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Project Summary

Evaluation of Propylene Carbonate in Air Logistics Center (ALC) Depainting Operations

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This report summarizes a two-phase, laboratory-scale screening study that evaluated solvent blends containing propylene carbonate (PC) as a potential replacement for methyl ethyl ketone (MEK) in aircraft radome depainting operations. The study was conducted at Oklahoma City Air Logistics Center (OC-ALC) at Tinker Air Force Base (TAFB). TAFB currently uses MEK to depaint B-52 and KC-135 aircraft radomes in a ventilated booth. Because MEK is highly volatile, many gallons vaporize into the atmosphere during each depainting session. Therefore, the U.S. Environmental Protection Agency (EPA) is supporting studies to identify effective, nonvolatile, less toxic substitutes for MEK.

The first phase of this study screened the performance of three solvent blends provided by Texaco Chemical Company.* These blends contained varying concentrations of PC, n-methyl pyrrolidone (NMP), dibasic ester (DBE), and other organic solvents. The performance of each blend was compared with that of MEK—both by the paint removal time and by a visual estimate of the amount of paint removed without any visible substrate damage (removal efficiency). The best performer was PC Blend 2, which contained 25% PC, 50% NMP, and 25% DBE. This solvent blend was then compared with MEK during the second phase of this study. The Phase 2 tests measured paint removal time and efficiency, paint adhesion, flexural properties, weight change of the substrate after paint removal, and hardness of unpainted substrate test panels.

Phase 2 test results revealed that PC Blend 2 performed favorably in comparison with MEK in removing paint from the fiberglass/epoxy (F/E) test panels and in subsequent paint adhesion tests, despite an indication of possible substrate damage. PC Blend 2 should continue to be evaluated as a substitute in the TAFB radome depainting operation. Additional qualification testing, required by the Air Force, and a full-scale demonstration project are recommended before implementation.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title. (See Project Report ordering information at back.)

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Introduction

This EPA Risk Reduction Engineering Laboratory (RREL) project was jointly supported by the Waste Reduction Evaluations at Federal Sites Program (WREAFS) and the Strategic Environmental Research Development Program (SERDP) to provide assistance to Tinker Air Force Base, Oklahoma. The WREAFS Program provides technical assistance and support to federal facilities in conducting waste minimization opportunity assessments and pollution prevention research. This project also focuses on EPA's 33/50 Voluntary Reduction Program, which plans to reduce generation of 17 hazardous substances—33% by the end of 1992 and 50% by the end of 1995. One of the 17 chemicals, the solvent MEK, is used for depainting aircraft radomes at the OC-ALC at TAFB.

TAFB removes paint from radomes on KC-135, EC-135, B-52, B-1, and E-3A aircraft. In a large ventilated booth, an MEK shower loosens the paint. The MEK attacks the primer through scribed breaks in the topcoat. The paint starts to bubble after 30 min of continuous showering. As the primer dissolves, the topcoat is flushed away from the radome by the MEK shower. Topcoat residue is filtered from the MEK. The solvent then flows to a sump for recycling to the shower head. The operation typically takes 1-1/2 to 3 hr. According to TAFB, a large percentage of the MEK is lost to the atmosphere through the booth exhaust system. After the MEK shower, any remaining paint residues are removed by hand sanding. Topcoat chips are captured in a sump and sent for disposal as a hazardous waste. In 1991, 719 lb of topcoat chips were sent for disposal and an estimated 8,250 gal of MEK evaporated to the atmosphere.

From previous research and background documents, RREL has identified PC as a possible alternative to MEK. To date, PC had not been performance-tested as a substitute for MEK in radome depainting operations. EPA conducted this proof-of-concept study to evaluate PC's performance as a substitute for MEK.

Texaco Chemical Company provided three PC blends.

