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The TNT Staining Problem on the M795 Coating System

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Abstract

The polyurethane coating used on the M795 to provide chemical agent resistance is stained when it comes into contact with TNT (2,4,6,Trinitrotoluene), which is loaded into the steel projectiles after fabrication and painting. This project was performed to evaluate the alternatives available to repair the stained areas and included overcoating with the standard military specification finish for ammunition and ammunition components (a fast drying alkyd enamel), overcoating with the original paint, and overcoating with a fast-curing version of the original paint. Although adhesion and corrosion resistance were acceptable for all three, none was a solution to the problem. The TNT stain permeated a cured polyurethane topcoat in moderate heat. The alkyd was incompatible with TNT-stained areas in the original polyurethane, and this led to serious surface appearance problems. The satisfactory repair of stained projectiles will probably require some stripping and refinishing.

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1. Background

Although the traditional protective coating system for large caliber projectiles consists of a fast-drying, styrenated alkyd (MIL-E-52891) applied to the pretreated steel substrate, the M795 has used a polyurethane topcoat to provide chemical agent resistance and improved chemical warfare survivability. This coating was developed in a joint effort between the Coatings Technologies Team of the Weapons and Materials Research Directorate (WMRD) of the Army Research Laboratory (ARL) and Hentzen Coatings of Milwaukee, WI. Since there is no material specification for a chemical agent resistant ammunition coating, the product was tested in the Experimental Products Program (EPP). This is a process similar to that of a qualified products list (QPL), but is user driven and designed to evaluate performance-based alternatives to military specification finishes. The M795 topcoat is a derivative of military specification MIL-C-53039, one of two chemical agent resistant coating (CARC) topcoats that are used on virtually all Army tactical vehicles, equipment, and aircraft. It is formulated in the olive drab (OD) color (typical for a high explosive projectile) and at a gloss level consistent with ammunition finishes rather than the low gloss required for vehicle camouflage. The coating is also modified to provide corrosion resistance not typically required of a topcoat since it is applied directly to the pretreated steel substrate. Film thickness constraints on the projectile's diameter preclude the use of an intermediate film of anticorrosive primer. In addition, the coating provides some environmental benefits. Unlike the standard alkyd system, it contains no lead or hexavalent chromium, and it has a volatile organic compound (VOC) content that meets Federal and local Clean Air Act regulations in the locations where it is applied. A similar black-colored coating is used on the sense and destroy armor munition (SADARM).

The M795 is manufactured and painted at the Scranton Army Ammunition Plant (SAAP). It is then shipped to the Iowa Army Ammunition Plant (IAAP), where it is loaded with TNT explosive. During the loading process, TNT is occasionally spilled onto the painted projectile and staining occurs. If it is not removed before the TNT curing process (approximately 6 hr long at 125 °F for the portion of the projectile immersed in water and 260 °F for the upper portion in air), the staining is not removable. When staining occurs on the traditional alkyd topcoat, it is apparently removed by steam cleaning, but that is not the case with the polyurethane topcoat. Other efforts, including cleaning with various solutions and solvents, were made by IAAP to remove the stains, but without success. This report summarizes the results of a test program by ARL to determine the feasibility of repairing the projectiles by applying additional topcoat to stained areas. Since staining typically occurred near the tips of the projectiles, film thickness constraints on the bourrelet diameter were not applicable. This effort was requested and funded by project manager, artillery munitions systems (PM, ARMS) at Picatinny Arsenal, NJ.

2. Test Procedures

Since the performance of the coating was otherwise acceptable, this effort was designed to validate the recoatability of stained coating after various surface preparation scenarios. There were four questions that drove our research: (1) Could the stained paint be overcoated to hide the stain? (2) Would the second layer adhere properly if the stained surface was adequately cleaned? (3) What type of cleaning or surface preparation would be sufficient? (4) Would the rework process be durable and last the life of the projectile while stored?

The Hentzen coating is designated "Zenthane Plus" by the manufacturer. The Zenthane is a moisture-cured polyurethane. The Plus is an amine activator for the polyurethane. A faster-drying version of the system (to be discussed later) was also considered, and it required a third component known as the accelerator. The Hentzen formulae for the three components are: Zenthane – 08692GUZ-1, activator – 08689CHA, and accelerator – 04699CHS. The mixing ratio for Zenthane Plus is 5:1 by volume for Zenthane:activator, and the accelerator (if used) is added at the rate of 3 cm^3/gal of Zenthane.

