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Accelerated Corrosion Analysis of Nonchromate Conversion Coatings on Aluminum Alloys 5083, 7039, and 6061 for DOD Applications

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Abstract

This study examines the effectiveness of six nonchromate conversion coatings on aluminum alloys 5083, 7039, and 6061. Evaluation methods included ASTM B117 (American Society for Testing and Materials. "Standard Method of Salt Spray [Fog] Testing." ASTM B117-90, 1990) salt fog, General Motors 9540P (General Motors. *General Motors Engineering Standard, Accelerated Corrosion Test.* GM 9540P, July 1991) cyclic salt spray, wet adhesion, and dry adhesion on painted test panels. Conversion-coated panels without paint were also screened to assess quality and pretreatment characteristics. Differences in behavior were noted between the salt fog data and the cyclic salt spray data obtained on scribed panels. How these data may relate with implementation of nonchromate pretreatments for military vehicles is discussed.

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1. Introduction

Nonchromate conversion coatings to be tested were selected in conjunction with industry following a model used in the National Center for Manufacturing Sciences (NCMS) study of nonchromate conversion coatings [1] and our previous study [2]. Based upon initial feedback from the Bradley (M2) Infantry Fighting Vehicle Environmental Management Team (EMT) committee meeting in February 1998, six vendors of nonchromate coatings were asked to coat test panels. Aluminum alloys 5083, 7039, 6061, and 2519 were selected by the committee for investigation with the chromate conversion coating alternatives. Aluminum alloy 2519 was examined and was the focus of a separate report [3]. All vendors canvassed agreed to have their pretreatments evaluated. Alodine 1200 chromate conversion coating, applied at Letterkenny Army Depot, and grit-blasted specimens supplied by Concurrent Technologies Corporation (CTC)* were also included for control purposes.

2. Experimental Procedure

Aluminum panels (104 each nominally 10 cm × 15 cm × 0.6 cm) of alloys 5083-H131 and 7039-T64 were machined from rolled armor plate stock. A similar amount of aluminum 6061-T6 standard test coupons was obtained from Q-Panel Products.† Before leaving U.S. Army Research Laboratory (ARL) facilities, all coupons were clearly labeled using a mechanical die to permanently indent the experimental designation. All panels were sent to vendors and Army depots for coating application. Thirteen panels with each conversion coating combination were prepared. From each set of 13 panels, 11 were painted with an epoxy primer [4] and chemical agent resistant coating (CARC) [5] topcoat, and 2 panels were left in the unpainted conversion-coated state. The duration between conversion coating application and initial application of primer varied due to the pretreatment completion times and the subsequent shipping times. Some vendors, such as Sanchem,‡ specified that the primer application follow within 24 hr of pretreatment. None of the pretreatments tested were coated within the 24-hr constraint. The specimen pretreatment numerical notations used were:

* Concurrent Technologies, 100 CTC Drive, Johnstown, PA 15904.

† Q-Panel Products, 26200 First Street, Cleveland, OH 44145.

‡ Sanchem, Inc., 1600 S. Canal Street, Chicago, IL 60616.

- 0 – Grit Blasted,
- 1 – Alodine 1200,
- 2 – Alodine 2000,
- 3 – Alodine 5200,
- 4 – Organo Silane,
- 5 – Brent,
- 6 – Sanchem,
- 7 – Trivalent Chromate (Naval Air Warfare Center [NAWC]),
- 8 – 8-mil Aluminum Thermal Spray, and
- 9 – 4-mil Aluminum Thermal Spray.

Salt fog testing in accordance with the American Society for Testing and Materials (ASTM) standard B117 [6], MIL-C-81706 [7], and MIL-C-5541E [8] was used to screen unpainted conversion coated panels as well as the CARC-coated panels. The solution used was the standard 5% NaCl. The panels with conversion coating only were visually monitored and rated for pitting, general corrosion, and staining (Table 1). Any uniform pitting beyond one or two random pits was considered a failure. The panels were all photographed prior to testing, upon significant changes, and at failure (or the suspension of testing at 336 hr). CARC-painted panels (three each) for each conversion coating were exposed for 2,000 hr of salt fog under identical conditions as used for the unpainted specimens. These panels were "X" scribed using a standard carbide-tipped hardened-steel scribe. Figure 1 shows a representative photo of initial specimen appearance after scribing (all the painted panels appeared visually identical before testing). Periodic observations were made and damage was assessed chronologically using a series of ratings based upon scribe corrosion, blistering, and any delamination or lifting of the paint from the substrate (Table 2). Final detailed ratings for the 2,000-hr duration were assessed using ASTM D1654A [9] that quantitatively indicates the damage caused by pitting or delamination outwards from the scribe (Table 3).

Table 1. Ratings for 336-hr ASTM B117 [6] salt fog on unpainted panels.

Pass	Fail
P0 = no spots	F1 = 6–50 spots
P1 = 1 spot	F2 = 50 spots to 33% corroded area
P2 = 2 spots	F3 = 33–74% corroded
P3 = 3 spots	F4 = 75–100% corroded
P4 = 4 spots	General = Uniform Corrosion
P5 = 5 spots	

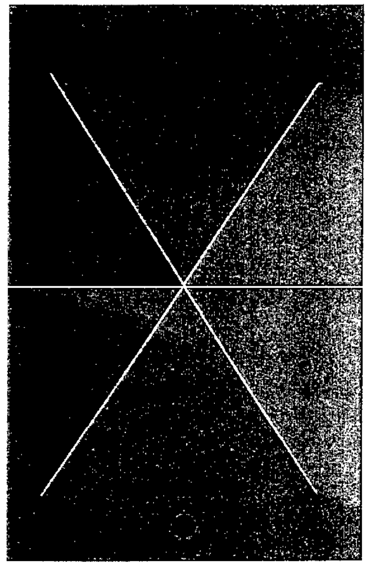


Figure 1. Initial scribed painted test panel.

Table 2. Chronological accelerated corrosion test rating method for painted test panels.

Pass:
P0 = no damage
P1 = white products in scribe from exposed substrate (no blisters)
Fail:
F1 = blistering on edges of scribe
F2 = blistering on remaining nonscribe area
F3 = scribe and nonedge blisters
F4 = total failure
(a) excessively large blisters
(b) rupturing of blisters

A cyclic corrosion test chamber (CCTC) was used to evaluate painted test panels. For each conversion coating tested, five primed and topcoated CARC panels were subjected to CCTC testing. As in salt fog, the panels were X scribed. The scribed panels were placed into the chamber and tested using General Motors (GM) Standard Test 9540P [10], Method B, which provides a more realistic accelerated environmental test than conventional salt fog [11]. The standard 0.9% NaCl, 0.1%$CaCl_2$, 0.25% $NaHCO_3$ test solution was used. In addition, standard plain carbon steel calibration coupons described in GM Standard Test 9540P [10] 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. The GM 9540P [10] test consists of 18 separate stages that include the following: saltwater spray, humidity, drying, ambient, and heated drying.