- PC Blend 1
  33-1/3 propylene carbonate
  33-1/3 n-methylpyrrolidone
  33-1/3 dibasic ester

- PC Blend 2
  25 propylene carbonate
  50 n-methyl pyrrolidone
  25 dibasic ester

- PC Blend 3
  15 propylene carbonate
  15 n-methylpyrrolidone
  15 methyl isoamy ketone
  40 dibasic ester
  15 dipropylene glycol monomethyl ether

The study was conducted in two phases. At the TAFB chemical laboratory, Phase 1 screened the three PC blends for paint removal performance with MEK as a standard. The screening had two goals: to determine if the PC blends removed paint as effectively as MEK without visible damage to the F/E substrate, and to select the best of the three blends for further testing. At the Foster Wheeler Development Corporation (FWDC) John Blizard Research Center Laboratory, Phase 2 tests measured paint removal time and removal efficiency under simulated depainting booth conditions, damage to the F/E substrate, and paint adhesion.

Phase 1: Screening Procedure

Test panels cut from a condemned radome were immersed into four beakers, each containing one of the three solvent blends or MEK. The backside and edges of the test unscribed panels were masked with aluminum foil tape to prevent damage to the honeycomb structure.

The panels were removed after 30 min and examined for signs of bubbling of the paint coating. Observations were recorded. The specimens were placed back into the bath and examined at intervals of 1, 2, 4, 8, and 24 hr after initial immersion. During each examination, the amount of paint removal was estimated and recorded. The panels remained in the bath for 24 hr, even if the paint was already removed, to observe any possible damage to the substrate.

Phase 2: Evaluation Tests

With the use of the selected PC Blend 2, Phase 2 simulated the depainting procedure to determine the time and removal efficiency for a spray operation, which is more representative of the depainting operation. TAFB selected other tests to analyze the solvent's effects on the substrate. Tests evaluated hardness, flexural properties, paint adhesion, and weight change.

Simulated Depainting Procedure

The simulated depainting procedure was used for both PC Blend 2 and MEK, each in a separate, identical unit. The apparatus consisted of a Kleer-Flo Cleanmaster parts washer fitted with a 1/4-in.- diameter spray nozzle. The parts washer flow rate was approximately 7 L/min. Both units were modified with a 0.07 hp orbital magnetic drive centrifugal pump, because the original pump's seal material was incompatible with both MEK and PC. The nozzle sprayed 2-in.-square test panels made of F/E honeycomb cut from a condemned B-52 radome.

The times required for the solvents to bubble and totally remove the paint were recorded, and a qualitative judgment of paint removal was recorded at various time intervals. After bubbling, the paint was removed by hand or with a blunt-edged wooden spatula.

Hardness

Hardness tests were performed in accordance with ASTM Test Method D 2583-87. Eight 2-in.-square test panels were cut from an unpainted F/E "prepreg" sheet used for another project at TAFB. "Prepreg" refers to fiberglass fibers that have been soaked or impregnated with a polyester or epoxy resin. The prepreg surface is identical to that of an unpainted radome. These tests determined indentation hardness with a Barcol Impressor, Model No. GYZJ 934-1. Indentations were made on the specimens and the hardness measured. In accordance with ASTM D 2583, 20 measurements were made on each test panel, 10 before and 10 after contact with the solvent. The panels were sprayed with solvent in the depainting simulation unit for 2 hr, and gently wiped dry with a paper towel.

Flexural Properties Test

The flexural properties test was performed in two parts. The first part measured flexural properties of the test panels in accordance with ASTM Test Method D 790-92, Test Method I, Procedure A. Sixteen test panels were prepared from an F/E prepreg sheet provided by TAFB and cut to test specifications. Six test panels were tested in the as-received condition, five panels were conditioned by exposure in the MEK depainting simulator for 2 hr, and five panels were conditioned by exposure in the PC Blend 2 depainting simulator for 2 hr. After drying 1 hr, the solvent-exposed panels were subjected to load in a tensile machine until breakage of outer fibers occurred.

