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CORROSION EVALUATION OF AIRCRAFT DEPAINTING CHEMICALS

Preston McGill
Pablo Torres
Metallic Materials Division
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Introduction

The National Aeronautics and Space Administration is participating in an interagency task agreement with the Environmental Protection Agency and the United States Air Force to evaluate alternative technologies for aerospace depainting operations that do not adversely affect the environment (Reference 2). An element of this study is directed towards the evaluation of environmentally advantaged chemical paint strippers, specifically, paint strippers that do not contain methylene chloride. Eight environmentally advantaged, or alternative, chemical paint strippers and two methylene chloride, or baseline, paint strippers were obtained from various manufacturers and incorporated into the depainting study. In addition to being evaluated on their ability to remove paint, the potential of these chemicals to promote corrosion and hydrogen embrittlement was evaluated. The corrosion and hydrogen embrittlement potential of the chemical paint strippers are presented in this report.

The tests conducted in this study are a subset of the prescribed corrosion evaluation tests listed in the SAE Aerospace Standard, MA4872, "Paint Stripping of Commercial Aircraft – Evaluation of Materials and Processes." This document was generated to outline technical requirements for the evaluation of materials and processes for stripping organic finishes from commercial aircraft (Reference 4). Specifically, three standard test procedures were implemented to determine the corrosion potential of these chemicals on clad and non-clad 2024-T3 aluminum substrates and the hydrogen embrittlement potential of these chemicals on AISI 4340 high strength steel. These procedures are summarized below.

- ASTM F483-90, "Standard Test Method for Total Immersion Corrosion Test for Aircraft Maintenance Chemicals," was conducted to determine the corrosiveness of these chemicals on aircraft metals (Reference 1). The test requires that a substrate material totally immersed in a test chemical for a specified amount of time be examined for weight change and surface damage.
- ASTM F1110-90, "Standard Test Method for Sandwich Corrosion Test," was conducted to determine the corrosiveness of these chemicals on aluminum alloys commonly used in aircraft structures (Reference 1). The test requires that filter paper saturated with the test chemical be place between substrate material for a specified amount of time. The extent of corrosion of the substrate is rated according to scales provided in the specification.
- ASTM F519-93, "Standard Test Method for Mechanical Hydrogen Embrittlement Testing of Plating Processes and Aircraft Maintenance Chemicals," was conducted to evaluate any hydrogen embrittlement potential that may arise from the introduction of hydrogen from the chemical paint stripper into the substrate (Reference 1). This test requires that preloaded high strength tensile specimens be immersed in the chemical and monitored for failures over a period of 150 hours. The hydrogen embrittlement potential is based on the number of failed specimens that occur during the exposure time.

The chemicals evaluated in this study and their classification based on the manufacturers reported pH levels include, Gage Stingray 874B (neutral), Turco 6813 (alkaline), Turco 6813-E (alkaline), Turco 6840-S (alkaline), McGean-Rohco Cee-Bee E-1004B (acidic), Calgon EZE 540 (acidic), Eldorado PR-2002 (acidic), and Turco 6776 (acidic). Two methylene chloride chemicals, McGean-Rohco Cee-Bee R-256 (alkaline) and McGean-Rohco Cee-Bee A-202 (acidic) were also included in the study. Manufacturers provided the chemicals reported in this study for evaluation. Mention of trade names or specific commercial products does not constitute endorsement or recommendation for or against their use. The clad aluminum tested in this study was purchased per AMS 4041 and QQ-A-250/5 specifications. The non-clad aluminum tested in this study was purchased per AMS 4037 and QQ-A-250/4 specifications. All aluminum substrate tested was 1.6mm (0.064 in) thick.

Corrosion Testing

Many aircraft maintenance chemicals are used on components and structures that would be adversely affected by corrosion (Reference 1). Loss of material due to corrosion in a component can contribute to fatigue problems as well as reduce strength capability. Total immersion corrosion and sandwich corrosion are two test methods used in the qualification and approval of compounds employed in aircraft maintenance operations to evaluate the corrosion potential of aircraft maintenance chemicals.

