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THE APPLICATION OF ULTRAVIOLET CURE RESINS FOR REPAIR OF COMPOS--ETC(U)
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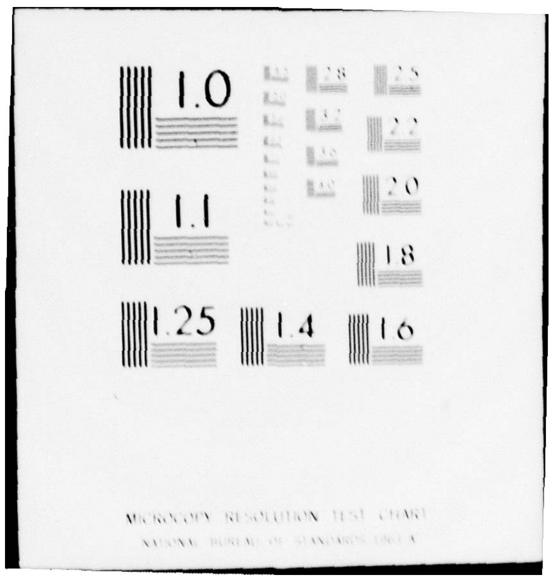
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AERONAUTICAL ANALYTICAL REWORK PROGRAM

TEST REPORT

THE APPLICATION OF ULTRAVIOLET CURE RESINS FOR REPAIR OF COMPOSITES

NOVEMBER 1977

CONTRACT NO. N62269-77-M-7197

ANALYTICAL REWORK/SERVICE LIFE PROJECT OFFICE

NAVAL AIR DEVELOPMENT CENTER, WARMINSTER, PA. 18974

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SUMMARY

This investigation has shown that it is possible to quickly, easily, and safely repair in the field damaged composites using UV curable resins. Although the best repair in this study restored 76% of the strength of the undamaged laminate, stronger repairs should be possible by optimizing the repair method. The nature of this study did not allow for a complete evaluation of all the variables which would affect the strength of these repairs. It is, therefore, reasonable to assume that stronger repairs would be possible by optimizing not only the resin system but also the method of cure (i.e. cure time, light intensity and wavelength), the surface preparation, and the reinforcing material.

FOREWORD

This study was conducted under the Analytical Rework Program sponsored by the Naval Air Systems Command (AIR-4114C, Mr. A. J. Koury).

THE APPLICATION OF ULTRAVIOLET CURE RESINS FOR REPAIR OF COMPOSITES

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I. INTRODUCTION

Present resin systems in use for field repair of composites in aircraft suffer from a number of disadvantages including high cure temperature and long cure time. Ultraviolet cure resins may offer unique advantages in this application. The whole area of radiation cure of coatings has been surveyed in a recent study,[1] which has shown the feasibility of a simple, portable, and efficient device for field application of this type of coating. The work presented in this report was aimed at evaluating the potential of ultraviolet cure resins for field repair of damaged composites.

II. EXPERIMENTAL

Substrate

The composite substrate for this study was a graphite/epoxy laminate of the type commonly used for naval aircraft. It was supplied by the Naval Air Development Center, Code 30P7.

Resins

The UV curable resins were all obtained from commercial sources. These resins, along with the companies from which they were obtained, are listed in Table 1.

Energy Sources

A variety of different light sources was used in this investigation, and these are listed in Table 2. The best low intensity lamp was that developed in the earlier program.[1] It contained five 6-watt fluorescent GE blacklight bulbs and gave excellent performance with minimum hazard. However, some of the resins in this investigation could not be cured by this lamp, and for these resins it was necessary to use a Hanovia 550-watt lamp. The high intensity light (about 30 watts) emitted in the far UV (2200-2800 Å) is quite dangerous, and, when in use, it must be enclosed to protect the workmen. Fortunately, the small size of this lamp (tube dimensions: about 9" x 2") allows for easy fabrication of an enclosure. For our experiments, plywood was used to make the enclosure, and all cracks were sealed with duct tape.

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1 "Feasibility Study of a One-Step Portable Coating System Using Electromagnetic Radiation Cure", Final Report Contract N62269-76-C-0147, Pennwalt Corporation, October 12, 1976.

Curing and Adhesion

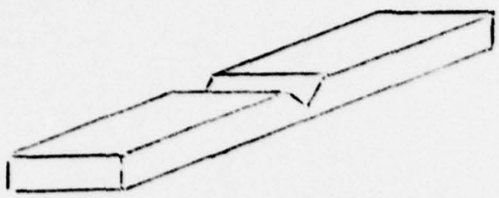
All of the resins were evaluated for the conditions necessary for curing and for the relative degree of adhesion to the epoxy/carbon cloth laminate. All of the resins, except those from Celanese and Polychrome, cured in five minutes or less when 5-10 mils thick, using the five 6-watt blacklight bulbs. The resins from Celanese and Polychrome could only be cured with the Hanovia lamp and required 30-60 minutes of exposure for complete curing of 30 mil thick layers. The Hanovia lamp also generated a considerable amount of heat, causing temperatures to reach about 70°C within a half hour of irradiation. The effect of this heat on the curing and strength of the resins has not been determined.

