License Plate Cosmetic Corrosion Test of Automotive Coated Steel Sheet

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ABSTRACT

A new standard laboratory test (SAE J2334) for evaluation of the cosmetic corrosion resistance of autobody steel sheet has been developed through the joint efforts of the Society of Automotive Engineers Automotive Corrosion Prevention Committee (SAE/ACAP) and the Auto/Steel Partnership (A/SP) Corrosion Task Force. Results from this test gave an excellent correlation with those of on-vehicle tests conducted for 5 years in Canada at St. John's, Newfoundland, and Montreal, Quebec. To determine how results of the Canadian tests related to environments in the United States, racks of identical materials were mounted on the front license plate brackets of cars driven in various locations in the U.S. snowbelt, including Bethlehem, Pennsylvania; Detroit, Michigan; and Chardon, Ohio. After 4 years to 5 years, these tests showed the U.S. environments produced less scribe creep and more red rust than those conducted in Canada. Similar rankings were obtained for the scribe creep resistance of the various coated steel sheet products when compared at equivalent amounts of corrosion. However, the ranking of materials changed at longer exposure times in Canada, and for that reason, it was concluded that the 5-year Canadian results used in the development of the SAE J2334 test provided a better real-world performance standard.

KEY WORDS: automotive, coatings, cosmetic corrosion, red rust, SAE J2334, scribe creep, snow, steel

INTRODUCTION

Laboratory accelerated corrosion tests are very useful for the automotive industry and its suppliers in the development of new materials, coatings, pretreatments, and finishing processes and in the selection and qualification of materials and quality control. In the early 1980s, it was recognized widely that an improved laboratory test for evaluation of the cosmetic corrosion resistance of coated steel sheet products was needed. The widely used salt spray test was notoriously unreliable. Although existing cyclic tests were more reliable than salt spray, they did not agree completely with real-world experience. Moreover, the large number of different types of cyclic tests made it difficult for auto manufacturers and suppliers to agree on a common test protocol.

To address this need, the Automotive Applications Committee of the American Iron and Steel Institute (AISI)[(1)] established the Corrosion Task Force in 1984 with the mission of developing an improved standard laboratory test. This group joined forces with the Society of Automotive Engineers Automotive Corrosion and Prevention (SAE/ACAP) Cosmetic Corrosion Subcommittee,[(2)] and the two groups proceeded with the test development. The Auto/Steel Partnership (ASP)[(3)] added its support in

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1995. The 12-year efforts of these groups culminated in establishment of a new corrosion test, SAE J2334, which was published by SAE in November 1998. Development of this test involved a number of key steps. The steps included in this development have been documented in a series of papers.[1-13]

First, a reservoir of standard test materials was established. These included cold-rolled and coated sheet products representing a broad range of performance. The materials were phosphated and painted to give a combination of 10 material variables. This reservoir made possible the evaluation of a broad range of tests with a common set of materials, thus giving a well-defined and consistent frame of reference for comparing test results.[3]

Next, to establish the real-world performance of the reference materials, on-vehicle tests were conducted for a 5-year period on pickup trucks operated in Canada (Montreal, Quebec, and St. John's, Newfoundland).[10] Results of these tests served as the real-world standard against which results of all other tests were compared.

The standard materials also were tested in a wide variety of test environments by the committee members and other cooperating laboratories worldwide. These included 19 laboratory tests, three proving ground tests, and static exposure with twice-weekly application of salt solution at seven outdoor sites.[6-7]

Methods were developed for comparing the results of the various tests to those of the real-world standard.[1-2,8] These comparisons clearly showed that none of the existing test methods evaluated was completely satisfactory. In particular, all of the evaluated tests underestimated the performance of zinc and zinc-alloy coated sheet relative to bare, cold-rolled steel sheet.

To overcome the shortcomings of existing tests, a statistically designed experiment (Plackett-Burmann L8 matrix) was conducted.[1-2] Effects of seven variables in a typical cyclic test were evaluated. Results of these tests indicated two of the variables were critical to obtaining a good correlation with real-world behavior.[1] First, it was discovered that the salt solution used in most tests (typically 5%) was too concentrated. Much better results were obtained with lower concentrations, such as 0.5% to 0.85%. Second, it was found that best results were obtained when the relative humidity in the dry stage was controlled at 50%.

