Exposure Study of Epoxy-Coated Reinforcement

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Epoxy-coated reinforcing bars (ECR) are often stored at the job-site for several months before being placed and embedded in concrete. In addition, during normal construction practices, certain bars are left protruding from one section of reinforced concrete until the next section is placed. The effect this outdoor storage has on the product's later performance in concrete has in recent years become a concern to ECR users because of findings in research resulting from premature corrosion problems experienced at some sites across North America. In 1993, C-SHRP initiated an exposure study to quantitatively assess whether the coating on ECR deteriorates during outdoor storage, and based on this information, recommend appropriate specification requirements for such storage. This technical brief describes the field program and highlights the results of the analysis conducted for C-SHRP by RDL Consulting. The results show that the coating on ECR do degrade from outdoor exposure and that current practice for field handling and storage of ECR should be changed. A report, entitled Effect of Outdoor Storage on the Condition of Epoxy-Coated Reinforcing Bars, is available with the complete analytical results.

C-SHRP EXPOSURE STUDY

Field Program

Thirty-six 0.9-metre-long straight 15M coated weldable steel reinforcing bars were placed on an outdoor test plot at each of three exposure sites. Eighteen of these bars were

![New Brunswick test stand of exposed epoxy-coated reinforcing bars. (Photo courtesy of the Ontario Ministry of Transportation)](image)

The Strategic Highway Research Program (SHRP) was established by the United States Congress in 1987 as a five-year, $150 million research program to improve the performance and durability of highways and to make them safer for motorists and highway workers. As a follow-on program to SHRP, Congress established in the Intermodal Surface Transportation Efficiency Act of 1991 programs to implement SHRP products and to continue SHRP's long-term pavement performance (LTTP) program. The Canadian Strategic Highway Research Program (C-SHRP) is directed at extracting the benefit of the US work for Canada.
coated with Akzo Nobel Resicoat 500607 fusion-bonded epoxy powder coating applied over a blast-cleaned and chromate-pretreated steel surface. These samples were prepared by Harris Rebar in Stoney Creek, Ontario and are designated as Supplier H specimens. The other eighteen bars were coated with 3M Scotchkote 213 fusion-bonded epoxy powder coating applied over a standard blast-cleaned steel surface. These samples were prepared by Nantucket Rebar in Scarborough, Ontario and are designated as Supplier N specimens.

Six 4-mm diameter holes were drilled through the coating on each bar. These holes were situated in a row on what became the top of the bar during the exposure phase of the program. Three of the six intentional holes and all cut ends were repaired with a two-component liquid epoxy patch material prior to beginning the study. Supplier H used CP105467 patch material supplied by Niagara Paint and Chemical. Supplier N used Scotchkote 213 patch compound supplied by 3M.

Before the exposure program began, two extra bars for each coating and each site were tested for dry coating adhesion. These bars were used to obtain baseline data and were not subjected to outdoor storage.

The remaining specimens were exposed at three outdoor sites:

1. Alberta (AB) – a dry, cold area with large temperature fluctuations and high UV radiation.
2. New Brunswick (NB) – a marine environment, and
3. Southern Ontario (ON) – a humid, temperate climate.

The ECR were exposed for a period of up to twelve months. After exposure for 1, 2, 3, 6, 9, and 12 months, three bars of each coating were removed from the outdoor plots for visual examination, measurement, and destructive testing. The test period was from late September 1993 to late September 1994.

**Summary Results:**

**ECR Performance Measures**

The 36 coated bars from each exposure site were evaluated for the following:

- coating thickness,
- holidays,
- AC resistance,
- dry knife adhesion, and
- degree of visible coated rebar corrosion and the condition of patches.

Twenty-six of these coated bars from each exposure site were evaluated for the following:

- bend,
- seven-day ambient temperature cathodic disbondment, and
- 500-hour salt spray.

The **coating thickness** on each specimen was measured at the beginning of the program at several random locations along the bar length. The average coating thickness of all but one specimen was within the specified 7 - 12 mil range. One outlier had an average coating thickness of 13.8 mils. As epoxies chalk upon prolonged exposure to sunlight, the coating thickness was measured for the Alberta specimens both before and after exposure. Time of exposure could not be correlated to a change in coating thickness of these data.

The **holidays** and other coating discontinuities found in the specimens were measured with a holiday detector before and after exposure. During the first three months of exposure very few new holidays were formed. After this point, certain bars appeared to be more susceptible to holiday formation than others. Changes appeared to be taking place in the specimens exposed for nine and twelve months with steel pitting and roughness in the coating at defects observed.