To answer the questions, PM, ARMS and ARL agreed that appropriate testing could be performed on steel coupons pretreated with the zinc phosphate process used on the projectiles. These coupons would be topcoated with the paint used by SAAP, stained with molten TNT at IAAP, and sent to ARL for the rework study. ARL would divide the panels into three sets to try different surface preparation processes and then apply the topcoat. For reasons to be discussed later, three topcoats were evaluated, thereby dividing the coupons into a total of nine subsets.

Prior to testing the rework processes, all panels were to be run through an accelerated aging process as defined by MIL-STD-331B, Test C1, temperature and humidity, to simulate extended storage conditions. After this four-week aging process of daily cycles between 71 °C (160 °F) at 95% relative humidity and −54 °C (−80 °F), the aged panels would be subjected to corrosion and adhesion testing to verify the rework process. A diagram of the aging procedure from the Military Standard is shown in Figure 1.

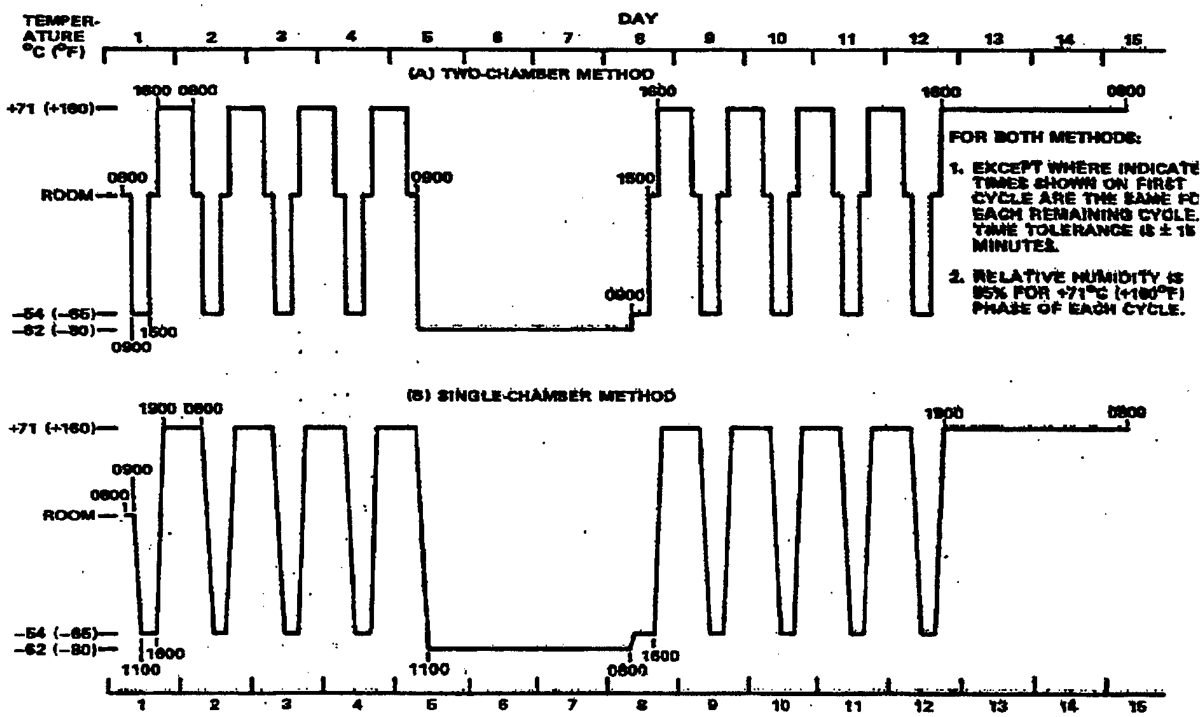

Figure 1. Temperature and Humidity Cycles.

A total of 57 4- × 6-in unpolished steel panels were painted with the OD Zenthane Plus. The panels used were from ACT Laboratories and were pretreated with Bonderite 952 zinc phosphate using a deionized water final rinse (nonchromate process). The Zenthane Plus was Hentzen batch 27G815 using activator 22A905. After an air dry cure of seven days, the panels were packed and subsequently delivered during TDY to IAAP. The dry film thickness for each of the panels is listed in Table 1.