Based on those findings, a new cyclic test (SAE J2334) was designed and evaluated. The new test showed excellent correlation with the on-vehicle tests conducted in Canada, and it is a major improvement over any of the existing tests.[1]

To determine whether the mechanisms of corrosion occurring in the new test environment were similar to those taking place in the on-vehicle tests, Lehigh University conducted a detailed study of the test specimens. This study showed an excellent match of the corrosion products and morphologies of attack for SAE J2334 and the real world.[11]

The precision of the new test was determined in a round-robin, or interlaboratory, test program conducted by nine laboratories on the standard set of 10 materials.[12] It also was shown that the SAE J2334 test might be useful for evaluation of the perforation corrosion resistance of autobody steel sheet materials.[13]

In 1992, license plate test racks containing a subset of the standard materials were distributed to committee members. These racks were mounted on the front license plate brackets of cars driven in locations within the U.S. snowbelt, including Ohio, Pennsylvania, and Michigan. These tests were initiated to determine whether the real-world standard of results established in Canada at Montreal and St. John's was truly representative of a wide range of environments, particularly in the United States.

The purpose of the present work was to report results of the license plate tests after 4 years to 5 years of on-vehicle testing.

TABLE 1
Test Materials[A]

Material	Coating Metal	Coating Process	Coating Mass (g/m^2)
EG30	Zinc	Electroplated	30
EG70	Zinc	Electroplated	70
GA67	Zinc-iron alloy	Hot-dipped	67
ZN44	Zinc-nickel alloy	Electroplated	44
CRSB	Bare cold-rolled steel	–	–

[A] All materials were spray zinc-phosphated, primed with cationic electrocoat, and sprayed with white base coat and clear coat layers.

EXPERIMENTAL

Materials

A total of 10 material combinations were tested in many types of environments during development of the SAE J2334 test. Because of space limitations on the type of test rack used in the present study, the number of substrates was reduced to the five listed in Table 1. These were: 30 g/m^2 electrogalvanized (EG30), 70 g/m^2 electrogalvanized (EG70), 67 g/m^2 galvannealed (GA67), 44 g/m^2 zinc-nickel electroplated (ZN44), and bare cold-rolled steel (CRSB). Originally, these materials had been sheared into 100-mm by 300-mm panels and coated with an automotive paint system comprising spray-applied, nickel-modified zinc phosphate, cationic electrophoretic primer, and spray-applied white top coat and clear coat. For the license plate tests, the

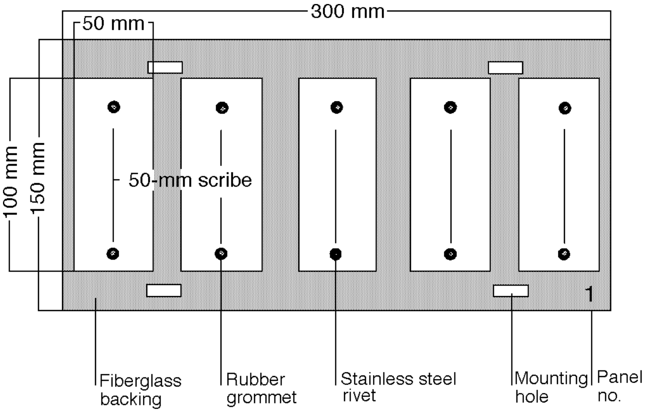

FIGURE 1. *License plate test rack assembly.*

painted panels then were cut into 50-mm by 100-mm test coupons. Cut edges of the coupons were protected by coating with epoxy resin and covering with aluminum adhesive tape.

License Plate Racks

The license plate rack assembly was selected so that residents of states that did not require front license tags could participate conveniently in the test program by mounting the rack on the front license plate bracket (Figure 1). A total of 50 test racks were prepared by a commercial lab from fiberglass-reinforced plastic. The test coupons were attached to the racks with stainless steel rivets and rubber insulating grommets. Each rack was stamped with identification and distributed to members of the committees for mounting on private vehicles at various locations within the United States for up to 5 years.