Table 3. Corrosion damage assessment—ASTM D1654A [9].

Rating of Failure at Scribe (Procedure A)		
Representative Mean Creepage From Scribe		
Millimeters	Inches (approximate)	Rating Number
Over 0	0	10
Over 0 to 0.5	0 to 1/64	9
Over 0.5 to 1.0	1/64 to 1/32	8
Over 1.0 to 2.0	1/32 to 1/16	7
Over 2.0 to 3.0	1/16 to 1/8	6
Over 3.0 to 5.0	1/8 to 3/16	5
Over 5.0 to 7.0	3/16 to 1/4	4
Over 7.0 to 10.0	1/4 to 3/8	3
Over 10.0 to 13.0	3/8 to 1/2	2
Over 13.0 to 16.0	1/2 to 5/8	1
Over 16.0 to more	5/8 to more	0

The environmental conditions and duration of each stage for one complete GM 9540P [10] cycle are given in Table 4. Again, the panels were photographed or digitally scanned prior to testing, upon significant observations, and at the suspension of the testing (120 cycles). As with ASTM B117 [6] salt fog, the extent of damage was assessed both chronologically and at the conclusion of exposure using the same methods.

Table 4. GM 9540P [10] 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	15	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

Outdoor exposure was initiated on two panels of each conversion coating at the outdoor test site located at Cape Canaveral, FL (Figure 2). Long-term performance data will be obtained and presented at future Bradley EMT meetings and published in subsequent ARL Technical Reports.

Figure 2. Aluminum armor test panels at Cape Canaveral outdoor exposure site.

Paint adhesion for both primed and topcoated panels was determined using a wet adhesion test (Method 6301 of MIL-C-81706 [12]). In this test, a standard adhesive tape is used to check adhesion on painted specimens after soaking for 24 hr in deionized water. After soaking, each panel is removed and then quickly dried. Two parallel scribes 1 in apart are made within the first minute after removal. Tape is uniformly applied across the scribes and then immediately removed. Upon removal, any evidence of paint separation is noted by visual observation of both the panel and the tape. MIL-C-81706 [7] describes adhesion based on a pass or fail system. To receive a "pass" rating, there must be no separation of the paint from the substrate or between layers of the paint. Additionally, a more detailed rating in accordance with ASTM D3359A [13] was used (Table 5).

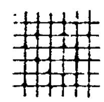
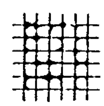
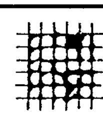
Dry adhesion measurements were conducted in accordance with ASTM D3359B [13]. This method employs a 6 $\times$ 6 grid of perpendicular scribes spaced at 2-mm intervals. Standard tape as similarly used in wet adhesion is uniformly applied over the cross-hatched area and then immediately removed. Once again, upon removal, any evidence of paint separation is noted by visual observation of both the panel and the tape. The rating method for ASTM D3359B [13] is described in detail in Table 6.

Table 5. Wet adhesion rating—Method ASTM D3359A [13].

Method A: Wet Adhesion	
Rating	Description of Coating After Tape Removal
5[a]	No peeling or removal
4	Trace peeling or removal along scribes
3	Jagged removal along scribes up to 1/16 in (1.6 mm) on either side
2	Jagged removal along most of the scribes up to 1/8 in (3.2 mm) on either side
1	Removal from most of the area between the scribes under the tape
0	Removal beyond the area of the scribes

[a]Passes military performance criteria.

Table 6. Dry adhesion rating (1X)—ASTM D3359B [13].

Classification	Surface of cross-cut area from which flaking has occured. (Example for 6 parallel cuts)
5	None
4	
3	
2	
1	

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3. Results

3.1 Salt Fog (ASTM B117 [6])

The unpainted pretreated panels were periodically observed and assigned one of the rating codes in Table 1. The observations are summarized in Figures 3–5.

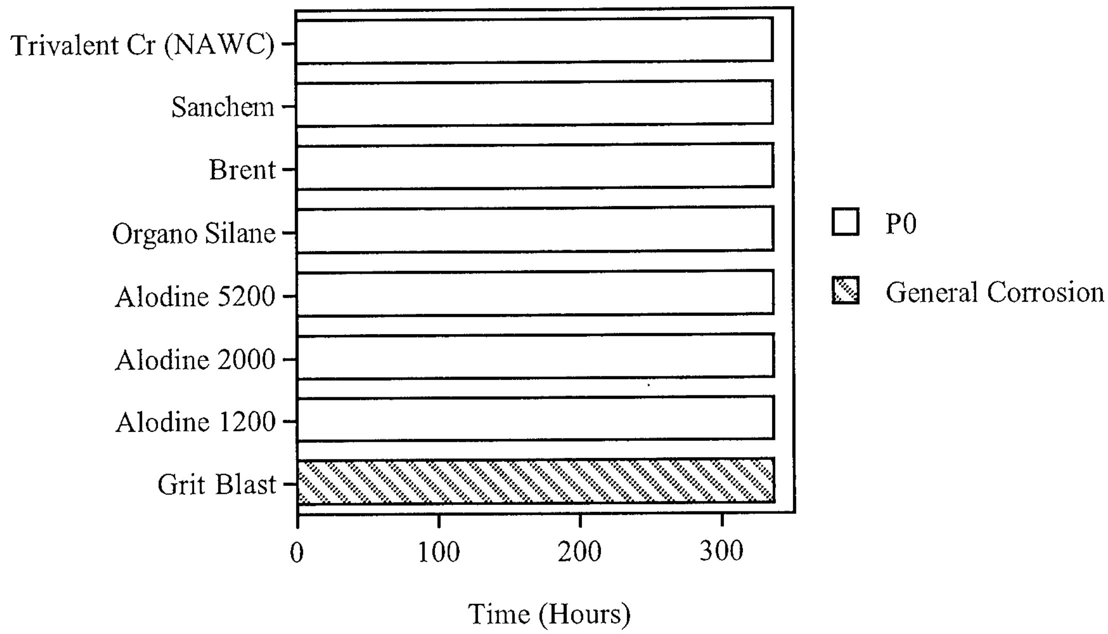


Figure 3. ASTM B117 [6] performance of unpainted 5083 panels.