The samples from Daubert and Polychrome required an inert atmosphere for curing, and a novel technique was devised for achieving anaerobic curing conditions. This technique involves application of a UV transparent plastic film over the sample to be cured prior to irradiation. The plastic film used was Pennwalt's KYNAR, a polymer which is almost completely transparent to and not degraded by UV radiation. This technique was very successful for the resins in this investigation and may find application in other areas where UV curing in an inert atmosphere is required. The adhesion of the various resins to the graphite/epoxy laminates is summarized in Table 3. There is a large variation in the adhesion of the various resins to the unsanded laminates ranging from no lift to 90% lift with the tape crosshatch test.

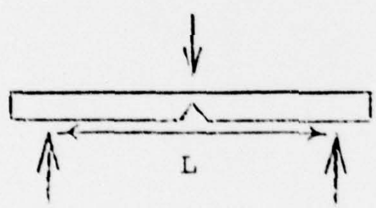
On the other hand the adhesion to the sanded laminate surface is good to excellent for all the resins tested. Thus the surface preparation is important for good adhesion, especially for some of the resins. Those from Celanese appeared to have the best overall adhesion to the laminate substrate.

Strength of Repair

A series of experiments was performed in order to determine the relative ability of the various resins to repair graphite/epoxy laminate structures. Specimens 2" long and 0.46" wide were cut from larger laminate sheets 0.15" thick. Most of these samples were then machined to produce a groove 0.05" deep and 0.10" wide at the top, as shown in this drawing:



The samples were then repaired either by just filling the groove with resin and subsequent curing or by filling the groove with resin and then placing a fiberglass strip saturated with resin on top followed by curing, or by sanding and proceeding as above. The resulting samples were then tested with an Instron as shown in this drawing:



The flexural strength of each sample was determined from the equation

$$\frac{3PL}{2bd^2}$$

where
P = pressure at break or failure
L = span
d = sample thickness
b = sample width

For all of the grooved samples d was taken as the laminate thickness before grooving. The results of the experiments are summarized in Tables 4 and 5. The conclusions from these experiments are summarized below.

1. Just filling the grooves with a UV cure resin does little to strengthen a damaged composite.

2. Sanding a damaged laminate and applying a patch greatly increase the ability of a UV cure resin to restore a damaged composite to its normal strength.

3. Of the resins tested those from Celanese were able to repair the grooved laminates best.

III. SUMMARY

This investigation has shown that it is possible to use UV curable resins to make quick, easy, and safe repairs in the field on damaged composites. Although the best repair in this study restored 76% of the strength of the undamaged laminate, stronger repairs should be possible by optimizing the repair method. The nature of this study did not allow a complete evaluation of all the variables that would affect the strength of these repairs. It is, therefore, reasonable to assume that stronger repairs would be possible by optimizing not only the resin system but also the method of cure (i.e., cure time, light intensity, and wavelength), the surface preparation, and the reinforcing material.

Table 1. Ultraviolet Cure Resins Studied

Trademark	Manufacturer	Chemical Description as Given by Manufacturer
Celrad 3700	Celanese	Bisphenol-A Epoxy-Diacrylate Ester
Celrad 3701	Celanese	Acrylated Epoxy
Atlac 382	ICI United States	Bisphenol-A Polyester
Atlac 580	ICI United States	Bisphenol-A Modified Vinyl Ester
Atlac 4010K	ICI United States	Polyester
Uvimer 530	Polychrome	a
Uvimer 580	Polychrome	a
Uvimer 775	Polychrome	a
Photopolymer RCC-4	W. R. Grace & Co.	a
Photopolymer RCC-14	W. R. Grace & Co.	a
Photopolymer RCC-11	W. R. Grace & Co.	a
Photopolymer XRCP-3811	W. R. Grace & Co.	a
Photopolymer SIV-4	W. R. Grace & Co.	a
Photopolymer 9061C	W. R. Grace & Co.	a
3M 1301	3M	Epoxy
Melcril 2101	Daubert	Acrylic Polyester

a. No description given

Table 2. Ultraviolet Light Sources Studied

Description of light source	Number of Bulbs	Manufacturer
General Electric Blacklight Fluorescent 6 Watts	5	Fabricated at Pennwalt
General Electric G-15T8 Germicidal Lamps 15 Watts	3	Fabricated at Pennwalt
Sylvania 100 spot bulb in black-ray lamp	1	Black-ray lamp built by Ultra-Violet Products Inc. (San Gabriel, Calif.)
Hanovia 673A Lamp 550 Watts Quartz mercury vapor (high pressure)	1	Conrad Hanovia Inc. (Newark, New Jersey)
Oriel C-13-61 Mercury Argon C-73-16 AC Power Supply - 14 Watts	1	Oriel Corporation (Stamford, Conn)

