D. Aluminum Automotive Closure Panel Corrosion Test Program

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Contractor: U.S. Automotive Materials Partnership
Contract No.: FC26-020R22910

Objective

- Develop a standardized cosmetic corrosion test for finished aluminum autobody panels that provides a good correlation with in-service testing and field performance.

Approach

- Define test matrix.
- Specify and obtain materials.
- Specify phosphate and paint system.
- Pretreat and paint large reservoir of test specimens.
- Conduct laboratory testing, outdoor exposures, test track exposures, and in-service testing.
- Evaluate test data to determine which accelerated tests correlate with in-service testing.
- Conduct second iteration of laboratory testing to determine reproducibility and repeatability of accelerated tests down-selected based upon initial data.

Accomplishments

- Completed test track exposures and initial laboratory tests.
- Exposed in-service tests for 2 years out of 5 planned.
- Completed initial evaluation of test track exposures laboratory test samples.
- Conducted corrosion product analyses for some laboratory tests.

Future Direction

- Complete analysis of initial laboratory test data and define second iteration of lab tests.
- Continue long-term in-service testing.
- Conduct corrosion product analyses for in-service tests.

Introduction

The use of aluminum closure panels such as hoods, deck lids, and lift-gates continues to increase as the need to lower overall vehicle weight and thereby improve fuel economy increases. One of the key requirements for closure panel materials is a very high degree of corrosion resistance and excellent paint durability. Although aluminum closures have been used for many years on a limited number of vehicles with satisfactory performance, the general level of confidence and ability to predict corrosion lifetimes in service remains uncertain. Over the years, many laboratory corrosion test environments have been developed to determine the performance of painted closure panels. Although the results of these tests are useful for relative comparisons of alloys or paint systems, the correlation of these lab test results with in-service performance has not been established in a systematic way. Extensive studies have been carried out in order to establish this correlation for finished cold-rolled and galvanized steel substrates[1] through cooperative efforts between the automotive companies and steel, pretreatment, and paint suppliers. With the increased use of aluminum, it was recognized that a program was required to establish the correlation between lab test results and in-service performance for finished aluminum closure panels.

In response to this need, a group composed of representatives from the auto companies, the aluminum industry, and associated suppliers was established in June 2000 to formulate a program that would provide this correlation. The establishment of a standard test method for corrosion of aluminum closure panels through this effort will accelerate the adoption of lightweight aluminum materials to lower overall vehicle weight and reduce manufacturing costs by eliminating multiple test programs. A single corrosion test accepted throughout the industry could also be used to allow rapid selection and verification of alloy, pretreatment, and paint performance. In this report, an outline of the test program, evaluation procedures, and discussion of the preliminary results from initial laboratory tests and test track exposures are presented.

Experimental

Reservoir of Painted Materials

In 2001, the first step in the development of a new cosmetic corrosion test occurred with the establishment of a reservoir of painted panels. These panels would then be used in the subsequent evaluation of all test methods. As listed in Table 1, the substrate materials, metal finish, and paint processing variables were selected to give a range of cosmetic corrosion performance. Several aluminum alloys used in the Unites States and in Europe, both current and historical, were included. Electrogalvanized steel and uncoated cold-rolled steel were included as reference materials. Two aluminum alloys were sanded to simulate metal finishing in an automotive assembly plant body shop.

The materials were painted with a typical automotive paint system. This paint system included zinc phosphate pretreatment, medium-build cathodic electrophoretic priming (e-coat), and spray painting with a primer surfacer and white basecoat—clear topcoat system for a total paint film thickness of approximately 100 μm. An additional set of 6111 panels was processed through the phosphate pretreatment with lower fluoride concentration (comparable to the fluoride level used for steel-only vehicles). Also, since qualification testing is often done on panels that are processed only through the electrophoretic primer (e-coat) step, another set of 6111 panels was processed only through the e-coat step, that is, standard fluoride for aluminum but no basecoat or clear coat applied.

Panels were prepared for testing with a single scribe penetrating through the coatings to the substrate. The painted and scribed samples were then sent to laboratories for testing in a variety of environments, including laboratory, static outdoor exposure, proving ground, and on-vehicle tests.