Total Immersion Corrosion Testing

The total immersion test method is used to evaluate the corrosiveness of aircraft maintenance chemicals on aircraft metals. The test is conducted by immersing the substrate in the chemical for a prescribed time. Corrosiveness of the chemical is determined quantitatively by weight change and a visual qualitative assessment. Total immersion test coupons were fabricated from 1.6 mm (0.064 in) thick clad and non-clad 2024-T3 aluminum alloy. The non-clad material was anodized per MIL-A-8625C, Type 1 for chromic acid. All chemicals were tested in the as received condition. The total immersion corrosion tests were conducted per ASTM F483-90. Per specification, the samples were weighed prior to testing, after 24 hours, and again after seven days of exposure.

Average weight loss rates for each of the chemicals is provided in Table 1. These measurements represent average weight loss divided by total coupon area (28.2 cm^2) expressed as loss in milligrams per square centimeter per 24 hours. Acceptable weight loss rates as provided in the SAE MA4872 specification are 0.2 $mg/cm^2/24hr$ for non-clad 2024-T3 and 0.3 $mg/cm^2/24hr$ for clad 2024-T3. An assessment of these data suggests that almost no weight loss was exhibited over the test period by coupons treated with alkaline/neutral strippers. Alkaline/neutral chemicals that did exhibit weight loss were well within acceptable rates. Negative numbers indicate weight gains most likely due to the presence of remnant surface deposits since these test coupons were not electrolytically cleaned. Significantly higher weight loss rates were seen for coupons treated with acidic strippers. Three of the five acidic strippers, including the methylene chloride baseline, exhibited weight loss rates for non-clad material exceeding the acceptable rate. For the clad material one of the five chemicals, an alternative paint stripper, exhibited a weight loss rate exceeding the specification limits.

Summaries of the visual observations after 168 hours of exposure are shown in Tables 2 and 3 for non-clad and clad substrate respectively. Visual requirements set forth in the SAE MA4872 specification requires that no evidence of corrosion be present on the samples. The alkaline/neutral strippers produced no visible etching, pitting or accretions (corrosion product) on any samples. The acidic strippers demonstrated signs of etching on all samples, clad and non-clad. All but one chemical, an alternative stripper, promoted pitting and localized attack of non-clad substrate. With respect to the clad substrate, two chemicals, both alternative strippers, showed no signs of pitting or localized attack. No accretions were noted on any samples.

Sandwich Corrosion Testing

Sandwich corrosion testing was performed to evaluate the corrosion potential of chemicals entrapped in faying surfaces. Sandwich corrosion test coupons were fabricated from 1.6 mm (0.064 in) clad and non-clad 2024-T3 aluminum alloy. The non-clad material was anodized per MIL-A-8625C, Type 1 for chromic acid. Testing was performed per ASTM Specification F1110-90. Four test coupon sandwiches were tested per chemical per alloy each comprised of two individual test coupons sandwiched together in pairs of the same alloy and surface treatment. Both clad and non-clad sandwiched pairs were used to test all chemicals and all chemicals were mixed thoroughly to ensure uniformity before being applied to the test coupons. Four coupon sandwiches were tested with reagent deionized water as controls for comparative purposes. In each case, a piece of glass fiber filter paper was fit over one coupon of the sandwiched pair. The filter paper was then saturated with the as-received test solution and the wet paper was covered with the second coupon of the sandwiched pair. The specimens were exposed to alternate warm air and warm humid air for seven days. Each set was exposed individually (not stacked) in a horizontal position. After exposure, the panels were cleaned and examined under 10x magnification. They were then assigned a qualitative rating per ASTM F1110-90 as shown in Table 4. Corrosion ratings were then compared between

