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CARC FINISHES ON LAMINATE ARMOR MATERIALS

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Report 2426

CARC FINISHES ON LAMINATE ARMOR MATERIALS

Department of the Army
Belvoir Research, Development
& Engineering Center
Ft. Belvoir, Virginia 22060-5606

by
Jeffrey L. Duncan
and
Stanley F. Koutek

DATE OF REPORT: April 1986

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With the increased use of non-metallic materials on tactical vehicles, acceptable performance of the Chemical Agent Resistant Coating (CARC) system, scheduled for full implementation in FY86, must be verified for these new substrates. The intent of this project was to test and evaluate CARC on laminate armor materials under consideration for a proposed new vehicle. Because the mission requirements include transportability, agility, and survivability, weight is to be minimized. This requires the use of lightweight, high strength materials and applique (removable) armor. The tested substrates included hardened steel, two aluminum alloys, five varieties of Kevlar, and one type of glass reinforced plastic. Normal cleaning and pretreating procedures were used, except that the potential for hydrogen embrittlement precluded the use of standard acidic cleaning or wash primer on the hardened steel substrate. The anticorrosive primers were all epoxies. The interior topcoat was a gloss white epoxy, and the exterior topcoat was a lusterless Forest Green polyurethane. Physical testing of the coated panels included salt fog, accelerated weathering, humidity-thermal cracking, wet adhesion, DS2 resistance, and exterior exposure.

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CONTENTS

TABLES

CARC FINISHES ON LAMINATE ARMOR MATERIALS

I. PURPOSE AND OBJECTIVES

The purpose of this project was to test and evaluate the use of the Chemical Agent Resistant Coating (CARC) system on laminate armor materials under consideration for a proposed new combat vehicle, the MPGS. Because the mission requirements include transportability, agility, and survivability, weight is to be minimized. This requires the use of lightweight, high-strength materials and applique (removable) armor. Since the CARC system will be fully implemented starting in FY86, its performance on the proposed substrates needed to be verified.

II. SUBSTRATES

The tested substrates included hardened, high-strength steel, two alloys of aluminum (CW and 5083), five variations of Kevlar, and one type of glass-reinforced plastic (GRP). With the exception of the steel substrate, normal cleaning and pretreating procedures were used, but the potential for hydrogen embrittlement of the hardened steel precluded the use of standard acidic cleaning or wash primer. The anticorrosive primers were all epoxies, the interior topcoat was a gloss white epoxy, and the exterior topcoat was a lusterless forest green polyurethane. The physical testing of the coated panels included salt fog, humidity-thermal cracking, accelerated weathering, wet adhesion, DS2 resistance, and exterior exposure.

III. PROCEDURE

1. Test Panels. The test panels fell into five substrate types. However, several of the types were subdivided further, so that variations in cleaning, pretreating, priming, or topcoating could be investigated. This resulted in a final count of 19 sets of panels. Since 16 panels/set were required for the number of tests to be run, a total of 304 panels were prepared for testing.

Each aluminum alloy was divided into three sets, so that three different anticorrosive primers could be tested. The Kevlar substrate was divided into nine sets in order to compare the effects of scuff sanding, wash priming, surface texture, and a Tedlar overlay. The glass-reinforced plastic was divided into three sets in order to check the differences caused by scuff sanding and wash priming.

All test panels were nominally 3 in. X 9 in. The upper limit thickness was ½ in., because of the weatherometer configuration. Metallic panels were thinner due to the 1.5-lb/panel weight limitation for application by automatic spray equipment.

The hardened steel substrate was 4340 electroslag, remelted, steel alloy from Republic IAW MIL-S-46188. It was quenched and tempered to a hardness range of T53 to T56. It started as ¼-in. plate, but the back side was ground down to reduce the panel weight. The as-rolled (unground) side was the coated and tested substrate. The 5083 aluminum was the alloy 5083-H131, IAW MIL-A-46027, a strain-hardened alloy, which was tested as-rolled at 3/8-in. thick. The Alcoa CW34 alloy has been designated 2519-T87, IAW a proposed specification, MIL-A-46xxx. Samples were cut from 1-in. plate, but one side was ground to reduce panel weight. The unground side was coated and tested.

