PERFORMANCE EVALUATION OF CORROSION CONTROL PRODUCTS

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Abstract

A major goal of the National Aging Aircraft Research Program (NAARP) is to provide the FAA and the aviation industry with analytical tools, predictive capabilities, sound practices and new methodologies to ensure structural integrity in aging aircraft, including corrosion control and prevention. In this paper we report on the results of a two phase study designed first, to determine what corrosion prevention and control products (CPCP's) are being used by commuter and general aviation operators, and second, to obtain a quantitative measure of their effectiveness.

Surveys to collect corrosion prevention and control information were mailed to the membership of the National Air Transportation Association (NATA), and the results of the survey were used to determine what CPCP's were to be tested. Three classifications of product type were identified: water displacing hard films, water displacing soft films and non water displacing soft films. Using aircraft grade 2024 T-3 and 7075 T-6 aluminum, the ten most reportedly used CPCP's were tested in accordance to ASTM Standard B-117. Each product was tested three separate times, using two samples of each aluminum alloy for each test. After exposure, the corrosion rate for each sample was determined and reported in terms of mils per year.

For the products tested, corrosion rates ranged from the order of 0.01 to 5.0 mils per year (mpy). No direct correlation was found between product classification type and corrosion rate, however, the measured rates of corrosion does correlate with CPC viscosity. Products with a comparatively high viscosity exhibited the best protection, but were more difficult to apply. The lower viscosity CPCP's were easier to apply, but more readily removed during salt fog exposure.

Introduction

One of the goals of the NAARP is to provide aircraft operators with a broad-based corrosion prevention and control program that will provide guidelines where none exist for the inspection, prevention and control of corrosion in aircraft structures. To insure the continued air worthiness and operational safety of aircraft, corrosion control must be a fundamental part of any maintenance program. This is a particularly important issue for aging aircraft. Even when designed for corrosion resistance, proper cleaning, inspection and maintenance procedures are required to keep aircraft in air worthy operating condition. Thus, an aggressive corrosion prevention and control program should be pursued. Proper use of effective corrosion control products is central to all corrosion programs.

Within the last several years the FAA has issued several air worthiness directives (AD's) mandating that an effective corrosion prevention plan be established if none exists. However, these air worthiness directives are limited to eleven models of large transport aircraft. The problem still exists with the commuter industry which does not have sufficient resources to develop an overall corrosion program that is applicable to current manufacturers, or for aircraft for which the manufacturer is no longer in business.

Historically, the military has significant experience in the use of corrosion prevention and control compounds for aviation applications. Specifically, the U.S. Department of Defense is currently the only federal organization with standards mandating the use of specific protective methods and procedures by means of military specifications such as MIL-C-81309, MIL-C-16173 and MIL-C-85054. The CPCP's specified fall into three basic categories which include water displacing soft films, water displacing hard films, and non-water displacing soft films. Although the armed services have had great success in extending product life through the use of specified CPCP's, no comparison has been made regarding the relative performance of one acceptable CPCP versus another or how military standards should be used to impact the private sector.

The objective of this research project is to assess and to compare the corrosion prevention ability of commonly used CPCP's. The resulting information can then be used to help set uniform guidelines for future corrosion prevention procedures as they apply to 2024-T3 and 7075-T6 aluminum alloys – alloys used extensively in the construction of transport and commuter aircraft.

Survey

In order to establish a viable test matrix, a survey form was sent to 1096 members of the National Air Transportation Association (NATA). Listed on the form by category were the names of 97 commercially available CPCP's. The responder was asked to circle the name(s) of all products routinely used in maintenance and to add the name(s) of any product used that was not listed. Of the 1096 forms sent out, a total of 210 useful responses were obtained. Based on the fact that this was a blind survey, and many of the NATA members are not involved in aircraft maintenance, a 19% return is felt to be quite respectable.

The results of the survey were tabulated, and a rank order listing in terms of frequency of use is given in Appendix A. Twenty six of the products were not on the original check sheet that was sent out, but were written in by the respondent. Because of the use of multiple products by the majority of respondents, the total number of products cited is much greater than 210. The most significant finding is that of the 60 CPCP's reportedly used, the top ten account for 80 percent. Based on the results of this survey, it was decided to use the top ten CPCP's cited as the basis for testing and data collection. The products tested include two non-water displacing soft films, six water displacing soft films, and two water displacing hard film CPCP's. Thus, all three classes of CPCP's are represented in the test matrix.

