
S - shear failure

Table B-36
Raw Flexure Data, Tests 8A2, 8A3, 8B2, 8B3

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
9A2-1	1.0020	0.0889	595	0.3937	260	171.1	10.1	T
9A2-2	1.0010	0.0899	600	0.3691	275	169.3	10.4	T
9A2-3	1.0000	0.0894	610	0.3888	265	173.8	10.2	T
9A2-4	0.9990	0.0888	590	0.3986	265	170.4	10.4	T
9A2-5	1.0005	0.0904	590	0.3789	265	164.5	9.8	T
9B2-1	0.9820	0.0886	550	0.3592	245	163.3	9.8	T
9B2-2	1.0000	0.0891	595	0.3789	260	171.0	10.1	T
9B2-3	1.0005	0.0882	610	0.3888	270	178.6	10.8	T
9B2-4	0.9990	0.0885	570	0.3543	260	166.8	10.3	S
9B2-5	1.0005	0.0883	555	0.3789	260	162.4	10.4	T
10A2-1	1.0000	0.0908	575	0.3961	250	158.6	9.2	T
10A2-2	0.9995	0.0909	605	0.3937	265	166.6	9.7	T
10A2-3	1.0000	0.0898	580	0.3961	260	163.6	9.9	T
10A2-4	1.0000	0.0899	585	0.3937	260	164.7	9.8	T
10A2-5	0.9995	0.0889	585	0.3937	250	168.6	9.8	T
10B2-1	1.0000	0.0899	570	0.3765	255	160.9	9.6	T
10B2-2	1.0010	0.0917	595	0.3986	255	160.6	9.1	T
10B2-3	1.0010	0.0903	610	0.3888	270	170.1	10.1	T
10B2-4	1.0000	0.0887	585	0.3691	265	169.9	10.4	T
10B2-5	0.9990	0.0896	590	0.3937	260	167.4	9.9	T

* T - tension failure
C - compression failure
S - shear failure

Table B-37
Raw Flexure Data, Tests 9A2, 9B2, 10A2, 10B2

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
8A8-1	0.9960	0.0975	560	0.3789	250	134.3	7.4	T/C
8A8-2	0.9935	0.0978	510	0.3100	260	123.1	7.7	C
8A8-3	0.9835	0.0977	570	0.3445	270	138.5	8.1	S
8A8-4	0.9965	0.0968	540	0.3494	253	131.9	7.7	T/S
8A8-5	0.9940	0.0970	530	0.3838	258	128.6	7.8	T/S
8B8-1	0.9870	0.0968	540	0.3543	245	133.1	7.5	T/S
8B8-2	0.9930	0.0975	470	0.2854	255	114.6	7.6	S
8B8-3	0.9955	0.0982	475	0.2707	270	114.1	7.9	C
8B8-4	0.9955	0.0972	495	0.3149	250	120.6	7.5	C
8B8-5	0.9945	0.0983	475	0.2903	255	113.7	7.4	C
9A8-1	0.9950	0.0917	515	0.3691	238	140.4	8.5	T
9A8-2	0.9835	0.0927	590	0.3789	270	158.9	9.5	T/S
9A8-3	0.9815	0.0917	575	0.4084	263	158.0	9.5	T/C/S
9A8-4	0.9945	0.0920	595	0.4084	265	160.3	9.4	T
9A8-5	0.9860	0.0913	610	0.3986	270	168.6	9.9	T/S
9B8-1	0.9990	0.0947	585	0.3789	265	148.5	8.6	T/S
9B8-2	0.9990	0.0948	620	0.3888	280	156.8	9.0	T/S
9B8-3	0.9880	0.0935	570	0.3543	271	150.7	9.2	T/S
9B8-4	0.9955	0.0935	620	0.3838	285	162.0	9.6	T/S
9B8-5	0.9875	0.0927	600	0.3888	270	160.7	9.4	T

* T = tension failure
C = compression failure
S = shear failure

Note: All -1 specimens have an exposed edge

Table B-38
Raw Flexure Data, 8A8, 8B8, 9A8, 9B8

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
9A3-1	0.9960	0.0905	570	0.3740	265	159.4	9.9	T
9A3-2	0.9955	0.0898	590	0.3789	280	167.6	10.7	T
9A3-3	0.9975	0.0898	605	0.3888	263	171.3	10.0	T
9A3-4	0.9935	0.0895	565	0.3592	265	162.4	10.2	T
9A3-5	0.9955	0.0897	610	0.3986	280	173.2	10.7	T
9B3-1	0.9975	0.0902	575	0.3691	270	161.7	10.1	T
9B3-2	0.9975	0.0900	575	0.3592	275	162.7	10.4	T/S
9B3-3	0.9870	0.0893	590	0.3937	270	170.6	10.5	T/C/S
9B3-4	0.9925	0.0888	590	0.3838	270	171.9	10.7	T
9B3-5	0.9980	0.0898	565	0.3592	273	160.5	10.4	T/S
10A3-1	0.9905	0.0915	570	0.3838	265	156.5	9.6	T
10A3-2	0.9875	0.0923	545	0.3740	255	147.6	9.0	T
10A3-3	0.9955	0.0907	555	0.3691	260	154.7	9.6	T/S
10A3-4	0.9950	0.0907	580	0.3888	270	161.3	10.0	T
10A3-5	0.9950	0.0908	560	0.3740	260	155.7	9.6	T
10B3-1	0.9960	0.0928	590	0.3937	270	156.2	9.3	T
10B3-2	0.9980	0.0922	595	0.3986	270	159.3	9.5	T
10B3-3	0.9970	0.0920	575	0.3888	265	155.0	9.4	T
10B3-4	0.9955	0.0915	585	0.3937	265	159.6	9.5	T
10B3-5	0.9930	0.0918	550	0.3642	257	150.0	9.2	T

* T - tension failure
C - compression failure
S - shear failure

Note: 9A3-5 and 9B3-5 specimens have an exposed edge

Table B-39
Raw Flexure Data, Tests 9A3, 9B3, 10A3, 10B3

specimen number	width (in.)	depth (in.)	failure load (lbs.)	cross. defl. (in.)	ref. load (lbs.)	failure stress (ksi)	bending stiff. (msi)	failure mode *
10A8-1	0.9915	0.0910	475	0.4380	215	130.7	7.9	T
10A8-2	0.9940	0.0920	575	0.4084	250	155.0	8.9	T/S
10A8-3	0.9860	0.0920	580	0.4134	250	157.5	8.9	T/S
10A8-4	0.9945	0.0933	580	0.3888	260	152.2	8.8	T/S
10A8-5	0.9965	0.0933	585	0.3888	263	153.3	8.9	T
10B8-1	0.9940	0.0917	550	0.3691	255	150.1	9.1	T/S
10B8-2	0.9930	0.0923	600	0.3691	275	161.7	9.7	T/S
10B8-3	0.9945	0.0920	585	0.3937	263	157.9	9.3	T/S
10B8-4	0.9960	0.0923	575	0.3937	260	154.0	9.1	T/T
10B8-5	1.0005	0.0940	550	0.3543	263	142.0	8.7	T/S

* T - tension failure
C - compression failure
S - shear failure

Note: All -1 specimens have an exposed edge

Table B-40
Raw Flexure Data, Tests 10A8, 10B8

specimen number	*	failure stress (ksi)		bending stiff. (msi)	
		d-actual	d-normal. 0.08	d-actual	d-normal. 0.08
2A2	C	151.8	185.8	9.2	12.4
2A3	C	155.9	196.2	9.2	12.9
2B2	C	152.9	186.9	10.0	13.4
2B3	C	153.9	199.4	9.2	13.5

* T - surface of interest in tension
C - surface of interest in compression

Table B-41
Normalized Flexure Data, Tests 2A2, 2A3, 2B2, 2B3

specimen number	*	failure stress (ksi) d-actual	failure stress (ksi) d-normal. 0.08	bending stiff. (msi) d-actual	bending stiff. (msi) d-normal. 0.08
3A2	C	149.9	198.4	8.9	13.5
3A3	C	151.7	202.6	8.9	13.6
3B2	C	148.5	202.0	8.9	13.9
3B3	C	153.0	212.8	8.7	14.1

* T - surface of interest in tension
C - surface of interest in compression

Table B-42
Normalized Flexure Data, Tests 3A2, 3A3, 3B2, 3B3

specimen number	*	failure stress (ksi) d-actual	failure stress (ksi) d-normal. 0.08	bending stiff. (msi) d-actual	bending stiff. (msi) d-normal. 0.08
2A8	C	147.9	194.0	9.3	13.8
2B8	C	146.8	200.2	8.7	13.7
3A8	C	148.3	198.8	9.0	13.8
3B8	C	134.1	194.5	8.1	13.9

* T - surface of interest in tension
C - surface of interest in compression

Note: No -1 specimens were included

Table B-43
Normalized Flexure Data, Tests 3A2, 3A3, 3B2, 3B3

specimen number	*	failure stress (ksi)		bending stiff. (msi)	
		d-actual	d-normal. 0.08	d-actual	d-normal. 0.08
4A2	C	122.2	147.3	8.6	11.3
4A3	C	141.8	176.3	8.7	12.0
4B2	C	146.9	196.9	8.7	13.4
4B3	C	146.1	210.7	8.2	14.0

* T - surface of interest in tension
C - surface of interest in compression

Table B-44
Normalized Flexure Data, Tests 4A2, 4A3, 4B2, 4B3

specimen number	*	failure stress (ksi) d-actual	failure stress (ksi) d-normal. 0.08	bending stiff. (msi) d-actual	bending stiff. (msi) d-normal. 0.08
5A2	C	152.9	187.7	9.8	13.3
5A3	C	153.9	192.8	9.6	13.3
5B2	C	146.6	182.5	10.0	13.8
5B3	C	134.2	178.9	9.3	14.2

* T - surface of interest in tension
C - surface of interest in compression

Table B-45
Normalized Flexure Data, Tests 5A2, 5A3, 5B2, 5B3

specimen number	*	failure stress (ksi) d-actual	failure stress (ksi) d-normal. 0.08	bending stiff. (msi) d-actual	bending stiff. (msi) d-normal. 0.08
4A8	C	137.2	177.4	8.0	11.7
4B8	C	144.5	207.7	8.1	13.8
5A8	C	148.7	192.0	8.9	12.9
5B8	C	130.7	181.9	8.4	13.6

* T - surface of interest in tension
C - surface of interest in compression

Note: No -1 specimens were included

Table B-46
Normalized Flexure Data, Tests 4A8, 4B8, 5A8, 5B8

specimen number	*	failure stress (ksi) d-actual	failure stress (ksi) d-normal. 0.08	bending stiff. (msi) d-actual	bending stiff. (msi) d-normal. 0.08
6A2	C	154.0	201.5	9.5	14.1
6A3	C	157.9	204.6	9.4	13.7
6B2	C	157.5	199.2	10.1	14.2
6B3	C	147.6	198.1	9.2	14.1

* T - surface of interest in tension
C - surface of interest in compression

Table B-47
Normalized Flexure Data, Tests 6A2, 6A3, 6B2, 6B3

specimen number	*	failure stress (ksi)		bending stiff. (msi)	
		d-actual	d-normal. 0.08	d-actual	d-normal. 0.08
7A2	C	164.8	191.4	11.0	13.7
7A3	C	167.7	203.5	10.9	14.5
7B2	C	171.4	209.4	10.9	14.6
7B3	C	166.8	216.5	10.0	14.6

* T - surface of interest in tension
C - surface of interest in compression

Table B-48
Normalized Flexure Data, Tests 7A2, 7A3, 7B2, 7B3

specimen		failure stress (ksi)		bending stiff. (msi)	
number	*	d-actual	d-normal. 0.08	d-actual	d-normal. 0.08
6A8	C	140.1	188.9	8.8	13.6
6B8	C	148.3	200.1	8.5	13.2
7A8	C	159.8	198.7	9.7	13.3
7B8	C	163.3	211.6	9.8	14.3

* T - surface of interest in tension
C - surface of interest in compression

Note: No -1 specimens were included

Table B-49
Normalized Flexure Data, Tests 6A8, 6B8, 7A8, 7B8

specimen number	*	failure stress (ksi) d-actual	failure stress (ksi) d-normal. 0.08	bending stiff. (msi) d-actual	bending stiff. (msi) d-normal. 0.08
8A2	C	140.6	202.4	7.9	13.5
8A3	C	135.7	193.0	8.2	13.8
8B2	C	133.4	190.2	8.1	13.7
8B3	C	131.4	194.1	7.6	13.5

* T - surface of interest in tension
C - surface of interest in compression

Table B-50
Normalized Flexure Data, Tests 8A2, 8A3, 8B2, 8B3

specimen number	*	failure stress (ksi) d-actual	failure stress (ksi) d-normal. 0.08	bending stiff. (msi) d-actual	bending stiff. (msi) d-normal. 0.08
9A2	C	169.8	213.6	10.2	14.2
9B2	C	168.4	207.3	10.3	13.9
10A2	C	164.4	209.6	9.7	13.8
10B2	C	165.8	211.2	9.8	14.0

* T - surface of interest in tension
C - surface of interest in compression

Table B-51
Normalized Flexure Data, Tests 9A2, 9B2, 10A2, 10B2

specimen number	*	failure stress (ksi) d-actual	failure stress (ksi) d-normal. 0.08	bending stiff. (msi) d-actual	bending stiff. (msi) d-normal. 0.08
8A8	C	130.5	195.0	7.8	14.1
8B8	C	115.8	174.4	7.6	13.9
9A8	C	161.5	214.7	9.6	14.5
9B8	C	157.6	217.5	9.3	14.9

* T - surface of interest in tension
C - surface of interest in compression

Note: No -1 specimens were included

Table B-52
Normalized Flexure Data, Tests 8A8, 8B8, 9A8, 9B8

TABLE 13

Wright Patterson
Flexure Specimens , Panel 9A3,9B3,10A3,10B3

specimen number	*	failure stress (ksi) d-actual	failure stress (ksi) d-normal. 0.08	bending stiff. (msi) d-actual	bending stiff. (msi) d-normal. 0.08
9A3	C	165.2	209.7	10.2	14.4
9B3	C	166.7	210.1	10.4	14.6
10A3	C	155.1	202.9	9.6	14.1
10B3	C	156.0	208.1	9.4	14.3

* T - surface of interest in tension
C - surface of interest in compression

Note: No -5 specimens were included for 9A3 and 9B3

Table B-53
Normalized Flexure Data, Tests 9A3, 9B3, 10A3, 10B3

specimen number	*	failure stress (ksi) d-actual	d-normal. 0.08	bending stiff. (msi) d-actual	d-normal. 0.08
10A8	C	154.5	208.8	8.9	13.8
10B8	C	153.9	207.8	9.2	14.3

* T - surface of interest in tension
C - surface of interest in compression

Note: No -1 specimens were included

Table B-54
Normalized Flexure Data, Tests 10A8, 10B8

APPENDIX C

COATINGS LITERATURE

Coating No. 1

Control

Coating No. 2

DS10-7133

Product Information

LORD Industrial Coatings

CHEMGLAZE M1433
GRAY, ELASTOMERIC POLYURETHANE RAIN EROSION COATING

M1433 is an aromatic, elastomeric polyurethane which functions as a rain erosion coating for radomes, leading edges and antennae.

M1433 is tough, flexible over a wide temperature range, and has excellent resistance to wear, abrasion and impact.

M1433 is a two-package coating. It is cured by the addition of a reactive curing agent, M201, in a ratio of three parts of A to one part of B by volume. It is supplied in premeasured kits.

TYPICAL PHYSICAL PROPERTIES

	Part A	Part B	Mixed
Color	Gray	Clear Light to Dark Amber	Gray
Mixing ratio:			
by volume	3	1	---
Solids content:			
by weight	71	9	58
by volume	65	7.5	50
Weight/unit			
lb/gal	8.65	7	8.2
kg/l	1.04	0.84	0.98
Viscosity:			
centipoises	800-1200[a]	water thin	200-600[b]
N. s/m^2	0.8-1.2	water thin	0.2-0.6
Flash Point			
Seta Flash	66°F	110°F	---
	18.9°C	43.3°C	---
Pot Life at 77°F (25°C)	---	---	2 hours
Drying time @ 77°F (25°C) and 50% relative humidity	---	---	2-3 hours
Volatile Organic Compounds			
pounds/gallon	---	---	3.5
grams/liter	---	---	420

THEORETICAL COVERAGE

Wet Film		Dry Film		Coverage		
mils	µm	mils	µm	ft^2/gallon	m^2/l	m^2/gallon
2.0	50.8	1	25.4	800	19.7	74.3
10.0	254	5	127.0	160	3.9	14.9
24.0	610	12	305.0	66.7	1.6	6.2
				ft^2/quart		m^2/qt.
		1	25.4	200	---	18.6
		5	127.0	40	---	3.7
		12	305.0	16.7	---	1.6

STORAGE AND SHELF LIFE

The containers should be stored in a dry area protected from all forms of precipitation. An ideal storage temperature would be 60°F. However, if the storage temperature drops below 50°F, a portion of the Part A will crystallize. Should this happen, the containers should be stored at 60°F, for two days before using. The mixed coating shall be kept at 60°F minimum until applied. Do not mix or use coating which is frozen.

The shelf life of the Part A and Part B in unopened containers is 6 months.

MIXING PROCEDURES

M1433/M201 comes in a premeasured kit. Mix the Part A, the pigmented part, well. Then add, while stirring, the Part B, M201. Once thoroughly mixed the coating is ready for spraying

NOTE: The M201 Part B is very sensitive to atmospheric moisture. If over exposed to moisture, a short pot life will result. Open the Part B when ready to use.

PROCEDURE FOR COATING FRP RADOME

The coating of a radome consists of the following steps:

1. Surface preparation
2. Application of primer
3. Application of elastomeric rain erosion coating
4. Application of top coat

1. Surface Preparation

The radome surface should be solvent wiped with 9951 or 9954 xylene or methyl ethyl ketone (MEK) to remove all oil, grease and dirt.

Next the surface should be lightly sanded to provide an anchor pattern. Use emory cloth or medium to very fine sandpaper (320-500 grit). Then solvent wipe the surface to remove grit and dust.

2. Application of Primer

Even though the radome is plastic, the CHEMGLAZE wash primer 9924 (a metal primer) is applied. The 9924 primer is easily dissolved by thinners, 9951, or methyl ethyl ketone (MEK). Because of solvent sensitivity the 9924 primer functions as a weak link when the radome needs to be repaired. Use a sharp blade and make cuts in the coating then cover with solvent soaked rags. Bulletin for 9924 tells how to mix it. Apply 0.3-0.5 dry mils.

The primer is best applied by spray application. Allow the 9924 to dry. A completely dry 9924 surface will have a dull matte appearance.

3. Application of M1433 Elastomeric (Rain Erosion) Polyurethane Coating

The elastomeric polyurethane coating is a two package (2-part) product. Both the M1433. A Part, and the M201, B Part are sensitive to atmospheric moisture. The A & B parts should be protected from moisture until they are mixed and ready to use.

A. The mix ratio is 3:1 A:B by volume. It is very important that the mix ratios are accurate and the A and B is thoroughly mixed. Thinning is not necessary.

B. Spray apply 12-14 mils dry in several multiple passes. The nose portion of the radome should receive the 12-14 mils dry. Feather the elastomeric coating toward the trailing edge.

C. Allow the M1433/M201 to cure 3-4 hours before top coating.

D. In many instances, a pressure pot spray gun was found to work better than a syphon spray gun for the elastomeric coating application.

4. Application of Top Coat

The elastomeric polyurethane rain erosion coating is not a cosmetic coating because it will change color and chalk. It should be top coated with an aliphatic polyurethane.

The aliphatic CHEMGLAZE A-line moisture curing polyurethane top coat should be thinned 15% by volume with the CHEMGLAZE thinner 9954. Spray a light tack coat followed witn a thin hide coat, about 1 mil dry.

USABLE POT LIFE

The mixed M1433/M201 has a usable pot life of 2 hours. However, very high levels of humidity and high temperatures may shorten the pot life.

RECOAT TIME

Allow the applied M1433/M201 to cure at shop temperatures for 3-4 hours before applying the cosmetic aliphatic top coat.

CLEAN UP

Spray equipment must be cleaned immediately after spraying since the coating will cure inside guns, filter screens, and hoses. Once the elastomeric coating cures, it is almost impossible to remove. CHEMGLAZE Thinner 9954, or xylene, MEK, MIBK, or blends of xylene/MEK may be used for cleaning equipment.

CAUTIONARY INFORMATION

Personnel who handle, mix, and spray CHEMGLAZE elastomeric coatings must protect themselves from vapors, liquid coatings and spray mist. The use of protective creams, safety glasses, solvent resistant gloves, protective clothing, and NIOSH approved respirators are required. Direct, mist or vapor contact with the solvents, urethane prepolymers and curing agents may cause skin or respiratory irritation in some individuals.

Spray applicator personnel should wear a fresh air supplied hood while spraying coating in a confined area. Helpers, supervisors and visitors to the spray site should use approved respiratory protection.

Keep away from heat, sparks, and open flame. Avoid prolonged contact with skin. Wash thoroughly after using or before smoking or eating.

Harmful or fatal if swallowed. If swallowed, DO NOT induce vomiting. CALL A PHYSICIAN IMMEDIATELY!!

JRW/sr
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8089i

For additional information, contact Lord Corporation at 814:868-3611, Telex: 91-4445 or write: Lord Corporation, Industrial Coatings Division, 2000 West Grandview Blvd., P. O. Box 10038, Erie, Pa. 16514-0038.

Coating No. 3

AEROSPACE

4086-176

COATING NAME: CLEAR SPRAY SEALANT
SPECIFICATION NONE COLOR

MIXING:
CODE NUMBERS: BASE 4086-176 ACTIVATOR NONE THINNER
MIXING INSTRUCTIONS:
MIXING RATIO
EQUIPMENT CLEAN UP Use MEK POT LIFE Indefinite

APPLICATION:
METHOD Air Spray EQUIPMENT Conventional Gun
APPLICATION TEMP Ambient HUMIDITY >50% RH
THICKNESS PER COAT 2-3 mil DRY TIME BETWEEN COATS 30-40 mil
FILM THICKNESS: MAX 3 mil MIN .5mil
TOUCH UP OR RECOAT PROCEDURE Respray

SUBSTRATE:
TYPE Aluminum or Composite CHEM TREATMENT Not Necessary
PRIMER 513X639 OTHER NA

CURING SCHEDULE:
NORMAL SCHEDULE 7 days at RT & 50% RH ALTERNATE CURE
DRY TO TAPE 2 hr DRY TO TOPCOAT 1 hr FULL CURE 14 days at RT

STORAGE:
STORAGE LIFE 6 months STORAGE CONDITIONS RT or Below
FLASH POINT -SETAFLASH- 22F HAZARD-TOXICITY INFO see MSDS

PHYSICAL CONSTANTS:

	WT/GAL	WT/SOLIDS	VOL/SOLIDS	PIGMENT
BASE:	7.7 +/-.2 lbs.	43.9 +/-2 %	35.8 %	%
ACTIVATOR:				
THINNER:				
ADMIXED:				

VISCOSITY: BASE ADMIXED
DRY FILM WEIGHT .00591 #/sqft @ 1 mil THEORETICAL COVERAGE 573 sqft/gal @ 1mil
COMPLIANCE REGULATIONS VOC 518 g/l calc.

SPECIAL FILM PROPERTIES:
SERVICE TEMPERATURE: MIN -65F MAX 250-350
FILM HARDNESS NA FLEXIBILITY
IMPACT RESISTANCE NSILE COLOR STANDARD NA
GLOSS: 60 DEGREES NA 85 DEGREES NA 20 DEGREES NA
OTHER Spraying of more than 3mil at a time is not desirable

RESISTANCE PROPERTIES:
WATER NA SKYDROL NA SALT SPRAY NA
FILIFORM NA WEATHERING NA STRIPPER NA

SPECIFICATIONS

Koroflex meets the U.S. Navy primer specification Mil-P-85853. This primer meets or exceeds the performance requirements for Mil-P-87112, Mil-P-23377, FMS 3035 (General Dynamics) and GP 111 CT 1, GP 111 CT 2, GP 111 CT 3, GP 111 CT 4 (Grumman).

PRIMER COMPARISON

The performance of Koroflex primer is compared below to a coating which is qualified to Mil-P-23377.

	KOROFLEX	MIL-P-23377
CORROSION		
2000 Hours Salt Spray	Pass	Pass
30 Days Filiform	Pass	Pass
3000 Hours Humidity	Pass	Pass
IMPACT FLEXIBILITY		
Reverse (8 [illegible] lbs.)	Pass	Fail
G.E.	60%	20%
FLEXIBILITY @ -65°F. (-54°C.) (MANDREL BEND)		
Primer only (1/8" bend)	Pass	Fail
Primer and Topcoat (3/8" bend)	Pass	Fail
ELONGATION		
Initial	81%	10%
24 Hrs @ 250°F. (121°C.)	81%	6%
TENSILE STRENGTH		
Initial	2810 psi	2600 psi
24 Hrs @ 250°F. (121°C.)	3160 psi	4800 psi
FLUID RESISTANCE (PRIMER)		
Initial Pencil	HB	F
1 Week Skydrol	<4B	<4B
1 Week Type III Fuel	2B	B
1 Week Mil-L-5606	B	B
1 Week Water	HB	2B
FLUID RESISTANCE (PRIMER AND TOPCOAT)		
Initial Pencil	HB	F
1 Week Skydrol	2B	HB
1 Week Type III Fuel	2B	2B
1 Week Mil-L-5606	B	HB
1 Week Water	B	HB
Wet Tape Test	Pass	Pass

SURFACE PREPARATION

Good surface preparation is essential to ensure that the full protective properties of a coating be realized. The following is an outline of recommended surface preparation procedures for Koroflex primer over aluminum, aged epoxy, aged Koroflex primer, and composite substrates.

I. Aluminum Substrates

For application of Koroflex to aluminum substrates, the aluminum should be chemically cleaned and treated with a chromate conversion coating such as Alodine 1200 (Mil-C-5541) or Alodine 1000. Recommended cleaning procedures follow:

A. Clean: Use of of the following methods

1. Wet abrade
    - a. Solvent clean with DeSoclean or Oxsolv Wipe dry with clean wipers
    - b. Wet abrade with fine Scotchbrite and water (not solvent)
2. Etch clean
    - a. Wash surface with alkaline cleaner
    - b. Rinse
    - c. Deoxidize and etch surface using alcoholic-phosphoric acid solution
3. Steam - etch clean
    - a. Steam clean with alkaline cleaner
    - b. Rinse
    - c. Deoxidize and etch surface using alcoholic-phosphoric acid solution

B. Surface Treat

1. Rinse using clean cotton wipers to agitate the surface
2. Final rinse with deionized water
3. Observe surface for waterbreaks. If any are found, repeat steps A. and B.
4. Apply conversion coating such as Alodine 1200 or Alodine 1000
5. Rinse
6. Deionized water rinse
7. Observe surface for waterbreaks. If any are found, repeat steps A. and B.
8. Keep conversion coating clean prior to application of Koroflex

C. Time limit for Koroflex application.

Apply Koroflex within eight hours after the surface treatment. Between 8 and 24 hours clean the conversion coating with DeSoclean or Oxsolv before applying Koroflex. After 24 hours repeat steps A. and B. before applying Koroflex.

II. Aged Epoxy Primer

Aged epoxy primer is considered to be primer which is more than 3 days old after application. A typical procedure for applying Koroflex to this type of surface requires the following steps:

1. Lightly sand epoxy primer with 240 grit sandpaper or fine Scotchbrite
2) Solvent wipe with DeSoclean or Oxsolv to remove contaminants

III. Aged Koroflex Primer

Koroflex can be reapplied to itself up to one year after the first application without removal or sanding. However, it is important that the surface be cleaned and free of contaminants. Use Oxsolv to clean and reactivate the surface

IV. Composite Substrates

Solvent wipe substrate to be primed using DeSoclean or Oxsolv

APPLICATION INSTRUCTIONS

Mixing

Shake Koroflex on a paint shaker for 8-10 minutes. Make sure that no settled material remains on the bottom of the can.

FILM THICKNESS

Apply one coat of primer at a dry film thickness of 1.5 ± 0.3 mils (38 ± 7 microns). If a second coat is required, allow one hour between coats.

POT LIFE

Koroflex Primer while in the container should always be covered and protected from moisture or alcohol contamination. If protected from moisture, Koroflex will have indefinite pot life.

EQUIPMENT

Standard spray equipment can be used to apply Koroflex primer. Good results are obtained with a DeVilbliss MBC spray gun, air cap #765, E or FF fluid tip, and needle. Equivalent spray equipment is available from other manufacturers.

REDUCTION

Reduction of Koroflex primer is not required for spray application. Urethane grade methyl ethyl ketone may be used to reduce Koroflex when lower viscosities are needed for spraying. Compliance Koroflex may be reduced with 1,1,1 trichloroethane.

