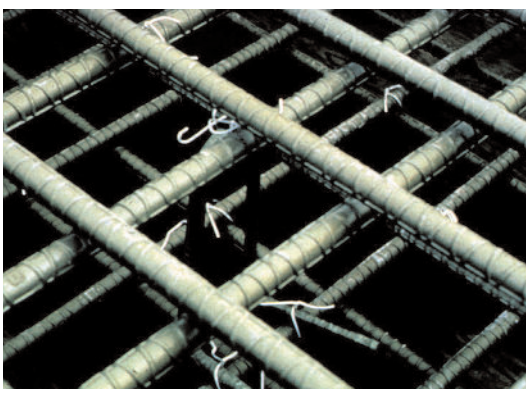
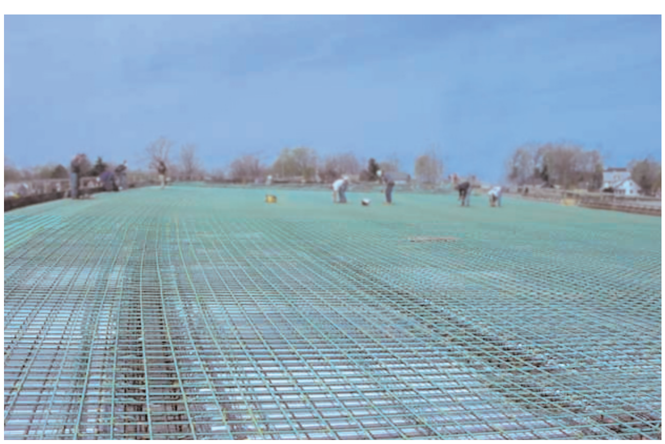
Improving the Quality of Epoxy-Coated Steel Reinforcing Bars through CRSI's Epoxy Coating Applicator Plant Certification Program





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Abstract

This paper presents an overview of the Concrete Reinforcing Steel Institute's Voluntary Certification Program for Epoxy Coating Applicator Plants. The Plant Certification Program was developed to provide a means of ensuring that applicator plants are capable of producing epoxy-coated steel reinforcing bars in accordance with industry standards and recommendations. There are currently 34 certified applicator plants in the United States and Canada. Eighteen state and provincial transportation departments require that epoxy-coated reinforcing bars be supplied by CRSI-certified plants.

Keywords: anchor profile, blasting abrasive, blast clean, cure (coating), epoxy coating, holidays, near-white metal, third party inspection, and visual standards.

Introduction

It is widely recognized that one of the best ways to prevent corrosion of the reinforcing steel in reinforced concrete structures is to provide a barrier that protects the steel from water, chlorides, and other aggressive chemicals. Fusion-bonded epoxy coating is based on this concept; the tough, durable epoxy coating effectively isolates the steel from the elements required for corrosion. Use of epoxy-coated steel reinforcing bars has increased dramatically over the last 30 years and it is a proven method of preventing corrosion. The effectiveness of the coating is strongly dependent on its quality.

The importance of the coating quality can be seen in the results of a 1998 FHWA study, Corrosion Evaluation of Epoxy-Coated, Metallic-Clad and Solid Metallic Reinforcing Bars in Concrete. The test specimens in this long-term corrosion study reflected a variety of practices with respect to both material specifications and quality of construction. Of the 11 specimens, six only had epoxy-coated bars in the top mat and two had epoxy-coated bars in both top and bottom mats. Some of the specimens had "pre-formed" concrete cracks over the top mat. The testing included both straight and bent bars, as well as bars with different amounts of intentional damaged coating.

What is most striking about the results of this study, as summarized in Table 1, is the wide range of measured voltages. Test 6 representing a bar with good quality coating in good quality concrete, had a voltage of 5 μV. This voltage corresponds to a very low corrosion rate. In contrast, Test 11 representing a bar with no coating in poor quality concrete had a voltage of 4,052 μV. The potential for corrosion in this test was thus more than 800 times greater than Test 6. Comparing Test 1 to Test 8 and Test 3 to Test 7, it can be seen that the bars with damaged coating had a significantly higher voltage. These tests clearly show that a quality coating will provide better corrosion protection.

