Army Research Laboratory

Qualification of Ammunition Coatings for Renovating 155-mm M549A1 Projectiles

by Pauline M. Smith and Kestutis G. Chesonis

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1. Introduction

The traditional protective coatings for mortar and artillery projectiles are based on quick drying enamels. The main requirements are thin coats, fast dry, corrosion resistant films, durability, and ease of application. Coatings on various ammunition components typically contained substances that were either toxic or hazardous, with high levels of volatile organic compounds (VOCs), and hazardous air pollutant (HAP) solvents, hexavalent chromium (Cr^{+6}) and other heavy metals. Increasingly stringent environmental regulations have forced ammunition manufacturers and maintenance facilities to reconsider their traditional coating processes and waste streams. The ammunition coatings procured to the same specifications have also evolved over the years (resins, pigments, and solvents) and have resulted in various coating related issues.

Recently, a new environmentally compliant coating system (primer and topcoat) has been developed and implemented into ammunition manufacturing sites. However, the new coating system has not been evaluated for the ammunition renovation effort, which consists of different surface preparation and pretreatment processes. The current coating system for stripping and re-painting high explosive (HE) ammunition is an alkyd enamel topcoat with high levels of VOCs over a pretreatment coating.

The fast-drying enamels used on containerized mortars are military specifications MIL-E-11195E (*1*) and MIL-P-11414E (*2*). They are lead and chromate free and meet federal regulation limits of 420 g/L of VOC. However, the topcoat MIL-E-11195E has a few limitations and cannot be used by itself on some projectiles due to inadequate corrosion resistance. Some projectiles require use of a single coat due to close dimensional tolerances, systems combining the functions of primer and topcoat. Generally, single coats are used on products that need only basic corrosion protection.

Several manufacturers have been tasked to retrofit and renovate the M549A1 projectiles. Because the current coating system exceeds the limit of 3.5 lb of VOCs per gallon of coating, it has been proposed to use a VOC-exempt alternate coating system with a pretreatment coating. Also, a few companies are currently renovating the same ammunition with a coating system that has previously been used for renovation of 155-mm projectiles, but no documented performance data are available. These coatings are considered too thick for dimensionally tight 155-mm projectiles and may not provide adequate field protection without a pretreatment coating.

2. Technical Approach

The initial effort consists of evaluating various coating candidates in a laboratory environment and selecting a suitable candidate for field testing at a renovation facility. The Coating Technology Team at the U.S. Army Research Laboratory (ARL) conducted the laboratory testing using cold-rolled steel (CRS) (S36 and D36) panels from the Q-Panel Company. The selected coating candidates will be applied in the depainting and repainting line at a renovation facility using empty ammunition metal parts (specifically the 155-mm and M795 high fragmentation [HF] steel bodies) to ensure the technical practicability. The coated metal parts will then be sectioned by the renovation facility and sent back to the U.S. Army coating laboratory for final testing and evaluation.

3. Experimental

The standardized test surface was CRS, Type R, and Type S panels 4 H 6 H 0.032 in from the Q-Panel Company. Type R panels have a dull matte finish, whereas the Type S has a ground side that imparts a smoother surface.

For comparison, a limited number of coatings were tested using Bondrite B952, zinc phosphate panels (ACT Laboratories). The test specimens were horizontally oriented during paint application. A conventional air-atomizing spray was used to apply the candidate paints to the appropriate substrates. They were allowed to cure at ambient temperature (~75 ºF) and humidity for 7 days. Table 1 lists all coatings used in the matrix.

The topcoats were applied at ~1.2 mil, while the primer was applied at ~0.9 mil and the pretreatment at 0.3 mil.

4. Results and Discussion

4.1 Spraying Properties

All individual coatings when sprayed were given a satisfactory or a passing rating, presenting uniform films, without any surface defects.

4.2 Hydrocarbon Fluid Resistance

After exposure for 7 days to a mixture of 75% isooctane and 25% toluene, American Society for Testing and Materials (ASTM) D 1308-02 (*3*) and ASTM D 609-00 (*4*) were used for evaluation of the coatings, following chemical immersion exposure tests. All coating systems passed except

Table 1. Samples for testing.