CLEAN UP

Clean up should be done promptly to avoid cured paint remaining in or on equipment. Methyl ethyl ketone or a strong solvent complying with local Air Quality regulations is recommended for this use.

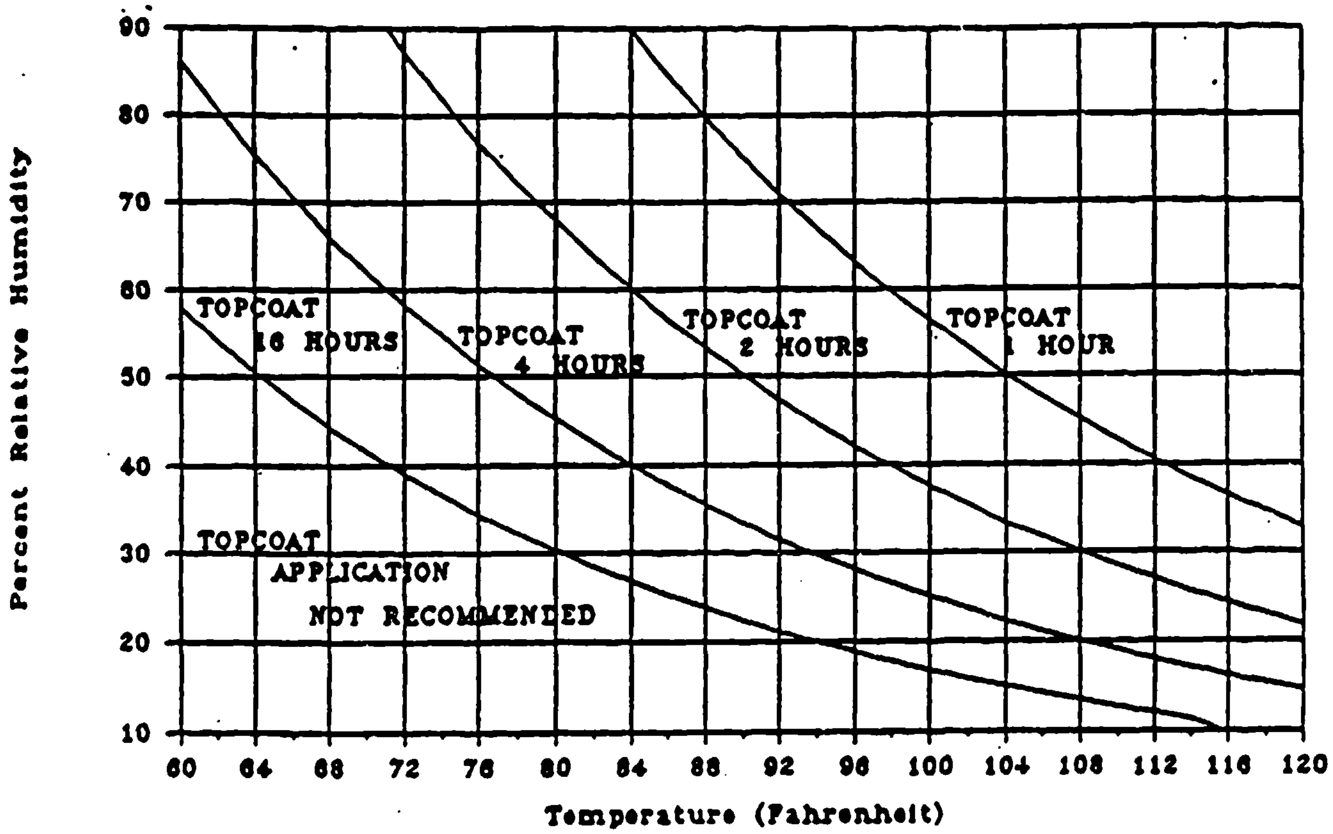
TOPCOAT APPLICATION

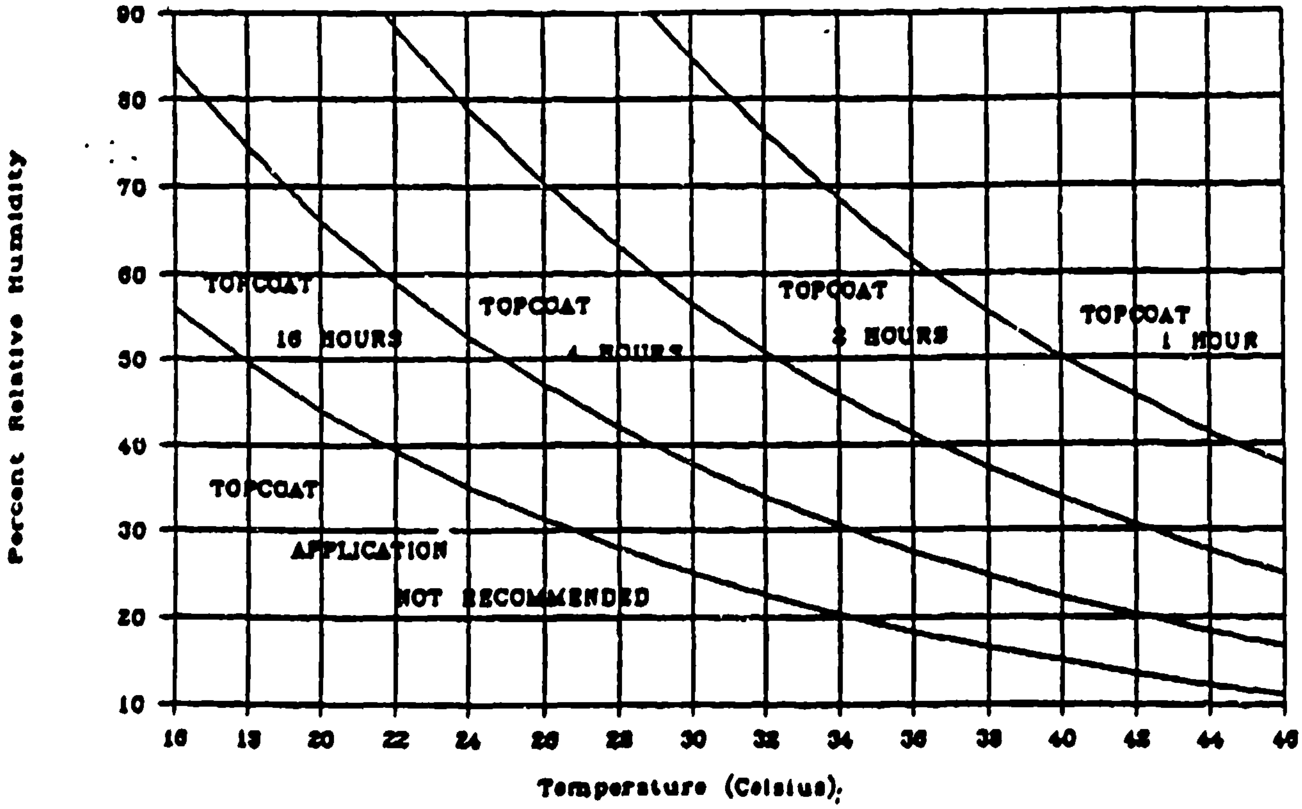
Koroflex should be dried as recommended in the "Time To Topcoat" section before topcoating. The length of time for drying before topcoating depends on temperature and relative humidity conditions during application and cure. (See attached information on dry time).

After the proper dry time, apply DeSoto DeSothane or Mil-C-83286 topcoat in two wet coats to a dry film thickness of 2.0 ± 0.3 mils (51 ± 7 microns). Allow thirty minutes dry time between coats.

KOROFLEX PRIMER

Time To Topcoat Guide





DRY TIME

The curing mechanism of Koroflex primer requires the presence of moisture. There are two ways to express the moisture content in the air. The first is relative humidity which is ratio of the moisture in the air to what the air could hold at a given temperature. At 50% R.H., the air is holding half of the amount of moisture it could hold at that temperature. Relative humidity does not directly indicate the amount of moisture present in the air.

The second method expresses the amount of moisture in the air in grains per cubic foot. The speed of Koroflex cure can be related to the grains of moisture present in the air. Refer to the chart on the next page for this relationship.

TIME TO TOPCOAT

Since most paint facilities have no means of measuring grains of moisture, a conversion chart is attached to convert grains of moisture into temperature and % relative humidity. There are four lines on the chart which represent 3.33, 5.0, 7.5 and 11.25 grains of moisture. These lines define four areas of dry time before topcoating of 16 hours, 4 hours, 2 hours, and 1 hour respectively.

To use the attached chart measure the temperature and the relative humidity and locate this point on the graph. The location of this point will determine the length of time to topcoat. For example, if conditions were 76°F. (24°C.) and 60% RH, 4 hours should be allowed after final primer application before applying topcoat.

FORCE CURING OF KOROFLEX

The cure rate of Koroflex primer can be increased by raising humidity and temperature simultaneously. The moisture content of the air is the main determinant of Koroflex cure rate, raising the temperture will help speed up the cure mainly by allowing more moisture to be added to the air. Koroflex can be accelerated when low humidity exists with the addition of 910X751. The potlife and dry-to-topcoat time will be shortened to two hours, respectively.

DRY TO STACK

While heating alone in the absence of moisture will not accelerate the cure of Koroflex, heating will drive off the solvent and result in a tack free or dry to stack condition. Dry to stack can be achieved by heating at 250° F. (121° C.) for 10 minutes or 200° F. (93° C.) for 30 minutes. Koroflex will not have attained resistance properties to solvent after these conditions. Total properties will only be achieved when painted parts have had adequate time, moisture, and temperature exposure as discussed above.

WET TAPE TESTING

Koroflex primer and topcoat should be allowed to cure for seven days before running a wet tape test on the aircraft or painted parts.

REPAIR PROCEDURE

1) Solvent wipe with DeSoclean or Oxsolv
2) Sand area to be repaired with 240 grit sandpaper or wet Scotchbrite
3) Solvent wipe with clean DeSoclean or Oxsolv
4) Deoxidize all bare areas and rinse with clean water.
5) Alodine bare areas and rinse with clean water.
6) Fine rinse with deionized water
7) Check for water break free surface.
8) The bare areas must be water break free; if not repeat steps 2-5.
9) Dry all areas.
10) Mask the repair areas.
11) Spray or brush apply one coat of Koroflex primer at 1.5 ± 0.3 mils (38 ± 7 microns) and air dry according to the Koroflex time to topcoat guide
12) Topcoat with Mil-C-83286 Super DeSothane and allow overnight air dry before removing the mask.

AVAILABILITY

DeSoto supplies Koroflex in gallons and quarts under the following code numbers:

SPECIFICATION NUMBER	DESOTO PRODUCT NUMBER	DESCRIPTION
Mil-P-85853, Type I, Class 1	823X439	Yellow, standard version, VOC** 590 g/l
Mil-P-85853, Type II, Class 1	825X480	Dark green, low IR version, VOC** 590 g/l
Mil-P-85853, Type I, Class 2	823X465	Yellow, Compliance version, VOC** 350 g/l
Mil-P-85853, Type II, Class 2	825X513	Dark green, low IR version, VOC** 350 g/l
FMS 3035	823X439	Yellow
GP 111 CT 1	823X439	Yellow
GP 111 CT 2	825X480	Dark green, low IR
GP 111 CT 3	823X465	Yellow, VOC** 350 g/l
GP 111 CT 4	825X513	Dark green, low IR, VOC** 350 g/l

ORDERING

The topcoats, primers, thinners and solvent cleaners may be ordered from:

DeSoto, Inc.
Fourth and Cedar Streets
Berkeley, California 94710

Telephone: 415-526-1525
TWX: 910-366-7207
FAX: 415-525-5669

Additional technical and product information is available from the DeSoto representative in your area or the above location.

PRECAUTIONS:

This material contains high vapor pressure, low flash point organic solvents and adducts of isocyanates. It is flammable and should be kept away from heat, sparks and open flames.

Inhalation of isocyanates can cause allergic sensitization. Skin sensitization is also possible. Avoid skin contact or breathing solvent or spray mist. Mix, apply material and clean-up only in a well ventilated area. Protect painters by use of respirators, splash proof goggles, protective gloves and protective clothing such as coveralls. Air supplied respirators provide the best protection against exposure especially in areas of poor ventilation. Paint spray respirators (chemical cartridge with particulate filters) may offer protection against isocyanates. Consulation with respirator manufacturers who are familiar with National Institute For Occupational Safety Guidelines is recommended.

If the material being applied gets into the eyes, they should be flushed for at least fifteen minutes with large quantities of water from an eye bath or with a gentle, copious flow of water from a hose. See a physician immediately.

If skin contact occurs, wash off immediately with large quantities of soap and water. Solvents or thinners should not be used to clean skin. If clothes are contaminated, they should be removed and laundered before using again.

Additional information regarding the safe handling of urethane coatings can be found in the DeSoto booklet "DeSoto Aerospace Coatings - Safe Handling Guide". This booklet is available from the Aerospace Group, DeSoto, Inc., Administrative and Research Center, 1700 South Mt. Prospect Road, Des Plaines, Illinois 60017, telephone: 312-391-9386.

Revised 5/87 CEO

[illegible] Aerospace Coatings

Product Information

4086-168

COATING NAME: CLEAR KOROFLEX

SPECIFICATION NONE COLOR

MIXING:

CODE NUMBERS: BASE 4086-176 ACTIVATOR NONE THINNER
MIXING INSTRUCTIONS:
MIXING RATIO
EQUIPMENT CLEAN UP Use MEK POT LIFE Indefinite

APPLICATION:

METHOD Air Spray EQUIPMENT Conventional Gun
APPLICATION TEMP Ambient HUMIDITY >50% RH
THICKNESS PER COAT 2-3 mil DRY TIME BETWEEN COATS 30-40 mil
FILM THICKNESS: MAX 3 mil MIN .5mil
TOUCH UP OR RECOAT PROCEDURE Respray

SUBSTRATE:

TYPE Aluminum or Composite CHEM TREATMENT Not Necessary
PRIMER 513X639 OTHER NA

CURING SCHEDULE:

NORMAL SCHEDULE 7 days at RT & 50% RH ALTERNATE CURE
DRY TO TAPE 2 hr DRY TO TOPCOAT 1 hr FULL CURE 14 days at RT

STORAGE:

STORAGE LIFE 6 months STORAGE CONDITIONS RT or Below
FLASH POINT -SETAFLASH- 22F HAZARD-TOXICITY INFO see MSDS

PHYSICAL CONSTANTS:

	WT/GAL	WT/SOLIDS	VOL/SOLIDS	PIGMENT
BASE:	7.7 +/-.2 lbs.	43.9 +/-2 %	35.8 %	%
ACTIVATOR:				
THINNER:				
ADMIXED:				

VISCOSITY: BASE ADMIXED
DRY FILM WEIGHT .00591 #/sqft @ 1 mil THEORETICAL COVERAGE 573 sqft/gal @ 1mil
COMPLIANCE REGULATIONS VOC 518 g/l calc.

SPECIAL FILM PROPERTIES:

SERVICE TEMPERATURE: MIN -65F MAX 250-350
FILM HARDNESS NA FLEXIBILITY
IMPACT RESISTANCE NSILE COLOR STANDARD NA
GLOSS: 60 DEGREES NA 85 DEGREES NA 20 DEGREES NA
OTHER Spraying of more than 3mil at a time is not desirable

RESISTANCE PROPERTIES:

WATER NA SKYDROL NA SALT SPRAY NA
FILIFORM NA WEATHERING NA STRIPPER NA
OTHER COMMENTS

Excellence, The DeSoto Commitment

DATE 9/29/88

PRODUCT AND APPLICATION DATA SHEET

KOROFLEX PRIMERS

GENERAL DATA SHEET
Mil-P-85853

Koroflex primer is a one component, moisture cure polyurethane with outstanding flexibility which provides excellent corrosion prevention. Koroflex outperforms most conventional primers because it resists cracking around aircraft fasteners and at laps and joints - a major source of corrosion on aircraft. Cracking of a protective coating is caused by the flexing and vibration of the aircraft and usually occurs at the fasteners where high stress and flexing is concentrated. Such cracks provide a pathway to the fasteners and surrounding metal for corrosive salts and acids which initiate corrosion. Koroflex primer withstands the stress applied to the fasteners without cracking and thereby provides superior corrosion protection.

The primer topcoated with Mil-C-83286 will pass 3/8" mandrel bend test at -65°F.(-54°C.) and after exposure for four hours at 350°F. (177°C.). In addition to flexibility, the primer has resistance to lubrication oil (diisooctyl adipate), jet fuels (type III), humidity and salt spray.

Field exposure of the Koroflex primer has proved its excellent corrosion prevention properties. The U.S. Navy reports greater than 30% man-hour savings on corrosion maintenance for carrier-based aircraft primed with Koroflex. The U.S. Navy and the U.S. Air Force have each conducted evaluations of Koroflex primer and reported that Koroflex has excellent corrosion prevention properties as well as having flexibility and adhesion.

To date, Koroflex has been applied to several types of aircraft and used in a variety of applications. Aircraft primed with Koroflex primer include the E-2C, the C-2, the F-14, the KC-135A and the B-52. Koroflex primer has also been used over Kevlar composites and rubber substrates where it provides excellent intercoat adhesion between the rubber and topcoat.

Koroflex has found use as an alternative to polysulfide sealant type primers. Koroflex is easier to apply than polysulfide primers and provides an indefinite pot life, a smoother surface, and improved strippability. Additional information on Koroflex as a replacement for polysulfide type primers is available from DeSoto.

Koroflex primer is also recommended for use under brittle topcoats because it will continue to protect the substrate in the event that the topcoat should crack. Most primers in similar situations will also crack and both primer and topcoat may delaminate leaving the metal unprotected and subject to the onset of corrosion.

Koroflex primer is the primer of choice when excellent adhesion and corrosion protection are required in conjunction with excellent flexibility.

Coating No. 4

No technical literature available.

Coating No. 5

No technical literature available.

Coating No. 6

PRATT & LAMBERT INDUSTRIAL COATINGS DIVISION

Specialty Coatings

PRODUCT INFORMATION

EPOXY PRIMER - FILLER TYPE
TAN #487-600

#487-600 Primer-Filler Type is a two package Epoxy Primer consisting of a pigmented component, #487-600 and #120-900 Curing Agent. (#432-300 is a blue tinted version of this primer.)

TYPICAL USES: This product is designed to be used as a surfacer/filler for composite materials, Bondtite areas, fiberglass parts and may be applied as an intermediate primer where hi-fill characteristics are needed.

PHYSICAL PROPERTIES:

Epoxy Primer-Filler Type #487-600

Pounds per Gallon:	11.0 ± .5 Lbs.
Solids by Weight:	60.7 ± 1.0%
Solids by Volume:	40.0 ± 1.0%

Curing Agent #120-900

Pounds per Gallon:	7.25 ± .2 Lbs.
Solids by Weight:	15.2 ± 1.0%
Solids by Volume:	14.2 ± 1.0%

Admixed Material

Solids by Weight:	38.5 ± 1.0%
Solids by Volume:	27.1 ± 1.0%
Color:	Tan
Gloss:	Matte

MIXING INSTRUCTIONS: Mix one (1) volume of #487-600 Epoxy Primer-Filler and one (1) volume of #120-900 Curing Agent. Thorough mixing is a "must" to properly distribute the catalyst through the system. To maximize performance properties mechanical mixing is strongly recommended of the catalyzed material 10-15 minutes on a mechanical paint shaker/conditioner.

RECOMMENDED THINNING:	If further reduction is required use Epoxy Thinner #110-588.
INDUCTION TIME:	Allow admixed material to stand 20-25 minutes before applying.
SURFACE PREPARATION:	Composite Surfaces: Properly remove surface contamination. Sand or scuff as necessary. Surfaces must be clean and dry before primer/surfacer application. Bondtite Areas: Sand and "work" to desired smoothness. This filler/surfacer may be used in a one coat squeegee application to fill pin hole areas. Other filler putties also may be used to assure a smooth surface. All Bondtite areas must have a final coat of this primer/surfacer.
APPLICATION INSTRUCTIONS:	Apply the primer/surfacer system using a medium wet coat application sequence. two or three coats should be adequate to "fill" and "surface". These coats may be applied 3-4 minutes apart. Conventional air or airless equipment may be used.
RECOMMENDED FILM THICKNESS:	Total dry film thickness before sanding will range from 3-5 mils. Final film thickness before finish coat application should be 1.0-1.5 mils.
DRY TIME:	Allow to dry 4-6 hours at 77°F and 50% relative humidity to insure proper sanding characteristics. A force dry of 125°F for 1-2 hours may be used to speed sanding time. JET GLO should be applied within 24 hours.
CLEAN UP SOLVENT:	#110-588, #110-755 Thinners, or MEK.

CAUTION: Keep away from heat and open flame. Avoid prolonged contact with skin and breathing of vapor or spray mist. Do not take internally. Close container after each use.

IMPORTANT: Any worker who does not fully understand these application instructions and safety precautions or who is unable to comply with them should contact his supervisor before using this product.

The information in this report is based on tests in our laboratory. The user should thoroughly check this material for his specific requirements.

The first production Beech Starship is shown here leaving its Wichita completion centre for flight test. Instead of the more usual "green" zinc chromate, the all-composite Starship is treated with two coats of powder blue filler/primer compound before final painting. NC-4 will be delivered to the first Starship retail customer.

INTERAVIA 6/1989

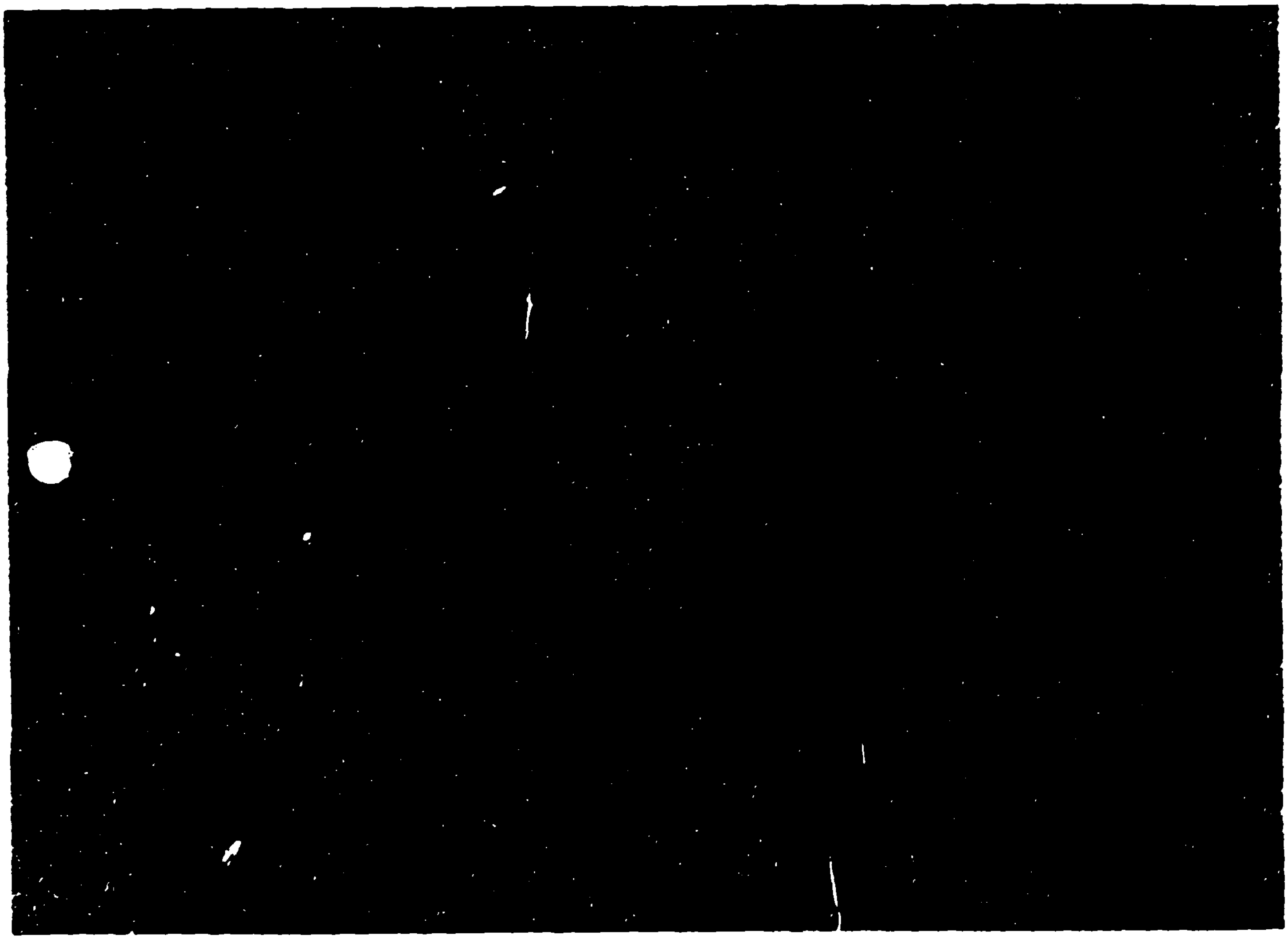
CPS 5/89

Coating No. 7

HIGH MODULUS

SYNSKIN™

COMPOSITE SURFACING FILMS



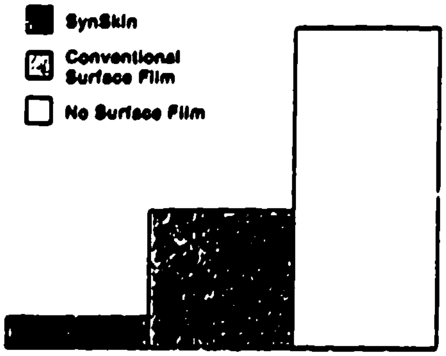
SEE THE DIFFERENCE.

HYSOL
Aerospace Products

SYNSKIN™

WHY THERE'S NO OTHER SURFACING F

SynSkin is a revolutionary composite surfacing film. It's the *only* film that provides aerodynamic smoothness and protects composite surfaces with a resistant, paintable surface – *without* the costly sanding and filling steps required with other conventional adhesive film surfacing materials.



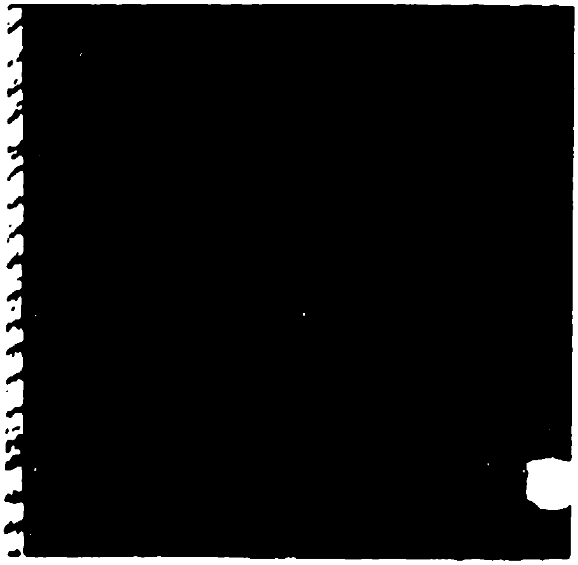
Comparison of composite surface preparation costs (per square feet).

Conventional composite surfacing films are lightweight epoxy film adhesives designed for structural bonding that have been adapted secondarily for a surfacing application. *They require extensive filling, sanding and leveling to remove surface irregularities.* Those extra steps are not only time consuming and costly, but they also frequently damage the composite part.

SynSkin, on the other hand, is composed of a unique combination of materials in a proprietary resin matrix. And because it was specifically formulated to solve honeycomb core mark-through, porosity and core crush problems, it provides a high quality smooth paintable surface with little or no secondary preparation.

LOWER COMPOSITE COSTS ..

A one step composite surfacing concept. Eliminates expe and surfacing. The result — *reduced composite manufactu*



Hysol® SynSkin surfacing films provide a smooth, paintable surface. Without costly secondary preparation steps.

Close-up of SynSkin. Its unique pressure distributing quality prevents prepreg displacement and eliminates surface porosity.

Conventional surfacing films cause core crush (left) while SynSkin surfacing films maintain core shape (right).

MAXIMUM LEVELING PROPERTIES.

What's more, SynSkin features excellent leveling properties by distributing itself evenly across uneven pressure areas. Therefore, core crush due to prepreg and surfacing ply movement along with the honeycomb pattern imprint is eliminated

PREVENTS POROSITY.

SynSkin surfacing films prevent porosity that could cause moisture to penetrate the composite. SynSkin is compatible with a wide variety of composite matrix resins and surfaces.

PERFORMANCE TESTED.