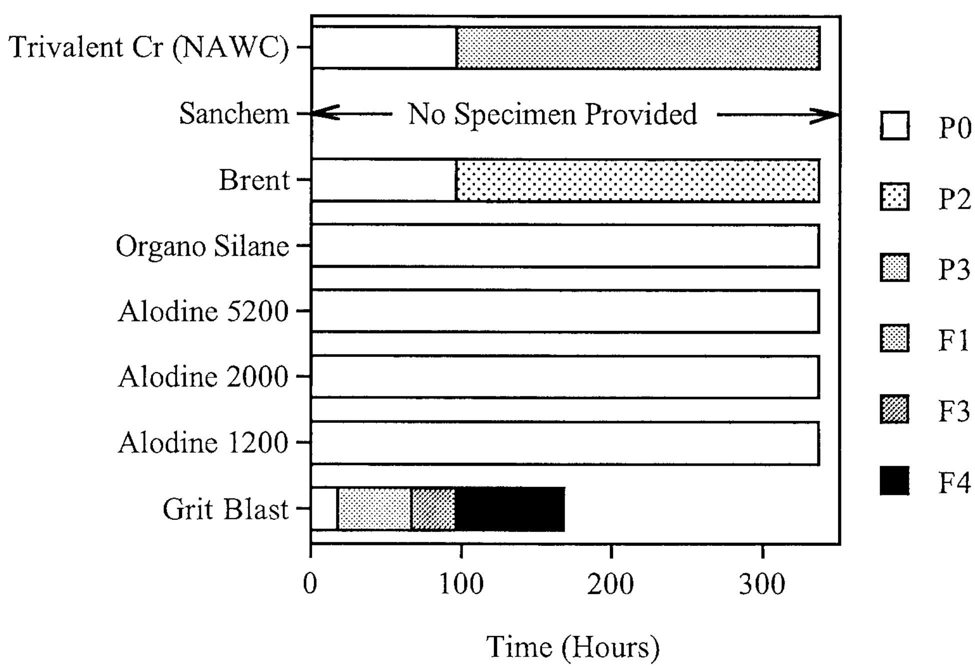


Figure 4. ASTM B117 [6] performance of unpainted 7039 panels.

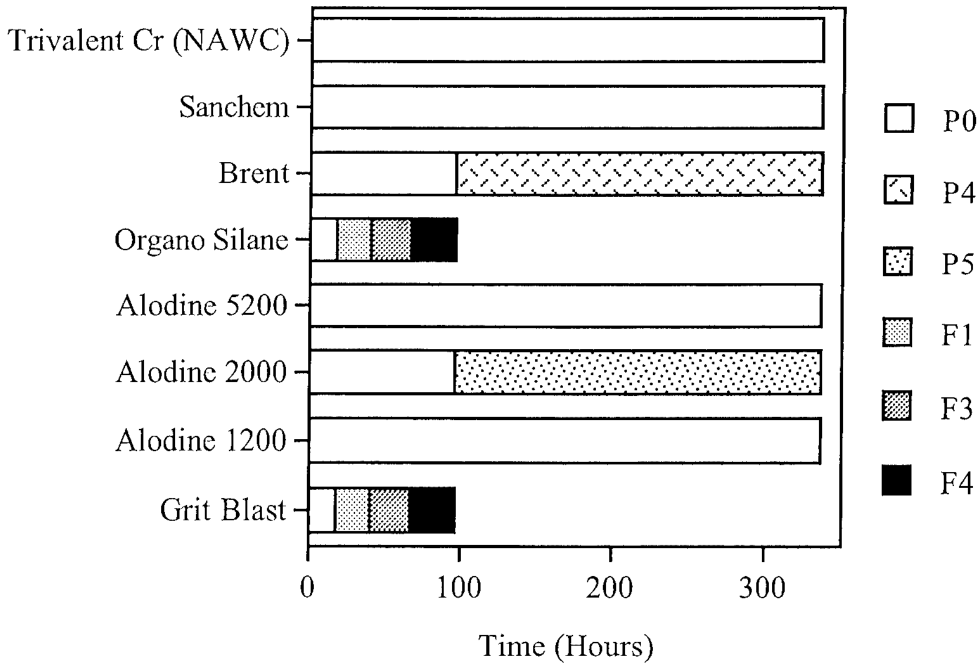


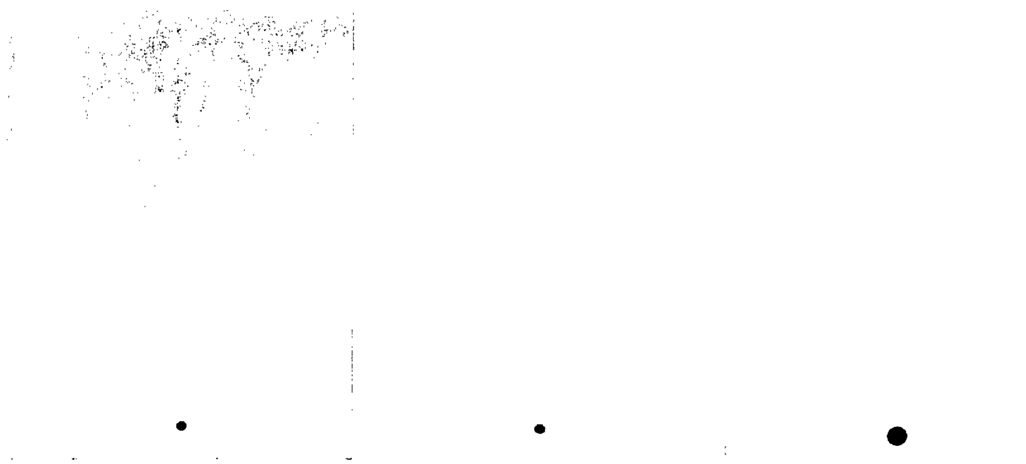
Figure 5. ASTM B117 [6] performance of unpainted 6061 panels.

Unlike the NCMS [1] study for Al 2024, and previous ARL studies of Al 2519 [2, 3], performance was satisfactory for most of the pretreatments on all three alloys. With the exception of the Grit-Blasted panels and the Organo Silane on Al 6061, all met the 336-hr qualification standard of MIL-C-81706 [7]. As a result, screening was terminated early on just three panel sets: (1) 7039 Grit Blast at 168 hr, (2) 6061 Organo Silane at 96 hr, and (3) 6061 Grit Blast at 96 hr (Figure 6). Some panels screened did not pit but did exhibit staining without pitting or loose corrosion product generation over the course of the 336-hr screen. The pretreatment combinations that stained but did not pit or actively corrode were:

- Grit Blast on 5083,
- Brent and Trivalent Chromate for Al 7039, and
- Alodine 2000 and Brent for 6061 (Figure 6).

The assessment for the painted panels differs from the unpainted panels, additional factors such as blistering and paint adhesion are considered. The performance metric for the painted panels is listed in Table 2.

Chronological performance for each pretreatment through the ASTM B117 [6] exposure is given in Figures 7(a), 8(a), and 9(a).



7039 Grit Blast at 168 hr Stains and Pits | 7039 with Brent at 336 hr Widespread Staining | 6061 with Organo Silane at 96 hr with Pitting

Figure 6. Corrosion damage of unpainted ASTM B117 [6] test panels.