The Kevlar laminates conformed to MIL-L-62474, Type 1, Class A. They are flat molded sheets with 21 plies of Kevlar 29 (1500 denier yarn grade) in a phenolic/polyvinyl butyral binder with a total thickness of 0.44 in. The standard smooth surface was produced by a release film on both sides of the laminate. The nylon fabric texture surface was produced by a release film topped with nylon fabric IAW MIL-C-12369, Class 1. The peel ply texture surface was produced by a dacron fabric, and the substrate with overlay had a 4-mil film of Dupont 400BS30WH bondable Tedlar, a polyvinyl fluoride.

2. Test Panel Preparation.

a. The set of steel panels was sandblasted, solvent wiped with lacquer thinner, primed at 1.0-mil dry film thickness (dft) with MIL-P-52192, and top-coated with 2.0-mil dft of forest green MIL-C-46168.

b. The six sets of aluminum panels (two types and three sets in each) were alkaline cleaned in hot (180 degrees F) trisodium phosphate, rinsed with 10 percent nitric acid to a water break-free surface and pretreated with 0.4-mil dft of MIL-P-15328 wash primer. The six sets were then primed with either 0.8-mil dft of MIL-P-23377, 1.0-mil dft of MIL-P-53022, or 1.0-mil dft of MIL-P-53030. All panels got a topcoat at 2.0-mil dft of forest green MIL-C-46168.

c. The GRP panels were divided into three sets. One set was topcoated; one set was scuff sanded and topcoated; and the third set was scuff sanded, pretreated with 0.4-mil dft of MIL-P-15328, and topcoated. In all cases, the topcoat was 2.0-mil dft of forest green MIL-C-46168.

d. The Kevlar panels were divided into nine sets. Group 1 (GR1) included two sets of Kevlar with smooth faces, which were scuff sanded. One set received 0.4-mil dft of MIL-P-15328 wash primer, and both were topcoated with 1.5-mil dft of white MIL-C-22750. Group 2 (GR2) also contained two sets of Kevlar with smooth faces. One set was wash primed at 0.4-mil dft with MIL-P-15328, and both were topcoated with 1.5-mil dft of white MIL-C-22750. Group 3 (GR3) consisted of two sets of Kevlar panels with nylon fabric texture, which were coated the same as the GR2 sets. Group 4 (GR4) contained two sets of Kevlar panels with peel ply texture, which were coated the same as the GR2 sets. Group 5 consisted of one set of Kevlar panels with a white Tedlar overlay and was not treated or coated.

e. The procedure used for each set of panels is summarized in Table 1. Note that because no alternates were considered acceptable, only one system was used on the hardened steel. Therefore, the results were of the pass/fail variety instead of comparative. On the other hand, the two aluminum alloy sets were designed to compare the performance of three anticorrosive epoxy primers, and the KRP and GRP sets were designed to compare the merits of scuff sanding and/or wash priming with merely topcoating. Another variable in the KRP series was the comparison of three different surface textures (smooth, nylon fabric, and peel ply).

f. MIL-P-52192 red epoxy primer was used to edge and back all panels.

3. Test Methods. Within each set of 16 panels, the following assignments were made:

Panels 1, 2, 3, and 4 — salt fog
Panels 5, 6, 7, and 8 — accelerated weathering
Panels 9 and 10 — humidity-thermal cracking
Panels 11 and 12 — wet adhesion
Panels 13 and 14 — DS2 resistance
Panels 15 and 16 — exterior exposure

For those substrates in which there were more than 16 panels (e.g., each aluminum alloy), the assignments were continued in the same manner for each subsequent set of 16. Thus, panels 17, 18, 19, and 20 were for salt fog; 27 and 28 were for wet adhesion; 37, 38, 39, and 40 were for accelerated weathering, etc.