Exposure Conditions

Of the initial 50 racks, only 12 were retrieved after 5 years that were suitable for analysis. The unexpectedly high loss was attributed to a tendency of the racks to break off at the bolt-mounting holes as a result of the brittleness of the fiberglass-reinforced plastic. If another test of this type were run, attrition would be attempted to be reduced by opting for a tougher rack material, as well as by putting a return address label on the racks to aid in the return of lost racks.

Exposure conditions and times for the retrieved racks are summarized in Table 2. Seven of the racks were mounted on cars driven in the Detroit, Michigan, region; three were driven in and around Bethlehem, Pennsylvania; and two were operated around Chardon, Ohio. All of these locations are in the U.S. snowbelt where deicing salts are used extensively during the winter months.

Results from the license plate tests were compared to those obtained for coupons of identical materials that were mounted on pickup trucks operated for 5 years in the severely corrosive Canadian environments at Montreal, Quebec, and St. John's, Newfoundland. Details of the Canadian tests and results have been given previously.[10] Results were reported as the average of vertically and horizontally oriented coupons exposed at the two Canadian sites.

Evaluation Procedures

After testing, the racks were removed from the test vehicles and returned to the supplier for evaluation. Red rust in the scribe was rated visually on a scale of 0 to 3, where 0 was no rust, 1 indicated a few spots of rust in the scribe, 2 indicated at least 90% rust in the scribe, and 3 was heavy rust along

TABLE 2

Scribe Creep Results for 4 Years to 5 Years in the United States

			Material				
Region	Rack No.	Years	EG30	EG70	GA67	ZN44	CRSB
Detroit, MI	7	5	3	2	2	4	12
Detroit, MI	8	5	2	1	2	3	10
Detroit, MI	10	4	2	4	3	6	13
Detroit, MI	34	5	2	2	2	3	6
Detroit, MI	36[(A)]	4	1	1	1	2	3
Detroit, MI	42	4	3	2	2	5	7
Detroit, MI	30	5	2	3	2	5	6
Chardon, OH	26	5	3	2	2	5	14
Chardon, OH	28	5	3	4	2	6	12
Bethlehem, PA	16[(A)]	5	2	2	1	3	5
Bethlehem, PA	18	5	2	2	2	3	6
Bethlehem, PA	19[(A)]	5	1	1	1	2	2
Average	–	–	2.2	2.2	1.8	3.9	8.0
Standard deviation	–	–	0.7	1.0	0.6	1.4	4.0

[(A)] Garage kept.

the entire scribe with bleeding stain. Loose paint was removed by scraping and tapping, and scribe creep was determined as the average of the total width of paint delamination at five places, each 1 cm apart along the scribe.

RESULTS AND DISCUSSION

Scribe Creep

Ranking of Materials — Scribe creep for the 12 racks of coupons is summarized in Table 2. Given the variation in the results as indicated by the standard deviations, there was essentially no difference between the scribe creep seen on EG30, EG70, and GA67. ZN44 exhibited slightly more creep, and CRSB exhibited much more. Thus, in terms of overall averages, the materials appeared to fall into three groups, with the following order of decreasing scribe creep resistance: (EG30 = EG70 = GA67) > ZN44 » CRSB. Although this order of ranking was different from the 5-year Canadian results, it was similar to the Canadian results at shorter times when the amounts of corrosion were comparable.

Effects of Exposure Conditions — Table 3 compares the scribe creep results for various conditions. Although it was difficult to draw firm conclusions from these limited data, results suggested a relative corrosiveness for the three regions that decreased in the order: Chardon > Detroit > Bethlehem.

The order of these results was the same as the average annual snowfalls reported for these regions as: 140 cm for Chardon (Cleveland), 104 cm for Detroit, and 81 cm for Bethlehem (Allentown).[14] Given that road salt use increased with increasing snowfall, the corrosiveness was determined probably by the amounts of salt used in these regions.

As indicated in Table 2, three sets of coupons in this study were exposed on vehicles that were kept in garages. When the data from these vehicles were omitted, the average values increased slightly (Table 3). This difference may have indicated a beneficial effect of keeping a vehicle in a garage, but it could also have been part of a pattern of better overall care by owners of the garaged vehicles. In either event, the effect of garaging was small relative to the effect of location.