Three **AC resistance** measurements (an initial reading and subsequent readings after five and ten minutes) were taken at each of the locations for a total of nine measurements on each bar both before and after exposure. However, values above 1100 k ohms could not be measured and this reduced the amount of usable data from the study. Coating performance trends could only be seen in the Alberta results, where analyses suggested that AC resistance steadily decreased the longer the bars were exposed. This trend may have been evident in the Alberta samples while the other samples remained above 1100 k ohms over the exposure period due to a combination of thinner average coating thickness and more initial coating discontinuities. These characteristics appear to have disadvantaged the Alberta specimens from the beginning of the program.
Dry knife adhesion tests were performed randomly along the length of each bar after completion of the exposure period. The tests were performed by scribing an "X" in the valley between deformations with a utility knife and attempting to pick back the coating from the centre of the scribe. A rating scale of 1, 3 or 5 was used to evaluate the dry coating adhesion performance. A 1 rating was received if the operator found a well-adhered coating that could not be lifted from the steel substrate. A 3 rating was received if the coating could be pried up from the substrate in small pieces. A 5 rating was received if the coating could be easily peeled off the substrate. All of the Supplier H specimens for the three exposure sites received 1 dry knife adhesion ratings. For Supplier N samples, some 3 ratings were observed. However, the adhesion test results appeared to be related more to the individual bar than to the duration of exposure.

Observations of the degree of visible coated rebar corrosion and the condition of patches were generally of the same type and at approximately the same exposure time at all three sites. Colour change and gloss loss are early indicators that degradation of the coating is occurring at the surface. Supplier H specimens began to show slight gloss loss on top over the first few months of exposure and gloss was fully lost by nine months exposure. No significant colour change was noted. The Supplier N coating was more susceptible to coating colour change and gloss loss as these samples lost their gloss and became olive green by one month of exposure.

No undercutting of the coating adjacent to intentional defects was reported for the Supplier H specimens (chromate-pretreated blasted steel) over the twelve month exposure period. The Supplier N samples (blasted steel only) were found to have rust spreading slightly under the coating adjacent to the intentional defect by two months. This undercutting increased throughout the exposure period and the coating was visibly lifted away from the steel around the defect by nine and twelve months exposure.

The patches on Supplier H specimens were not dry when the bars were packed for submission to the program. The patches on these bars were rough and low in gloss prior to exposure and began to show rust staining as early as one month after exposure. The bar ends were reported as being rusty by six months and substantially rusty by nine months. The patch material was applied to saw-cut and not sheared bar ends; the latter being typical of ECR production and much more difficult to coat effectively.

The patches on the Supplier N bars were found to be glossy when observed at one through three months, have slight gloss loss at six months, and have little remaining gloss by nine months exposure. The Supplier N patches on bars exposed in New Brunswick were reported to be wearing away after one month exposure and for the most part were gone by six months. The Ontario specimens began to show rust stains on the ends after one month exposure. Besides this observation, most of the end patches performed fairly well until six months exposure. The bar ends on the Supplier N samples were saw-
cut and the sharp edge was ground down prior to patch application.

Other observations noted the formation of a salt film on top of the New Brunswick specimens at twelve months exposure. Pit corrosion was seen by New Brunswick at some intentional coating defects and in some patched holes.

Seventy-eight of the exposed specimens were subjected to 180 degree **bend testing** with the top side of the bar on the outer radius of the bend. The coating on 59% of the Supplier H specimens and 10% of the Supplier N specimens developed random lateral cracking in the bend tests. This type of cracking is more commonly observed as a coating application and/or powder quality problem than as an exposure phenomenon. In an attempt to separate coated bar problems from coating performance data, all of the bars which contained random lateral cracking were removed from further consideration. The gaps in the remaining data limit what can be deduced, however it is clear by nine months exposure the coating had lost a significant portion of its elasticity and pinholes were found at the base of most deformations.

**Seven-day ambient temperature cathodic disbondment testing** was carried out on samples cut from the bars prior to bend tests. For both coatings, no correlation was found between exposure time and the amount of coating cathodic disbondment which occurred. However, there is an order of magnitude difference between the Supplier H and Supplier N bars in coating resistance to disbondment in this test. The overall average cathodic disbondment for the Supplier H bars was 0.95 mm compared with 9.57 mm for the Supplier N bars.

A second set of samples cut from the bars were **500-hour salt spray tested**. Again, no correlation was seen between exposure time and the amount of coating disbondment which occurred from exposure to salt spray. The order of magnitude difference between the Supplier H and Supplier N bars in coating disbondment was noted again in this test. The overall average disbondment for the Supplier H bars was 0.75 mm compared with 6.63 mm for the Supplier N bars in this test.

The summary of results of the ECR performance measures indicate that the coating on the bars was degrading as exposure time increased. The AC resistance data and the change in coating colour and gloss suggested the coatings were changing over time. Up to three months exposure, the bars appeared to be in satisfactory condition. After this point, certain bars seemed to be more susceptible to degradation from exposure than others. The increase in coating holidays on straight bars, coating pinholing in the bend tests, and the complete loss of coating gloss in the directly-exposed sides of the bars suggested that the coatings were significantly degraded by nine months of exposure.