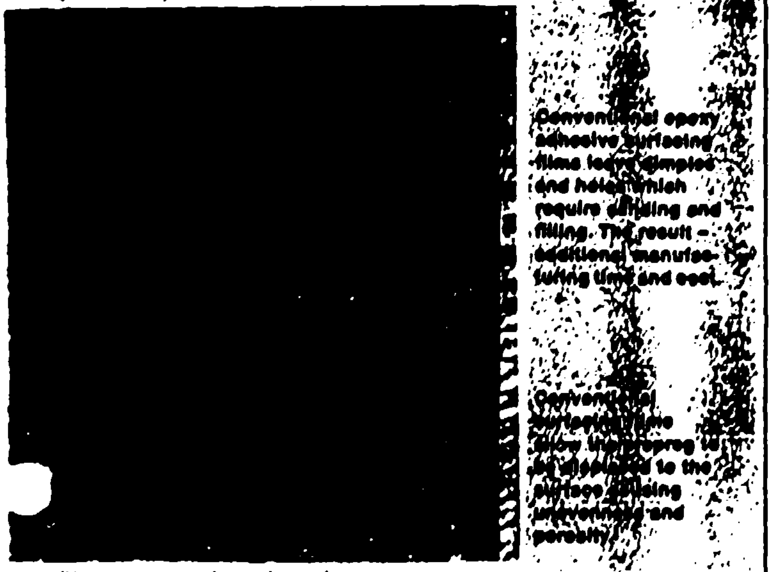
You can rely on SynSkin to deliver advanced performance under extreme conditions. Its moisture penetration resistance is proven with over 2000 simulated hot/wet flight cycles without exhibiting microcracking. On top of that, SynSkin survived 65 days in 140°F water without paint blistering. SynSkin also protects sensitive composite surfaces from environmer fluids and resists jet fuel, alcohol an. hydraulic fluids.

[illegible]

M LIKE IT.

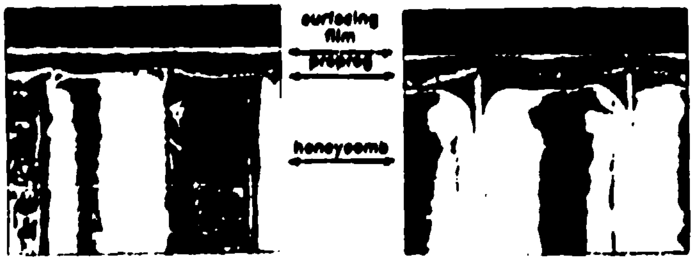
HE SYNSKIN ADVANTAGE!

secondary surface preparation like sanding, filling
costs, higher quality and efficiency.



Conventional epoxy adhesive surfacing films leave dimples and holes which require sanding and filling. The result – additional manufacturing time and cost.

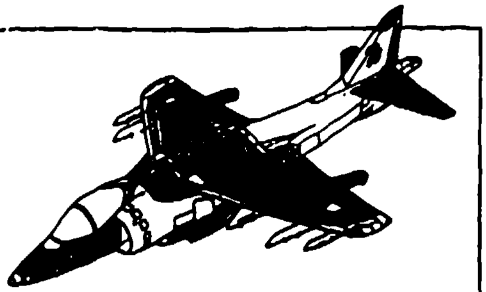
Conventional surfacing films allow the prepreg to be displaced to the surface causing [illegible] and porosity.



With SynSkin surfacing films, pressure is evenly distributed and does not allow the carbon prepreg to displace the surfacing film, thus eliminating core markthrough.

Core markthrough is caused by carbon fiber prepreg forced to the part surface by the pressure exerted through the cell walls in conventional surfacing films.

SEE THE DIFFERENCE WITH SYNSKIN!



Composites have become the structural materials of the future. Blue area shows composites usage on current fighter aircraft.

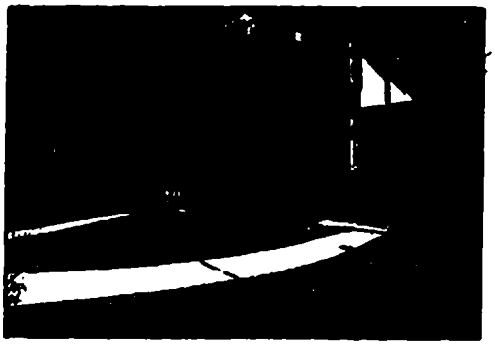
WHY SYNSKIN IS THE NEW GENERATION IN COMPOSITE SURFACING MATERIALS.

- No time consuming finishing steps. That means greater productivity, and no damage to sensitive parts.
- Delivers high quality surfaces with no core mark-through.
- Prevents core crush during cure of honey-comb stiffened parts.
- Provides durable high quality paintable surfaces.
- Compatible with a wide variety of composite prepregs and materials.
- Storable at ambient temperatures which provides long outtime to accommodate large composite assembly.
- Cocurable, sandable and machinable.
- Easy lay up.
- Protects composite surfaces during machining, routing and drilling.
- Supplied with lightweight compatible fiber mat carrier.

For more information contact:
DEXTER ADHESIVES &
STRUCTURAL MATERIALS
DIVISION, Pittsburg, CA
(415) 687-4201

HYSOL
Aerospace Products

SYNSKIN™



Hysol Aerospace Products Research Center, Pittsburg, CA

DEXTER
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Fax: (415) 687-4205
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Coating No. 8

DEXTER HYSOL

AEROSPACE ADHESIVE PRODUCTS

SYNSKIN SURFACING FILMS

APPEARANCE PANEL LAY-UP PROCEDURES

The following instructions describe the general procedure used to fabricate appearance panels using SynSkin surfacing films. The appearance panels are used as Dexter's baseline for sample specimens.

SPECIMEN MATERIALS

Honeycomb Core - HRH-10-1/8"-3.0 (Hexcel)
Cut to 8"x 12" and beveled to 5"x 9"
Ribbon in 12" direction
Prepreg - Fiberite 934 Plain Weave
Adhesive - EA 9628.06NW (used with 250F cure SynSkin)
EA 9680.05 OST (used with 350F cure SynSkin)
SynSkin - LP68908 - 250F cure version
XHC 9837 - 350F cure version

LAY-UP MATERIALS

Frekote 700 release agent
Air Weave Breather Cloth
PTFE Film
Polyester String
1/2" Aluminum Plate Tool - Polish out scratches to 400 grit smoothness

PROCEDURE

1. Place a 12"x 16" sheet of Synskin surfacing film on tool with scrim side facing upward.
2. Place one ply 12"x 16" of ± 45° prepreg on the SynSkin surfacing film.
3. Add one ply 12"x 16" of 0°/90° prepreg to lay-up.
4. Cut two 2"x 10" and two 2"x 14" strips of prepreg and place along the edges of the prepreg.
5. Cut an 8"x 12" sheet of adhesive and place in the middle of the lay-up.

6. Place honeycomb core on prepreg lay-up with 8"x 12" side towards the adhesive.

7. Cut another 8"x 12" sheet of adhesive and place on top of the honeycomb core.

8. Cut two 3"x 10" strips and two 3"x 14" strips of prepreg and place along the four edges of the lay-up.

9. Place one ply 12"x 16" of 0°/90° prepreg with a 4"x 6" cutout in the center of the lay-up.

10. Place one ply 12"x 16" of ±45° prepreg on the lay-up.

11. Cut a strip of 1" wide air-weave breather cloth and place 1" from edge of lay-up.

12. Place polyester strings on each of the four corners of the lay-up to bridge the lay-up to the airweave.

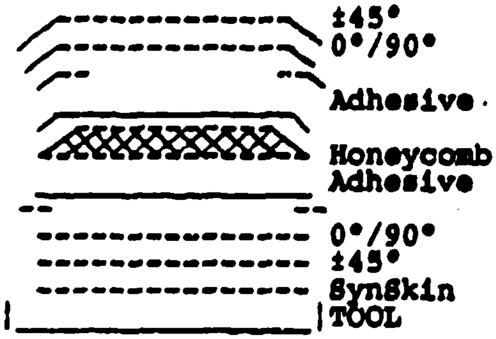
13. Place PTFE film over lay-up.

14. Bag the lay-up and pull a vacuum of 25-30 inches of mercury.

15. Cure the lay-up following the cure schedule listed in the data sheet.

16. After cure, remove the panel from the tool and lightly wet sand to remove surface imperfections and release chemicals.

LAY-UP DIAGRAM



HYSOL
Aerospace Products

STRUCTURAL ADHESIVES

PRELIMINARY DATA SHEET

SynSkin

XHC 9837
Experimental 350°F Surfacing Film

DESCRIPTION

XHC 9837 is an epoxy-based surfacing film designed to improve the surface quality of honeycomb stiffened composite parts. The product is manufactured with a non-woven fabric for support. It is offered in a thickness of 5-6 mils with a weight of .040 psf.

FEATURES

- Cocurable
- Prevents core crush and porosity
- Provides high quality paintable surface
- Maximum leveling properties

HANDLING

The product is supplied in sheet form and is ready to use as received. The film should be removed from cold storage and allowed to warm to room temperature. The fabric side of the film should be positioned and co-cured on the prepreg side of the part. This will allow easy repositioning if necessary.

APPLICATION

Surface preparation for painting consists of light wet sanding to remove release chemicals and tool imperfections.

Shelf Life: 1 year at 0°F or 6 months at 77°F

Open Assembly Time: > 30 days at 77°F

Curing: 1 hour at 350° F with 45 psi pressure (3-5°F/min heat up rate).

HAZARD WARNING
For Industrial Use Only!

CAUTION: The uncured adhesive causes eye irritation and may cause skin irritation as allergic dermatitis. Contains epoxy resins. Use good ventilation. Avoid contact with eyes or skin. Wash thoroughly with soap and water after handling. Do not handle or use until the safety Data Sheet has been read and understood. These warning are based on *Guides for Classifying and Labeling Epoxy Products According to Their Hazardous Potentialities* prepared by the Epoxy Resin Formulators and the Society of the Plastics Industry, Inc. and are based on ANSI Z129 standard.

WARNING: Before Using this product, read the contents of the Material Safety Data Sheets carefully.

AVAILABILITY
This product is available from Hysol Dexter Adhesives & Structural Materials Division, 2850 Willow Pass Road, P.O. 312, Pittsburg, CA 94565-3299. Telephone 415/687-4201, TWX 910/387-0363. FAX 415/687-4205.

8/89

DEXTER HYSOL EA 9628

AEROSPACE ADHESIVE PRODUCTS

DESCRIPTION

EA 9628 is a modified epoxy film adhesive designed for structural bonds requiring toughness. EA 9628 is available with two carrier fabrics: a knitted nylon (EA 9628) or a non-woven nylon mat (EA 9628NW). EA 9628 has excellent resistance to most environments.

FEATURES

- Film Adhesive
- 225-250°F Cure
- Good Toughness
- Bonds Many Materials
- Excellent Durability

HANDLING

This product is in sheet form and is ready to use as received. The adhesive should be removed from cold storage and allowed to warm to room temperature. All moisture should be removed from the protective packaging before opening. The adhesive film has a protective liner(s) on it which must be removed prior to parts assembly (see "Applying" below). The liner(s) always will be a contrasting color from the adhesive to allow the user easy confirmation of removal.

APPLICATION

Shelf Life – EA 9628 requires refrigerated storage. Store at 0°F or below for maximum storage. Shelf life at 0°F is greater than 6 months. Store only in sealed containers to prevent moisture contamination. Allow all moisture to evaporate from container before opening for use.

Applying – Bonding surfaces should be clean, dry and properly prepared. For optimum surface preparation consult Hysol Bulletin G1-600 "Preparing the Surface for Adhesive Bonding." The adhesive film, with one liner left on it, may be tacked to the detail part for cutting to shape and size. The liner should remain with the adhesive until just before assembly of the detail to the other faying surface. This will minimize contamination of the adhesive bond. The bonded parts should be held in contact until the adhesive has cured. Usually 25 to 50 PSI is sufficient to assure proper part mating.

Open Assembly Time – EA 9628 may be used within the following schedule after removing from cold storage:

At 75°F	at least 20 days
At 90°F	at least 10 days

Curing – EA 9628 may be cured for 1 hour at 250°F, or 90 minutes at 225°F. Heat up rate to the cure temperature is not critical, but should be between 4°F and 7°F per minute. Pressure should be applied before heating the parts to be bonded and maintained until cool down of the assembly.

Cleanup – It is important to remove excess adhesive from the part and bonding tools before it hardens. Once the adhesive is cured, it is difficult to remove except by mechanical abrasion. Uncured adhesive may be removed with denatured alcohol and many common industrial solvents. Be careful to prevent any solvent from entering the uncured bondline as solvent will degrade the final bond performance. Consult with your supplier's information pertaining to the safe and proper use of solvents.

BOND STRENGTH PERFORMANCE

Tensile Lap Shear Strength

Tensile lap shear strength tested per ASTM D 1002 after curing as shown below. Adherends are 2024-T3 clad aluminum treated with phosphoric acid anodize per BAC 5555. Performance is comparable when a state of the art corrosion inhibiting primer is used, such as Hysol's EA 9228. Film weight is 0.060 PSF.

	Typical Results (PSI)	
Test Temperature, °F	**Knit Support Cured 1 hr.@250°F**	**Non-Woven Support Cured 1.5 hrs.@235°F**
-67	5500	5500
75	6000	5800
180	4000	—

Bulk Resin Properties

Tensile Properties – tested using 0.125 inch castings per ASTM D 638.

Tensile Strength, PSI @ 75°F	7500
Tensile Modulus, PSI @ 75°F	345,000
Elongation at Break, % @ 75°F	7.5
Shore D Hardness @ 75°F	83.0
T_g dry	248
T_g wet	210
Shear Modulus dry (via Dynamic Mechanical Thermal Analyzer, KHI)	90.5

Compressive Properties – tested using 0.5 inch castings per ASTM D 695.

Compressive Strength, PSI @ 75°F	11,500
Compressive Modulus, PSI @ 75°F	310,000

Electrical Properties – tested per ASTM D 149, D 150.

Dielectric Constant	0.087 @ 1 KHz
Dissipation Factor	356 @ 1 KHz
Dielectric Strength	>358 volts/mil

HAZARD WARNING

For Industrial Use Only!

CAUTION: The uncured adhesive causes eye irritation and may cause skin irritation as allergic dermatitis. Contains epoxy resins. Use good ventilation. Avoid contact with eyes or skin. Wash thoroughly with soap and water after handling. Do not handle or use until the Safety Data Sheet has been read and understood. Do not cut or weld empty container. These warnings are based on *Guides for Classifying and Labeling Epoxy Products According to Their Hazardous Potentialities*, prepared by the Epoxy Resin Formulators Division and the Society of the Plastics Industry, Inc., and are based on ANSI Z129 standard.

WARNING: Before using this product, read the contents of the Material Safety Data Sheets carefully.

AVAILABILITY

This product is available from Hysol Aerospace and Industrial Products Division, 2850 Willow Pass Road, P.O. Box 312, Pittsburg, CA 94565-3299. Telephone 415/687-4201. TWX 910/387-0363

Revised 2/88

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A DIVISION OF THE SPECIALTY CHEMICALS & SERVICES GROUP
THE DEXTER CORPORATION

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After Exposure to/Test Temperature

Test Temperature, °F	Typical Results (PSI)	
	Knit Support Cured 1 hr.@250°F	Non-Woven Support Cured 1.5 hrs.@235°F
Control	6300	6300
75°F Water-30 days/75°F	6300	6300
120°F-100%RH-30 days/75°F	5900	5900
Hydraulic Oil-7 days/75°F	6500	—
JP-4 Fuel-7 days/75°F	6100	6100
Salt Spray-105°F-30 days/75°F	6100	6100
75°F Anti-icing F' -7 days/75°F	6300	6300

Peel Strength
T Peel strength tested per ASTM D 1876 after curing as shown above. Adherends are 2024-T3 clad aluminum treated with phosphoric acid anodize per BAC 5555.

Test Temperature, °F	Typical Results (PLI)	
	Knit Support Cured 1 hr.@250°F	Non-Woven Support Cured 1.5 hrs.@235°F
-67	28	—
75	37	—
180	34	—

Metal to Metal Climbing Drum Peel strength tested after curing as shown above. Adherends are 2024 T3 clad aluminum treated with phosphoric acid anodize per BAC 5555.

Test Temperature, °F	Typical Results (In. Lb./In.)	
	Knit Support Cured 1 hr.@250°F	Non-Woven Support Cured 1.5 hrs.@235°F
-67	50	45
75	70	65
180	60	55

Crack Extension tested per ASTM D 3433

Test Mode, °F	Typical Results (Lb./In.)	
	Knit Support Cured 1 hr.@250°F	Non-Woven Support Cured 1.5 hrs.@235°F
G_{Ic}	8	16.4
G_{Ia}	6	11.9
G_{Iscc} (5 weeks)	—	7.4
G_{Iscc} (15 weeks)	—	5.7

Honeycomb Sandwich Performance
Honeycomb sandwich strength tested after curing as shown above. Adherends are 2024 T3 clad aluminum with ¼ inch cell 5052 nonperforated aluminum core.

Honeycomb Climbing Drum Peel Strength

Test Temperature, °F	Typical Results (In. Lb./In.)	
	Knit Support Cured 1 hr.@250°F	Non-Woven Support Cured 1.5 hrs.@235°F
-67	18	15
75	20	21
180	16	15

Flatwise Tensile Strength

Test Temperature, °F	Typical Results (PSI)	
	Knit Support Cured 1 hr.@250°F	Non-Woven Support Cured 1.5 hrs.@235°F
75	1400	1300

Service Temperature
Service temperature is defined as that temperature at which this adhesive still retains 1000 PSI using test method ASTM D 1002 and is 250°F.

Coating No. 9

Aerospace
Technical Data Sheet

Issue No. 2
March, 1986
Supersedes previous product data

Structural Adhesive Film AF-32

Introduction:

"Scotch-Weld" Brand Bonding Film AF-32 is an unsupported, thermosetting film adhesive designed for metal to metal bonding where especially high peel strengths are required.

AF-32 film adhesive offers the following advantages:

- Exceptionally high peel strength at service temperatures from −67°F. to 250°F.
- Good flexibility and shear strength at service temperatures from −67°F. to 250°F.
- Easy application in a dry film which can be pressure, heat or solvent tacked in position.
- Excellent retention of strength after aging in many environments.
- Excellent adhesion to most metals including aluminum, titanium, stainless steel, cadmium, nickel, brass and others.
- Qualification to military specification MMM-A-132 Type I Class 2 and EC-1660 primer. This system is known as AF-6032.

Description:

Form:	Flexible unsupported film, protected by a suitable liner.
Color:	Yellow to Brown
Nominal Caliper:	10 mils
Weight:	0.050 - 0.060 lbs./sq. ft.
Volatile Content:	Less than 5% (2-4 gm. sample cured 1 hr. @ 350°F.)
Availability:	Maximum width is 20 inches. Standard roll is 36 yds.
Shrinkage:	5% maximum (24 hrs. @ 75 ± 5°F. in horizontal position)

Product Performance:

I. MMM-A-132 Type I Class 2 Test Data

The following is a summary and a list of average test results for the structural adhesive system AF-32 with EC-1660 primer when bonded specimens were prepared and tested in accordance with Military Specification MMM-A-132, Type 1 Class 2.

Product Performance: (cont.)

Test Condition	MMM-A-132 Type 1 Class 2 Requirement	AF-32/EC 1660 Test Results
A. Tensile Shear		
1. Normal Temp. (75°F.)	2500 psi	4085 psi
2. 10 min. @ 180°F.	1250 psi	2286 psi
3. 10 min. @ −67°F.	2500 psi	5086 psi
4. Normal Temp. (75°F. after 30 days immersion in Salt Water Spray)	2250 psi	3818 psi
5. Normal Temp. (75°F. after 30 days immersion @ 120°F. and 95-100% Relative Humidity)	2250 psi	3825 psi
6. Normal Temp. (75°F. after 30 days immersion in Tap Water)	2250 psi	3898 psi
7. Normal Temp. 75°F. after 7 days immersion in JP4 Fuel (MIL-J-5624)	2250 psi	3631 psi
8. Normal Temp. 75°F. after 7 days immersion in Anti-icing fluid (MIL-F-5566)	2250 psi	3798 psi
9. Normal Temp. 75°F. after 7 days immersion in Hydraulic Oil (MIL-H-5606)	2250 psi	4238 psi
10. Normal Temp. 75°F. after 7 days immersion in Type III Hydrocarbon Fluid (MIL-S-3136)	2250 psi	3643 psi
B. Creep Rupture		
11. Normal Temp. (75°F.) 192 hrs. @ 1600 psi	0.015" maximum deformation	0.012 inches
12. 180°F., 192 hrs. @ 800 psi	0.015" maximum deformation	0.014 inches
C. Fatigue		
13. Normal Temp. (75°F.) 750 psi @ 10^6 cycles	No glue line failure	No glue line failure
D. Other Tests		
14. Normal Temp. (75°F.) T-Peel	15 piw	58 piw
15. Tensile Shear (75°F.) Blister Detection	2250 psi	3858psi

II. Miscellaneous Test Data

A. AF-32/EC-1660 Storage Life Testing

The following data indicates that the AF-32 — EC-1660 system does not degrade on aging at 75 ± 5°F. for 3 months.

A cure cycle of 100 psi bonding pressure applied by a platen press and a 200° F./minute bond line temperature rise from 80°F. to 350°F. with 120 ± 1 minute at 350 ± 2°F. was used. All properties were measured on 1" wide, ½" overlap specimens cut from .063" thick 4" x 7" bonded panels of 2024 T3 clad aluminum. Tests were conducted according to MMM-A-132 methods.

Test	Test Temperature	Unaged	Average Aged 3 months (75 + 5°F)	Type Failure
Shear Strength	75 ± 2°F	3825	4191 psi	Cohesive
Shear Strength	180 ± 2°F	2287	2222 psi	Cohesive
Shear Strength (After 30 day Salt Spray FED STD 151)	75 ± 2°F	3818	4020 psi	Cohesive

Product Performance: (cont.)

B. AF-32/EC-1660 Primer Shear Strength on Aluminum

−67°F.	5067 psi
75°F.	3835 psi
180°F.	2287 psi
250°F.	1480 psi
350°F.	970 psi
400°F.	630 psi
500°F.	390 psi

C. AF-32/EC-1660 Primer T-Peel Strength

T-Peel bonds consist of two EC 1660 primed 8" x 8" x .020" 2024 T3 clad panels bonded together with a 6" x 8" section of film. This panel is then cut into 1" x 8" T-peel specimens which are peeled at a 90° angle to the bond line with a jaw separation rate of 20 inches/minute. Cure cycles were as indicated.

Platen Press Cure: 350°F., 60 minutes, 150 psi, 10°F./minute temperature rise rate.

−67°F.	10 piw
75°F.	60 piw
180.F.	25 piw
250°F.	15 piw

D. AF-32/EC-1660 Primer Overlap Shear After Aging For 1, 2, and 3 Years In South Florida

	Control	1 Year	2 Years	3 Years
−67°F.	4491 psi	4560 psi	4900 psi	4800 psi
75°F.	4216 psi	3880 psi	4350 psi	3930 psi
180°F.	2186 psi	2250 psi	2510 psi	2340 psi
250°F.	1336 psi	1320 psi	1550 psi	1520 psi
300°F.	1036 psi	1120 psi	1140 psi	940 psi

Cured 60 minutes @ 350°F., 100 psi, 10°F./minute rise rate

III. Miscellaneous Data AF-32

A. AF-32 Coefficient of Thermal Expansion

Below 5°F.	860 x 10^{-7} in/in/°F.
Above 5°F.	1700 x 10^{-7} in/in/°F.

B. AF-32 Modulus of Elasticity

−67°F.	234,000 psi
75°F.	3,900 psi
180°F.	1,630 psi
300°F.	1,415 psi

C. AF-32 Ultimate Tensile Stress

−67°F.	9320 psi
75°F.	2290 psi
180°F.	763 psi
250°F.	606 psi

Application:

Proper adhesive application is as important as proper bond design and adhesive choice to obtain maximum joint properties. Improper adhesive application techniques can result in partial or complete failure of an assembly.

AF-32 performance data reported in a later section (Test Results) was developed using the following suggested procedures. Variations from these procedures should be fully evaluated to insure bond properties sufficient to meet the requirements of your particular application.

Surface Preparation

A thoroughly cleaned, dry, grease free surface is essential for maximum performance. Cleaning methods which will produce a break-free water film on metal surfaces are generally satisfactory. Surface preparations should be fully evaluated with the adhesive, especially if resistance to specific environments are anticipated.

Suggested Cleaning Procedure for Aluminum

1. Vapor Degrease — Perchloroethylene condensing vapors for 5-10 minutes.
2. Alkaline Degrease — Oakite 164 solution (9-11 oz./gallon of water) at 190 ± 10°F. for 10-20 minutes. Rinse immediately in large quantities of cold running water.
3. Acid Etch — Place panels in the following solution for 10 minutes at 150 ± 5°F.

   Caution: Use adequate respiratory, eye and skin protection when using etch solutions.

Sodium Dichromate ($Na_2Cr_2O_7 2H_2O$)	4.1 - 4.9 oz./gallon
Sulfuric Acid, 66° Be	38.5 - 41.5 oz./gallon
2024T-3 aluminum (dissolved)	0.2 oz./gallon minimum
Tap Water	Balance

4. Rinse — Rinse panels in clear running water.
5. Dry — Air dry 15 minutes
   Force dry 10 minutes at 150°F. ± 10°F.
6. It is advisable to coat the freshly cleaned surfaces with primer within 4 hours after surface preparation.

Primer Application

Advantages

Priming of bonding surfaces offers two distinct advantages: (1) Priming insures complete wetting of metal surfaces which normally results in superior environmental and low temperature properties, and (2) Priming simplifies production by protecting cleaned parts until bonding can be completed. EC-1660 has been applied successfully by flow coating, brushing and spraying.

Caution: EC-1660 is flammable. See the EC-1660 Product Specification Sheet for application techniques and precautionary measures.

Primer Dry

A primer dry which will result in a solvent free coating is generally satisfactory. Drying temperatures above 300°F. should be avoided, since a primer overcure will hinder the wetting action of the adhesive film to the primer. Suggested EC-1660 Dry Cycle:

Air Dry	30 minutes at 75 ± 5°F.
Force Dry	Circulating air oven with part above 200°F. but not exceeding 250°F. for 30 minutes.

Film Application

1. Cut portion of film to be used from roll with protective liner in place.
2. Place film on metal using the liner as a protective cover.
3. Roll film into position with a rubber roller insuring that no air is trapped between primer and film.
4. Remove protective liner.
5. Assemble parts and cure.

Application (cont.)

Cleanup

Excess primer and equipment may be cleaned up, prior to curing, with ketone* type solvents.

*Note: When using solvents for cleanup, extinguish all sources of ignition in the area and observe proper precautionary measures for handling such materials.

Cure Cycle

General Cure Requirements

Time, temperature and pressure determine the final bond properties and may be effected by the type of curing equipment used for each specific application. In general, the cure properties of AF-32 are as follows:

Tack, Flow and Cure Initiation Temperatures

The tack, flow and cure initiation temperatures for AF-32 are a time temperature relationship and depend upon the rate of heat input. Normally, AF-32 will have the following properties:

Tack Temperature: 160-180°F.
Flow Temperature: 180-220°F.
Cure Initiation Temp.: 220-270°F.

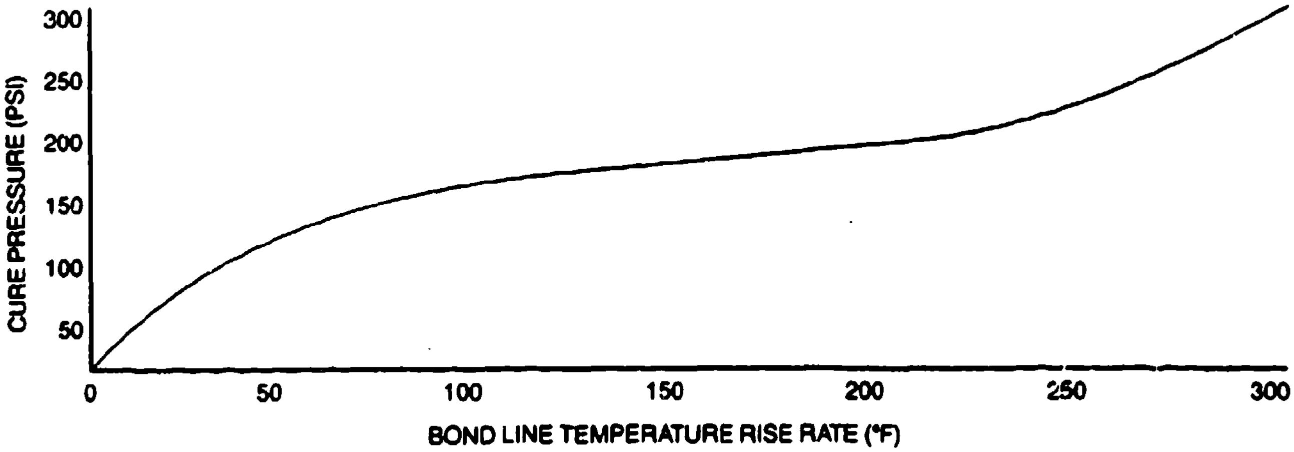
Cure Pressure

Pressure is required during cure to form the part being bonded and contain any volatiles given off by the adhesive. Cure pressure may be applied in any manner which will insure uniform constant pressure throughout the bond area. *Pressure must be uniformly applied before the curing reaction begins and maintained until a complete set has been effected.* (i.e., the bond line temperature has reached approximately 300°F.) After this point is reached, the cure may be completed without pressure if the hot strength of the adhesive is sufficient to maintain contact of the parts being bonded.