Comparison to Canadian Tests — In comparing the U.S. results (Table 3) to those of tests previously conducted in Canada (Table 4), it appeared that the U.S. sites generally were less corrosive in terms of scribe creep. Overall averages of scribe creep in the U.S. tests after 4 years to 5 years were similar to that observed in the Canadian tests after only 1 year to 3 years. Thus, it appeared that, on average, the Canadian sites were about twice as corrosive as the U.S. sites. The greater corrosiveness of the Canadian sites also could be explained on the basis of greater snowfall.[15-16] In Figure 2, average annual snowfall for all of the regions considered is shown to correlate well with the amounts of scribe creep on cold-rolled steel after 5 years.

As previously reported, the scribe creep resistance of materials observed in the Canadian tests decreased in order of decreasing coating weight: (EG70 = GA67) > ZN44 > EG30 » CRSB.[1,10] This ranking was different from that observed in the United

TABLE 3
Scribe Creep Results for 4 Years to 5 Years in the United States by Region

Material	Average Scribe Creep (mm)				
	U.S. Average	U.S. Average (No Garage)	PA	MI	OH
EG30	2.2	2.4	1.7	2.1	3.0
EG70	2.2	2.4	1.7	2.1	3.0
GA67	1.8	2.1	1.3	2.0	2.0
ZN44	3.9	4.4	2.7	4.0	5.5
CRSB	8.0	9.6	4.3	8.1	13.0

TABLE 4
Scribe Creep Results in Canadian On-Vehicle Tests

Material	Average Scribe Creep (mm)				
	1 Year	2 Years	3 Years	4 Years	5 Years
EG30	0.8	1.4	2.2	3.7	5.4
EG70	0.7	0.8	1.1	1.2	1.9
GA67	1.0	1.0	1.0	1.4	1.6
ZN44	1.5	1.7	2.0	2.4	3.2
CRSB	3.0	8.6	12.5	17.4	23.4

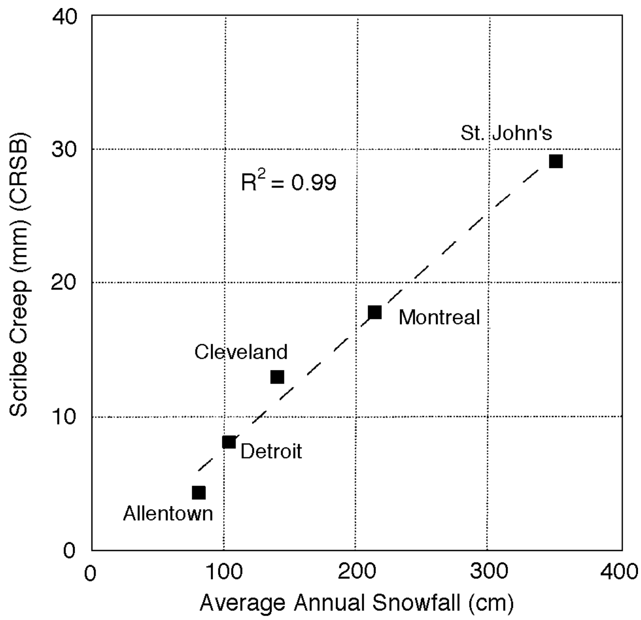

FIGURE 2. *Five-year scribe creep of CRSB compared to average annual snowfall at various test locations.*

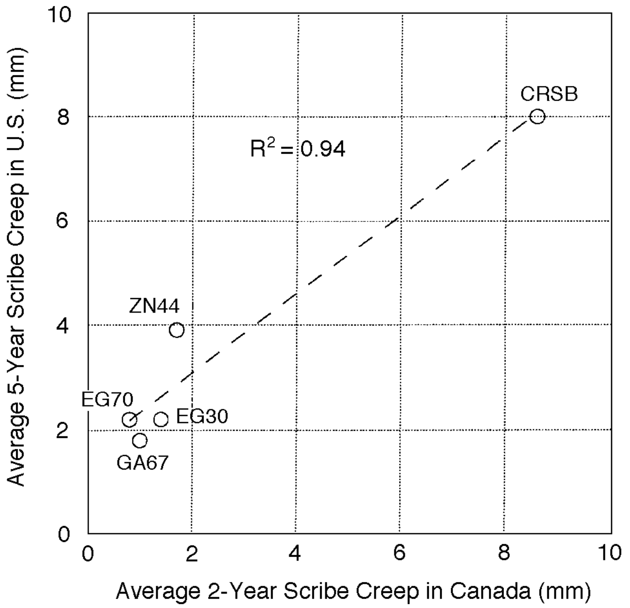

FIGURE 3. *Five-year U.S. scribe creep compared to 2-year Canadian scribe creep.*