Table 1. Materials

	Alloy	Metal finish	Paint system
A	AA6111-T4PD	No	Standard
B	AA6111-T4PD	No	Low F-
C	AA6111-T4PD	No	E-coat only
D	AA6111-T4PD	Yes	Standard
E	AA6016	No	Standard
F	AA6022-T4E29	No	Standard
G	AA2036	Yes	Standard
H	Cold -rolled steel	No	Standard
I	EG 60 Steel	No	Standard

Evaluation Method

The evaluation of scribe corrosion has traditionally been performed visually with a simple ruler by measuring creepage distance. While this simple technique of measuring creepage distance has provided some quantitative measure of corrosion severity, the one-dimensional (1-D) interpretation (length only) of manual technique provides only a partial quantification of the two- (if not three-) dimensional (2- or 3-D) creepage phenomena. In the case of filiform corrosion found in aluminum substrate where creepage does not propagate uniformly along the scribe line, as in steel substrate, but rather forms threadlike, circuitous filament lines, this 1-D manual technique of measuring straight-line distance may incorrectly quantify corrosion.

Optical macro imaging is a proven instrumentation technology that, when applied to the evaluation of 2-D surface defects, provides more reliable and accurate measurements of geometrical shapes than are obtainable with traditional human visual evaluation methods or 1-D extrapolative analysis of 2-D shapes. For this study, an optical imaging system developed by Atlas Material Testing Technology, LLC, was employed to properly and quantitatively interpret the degree of filiform corrosion. (See Figure 1.) A state of the art imaging system such as VIEEW^{TM} should employ controlled illumination conditions (geometry and intensity), high-resolution digital image capture and advanced algorithm-based image and data analysis methodologies. The use of optical imaging techniques eliminates the deleterious influences of human subjectivity by digitally capturing all sample images under the same enhanced illumination conditions and then subjecting them to a consistent image analysis administered by objective computer software.[2–6]

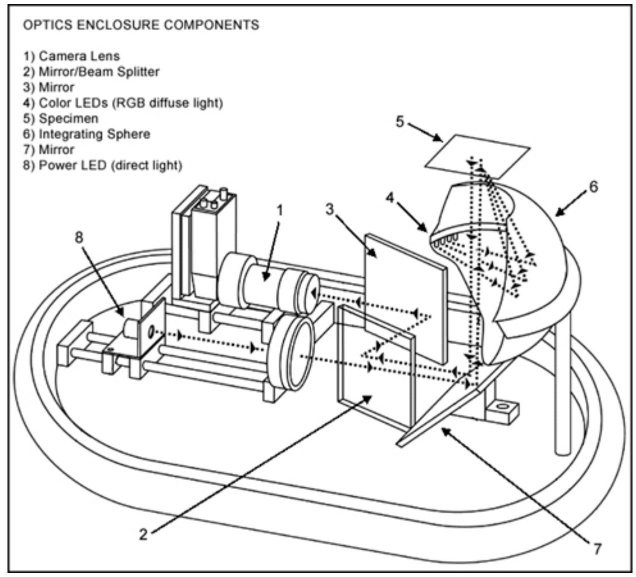

Figure 1. VIEEW^{TM} System physical layout.

Application of the optical imaging system for the corrosion creepage analysis requires three functional steps to "train" the system for the specific test specimen topology: (1) selection of optimal illumination setting, (2) selection of region of interest setting, (3) selection of image processing routine. Once the steps are programmed into a macro function, the test is performed automatically. When so initiated, the instrument recreates the programmed conditions (illumination, region scanning, image processing, and detection) as a recurring process.