During the second part of the test, the failed test panels were examined with a scanning electron microscope (SEM) to determine if the solvents damaged the interface of the F/E and laminate structure. For SEM examination, the panels were cut into 1-in. squares with the failure break in the center of the square. The squares were then mounted on an aluminum stud using carbon paint, which provides a conductive bond between the stud and the panel. The squares were then sputtered with gold in a vacuum chamber to make them conductive. After about 10 min of sputtering at various angles to ensure that the gold was applied underneath the fibers, the squares were placed in another vacuum chamber and examined with the SEM. The surface was examined at 30X, 300X, and 1200X magnification; the cross section was examined at 1200X magnification to observe any fiber/matrix interface separation. Microphotographs were taken at each magnification to document the conditions observed. Squares of test panels not exposed to any solvent were also examined by the SEM to obtain a baseline comparison.

Paint Adhesion

Paint adhesion testing was performed in accordance with ASTM Test Method D 3359-92a, Method A using F/E with honeycomb test panels. After paint removal in the depainting simulation unit, test panels were repainted by TAFB personnel with the rain erosion coatings currently applied to B-52 radomes. The same 10- to 12-mil thickness of coating and painting procedure used for actual radomes was applied to these test panels. For the adhesion tests, two incisions were made in the panels down to the substrate layer. A pressure sensitive tape was then applied to the intersection of the cuts for a period of 90 ± 30 sec. The tape was 1-in. wide PermaCel 99™ (manufactured by PermaCel, New Brunswick, NJ). After tape removal, the X-cut area was visually inspected. The adhesion is rated according to a scale of 0A (removal beyond area of X-cut) to 5A (no peeling or removal).

Weight Change Test

The weight change test, developed by TAFB, determines if damage occurs to the substrate material. A clean, unpainted F/E prepreg test panel is weighed before and after immersion in the solvent. A weight loss indicates that the solvent has attacked the substrate. A weight gain reveals that the solvent is absorbed through microcracks in the substrate. The test panel was immersed in the solvent for 4 hr, four times longer than the time required to strip the panel in the screening test. After immersion, the panels were gently wiped by hand and dried in a 150˚F oven for 1 hr.

A parallel experiment was also conducted on standard 2-1/2-in.-square, 316-stainless-steel (SS) plates to validate the drying procedure. The 316 SS is inert; it is not affected by the solvent. A weight gain indicates the presence of solvent residue on the surface.

Results and Discussion

Screening Results

Table 1 presents the results of the screening tests. Although each of the three PC blends removed the paint, PC Blend 2 removed it most rapidly. For each solvent, any paint remaining after the paint had completely bubbled from the surface was removed by hand. The paint bubbled in one piece, which included primer layer, rain erosion coating, and topcoat.

The inconsistency of the paint removal times for the test panels may be explained by the condition of the panels before depainting. Some panels had a mottled appearance, suggesting certain areas of the topcoat layer were worn, exposing the white, rain-erosion coating layer. For these panels, paint removal would be easier, since the paint layer was thinner than when originally applied. Runs 1, 2, 3 used panels with varying degrees of mottled appearance, which explains the inconsistency of time needed to reach complete bubbling. In Run 4, panels were selected for similar surface conditions. These panels did not have a mottled appearance and, therefore, provided a better comparison. As the results in Table 1 show, complete bubbling took longer in Run 4 than in the previous runs.

The MEK did not perform as well as expected. During the first run, significant evaporation occurred in the MEK beaker. To minimize the evaporation, a plastic bag was placed over both beakers after about 8 hr into the second run. On the third and fourth runs, a watchglass was placed over the beakers during the entire 24-hr period. As Table 1 indicates, MEK performance declined in Runs 3 and 4 when the beaker was covered. This behavior suggests that the paint removal properties of MEK may be enhanced by moisture in the air. A separate experiment conducted by FWEI for a parallel project indicated a mixture of 12.5% by weight water in MEK removes paint faster and more completely than pure MEK. When covered, the MEK/water mixture also decreased its removal efficiency. In TAFB's actual depainting operation, the combination of the spraying and the presence of air probably contribute to MEK's performance.