Table 1 - Average Corrosion Rates for Clad and Non-Clad 2024-T3 Test Coupons During Total Immersion Corrosion Testing				
Chemical Tested	Corrosion Rate ($mg/cm^2/24hr$)			
	Non-Clad 2024-T3		Clad 2024-T3	
	Exposed for 24 Hrs	Exposed for 168 Hrs	Exposed for 24 Hrs	Exposed for 168 Hrs
Turco 6813 (Alkaline)	0.0035	-0.0005	0.0000	-0.0025
Turco 6813-E (Alkaline)	0.0071	-0.0015	0.0000	-0.0020
Turco 6840-S (Alkaline)	0.0000	-0.0010	-0.0071	-0.0020
Stingray 874B (Neutral)	0.0000	-0.0005	0.0000	-0.0010
Cee-Bee R-256 (Alkaline baseline)	0.0000	0.0015	0.0000	-0.0015
Turco 6776 (Acidic)	0.3121	0.4189	0.2092	0.3440
EZE 540 (Acidic)	0.2943	0.2771	0.2624	0.2036
PR-2002 (Acidic)	0.0319	0.0709	0.0000	0.1054
Cee-Bee E-1004B (Acidic)	0.1986	0.1717	0.1773	0.1327
Cee-Bee A-202 (Acidic baseline)	0.2979	0.2594	0.1950	0.1753

coupons tested with chemicals and coupons tested with reagent water. These comparisons only considered the surfaces under the filter paper and any corrosion at the edges was disregarded. Per ASTM specifications, any corrosion in excess of that shown by the deionized water is considered cause for rejection.

Test results (ratings) from the sandwich corrosion testing are presented in Table 5. The coupons tested with reagent water showed significant discoloration and spotting over the surface. Pitting on coupons in reagent water was also evident. As a result the coupons tested in reagent water were given a corrosion rating of 3. All alkaline/neutral chemicals performed better than the reagent water. On the non-clad material three of the four alternate alkaline/neutral chemicals performed better than the methylene chloride baseline. On clad material, the methylene chloride baseline performed better than the alternate alkaline/neutral chemicals. With respect to the acidic chemicals, on the non-clad material the chemicals caused more corrosion that the reagent water. However, the alternate chemicals performed better than the methylene chloride baseline on the non-clad material. On clad material, four of the five acidic chemicals, including the methylene chloride baseline, performed as well or better than the reagent water. However, only one of the four alternate chemicals performed better than the methylene chloride baseline.

Mechanical Hydrogen Embrittlement Testing

Hydrogen embrittlement testing was performed to evaluate the potential of the paint stripping chemicals to embrittle cadmium plated high-strength AISI 4340 steel. Testing was conducted per ASTM F519-93. Test specimens were Type 1A notched round tensile specimens fabricated from AISI 4340 steel that was heat treated per

MIL-H-6875 to obtain a hardness of 51 to 54 HR_C with an ultimate tensile strength of 1800 to 1930 MPa (260 to 280 ksi). The sensitivity of the 4340 steel to embrittlement was determined using the methodology presented in ASTM F519-93. After machining, the notched round tensile specimens were degreased, dry abrasive blasted with alumina, rinsed with tap water and immediately electroplated using a low-embrittlement cadmium cyanide bath. After electroplating the specimens were baked at 191 ± 14 °C (375 ± 25 °F) for 23 hours.

Table 2 - Visible Changes in Non-Clad 2024-T3 Test Coupons After Total Immersion Corrosion Testing (168-Hour Exposure)

Chemical Tested	Coupon Number	Discoloration or Dulling	Etching	Accretions Presence and Relative Amounts	Pitting	Selective or Localized Attack
Turco 6813 (Alkaline)	1	yes	no	no	no	no
	2					
	3					
Turco 6813-E (Alkaline)	4	yes	no	no	no	no
	5					
	6					
Turco 6840-S (Alkaline)	7	no	no	no	no	no
	8	small spots				
	9	no				
Stingray 874B (Neutral)	10	very little	no	no	no	no
	11	a little				
	12	no				
Cee-Bee R-256 (Alkaline baseline)	13	very little	no	no	no	no
	14	very little				
	15	no				
Turco 6776 (Acidic)	16	yes (coupons whitened)	yes	no	no	no
	17					
	18					
EZE 540 (Acidic)	19	yes	yes	no	some	yes
	20					
	21					
PR-2002 (Acidic)	22	yes (many spots)	yes	no	yes	yes
	23					
	24					
Cee-Bee E-1004B (Acidic)	25	yes	yes	no	some	yes
	26					
	27					
Cee-Bee A-202 (Acidic baseline)	28	yes	yes	no	yes	yes
	29					
	30					