1. Selection of illumination setting: To detect the filiform or blisters on the reflective coating surface, direct illumination with a hint of monochromatic diffuse illumination should bring out the topological differences of the defect region from the flat background and identify the initial scribe line. (See Figure 2.) It is the contrast difference by the direct illumination that distinguishes the region of interest from the background. Once the optimal setting is chosen, it is saved as an illumination setting file.
2. Selection of region of interest setting: The X-Y automatic scanning stage can be programmed to scan only the region of interest. Because most corrosion testing is performed in a geometrically consistent manner, the automatic scanning mechanism is useful for multisample testing in the case of the scribe corrosion test. The automatic stage is indexed to successive X-Y coordinates, and the exact sample location is

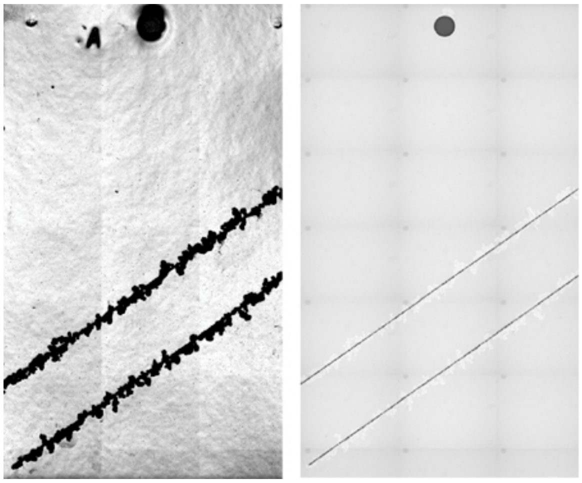

Figure 2. Filiform optically captured with direct illumination compared with common diffuse illumination.

reproduced as long as loading of the sample into the stage sample holder is performed in a consistent manner by users.

3. Selection of image processing routine: For the detection of filiform filaments, digitized gray images are divided into two gray regions: the corrosion region and the non-corroded background, through the use of a gray thresholding technique. During this step, the thresholding point (gray value) is recorded. As the subsequent samples are imaged with identical illumination geometry and intensity, the thresholding point allowed automatic determination of the region of interest. It is also at this step that the original image was digitally overlaid with a pseudo-color to more clearly identify the corrosion region. Once the region of interest is automatically detected, a few interactive processes takes place to “tell” the system where the scribe line is so that measurements can be made automatically. For this study, four geometrical attributes are measured: area of corrosion, maximum creepage, minimum creepage, and average creepage. Refer to Figure 3 for an example.

Evaluation of Existing Lab Tests

To evaluate existing cosmetic corrosion test methods, the Task Force decided to use triplicate sets of the standard materials chosen for evaluation. These materials were provided to the testing laboratories as shown in Table 2. Each test set also

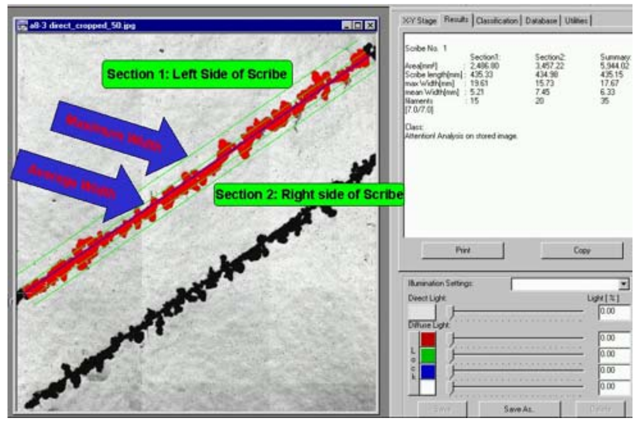

Figure 3. Automated corrosion measurement.

includes a minimum of two bare steel and two bare zinc mass loss coupons. There are laboratory (9), automotive proving grounds (3), and static outdoor tests (3) included in these evaluations.

As used in previous Society of Automotive Engineers (SAE) Automotive Corrosion and Prevention (ACAP) task force corrosion tests, these results will be quantitatively compared using scribe-creep results. The scribe-creep results will be compared to real-world standard results utilizing two methods; (a) coefficient of variation (COV) and (b) R^2 + C-ratio technique. A detailed description of these methods will be provided in subsequent presentations when enough field test data are available to compare to the laboratory test results.