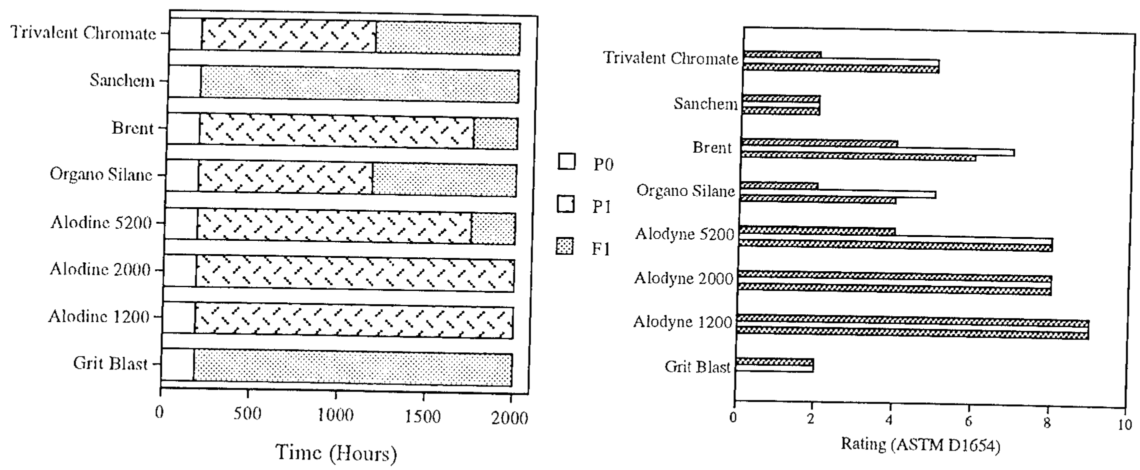
The primary failure mode for the painted panels was blistering along the scribe. The earliest blistering of the specimens occurred by 168 hr. The first panels to blister were the Grit Blast and the Sanchem panel sets at 168 hr which was consistent for all three. Next to blister was Alodine 1200 and Trivalent Chromate, each on 7039 at 504 hr. At 1,176 hr, blisters were visible on most of the remaining panels:

- Alodine 2000 for 6061,
- Alodine 5200 for 7039/6061,
- Organo Silane for 5083/7039/6061,
- Brent for 7039/6061, and
- Trivalent Chromate for 5083/6061.

Last to fail were Brent and Alodine 5200, each on 5083 at 1,752 hr. Only four panel sets had any representatives, which lasted the full 2,000-hr duration: Alodine 1200 for 5083/6061 and Alodine 2000 for 5083/7039. The final corrosion damage assessments per ASTM D 1654A [9] at 2,000 hr, including the data range for each set of the three panels, is given in Figures 7(b), 8(b), and 9(b). Figure 10 is representative photographs depicting corrosion damage at 2,000 hr.

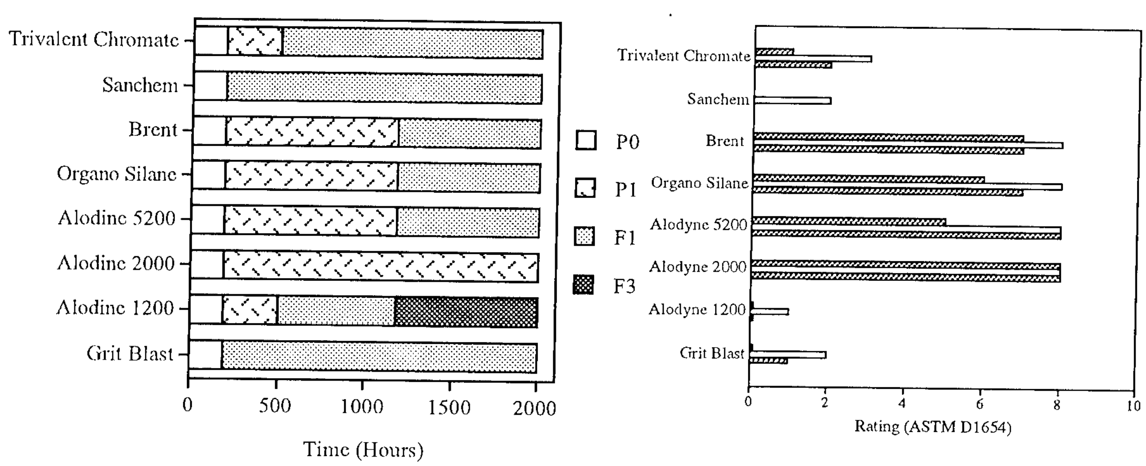
3.2 Cyclic Corrosion Test Chamber (CCTC)—9540P [10]

The painted panels were all subjected to 120 cycles of GM 9540P [10]. Chronological performance for each pretreatment through the cyclic exposure is given in Figures 11(a), 12(a), and 13(a). The assessment used for GM 9540P is identical to the assessment for ASTM B117 [6] salt fog for painted specimens (Table 2).



(a) Incremental (b) Final

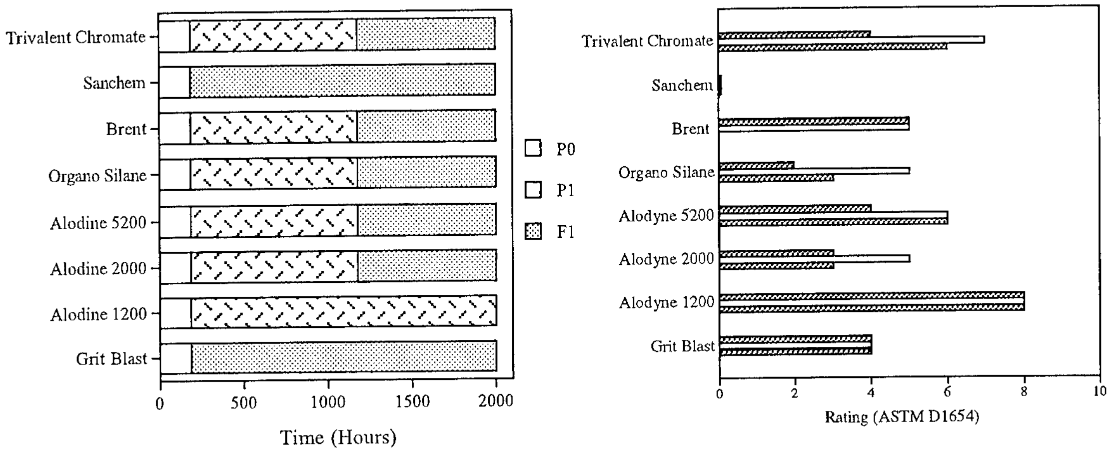
Figure 7. ASTM B117 [6] performance on scribed CARC 5083 panels.