a. Salt-fog testing was run under the requirements of ASTM B117. The forest green panels (exterior color) were tested in one cabinet, and the white panels (interior color) were tested concurrently in another. Two of the four panels in each set were scored with an "X" in the lower half of the panel. The non-metallic panels were weighed before and after exposure to check for potential water absorption. The frequency at which the panels were observed was determined by the rate at which defects (if any) were detected. Since corrosion was not a problem on non-metallic panels, the panels were only checked every 200 h or so. The metallic panels were checked every 48 h initially, but the frequency tapered off when it became obvious that defects would be few. All panels were exposed for 1000 h.

b. Accelerated weathering was run according to ASTM G26, Method A, Type BH. Of the four panels in each set allocated to this test, the first three were exposed and the fourth was the control. Spectrophotometric measurements were made of all panels (visible and near infrared) before testing and after each 300-h increment of exposure, so that changes in color and/or infrared reflectance could be followed throughout the 1500 h of exposure. In addition, the 60-degree and 85-degree gloss of the forest green panels was determined at the start and conclusion of the test. The texture of the Kevlar panels precluded meaningful gloss determination.

c. Humidity-thermal cracking was run IAW ASTM D2246. The typical cycle was 24 h at 150 degrees F and 100 percent relative humidity, 20 h at -10 degrees F and 4 h at room temperature. Panels were stored under ambient conditions during delays caused by equipment problems. A total of 15 cycles of 48 h were run.

d. The wet adhesion test was run IAW Federal Test Method Standard (FTMS) 141, Method 6301. Panels were immersed for 24 h in deionized water, wiped dry, and scored. Tape was applied across the score, rolled flat, and then removed in one motion.

e. Resistance to DS2 was checked by means of a spot test. Exposure was for ½ h, after which the panels were rinsed with water, dried, and examined for defects.

f. Exterior exposure was initiated in general compliance with the guidelines in ASTM D1014. The panels were not scored, and the location is on the roof of the Materials, Fuels and Lubricants Laboratory at Fort Belvoir, Virginia.

IV. DISCUSSION

4. Salt Fog. Performance of the CARC system on these laminate armor materials was, in general, very good. Since corrosion is not a problem on non-metallic substrates, deterioration of the film is the concern. For metallic samples, corrosion of the substrate is the obvious result of paint problems.

The scored panels of hardened steel were classified as failures at 216 h due to score rusting and blistering. However, the unscored panels lasted for 360 h. The requirement in MIL-P-52192 is for 336 h on an unscored panel. Therefore, the CARC system is acceptable on this substrate. Although not allowed because of potential hydrogen embrittlement, a pretreatment of any type would probably have significantly improved the salt-fog performance.

None of the aluminum substrate panels failed in the 1000 h of salt-fog testing. Of the two types. the CW alloy performed slightly better than the 5083 alloy. No defects were observed on any unscored CW panel. regardless of the anticorrosive primer that was used. The only defects noted on scored CW panels were one-to-two score blisters on each panel and one-to-two very small surface blisters on each panel primed with MIL-P-53022. On the other hand. the 5083 alloy never exhibited a score defect of any kind. regardless of the primer used. The only defects seen on any panel were one-to-four scattered surface blisters. Of the three primers. MIL-P-53030 seems to have performed slightly better on both aluminum substrates. and MIL-P-53022 and MIL-P-23377 were roughly equivalent. Performance of all met or exceeded specification requirements.

The Kevlar substrate panels only began to exhibit interesting developments after the salt-fog exposure had been completed. No defects were observed on any of the panels for the entire 1000-h exposure. However, when the panels were removed and dried. it was found that all had undergone a significant weight gain. The weight data is summarized in Table 2. but in general the weight gain was higher for scored panels than for unscored panels. This is the expected behavior if the water is absorbed through uncoated Kevlar more than through the epoxy paint film. Even the Kevlar with the Tedlar overlay (and no epoxy paint) showed similar behavior. In all cases where there was a weight gain, most of it was retained two weeks after the testing was completed. In addition. one week after salt-fog exposure had been completed. surface blisters began to appear on all panels, and a crust of salt began to develop at all of the scores. These are apparently the result of the absorbed saltwater trying to escape from the substrate (blisters) and leaving a salt residue where the water can evaporate at the score.