In-Service (On-Vehicle) Cosmetic Corrosion Tests

It is critical when developing a laboratory-based test that test-to-field correlation be performed. In an effort to capture real-world data in developing this test, it is necessary to expose these panels to severe corrosive environments that represent real-world “worst case” scenario. Suitable environments exist in the northeastern United States, southeastern coastal areas of the United States, and southeastern Canada. The four sites selected for this study were (1) Detroit, Michigan; (2) Orlando, Florida; (3) St. John’s, Newfoundland; and (4) Ohio–New York route.

Each site (two vehicles per site) will expose 4 sets of 24 test panels that are 2 in. by 4 in. with precut edges. Each set of 24 (3 each of 8 material variables) will be attached to a mounting panel (16 in. by 12 in.) using 3-M double-backed tape

Table 2. Cosmetic corrosion tests evaluated by the Corrosion Task Force

Accelerated laboratory tests			
SAE J2334—40, 60 and 80 cycles	General Motors Company	GM 9540—40 and 80 cycles	General Motors Corp.
Ford APGE—35 and 70 cycles	Ford Motor Company		
ASTM 2803—50, 80, and 100%RH	Alcan		
ASTM G85 Annex 2–3 weeks	Alcoa		
VDA 621-415	ACT		
ASTM B117	National Exposure Testing		
CCT 4	Ford Motor Company	HCL dip	Alcan
HCL dip	Alcoa		
Volvo Mud Test	Ford Motor Company		
Original equipment manufacturer (OEM) test track			
Chrysler Proving	Daimler Chrysler Corp.		
Ford Proving Ground	Ford Motor Company		
GM Proving Ground	General Motors Corp.		
Outdoor exposure site			
Miami, Florida			
Pittsburgh, Pennsylvania			
Cape Canaveral, Florida			
In-service (on-vehicle) exposure			
Orlando, Florida			
Detroit, Michigan			
St. John’s, Newfoundland			
Cleveland, Ohio, to Massena, New York, truck route			

prior to mounting on vehicle. One set will then be on the hood of each vehicle (horizontal orientation) and one set on the right front door of each vehicle (vertical location). Each panel contains two diagonal scribe lines, which are 2 in. long and 1 in. apart. The panels will be exposed for 5 years of in-service exposure.

OEM Test Track Exposures

Proving ground tests have historical background and are based on extensive test-to-field correlation studies. The four proving grounds selected for this study were (1) GM—Milford, Michigan; (2) Ford—Flagstaff, Arizona; (3) DCX—Chelsea, Michigan; and (4) ARL—Aberdeen, Maryland.

Each site will expose two sets of 24 test panels that are 2 in. by 4 in. with precut edges. Each set of 24 (three each of eight material variables) will be attached to a mounting panel (16 in. by 12 in.) using 3-M double-backed tape prior to mounting on vehicle. One set will then be on the hood of each vehicle (horizontal orientation) and one set on the right front door of each vehicle (vertical location). Each panel contains two diagonal scribe lines that are 2 in. long and 1 in. apart. The panels will be run for a predetermined time that is representative of 10 years of field exposure.

Outdoor Exposures

In addition to on-vehicle and OEM test track exposures, static exposure for the products at the following three testing sites were elected for this study: (1) South Florida Test Services in Miami, Florida; (2) ARL Exposure Site in Cape Canaveral, Florida; and (3) Alcoa Exposure Site in Pittsburgh, Pennsylvania.

Each test site will expose 24 (3 each of 8 material variables) test panels that are 4 in. by 6 in. with precut edges and a 5/16-in. diameter hole for mounting. Each panel contains two diagonal and parallel scribe lines, which are 4 in. long and 1 in. apart. The panels will be exposed for 2 years of static outdoor exposure.

Corrosion Product Analysis

To state categorically that any lab test correlates well with in-service corrosion performance, it is essential that the chemical nature of the corrosion products formed on lab-tested materials match those on identically prepared materials exposed to in-service environments. Apart from the extent of corrosion found on painted coupons, the chemical composition of the corrosion products from lab and in-service exposure should be the same if a good correlation exists. To initiate this comparison, the corrosion products from samples of AA6111 that had been exposed to various corrosion test environments were analyzed using a variety of electron-optical techniques. This work was carried out in cooperation with the Surface Science group at the University of Western Ontario. A more complete description of this work is being presented at this year's SAE Congress.[7] In this paper, only a very brief description of this work will be provided.