Table 1. Test Panel Dry Film Thickness

Panel No.	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5	Average	Std. Deviation
1	1.25	1.06	1.25	1.03	1.17	1.15	0.10
2	0.96	1.06	0.98	1.06	1.06	1.02	0.05
3	0.96	1.04	1.04	1.04	1.07	1.03	0.04
4	1.01	1.07	1.03	0.94	1.03	1.02	0.05
5	1.06	1.07	1.09	1.07	1.07	1.07	0.01
6	1.07	1.05	1.15	1.08	1.05	1.08	0.04
7	1.02	0.92	1.16	1.04	1.15	1.06	0.10
8	1.25	0.99	1.24	0.97	0.98	1.09	0.15
9	0.81	1.10	1.02	1.31	1.26	1.10	0.20
10	1.00	0.93	1.02	1.01	0.98	0.99	0.04
11	0.98	0.98	0.95	1.09	1.08	1.02	0.06
12	1.01	1.01	0.81	1.04	1.01	0.98	0.09
13	0.97	0.90	0.98	0.91	0.98	0.95	0.04
14	0.95	0.96	1.06	1.03	0.97	0.99	0.05
15	1.07	1.15	0.83	1.04	1.00	1.02	0.12
16	1.12	0.84	1.11	0.97	0.92	0.99	0.12
17	1.04	1.03	0.94	0.96	1.10	1.01	0.06
18	0.96	1.15	1.20	1.14	1.20	1.13	0.10
19	0.96	1.02	1.02	0.96	1.07	1.01	0.05
20	1.15	0.86	1.22	0.93	1.29	1.09	0.19
21	1.10	1.15	1.24	1.10	1.11	1.14	0.06
22	0.83	1.04	1.14	1.15	0.89	1.01	0.15
23	0.90	1.27	1.10	0.93	1.02	1.04	0.15
24	1.11	1.31	0.90	1.04	0.93	1.06	0.16
25	1.02	0.98	1.17	0.93	1.04	1.03	0.09
26	1.28	0.96	1.05	0.91	0.97	1.03	0.15
27	1.28	1.07	1.17	1.04	1.07	1.13	0.10
28	1.15	1.17	1.14	1.21	1.01	1.14	0.08
29	1.15	1.21	1.25	1.06	1.19	1.17	0.07
30	1.27	1.38	1.22	1.26	1.27	1.28	0.06
31	1.30	1.39	1.12	1.36	1.19	1.27	0.11
32	1.24	1.04	1.35	1.11	1.15	1.18	0.12
33	1.46	1.29	1.46	1.30	1.24	1.35	0.10
34	1.39	1.33	1.19	1.15	1.22	1.26	0.10
35	1.33	1.49	1.49	1.36	1.33	1.40	0.08
36	0.40	1.26	1.22	1.19	1.33	1.08	0.38
37	1.08	1.11	1.10	0.90	1.10	1.06	0.09
38	1.10	1.12	1.19	1.12	1.31	1.17	0.09
39	1.10	1.26	1.28	1.07	1.19	1.18	0.09
40	1.28	1.45	1.41	1.17	1.31	1.32	0.11

Table 1. Test Panel Dry Film Thickness (continued)

Panel No.	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5	Average	Std. Deviation
41	1.24	1.13	1.25	1.00	1.03	1.13	0.12
42	1.05	1.04	1.02	1.02	1.03	1.03	0.01
43	1.27	1.12	1.09	1.06	1.19	1.15	0.08
44	1.15	1.13	1.52	1.05	1.00	1.17	0.20
45	1.30	1.30	1.08	1.26	1.02	1.19	0.13
46	1.48	1.31	1.07	1.30	1.27	1.29	0.15
47	1.15	1.14	1.36	0.97	0.97	1.12	0.16
48	1.06	1.14	1.41	1.04	1.09	1.15	0.15
49	1.37	1.10	1.35	1.30	1.45	1.31	0.13
50	1.69	1.43	1.04	1.27	1.37	1.36	0.24
51	1.20	1.37	1.35	1.19	1.23	1.27	0.09
52	1.07	0.95	1.04	1.00	0.99	1.01	0.05
53	0.87	1.03	0.83	0.95	0.86	0.91	0.08
54	0.85	1.13	1.01	1.07	1.00	1.01	0.10
55	1.18	1.00	1.06	1.19	1.20	1.13	0.09
56	1.02	0.99	1.13	1.13	1.21	1.10	0.09
57	1.05	0.96	0.94	0.9	0.96	0.96	0.05