After the 24-hr period, each of the test panels were evaluated for visible substrate damage. No substrate damage was visible, although white spots indicated some fibers may have been exposed. The TAFB Materials Engineer examined the panels. Under magnification he concluded that there may have been exposed fibers, although all panels, including the MEK, exhibited this characteristic.

Based on these results, PC Blend 2 was selected for Phase 2 testing to evaluate the effect of the solvent on the F/E substrate.

Evaluation Test Results

Simulated Depainting Procedure

It was discovered during this exercise that the paint system on the panels used in the Phase 2 tests differed from the paint used on the panels tested during Phase 1 screening. TAFB stated that some panels were probably painted with a neoprene-based coating, which consisted of a yellow primer, white primer, and black topcoat. This older paint system bonded very well to the substrate and was extremely difficult to remove. TAFB discontinued using it over 6 years ago.

The current paint system consists of a dark red primer, followed by a white, rain-erosion coating and a black topcoat. This paint system had been applied to the radome test panels used in the screening tests. The paints appear identical on the test panels. Only when the panels are stripped can the paint system be identified.

The specimens tested in Runs 3 and 4 for the depainting simulation with PC Blend 2 had been painted using the current paint system. The solvent removed the paint in one piece in less than 1 hr, as in the screening phase. In Runs 1 and 2, the PC Blend 2 removed the neoprene paint coat-

Table 1. *Screening Results*

	Time to reach complete bubbling hr			
Solvent	*Run 1*	*Run 2*	*Run 3*	*Run 4*
PC Blend 1	*1*	*4*	*2*	*4*
PC Blend 2	*1*	*1*	*1*	*2*
PC Blend 3	*4*	*2*	*8*	*4*
MEK	*8*	*8*	*Not complete bubbling*	*Not complete bubbling*

ing in about 3-1/2 hr with the aid of vigorous scraping. PC Blend 2 appeared to remove the neoprene paint coating more completely than MEK. The four panels tested with MEK had been painted with the neoprene paint coating; they took an average of 4-1/2 hr to remove the paint, also with vigorous scraping.

Because of time considerations, additional runs could not be scheduled to test panels coated with TAFB's current paint system. The panels used for the paint adhesion test were, however, painted with the current system. An additional step of recording the paint removal time was added to the test, and the results for the simulated depainting tests were disregarded. Removal times for paint adhesion test panels are provided in Table 2.

Hardness

Average hardness results are summarized in Table 3. The test objective was a Barcol hardness of 55 or greater. As indicated in Table 3, hardness measurements met this objective; they did not change significantly after exposure to solvent. Measurements ranged from 75 to 85 Barcol hardness units, with an overall average of 80.4. These results show that MEK and PC Blend 2 do not chemically embrittle the substrate.

Flexural Properties Test

The test results for flexural strength, maximum strain, and modulus of elasticity, as calculated in accordance with ASTM D790-92, are listed in Table 4.

The data presented in Table 4 demonstrate that exposure to either PC Blend 2 or MEK did not affect the flexural strength of the panels. Although most panels failed at approximately 72,000-psi loading, four test panels had lower flexural strength, failing at a loading of approximately 52,000 psi. These panels failed with a straight break across the test panel rather than with the zigzag pattern exhibited with the stronger panels. Similar results in tests on unexposed, PC Blend 2-exposed, and MEK-exposed panels suggest that these four test panels were cut from a weaker section of the prepreg sheet. A statistical analysis revealed a bimodal distribution, proving that the four panels were taken from a different sample population than the stronger specimens. Comparison of individual readings within the respective populations showed that flexural strength was unaffected by exposure to either solvent.