The pressure required to contain volatiles is dependent on the rate at which bond line temperature is brought to the cure temperature. The bond line temperature rise rate for AF-32 can be varied from 1°F. to 300°F./minute. Rise rate (and cure pressure required) will depend on application, cure temperature, bonding equipment, method of heat application, production limitations and bond properties required.

Figure I depicts typical pressures required for various bond line temperature rise rates in platen presses.

CURE PRESSURE vs BOND LINE TEMPERATURE RISE RATE IN PLATEN PRESSES



Application (cont.)

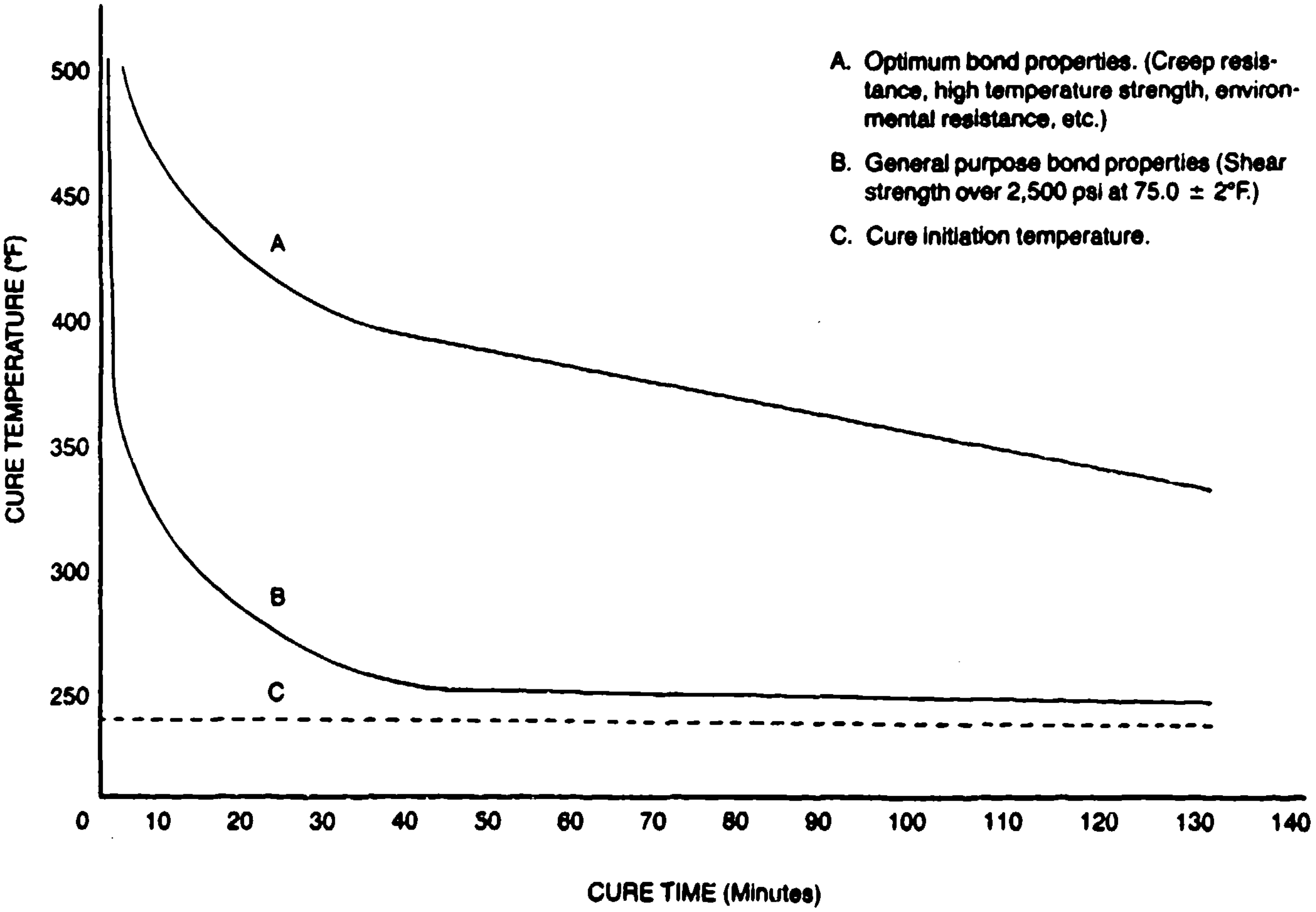
Cure Temperature

The cure temperature may be varied from 250°F. to 450°F., depending on the materials being bonded, equipment available and bond properties desired. The desired pressure must be applied before the glue line reaches 160°F. The film will soften as temperature is increased to 180-210°F. and will wet the surface to which it has been applied. A chemical cure will be initiated between 200 and 270°F. and a low strength gel formed. Continued heating chemically converts this gel into a high strength, solvent resistant bond. AF-32 will change color only slightly upon application of heat. Edges of the bond which are exposed to air will change from yellow to rusty brown.

Cure Time

Cure time depends on the cure temperature used, methods of heat application, production limitations and bond properties required. Since no two bonding operations are exactly alike it is suggested that a few simple experiments be conducted, varying both temperature and cure time to determine optimum conditions for the particular application. Figure II is a guide from which an approximate cure cycle can be taken for various cure times or temperatures.

FIGURE II



A. Optimum bond properties. (Creep resistance, high temperature strength, environmental resistance, etc.)

B. General purpose bond properties (Shear strength over 2,500 psi at 75.0 ± 2°F.)

C. Cure initiation temperature.

Application (cont.)

Suggested Cure Cycle

The following press cure cycle is suggested to obtain dense glue lines and was used to obtain the strengths reported in the Test Results section unless otherwise stated.

1. Apply a pressure of 100 psi prior to reaching a bond line temperature of 150°F. and maintain throughout the press cure cycle.
2. Raise the bond line temperature from ambient to 350°F. at a rate of 10-12°F. per minute.
3. Cure for 120 ± 1 minute at 350°F.
4. Cool to below 200°F. bond line temperature prior to release of pressure. (In laboratory tests, panels have been removed at 350°F. with no adverse effects.)

Storage and Handling:

Storage at 40 ± 5°F. is suggested for AF-32 (film) and EC-1660 (primer) to obtain maximum shelf life. Rotate stock on a "first in-first out" basis. *Caution* — AF-32 should be permitted to warm to room temperature (75 ± 5°F.) before being used to prevent moisture condensation.

Precautionary Information:

See Material Safety Data Sheet for precautions during use.

Important Notice to Purchaser:

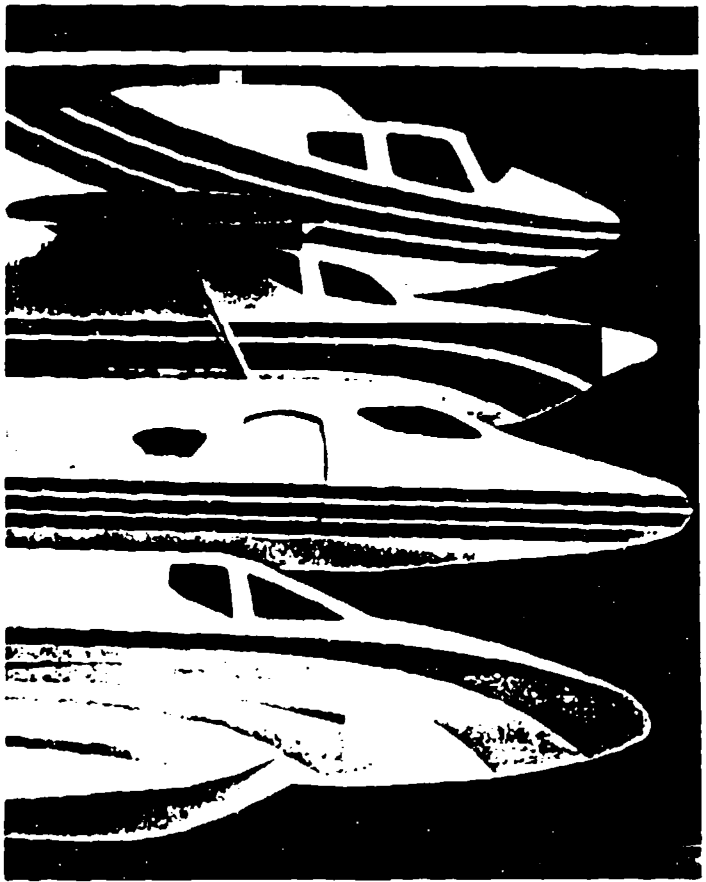
All statements, technical information and recommendations contained herein are based on tests we believe to be reliable, but the accuracy or completeness thereof is not guaranteed, and the following is made in lieu of all warranties, express or implied:

Seller's and manufacturer's only obligation shall be to replace such quantity of the product proved to be defective. Neither seller nor manufacturer shall be liable for any injury, loss or damage, direct or consequential, arising out of the use of or the inability to use the product. Before using, user shall determine the suitability of the product for his intended use, and user assumes all risk and liability whatsoever in connection therewith.

No statement or recommendation not contained herein shall have any force or effect unless in an agreement signed by officers of seller and manufacturer.

Coating No. 10

DUPONT · IMRON



AIRCRAFT · FINISHES

DU PONT
AIRCRAFT
REFINISH
PRODUCTS

The Aircraft Finishing System with the "Wet Look" That Lasts

Introduction

This booklet is intended as a guide for the professional applicator and for those possessing the basic knowledge of materials and the skills required for aircraft painting.

It will also be useful to aircraft owners to acquaint them with the requirements of proper aircraft finishing and to aid them in selecting and specifying the best finish for their plane.

Contents

IMRON® Offers You:

1. A hard finish that keeps a just-painted "wet look" up to 20 to 40 percent longer than its nearest competitor.
2. Superior flexibility for great chip resistance.
3. Excellent gloss and chemical resistance.
4. A slick surface that shrugs off most dust, dirt and grime.
5. A choice of more than 2,100 colors.
6. Ease of application: Just add activator, stir well and spray.
7. No reducers or thinners are required for normal application, however, a reducer and a retarder are available if desired.
8. Short dry-to-tape time—two to three hours with 189S Accelerator.
9. Pot life of eight hours under normal conditions.

Products

Du Pont makes a complete line of materials to provide a top-quality finish for aircraft.

IMRON® Polyurethane Enamel Aircraft Finish
IMRON 192S Activator
IMRON 189S Dry Time Accelerator
IMRON 259S Paint Additive (for control of fisheyes and cratering)
8485S Reducer
8100S Retarder
CORLAR® Epoxy Primer **824S** Light Gray or **825S** Red Oxide
CORLAR® 826S Activator
VARIPRIME 615S Primer
VARIPRIME 616S Convertor
36025 Thinner
3812S or **3832S** Reducer/Cleaner
3919S or **3929S** **PREPSOL®** Solvent/Cleaner
224S Steel Conversion Coating
225S Aluminum Metal Cleaner

226S Aluminum Conversion Coating

227S Galvanized Iron and Zinc Conversion Coating

5662S Paint Remover

These products are readily available through a large nationwide network of jobbers. In addition, there is a complete line of Du Pont automotive refinish products available through these outlets.

For the name of your local jobber, call the nearest Du Pont Service Center listed on the back cover of this booklet.

For the name of the nearest applicator of Du Pont Aircraft Finishes, see our listing under Services-Painting in the AVIATION BUYER'S DIRECTORY.

General Information

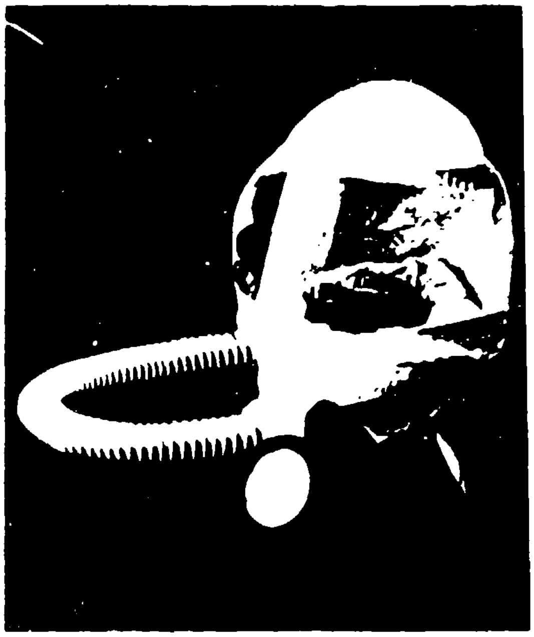
IMRON polyurethane enamel is a superior finish for aircraft. It provides outstanding appearance, excellent chemical resistance and superior durability. (See graph on page 6). However, in order to perform properly, it must have a well-prepared base. Carefully follow the recommendations of this booklet for the substrate on which you are working.

Strip the Plane
Besides adding unwanted extra weight to an aircraft, excessive paint thickness on metal or fiberglass can cause the finish to crack. Don't paint over the old finish even if it's the original one. (A three-color repaint can build up to twelve coats of paint in some areas. This can result in cracking, a disappointed owner and the need to repaint).

Avoid Filiform Corrosion
Filiform corrosion is a line of corrosion between the aluminum skin of the aircraft and the paint film. It involves an inorganic chemical salt and can be triggered by high humidity (65% or more) or by metropolitan area or industrial air pollution.

Filiform corrosion can ruin an otherwise beautiful paint job. Guard against filiform corrosion and normal oxidation by using the proper Du Pont metal treatment and/or conversion coating.

Safety
When using the products recommended in this booklet, read all product labels carefully and observe the warnings given thereon. Observe OSHA requirements and wear safety goggles, protective clothing, gloves and respirator as specified on the label



Many of these products are extremely flammable. The vapors may cause a flash fire. Keep away from heat, sparks and open flame.

Some products contain aliphatic polyisocyanates and most contain a variety of solvents. The vapors and spray mist are harmful if inhaled. They may irritate skin and eyes and are harmful or fatal if swallowed. Read label warnings and follow all precautions.

First aid treatment is given on each label and may be different for different products. If necessary to administer first aid be sure to follow the directions given on the label of the product in use. If any product is swallowed, call a physician immediately.

Overall Refinishing

In order to assure complete coverage and avoid bare spots or ding, all control surfaces should be removed and stripped and ited separately. When repainted, the control surfaces should be nstalled and balanced according to appropriate procedures set forth in Federal Aviation Administration Regulations.

Metal

Surface Preparation

Mask off all bond joints, assembly seams, fiberglass and plastic parts with aluminum tape. Mask all window areas with aluminum tape and aluminum foil. Be sure masking is tightly sealed to prevent vapor penetration. Some solvents in stripper or cleaners can cause clouding or crazing of acrylic glazing.

Remove old finish with Du Pont 5662S Paint Remover or a commercial-grade aircraft stripper.

Rinse thoroughly with water. Remove tape and foil. After the skin has dried, solvent wipe with Du Pont 3613S Lacquer Thinner.

Clean and condition metal surfaces with the proper cleaner (listed at right) according to label directions. Follow with an application of the proper conversion coating, again following label directions.

Apply primer as soon as possible after preparing the surface, but first thoroughly inspect the areas where conversion coating can collect. Examine to determine that the areas are dry. Exposure of unprimed metal to moisture in the air, even after metal treatment, can cause adhesion problems when painted.

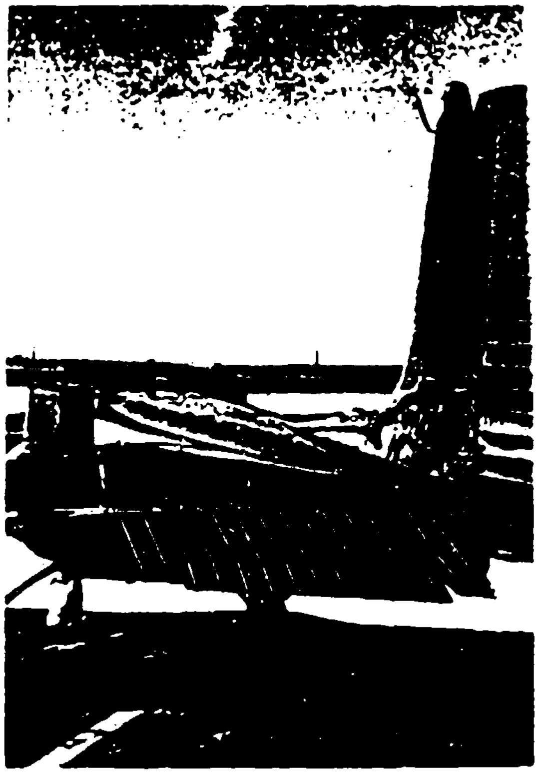
Undercoat Application

The service and conditions of use encountered by aircraft require maximum adhesion of the finish to the aircraft surface. For this reason we recommend either Corlar® Epoxy Primer or Variprime® Primer for overall refinishing.

For aluminum, magnesium or fiberglass surfaces, Corlar® or Variprime® may be used. For steel surfaces we recommend Corlar® 825S Red Oxide or Variprime® applied according to label directions.

CORLAR® is a two package system requiring that 826S Activator be mixed with 824S or 825S Epoxy Primer. Care must be taken to assure thorough mixing of the two components. Mechanical agitation is suggested. If the activator and primer are not thoroughly mixed, unactivated primer may be applied to the surface. This can cause blushing, lifting, poor adhesion, or other problems.

After adding activator, thin to correct viscosity with up to 35% 3602S thinner. Viscosity should be 20-23 seconds with Du Pont Viscosity Cup or #2 Zahn Cup. Before spraying, allow the mix to induct at least one hour at 70°F. or above, two hours at 55-70°F. Do not spray CORLAR if temperature is 55°F. or less. Use mixed material within three days (at 70°F.).



Prime entire surface to be painted with CORLAR epoxy primer. Spray one full wet coat.

At normal temperature and film build, allow primer to dry at least four hours before topcoating. Lower temperatures or high film build will require longer dry time. Sand lightly and wipe with 3812S or 3832S.

Variprime® is also a two component primer. The easy-to-mix product is ready to spray without an induction period. 8100S may be used as a retarder. Optimum viscosity is 17-19 seconds with the Du Pont M-50 Viscosity Cup or #2 Zahn Cup. Pot life of the mixed material is 3-4 days.

Prime entire surface to be painted with Variprime®. Spray one full wet coat. Variprime® is a non-sanding primer if topcoated within 24 hours. If sanding is necessary, allow a minimum of one hour dry at 70°F. Sand lightly and wipe with 3812S or 3832S.

A special note: Over most substrates Variprime® is self-etching, but for aircraft usage we recommend both cleaning and conditioning the metal surfaces to ensure maximum adhesion.

Topcoat Application

Mixing: Stir thoroughly. Mix three parts IMRON with one part 192S Activator. Mix thoroughly. To obtain faster tape-free time, faster cure and easier handling, we recommend the use of 189S Accelerator (4 ounces per gallon). Mix no more material than will be used in an eight-hour period. Pot life of mixture is eight hours at 70°F. Following mixing, strain material. Spray viscosity should be 18-22 seconds (Du Pont Viscosity Cup or #2 Zahn Cup). If desired, material may be further reduced with Du Pont 8485S Reducer or 8100S Retarder. This will help to eliminate dry overspray in hot weather. Check viscosity every four hours and reduce if necessary.

Dust and tack wipe surface before spraying.

METAL	CLEAN WITH	CONDITION WITH
Aluminum or anodized aluminum	225S	226S
Magnesium	3812S or 3832S	226S with 5 parts water
Steel	3812S or 3832S then 5717S	224S
Zinc, Galvanized Metal, Brass, Bronze, Copper, Nickel	3812S or 3832S then 5717S	227S
Stainless Steel, Iron	3812S or 3832S sand, then 5717S	224S
Chrome, Tin	3812S or 3832S	225S

Application of Solid Colors
With siphon equipment, use 50 pounds pressure at the gun. Spray a medium first coat. Allow to tack up and follow with full second coat.

With pressure pot equipment, use 65-70 pounds pressure at the gun and a fluid delivery rate of 12-20 ounces per minute.

With airless spray equipment, use a tip with a .009"-.013" orifice and 1,000-1,400 pounds pressure.

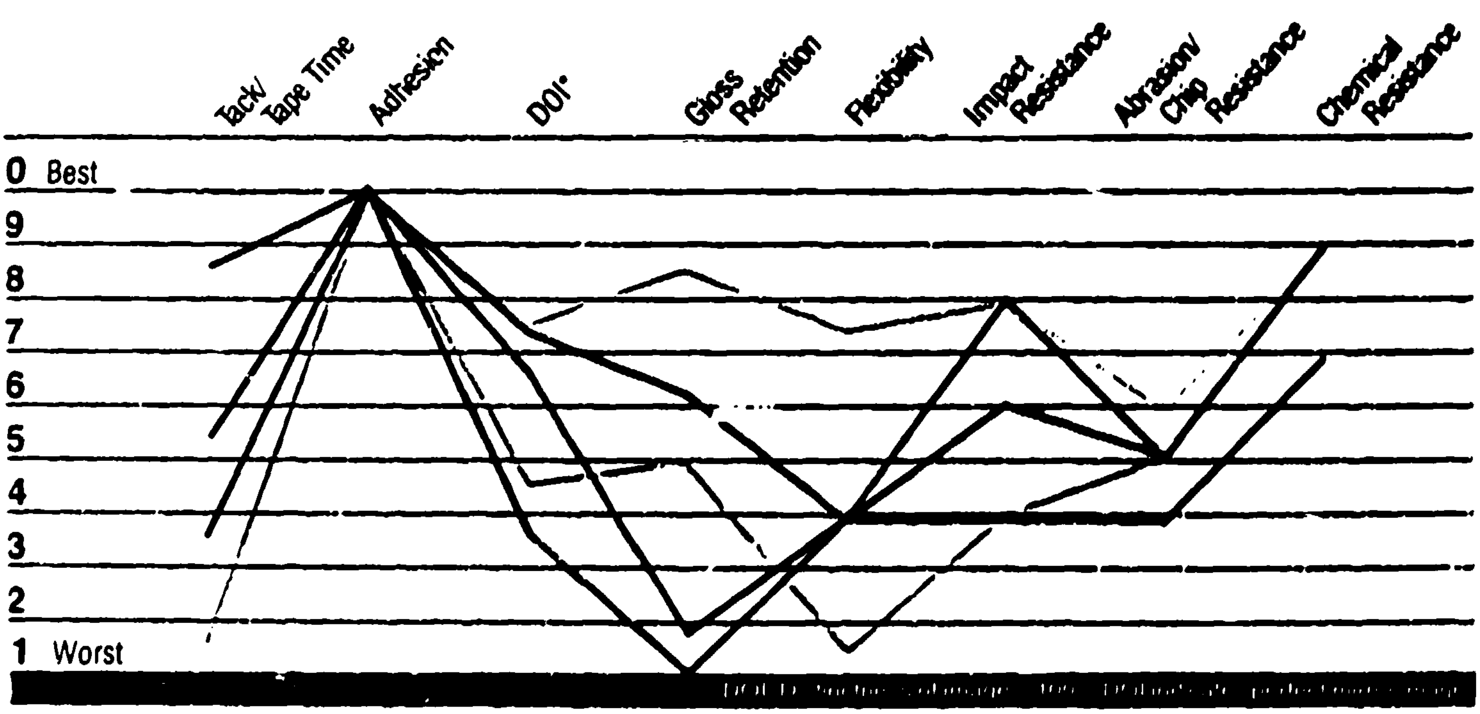
Application of Metallics
With siphon equipment, use 65 pounds pressure and apply a light medium coat as a tack coat. Allow to set up 20 minutes, then apply a second light medium coat. Further reduce 15% with 8485S (17-18 seconds Du Pont Viscosity Cup or #2 Zahn Cup) and apply a third light medium coat. If desired, another light medium coat of the reduced material may be used. Metallics can be clear coated with 500S IMRON® Clear if desired.

With pressure pot equipment, use 65-75 pounds at the gun and a fluid delivery rate of 8-14 ounces per minute.

Recoating, Two-Toning, Striping, Lettering and Decalcomania
Recoating can be done at any stage of dry. Two-toning, striping, lettering or decals may be applied when tape-free (see pg. 9). For films cured over 72 hours, scuffsand before recoating, striping, lettering or applying decals. Do not scuff-sand metallics when clear coating with 500S. (Follow label directions.)

IMRON®... The Look of Leadership

See for yourself how IMRON® polyurethane enamel compares with competitive urethanes.



Tape-Free Time
At 77°F., 50% relative humidity, IMRON will dry tape-free in 2-4 hours when 189S Accelerator is used (4 oz./gal.). Without accelerator, tape-free time is 6-10 hours. If temperature is below 77°F., overnight dry is recommended.

Fisheyes
Use 259S Paint Additive (¼ to 1 ozs./gal.) in case of fisheyes. Do not use FEE.

Force Drying
Although IMRON without additives may be force dried up to 250°F., the temperature should not exceed 150°F. for aircraft.

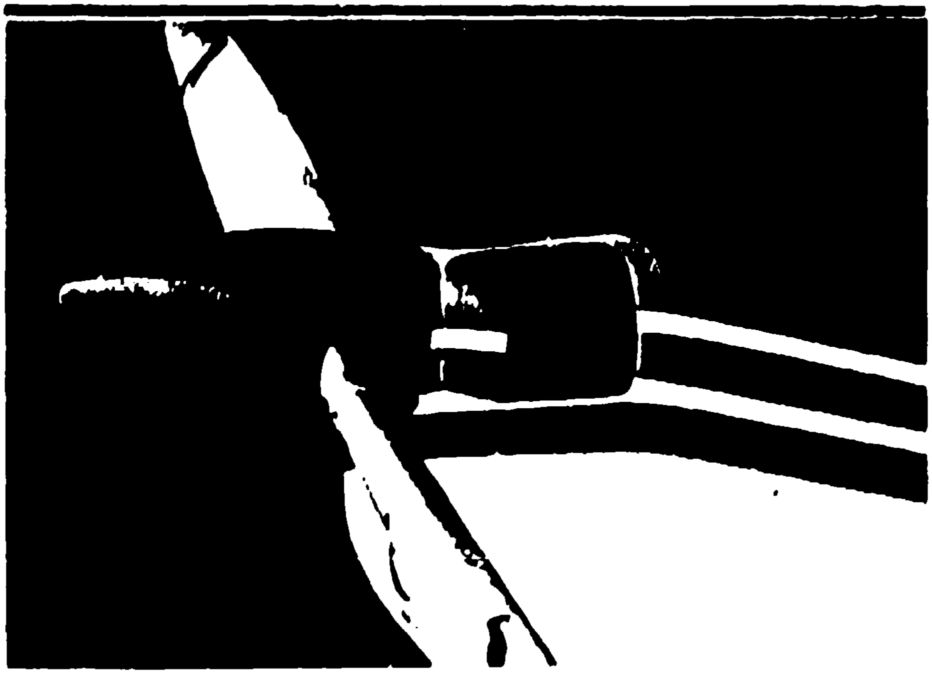
Cleanup
Clean up equipment promptly with Du Pont lacquer thinner or 8485S Reducer. DO NOT LEAVE MIXED MATERIAL IN EQUIPMENT.

Fiberglass-Reinforced Polyester

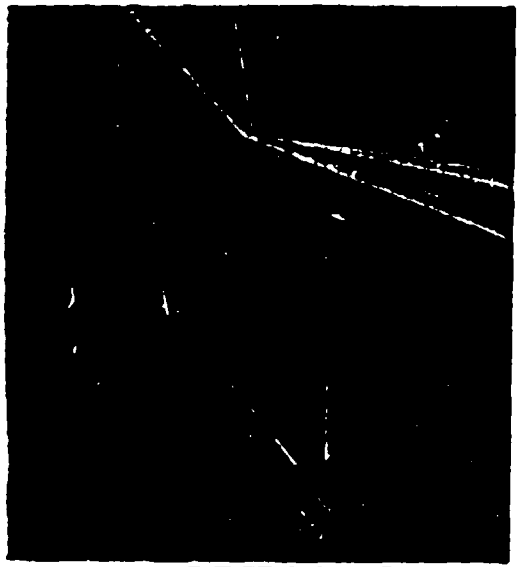
Surface Preparation
Wash old finish with soap and water and clean with PREPSOL. Remove old finish completely by sanding and wipe with 3812S or 3832S to remove sanding dust. Do not use prepared paint strippers to remove the old finish. They will attack and soften the plastic. It is not necessary to prime polyester if the gel coat is not porous. Apply the first coat of IMRON immediately.