(a) Incremental (b) Final

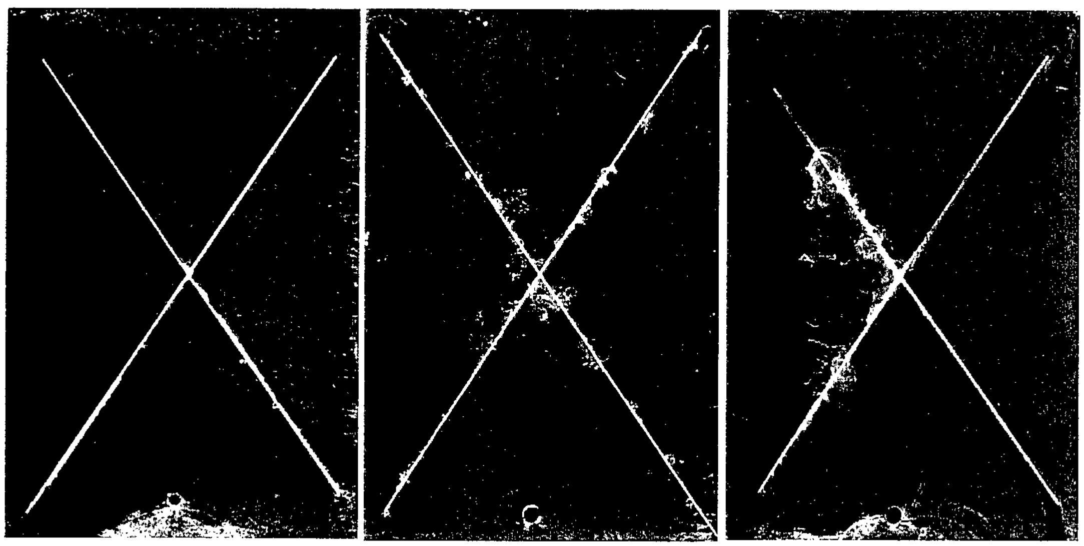
Figure 8. ASTM B117 [6] performance on scribed CARC 7039 panels.

As in salt fog, the failure mode for the painted panels was blistering along the scribe. Most panels sustained the full 120-cycle duration without damage. The first blistering detected occurred on Sanchem-treated panels at 80 cycles on 7039 and 6061 panels. At 100 cycles, blisters were observed on Sanchem-treated 5083 panels, Alodine 1200 for 7039/6061, and Grit Blast for 7039/6061. At the conclusion of 120 cycles, it was noted that blistering started for Alodine 2000 on 7039/6061. Panels that did not fail 120 cycles included:



(a) Incremental (b) Final

Figure 9. ASTM B117 [6] performance on scribed CARC 6061 panels.



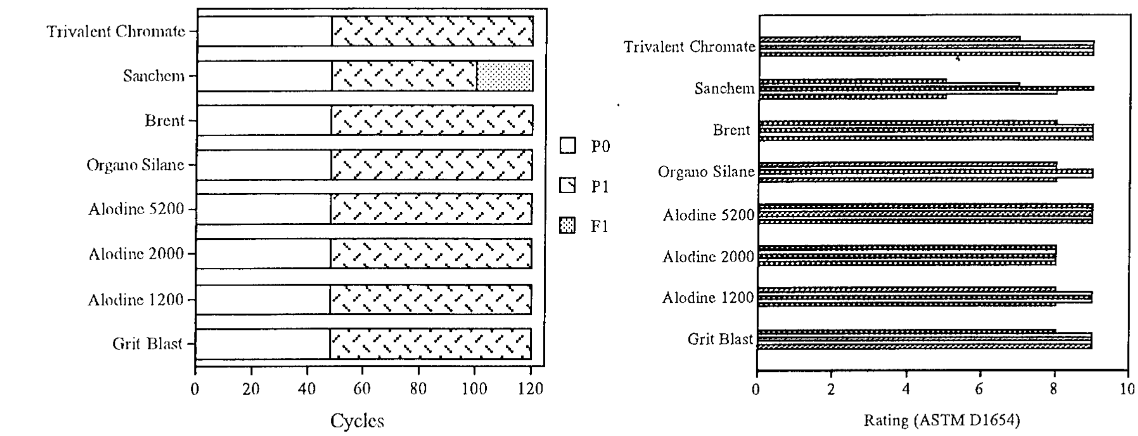
Alodine 1200 on 7039 Filiform at 2,000 hr

Grit Blast on 5083 Blisters at 2,000 hr

Sanchem on 5083 Blisters at 2,000 hr

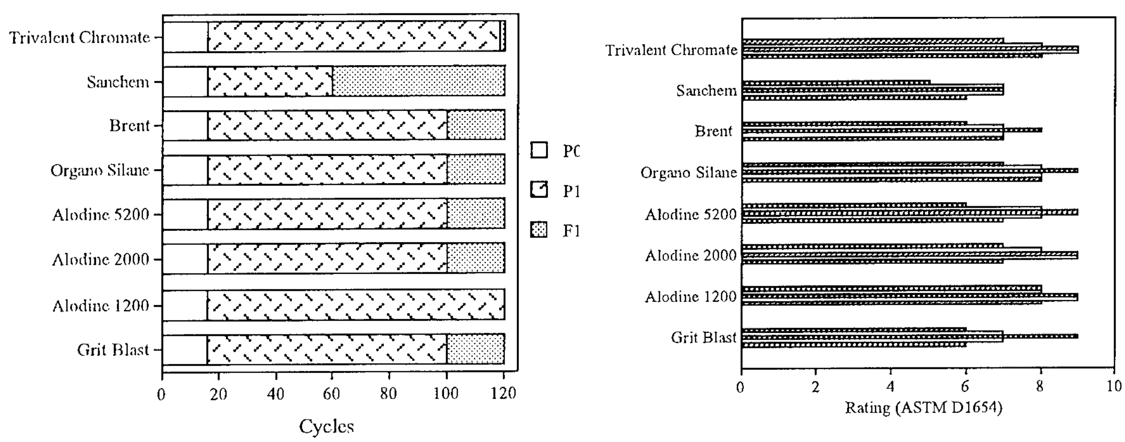
Figure 10. ASTM B117 [6] corrosion damage of scribed CARC-painted panels.

- Grit Blast for 5083,
- Alodine 1200 for 5083,
- Alodine 2000 for 5083,
- Alodine 5200 for 5083/7039/6061,



(a) Incremental (b) Final

Figure 11. GM 9540P [10] performance on scribed CARC 5083 panels.