The second part of the test required inspection of the failed test panels under a scanning electron microscope (SEM). The SEM microphotographs indicated no damage from either solvent to the fiber

Table 2. *Paint Removal Times (min)*

Run	PC Blend 2	MEK
1	45	30
2	21	29
3	25	25
4	25	25

Table 3. *Average Hardness† Readings*

	PC blend 2		MEK	
Run	Before	After	Before	After
1	80.0	82.6	81.4	81.4
2	79.7	79.7	79.6	81.8
3	80.4	80.7	80.0	80.5
4	79.8	79.4	78.9	79.6

† *Barcol hardness.*

Table 4. *Flexural Properties Summary*

Solvent	Run	Flexural strength, psi	Maximum strain, in/in	Modulus of elasticity psi
Unexposed	1	71,750	0.02520	3.64×10^6
	2	70,980	0.02470	3.60×10^6
	3	69,930	0.02380	3.70×10^6
	4	52,390	0.02460	3.30×10^6
	5	71,280	0.02410	3.60×10^6
	6	72,562	0.02490	3.67×10^6
PC Blend 2	1	52,240	0.02710	3.46×10^6
	2	74,670	0.02430	3.84×10^6
	3	71,127	0.02505	3.66×10^6
	4	51,682	0.02350	3.59×10^6
	5	71,160	0.02341	3.66×10^6
MEK	1	72,544	0.02350	3.84×10^6
	2	53,286	0.02380	3.63×10^6
	3	71,015	0.02485	3.66×10^6
	4	72,694	0.02738	3.54×10^6
	5	71,433	0.02587	3.64×10^6

matrix interface or to the fibers. If damage had occurred, the microphotographs would have shown noticeable gaps where the fibers interface with the matrix (most visible at the 300X magnification). Also, individual fibers appeared to be intact, indicating that the solvent did not attack the resin binding the fibers.

Paint Adhesion

The paint adhesion ratings were 5A for each test panel. This rating indicates no peeling or removal of paint by the pressure sensitive tape. This suggests complete paint adhesion after the depainting/ repainting cycle.

Weight Change Test

Table 5 presents the results of the weight change test. The test panels exposed to both PC Blend 2 and MEK showed weight loss, indicating slight substrate damage; this was considered to be negligible by TAFB. A parallel experiment with 316-SS standards confirmed that the solvent residue had evaporated from the surface of the test panels.

Table 5. *Weight Change Test Results*

	Weight change grams	
Run	PC Blend 2	MEK
1	-0.011	-0.008
2	-0.009	-0.006
3	-0.020	-0.013
4	-0.025	-0.009

Conclusions and Recommendations

The evaluation test results indicate that PC Blend 2 is a potentially viable replacement for MEK. Further study must qualify its use in TAFB's radome depainting operations.

Other conclusions from the test results are listed below:

- Screening tests indicated that PC Blend 2 performed the best of the three PC blends provided by Texaco.
- PC Blend 2 removed 100% of the paint in about the same time as MEK and required a little more scraping for total removal.
- PC Blend 2 showed possible damage to the top resin layer of the F/E substrate. The potential impact of such damage requires further study.
- PC Blend 2 and MEK do not embrittle the F/E substrate.
- PC Blend 2 and MEK do not affect flexural properties of the F/E substrate.
- Examination by SEM found no significant damage to the fibers or to the fiber-matrix interface.
- PC Blend 2 and MEK panels exhibited a small weight loss after immersion for 4 hr.
- PC Blend 2 and MEK did not impact paint adhesion.

Recommendations for future courses of action are:

- Further evaluation of the potential adverse effects of the solvent on the substrate, and either
- Reformulation of the solvent blend to eliminate or reduce any identified damage, or full-scale demonstration of PC Blend 2 in TAFB's radome depainting operation, if no damage is identified.

In a full-scale demonstration project, these areas should be addressed:

- Equipment compatibility with PC Blend 2
- Waste disposal practices for PC Blend 2 and paint chips
- Procedures for removing nonvolatile PC Blend 2 residue

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S. Rosenthal and A. M. Hooper served as the Foster Wheeler Enviresponse project team.
Johnny Springer, Jr., and Kenneth R. Stone *are the EPA Project Officers (see below).*
The complete report, entitled "Evaluation of Propylene Carbonate in Air Logistics Center (ALC) Depainting Operations," (Order No. PB94-214618/AS; Cost: $17.50, subject to change) will be available only from:
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