States because of a reversal in the behavior of EG30 and ZN44 that occurred with time of exposure in Canada. Initially, after 1 year in the Canadian tests, the average scribe creep of ZN44 was slightly greater than that of the other coated products. However, the creep rate of EG30 increased with time so that by 3 years the relative average values for EG30 and ZN44 were reversed. By 5 years, the creep for EG30 was significantly greater. This resulted in a 5-year rank order that was different from that of the U.S. tests. However, the important point was that when results of the U.S. and Canadian tests were compared at times of equivalent levels of scribe creep (i.e., 2-year Canadian results to 4-year to 5-year U.S. results), the material rankings were similar.

A correlation plot shows the similarity in the overall levels of scribe creep and the order of performance of the five materials when compared at equivalent amounts of scribe creep (Figure 3). The square of the correlation coefficient (R^2 = 0.94) for the least-squares regression line drawn through these data indicated that 94% of the variation in 5-year U.S. creep was predicted by the regression line from the 2-year Canadian creep.

Based on this discussion, the scribe creep resistances from the license plate tests conducted in the United States for 4 years to 5 years were in good agreement with the Canadian on-vehicle tests at about the 2-year point. Longer exposure times in the U.S. tests eventually would lead to similar amounts of scribe creep and rank order of materials as seen in Canada after 5 years. Moreover, the Canadian tests included a larger number of materials (10 vs 5). Therefore, it was concluded that the 5-year Canadian tests provided a better long-range indication of the relative scribe creep resistance of materials, and were well suited as the real-world standard of scribe creep resistance used in development of the new SAE J2334 test.

Red Rust

Red rust ratings showed that the 4-year to 5-year U.S. results were generally more severe than the 5-year Canadian results, with regard to the appearance of red rust at the scribe (Table 5). This result may have been consistent with the higher scribe creep in Canada if it was assumed that the more corrosive Canadian environment also was more conductive, thereby enabling galvanic protection by the sacrificial zinc coatings to be effective over larger distances. In particular, GA67, which is regarded as less galvanically active than a pure zinc coating, showed the greatest difference in red rust resistance.

CONCLUSIONS

❖ Five materials were exposed on the front license plate brackets of 12 cars operated in the snow belt of the United States (Chardon, Ohio; Detroit, Michigan; and Bethlehem, Pennsylvania) for 4 years to 5 years and compared to the results of previous tests of the same materials in Canada (St. John's, Newfoundland, and Montreal, Canada).
❖ In terms of resistance to scribe creep, the U.S. sites were about half as severe as the Canadian sites.
❖ When the U.S. results were compared to those in Canada at equivalent levels of scribe creep after ~ 2 years, a similar ranking of materials was obtained.

TABLE 5
Red Rust Results

	Red Rust Rating (0 None, 3 Poorest)					
Material	**U.S. Average**	**U.S. Average (No Garage)**	**PA**	**MI**	**OH**	**Canada**
EG30	1.5	1.6	1.7	1.4	1.5	0.9
EG70	0.8	1.0	0.7	0.9	1.0	0.5
GA67	2.0	2.1	1.7	2.1	2.0	0.8
ZN44	1.8	1.8	2.0	1.9	1.5	1.4
CRSB	3.0	3.0	3.0	3.0	3.0	2.3

❖ In terms of red rust, the U.S. sites were generally more severe than the Canadian sites. This might have been the result of decreased galvanic activity in the less corrosive U.S. environments.

❖ Because the ranking of materials changed at longer exposure times in Canada, it was believed that the 5-year Canadian results provided a better long-range indication of the relative scribe creep resistance of materials. Therefore, they were well suited as the real-world standard of scribe creep resistance used in development of the new SAE J2334 test.

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