The GRP substrate panels were excellent in salt-fog resistance. No defects were observed on any of the panels. and they did not absorb any significant quantity of saltwater (see Table 2).

5. Accelerated Weathering. Performance of the CARC system in this test was good for the exterior finish and typically poor for the interior finish. Since epoxies have poor resistance to UV radiation. they cannot be used in exterior topcoat applications. even though they are chemical agent resistant. That is the reason that the exterior CARC finish is polyurethane. Therefore. accelerated weathering really is an unfair test for the epoxy topcoat. because UV exposure is not a problem in an interior application.

The color changes resulting from accelerated weathering are summarized in Table 3. All of the KRP panels had the white epoxy topcoat. and all other substrates had the forest green polyurethane topcoat. The best results were obtained by the Kevlar with the Tedlar overlay. After 1500 h exposure. this system had a color change of 1.27 units. which is roughly half the color change allowed for only 300 h of exposure (2.5 unit maximum). The forest green typically exceeded this maximum between 900 and 1200 h. regardless of the substrate. The white epoxy exceeded the limit at 300 h.

The differences in weathering. due to the particular coating system used. are more difficult to explain. For example. all of the four groups of painted KRP (GR1 through GR4) showed slight differences in performance between the first set (panels 5 to 7) which was not wash primed and the second set (panels 21 through 23) which were wash primed. However. the differences are small and are not thought to be significant. in comparison to the large color charges of the epoxy topcoat.

For the aluminum substrates. an interesting pattern exists. For each alloy. three different epoxy primers were used. The first set (panels 5 to 7) used MIL-P-23377: the second set (panels 21 to 23) used MIL-P-53022: and the third set (panels 37 to 40) used MIL-P-53030. For both alloys. the color difference was higher for panels primed with MIL-P-53022. and this may be due to the white color of the primer. Whatever light penetrates the topcoat is reflected more effectively by a white than by a non-white primer. possibly subjecting the topcoat to a "double exposure." However. this is merely conjecture.

The GRP substrate also exhibited a non-uniform color change in that the middle set (scuff sanded and topcoated) had a larger change than the first (topcoated only) or the third (scuff sanded, wash primed, and topcoated). There is no obvious explanation for this difference, but the middle set did have an "open" (roughened by sanding) surface while the other two had sealed (original GRP or wash primer) surfaces.

Table 4 summarizes the changes in 60-degree and 85-degree gloss which occurred during the 1500 h of accelerated weathering on the forest green panels. The changes are not significant. Although the gloss of the white panels could not be measured due to the textured surface, the gloss of the epoxy-painted panels dropped drastically (as anticipated), and the gloss of the Tedlar overlay was essentially unchanged.

6. Humidity-Thermal Cracking. Although minor equipment problems delayed this test somewhat, it is believed that the final results were not materially affected. There were no surprises, and no defects were observed during the 15 cycles of 48 h. The white epoxy did yellow somewhat, probably due to the extended exposure to elevated temperatures. In addition, about a week after the test was finished, surface blisters began to appear on the epoxy-painted KRP panels. Since this behavior had been observed in the salt-fog testing, it was expected here. The best guess is that water is absorbed by the substrate, and then forms blisters as it tries to escape. If the absorption is due to incomplete sealing of the panel edges, then there should be no problem in the final application. If the absorption is through the paint film, then the laminates could develop coating adhesion problems (because of the blistering) in certain situations, such as warm and humid environments.

7. Wet Adhesion. This test provided little in the way of comparative data, because there were no failures. Every panel tested showed no significant loss of adhesion, either intercoat or surface. For the nonmetallic substrates, this indicates that neither sanding nor wash priming is necessary for good adhesion of the topcoat. Thorough cleaning is the only requirement. For the metallic substrates, the test results indicate that a properly applied CARC coating system will have satisfactory intercoat and surface adhesion.