After the panels were stained with TNT, they were shipped back to ARL for the recoat evaluations. Three surface preparation processes had been chosen: nothing (as a control), an acetone wipe (a solvent readily available at IAAP and not a VOC), and a ScotchBrite scuff followed by an acetone wipe (to see if roughening the surface prior to recoating helped promote intercoat adhesion). At this point, PM, ARMS indicated that potentially either Zenthane Plus, accelerated Zenthane Plus, or the standard alkyd could be applied in the rework process. Due to potential changes needed in the IAAP production line, the dry time of the topcoat would be a large factor in the final decision. The OD alkyd used was from Sentry Paint, batch 9A54. Consequently, the 57 panels were divided into nine subsets to cover the three surface preparation variables and the three potential topcoats, as shown in Table 2.

Table 2. Test Panel Subsets

Surface Preparation	Alkyd	Zenthane Plus	Accelerated Zenthane Plus	Not Committed
None	Panels 1–6	Panels 7–12	Panels 13–18	Panel 19
Acetone	Panels 20–25	Panels 26–31	Panels 32–37	Panel 38
ScotchBrite/Acetone	Panels 39–44	Panels 45–50	Panels 51–56	Panel 57

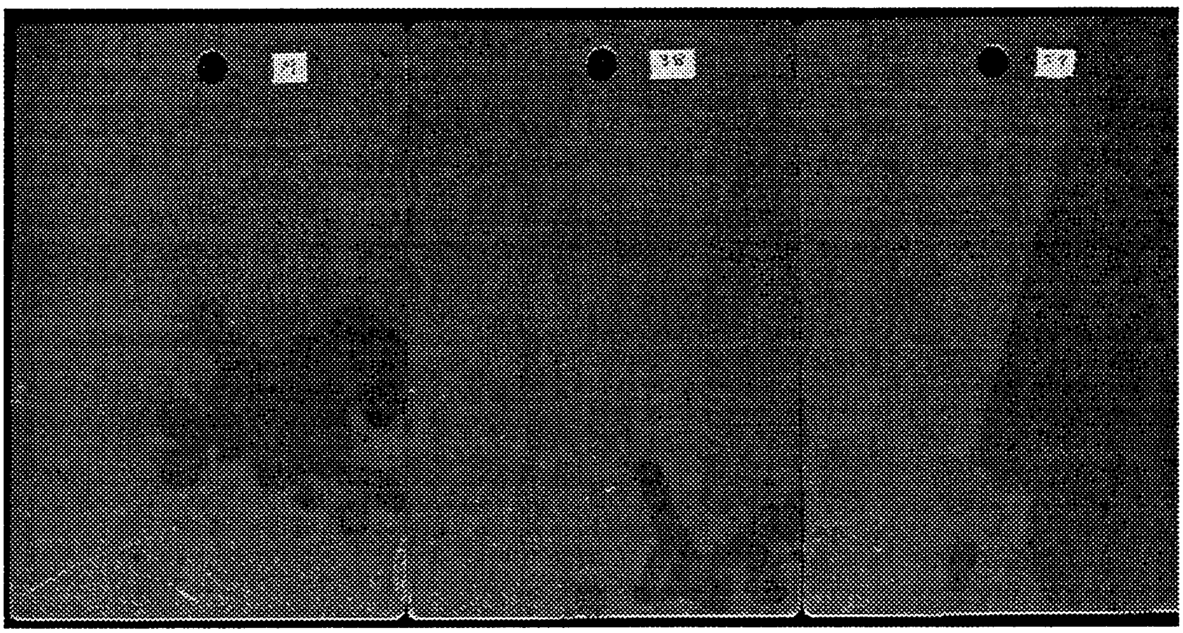

Figure 2. Stained Test Panels.

Figure 2 shows uncommitted panels and the appearance of the panels after staining at IAAP. Each of the subsets had six panels, allowing for ASTM B 117 salt spray on four panels (two of each, scribed and unscribed), ASTM D 3359 method B cross cut adhesion testing on one, and FED STD 141 method 6301.2 wet adhesion testing on the other. Three panels were not committed at that point. A seven-day dry/cure time was allowed before the panels were subjected to the MIL-STD-331 aging process.