Samples for M549A1			
Sample ID	**Pretreatment**	**Primer**	**Topcoat**
A (Control)	DOD-P-15328D (*5*) (Sherwin Williams) Wash primer -SW (VOC non-compliant)	None	MIL-E-52891B (*6*) (Sherwin Williams) Ammunition topcoat (VOC non-compliant)
B	E61G520 (Sherwin Williams) Commercial wash Primer pretreatment (VOC compliant)	None	12997567 (Sherwin Williams) MIL-E-11195 F93GC353 (TYP 11)
C	None	None	12997567 (Sherwin Williams) MIL-E-11195 F93GC353 (TYP 11)
D	None	12991256 (Sherwin Williams) MIL-P-11414E (E90R351) (VOC compliant/HAP free)	12997567 (Sherwin Williams) MIL-E-11195 F93GC353 (TYP 11)
E	None	TT-P-664 (*7*) Red oxide alkyd primer (VOC compliant)	TT-E-516 (*8*) Ammunition topcoat (State VOC exempt–CAAA)
F	None	MIL-P-11414E	TT-E-516 Ammunition topcoat (State VOC exempt–CAAA)
G	02887GWP (Hentzen Coatings) Universal pretreatment Hentzen (low VOC)	None	12997567 (Sherwin Williams) MIL-E-11195 F93GC353 (TYP 11)
H	02887GWP (Hentzen Coatings) Universal pretreatment Hentzen (low VOC)	None	MIL-E-52891B (Sherwin Williams) Ammunition topcoat (VOC noncompliant)
I	None	MIL-P-11414E (Randolph Paints) E9962 QPL# Low VOC, HAPs free	12997567 (Sherwin Williams) MIL-E-11195 F93GC353 (TYP 11)
J	None	MIL-P-11414E (Randolph Paints) E9962 QPL# Low VOC, HAPs free	TT-E-516 Ammunition topcoat (State VOC exempt–CAAA)
K	DOD-P-15328D (Sherwin Williams) Wash primer (VOC noncompliant)	None	MIL-E-52891B (Marcus Paints) Ammunition topcoat (VOC compliant) Experimental
L	None	None	MIL-E-52891B

Note: The group of candidates was generated based on general use.

for coating B and coating J. Coating B softened after exposure and exhibited wrinkling on the exposed panel surface. Coating J showed color and gloss changes and did not recover even after 24 hr. These two coatings were rated unsatisfactory for gloss and color. Coatings F, G, H, and I showed some wrinkling, but recovered after 24 hr. The remaining coatings (A, C, D, E, and K) satisfied the specification requirements, displaying no coating defects upon exposure to this fluid immersion test.

4.3 Water Immersion Resistance

ASTM D 1308-02 involves exposing an organic coating to a reagent to determine adverse affects. Fifty percent of the coated panels were immersed in deionized water at room temperature (23 ± 5 °C) for 7 days. The panels were examined for any defects, such as blistering, loss of adhesion, color and gloss change, immediately upon removal and after a 24-hr recovery period. All panels passed the water immersion test. Results are listed in Table 2.

Table 2. Hydrocarbon fluids and water resistance.

Sample ID	Hydrocarbon Fluid Resistance	Water Immersion Resistance
A	Pass	Pass
B	Fail	Pass
C	Pass	Pass
D	Pass	Pass
E	Pass	Pass
F	Conditional/Pass	Pass
G	Conditional/Pass	Pass
H	Conditional/Pass	Pass
I	Conditional/Pass	Pass
J	Fail	Pass
K	Pass	Pass

4.4 Flexibility

The Mandrel Bend Test was performed on all coatings in accordance with ASTM D 522-93 (*9*). The purpose of this test is to rate each coating's resistance to cracking and to rate the flexibility of each coating. This test demonstrated that all coatings were generally flexible. Except for J and F, when bent over a 1/4-in mandrel diameter, none showed any signs of cracking. Coatings J and F had fine cracks within the paint after being bent over the 1/4-in mandrel. However, Sample F did not show cracks through to the metal, but sample J coatings could be best described as brittle because cracking was evident through the entire thickness of coating.

4.5 Impact Resistance

The standard test for resistance to deformation (impact) was performed using an impact tester. Impact resistance can be described as a paint property that quantitatively characterizes the durability of a coating with respect to a rapid impact event. After curing 7 days at ambient laboratory conditions, the impact resistance test based on ASTM D 2794 (*10*), using 40 lb/in, was performed on all coatings. All coatings passed using 40 lb/in. Increasing to 60 lb/in, coatings A, B, C, G, H, and K maintained relatively high-impact resistance. Coating J failed for cracks while coating I, F, and D showed fine cracking but were rated borderline/satisfactory. Table 3 lists results for the 60 lb/in.

Table 3. Impact resistance.