Electron optical techniques were selected to do this analysis because the amount of corrosion product on aluminum closure panels is very small, making more traditional analytical procedures impractical. In addition, the use of these methods allows not only for a measurement of the chemical species present, but also for an analysis of the distribution of these species in and around the corroded area on the panel. Work to date has shown that some lab tests, such as the SAE J2334, result in corrosion product formation where high localized concentrations of certain elements such as chloride are found at the periphery of the corrosion site; whereas in other tests, such as the CCT IV, the distribution of chemical species is much more homogeneous throughout the corrosion product. It is anticipated that initial comparisons of corrosion product in lab tests and in-service environments will be carried out in 2005.

Results and Discussion

Nine different laboratory-accelerated corrosion tests were run by multiple test labs in an effort to determine both reliability and repeatability of the tests as well as the correlation of those tests to in-service exposure. The tests that were selected for this project are standard test methods that are requested by the automotive manufacturers as well as tests that the aluminum suppliers use to make decisions in their laboratories. They include salt spray tests and cyclical exposure tests.

One of the goals in the analysis of the accelerated corrosion tests was to identify the most reliable measure of corrosion on aluminum panels. A method used to identify a reliable measure was to analyze the variation in corrosion between the two scribes on the same panel and between the laboratories that were running the particular test.

The chart in Figure 4 shows the corrosion performance for two labs that ran the VDA test, measured by corrosion area. The corrosion area is consistent between the two scribes on the same panel for both labs that ran this test.

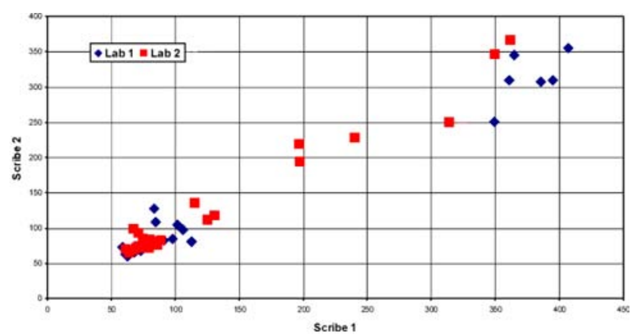

Figure 4. Lab-to-lab comparison for VDA test.

In Figure 5, there is also good correlation in the corrosion performance of the SAE J2334 test, as measured by corrosion area, between the scribes. The general trend for all of the accelerated corrosion tests run in this study is that corrosion area appears to be a reproducible measure of corrosion performance.

The standard measure of corrosion in the automotive industry is creepback from the scribe, primarily in terms of maximum creepback, or the maximum distance that corrosion has propagated from the scribe line. In general, the measure is

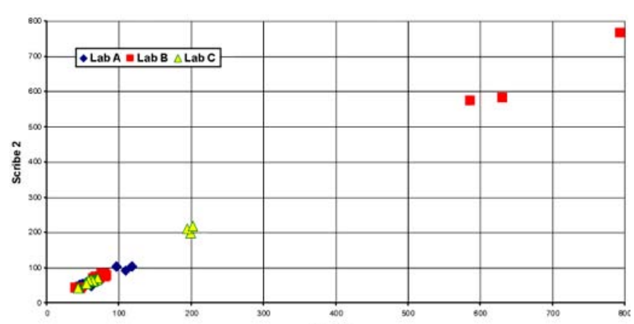

Figure 5. Lab-to-lab comparison for SAEJ2334.

subjective. The following charts exhibit the reliability of that measure.

Figure 6 shows the variation in maximum creepback between the two scribes on the same panels for the VDA test. It is obviously much more difficult to get a consistent measure of corrosion performance, even on the same panel.