Each chemical was tested in the as-received condition at 20 to 30 °C (68 to 86 °F). The containment chamber was isolated around the test specimens and the specimens were completely submerged in the chemical. Three specimens per chemical were assembled and loaded in tension to 45% of the notched ultimate tensile strength. Constant strain test fixtures (as opposed to constant load test fixtures) were used to conduct the tests. To ensure that no load relaxation occurred during the test, the recovered strain upon unloading the non-failed specimens was measured and compared to the initial strain required to load the specimen to confirm that the initial load was maintained. The loaded specimens were immersed in the chemicals and the time to failure recorded. The test was discontinued after 150 hours. Per ASTM F519-93 specifications, a chemical is considered non-embrittling under the conditions tested if no specimens fail within 150 hours after immersion in the chemical at 45% of the notch tensile load. A chemical is considered embrittling under the conditions tested if two or more break in less than150 hours.

Table 3- Visible Changes in Clad 2024-T3 Test Coupons After Total Immersion Corrosion Testing (168-Hour Exposure)

Chemical Tested	Coupon Number	Discoloration or Dulling	Etching	Accretions Presence and Relative Amounts	Pitting	Selective or Localized Attack
Turco 6813 (Alkaline)	49	some	no	no	no	no
	50	very little				
	51	some				
Turco 6813-E (Alkaline)	52	some	no	no	no	no
	53					
	54					
Turco 6840-S (Alkaline)	55	very little	no	no	no	no
	56					
	57					
Stingray 874B (Neutral)	58	no	no	no	no	no
	59					
	60					
Cee-Bee R-256 (Alkaline baseline)	61	some	no	no	no	no
	62	very little				
	63	very little				
Turco 6776 (Acidic)	64	yes (coupons whitened)	yes	no	no	no
	65					
	66					
EZE 540 (Acidic)	67	yes	yes	no	no	no
	68					
	69					
PR-2002 (Acidic)	70	yes	yes	no	yes	yes
	71	some			no	no
	72	yes			yes	yes
Cee-Bee E-1004B (Acidic)	73	yes	yes	no	almost none	no
	74					
	75					
Cee-Bee A-202 (Acidic baseline)	76	yes	yes	no	yes	yes
	77					
	78					

Table 4 - Rating Scale for Sandwich Corrosion Testing	
Rating	**Condition**
0	No visible corrosion
1	Very slight corrosion or discoloration (up to 5% of the surface area corroded)
2	Slight corrosion (5 to 10% of the surface area corroded)
3	Moderate corrosion (10 to 25% of the surface area corroded)
4	Extensive corrosion or pitting (25% or more of the surface area corroded)

Results of the hydrogen embrittlement testing are presented in Table 6. Numbers listed in parentheses represent the time interval in which the specimen failed. The failure ratio is the number of specimens that failed over the number of specimens tested under the same conditions. The acidic chemicals, including the methylene chloride baseline, failed this test. All specimens failed within 48 hours of exposure. However, all of the specimens exhibited average failure times exceeding the methylene chloride baseline. Scanning electron microscopy of failure surfaces revealed a large region of intergranular fracture. Metallographic cross sectioning of these samples revealed secondary cracking below the failure surface indicative of grain boundary attack. Two out of three specimens tested in the neutral chemical (Group 1) failed between 98 and 145 hours. Microscopy and metallography of these specimens also revealed a region of the failure surface exhibiting an intergranular fracture with secondary cracking. The remaining specimen that passed the test was loaded to failure and exhibited a ductile failure surface. Since other laboratory data indicated acceptable performance of a neutral chemical three additional samples were tested and are listed in Table 5 as Group 2 specimens (Reference 3). All of these specimens met the 150 hour exposure requirement. The exposure time was extended beyond 150 hours and one specimen failed after 191 hours. The reason for the Group 1 and Group 2 failures for the neutral chemical may be related to the pH of the chemical. The pH of the neutral chemical was measured as 5.7. This is in contrast to the manufacturers reported pH of 6.5. The lower pH of the chemical as tested may be responsible for the failures in the neutral Group 1 and Group 2 specimens. All specimens tested in the alkaline chemicals passed the test with no failures noted. Test specimens loaded to failure post test exhibited ductile failure surfaces.