Wood or rigid plastics other than fiberglass-reinforced polyester may be treated in the same way, except do not wash wood or porous plastics with soap and water.

Topcoat Application
Follow the same procedure as recommended for metal surfaces (page 7).



*Shop Photos Courtesy AIRCRAFT REFINISHERS, Middletown, DE



Fabric

Du Pont has conducted no tests and has no data on the performance of IMRON when applied to fabric.

IMRON cannot be applied to undoped fabric. However, we are aware of cases in which IMRON applied to properly doped fabric has performed satisfactorily.

The procedure used for Grade "A" Cotton or Irish Linen has been as follows:

After the fabric has been shrunk with distilled water and thoroughly dried, apply three brush coats of nitrate dope.

Add 3-3½ ounces of aluminum paste to each gallon of butyrate dope and apply five wet spray coats. Dry after each coat and scuff sand with 360 grit sandpaper.

Activate IMRON 500S Clear polyurethane enamel with 192S Activator according to label directions. Then, with strong agitation, add 12-14 ounces of aluminum paste per gallon of IMRON. Spray one full wet coat and allow to dry overnight.

NOTE: This first coat of IMRON must be applied after the last butyrate coat has dried at least 16 hours but no more than 96 hours.

Scuff sand with 360 grit sandpaper and proceed with topcoat application as described on page 7.

Synthetic fabrics may be topcoated with IMRON in the same way after using the recommended dope system. Again, be sure the first coat of IMRON (500S Clear with aluminum) is applied after the last butyrate coat has dried at least 16 hours but not more than 96 hours.

We must emphasize that because of our lack of experience with this system, Du Pont cannot recommend this procedure. The use of IMRON on fabric surfaces is the responsibility of the owner and applicator and is done strictly at their own risk.

Panel Repair

In spot or panel refinishing, always be sure that masking is sufficient to protect all other areas of the plane from overspray. It is good practice to drape the whole plane except for the panel being refinished.

Surface Preparation
Wash entire panel to be painted with soap and water, then wipe with PREPSOL® solvent to remove all traces of wax, polish, grease and silicones.

Wipe off with a clean cloth before PREPSOL has a chance to dry. Change cloths frequently.

Sand area to be finished with #400 grit paper.

Treat bare metal with proper DuPont Cleaner and Conversion Coating as for surface preparation of metal for overall repainting (see table on pages 4 & 5).

Undercoat Application
Prime bare metal with CORLAR epoxy primer or VARIPRIME enamel primer following recommendations under Overall Refinishing.

Topcoat Application
Mask off adjacent areas. Spray medium first coat. Allow to tack up and follow with a second coat.

Follow mixing and spraying recommendations on page 5.

Cautions

Radomes
Do not use metallic paint on radomes. It contains aluminum flake which will distort or destroy the radar/radio signal.

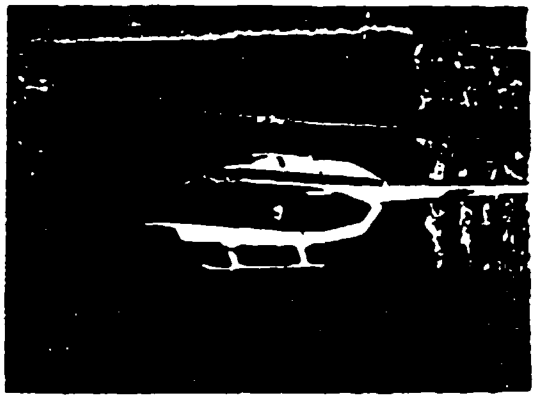
Effect of Color and Heat on Fiberglass
Darker colors absorb heat to a much greater extent than lighter ones. Aircraft painted darker colors may reach temperatures sufficiently high to cause damage to structural plastic parts if used. This must be taken into consideration when choosing colors for planes with fiberglass airframes. For detailed information and a graph relating ambient air temperature to peak surface temperature for various colors, write Du Pont Company, Room B-5256, Wilmington, DE 19898.

"Skydrol Resistance"
Many jet airframe manufacturers require a finish to meet a test for resistance to Skydrol Hydraulic Fluid.

The test, titled "Fluid Resistance" in Boeing Specifications calls for immersing a painted panel in Skydrol for 30 days. The finish must exhibit no blistering, wrinkling or other visible defects, except slight discoloration. Pencil hardness after this period must be a minimum of HB, which means that the finish must be able to withstand pressure from a drawing pencil of medium hardness.

Most finishes are not formulated to withstand a 30-day exposure to this hydraulic fluid. However, it should be noted that in laboratory tests the IMRON system (225S Aluminum Metal Cleaner, 226S Aluminum Conversion Coating, CORLAR® epoxy primer and IMRON with 189S Accelerator) exhibited no blistering, wrinkling or other visible film defects. Slight loss of pencil hardness is noted.

The vast majority of aircraft do not require or use "Skydrol". Thus, strict compliance to the Boeing test may or may not be important to your own particular use of IMRON.



May We Help You?

There's a convenient Du Pont Service Center that will gladly provide color information and technical service as well as provide you the name of your nearest Du Pont Aircraft Finishes jobber.

Call or write the Du Pont Service Center nearest you:

NORTHEAST REGION

BALTIMORE, MD 21218
400 East 29th Street
301-235-0278

WILMINGTON (BOSTON),
MA 01887
One Cornell Place, P.O. Box 483
617-658-9140

SPRINGFIELD (NEWARK), NJ 07081
15 Stern Avenue, P.O. Box 88
201-376-5151

PHILADELPHIA, PA 19124
4242 Whitaker Avenue
215-425-4300

SOUTHEAST REGION

ATLANTA, GA 30325
1737 Ellsworth Ind. Dr., N.W.
P.O. Box 19714
404-355-1235

CHARLOTTE, NC 28208
2801 Interstate Street, P.O. Box 8748
704-394-6354

JACKSONVILLE, FL 32217
8301 Western Way, P.O. Box 23100
904-737-2323

HARAHAN (NEW ORLEANS),
LA 70183
601 Edwards Avenue
P.O. Box 23565, Harahan Branch
504-733-7530

CENTRAL REGION

MORTON GROVE (CHICAGO),
IL 60053
7828 N. Merrimac Avenue
312-965-6580

INDIANAPOLIS, IN 46202
1825 W. 18th Street
317-634-6295

MINNEAPOLIS, MN 55435
5251 West 74th Street
612-835-5488

MARYLAND HGTS. (ST. LOUIS),
MO 63043
11708 Northline Industrial Blvd.
314-567-1155

CLEVELAND REGION

BUFFALO, NY 14225
1696 Walden Avenue
716-896-7979

GARFIELD HGTS. (CLEVELAND),
OH 44125
9200 Midwest Avenue
216-587-4155

COLUMBUS, OH 43215
1450 Dublin Road
614-486-7191

DETROIT, MI 48234
19930 Conner Avenue
313-366-8800

PITTSBURGH, PA 15205
2222 Noblestown Road
412-921-9190

SOUTHWEST REGION

DALLAS, TX 75247
8510 Ambassador Row
P.O. Box 470188
214-637-1500

HOUSTON, TX 77055
8125 Kempwood Drive
P.O. Box 55404
713-461-5650

KANSAS CITY, MO 64141
6015 Manchester Trafficway
P.O. Box 678
816-363-4410

OKLAHOMA CITY, OK 73105
37 N.E. 31st Street
P.O. Box 53485
405-521-1664

WEST REGION

DENVER, CO 80239
11000 E. 53rd Avenue
P.O. Box 39837
303-373-5513

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(BR. OF DENVER), UT 84119
875 W. 2600 South
801-972-1436

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2000 S. Garfield Ave.,
P.O. Box 22002
213-723-8404

PORTLAND, OR 97202
5510 S.E. McLoughlin Boulevard
P.O. Box 02128
503-232-6177

HAYWARD (SAN FRANCISCO),
CA 94540
1809 Sabre St., P.O. Box 3218
415-782-0213

HONOLULU, HI 96819
2929 Koapaka Street
808-836-2881

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DUPONT
AIRCRAFT
REFINISH
PRODUCTS

Coating No. 11

Mobay Corporation

A Bayer USA INC. COMPANY

Urethane Resins For High Performance Coatings

Performance Index

	POLYOLS	POLYISOCYANATES					
		DESMODUR					
	PRODUCT SOLIDS EQ. WT. SOLVENTS* %OH/%NCO	N-75 75 255 1/1 BA/Xylene 16.5	N-751 75 256 BA 16.5	N-100 100 191 22.0	N-3200 100 181 23.2	N-3300 100 194 21.8	N-3390 90 216 1/1 A100/BA 19.4
DESMOPHEN	650A-65 65 327 6/1 PMA/Xylene 5.2	1	1	1	1	1	1
	651A-65 65 327 6/1 PMA/Xylene 5.2	2	2	2	2	2	2
	670A-80 80 486 BA 3.5	3	3	3	3	3	3
	800 100 193 8.8	4	4	4	4	7	7
	1100 100 262 6.5	8	8	8	8	8	8
	1300-75 75 567 Xylene 3.0	8	8	8	8	8	8
	1652 100 1000 1.7	9	9	9	9	9	9
	A 160 60 1058 A100 1.6	10	10	10	10	10	10
	A 450 50 1700 1/1 BA/Xylene 1.0	12	12	12	12	12	12
MULTRON	R 12-A 100 340 5.0	6	6	6	6	6	6
	R 221-75 75 515 PMA 3.3	13	13	13	13	13	13
	R-18 100 944 1.8	6	6	6	6	6	6

PERFORMANCE CODE

1 The Desmodur N series of polyisocyanates in combination with Desmophen 650 will yield coatings with excellent hardness and flexibility, chemical and solvent resistance and gloss retention on outdoor exposure. This combination can be recommended for all applications requiring high film performance.

2 The properties of Desmophen 651 in combination with the Desmodur N series of polyisocyanates will be similar to that of Desmophen 650 but will yield improved gloss retention on outdoor exposure.

3 The properties of Desmophen 670 in combination with the Desmodur N series of polyisocyanates will yield coatings that are flexible and exhibit excellent weathering properties. This combination is recommended where flexibility is of prime concern including plastics (e.g., RIM, PUR-foam), and for coil coating primers and topcoats.

4 Medium weathering, intermediate hardness and moderate flexibility Medium solids.

5 Not compatible.

6 Not commonly used; may be of interest in special applications.

7 General industrial, hard, chemical resistant, good for higher solids.

8 Not recommended; very hard and brittle.

9 Very soft, used only in combination with other resins to improve flexibility.

10 A 160 in combination with Desmodur N products yields coatings with good weathering, chemical and corrosion resistance. Excellent roll and brush properties for maintenance, new construction, marine and architectural applications. Very short dust-free time.

11 Hard, flexible with very good resistance to solvents, chemicals and weathering.

12 Hard, weather resistant, medium flexibility, fast cure.

13 General topcoat for metal and plastics. Good hardness and good chemical resistance (preferred in combination with other polyesters).

SPECIALTY PRODUCTS

BLOCKED ISOCYANATES

PRODUCT	APPLICATIONS
DESMODUR BL-1260A aromatic blocked isocyanate 60% solids 933 equivalent weight 4.5% NCO	solvent borne, one component, baking enamels, primers and chip resistant coatings; non light stable
DESMODUR BL-1165A aromatic blocked isocyanate 85% solids 1750 equivalent weight 2.4% NCO	solvent borne, one component, baking enamels, primers and chip resistant coatings; non light stable
DESMODUR BL-3175 aliphatic blocked isocyanate 75% solids 370 equivalent weight 11.3% NCO	like Desmodur N; for solvent borne, one component, baking enamels; coil coating, automotive primer, high performance topcoat
DESMODUR AP STABIL aromatic blocked isocyanate 100% solids 300 equivalent weight 14.0% NCO	powder easily dissolved; one component surface and magnet wire coating, solderable type
DESMODUR CT STABIL aromatic blocked isocyanate 100% solids 300 equivalent weight 14.0% NCO	powder easily dissolved; for use with heat resistant isophthalate polyesters; one component magnet wire coating
DESMOCAP 11A blocked NCO terminated prepolymer 100% solids 1750 equivalent weight 2.4% NCO	flexibilizer for amine cured epoxies; room temperature reaction with amines; high tensile strength and elongation
DESMOCAP 12 blocked NCO terminated prepolymer 100% solids 2471 equivalent weight 1.7% NCO	flexibilizer for amine cured epoxies; flexibilizer for Desmocap 11A formulations; room temperature reaction with amines; high tensile strength and elongation; for sealant applications

POWDER COATING RESINS

CRELAN UI cycloaliphatic diisocyanate adduct 365 equivalent weight 11.5% NCO	light stable, one component powder coatings with PUR performance
CRELAN UT cycloaliphatic diisocyanate adduct 336 equivalent weight 12.5% NCO	non light stable, one component powder coatings with PUR performance
CRELAN U 502 polyester polyol 1122 equivalent weight 1.5% OH	powder coatings; used with CRELAN UI or CRELAN UT
CRELAN U 502 MB-A polyester polyol with flow modifier 1403 equivalent weight 1.2% NCO	powder coatings; used with CRELAN UI or CRELAN UT

AROMATIC POLYISOCYANATES

PRODUCT	APPLICATIONS
DESMODUR E-21 aromatic polyisocyanate prepolymer 100% solids 263 equivalent weight 16.0% NCO	excellent corrosion and chemical resistance as one component moisture curing systems for primers and intermediate coats; excellent adhesion to steel, concrete and wood; for two component coatings for anti-corrosion and underground applications
MONDUR XP-743 aromatic polyisocyanate prepolymer 100% solids 525 equivalent weight 8.0% NCO	flexibilizer for MDI based moisture curing or two component systems
MONDUR CB-60 aromatic polyisocyanate adduct 60% solids 404 equivalent weight 10.4% NCO	fast drying primers and topcoats; for metal, plastic, wood and mineral substrates; for interior applications
MONDUR IL aromatic polyisocyanate adduct 51% solids 525 equivalent weight 8.0% NCO	extremely fast curing two component coatings; used to modify MONDUR CB-60
MONDUR HL aliphatic/aromatic polyisocyanate adduct 60% solids 400 equivalent weight 10.5% NCO	fast curing two component coatings; improved light stability over other aromatic polyisocyanate adducts
MONDUR CD modified aromatic diisocyanate 100% solids 143 equivalent weight 29.3% NCO	for formulation of in-mold coatings
MONDUR MR aromatic polymeric isocyanate 100% solids 132 equivalent weight 32.0% NCO	high solids coatings and sealants
MONDUR MRS aromatic polymeric isocyanate 100% solids 132 equivalent weight 32.0% NCO	high solids coatings and sealants
MONDUR MRS 5 aromatic polymeric isocyanate 100% solids 130 equivalent weight 32.4% NCO	solventless coatings; flooring

ADDITIVES

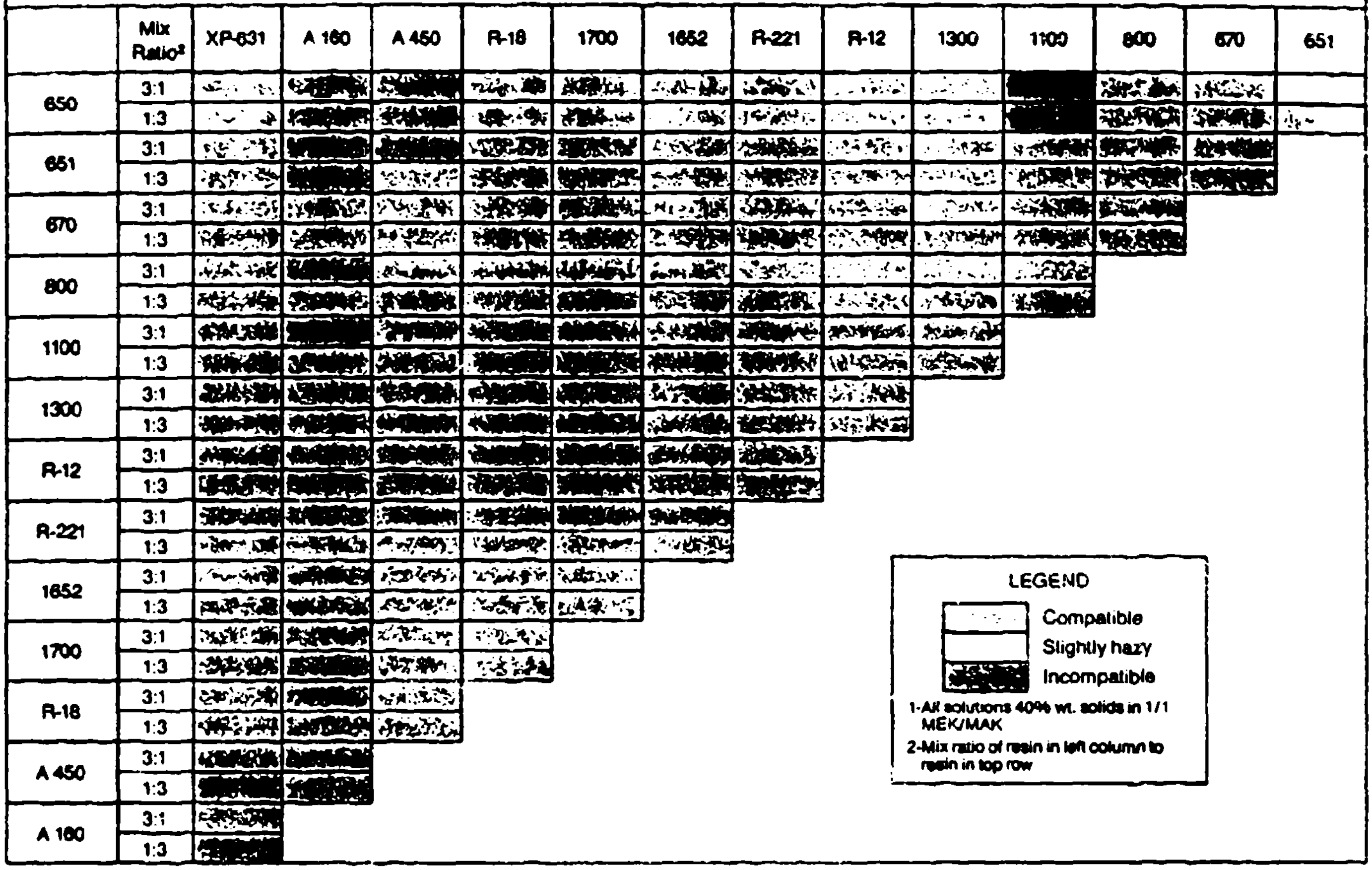
HARDENER OZ oxazolidine latent urethane crosslinker 100% reactive 244 amine equivalent weight; 122 amine plus hydroxyl equivalent weight	reacts with moisture; bifunctional or tetrafunctional; thick section coatings and sealants
ADDITIVE OF alkyl ortho formate 100% reactive	moisture scavenger in one component coating or in polyisocyanate portion of two component coating
DESMORAPID PP tertiary amine catalyst 100% reactive	catalyst for aromatic and aliphatic polyisocyanates

MISCELLANEOUS

ROSKYDAL UNSATURATED POLYESTERS
wood coatings; UV cure and air dry

BAYBOND POLYURETHANE DISPERSIONS
rigid to flexible; general industrial coatings; textile, wood, paper, and leather coatings; printing inks

SOLUTION COMPATIBILITY OF MOBAY POLYOL RESINS[1]



	Mix Ratio[2]	XP-631	A 160	A 450	R-18	1700	1652	R-221	R-12	1300	1100	800	670	651
650	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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1100	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
	1:3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
1300	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
	1:3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
R-12	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						
	1:3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						
R-221	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							
	1:3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							
1652	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]								
	1:3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]								
1700	3:1	[illegible]	[illegible]	[illegible]	[illegible]									
	1:3	[illegible]	[illegible]	[illegible]	[illegible]									
R-18	3:1	[illegible]	[illegible]	[illegible]										
	1:3	[illegible]	[illegible]	[illegible]										
A 450	3:1	[illegible]	[illegible]											
	1:3	[illegible]	[illegible]											
A 160	3:1	[illegible]												
	1:3	[illegible]												

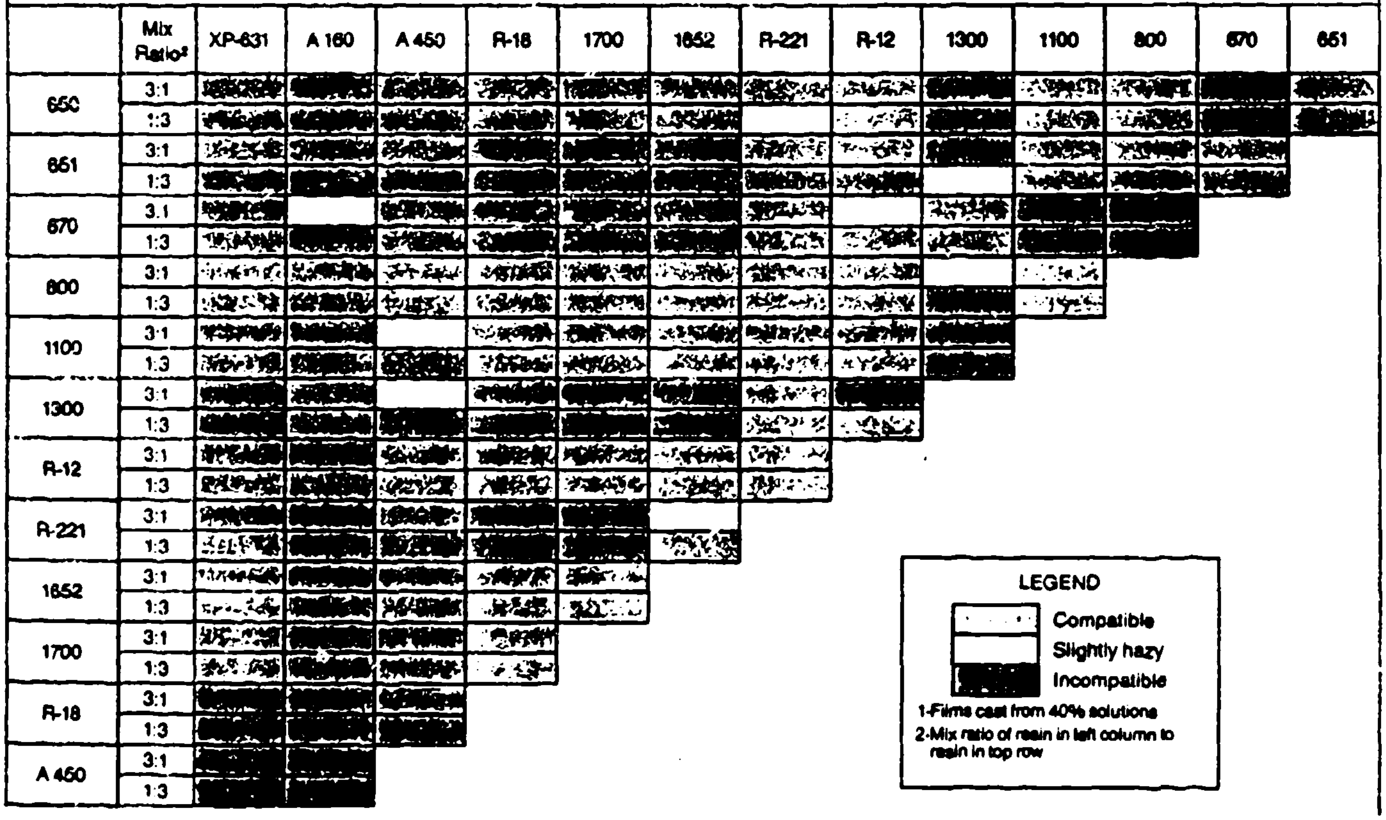
LEGEND

░	Compatible
□	Slightly hazy
▓	Incompatible

1-All solutions 40% wt. solids in 1/1 MEK/MAK

2-Mix ratio of resin in left column to resin in top row

COMPATIBILITY OF SOLVENT-FREE FILMS OF MOBAY POLYOL RESINS[1]



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670	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
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1100	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
	1:3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
1300	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
	1:3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
R-12	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						
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R-221	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							
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1652	3:1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]								
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R-18	3:1	[illegible]	[illegible]	[illegible]										
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A 450	3:1	[illegible]	[illegible]											
	1:3	[illegible]	[illegible]											

LEGEND

░	Compatible
□	Slightly hazy
▓	Incompatible

1-Films cast from 40% solutions

2-Mix ratio of resin in left column to resin in top row

POLYISOCYANATES						POLYOLS	
DESMODUR				MONDUR			
Z-4370 70 385 1/1 PMA/Xylene 11.5	Z-4730/2 70 385 A100 11.5	HL 60 400 BA 10.5	IL 51 525 BA 8.0	CB-60 60 404 5/3 PMA/Xylene 10.4	CB-75 75 323 EA 13.0	PRODUCT SOLIDS EQ. WT. SOLVENTS* %OH/%NCO	
8	8	[illegible]	[illegible]	[illegible]	[illegible]	650A-65 65 327 6/1 PMA/Xylene 5.2	DESMOPHEN
8	8	[illegible]	[illegible]	[illegible]	[illegible]	651A-65 65 327 6/1 PMA/Xylene 5.2	
11	11	[illegible]	[illegible]	[illegible]	[illegible]	670A-80 80 486 BA 3.5	
8	8	[illegible]	16	19	21	800 100 193 8.8	
6	6	15	18	20	20	1100 100 262 6.5	
6	6	17	17	22	22	1300-75 75 567 Xylene 3.0	
9	9	9	9	24	24	1652 100 1000 1.7	
14	14	8	8	26	26	A 160 60 1058 A100 1.6	
14	14	23	23	23	23	A 450 50 1700 1/1 BA/Xylene 1.0	
6	6	25	23	28	28	R 12-A 100 340 5.0	MULTRON
6	6	27	27	29	29	R 221-75 75 515 PMA 3.3	
6	6	6	6	8	8	R-18 100 944 1.8	

14 Very fast drying, sometimes used in combination with other resins to improve physical drying.

15 Wood coatings, fast drying, intermediate weathering.

16 Metal and wood coatings, non light stable, high chemical resistance for maintenance, fast drying.

17 Fast drying wood, paper and foil coatings, intermediate in weathering.

18 Wood coatings, fast drying.

19 General industrial coatings, non light stable, high chemical resistance for maintenance.

20 General industrial coatings, chemical resistance plus flexibility, non light stable.

21 Metal coatings, wood coatings, non light stable, high chemical resistance for maintenance.

22 General industrial coatings, hard, flexible, chemical resistant, topcoats plus primers.

23 Wood coatings, fast drying.

24 Flexible roof coating; non light stable.

25 Fast drying topcoats for floors, medium light stability.

26 Penetrating and traditional sealers for porous substrates, non light stable, not very commonly used.

27 High performance wood coating, pigmented and clear, medium weathering.

28 Clear topcoat for floors, interior. General industrial coating.

29 General purpose industrial finish. Hard, chemical resistant.

LEGEND

■ Light stable coating combination.

☐ Non-light stable coating combination.

■ Not recommended combination.