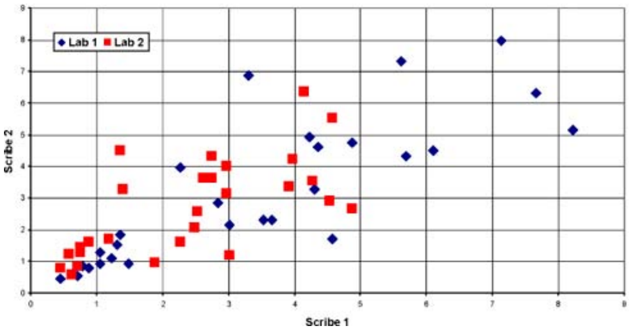

Figure 6. Variation in maximum scribe creepback between two scribes on the sample.

The chart in Figure 7 also shows the variation in corrosion performance, as measured by maximum length, for the SAE J2334 test. Again, it is difficult to get a consistent measure of corrosion performance, even on the same panel.

The results of all of the accelerated corrosion tests are similar to these two examples. It would appear that corrosion area is the preferred measure of corrosion performance, from a reliability perspective. But no conclusive judgments can be made until a correlation is found between the accelerated corrosion test results and the in-service exposure.

Steel panels were run in conjunction with the aluminum in the accelerated corrosion tests as a control. In most cases, the amount of corrosion on

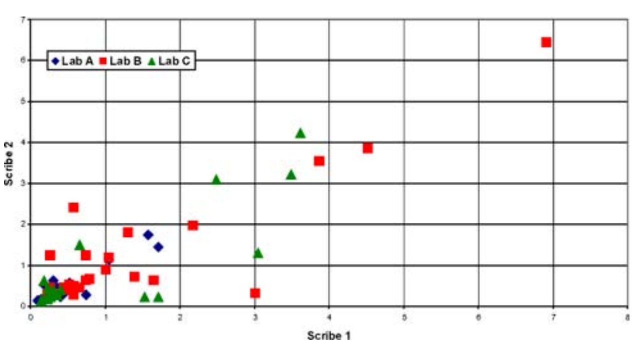

Figure 7. Variation in corrosion performance, as measured by maximum length, for the SAE J2334 test.

the aluminum was significantly less than that found on the steel. The chart in Figure 8 shows the disparity in corrosion performance.

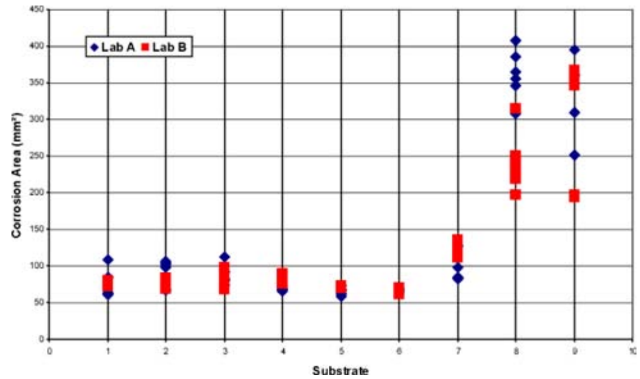

Figure 8. Disparity in corrosion performance of aluminum and steel substrates in VDA test.

Substrates 1 through 7 are aluminum, while substrates 8 and 9 are steel. Although this chart shows the results for the VDA test, the results are consistent for all of the accelerated tests run in this study. Only a few of the tests showed any significant differences in the aluminum substrates based upon the measurement of corrosion area or maximum length (creepback) using the Atlas Vieew technique.

At this point in the program, panels from the test tracks have been analyzed, and correlations between test tracks and the accelerated corrosion testing are currently being evaluated. Also at this point only a very limited amount of service-relevant results from the on-vehicle tests are available. From the preliminary on-vehicle results, it is qualitatively apparent that the panels with metal finishing (D & G in Table 1) have significantly more corrosion than the other substrates. Based on this preliminary observation, accelerated tests that also show a significant difference between the substrates with metal finishing (i.e. sanding) and those without metal finishing would appear to correlate better with the preliminary observations from on-vehicle testing. Many of the accelerated lab tests do not show a significant difference between the substrates with and without metal finishing. Of the laboratory test methods evaluated thus far in the program, only the HCl dip test, the ASTM G85-A2 test, and possibly the APGE test appear to show a significant difference in corrosion performance between the substrates with metal finishing (i.e., sanding) and those without metal finishing.