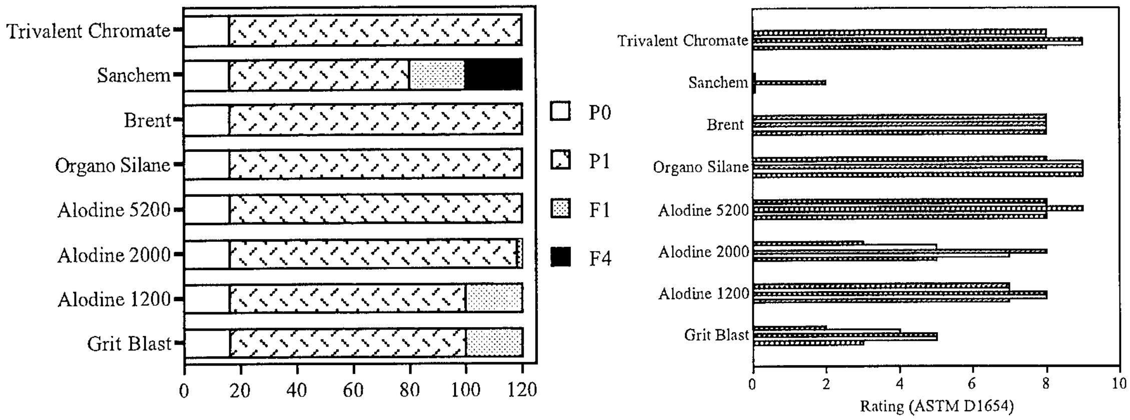
(a) Incremental (b) Final

Figure 12. GM 9540P [10] performance on scribed CARC 7039 panels.

- Organo Silane for 5083/7039/6061,
- Brent for 5083/7039/6061, and
- Trivalent Chromate for 5083/7039/6061.

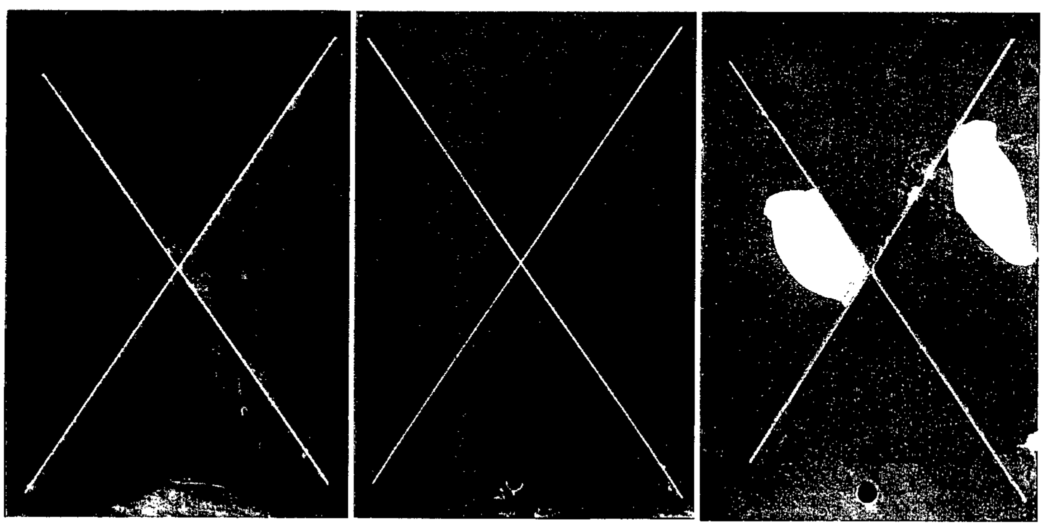
The severe "F4" rating for Sanchem on 7039, despite the relatively low scribe creepback, resulted from separate blisters not associated with the scribe. The final corrosion damage assessments per ASTM D1654A [9] at 120 cycles, including the data range for each of the five panels, is given in Figures 11(b), 12(b), and 13(b).

Figure 14 consists of photographs depicting corrosion damage on some of the panels at 120 cycles.



(a) Incremental (b) Final

Figure 13. GM 9540P [10] performance on scribed CARC 6061 panels.

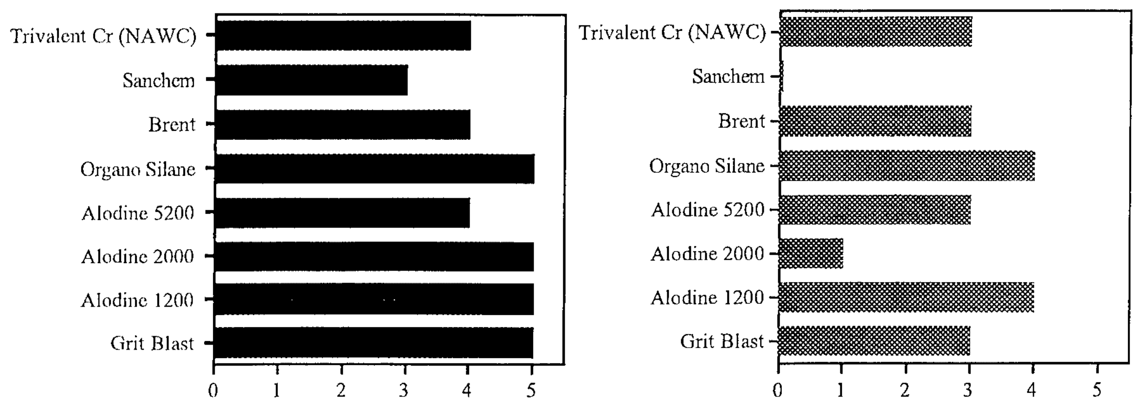


Organo Silane on 7039	Grit Blast on 5083	Sanchem on 6061
Blisters at 120 cycles	No Damage at 120 cycles	Failure at 120 cycles

Figure 14. GM 9540P [10] corrosion damage of scribed CARC-painted panels.

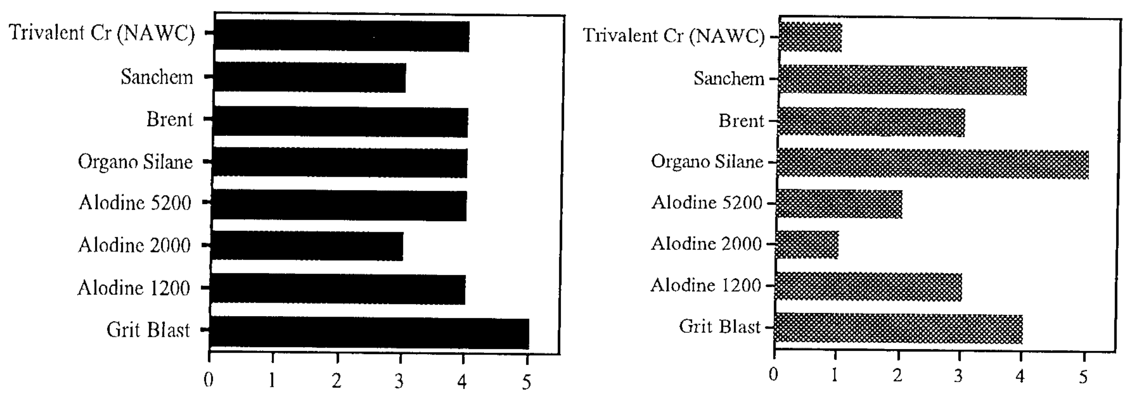
3.3 Wet Adhesion

The data from the wet adhesion test, in accordance with ASTM D3359A [13], is illustrated in Figures 15(a), 16(a), and 17(a). However, Federal Test Method Standard 141-Method 6301 [12] used by the military, calls for no intercoat separation whatsoever at the scribe in either wet or dry testing, which corresponds to a "5" rating on the ASTM scale (Table 5). Most of the



(a) Wet Rating (ASTM D3359A [13]) (b) Dry Rating (ASTM D3359B [13])

Figure 15. Adhesion results for 5083 CARC panels.