*SOLVENTS

A-100 = Aromatic 100
BA = Butyl Acetate
EA = Ethyl Acetate
PMA = Propylene Glycol Monomethyl Ether Acetate

COMPATIBILITY OF FILMS PREPARED FROM ISOCYANATES AND POLYOLS AT NCO:OH = 1

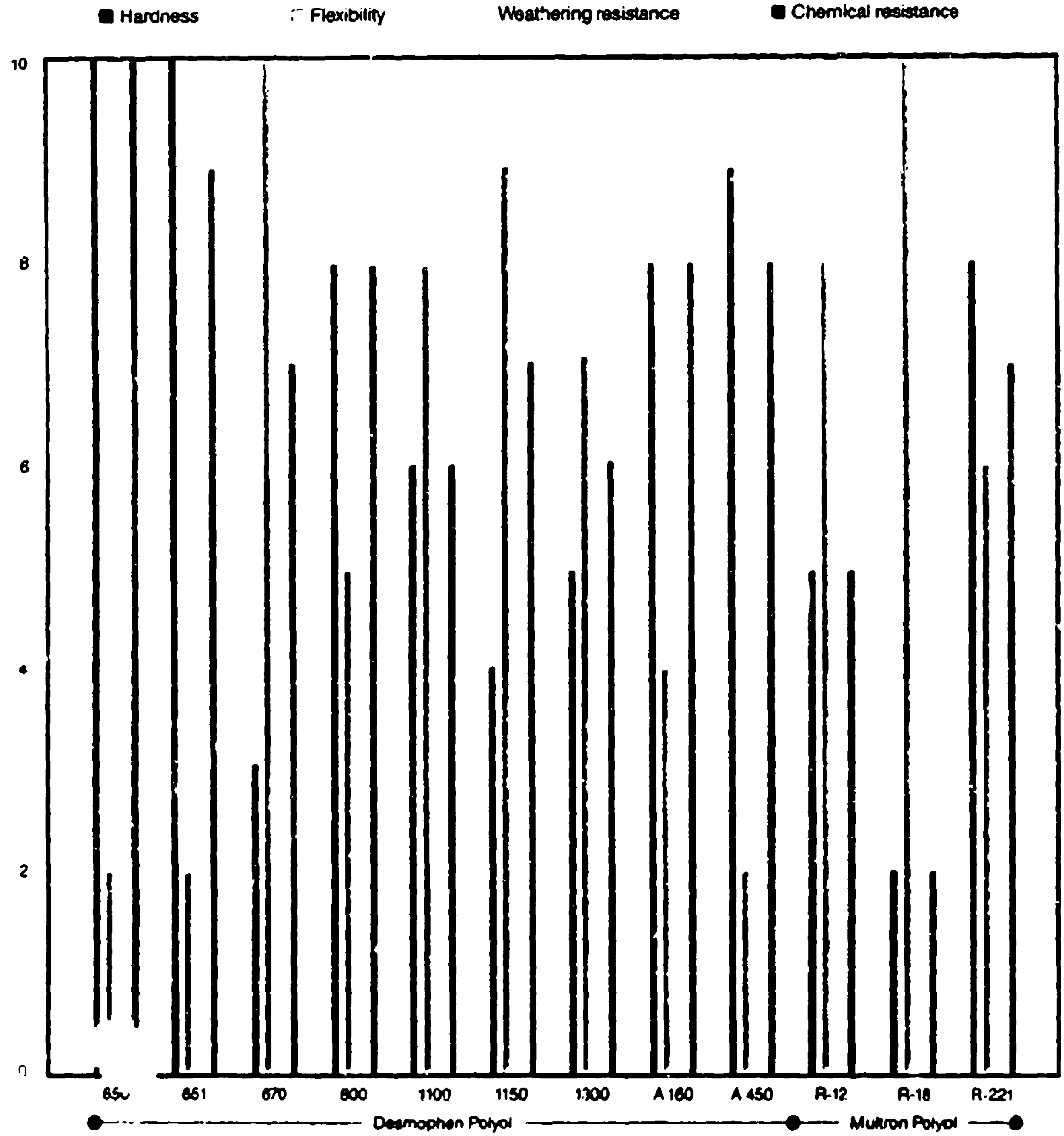
		POLYISOCYANATES																				
		DESMODUR												MONDUR								
	POLYOLS	N-75	N-100	N-751	N-3200	N-3300	N-3390	Z-4370	Z-4372	HL	IL	E 21	BL-1185	BL-1260	BL-3175	CB-60	CB-75	CB-601	XP-743	MR	MRS	MRS5
DESMOPHEN	650	▨	▨	▨	▨	■	■	■	■	▨	▨	■	■	▨	▨	▨	▨	▨	■	■	■	■
	651	▨	▨	▨	▨	■	■	▨	▨	▨	▨	■	■	▨	▨	▨	▨	▨	■	■	■	▨
	XP-631	▨	▨	▨	▨	■	■	▨	▨	▨	▨	▨	■	▨	▨	▨	▨	▨	▨	▨	▨	▨
	670	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	■	▨	▨	▨
	800	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	■	■	▨	▨	▨	▨	▨	■	■	■	▨
	1100	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	■	☐	▨	▨	▨	▨	▨	■	▨	▨	▨
	1300	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	1652	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	■	▨	▨	▨	▨	▨	▨	■	▨	▨	▨
	1700	☐	☐	☐	▨	▨	▨	■	■	▨	▨	■	▨	▨	▨	▨	▨	▨	■	▨	▨	▨
	A 160	▨	▨	▨	▨	▨	▨	▨	▨	■	■	▨	▨	☐	▨	▨	▨	▨	▨	▨	▨	▨
	A 450	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
MULTRON	R-12	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	R-18	▨	☐	▨	▨	▨	▨	■	■	▨	▨	■	▨	▨	▨	▨	▨	▨	■	▨	▨	▨
	R-221	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	■	▨	▨	▨	▨	▨	▨	▨	▨	▨

LEGEND

▨ Compatible, clear ☐ Slightly hazy ■ Incompatible

PROPERTIES OF COATINGS BASED ON POLYOL + DESMODUR N-75 POLYISOCYANATE

Rating: 10 = high, 0 = low



EQUATIONS USEFUL IN FORMULATING TWO-COMPONENT COATINGS

Equivalent Weight Calculations: Equivalent weight of polyol $= \frac{17 \times 100}{\%\,OH}$

Equivalent weight of polyisocyanate. $= \frac{42 \times 100}{\%\,NCO}$

For NCO OH ratio = 1, add 1 equivalent weight of the polyisocyanate to 1 equivalent weight of the polyol.

e.g., for NCO OH ratio = 1, $\frac{42 \times 100}{19.4} =$ 216g of Desmodur N-3390 polyisocyanate

are added to $\frac{17 \times 100}{1.6} =$ 1062g of Desmophen , 160 polyol

Example: How many grams of Desmodur N-3390 is needed to crosslink 100g of Desmophen A 160 if the NCO:OH is 1.05?

a) 100g Desmophen A 160 has $\frac{100}{1062} =$ 0.0942 equivalents OH.

For an NCO:OH of 1.00, 0.0942 × 216 = 20.3g Desmodur N-3390 are required to crosslink 100g Desmophen A 160.

b) For an NCO:OH of 1.05, 20.3 × 1.05 = 21.3g Desmodur N-3390 are required to crosslink 100g Desmophen A 160.

Health and Safety Information

Appropriate literature has been assembled which provides information concerning health and safety precautions that must be observed when handling Mobay products mentioned in this publication. For materials mentioned that are not Mobay products, appropriate industrial hygiene and other safety precautions recommended by their manufacturer should be followed. Before working with any product mentioned in this publication, you must read and become familiar with the information available on its hazards, proper use and handling. This cannot be overemphasized. Information is available in several forms, such as material safety data sheets and product labels. Consult your Mobay representative or contact the Industrial Hygiene and Regulatory Compliance Group of the Coatings Division.

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A Bayer USA INC COMPANY

Bayer MOBAY

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NJ: Raritan Plaza III, Edison, NJ 08837-3806 • 201 225-1030
CA: 4101 Westerly Pl., Suite 101, Newport Beach, CA 92660-2366 • 714 833-2361

Coating No. 12

PRODUCT SPECIFICATION

Base Component: 921X008
Curing Solution: 910X943
Flow Control Component/Thinner:

Coating Name: Fuel Bladder Coating
Specification: MMS 365
Color/Color Number: White
Description: Sprayable Fuel Bladder Coating

FILM PROPERTIES

Gloss 60° :	95	Low Temp Flex :	GOOD
Gloss 85° :	N/D	Service Temp Max :	250F
Gloss 20° :	N/D	Service Temp Min :	-65F
L* :	N/D	Film Hardness :	N/D
a* :	N/D	Dry to Tape :	N/D
b* :	N/D	Dry between Coats :	1 hr
Impact Resistance :	3800-4200psi Tensile	Dry to Topcoat :	1 hr
Flexibility :	480-520% Elongation	Full Cure :	7 Days,77 F, 50% RH

EXPOSURE DURABILITY

Type of Exposure :	N/D	Color, Δ E :	N/D
Time of Exposure :	N/D	Flexibility :	N/D
Gloss Value 60° :	N/D	Impact Resistance :	N/D
		Strippability : (with Turco 5351)	GOOD

RESISTANCE TO

		TEST CONDITIONS			
Water : GOOD	Time :	60-120 D	Temp : 160 F	Primer :	N/A
Skydrol : POOR	Time :	30 D	Temp : RT	Primer :	N/A
Filiform : Not Applicable	Time :		Temp :	Primer :	
Exfoliation : Not Applicable	Time :			Primer :	
Salt Spray : Not Applicable	Time :			Primer :	

PHYSICAL CONSTANTS

	Wt/Gallon	Wt % Solids	Vol % Solids	Resistivity
Base (B) :	8.62	47.8	37.6	N/D
Curing Solution (C) :	8.69	72.0	70.0	N/D
Flow Control (T) :	N/A			
Mixed B + C :	8.65	59.0	53.6	
Mixed B + C + T :	N/A			

Dry Film Weight :	.00601	#/sqft at 1 mil
Theoretical Coverage :	859	sqft/gal at 1 mil
Flash Point, Type/Value :	TCC/23F	
Pot Life :	30 Min >	

COMPLIANCE

	Voc(g/l)	Compliance Regulations: Solvent Density	Wt % Exempt	Vol % Exempt
Base (B):	539.2	7.0	0.0	0.0
Curing Solution (C):	291.6	8.1	0.0	0.0
Flow Control (T):	N/A			
Mixed B + C:	415.0	7.35	0.0	0.0
Mixed B + C + T:	N/A			

SURFACE PREPARATION

MIXING

	Base	Curing Solution	Flow Control/Thinner
Ratio (by Volume):	1.0	1.0	

Special instructions: Shake the pigmented component well and add to the clear component. Tensile strengths were measured on alternate black and white films.

VISCOSITY

	Base	Mixed	Thinned	At Pot Life
Method :	BF,#1,50	BF,#2,50		
Value :	150-190	290-300	cps	

APPLICATION		FILM THICKNESS	
Temperature Range:	70-80F	Per Coat:	10 mil MAX
Relative Humidity Range:	40-60%RH	Recommended Total:	45-50 mil
Extreme Conditions:			

ACCELERATED CURING SCHEDULE

Flash Time : 1 hr Temperature: 75-80 Time:

Revised: Nov. 15 1989 (Month/Year) DR: 36254 AKC (Initials) [illegible] Aerospace Coatings

4086-168

Product Information

COATING NAME: CLEAR BLADDER COATING BASE
SPECIFICATION NONE COLOR

MIXING:
CODE NUMBERS: BASE 4086-168 ACTIVATOR 4086-175A THINNER
MIXING INSTRUCTIONS: Mix Base with Activator
MIXING RATIO Mix 100 ml base with 100 ml activator
EQUIPMENT CLEAN UP Use MEK POT LIFE 30 minutes maximum

APPLICATION:
METHOD Air Spray EQUIPMENT Conventional Gun
APPLICATION TEMP Ambient HUMIDITY 50% RH
THICKNESS PER COAT 6-7 mil DRY TIME BETWEEN COATS 30-40 mil
FILM THICKNESS: MAX 10 mil MIN 4 mil
TOUCH UP OR RECOAT PROCEDURE Respray

SUBSTRATE:
TYPE Aluminum or Composite CHEM TREATMENT Not Necessary
PRIMER 513X639 OTHER NA

CURING SCHEDULE:
NORMAL SCHEDULE 14 days at RT & 50% RH ALTERNATE CURE 48-72 hr at 130 F
DRY TO TAPE 2 hr DRY TO TOPCOAT 1 hr FULL CURE 14 days at RT

STORAGE:
STORAGE LIFE 6 months STORAGE CONDITIONS RT or Below
FLASH POINT -SETAFLASH- 22F HAZARD-TOXICITY INFO see MSDS

PHYSICAL CONSTANTS:

	WT/GAL	WT/SOLIDS	VOL/SOLIDS	PIGMENT
BASE:	7.7 +/-.2 lbs.	38.0 +/-2 %	32.0 %	%
ACTIVATOR:	8.7 +/-.2 lbs.	74.0 +/-2 %	70.4 %	
THINNER:				
ADMIXED:	8.2 +/-.2 lbs.	57.1 +/-2 %	51.3 %	

VISCOSITY: BASE ADMIXED
DRY FILM WEIGHT .00571 #/sqft @ 1 mil THEORETICAL COVERAGE 811 sqft/gal @ 1mil
COMPLIANCE REGULATIONS VOC 423 g/l calc.

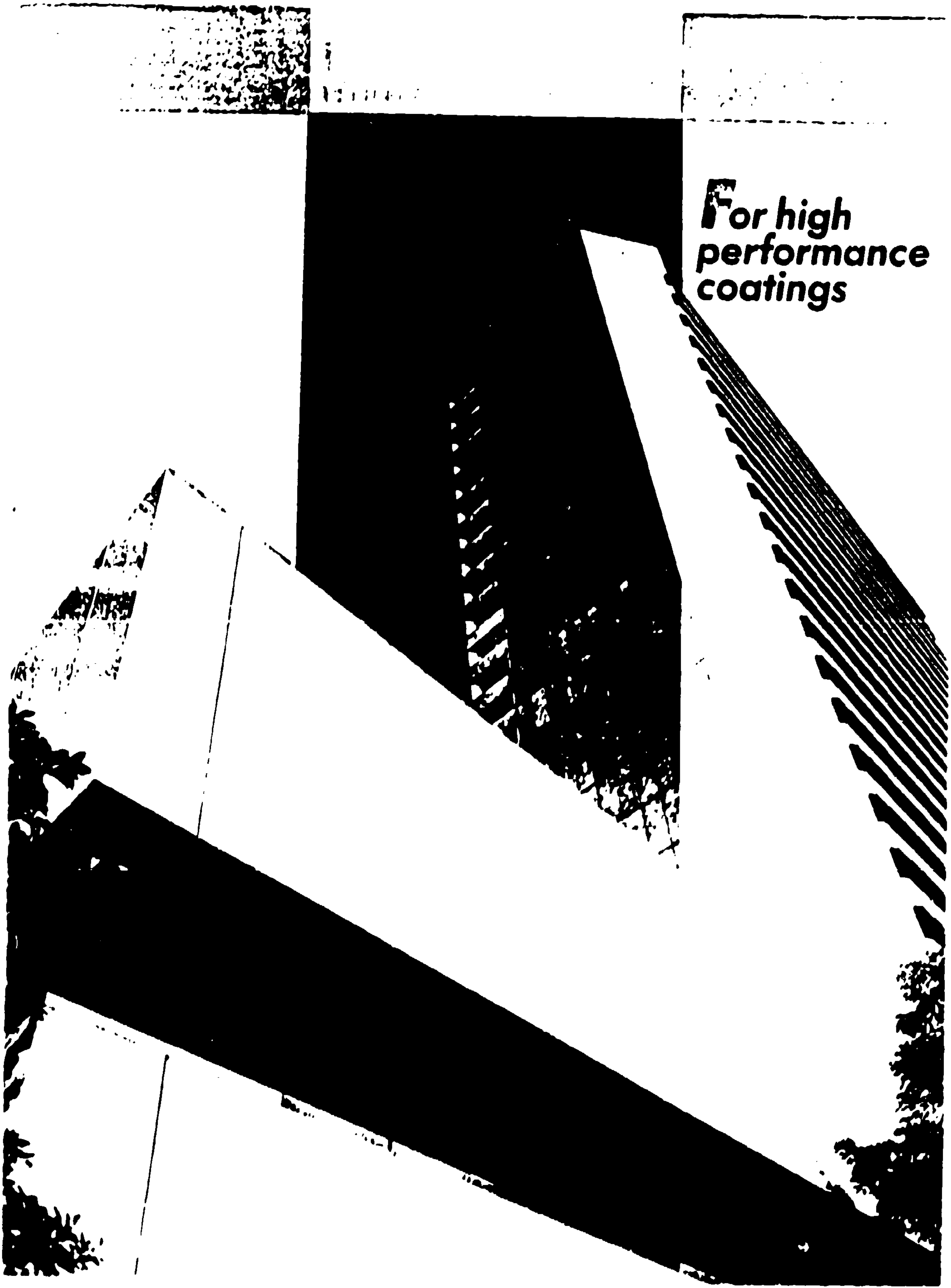
SPECIAL FILM PROPERTIES:
SERVICE TEMPERATURE: MIN -65F MAX 250-350
FILM HARDNESS NA FLEXIBILITY
IMPACT RESISTANCE NSILE COLOR STANDARD NA
GLOSS: 60 DEGREES NA 85 DEGREES NA 20 DEGREES NA
OTHER Spraying of more than 10mil at a time is not desirable

RESISTANCE PROPERTIES:
WATER NA SKYDROL NA SALT SPRAY NA
FILIFORM NA WEATHERING NA STRIPPER NA
OTHER COMMENTS

DATE 9/29/88

Excellence, The DeSoto Commitment

Coating No. 13

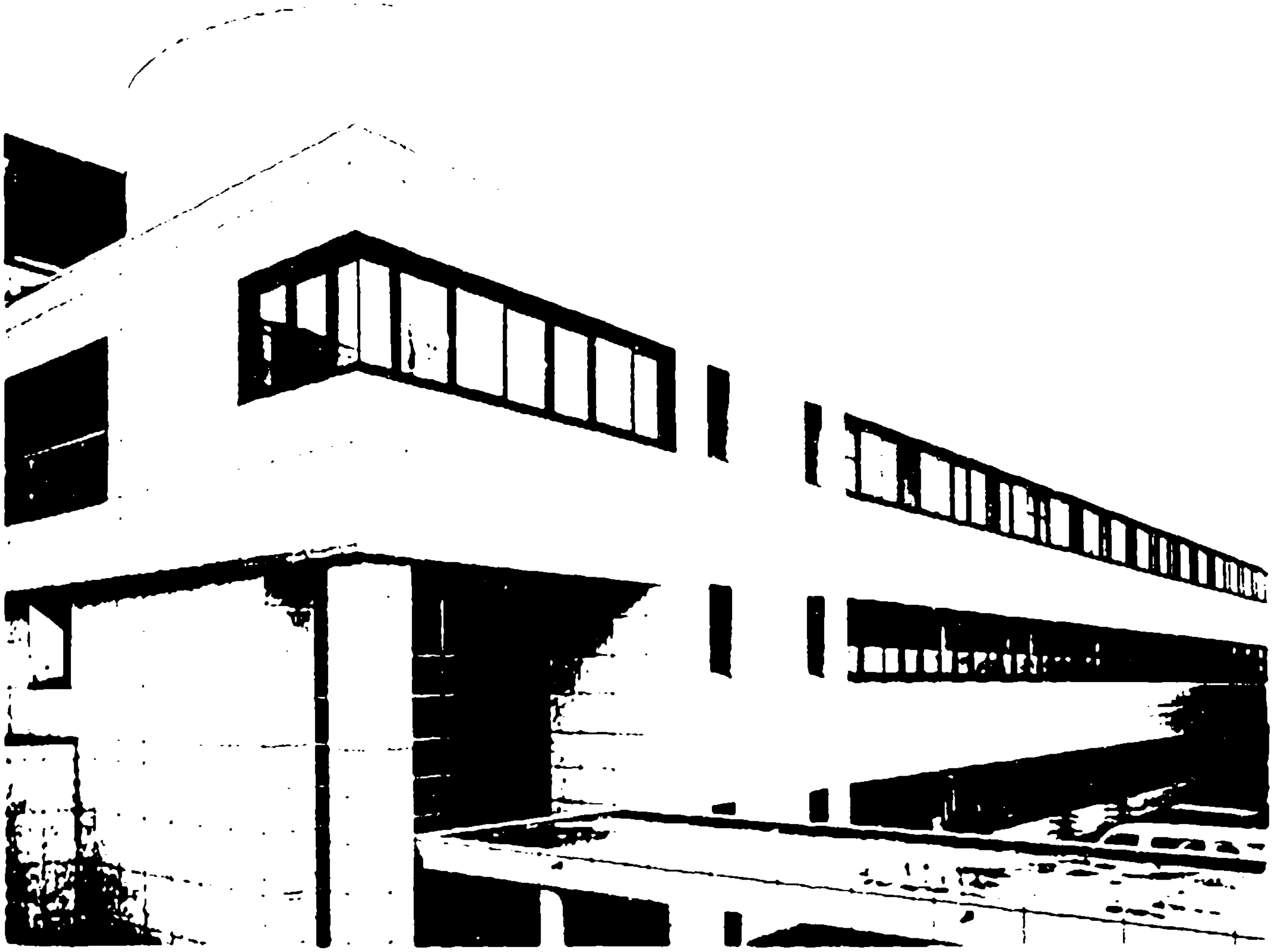


For high performance coatings

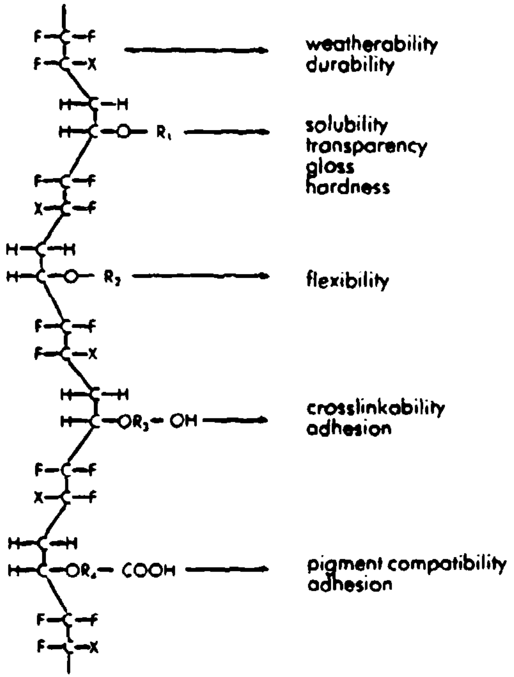
State of the art protection, appearance and versatility

Lumiflon high performance fluoropolymer resins offer superior weatherability plus the choice of ambient or high temperature curing. Now even components finished on site can enjoy the same protection as factory coated materials. Furthermore, the unique chemistry of Lumiflon allows touch-up with the same durable coating system used in the original application. No separate or inferior touch-up system is needed.

Since high temperatures are not required to cure Lumiflon, long term protection can be afforded heat sensitive substrates such as plastic film and FRP. In addition, Lumiflon provides remarkable protection for such conventional substrates as aluminum, steel, concrete—and even glass.



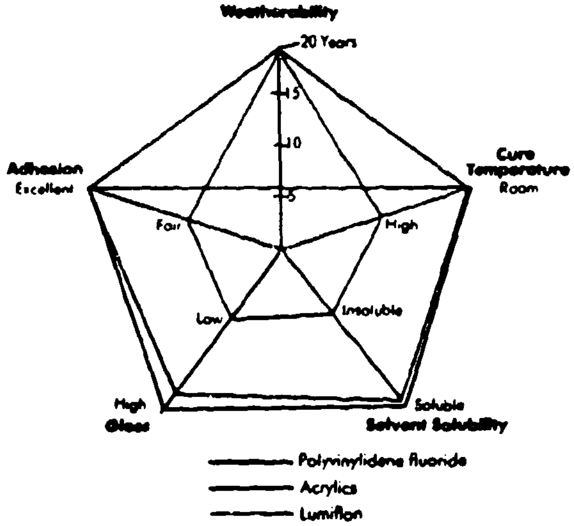
MOLECULAR STRUCTURE OF LUMIFLON POLYMERS



COMPARISON OF LUMIFLON COATINGS WITH OTHER WEATHER RESISTANT COATINGS

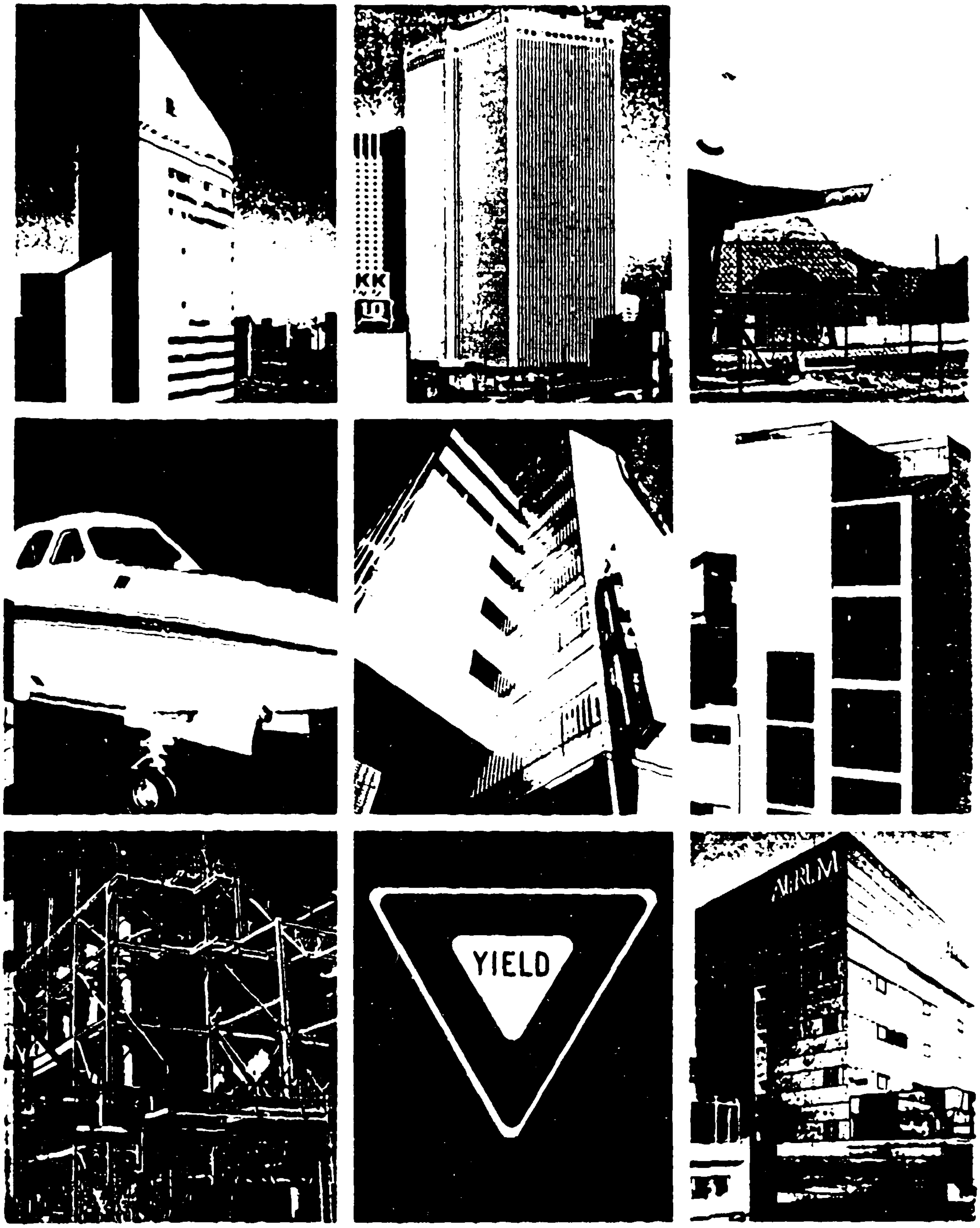
	Lumiflon	PVDF	Acrylics
Type	Solution	Dispersion	Solution
Cure temperature	room or high temperature	more than 250 C	room or high temperature
Weatherability	20 years	20 years	3-5 years
60° gloss	80	30	90
Stain resistance	Excellent	Excellent	Good
Chemical resistance	Good	Excellent	Poor
Flexibility	Good	Good	Good
Recoatability	Excellent	Poor	Excellent

PROPERTIES OF LUMIFLON RESINS IN COMPARISON WITH PVDF & ACRYLIC RESINS



Unlike other fluoropolymers, Lumiflon offers the choice of low, medium, or high gloss finishes without sacrificing performance. Additionally, Lumiflon allows a broad range of application techniques including spray, brush, dip, roll, or coil coating.

Lumiflon is a fluoropolymer engineered to combine the weatherability and chemical resistance features of polyvinylidene fluoride (PVDF) with the gloss, adhesion, and ambient cure characteristics of acrylics. It offers a unique set of properties which produces the finest architectural coatings and meets the stringent requirements of many of today's–and tomorrow's–specialty applications.