Conclusions

Total immersion corrosion, sandwich corrosion, and hydrogen embrittlement testing on ten chemical paint strippers has been performed. Testing was conducted on two methylene chloride baseline chemicals, one alkaline and one acidic. Testing was also conducted on eight non-methylene chloride alternate chemicals, three alkaline, one neutral, and four acidic. The test data indicates that alternate alkaline and neutral chemical paint strippers perform as well or better than a methylene chloride baseline with respect to corrosion requirements. These alternate alkaline/neutral chemical paint strippers also, in general, meet corrosion acceptance criteria as specified in SAE MA 4872. All alkaline chemical paint strippers and one group of the neutral chemical paint stripper met specification requirements for hydrogen embrittlement. Alternate acidic chemical paint strippers have been identified that, with respect to corrosion and hydrogen embrittlement requirements, perform as well or better than a methylene chloride baseline. However, these chemicals do not generally meet corrosion acceptance criteria for non-clad material or hydrogen embrittlement acceptance criteria as specified in SAE MA 4872.

Table 5 - Sandwich Corrosion Test Results				
Chemical Tested	**Non-clad 2024-T3**		**Clad 2024-T3**	
	Sandwich Number	**Rating**	**Sandwich Number**	**Rating**
Deionized Water (per ASTM D1193, Type IV)	1	3	121	3
	3	3	123	3
	5	3	125	3
	7	3	127	3
Turco 6813 (Alkaline)	9	1	129	3
	11	2	131	3
	13	2	133	3
	15	3	135	3
Turco 6813-E (Alkaline)	17	2	137	2
	19	2	139	3
	21	2	141	2
	23	2	143	3
Turco 6840-S (Alkaline)	25	3	145	2
	27	3	147	3
	29	2	149	2
	31	2	151	3
Stingray 874B (Neutral)	33	3	153	3
	35	3	155	3
	37	3	157	3
	39	3	159	3
Cee-Bee R-256 (Alkaline baseline)	41	2	161	1
	43	3	163	2
	45	2	165	2
	47	3	167	1
Turco 6776 (Acidic)	49	4	169	3
	51	4	171	3
	53	4	173	3
	55	4	175	3
EZE 540 (Acidic)	57	4	177	3
	59	4	179	4
	61	4	181	3
	63	4	183	3
PR-2002 (Acidic)	65	4	185	3
	67	4	187	3
	69	4	189	3
	71	4	191	3
Cee-Bee E-1004B (Acidic)	73	4	193	3
	75	4	195	2
	77	4	197	3
	79	4	199	2
Cee-Bee A-202 (Acidic baseline)	81	4	201	3
	83	4	203	2
	85	4	205	2
	87	4	207	3

Table 6 - Results of the Hydrogen Embrittlement Test		
Chemical Tested	**Failure Ratio**	**Time to Failure, Hours**
Turco 6813 (Alkaline)	0/3	No Failures
Turco 6813-E (Alkaline)	0/3	No Failures
Turco 6840-S (Alkaline)	0/3	No Failures
Stingray 874B – Group 1 (Neutral)	2/3	(98-145), (128-143)
Stingray 874B – Group 2 (Neutral)	1/3	(191-198)
Cee-Bee R-256 (Alkaline baseline)	0/3	No Failures
Turco 6776 (Acidic)	3/3	4.5, 6, (28-48)
EZE 540 (Acidic)	3/3	0.5, (8-24), (8-24)
PR-2002 (Acidic)	3/3	0.5, (7-23), (31-47)
Cee-Bee E-1004B (Acidic)	3/3	1.75, 1.75, 1.75
Cee-Bee A-202 (Acidic baseline)	3/3	0.5, 0.5, 0.5

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