At about the same time, due to a pending engineering change proposal (ECP) from IAAP, PM, ARMS requested a quick check of the adhesion of the two polyurethane topcoats to the Zenthane Plus used by SAAP. The test coupons used for this effort had been previously prepared using Zenthane Plus on 4- × 12-in ACT coupons, but were not sent to IAAP for staining because the film thickness was slightly high. That was not a problem for this quick adhesion test. Exactly as before, the surface preparation was either nothing (control), acetone wipe, or ScotchBrite followed by an acetone wipe. Only Zenthane Plus and accelerated Zenthane Plus were used as topcoats. To further reduce the variables involved, each of the two topcoats was applied to half of the same 4- × 12-in coupon after it was cut into two 4- × 6-in coupons. Table 3 lists the panels prepared for the quick recoat study.

Table 3. Quick Recoat Test Panels

Surface Preparation	Zenthane Plus	Accelerated Zenthane Plus
None	Panel A_1	Panel A_2
Acetone	Panel E_1	Panel E_2
ScotchBrite/Acetone	Panel I_1	Panel I_2

3. Test Results

The application of the Zenthane Plus and the accelerated Zenthane Plus was uneventful, with complete hiding and no apparent defects. However, the alkyd appeared to be incompatible with the TNT-stained substrate and exhibited many film defects, including nonhomogeneity and cratering. Shortly after the first high temperature and humidity cycle of the accelerated aging process was run, it became clear that topcoating with Zenthane Plus or the accelerated Zenthane Plus would not work. This was because the TNT stains, which were hidden after applying the rework topcoat, bled through and were once again visible. At the conclusion of the aging process, one panel from each of the nine subsets was provided to PM, ARMS to illustrate the poor appearance of the alkyd topcoat and the reappearance of the stains through the polyurethane topcoat. The panel labels were 6, 12, 16, 20, 26, 32, 43, 49, and 56. After removing these panels from the testing, each subset then contained five panels—four for salt fog exposure and one for wet and dry adhesion (Figures 3–5).

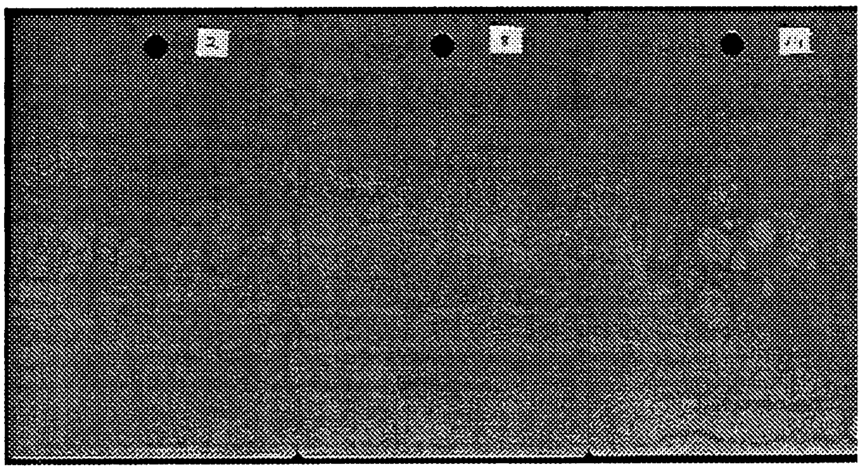

Figure 3. Test Panels Topcoated With Alkyd.

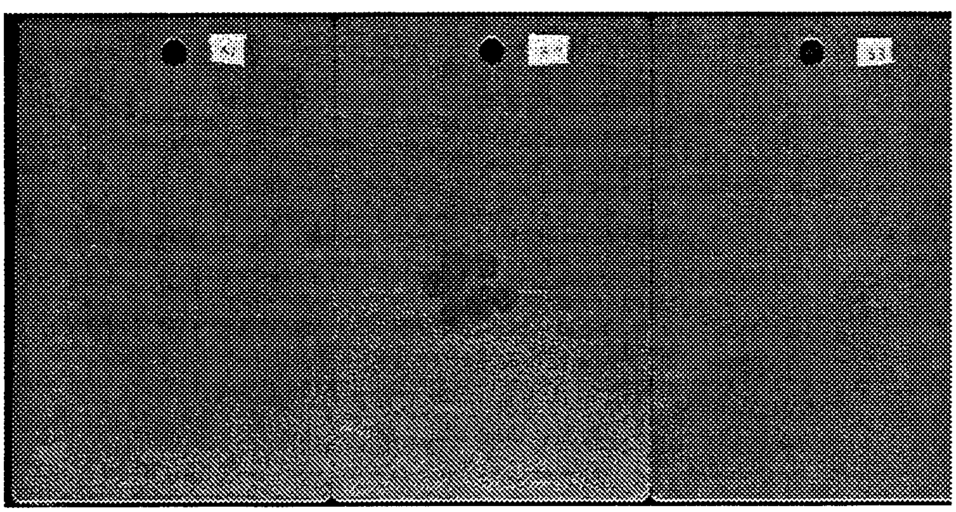

Figure 4. Test Panels Topcoated With Zenthane Plus.