Similarly, test track or proving grounds tests that show a difference in performance related to metal finishing would qualitatively correlate better with the preliminary field test observations. One of the OEM test track exposures appears to exhibit differences in the performance of substrates with and without sanding that are consistent with the preliminary on-vehicle observations, but the other two OEM test tracks are not consistent with this difference as illustrated in Figure 9.

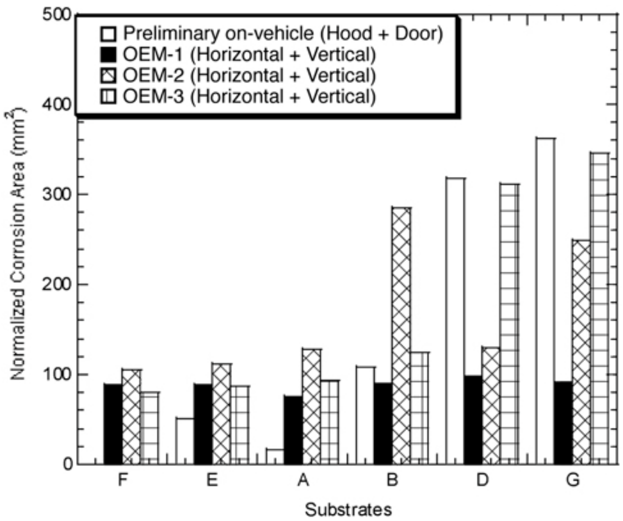

Figure 9. OEM test track and preliminary on-vehicle exposure results.

Summary and future work

Correlation of accelerated tests with on-vehicle exposures is critical for this test development effort. Accelerated tests that show signs of possible correlation with on-vehicle tests will therefore be selected for further evaluation in subsequent testing. The reproducibility of the tests is also an important consideration, which will require additional testing to evaluate. Most of the initial lab tests were run at two labs to provide an indication of reproducibility, but for those tests that are selected based on a possible correlation with on-vehicle results, testing will need to be conducted at a larger number of labs to better evaluate the lab-to-lab variability. Table 3 summarizes which tests appear to qualitatively correlate with the limited amount of in-service results available at this point in time and the reproducibility between labs as tested thus far. More in-service results are needed before decisions about selection of lab tests for further evaluation can be made. A large volume of lab test data has been

Table 3. Qualitative summary of correlation with preliminary on-vehicle results and lab-to-lab reproducibility

Accelerated Test	Significant Difference With and Without Metal Finish? (Y or N)			Reproducible Lab to Lab
	Lab 1	Lab 2	Lab 3	
Lab tests				
ASTM G85-A2	Y	?		?
Ford APGE	Y	N		N
ASTM D2803 50%RH	N	N		Y
ASTM D2803 80%RH	N	N		Y
ASTM D2803 100%RH	N	N		N
ASTM B117	N	N		N
HCl Dip	Y	Y		Y
SAE J2334	N	N	N	Y
VDA 621-415	N	N	N	Y
CCT 4	N	N		N
GM 9540P	N	N	N	Y
Test Tracks	H	V/D		
OEM-1	N	N		
OEM-2	N	N		
OEM-3	Y	Y		

H = Horizontal or Hood
V/D = Vertical or Door

generated. A more in-depth analysis of the lab test results is needed to compare corrosion morphologies and evaluate irregularities in the results (e.g. scribe-to-scribe and panel-to-panel variability for particular substrates).

Acknowledgments

The authors express sincere appreciation to the U.S. Automotive Materials Partnership, the U.S. Department of Energy, the Automotive Aluminum Alliance, the Society of Automotive Engineers' Automotive Corrosion and Prevention Committee and to the many members of the Corrosion Task Force for their contributions and commitment.

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