A secondary outcome of the exposure study was the opportunity to compare outdoor exposure performance of ECR prepared using standard blast-cleaning steel techniques and chromate pretreating the steel prior to coating application. In this study, Supplier H specimens were coated over chromate-pretreated blasted steel whereas Supplier N specimens were coated over blasted steel that had not been pretreated.

In the dry knife adhesion tests, all of the Supplier H specimens received 1 ratings, while 27 Supplier N samples received 3 ratings. Furthermore, all of the “X” scribes on the Supplier N specimens which ended up in the bend area during the bend test showed the coating disbonded from the steel and lifted away from the bar’s surface. The “X” scribes on the Supplier H specimens did not visually disbond during the bend test. No undercutting of the coating adjacent to intentional defects was reported on the Supplier H specimens over the entire twelve-month exposure period. The Supplier N bars were found to have corrosion spreading under the coating adjacent to the intentional defect by two months and this increased over the exposure period until the coating was visibly lifted away from the steel. The Supplier H bars showed approximately an order of magnitude smaller average coating disbondment than the Supplier N bars in cathodic disbondment and salt spray testing. Several of the Supplier N samples disbonded completely in these tests; particularly the salt spray test. The chromate pretreatment used in conjunction with the blast cleaning of the rebars prior to coating appears to improve the bond between the coating and the steel and to minimize undercutting adjacent to coating discontinuities.

**Climatic Conditions**

Climatic data were collected at the closest available weather stations to each of the three exposure sites and included:

- precipitation,
+ mean temperature, and
+ global solar radiation.

During the field program, precipitation was relatively low in Alberta from October through April and relatively high in May through September. In New Brunswick, there was generally a substantial level of monthly precipitation throughout the year, but the period of August to October 1994 was much drier than the same months the year before. In Ontario, the monthly precipitation was fairly constant across the time period. The cumulative precipitation results show that the specimens exposed in Alberta received the least precipitation (567 mm) during the twelve month period. Ontario received somewhat more (721 mm) and New Brunswick had the greatest precipitation (1796 mm).

Monthly minimum, maximum and average mean temperatures for each site showed that, during the exposure period, Alberta was colder than the other sites in the winter. Ontario was warmer than the other sites in the summer.

Over the exposure period, Alberta received more global solar radiation (6399 MJ/m²) than Ontario (4820 MJ/m²) which received more than New Brunswick (4399 MJ/m²). The data showed that the exposure period for the specimens began as the monthly global solar radiation was decreasing. If the exposure of the specimens had begun in March, the solar radiation and ambient temperature would have been on the increase. It has been hypothesized for outdoor testing of architectural coatings that beginning this type program in the spring is a more severe protocol. The higher solar radiation and ambient temperature in the summer months first have the opportunity to attack and weaken the coating’s integrity. Later, the freeze/thaw cycling in the winter months has the chance to try to crack the weakened coating.

CONCLUSIONS

Based on the observations in the exposure study, the following conclusions were drawn:

1. The ECR degraded from outdoor exposure over time. Up to three months exposure, the bars seem to be performing well. Between three and nine months exposure, the ECR are in transition and some bars are losing performance characteristics. The coatings are significantly degraded by nine months of exposure.

2. After three months exposure, certain bars are more susceptible to holiday formation than others.

3. Different epoxy coatings do not weather at the same rate or in the same manner.

4. The finding that thicker coatings and fewer coating discontinuities will improve ECR performance was again seen in this study.

5. The chromate pretreatment used in conjunction with the blast cleaning of the rebars prior to coating application appears to significantly reduce the undercutting adjacent to coating discontinuities.

6. The Supplier H patch material was ineffective in corrosion protection when the patches were not allowed to dry prior to handling. The patches on the Supplier N bars performed fairly well, but did not protect the bar ends over the full test period, even under the less-demanding coating application situation of cut and ground bar ends having been used.

7. The salt film on the coated bars and the corrosion pitting seen in New Brunswick suggest that if ECR are stored on site in a marine environment for a prolonged time, they should be washed off with fresh water prior to concrete embedment.

8. Based on the results of the study, current practice for field handling and storage of ECR should be changed. Recommendations covering handling, storage and protection of coated bars, placing ECR, and repairing damaged epoxy coating are proposed in the full project report. Interested readers should refer to Effect of Outdoor Storage on the Condition of Epoxy-Coated Reinforcing Bars (TAC, 1996) in which the recommended changes are outlined using Ontario’s specification OPSS 905.07.02 (May 1994) as a basis.
For full details of this research see:

Effect of Outdoor Storage on the Condition of Epoxy-Coated Reinforcing Bars
Bob Lampton, RDL Consulting
Canadian Strategic Highway Research Program
Transportation Association of Canada
Ottawa, ON 1996

See also:

Effectiveness of Epoxy-Coated Reinforcing Steel
Kenneth C. Clear, Kenneth C. Clear, Inc.
Canadian Strategic Highway Research Program
Transportation Association of Canada
Ottawa, ON 1992