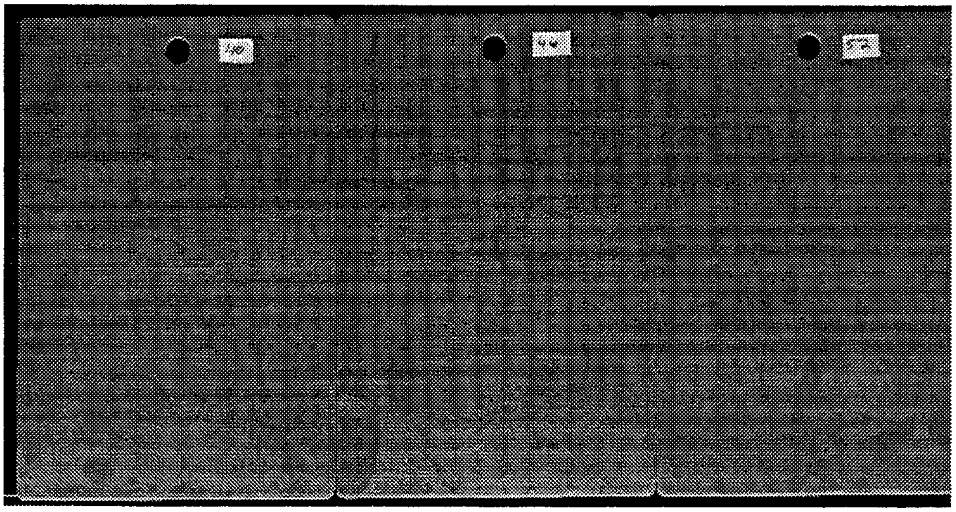

Figure 5. Test Panels Topcoated With Accelerated Zenthane Plus.

3.1 Salt Fog Testing. Table 4 lists the panels used in the salt fog testing in accordance with ASTM B 117. The back of each panel was coated with a red anticorrosive primer to prevent rusting. The test was run for 150 hr.

Table 4. Salt Fog Test Panels

Surface Preparation	Alkyd	Zenthane Plus	Accelerated Zenthane Plus
None	1, 2,[a] 3, 4[a]	7,[a] 8, 9, 10[a]	13, 14,[a] 15, 17[a]
Acetone	21,[a] 22, 23, 24[a]	27,[a] 28, 29,[a] 30	33,[a] 34, 35, 36[a]
ScotchBrite/Acetone	39, 40,[a] 41, 42[a]	45,[a] 46, 47, 48[a]	51, 52,[a] 53, 54[a]

[a] Scribed panels.

All panels passed this test. The final appearance of the panels with the polyurethane topcoat was better than those with alkyd, due to slightly less corrosion at the score. There were no significant differences observed in performance attributable to the surface preparation process used. Figures 6–8 illustrate these results.

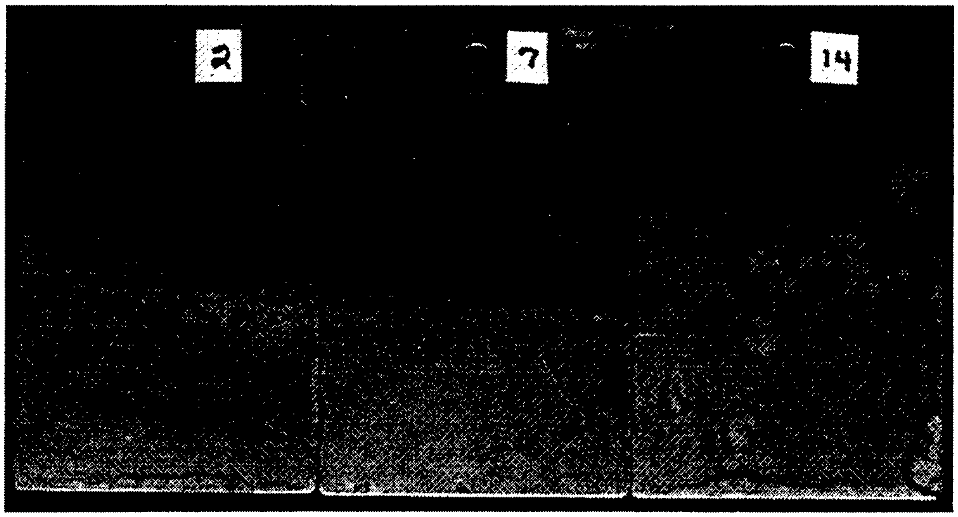

Figure 6. Alkyd-Topcoated Salt Fog Test Panels.