Table 3. Curing Requirements and Adhesion of UV Cure Resins to Graphite/Epoxy Composites

Resin	Curing Requirements[a]	Adhesion
Celrad 3700	Hanovia lamp - 20 minute cure	Excellent adhesion on both sanded and unsanded surfaces. No lift on either surface with crosshatch test.
Celrad 3701	" "	"
Atlac 382	GE blacklight lamp[b] - 1 minute cure	Poor adhesion on unsanded surface with 50% lift with crosshatch test. Good adhesion on sanded surface.
Atlac 580	" "	Fair adhesion on unsanded surface. Although no actual lift is observed in crosshatch test, some separation of resin from surface takes place. Good adhesion on sanded surface.
Atlac 4010K	" "	Poor adhesion on unsanded surface with 10-20% lift with crosshatch test. Good adhesion on sanded surface.
Uvimer 530	Hanovia lamp - 5 minute cure Kynar coating film needed for inert atmosphere during curing.	Poor adhesion on unsanded surface with 20% lift with crosshatch test. Good adhesion on sanded surface.
Uvimer 580	" "	Good adhesion on both sanded and unsanded surfaces.
Uvimer 775	" "	Poor adhesion on unsanded surface with 20% lift with crosshatch test. Good adhesion on sanded surface.
Photopolymer RCC-4	GE blacklight lamp - 1 minute cure	Poor adhesion on unsanded surface with 10% lift with crosshatch test. Good adhesion on sanded surface.

Table 3. (continued)

Resin	Curing Requirements[a]	Adhesion
Photopolymer RCC-14	GE blacklight lamp - 5 min. cure	Fair adhesion on unsanded surface. Although no actual lift is observed in crosshatch test, some separation of resin from surface takes place. Good adhesion on sanded surface.
Photopolymer RCC-11	" "	Poor Adhesion on unsanded surface with 10% lift with crosshatch test. Good adhesion on sanded surface.
Photopolymer XRCP-3811	" 2 minute cure	Fair adhesion on unsanded surface. Although no actual lift is observed in crosshatch test, some separation of resin from surface takes place. Good adhesion on sanded surface.
Photopolymer 9061C	" "	Very poor adhesion on unsanded surface with 90% lift with crosshatch test. Good adhesion on sanded surface.
3M 1301	" 20 minute cure	Good adhesion on both sanded and unsanded surfaces.
Melcril 2101	GE blacklight lamp - 5 min. cure Kynar coating film needed for inert atmosphere during curing	Good adhesion on both sanded and unsanded surfaces.

a. The curing time depends on the coating thickness. Most of the samples studied were 5-10 mil thickness.

b. The GE blacklight lamp was made of five 6-watt fluorescent bulbs, as described in Table 2.

Table 4. Flexural Strength Recovery of Damaged Graphite/Epoxy Composites. Importance of Substrate Preparation.

Sample Description[a]	Flexural Strength (1000 lbs/in^2)	% Strength Compared to Undamaged Composites
Undamaged Composite	54	--
Damaged Composite	10.8	20
Groove filled with Celrad 3700	11.8	22
Groove filled with Celrad 3701	10.8	20
Groove filled with Photopolymer XRCP-3811	11.2	21
Groove filled with photopolymer XRCP-3811. A patch made of fiber-glass cloth saturated with same resin was placed over the groove.	17.8	33
Groove filled with photopolymer XRCP-3811. A patch made of fiberglass cloth saturated with same resin was placed over the groove. The damaged laminate was sanded.	20.4	38

a. The samples were 2" long, 0.46" wide, and 0.15" thick. They were damaged by cutting a V-shaped groove 0.05" deep and 0.10" wide at the top, through the center of the sample, as described in the text of this report.

Table 5. Flexural Strength Recovery of Damaged Graphite/Epoxy Composites. Importance of Resin.

Resin[a]	Flexural Strength (1000 lbs/in^2)	% Strength Compared to Undamaged Laminate
Celrad 3700	20	37
Celrad 3701	41	76
Atlac 580	12	22
Photopolymer RCC-11	18.6	33
Photopolymer 9016C	21.6	40
Uvimer 580	b	b
3M 1301[c]	b	b

a. The samples were 2" long, 0.46" wide, and 0.15" thick. They were damaged by cutting a V-shaped groove 0.05" deep and 0.10" at the top, through the center of the sample, as described in the text of this report. They were repaired by first sanding around the groove, then filling the groove with resin, and finally placing a patch made of fiberglass cloth saturated with the same resin over the groove. The lamps used for curing were those specified in Table 3. Curing times were necessarily longer than those listed in Table 3 because of the thickness of the samples.

b. Separation of the fiberglass patch on handling.

c. Cured in several steps.