KK
10
YIELD

Versatile products for a variety of applications

Architectural

- roof and wall materials
- doors and windows
- decks, handrails, fences

Specialty

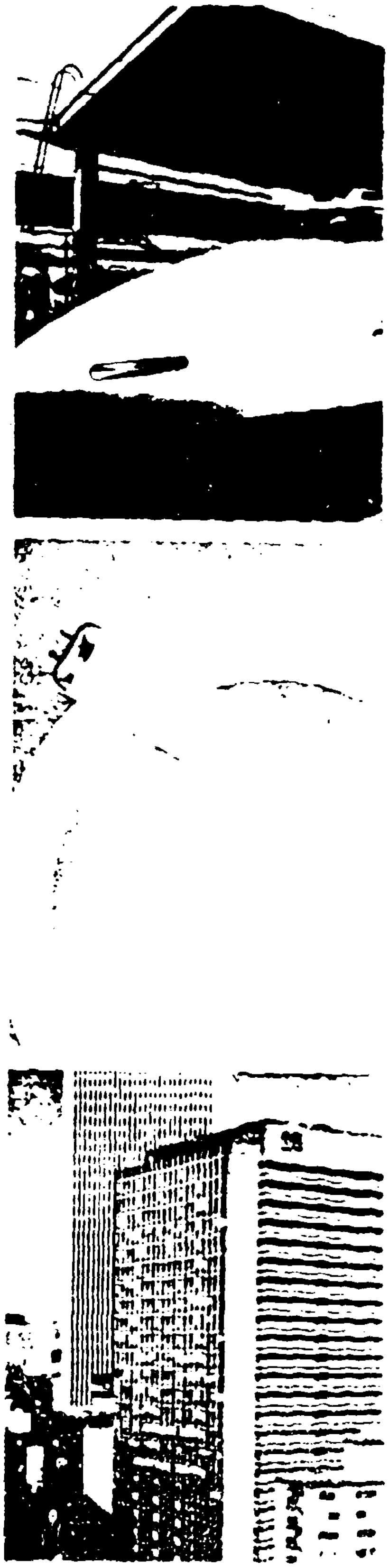
- plastic films
- aerospace
- solar energy hardware
- fluorescent and incandescent light coatings
- traffic signs and fixtures
- outdoor plastic structures

Maintenance

- industrial plants
- marine facilities
- remote structures

Transportation

- automotive
- aircraft
- ships

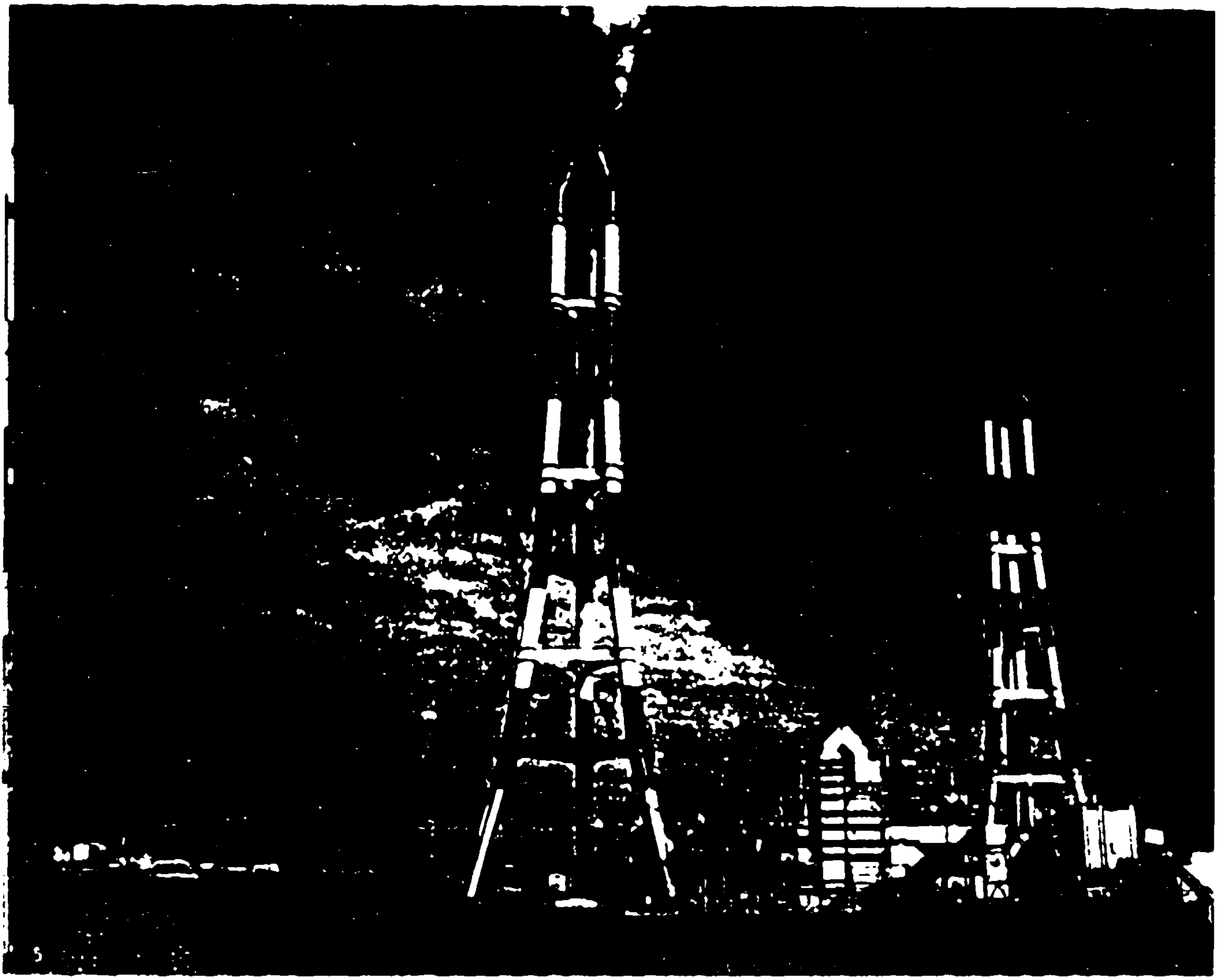


Lumiflon resins mean superior weatherability

Superior to acrylics, silicone polyesters, and even PVDF, Lumiflon based coatings provide long term protection and aesthetics.

Both case histories and accelerated weathering data indicate that Lumiflon based coatings typically have lifetimes in excess of 20 years, with minimal changes in appearance.

Lumiflon based coatings were used on this metallic substrate to protect it from the harsh chemical environment. Lumiflon was also specified for its ability to be touched up on site

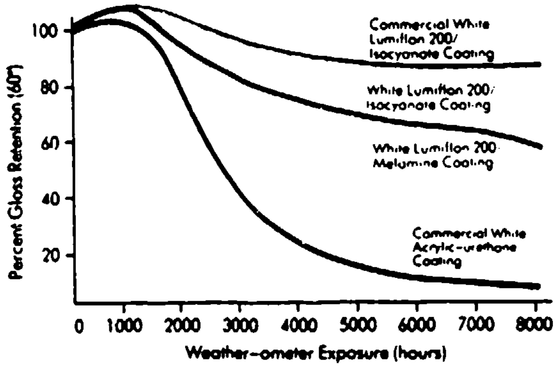


OUTDOOR EXPOSURE AT OKINAWA

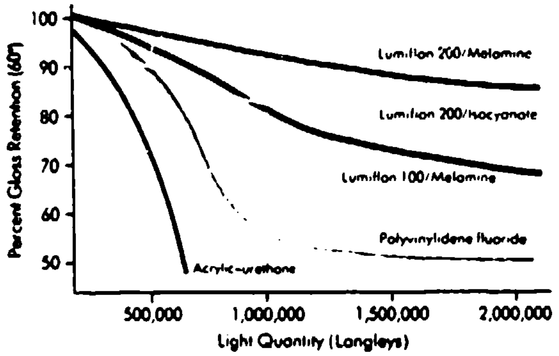
Coating		Exposure Time (years)					
		2 Years		3.5 Years		4.5 Years	
Color	Resin System	% G.R.[3]	ΔE	% G.R.[3]	ΔE	% G.R.[3]	ΔE
Brown[1]	Lumiflon 200/Melamine	100	2.0	104	2.1	99	4.7
Brown[1]	Polyvinylidene fluoride	101	2.0	110	2.7	139	2.8
Brown[2]	Polyester	25	18.2[4]	30	1.7[4]	34	2.4[4]
Brown	Polyvinyl chloride	76	4.5[4]	72	4.4[4]	89	4.4[4]

1. Aluminum substrate
2. Galvanized steel substrate
3. Percent gloss retention (60°)
4. Chalking observed

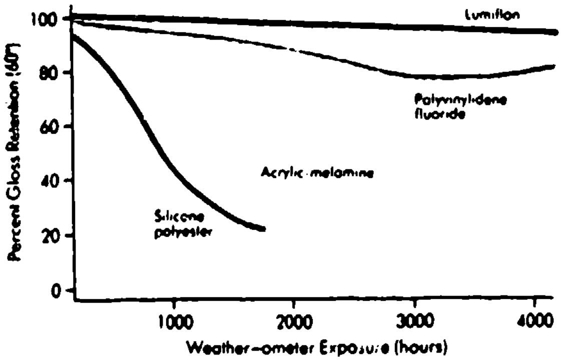
ACCELERATED WEATHERING IN XENON ARC WEATHER-OMETER



EMMAQUA WEATHERING TEST



ACCELERATED WEATHERING IN CARBON ARC WEATHER-OMETER



Lumiflon coatings have been exposed for thousands of hours in accelerated weathering tests and show consistently excellent performance. After 4,000 hours of Weather-ometer® testing, Lumiflon showed a gloss retention of 90% measured at 60°. Even after 8,000 hours, equivalent to over 30 years of natural exposure, gloss retention remains exceptional, with no significant chalking observed.

Extensive outdoor testing at various sites, including Florida and Okinawa, shows excellent gloss retention and no chalking after years of exposure. Accelerated natural exposure, Emmaqua® testing, in Arizona confirms the outstanding performance of Lumiflon.

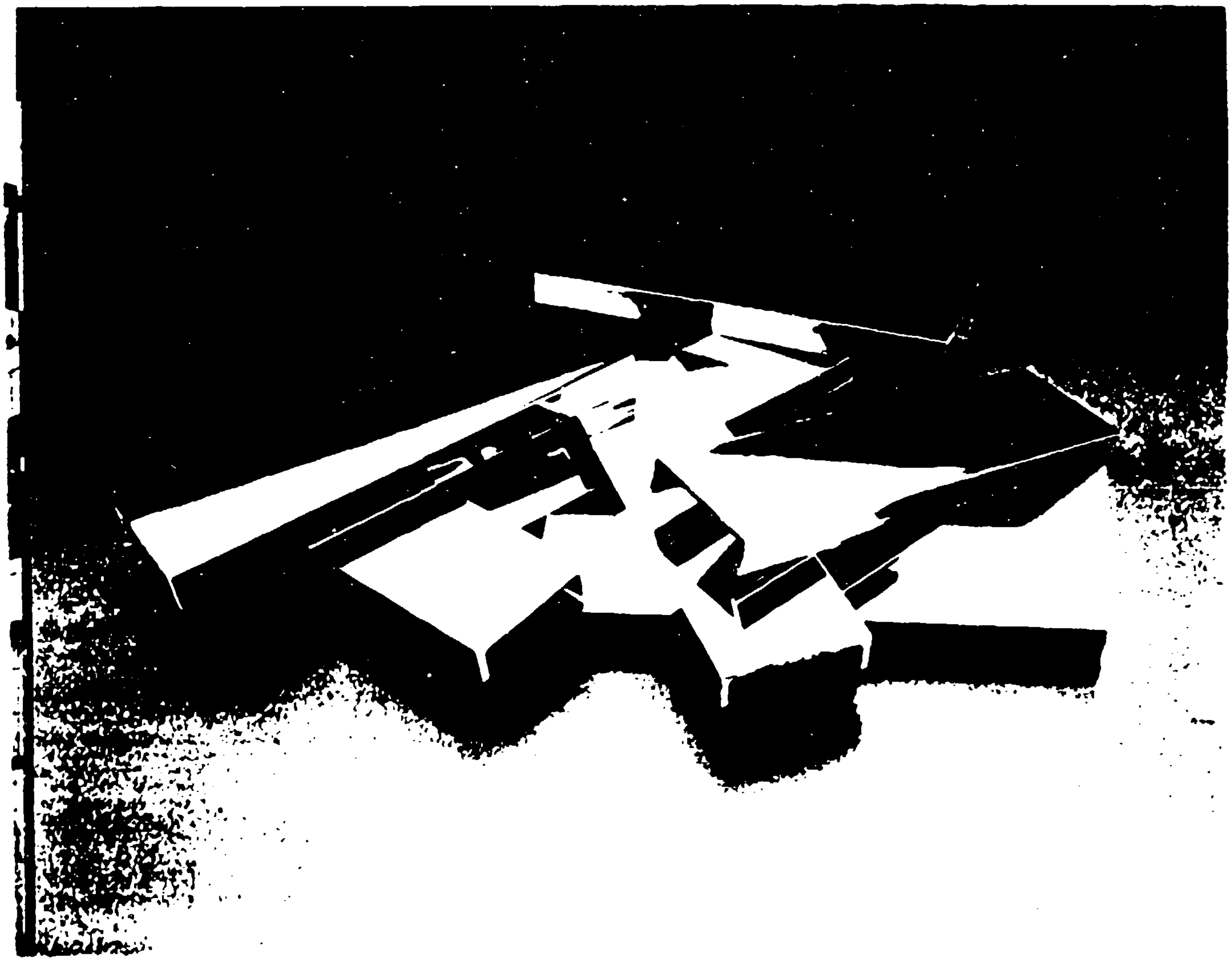
Lumiflon resins are the clear choice for applications where periodic recoating is undesirable or impractical and where long term retention of a coating's original appearance is important.

Lumiflon offers a choice of gloss

Lumiflon coatings can be formulated with a 60° gloss as high as 90%, or if you choose, at any low or medium gloss level. No other fluoropolymer offers this option.

Now, Lumiflon brings fluoropolymer protection to the automotive and architectural markets where control of gloss and gloss retention are essential.

Lumiflon offers the choice of low, medium, or high gloss coatings with no compromise in performance. Shown here is a high gloss, clear coating on extruded metal.

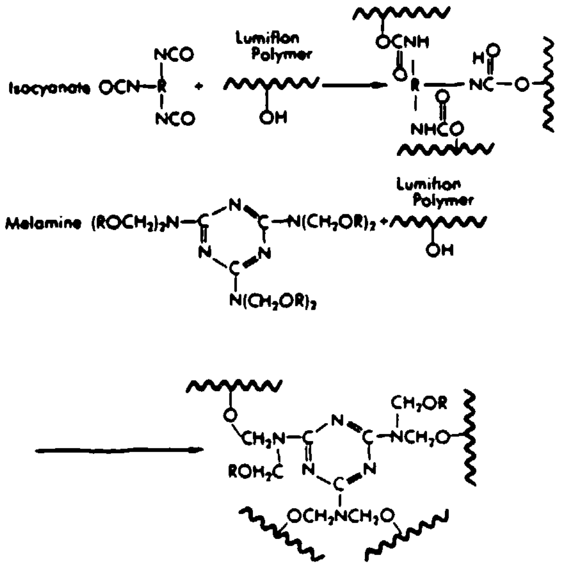


Lumiflon resins give you a choice of curing conditions

High temperature baking or ambient temperature curing makes little difference in the performance of Lumiflon based coatings, but makes a big difference in your application options.

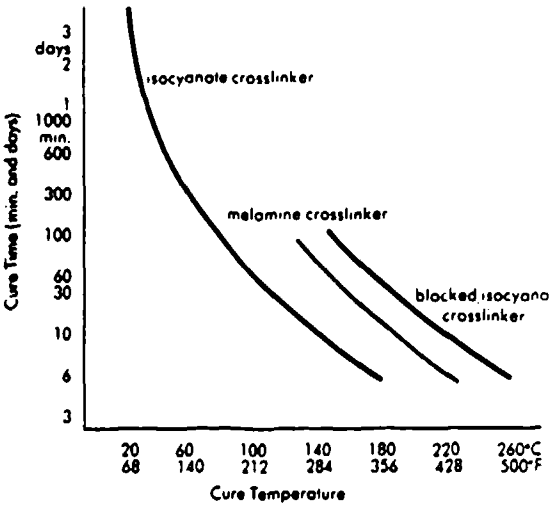
Through the choice of either isocyanate or melamine hardeners, Lumiflon coatings can be cured in minutes at elevated temperatures or cured at ambient temperature. Ambient temperature curing allows materials to be touched up with the same type of high performance coating that was applied in the factory. So every part can now have the same quality protection and finish, including those parts which must be fabricated and coated in the field. The long service life of Lumiflon coatings, plus their ability to be site applied and repaired, can make long term cost savings a reality.

CROSSLINKING REACTIONS OF LUMIFLON POLYMERS



CURE TIME AT VARIOUS TEMPERATURES

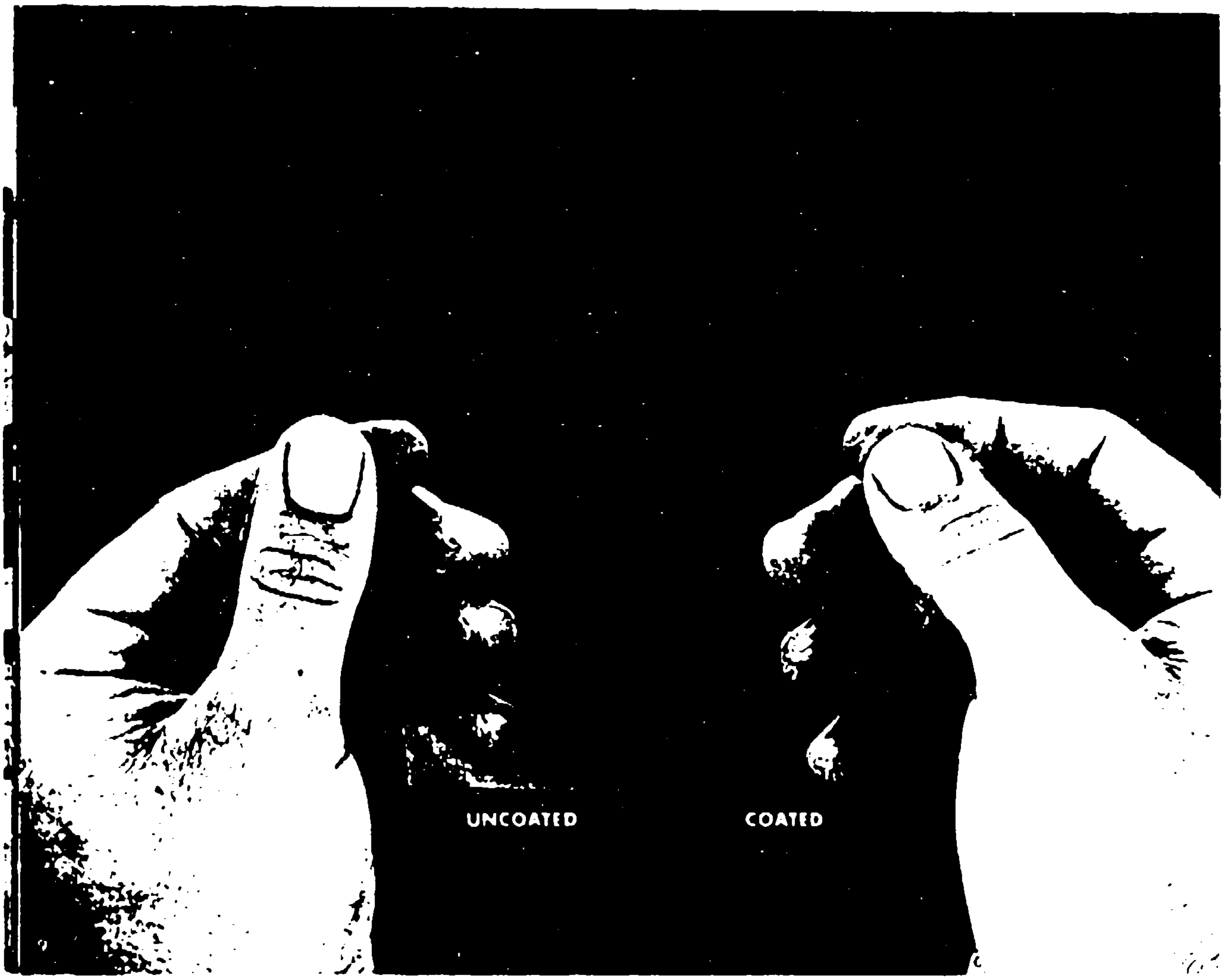
[illegible]



Clear transparent films with Lumiflon

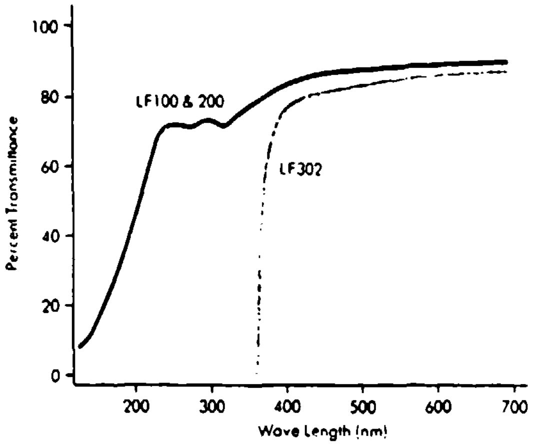
Clear coatings of Lumiflon resins transmit more than 90% of visible light so they can be used to protect substrates such as FRP, plastic film, and even topcoats, without changing color or clarity of the base material. Lumiflon 302 goes one step further by incorporating a UV absorber to protect the substrate itself from UV degradation.

The transparency and clarity of Lumiflon based clear coatings make them ideally suited for protecting clear plastic films or colored plastic substrates. Here a Lumiflon 302 coating protects this film from UV degradation, yet transmits more than 90% of visible light.

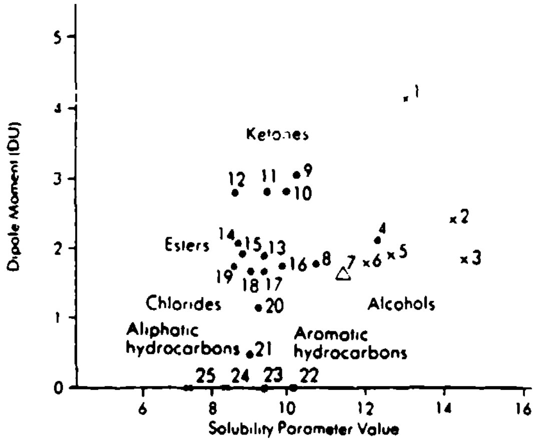


LIGHT TRANSMITTANCE OF CLEAR FILMS

[illegible]



SOLUBILITY IN ORGANIC SOLVENTS



• Soluble. △ Partly soluble: × Insoluble:

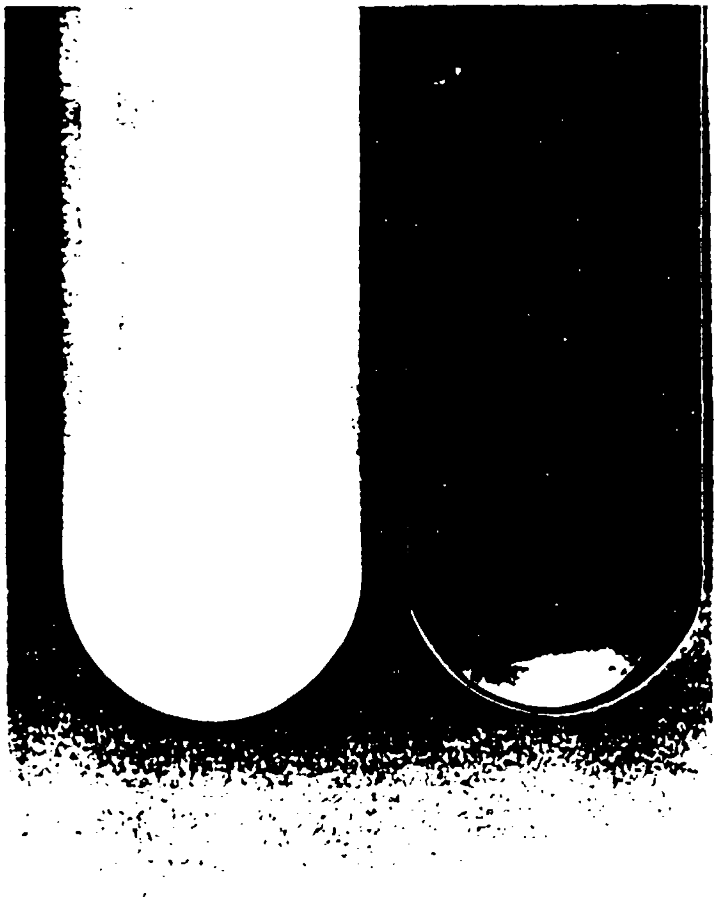
1 DMSO
2 Ethylene glycol
3 Methanol
4 DMF
5 Ethanol
6 Isopropanol
7 n-butanol
8 t-butanol
9 Acetone
10 Cyclohexanone
11 MEK
12 MIBK
13 Ethyl acetate
14 Butyl acetate
15 Glycol ether acetate EEA (Cellosolve ®)
16 Glycol ether DE (Carbitol ®)
17 Tetrahydrofuran
18 Glycol ether EB (Butyl Cellosolve)
19 1,1,1, trichloroethane
20 Trichloroethylene
21 Xylene
22 p-dioxane
23 Benzene
24 Cyclohexane
25 n-hexane

Lumiflon resins are solvent soluble

Because Lumiflon resins are soluble in a wide range of solvents, they offer both improved application properties and enhanced finish appearance when compared to other fluoropolymer systems.

The solubility of Lumiflon allows a diversity of application methods including spray, brush, roll, dip, and coil coating.

The solubility of Lumiflon 200 in xylene is compared with a commercial PVDF resin The excellent solvent solubility of Lumiflon contributes to its superior aesthetics and ease of application.



Lumiflon coatings adhere to most substrates

Lumiflon coatings can be successfully applied to metals such as mild, galvanized or stainless steel, aluminum and copper, and to plastics such as polyester, polyurethane, nylon, or PVC. Lumiflon coatings can even be used to coat glass.

Excellent adhesion properties make Lumiflon coatings ideal for recoating old, weathered surfaces.

ADHESION TO VARIOUS SUBSTRATES

	Substrate	Surface treatment	% Adhesion Retention*		
			Lumiflon Coating		Conventional Acrylic-urethane 7 days @ 25°C
			Isocyanate cured 7 days @ 25°C	Melamine cured 30 min @ 140°C	
METAL	Galvanized steel	Phosphoric acid	100	50	100
	Copper	Degreased	100	100	50
	Aluminum	Degreased	100	10	100
		Chromate Pretreatment	100	100	100
	304 Stainless steel	Degreased	50	10	10
		Degreased	100	50	50
GLASS	Float	Degreased	100	10	100
		Silane primer	100	100	100
PLASTICS	Unsaturated polyester FRP	Degreased	[illegible]		
	Epoxy	Degreased	[illegible]	[illegible]	
	Polyurethane	Degreased	[illegible]		
	Acrylic	Degreased	[illegible]		[illegible]
	Nylon 6	Degreased	[illegible]		[illegible]
	Rigid PVC	Degreased	[illegible]		
		Urethane primer	100		[illegible]
	Polypropylene	Corona discharge	100		[illegible]

*ASTM D3002 Tape Adhesion by Parallel Cut Method

COMPATIBILITY OF PIGMENTS WITH LUMIFLON RESINS

Pigment	Lumiflon Resin	
	Noncarboxylated LF100 & 200	Carboxylated LF400
Inorganic		
Titanium dioxide	Good	Good
Ochre	Good	Good
Red iron oxide	Good	Good
Other metal oxide complexes	Good	Good
Carbon black	Poor	Poor-Good*
Organic		
Quinophthalone yellow	Good	Good
Quinacridone red	Good	Good
Phthalocyanine green	Fair	Fair
Phthalocyanine blue	Poor	Fair

*Depends on grade

PROPERTIES OF LUMIFLON RESIN SOLUTIONS

	LF100	LF200	LF302	[illegible]
Percent Solids (wt %)	50	60	50	
Specific Gravity	1.08	1.13	1.08	
Density (lbs./gallon)	9.00	9.41	9.00	
Viscosity (cps @ 25°C)	5,000	4,000	800	
Solvent	Xylene	Xylene	Xylene	[illegible]
Appearance	Clear	Clear	Clear	[illegible]
OH Value (mg KOH/g)*	26	32	24	[illegible]
OH Equivalent Weight*	2,160	1,800	2,340	[illegible]
Acid Value (mg KOH/g)*	0	0	0	[illegible]

*Average values at supplied solids levels

Lumiflon coatings show good chemical resistance

Lumiflon coatings, regardless of curing conditions, show no change when exposed to such chemicals as:

- 10% H_2SO_4
- 10% HCl
- 5% CH_3COOH
- 10% $NaOH$
- 10% NH_4OH
- acetone
- benzene
- ethyl acetate
- trichloroethane

Lumiflon resins are the obvious choice for the protection of valuable substrates which are subject to harsh chemical environments.

The Lumiflon series

Four products are available to meet a range of applications:

Grade	Feature	Principal Uses
LF 100	High viscosity (5000 cps*)	Brush and roll applied coatings
LF 200	Low viscosity (800 cps*)	Spray applied coatings
LF 302	Absorbs UV light	Clear coatings for plastics
LF 400	Improved pigment compatibility	Dispersing organic and carbon black pigments

*50% solution in xylene

Each of these grades is crosslinkable with either isocyanate or melamine hardeners and shows cure rates similar to acrylic-urethane/acrylic-melamine systems.

Lumiflon coating formulations

Clear and pigmented coatings of various colors can be formulated with Lumiflon resins. While all grades may be used to formulate coatings containing almost any inorganic pigments, best results with carbon blacks and some organic pigments are obtained with the carboxylated LF 400 grade. In addition, wetting and dispersing agents may be needed to properly formulate Lumiflon coatings with these pigments.

All Lumiflon coatings are produced by mixing with a crosslinker capable of reacting with the hydroxyl groups of the Lumiflon resins. Various melamines and isocyanates can be used for this purpose as long as they are compatible with Lumiflon resins and have suitable reactivities.