Substrate	CRS R36	CRS D36	Bondrite B952/ P60
Control	Pass	Pass	Pass
B	Pass	Pass	Pass
C	Pass	Pass	Pass
D	Pass Minor cracks	Pass/B Cracks	Pass Minor cracks
E	Pass	Pass	Pass
F	Fails	Pass/B minor cracks	Pass/B minor cracks
G	Pass	Pass cracks	Pass
H	Pass	Pass	Pass
I	Pass	Pass	Fail
J	Fail Cracks	Pass Minor cracks	Pass
K	Pass	Pass	Pass
L	Pass	Pass	Pass Minor cracks

4.6 Crosshatch Adhesion Testing ASTM D 3359-93 (*11*) Method B

The ASTM cross cut adhesion testing was performed with 2-mm line spacing, appropriate for dry film thickness between 2 and 5 mil (1 mil = 0.001 in). All samples passed the dry adhesion test. Table 4 lists the results.

Table 4. Adhesion testing results.

Substrate	CRS R36	CRS D36	Bondrite B37 P60
Control	5B (pass)	5B (pass)	5B (pass)
B	5B (pass)	5B (pass)	5B (pass)
C	5B (pass)	5B (pass)	5B (pass)
D	5B (pass)	5B (pass)	5B (pass)
E	5B (pass)	5B (pass)	5B (pass)
F	5B (pass)	5B (pass)	5B (pass)
G	5B (pass)	5B (pass)	5B (pass)
H	5B (pass)	5B (pass)	5B (pass)
I	5B (pass)	5B (pass)	5B (pass)
K	5B (pass)	5B (pass)	5B (pass)
L	5B (pass)	5B (pass)	5B (pass)

Note: 5B rating means no removal.
4B rating means <5% removal.
3B rating means 5%–15% removal.
2B rating means 15%–35% removal.
1B rating means 35%–65% removal.

4.7 Accelerated Corrosion Testing

Accelerated corrosion testing was performed using both a neutral salt spray test per ASTM B 117 (*12*) and an accelerated cyclic corrosion test per General Motors (GM) 9540P (*13*).

Salt spray resistance is widely used by the paint industry as a quality control test and is not necessarily indicative of the long-term performance of a coating. Our test used three steel panels for each system with two intersecting scribes ("X") through the coatings to the substrate. The panels were "X" scribed using a standard carbide-tipped hardened steel scribe. The painted panels (three each) for each coating were exposed for 168 hr of salt spray. All the painted panels appeared visually identical before testing. Panels were evaluated using ASTM D 1654 (*14*) for evaluation of painted or coated specimens subjected to corrosive environments and ASTM D 714-87 (*15*) for evaluating degrees of blistering of paints. Final detailed ratings for the 168 hr duration, using ASTM D 1654 quantitatively, indicate the damage caused by pitting or delamination outwards from the scribe.

GM 9540P is an accelerated cyclic corrosion test that was developed by the automotive industry to more accurately replicate long-term outdoor performance of coatings than the conventional salt spray test. A cyclic corrosion test chamber (CCTC) was used to perform the GM 9540P test. The test consists of the repetition of one cycle with 18 separate stages including salt (1.25% by mass: 0.9% NaCl, 0.1%$CaCl_2$, 0.25% $NaHCO_3$) water mist, humidity, drying, ambient, and heated drying. The environmental conditions and duration of each stage for one complete 9540P cycle are given in Table 5. This process repeated 80 times to a scribed panel is claimed by industry specialists to be equivalent to 10 years of field exposure in South Florida. For this test, the groups of scribed coupons were exposed until failure or completion of 80 cycles.

The criteria for failure was either creep from scribe of >10 mm (ASTM D 1654 rating of <3) or an ASTM D 714 rating for blistering in excess of 6M in the unscribed regions. Upon removal, coupons were rinsed in deionized water. In addition, standard plain carbon steel calibration coupons described in GM 9540P and supplied by GM were initially weighed and subsequently monitored for mass loss at intervals set by the specification. Mass losses measured for steel coupons used for this test were within parameters stated in the GM specification. For each coating tested, three panels were subjected to CCTC testing. As in salt spray, the panels were "X" scribed. The scribed panels were placed into the chamber and tested using GM 9540P, Method B10, which provides a more realistic accelerated environmental test than conventional salt spray.

The analysis of the panels exposed in ASTM B 117 for 168 hr indicated that, for most panels, the rating was >5, meaning that creepage at the scribe was <3 mm. The only exception was sample C and sample H, which failed on both CRS substrates. Sample C passes on zinc phosphate panels. At the final inspection at 168 hr, coatings A, B, D, E, G, K, L, and M performed the best,

Table 5. GM 9540P cyclic corrosion test details.