Experimental Procedures

Materials

The materials used in this study consisted of .0625 in. thick 2024-T3 and 7075 T-6 aircraft grade aluminum alloy sheet purchased from Aviation Metals, Charlotte, North Carolina. The 4 ft. x 8 ft. sheets were sheared into 3 in. x 5 in. coupons to facilitate testing.

Specimen Preparation

Samples were prepared in accordance with military specification MIL-C-81039E. Prior to CPCP application the test coupons were hand polished through 600 grit emery paper, cleaned with methyl alcohol and water and blown dry. After preparation, the samples were weighed using a Mettler model AB204 precision balance and the CPCP's were applied according to specification directions. The samples were held at room temperature for 24 hours prior to testing.

Testing

All tests were conducted using a Singleton Model 21 salt fog chamber, a photo of which is shown in Figure 1.

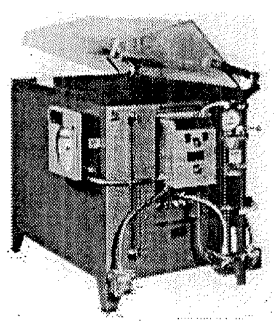

Figure 1. Singleton Model 21 salt fog chamber.

After setting up the chamber in accordance to ASTM Standard B-117 and prior to exposure, the salt fogger was run for 24 hours to ensure that the amount of water vapor in the mist fell within the specified range of 24-48 ml per twenty four hour period. If not, adjustments were made and the procedure repeated. Samples were then placed in the chamber on a rack angled 15° from vertical, and exposed to the salt fog for a minimum of 500 hours. Due to the size limitation of the chamber, each test run was limited to 36 samples. Thus, using two coupons per CPCP plus two control samples per alloy allowed for the testing eight CPCP's per run. In all, sufficient testing was performed to expose six samples per CPCP.

Analysis

After removal from the chamber, the samples were cleaned and evaluated in accordance with ASTM Standard G11. Removing tenacious scales required the use of a pickling solution consisting of 70% nitric acid. Coupons were immersed for thirty seconds; then rinsed, dried and weighed. The acid cleaning and weighing were then repeated. Subsequently, sample weight was plotted as a function of the total time of acid exposure. The sample weight loss was then determined by extrapolation. A straight line was drawn from the position at which the slope of the line changes to the ordinate as shown schematically in Figure 2. The final sample weight was taken as the point of intersection of the extrapolated line and the ordinate. In addition to corrosion rate measurements, pitting of the test coupons was classified in accordance with ASTM Standard G46.

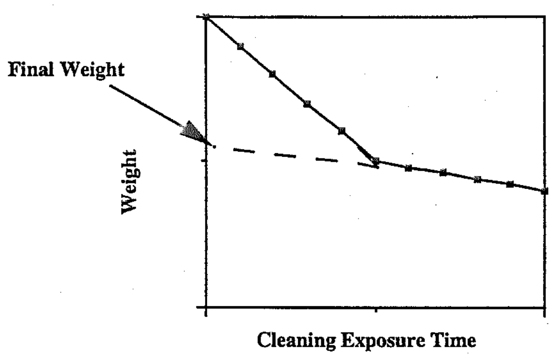

Figure 2. Method of defining final specimen weight.

Weight loss was converted to mils (1 mil = 0.001 in.) per year (mpy) using the equation

$$mpy = \frac{534\ W}{dAt}$$

Where W is weight loss in milligrams, d is density in grams per cubic centimeter, A is area in square inches, and t is time in hours.

Results and Discussion

Of the number of possible standardized testing methods available, ASTM Standard B-117 was chosen for this study because of its historical and widespread use as an accelerated testing technique. Before discussing the results it should be pointed out that numerical values obtained for corrosion rates are not indicative of atmospheric corrosion rates. Rather, the data should be viewed as a comparison of the effectiveness of the CPCP's in preventing corrosion in a salt fog environment. Salt fog exposure is more severe than simple atmospheric exposure.

The measured corrosion rates for the 2024 T-3 and 7075 T-6 alloys are given in Table 1 and Table 2, respectively.