It is advisable to use a catalyst to accelerate cure rates. A tin catalyst such as dibutyltin dilaurate is suggested for isocyanate cured coatings and an acid catalyst such as p-toluene sulfonic acid for melamine cured coatings.

Please consult the coating formulas inside the back cover for specific examples and recommendations.

MISCELLANEOUS PROPERTIES OF LUMIFLON 200 CLEAR FILMS

Hardener	Isocyanate	Butylated Melamine
Cure Conditions	7 days @ R T	5 min @ 210 C
Physical Properties		
Contact Angle of Water (degree)	85	78
Static Friction Coefficient	0.45	0.33
Water Absorption (wt%)	0.71	0.22
Water Permeability (g/cm² • sec • mm Hg)	$6.2 \times 10^{\text{[illegible]}}$	$4.3 \times 10^{\text{[illegible]}}$
Oxygen Permeability (cm² • sec • mm Hg)	$0.92 \times 10^{\text{[illegible]}}$	$0.85 \times 10^{\text{[illegible]}}$
Mechanical Properties		
Tensile Strength (kg/mm²)	2.8	3.0
Ultimate Elongation (%)	5	4
Tear Strength (kg/mm)	1.8	4.0
Flexural Fatigue (times)	200	60
Thermal Properties		
Glass Transition Temp. (°C)	35	63
Decomposition Temp. (°C)		214
Dimensional Change (%)		
after 600 hr @ 120°C	-1.7	4.3
after 24 hr @ -20°C	0.0	0.1
Discoloring (Yellow Index Change)		
after 200 hr @ 135°C	8.0	3.0
after 1000 hr @ 120°C	0.9	0.0
Electrical Properties		
Volume Resistivity Ωcm	$1.4 \times 10^{\text{[illegible]}}$	$1.3 \times 10^{\text{[illegible]}}$

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Oxygen Permeability ($cm^2 \cdot sec \cdot mm\ Hg$)	$0.92 \times 10^{[illegible]}$	$0.85 \times 10^{[illegible]}$
Mechanical Properties		
Tensile Strength (kg/mm^2)	2.8	3.0
Ultimate Elongation (%)	5	4
Tear Strength (kg/mm)	1.8	4.0
Flexural Fatigue (times)	200	50
Thermal Properties		
Glass Transition Temp. (°C)	35	63
Decomposition Temp. (°C)		214
Dimensional Change (%)		
after 600 hr @ 120°C	-1.7	4.3
after 24 hr @ -20°C	0.0	0.1
Discoloring (Yellow Index Change)		
after 200 hr @ 135°C	8.0	0.0
after 1000 hr @ 120°C	0.9	0.0
Electrical Properties		
Volume Resistivity Ωcm	$1.4 \times 10^{[illegible]}$	$1.3 \times 10^{[illegible]}$

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756-2 10/86 5M

Printed in U.S.A.

Coating No. 14

DEFT

DEFT, INC., 17451 VON KARMAN AVENUE, IRVINE, CALIFORNIA 92714 / (714) 474-0400

SPECIFICATION FOR DEFT 44-BK-6 WATER REDUCIBLE EPOXY PRIMER

Use:
1. Non-chromate corrosion and chemical resistant primer for ferrous and non-ferrous metals.
2. Sanding primer-surfacer for fiberglass.

Description: A water reducible, catalyzed epoxy, corrosion inhibiting primer to meet new clean air Volatile Organic Compounds requirements.

Performance:
1. Excellent corrosion resistance.
2. Excellent adhesion over all metal and fiberglass surfaces.
3. Excellent chemical and solvent resistance.
4. Excellent primed surface for polyurethane, thermosetting acrylic enamel, and acrylic enamels (air dry and bake).
5. No flash rusting on ferrous metals.
6. No foaming.
7. Low overspray.
8. No irritating odor.
9. Freeze-thaw stable.

PHYSICAL PROPERTIES (typical):

Component I - Pigmented Compound (L-9466)

Weight per gallon	13.2 lbs.
Non-Volatile by Weight	74.8 %
Fineness of Grind	5.0
Storage Stability	1 year
Flash Point	97°F TCC

Cont'd . . .

SPECIFICATION FOR DEFT 44-BK-6
(CONTINUED)

PHYSICAL PROPERTIES (typical):

Component II - Clear Compound (L-9467)

Weight per Gallon	9.7 lbs.
Non-Volatile by Weight	82.9 %
Storage Stability	1 year
Flash Point	87°F TCC

Catalyzed (Component I and Component II Mixture)

Weight per Gallon	12.3 lbs.
Non-Volatile Content	76.2% by weight
Non-Volatile Content	60.0% by volume

Catalyzed and Reduced with 175% Water for Application (Typical)

Weight per Gallon	9.8 lbs.
Non-Volatile Content	35.0% by weight
Non-Volatile Content	21.8% by volume
Theoretical Coverage at 1 mil dry film	960 sq. ft./gal. kit
Volatile Organic Compounds (VOC)	349 g/l (2.91 lbs./gal.
Flash Point	85°F TCC
Pot Life (under constant agitation)	6 hours min. @ 73°F (starting at 20 seconds)

Catalyzation Ratio (Typical)

Component I	Component II	Water
3 volumes	1 volume	7 volumes

DEFT

DEFT., INC., 17451 VON KARMAN AVENUE, IRVINE, CALIFORNIA 92714 / (714) 474-0400

MIXING INSTRUCTIONS FOR

44-BK-6

MIXING RATIO - 3:1 SYSTEM

Component I	Component II	Water
3 volumes	1 volume	7 volumes (approx)

MIXING COMPONENTS I & II BEFORE WATER ADDITION (Catalyzation)

1) Add all of Component II (Clear Component) to the short filled can containing Component I (Pigmented Component). Then use one of the following methods for catalization:

A. PAINT SHAKER METHOD

For mixing quart or gallon kits, use a standard gallon capacity paint shaker which vibrates at about 1300 cycles/minute. Vibrate on the shaker 5 minutes in the inverted position.

OR

B. MECHANICAL MIXING METHOD

For mechanical mixing (when paint shaker is not available) an air motor with a dispersion type blade attached to a steel rod (see recommended mixing equipment) may be used. Mix for about 5 minutes or until mixture is homogenous. Be sure to scrape the sides and bottom of container in order to include all the compound in the mixture. Proceed to Step #2.

2) WATER REDUCTION AND MIXING FOR APPLICATION

Transfer catalyzed primer into a larger mixing container.

KIT		APPROX. VOLUME		RECOMMENDED CONTAINER SIZE
SIZE	NUMBER	WATER	TOTAL MATERIAL	
Quart	1	1.75 qts	2.75 qts	1 gallon
Gallon	1	1.75 gal	2.75 gal.	5 gallons

Coating No. 15

DEFT, INC., 17451 VON KARMAN AVENUE, IRVINE, CALIFORNIA 92714 / (714) 474-0400

HIGH SOLIDS FLEXIBLE PRIMERS

02-Y-38 YELLOW, TYPE I
02-GN-66 GREEN, TYPE II
LOW VOC - 340 GRAMS/LITER

PRODUCT DESCRIPTION:

02-Y-38 AND 02-GN-66 ARE TWO COMPONENT PRIMERS HAVING A LOW VOC OF 340 GRAMS/LITER. THESE PRIMERS EXHIBIT A HIGH DEGREE OF ELONGATION AS WELL AS OTHER HIGH PERFORMANCE PROPERTIES.

PRODUCT CONSTANTS: (CATALYZED 1 TO 1 BY VOLUME)

VISCOSITY:	30" - 35" #2 ZAHN
VOC:	LESS THAN 340 GRAMS/LITER
COLOR:	YELLOW (STRONTIUM CHROMATE), TYPE I GREEN (LOW IR), TYPE II
% SOLIDS BY WEIGHT:	68.3%
POT LIFE:	10 SECONDS MAXIMUM RISE IN 4 HOURS
PENCIL HARDNESS (7 DAYS):	F
REVERSE IMPACT:	160 IN-LBS.
IMPACT (60% MIN. ELONGATION):	GREATER THAN 60%
FLEXIBILITY (1/8" MANDREL):	PASS

PERFORMANCE PROPERTIES: (TOPCOAT COMPLIES WITH MIL-C-83286, COLOR #17925)

WET ADHESION:	
24 HOURS AT ROOM TEMP.:	PASS
4 DAYS AT 120°F.:	PASS
HUMIDITY (30 DAYS):	PASS
ELONGATION:	GREATER THAN 100%
STRIPPABILITY:	PASS
SALT SPRAY (1000 HOURS):	PASS

CONT'D . . .

PERFORMANCE PROPERTIES (CONTINUED):

FILIFORM (30 DAYS): PASS
MIL-L-23699, 24 HRS @ 250°F: HB
MIL-H-83282, 24 HRS @ 150°F: HB
MEK RUBS (100 DOUBLE RUBS): PASS
FLEXIBILITY (4 HRS @ 250°F): 1/8" MANDREL
IMPACT (4 HRS @ 250°F): 60%
COLD FLEX (4 HRS @ -60°F): 1/8" MANDREL

THE ABOVE TESTS WERE TAKEN FROM MIL-P-85853 ELASTOMERIC POLYURETHANE. BOTH 02-Y-38 AND 02-GN-66 MEETS AND EXCEEDS THE PERFORMANCE REQUIREMENTS FOR MIL-P-85853.

SURFACE PREPARATION:

ALUMINUM SURFACES TO BE COATED SHOULD BE CONVERSION COATED TO FORM A SURFACE COMPLYING TO MIL-C-5541.

MIXING:

MIX ONE VOLUME OF BASE WITH ONE VOLUME OF CATALYST AND MIX THOROUGHLY.

THINNING:

THINNING IS NOT ALLOWED TO ACHIEVE THE VOC LIMIT OF 340 G/L.

APPLICATION:

APPLY BY SPRAY USING WET COATS TO ACHIEVE THE REQUIRED FILM THICKNESS. A MINIMUM OF ONE MIL DRY IS SUGGESTED.

TOPCOAT:

THIS PRODUCT IS DESIGNED FOR USE AS A PRIMER FOR TOPCOATS MEETING MIL-C-83286 OR MIL-C-83285. THE PRIMER SHOULD CURE A MINIMUM OF 10 HOURS PRIOR TO TOPCOAT APPLICATION. PRIMER THAT HAS CURED MORE THAN 24 HOURS SHOULD BE LIGHTLY SANDED PRIOR TO TOPCOAT APPLICATION. FORCE CURE OF THE PRIMER PRIOR TO TOPCOAT APPLICATION MAY BE UTILIZED. ONE HOUR AT 140°F IS A SUGGESTED FORCE DRY SCHEDULE.

CLEAN UP:

USE MIL-T-81772 TYPE II FOR CLEANING EQUIPMENT IMMEDIATELY AFTER USE.

SAFETY:

ALL PERSONNEL SHOULD READ AND UNDERSTAND ALL LABELS AND MATERIAL SAFETY DATA SHEETS PRIOR TO THE USE OF ANY MATERIALS.

Coating No. 16

Freeman
A SUBSIDIARY OF GEORGIA GULF CORP.
Specialty Products and Services Today for Tomorrow's Needs

Freeman Chemical Corporation
217 Freeman Drive
P. O. Box 996
Port Washington, WI 53074-0996
(414) 284-5541 -:- Telex: 2-6737

June 22, 1989

Mr. Martin van Buren
Arthur D. Little
Acorn Park
Cambridge, MA 02140

Dear Mr. van Buren:

You will find enclosed with this letter one each of your epoxy-graphite and aluminum test panels coated with peroxide curable coating formulations A804-62-E (urethane acrylate) and A804-62-F (epoxy acrylate).

The coatings are intended for your evaluation as a primer to protect the substrate from abrasion by plastic shot.

These materials were applied at 80% solids using a #14 wire wound rod and cured for one hour at 100°C.

Please let us know if you have any questions or comments.

Sincerely,

FREEMAN CHEMICAL CORPORATION

Rudi Boeckeler

Rudi H. Boeckeler
Senior Chemist
Research Department

RHB/cd

Enclosure

165,200/55

Coating No. 17

No technical literature available.

Coating No. 18

HUGHES
ELECTRO-OPTICAL & DATA SYSTEMS GROUP

August 14, 1989

Mr. Jay Cheney
Arthur D. Little, Inc.
Acorn Park
Cambridge, Massachusetts
02140-2390

Dear Jay,

Enclosed are three composite and two aluminum panels coated with HRG-3/A3 and three aluminum panels coated with HRG-3/A2 for testing on your Air Force contract.

If you need any further information, please call me at (213)607-7166.

Sincerely,

Susan Oldham
Senior Staff Engineer
Adhesives & Coatings Section

HIGH TEMPERATURE RESISTANT COMPLIANT MODIFIED EPOXIES

S.L. Oldham and W.E. Elias
Hughes Aircraft Company
El Segundo, CA 90245

ABSTRACT

Epoxy resins are widely used as adhesives, encapsulants, and coatings for a broad range of electrical and structural applications. In particular, these resins are useful since they provide mechanical protection, thermal stability, good substrate adhesion, and moisture resistance. However, a problem common to the myriad of epoxy systems is the development of thermomechanical stresses and strains when the encapsulated devices, bonded assemblies, or coated substrates are heated or cooled. Moreover, for space applications, the resin must be able to withstand large extremes in thermal exposure with little or no outgassing. In addition, the ease of repairability is important for purposes ranging from the replacement of critical components and hardware to cosmetic patching. A need exists for the production of space-grade materials with increased ductility and reduced sensitivity to thermal excursions.

At Hughes Aircraft Company, a family of compliant modified epoxies were synthesized for use as adhesives, coatings, and encapsulants. The base resins exhibited low viscosities, glass transition temperatures and outgassing characteristics with high peel strengths and decomposition temperatures. Baseline material data indicates that HRG-3, one of these modified resins, is a viable solvent-free toughened epoxy system where thermal stability, repairability, abrasion and moisture resistance, and low outgassing are important.

INTRODUCTION

Performance, weight, and environmental impact requirements for many future DOD and NASA programs dictate the extensive use of advanced materials that have capabilities exceeding those that are currently available to designers of structural, and electronic hardware. Epoxy resins are commonly used as adhesives, encapsulants, and coatings due to their processibility, versatility, and favorable use history. In particular, epoxies are heavily utilized when good mechanical protection, thermal stability, substrate adhesion, and moisture resistance are needed. However, a common problem with these systems is that the combination of good repairability, broad temperature capability, and thermal cycling and humidity resistance with low viscosity and outgassing characteristics is generally not found in a single system. High glass transition temperature (Tg) epoxy resins are usually brittle, viscous, difficult to repair, and sensitive to thermal cycling conditions. Flexibilized epoxies generally possess high viscosities with poor humidity, elevated temperature, and outgassing characteristics. These limitations become particularly critical for applications where large extremes in temperature can induce thermomechanical stresses and strains in encapsulated devices, bonded assemblies, and coated substrates. In addition, under the conditions found in space, volatile resin components can outgas and condense on sensitive optical devices, potentially blinding and shortening the operational lifetimes of commercial and military satellites. Moreover, abrasion and plasma resistant materials are needed, respectively, for ease of satellite assembly fabrication and low earth orbit (LEO) particulate bombardment. Repairability of any resin system destined for air, space, or ground use is highly desirable since it allows the replacement of critical components and hardware as well as the cosmetic patching of noncritical areas. In terms of environmental impact, the ability to apply a given resin system in its undiluted form becomes increasingly important as the restrictions on the use of the type of solvents become more severe.

Because of the problems associated with standard epoxies in meeting the increased demands of new structural, and electronic systems, a need exists for the production of space-grade materials with increased ductility and reduced sensitivity to thermal excursions.

Resin Studies

Investigations at Hughes Aircraft led to the synthesis and development of a family of ductile modified epoxies as base resins for the formulations of adhesive, encapsulants, and coatings. All of these HRG series resins exhibited low viscosities (250-528 centipose) low Tg's (0-42 °C), and high decomposition temperatures (310 °C $\leq$ Td $\leq$ 340 °C). Two of these resins, designated as HRG-1 and HRG-3, demonstrated good ductility and ASTM E595 outgassing characteristics. The high purity, shorter chain length HRG-1 exhibited T-peel strengths of 1.8-3.4 kilogram per centimeter width (10-19 pounds per inch width), with a total mass loss (TML) value of 0.64%, a collectable volatile condensable material (CVCM) value of 0.03%, and a water vapor recovery (WVR) value of 0.09%. The lower purity, longer chain length HRG-3 exhibited slightly lower T-peel strengths and higher, but still acceptable, outgassing values (Table 1).

Due to Tg considerations, the majority of the resin development was performed using the HRG-3 system. It can be seen from the data listed in Table 1 that this material exhibits high elongation, broad temperature capability, low tensile and lapshear strengths, and good electrical and moisture absorption characterstics. In addition, current coating studies have shown that the HRG-3 system can be easily applied in its neat form, eliminating the need for solvent dilution. This offers significant advantages with respect to environmental impact, as the Southern California Air Quality Management District (SCAQMD) restrictions on solvent usage (Rules 1124 and 442) become increasingly more severe. The development of ductile, repairable, space-grade, SCAQMD compliant resin systems is critical for future conformance to environmental and technological requirements.

TABLE 1
PROPERTIES OF HRG-3 CURED RESIN

Property	Value
Uncured resin viscosity at room temperature, cps	528
Glass transition temperature, °C	4 - 10
Decomposition temperature, °C	310
Outgassing:	
Total mass loss, %	0.98
Collectable volatile condensible materials, %	0.08
Water vapor recovery, %	0.11
Specific gravity	1.11
T-peel strength, kg per cm width (lb per in width)	1.7 (9.4)
Elongation, %	83
Tensile strength, MPa (psi)	2.3 (330)
Lapshear strength, MPa (psi)	2.7 (400)
Dielectric constant at 1 kHz	3.45
Volume Resistivity, Ω-cm	4.4 x 10^{15}
Dielectric strength, volts/mm (volts/mil)	4.06 x 10^{5} (1.03 x 10^{3})
Moisture Absorption, 24 hour Water boil, %	1.54

APPLICATIONS

A recent study was performed using HRG-3, in an unoptimized form, as an abrasion resistant coating for composites. A coating thickness of 0.0127 mm (0.005 inch) was applied to half of the surface of a twelve ply epoxy/graphite composite. After full cure, the entire panel surface was coated to a dry film thickness of 0.0152-0.0229 mm (0.006-0.009 inches) with epoxy-polyamide primer conforming to MIL-P-23377. The primed composite was then cured and topcoated to a dry film thickness of 0.0432-0.0584 mm (0.0017-0.0023 inches) with MIL-C-83286B polyurethane paint.

Thus, the protected half of the panel comprised an epoxy/graphite composite laminate, an interlayer of HRG-3, a primer layer, and a polyurethane paint layer. The unprotected half of the panel comprised an epoxy/graphite composite laminate, a primer layer, and a polyurethane paint layer.

The panel was then subjected to plastic bead blast, using abrasive blasting machines equipped with Polyextra 20/30 Type AGO plastic bead media, manufactured by U.S. Plastics and Chemical Co. The blast nozzle pressure was 10.5 megapascals (70 psi). The pellet blasts were directed at the center of the panel to simultaneously remove the paint on the unprotected half of the panel and on the half of the panel protected with HRG-3 as an interlayer.

It was found that the HRG-3 interlayer was still intact after complete paint and primer removal of a 38.1 mm (1.50 in.) long area, while extensive damage (removal of 5-12 plies of the composite) to the unprotected side resulted. In particular, a hole of approximately 59 mm^2 (0.09 in^2) through the composite was made by the pellet blasting within a 42.8 mm (1.69) long area (Figure 1). When the pellet blasting was repeated for a sufficient time to damage the HRG-3 interlayer in a fresh area of the composite, the bulk of the 37.4 mm (1.47 in.) long area still had intact its HRG-3 coating. A depression of approximately 87 mm^2 (0.14 in^2) was found at the center of the panel, where 2-3 plies of composite had been removed. On the unprotected side, extensive damage (removal of 5 to 12 plies of composite) resulted. In particular, a hole of approximately 263 mm^2 (0.41 in^2) through the composite was made by the pellet blast (Fig. 2).

This testing illustrates the excellent abrasion damage resistance of HRG-3 coatings. It is expected that the other HRG series resins will also exhibit this behavior. Investigations into simulated LEO particulate bombardment protection by HRG-3 coatings are currently underway. The develpment of optimized HRG coatings, adhesives, and encapsulants is seen as an area requiring future investigation.

SUMMARY

A family of modified epoxy resins possessing low viscosity, Tg and outgassing values with high peel strength and TD were synthesized for use as adhesives, coatings, and

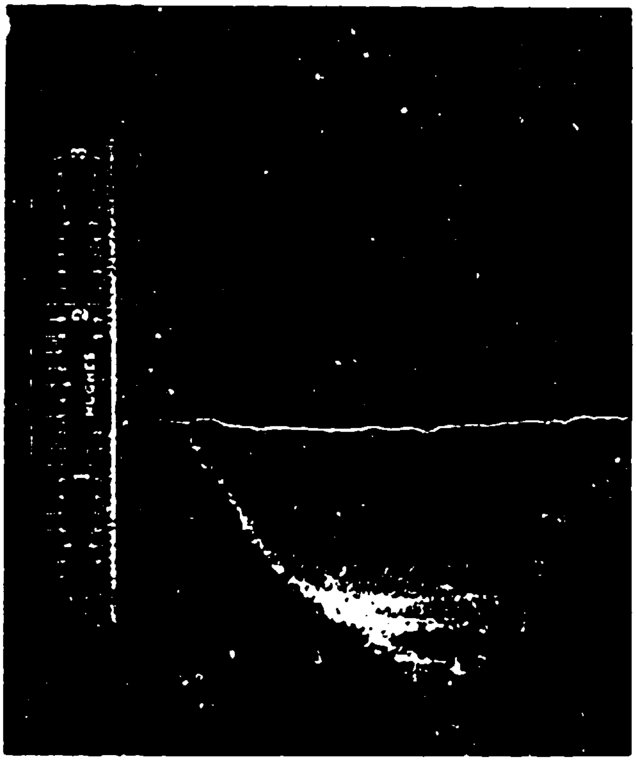

Figure 1: Abrasion Testing of HRG-3 Interlayer Composite

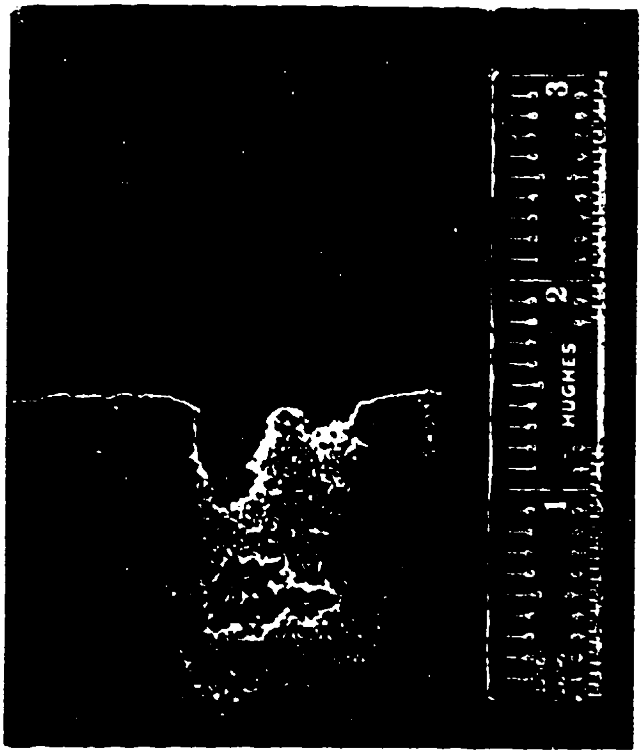

Figure 2: Abrasion Testing of HRG-3 Interlayer Composite

encapsulants. One of these materials, HRG-3, exhibited high elongation, broad temperature capability, low tensile and lapshear strengths, and good electrical, and moisture absorption characteristics. Coating studies with this resin system have demonstrated that it can be applied in its neat form, offering significant environmental impact advantages. Even in its unoptimized form, it possessed excellent abrasion resistance as a composite interlayer coating. The development of HRG-3 into optimized coatings, adhesives, and encapsulants is an area for future study to fulfill the need for repairable, ductile, space-grade SCAQMD compliant resin systems.

ACKNOWLEDGEMENTS

We gratefully acknowledge the invaluable contributions of Dr. Kreisler Lau, Ms. Desiree Prior, and Mr. Steven Bigus in making this development program a success.

BIOGRAPHIES

Susan L. Oldham and Bill E. Elias are a staff engineer and a member of the technical staff, respectively, in the Technology Support Division of Hughes Aircraft Company. Presently, they are investigating new polymeric materials and formulations for aerospace applications.

Ms. Oldham has eleven years experience in developing polymeric materials for structural and electrical applications. During this time, she has been subtask leader of various internal research and development programs as well as co-principal investigator of an AFWAL contract to develop a low dielectric constant printed wiring boards for advanced VHSIC applications. She received a B.A. degree in chemistry from the University of California, Irvine and an M.S. in chemical engineering at the University of Southern California. She has three issued patents and four technical publications.

(Continued on page 165)

Coating No. 19

PRODUCT DATA SHEET

chemical formulators since 1955

FIBER-RESIN CORP.

FIBER-RESIN CORP.
P.O. Box 4187
170 W. Providencia Ave.
Burbank, CA 91503
1-800-624-9487
Telefax: (818) 955-8979

FIBER-RESIN CORP
25200 Malvina
Warren, MI 48089
1-800-346-9876
In MI. 1-800-852-7724
Telefax: (313) 777-3490

FR-7020 A/B
GRAPHITE COMPOSITE REPAIR COMPOUND

DESCRIPTION:

FR-7020 A/B is a two component epoxy system that offers low temperature cure, high temperature strength and excellent resistance to hot water immersion. These factors led to the selection of FR-7020 A/B as a system for graphite composite repair on commercial and military aircraft.

FR-7020 A/B lamin[illegible] re set to handle within 6 hours at room temperature, or one [illegible]r at 150 F. without post cure, it can provide good strength to 300 F. Excellent property retention in 160 F. water is developed with 150 F. cure.

MIX RATIO:

Mix 58 parts by weight of FR-7020-B hardener, with 100 parts by weight of FR-7020-A.

POT LIFE:

The pot life of FR-7020 A/B is 40-50 minutes, per 150 gram mass.

CURE CYCLE:

FR-7020 A/B was designed as a room temperature curing epoxy to develop 300 F. strength, with short term aging. Cure can be greatly accelerated with moderate heat, as with heat lamps or a field repair heat source such as the ATACS Hot Bonder*. Data below was based on time @ 75 - 79 F. to reach the compressive strength of 41,000 PSI.

6 hours	Hard to the touch.
24 hours	28,000 PSI Compressive Strength
72 hours	39,000 PSI Compressive Strength
120 hours	41,000 PSI Compressive Strength

NOTE:

FR-7020 A/B achieves 41,000 PSI compressive after a 3 hour cure at 150 F. Allow room temperature gel before applying heat.

* ATACS PRODUCTS, INC. P.O. Box 88237 Tukwila Br. Seattle, WA. 98188. Telex Number; 329570

FR-7020 is also available in gray.

TYPICAL PHYSICAL PROPERTIES:

Color	Black or Gray
Specific Gravity, gms/cc	1.1
Viscosity, CPS	
Part A	25,000
Part B	3,200
Mixed	20,000
Tensile Lap Shear Strength, PSI	
AL/AL FPL etch, 7 day cure	
@ R. T.	2,400
@ 300 F.	600

NOTE: 300 F. properties can be improved with primer.

TYPICAL LAMINATE PROPERTIES:

20 PLIES THORNEL 300, 3K 24 x 23 PLAIN WEAVE, .009 INCHES PER PLY
VACUUM BAGGED AND CURED 2 HOURS @ 130 F. + 2 HOURS @ 250 F.

Compressive Strength, PSI	47,315
Compressive Modulus, PSI	6.1×10^6
Flexural Strength, PSI	113,473
Flexural Modulus, PSI	3.2×10^6
Tensile Strength, PSI	
@ R. T.	41,240
@ 300 F.	20,570
Tensile Modulus @ R.T., PSI	7.8×10^6
Short Beam Shear Strength, PSI	12,624
Interlaminar Shear Strength, PSI	4,960

STORAGE:

FR-7020-A should be refrigerated for long term stability. Storage life is 3 months at room temperature or 12 months at 40 F. hardener FR-7020-B is stable for one year at room temperature. Material should not be used if part A is waxy and does not return to a syrup like consistency with mild heat, (120 F.).

SAFETY AND HANDLING:

As with all resin systems, liquid and vapor may cause irritation to some people. Avoid contact with skin and use adequate ventilation. Wash skin with soap and water. Flush eyes with water copiously and get medical attention. 6/89

Coating No. 20

No technical literature available.

☆ U.S. Government Printing Office: 1992—648-127/62286