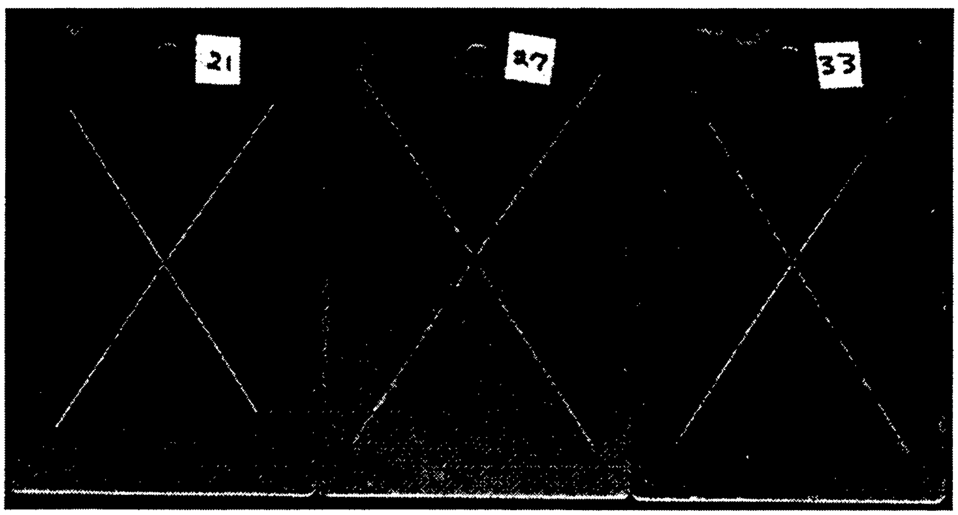

Figure 7. Zenthane Plus -Topcoated Salt Fog Test Panels.

3.2 Adhesion Testing. Tables 5 and 6 list the panels used in adhesion testing and the results. The ASTM cross cut adhesion testing was performed with 2-mm line spacing appropriate for dry film thicknesses between 2 and 5 mil (1 mil = 0.001 in). Only panel 44 was marginal in performance.

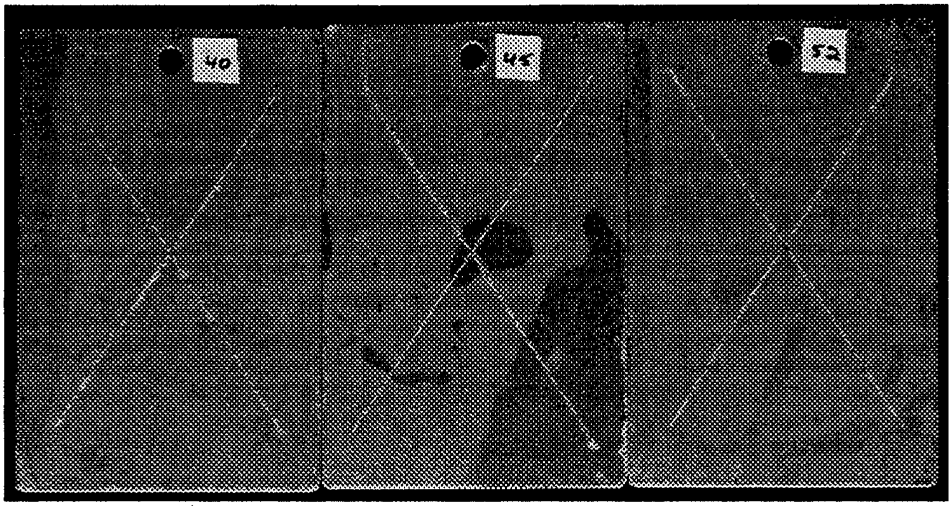

Figure 8. Accelerated Zenthane Plus-Topcoated Salt Fog Test Panels.