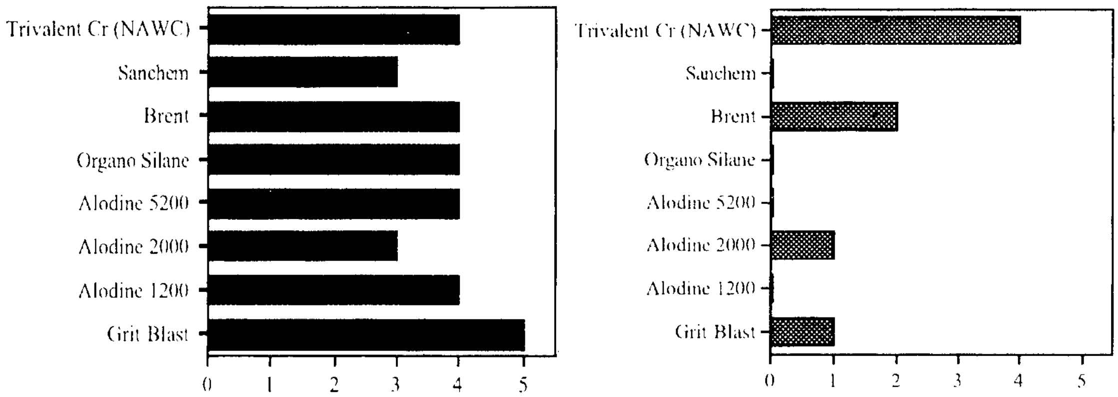
(a) Wet Rating (ASTM D3359A [13]) (b) Dry Rating (ASTM D3359B [13])

Figure 16. Adhesion results for 7039 CARC panels.

pretreatments showed good-to- excellent adhesion but did not pass the stricter Federal standard, especially on the 7039 and 6061 alloys.

The worst performing panels performed no worse than a "3" rating, which is fair but not poor. Panels which received a "3" included:

- Sanchem for 5083/7039/6061, and
- Alodine 2000 for 7039/6061.



(a) Wet Rating (ASTM D3359A [13]) (b) Dry Rating (ASTM D3359B [13])

Figure 17. Adhesion results for 6061 CARC panels.

Panels which did well with a "4" rating but failed the Federal specification included:

- Alodine 1200 for 7039/6061, Alodine 5200 for 5083/7039/6061,
- Organo Silane for 7039/6061,
- Brent for 5083/7039/6061, and
- Trivalent Chromate for 5083/7039/6061.

Panels that received the highest rating and passed the Federal standard were:

- Grit Blast for 5083/7039/6061,
- Alodine 1200 for 5083,
- Alodine 2000 for 5083, and
- Organo Silane for 5083.

3.4 Dry Adhesion

The dry adhesion performance data, in accordance with ASTM D-3359B [13], for the panels is plotted in Figure 15(b), 16(b), and 17(b). The dry adhesion test, by nature, is more severe than wet adhesion due to the mechanical nature of the scribes and their close proximity to one another. Due to this severity, a perfect score of "5" is much more difficult to attain. Only five pretreatments/alloy combinations had a "4" rating. These coatings were:

- Grit Blast for 7039,
- Alodine 1200 for 5083,
- Organo Silane for 5083,

- Sanchem for 7039, and
- Trivalent Chromate for 6061.

Panels with a marginal "3" rating included:

- Grit Blast for 5083,
- Alodine 1200 for 7039,
- Alodine 5200 for 5083,
- Brent for 5083/7039, and
- Trivalent Chromate for 5083.

Panels with a "2" rating were:

- Alodine 5200 for 7039, and
- Brent for 6061.

Panels with a "1" included:

- Grit Blast on 6061,
- Alodine 2000 for 5083/7039/6061, and
- Trivalent Chromate for 7039.

Panels which failed completely with a "0" included:

- Alodine 1200 for 6061,
- Alodine 5200 for 6061,
- Organo Silane for 6061, and
- Sanchem for 5083/6061.

The only pretreatment/alloy combination which achieved a perfect rating of "5" was Organo Silane on 7039.

4. Discussion

Aluminum alloys 5083, 7039, and 6061, which are the focus of this report, can be characterized as less active and susceptible to attack via pitting than 2000 series aluminum alloys with copper such as Al 2024 and Al 2519. A previous ARL study [2] defined desirable properties of a pretreatment with the following: (1) the presence of a uniformly distributed stabilized oxide layer at the metal surface, (2) an effective surface for adhesion of primer coats, (3) a contribution to the protective barrier of the entire coating system, and (4) inhibition of corrosion processes at coating holidays. The tests performed in this study are directed toward measuring these properties using several testing methodologies.

ASTM B117 [6] salt fog testing examines the degree of uniformity and porosity of the oxide layer, and also gives general information about the barrier properties of the conversion coating. The results in Figures 3–5 indicate that due to the inherent corrosion resistance of the alloys examined, there were few problems with any of the pretreatments.

Of the pretreatment/alloy combinations, only the Grit-Blasted panels showed degraded performance for all three alloys. This was most likely due to the activated surface and the surface profile introduced when the established mill finish was abrasively removed. A few of the pretreatments/alloy combinations exhibited corrosion, staining, or blemishes; however, only the Brent coating exhibited this behavior for more than one alloy. The inconsistency of fault distribution with any one pretreatment among the alloys generally indicates an application deficiency and not necessarily a problem with the pretreatment. The deficiency of a pretreatment application itself could be due to a number of factors such as cleaning, rinses, drying cycles, or uniformity of pretreatment application, as well as duration of any of the steps. The inherent corrosion resistance of the three alloys studied made ranking of the pretreatments more difficult than for more active alloys such as 2024 and 2519, especially when painted. As a result, the damage observed at the scribe was less severe and the range of damage from best to worst was compressed. In the case of conversion coatings evaluated for Aluminum 2519, there were perhaps one or two good performers for salt fog, whereas for Al 5083, 7039, and 6061 there were four or five for each. Of the nonchromate pretreatments, the Sanchem process consistently performed poorly for all three alloys. A subsequent discussion with the Sanchem vendor indicated a formulation error in which an unnecessary plasticizer was included that degraded corrosion performance. With the less active alloys, the ability for the conversion coating to heal itself was less of a factor than for 2XXX series conversion coatings.