8. DS2 Resistance. As with the wet adhesion test above, the DS2 resistance did little more than prove the quality of the CARC systems, because no serious problems were observed. The coatings were resistant enough to this strong alkaline agent that it is unlikely it could ever cause a problem on any of the substrates. The only effect on the forest green topcoat was the color change, and this color change is one of the validation tests done on *every* batch of MIL-C-46168 to insure that resistance to DS2 is within specification limits. Color change on the white topcoat was minimal, and the only unusual observation was an oily residue which appeared in the DS2 tested areas 24 h after the testing had been finished. These residues were easily rinsed off with water and did not recur. The Tedlar overlay was unaffected by DS2.

9. Exterior Exposure. This test is still in progress. After six mo, no defects have been observed, except that the gloss of the epoxy has decreased somewhat. Since approximately 18 mo remain, final results will be a supplement to this report. However, no problems are anticipated.

10. Post-Testing Checks. After all tests had been completed, wet adhesion and DS2 tests were performed on panels from each set with the forest green topcoat. The samples selected for these post-tests were from the steel, aluminum and GRP substrates, and included panels from every set which had been through salt fog and accelerated weathering. No defects were observed on any panel, indicating that even after environmental exposure, the adhesion and DS2 resistance were satisfactory for any of the pretreatment/primer combinations tested.

V. CONCLUSIONS

As evidenced by the results for the six tests which were performed on coated test panels, the Chemical Agent Resistant Coating (CARC) system should give satisfactory performance on any of the potential substrates under consideration for laminate armor.

One potential problem area, depending upon the specific application, is the apparent absorption of water by Kevlar laminates. Although test conditions were extreme (i.e., 100 percent relative humidity) in salt-fog and humidity testing, if water absorption and subsequent blistering are not prevented, adhesion could ultimately be affected.

Scuff sanding to improve adhesion of coatings to the non-metallic substrates is neither necessary nor advisable. Even though the sanded surface was extremely rough and fibers protruded through the applied coating, no serious defects were observed in any of the testing. However, no advantage was obtained in the process, so it is probably superfluous.

By the same token, no apparent advantage was detected in the use of wash primer on non-metallic substrates. Therefore, provided the surface is adequately cleaned, wash primer is also unnecessary to insure performance of the CARC system.

Although the differences in accelerated weathering results for the same topcoat over three different primers leads to some speculative conclusions, more study is necessary on this subject. The primer color is certainly the obvious difference, but even though all three are generic epoxies, there are compositional differences. If this data can be duplicated, it would indicate that the color stability of a polyurethane topcoat may well depend upon the anticorrosive primer used under it.

Table 1. Key to Test Panel Labels

		PRETREATMENT			PRIMER				TOPCOAT	
SUBSTRATE	PANEL LABEL	SAND BLAST	SCUFF SAND	DOD-P 15328	MIL-P 52192	MIL-P 23377	MIL-P 53022	MIL-P 53030	MIL-C 22750	MIL-C 46168
STEEL	1 TO 16	X			X					X
CW A1	1 TO 16			X		X				X
	17 TO 32			X			X			X
	33 TO 48			X				X		X
5083 A1	1 TO 16			X		X				X
	17 TO 32			X			X			X
	33 TO 48			X				X		X
KRP (GR1)	1 TO 16		X						X	
	17 TO 32		X	X					X	
(GR2)	1 TO 16								X	
	17 TO 32			X					X	
(GR3)	1 TO 16								X	
	17 TO 32			X					X	
(GR4)	1 TO 16								X	
	17 TO 32			X					X	
(GR5)	1 TO 16									
GRP (GR6)	1 TO 16									X
	17 TO 32		X							X
	33 TO 48		X	X						X

