CONF-961040--2 SAND--96-1483C SAND96-1483C

A Correlation Between EIS and Salt Spray Proof Tests for the Corrosion Resistance of Conversion Coated Aluminum Alloys

R. G. Buchheit[1], M. Cunningham[2], H. Jensen[2], M. W. Kendig[2], M. A. Martinez[1]

[1]Sandia National Laboratories
P. O. Box 5800
Albuquerque, NM 87185

[2]Rockwell Science Center
1049 Camino dos Rios
Thousand Oaks, CA 91360

Introduction

Salt spray exposure and electrochemical impedance spectroscopy (EIS) are two proof tests used to evaluate corrosion resistant conversion coatings. Because of the disparate nature of the test methods and the data generated, there is a question as to is whether a relationship exists between the results of the two tests. A second question is whether an EIS method can predict performance in a shorter amount of time and with greater sensitivity than salt spray. These issues have not been fully addressed by previous studies.

A recently completed study (1) provided an opportunity to explore the relative merits of these two types of tests and to determine if the results might be related in some way. In this study, 33 different conversion coatings were applied to 5 different aluminum alloy substrates. Salt spray exposure testing and EIS were conducted for the purpose of making a comparison. Using this large sample population, the results of the two test procedures were compared, and a relationship was developed.

Experimental

The composition of the Al alloy substrates used are listed in Table 1. Various chromate and non-chromate conversion coatings were applied to test panels. Coatings were applied by process vendors or developers. The coatings and suppliers are listed in (1).

Salt spray testing was conducted according to ASTM B117 which specifies exposure to a 5% salt fog at 95° F. A total of five panels were tested for each coating on each alloy. The condition of each panel was compared against the MIL-C-5541E performance criterion which states that no more than 5 individual pits or spots not greater than 0.31" in diameter may be present on a given panel. Based on this criterion, panels were given a pass or fail ranking at inspection intervals of 24, 48, 96, and 168 hours.

EIS testing was conducted by exposing coated panels to aerated 0.5 M NaCl solution for 24 ±1 hours at 23±3° C then conducting an impedance scan over frequencies ranging from 10 kHz to 10 mHz. EIS data were interpreted using an equivalent circuit model consisting of a solution resistance in series with a parallel element combination consisting of a constant phase element and a resistor. The parallel elements accounted for the impedance response of defects formed in the coating during exposure. The value of the resistor in this parallel combination, termed R_c, was used as the figure of merit from an EIS proof test.

Results

At each inspection interval in the salt spray test, each panel passed or failed the MIL-C-5541E performance criterion of 5 pits per panel and a panel was assigned a "1" if it passed and a "0" if it failed. The values were summed and divided by 5 to yield a value varying between 0 and 1 representing the combined performance of the five panels. This value was termed the passing frequency (PF). Each PF value was then paired with its corresponding R_c value determined from EIS testing such that each coating had a unique data pair:

$$(x_i,y_i) = (R_c,PF) \qquad \text{(eq. 1).}$$

For each alloy at each inspection interval the set of data pairs were ordered by increasing R_c. A new data pair was then created:

$$(x_i,z_i) = (R_c,CPF) \qquad \text{(eq. 2).}$$

The cumulative passing frequency (CPF) for the *i* th alloy-coating combination was determined by performing the following operation on the sorted data set:

$$CPF = \frac{\sum_{i=1}^{n} PF_i}{\sum PF} \qquad \text{(eq. 3).}$$

The pairs (R_c,CPF) are a relationship between EIS and salt spray test results that can be used as the basis for estimating the probability of finding a salt spray test panel with less than 5 pits for a given value of R_c measured by an impedance test.

Linear regression analysis was used on non-censored data to derive a relationship between CPF and R_c. Separate parameters were calculated for each alloy. Using these relations, an R_c value corresponding to an 80% CPF (R_{80}) was computed. Table 2 summarizes the R_{80} values for each of the 5 alloy substrates.

It is proposed that the R_{80} values define the minimum value for which a passing salt spray result should be regularly expected.Table 3 summarizes results of an evaluation of conversion coated 2024-T3 prepared in an independent study (2). This table shows that passing salt spray result occurs when the R_c value measured by EIS is greater than the R_{80} value, a marginal salt spray result occurs when R_c is nearly equal to R_{80}, and failing salt spray result occurs when R_c is less than R_{80}. These data suggest that the R_{80} values determined from a 24 hour EIS proof test may be applied as a reasonable substitute for the more lengthy 168 hour salt spray proof test.

Acknowledgments

This work was performed at Sandia National Laboratories under contract AC04-DE-94AL85000, and at Rockwell Science Center under the Internal Research and Development Program. The participation of the National Center for Manufacturing Sciences and Texas Instruments is gratefully acknowledged.

References

1.) "Alternatives to Chromium for Metal Finishing", Final Report 0273RE95, National Center for Manufacturing Sciences, Ann Arbor MI (1995).

2.) R.G. Buchheit, " Conversion Coating Formation on Al by inhibited Alkaline Solutions", Electrochem. Soc. Fall Meeting, Oct. 1995 (in press).

Table 1. Nominal compositions of the aluminum alloys used in this study.

	Alloying Element (w/o)					
Alloy	Cu	Mg	Zn	Si	Mn	Cr
356	---	0.35	---	7.0	---	---
2024-T3	4.4	1.5	---	---	0.6	---
3003	0.12	---	---	---	1.2	---
6061-T6	0.3	1.0	---	0.6	---	0.2
7075-T6	1.6	2.5	5.6	---	---	0.2

Table 2. R_{80} values computed using the regression analysis.

Alloy	80% CPF Threshold from Regression Models ($ohm \cdot cm^2$)
356	1.87×10^6
2024-T3	2.11×10^6
3003	1.84×10^7
6061-T6	2.09×10^6
7075-T6	8.80×10^6

Table 3. EIS and Salt Spray Proof Test Results for Conversion Coated 2024-T3.

2024-T3 Sample	R_c ($ohm \cdot cm^2$)	Salt Spray Result
bare	2.6×10^4	fail
light coat	6.2×10^4	fail
heavy coat	2.7×10^6	pass (stained)
heavy coat plus seal	1.0×10^7	pass (no corrosion)