Table 5. ASTM D 3359 Method B Adhesion Test Results

Surface Preparation	Alkyd		Zenthane Plus		Accelerated Zenthane Plus	
	Panel	Result	Panel	Result	Panel	Result
None	5	5B (pass)	25	4B (pass)	44	4B (pass)
Acetone	11	5B (pass)	31	5B (pass)	50	4B (pass)
ScotchBrite/Acetone	18	5B (pass)	37	5B (pass)	55	5B (pass)

Note: A 5B rating means no removal, and a 4B rating means < 5% removal.

Table 6. FTMS 141 Method 6301.2 Adhesion Test Results

Surface Preparation	Alkyd		Zenthane Plus		Accelerated Zenthane Plus	
	Panel	Result	Panel	Result	Panel	Result
None	5	Pass	25	Pass[a]	44	Pass[b]
Acetone	11	Pass	31	Pass	50	Pass
ScotchBrite/Acetone	18	Pass	37	Pass	55	Pass

[a] < 1/16-in removal at the score in a stained area.
[b] 1/16–1/8-in removal at the score (none in stained area).

3.3 Quick Recoat Study. Panels prepared in the quick recoat study were subjected to ASTM D 3359 cross cut adhesion and FTMS 141 Method 6301.2 wet tape adhesion testing to check for intercoat adhesion. All panels passed both test procedures, as shown in Table 7.

Table 7. Quick Recoat Adhesion Test Results

Surface Preparation	Zenthane Plus				Accelerated Zenthane Plus			
	ASTM		FTMS		ASTM		FTMS	
	Panel	Result	Panel	Result	Panel	Result	Panel	Result
None	A[a]	4B Pass[a]	A[a]	Pass	A[b]	5B Pass[a]	A[b]	Pass
Acetone	E[a]	5B Pass	E[a]	Pass	E[b]	5B Pass[a]	E[b]	Pass[b]
ScotchBrite/Acetone	I[a]	5B Pass	I[a]	Pass	I[b]	5B Pass	I[b]	Pass

Note: A 5B rating means no removal, and a 4B rating means < 5% removal.
[a] Minor removal at intersections.
[b] Down to the substrate, but < 1/32 in.

3.4 Dry Time Study. The dry times in Table 8 were provided to PM, ARMS to assist in evaluating an ECP proposing changes in the production line to accommodate using CARC to repair stained projectiles. In most cases, they are within the dry time limits found in MIL-E-52891. Testing was performed according to FTMS 141 method 4061.2, as shown in Table 8.

Table 8. Dry Time Test Results

Coating	Application	Set To Touch (min)	Dry Hard (min)	Dry Through (min)
MIL-E-52891 Requirement	drawdown	6	10	20
Zenthane Plus	drawdown	3–4	10	15
Zenthane Plus	spray	5	15	20
Accelerated Zenthane Plus	drawdown	3–4	10	15
Accelerated Zenthane Plus	spray	5	15	20

3.5 Stain Migration. One of the three stained panels not committed to the corrosion and adhesion testing was overcoated with accelerated Zenthane Plus, allowed to dry/cure for seven days, and placed in an oven at 105 °C. The underlying TNT stain permeated the cured topcoat (became visible) in about an hour.

4. Discussion

Most of the results of this study were predictable. All of the three potential topcoats, alkyd, Zenthane Plus, and accelerated Zenthane Plus, could be applied to TNT-stained Zenthane Plus that had been adequately prepared. Corrosion resistance and adhesion were satisfactory. What could not be predicted, however, was how easily the TNT stain permeated the Zenthane overcoat, thereby eliminating its use to hide the stains. The alkyd alternative proved to be unacceptable as well due to visible surface defects, regardless of the type of surface preparation. This behavior is probably related to its incompatibility with the TNT in the polyurethane film and may be the reason that TNT staining did not permeate the alkyd. On the other hand, the apparent compatibility of the polyurethane and TNT probably explains, at least in part, the ease with which TNT stains permeated the polyurethane topcoat.

5. Recommendations

(1) ARL does not recommend that the alkyd or the polyurethanes tested in this effort be used as a recoat to repair the stained projectiles.

(2) Further study of the mechanism of TNT migration through polyurethane films is warranted.

(3) It is best to prevent staining from occurring as much as possible, but stained projectiles will likely need to be stripped of stained topcoat and repainted.

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13. ABSTRACT *(Maximum 200 words)*

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