For greater correlation with actual outdoor field environments encountered in service life, the GM 9540P [10] cyclic corrosion test was used. As in the 2,000-hr salt fog test on the coated specimens the damage observed was far less than for the 2XXX series. The corrosion damage to the panels at the conclusion of 120 cycles was also less severe than noted for the 2,000-hr ASTM B117 [6] salt fog. Once again, there were several good performers for each pretreatment/alloy combination. As in ASTM B117, the most damage was observed for Sanchem, especially on 7039 and 6061. Similarly, the good corrosion resistance of Aluminum alloys 5083, 7039, and 6061 meant low damage, even after 120 cycles of GM 9540P exposure. The relative inactivity with respect to corrosion of the alloys examined made determination of why the cyclic corrosion test, overall, was less severe than the standard salt fog difficult. Previous reports [2, 3] cited the time at saturated humidity in ASTM B117 vs. GM 9540P (which includes drying and ambient cycles) as the probable cause for the disparity of damage. The mechanisms for this study are likely similar.

As previously mentioned, one of the key requirements for conversion coatings is an effective surface for adhesion of primer coats. When an aluminum alloy with good corrosion properties is chosen for a task, adhesion characteristics become the most important factor for choosing the right conversion coating. In the case of the armor alloys 5083 and 7039 which both had an exposed and established mill finish, Organo Silane consistently performed best in wet and dry adhesion. Only Alodine 2000 and Sanchem showed significant performance reduction with respect to the others. The remaining pretreatments, including Grit Blast, were comparable averaging "3" ratings for dry adhesion, and "4" ratings for wet adhesion. Interestingly, the Grit Blast performed as well as or better than most of the pretreatments indicating feasibility of substitution of conversion coating with Grit Blasting on corrosion resistant aluminum alloys. For 6061, dry adhesion results were fair to poor for all pretreatments except Trivalent Chromate which receive a "4" rating. The surface profile of the Q-Panel-supplied 6061 laboratory panels differed markedly from the armor alloys but was not likely a factor since the Grit-Blasted 6061 panels also performed much lower than their armor counterparts with only a "1" rating.

For this study, all three alloys examined were characterized by good corrosion resistance relative to 2XXX series alloys. As a result, coating adhesion became the dominant factor when considering conversion coating performance. However, the ability of chromate to inhibit corrosion at coating defects should not be overlooked. Most of the developers of new nonchromate-based conversion coatings strive to achieve the 336-hr salt fog resistance required by the qualification standard of MIL-C-81706 [7] and will often quote exposure times much greater. This "level" of performance can be easily met when using aluminum alloys such as 5083 with excellent corrosion resistance even when bare or by using an effective defect free "barrier" conversion coating that performs miserably at coating defects. As stated previously [2, 3], poor results of some pretreatments in the tests with scribed CARC systems indicate a factor that is often neglected: MIL-C-81706 [7] is a standard for chromate conversion coatings, and should not be considered a performance specification to qualify any nonchromate alternative. The corrosion resistance of the alloys examined in this study and the lack of corrosion damage indicated other factors such as adhesion of coatings were more essential. The Army (and the rest of the Department of Defense [DOD]) is replacing military specifications with performance specifications and it is crucial to assess those factors that are critical to the performance of the entire coating system. Utilizing the combination of cyclic corrosion tests, adhesion tests, and outdoor exposure remains the best method for assessing overall coating system performance. The tabulated results for the test panels using all of these methods are given in Table 7.

Table 7. Summary of test results.

Treatment	ASTM B117 [6] (average)	GM 9540P [10] (average)	Wet Adhesion	Dry Adhesion
Overall Rating Score Chart—5083				
Grit Blast	2	8.8	5	3
Alodine 1200	9	8.6	5	4
Alodine 2000	8	8	5	1
Alodine 5200	6.67	9	4	3
Organo Silane	3.67	8.4	5	4
Brent	5.67	8.8	4	3
Sanchem	2	6.8	3	0
Trivalent Cr (NAWC)	4	8.6	4	3
Overall Rating Score Chart—7039				
Grit Blast	1	7	5	4
Alodine 1200	0.33	8.4	4	3
Alodine 2000	8	8	3	1
Alodine 5200	7	7.6	4	2
Organo Silane	7	8	4	5
Brent	7.33	7	4	3
Sanchem	2	6.4	3	4
Trivalent Cr (NAWC)	2	8.2	4	1
Overall Score Chart—6061				
Grit Blast	4	3.8	5	1
Alodine 1200	8	7.4	4	0
Alodine 2000	3.66	5	3	1
Alodine 5200	5.33	8.2	4	0
Organo Silane	3.33	8.8	4	0
Brent	5	8	4	2
Sanchem	0	0.67	3	0
Trivalent Cr (NAWC)	5.67	8.4	4	4

6. Conclusions

- Grit-Blasted aluminum armor alloys 5083 and 7039 performed comparably to chromate-based Alodine 1200 under painted conditions, GM 9540P [10] cyclic corrosion, and adhesion tests.
- Organo Silane met or exceeded adhesion performance for Alodine 1200 on Aluminum 5083 and 7039 armor.
- Pass/fail criteria in current military specifications for chromate conversion coatings should not be directly applied to nonchromate coatings. The

disparities between ASTM B117 [6] salt fog and GM 9540P [10] cyclic salt spray results for many of the pretreatments confirm this.

- ASTM B117 [6] remains a beneficial standard for screening and is useful for analysis of coating systems when combined with a wider array of test methods including cyclic corrosion and adhesion, especially on alloys with good corrosion resistance in which differences under salt fog exposure are not readily manifested.

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13. ABSTRACT*(Maximum 200 words)*

This study examines the effectiveness of six nonchromate conversion coatings on aluminum alloys 5083, 7039, and 6061. Evaluation methods included ASTM B117 (American Society for Testing and Materials. "Standard Method of Salt Spray [Fog] Testing." ASTM B117-90, 1990) salt fog, General Motors 9540P (General Motors. General Motors Engineering Standard, Accelerated Corrosion Test. GM 9540P, July 1991) cyclic salt spray, wet adhesion, and dry adhesion on painted test panels. Conversion-coated panels without paint were also screened to assess quality and pretreatment characteristics. Differences in behavior were noted between the salt fog data and the cyclic salt spray data obtained on scribed panels. How these data may relate with implementation of nonchromate pretreatments for military vehicles is discussed.

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