Table 2. Weight (gm) of Non-Metallic Salt Fog Panels

GROUP	WEIGHING SESSION	PANEL NO. 1	2	3	4	17	18	19	20
GR1	START	257.7	257.7	261.9	263.6	257.5	257.0	257.5	256.9
	FINISH	270.3	278.4	280.4	291.0	259.6	269.0	259.1	281.4
	+ 2 WK	269.3	276.8	279.0	288.7	258.7	267.8	258.4	280.0
GR2	START	262.1	263.6	257.0	260.1	253.5	257.0	257.1	258.0
	FINISH	265.3	283.0	266.4	281.5	255.0	269.8	262.4	281.4
	+ 2 WK	264.3	281.5	265.5	279.8	254.5	268.6	261.6	277.9
GR3	START	261.9	264.2	254.6	255.2	259.0	261.0	259.8	265.2
	FINISH	263.4	288.9	278.5	278.2	260.5	272.9	261.4	279.6
	− 2 WK	262.9	287.1	276.9	276.3	260.0	271.9	260.9	278.6
GR4	START	268.0	265.2	265.0	265.5	264.9	266.4	257.9	265.5
	FINISH	269.6	278.8	269.6	277.3	266.9	290.0	259.9	289.9
	− 2 WK	269.2	277.9	269.1	276.5	266.5	289.1	259.6	288.7
GR5	START	259.4	256.8	260.8	261.7	–	–	–	–
	FINISH	261.3	269.3	271.2	275.1	–	–	–	–
	− 2 WK	261.0	268.6	270.7	274.1	–	–	–	–
GR6	START	326.6	339.4	340.0	327.4	309.3	337.4	316.9	327.0
	FINISH	326.9	339.7	340.3	327.6	309.6	337.7	317.1	327.3
	− 2 WK	326.6	339.4	340.0	327.4	309.3	337.4	316.9	327.0

Table 3. Color Difference in N.B.S. Units
(Average of 3 Exposed Panels)

Substrate	Panels	Exposure Time (h) 300	600	900	1200	1500
Steel	5 to 7	0.34	1.06	2.32	3.27	3.97
CW AL	5 to 7	0.10	0.48	1.59	2.42	2.10
	21 to 23	0.22	0.90	2.10	3.03	2.69
	37 to 40	0.16	0.55	1.29	2.02	1.63
5083 AL	5 to 7	0.26	0.86	2.01	2.91	3.37
	21 to 23	0.39	1.31	2.73	3.80	4.45
	37 to 40	0.36	0.97	2.19	3.15	3.62
KRP (GR1)	5 to 7	3.68	3.13	3.13	3.37	8.78
	21 to 23	3.57	3.07	3.24	3.37	8.30
KRP (GR2)	5 to 7	3.70	2.96	3.02	3.17	9.28
	21 to 23	3.70	3.01	3.23	3.39	8.87
KRP (GR3)	5 to 7	3.65	3.24	3.57	3.94	9.16
	21 to 23	3.60	3.05	3.18	3.33	7.02
KRP (GR4)	5 to 7	3.50	3.08	3.09	3.21	7.39
	21 to 23	3.50	2.94	3.20	3.34	7.17
KRP (GR5)	5 to 7	0.48	0.88	1.26	1.19	1.27
KRP (GR6)	5 to 7	0.22	0.85	1.96	2.91	2.46
	21 to 23	0.67	2.12	2.83	3.06	3.93
	37 to 40	0.51	1.59	2.14	2.85	2.26

Table 4. Gloss Changes Due to Accelerated Weathering

Substrate	Panels	60-Degree Gloss		85-Degree Gloss	
		Before	After	Before	After
Steel	5 to 7	0.5	0.6	2.0	1.7
CW Aluminum	5 to 7	0.5	0.6	2.1	1.9
	21 to 23	0.5	0.6	2.2	1.8
	37 to 39	0.5	0.6	2.0	1.5
5083 Aluminum	5 to 7	0.5	0.6	2.1	1.6
	21 to 23	0.5	0.6	2.0	1.6
	37 to 39	0.5	0.6	2.0	1.6
GRP (GR6)	5 to 7	0.5	0.6	1.9	1.6
	21 to 23	0.5	0.6	1.9	1.6
	37 to 39	0.5	0.6	1.8	1.5

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