Product Name	Description	Corrosion Rate (mpy)
DINITROL AV-30	(WDSF)	0.06 ± 0.02
LPS HARDCOAT	(WDHF)	0.11 ± 0.05
LPS 3	(NWDSF)	0.68 ± 0.46
DINITROL AV-8	(WDHF)	0.77 ± 0.31
LPS 500+	(NWDSF)	0.94 ± 0.21
AMALGUARD	(WDSF)	1.13 ± 0.42
CRC 3-36	(WDSF)	1.56 ± 0.52
CORROSION X	(WDSF)	2.07 ± 0.45
BOESHIELD T-9	(WDSF)	2.95 ± 0.31
ACF 50	(WDSF)	3.11 ± 0.52
BARE	(--------)	5.79 ± 1.73

Table 1. Measured corrosion rates of 2024 T-3 aluminum.
[WDSF = water displacing soft film, WDHF = water displacing hard film, NWDSF = non water displacing soft film.]

Product Name	Description	Corrosion Rate (mpy)
LPS HARDCOAT	(WDHF)	0.03 ± 0.01
DINITROL AV-30	(WDSF)	0.07 ± 0.02
LPS 3	(NWDSF)	0.15 ± 0.04
DINITROL AV-8	(WDHF)	0.47 ± 0.15
LPS 500+	(NWDSF)	0.48 ± 0.31
AMLGUARD	(WDSF)	0.51 ± 0.22
CRC 336	(WDSF)	3.42 ± 1.35
ACF 50	(WDSF)	3.54 ± 1.12
CORROSION X	(WDSF)	3.87 ± 1.26
BOESHIELD T-9	(WDSF)	5.27 ± 1.84
BARE	(--------)	6.08 ± 2.73

Table 2. Measured corrosion rate for 7075 T-6 aluminum.
[WDSF = water displacing soft film, WDHF = water displacing hard film, NWDSF = non water displacing soft film.]

Comparing the corrosion rates obtained for the 2024 T-3 and the 7075 T-6 aluminum, by ranking, the CPCP's tested were similarly effective on both. Dinitrol AV-30 and LPS hardcoat were the most effective, ranking either first or second. LPS 3, Dinitrol AV-8, LPS 500+, Amalgard, and CRC- 336 follow successively for both alloys. For the 2024 aluminum, the top ten were rounded out by Corrosion X, Boeshield T-9 and ACF 50. The ranking of the last three for the 7075 aluminum was ACF 50, Corrosion X, and Boeshield T-9.

From product to product, the numerical values obtained for corrosion rate vary in a similar manner for the two alloys, ranging form several hundredths of a mpy to slightly over five. By comparison, the bare alloys exhibited a corrosion rate of approximately six mpy. To put these results in perspective, Table 3 provides a ranking of what is considered excellent to unacceptable corrosion resistance in term of corrosion rate.

Table 3. Relative corrosion resistance

Relative Corrosion Resistance	mpy	mm/yr	μm/yr	nm/hr	pm/sec
Outstanding	<1	<0.02	<25	<2	<1
Excellent	1-5	0.02-0.1	25-100	2-10	1-5
Good	5-20	0.1-0.5	100-500	10-50	5-20
Fair	20-50	0.5-1	500-1000	50-150	20-50
Poor	50-200	1-5	1000-5000	150-500	50-200
Unacceptable	200+	5+	5000+	500+	200+

(from: M. G. Fontana, *Corrosion Engineering*, 3rd Edition, McGraw-Hill, 1986, p. 172)

Based on Table 3, all ten products tested provided excellent to outstanding corrosion resistance. The bare aluminum samples exhibited what would be considered good corrosion resistance.

Based on the results of this study there appears to be no correlation between product type and corrosion rate. That is to say, hard films are not necessarily better than soft films, and water displacing films are not necessarily better than non-water displacing films. The most significant correlation is between measured corrosion rate and the viscosity of the CPCP's tested. The higher the viscosity, the lower the measured corrosion rate. Products of low viscosity are more easily removed during salt fog exposure, thereby reducing their effectiveness as a function of exposure time. If the comparatively low viscosity CPCP's such Corrosion X, ACF 50 and Boeshield T-9 were periodically reapplied during exposure, then the observed corrosion rates would most likely decrease.

All samples exhibited some degree of pitting. However, this pitting was found to correlate with the measured weight loss (corrosion rate). Using the classification scheme of ASTM Standard G-46 as the means of evaluating pitting severity, samples with a corrosion rate of less than about 1 mpy exhibited a pitting density of A1 to A2. For those samples whose corrosion rate was greater than approximately 1 mpy, the corresponding pitting density ranged from A3 to A5 as the corrosion rate increased.