Interval	Description	Interval Time (min)	Temperature (±!3 °C)
1	Ramp to salt mist	15	25
2	Salt mist cycle	1	25
3	Dry cycle	152	30
4	Ramp to salt mist	70	25
5	Salt mist cycle	1	25
6	Dry cycle	15	30
7	Ramp to salt mist	70	25
8	Salt mist cycle	1	25
9	Dry cycle	15	30
10	Ramp to salt mist	70	25
11	Salt mist cycle	1	25
12	Dry cycle	15	30
13	Ramp to humidity	15	49
14	Humidity cycle	480	49
15	Ramp to dry	15	60
16	Dry cycle	480	60
17	Ramp to ambient	15	25
18	Ambient cycle	480	25

with the least amount of creep from the scribe and no blisters. Coatings F, J, and I trailed behind with increased creep and blister formation. Coating H also showed small blisters. Results are listed in Table 6.

Table 6. ASTM B 117 results.

Sample ID	R36 Scribed Area	R36 Unscribed Area	D36 Scribed Area	D36 Unscribed Area	B952 Scribed Area	B952 Unscribed Area	Rank
A	8, 6	6, 6	—	—	—	—	Pass
B	6, 5	9, 10	5	9	—	—	Pass
C	0, 1	6, 7	0	3	—	10	Fail
D	5, 6	10, 8	—	—	8	10	Pass
E	6, 7	9, 8	6	10	—	—	Pass
F	5	8	6, 5, 7	10, 9, 9	8	9	—
G	7	10	6	10	8	10	Pass
H	1, 0	3, 2	0	0	—	—	Fail
I	6, 5	9, 9	8, 7	9, 9	—	—	Pass
J	4, 6, 5	9, 8, 7	—	—	7	9	Pass
K	5, 8	8, 9	8, 8	7, 8	—	—	Pass
L	—	—	—	—	8, 8	6, 5	Pass

The analysis of the panels exposed in GM 9540P for 38 cycles indicated that most samples passed the criteria. As with the salt spray results, an exception was sample C, which failed on both CRS substrates. Sample C passes on zinc phosphate panels. At final inspection, coatings A, B, D, and G performed the best, with the least amount of creep from the scribe and no blisters.

Initially, coating B looked the best, but after scraping the scribed areas with a blunt knife, coatings A, B, D, and G were visually equivalent. Results are listed in Table 7.

Table 7. GM 9540P results.

Sample ID	R36 Scribed Area	R36 Unscribed Area	D36 Scribed Area	D36 Unscribed Area	B952 Scribed Area	B952 Unscribed Area	Rank
A	5, 6	8, 9	5	9	NA	NA	Pass
B	5, 6	9, 9	4	9	NA	NA	Pass
C	0	5	0	4	7	7	Fail
D	3, 3	9, 10	—	—	7	8	Pass
E	4, 2	8, 7	5	7	NA	NA	Pass
F	6, 3	10, 10	5	8	NA	NA	
G	9	10	5, 6	6, 6	8	10	Pass
H	3, 3	7, 10	3	8	NA	NA	Pass
I	4, 6	8, 5	5	6	NA	NA	Pass
J	4, 3	9, 9	4	7	NA	NA	Pass
K	6, 4	7, 5	5	6	NA	NA	Pass
L	—	—	—	—	9, 8	6, 5	Pass

5. Summary

Eleven candidate off-the-shelf coatings were tested in the laboratory and analyzed using rigorous test methods.

The performance of coatings B, D, and G indicates outstanding performance. Coatings D and G are suitable replacements for the current system. They are applied at the smallest film thickness of applied coating and would be the easiest to implement.

Sample D could be a practical coating, but there are some issues with the tight tolerances on some projectiles that would have to be addressed. This coating combination is considered too thick for the dimensionally tight 155-mm projectiles and may not provide adequate field protection without a pretreatment coating.

Samples B and G will be applied to the ammunition parts at the production sites. After assessment, the parts will be shipped to the ARL facility for final evaluation.

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14. ABSTRACT
Increasingly stringent environmental regulations have forced ammunition manufacturers and maintenance facilities to reconsider their traditional coating processes. The demands on the ammunition coating specifications have changed over the years. The treatments of hazardous emissions and waste generation at all levels of production are very costly, and any reduction in emissions through improved coatings will save money. The current coating system for high explosive ammunition is an alkyd enamel topcoat, which contains high levels of volatile organic compounds applied to a pretreated surface. The need to reduce or eliminate these hazardous substances is dictated by federal and state environmental regulations, controlling the amount and types of solvents and methods for waste disposal, and by changes in the coating process. This regulatory and performance-driven process led to a major consolidation effort by the U.S. Army Research Laboratory Coatings Team and the U.S. Army Armament Research, Development, and Engineering Center Munitions Metal Parts to eliminate coatings with hazardous materials and high levels of polluting solvents. Eventually, these improvements will reduce life-cycle costs. Experimental stress tests such as corrosion resistance, impact resistance, and adhesion were used to characterize and identify the optimal coatings.

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