Summary

In this study, a national survey of NATA members was taken to determine what CPC's are used in the aviation industry. From the results of this survey the ten most often cited products were tested for effectiveness using aircraft grade 2024 T-3 and 7075 T-6 aluminum alloys in accordance with ASTM Standard B-117.

The results of the survey indicate that of the many products available, the top ten account for 80% of all CPCP's used. Included in the top ten are examples of all three classes of CPCP's: water displacing soft films, water displacing hard films and non-water displacing soft films.

Six samples of each alloy type were tested for each product and the average corrosion rate was reported in terms of mpy. The results indicate that the effectiveness of each product was similar for both alloys. All products were shown to provide outstanding to excellent protection. No correlation was noted between product classification and effectiveness. The viscosity of the CPCP appears to be the major factor determining its effectiveness, which would tend to imply that corrosion protection is primarily a barrier phenomenon.

The results of this study provide CPCP performance data required to develop a viable and effective corrosion prevention and maintenance program for the commuter and general aviation industry.

Acknowledgements

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Appendix A. Corrosion Control Survey Results

Rank order based on 210 responses from a mailing of 1096 members of NATA

KEY: WDHF = water displacing hard film
NWDSF = non water displacing soft film
WDSF = water displacing soft film
? = write-in product

	PRODUCT NAME	DESCRIPTION	RESPONDENTS
1.	LPS 3	(NWDSF)	151
2.	ACF 50	(WDSF)	121
3.	Corrosion X	(WDSF)	44
4.	CRC-3-36	(WDSF)	25
5.	Dinitrol AV8	(WDHF)	22
6.	LPS 500 PLUS	(NWDSF)	12
7.	Dinitrol AV 30	(WDSF)	11
8.	BOSHIELD 9	(WDSF)	9
9.	LPS HARDCOAT	(WDHF)	9
10.	ALMGARD	(WDSF)	8
11.	ROYCO 103	(NWDSF)	7
12.	BRAYCOAT 103	(NWDSF)	6
13.	LPS PROCYON	(WDHF)	5
14.	TECTYL 502C	(NWDSF)	5
15.	PAR-AL-KEYTONE	(?)	5
16.	WD 40	(WDSF)	5
17.	Dinitrol AV 25	(WDSF)	5
18.	LPS-814-BULK	(WDSF)	4
19.	BRAYCOAT 137	(NWDSF)	4
20.	Zn-Chromate primer	(paint)	4
21.	CRC 556	(?)	4
22.	ARDOX 3205	(WDSF)	3
23.	BRAYCOAT 153	(NWDSF)	3
24.	LPS 1	(?)	3
25.	LPS 2	(?)	3
26.	AVL 3	(?)	3
27.	TECTYL 890	(NWDSF)	2
28.	ROYCO 482	(?)	2

29.	NOX RUST VC1-105	(?)	2
30.	ALNOX 2028C	(WDSF)	1
31.	ALNOX 2028D	(WDSF)	1
32.	ARDOX 3204 aerosol	(WDSF)	1
33.	BATCO Rust Prev. Type II	(WDSF)	1
34.	22028 CM BULK	(WDSF)	1
35.	Octoil 5068	(WDSF)	1
36.	Technolube FE-008	(WDSF)	1
37.	BRAYCOAT 194	(NWDSF)	1
38.	LubraKote Black 201B	(NWDSF)	1
39.	NOKORODE 731	(NWDSF)	1
40.	NORUST X10	(NWDSF)	1
41.	OAKITE SPECIAL	(NWDSF)	1
42.	STEELGARD MS1	(NWDSF)	1
43.	INTERFILM Type II	(NWDSF)	1
44.	502-BC-1	(NWDSF)	1
45.	511-BC-1	(NWDSF)	1
46.	890-BC-1	(NWDSF)	1
47.	NoxRust 105 Daubert	(?)	1
48.	Mobil 29 grease	(?)	1
49.	Mobil 22 grease	(?)	1
50.	ALMGARD-SOURCE	(?)	1
51.	ROYCO 482	(?)	1
52.	Rustoff W-1	(?)	1
53.	INOX	(?)	1
54.	Wadis 24	(?)	1
55.	Mastinox	(?)	1
56.	Banner Labs 1742 Release	(?)	1
57.	TRIFLOW	(?)	1
58.	SB-80	(?)	1
59.	FRIENDLY SYS. PC-400	(?)	1
60.	CHEMSEARCH AR-19	(?)	1