CRSI's Voluntary Certification Program for Epoxy Coating Applicator Plants

Although epoxy-coated steel has been used in the United States since the early 1960s for oil and gas pipelines, epoxy-coated reinforcing bars were not used until 1973, on a bridge deck in Philadelphia. CRSI developed the Plant Certification Program in the early 1990s, because it had become clear that the quality of the coating could have a significant impact on the service life of reinforced concrete structures. The Plant Certification Program established stringent

Table 1—Average voltage across resistor for two replicate Sample Bars, μV

Test Number	Description of Test Specimen				Voltage, μV
	Straight (S) or Bent (B)	Bottom Mat Coated?	Pre-formed Concrete Crack?	Damaged Coating	Average of 5 Proprietary Epoxy Coatings
1	S	No	Yes	0.5%	356
2	S	Yes	No	0.5%	9
3	B	No	Yes	0.5%	423
4	S	No	Yes	0.04%	782
5	S	No	No	0.04%	37
6	S	Yes	No	0.04%	5
7	B	No	Yes	0.04%	22
8	S	No	Yes	0.04%	280
Control Group					Uncoated
9	S	No	No	NA	3,525
10	B	No	Yes	NA	2,142
11	S	No	Yes	NA	4,052

quality-control procedures that exceeded the requirements of most standard specifications. Although the procedures are based on ASTM A775/A775M, Standard Specification for Epoxy-Coated Steel Reinforcing Bars, purchasers have their own variations to the specification. With the Certification Program in place to address concerns about coating quality, the use of epoxy-coated bars has continued to increase. There are currently 34 certified applicator plants in the United States and Canada. Eighteen state and provincial transportation departments require that epoxy-coated reinforcing bars be supplied by CRSI-certified plants.

The Certification Program has two main objectives. First, it verifies that a plant has the appropriate capabilities in both staff and equipment as well as the procedures in place to produce epoxy-coated bars in accordance with current standards and industry recommendations. Second, it provides recognition to those plants that successfully implement and follow the program's requirements.

Quality Policy and Procedures

The first and foremost requirement of the Certification Program is that the plant's quality control personnel must be knowledgeable with respect to the required quality-control procedures. These individuals must understand the requirements of the program and must be capable of correctly performing the tests specified by the program. In addition, there must be enough trained personnel that quality-control tests can be performed in a timely manner and documented as required by the program. Quality-control personnel must have the authority to make changes that are necessary to ensure the requirements of the program are met.

During the inspections required for certification, the independent third-party inspector will observe the quality-control personnel conduct the required tests. In addition, the inspector will review the documentation that the plant is required to keep on file as a record of their quality-control procedures.

Certification indicates that the plant's procedures comply with the program requirements for:

- Examination of the uncoated bars
- Surface preparation
- Testing for contamination and gradation of the blast abrasive
- Measuring of bar temperature
- Application of the epoxy powder
- Curing of the epoxy.
- Tests for coating quality (continuity of coating, coating thickness, coating flexibility, cathodic disbondment)
- Storage and handling of the epoxy powder
- Handling and storage of the coated bars

Examination of Uncoated Steel Reinforcing Bars

The first step in the coating process is to ensure that the uncoated steel reinforcing bars are free of contaminants such as dirt, oil, grease, paint, and salts. This is simply a visual inspection and is performed at the "shake-out table." Bars with significant amounts of contaminants can contaminate the blast media, which can then contaminate subsequent bars. Contaminants must be removed before the bars are blast cleaned; bars with contaminants that cannot be removed should not be processed further.

The bars are also visually inspected to ensure that deformations do not have sharp edges or rolled-in slivers. Bar with sharp edges or slivers should not be coated; during the coating process, the uncured coating will tend to flow away from these edges and leave exposed steel.

Surface Preparation

After verifying that the condition of the bars is satisfactory, the next step is to blast clean the bars. The objectives of the blast cleaning are to remove the rust, mill scale, and other contaminants and establish an anchor profile on the bar. A clean steel surface is essential because contaminants on the surface of the bar will interfere with the bond between the coating and the steel, thus reducing the overall effectiveness of the coating. Four tests are used to ensure that the bar has been properly cleaned: the Backside Contamination Tape Test, the Visual Comparison Against Cleanliness Standard, the Detection of Chlorides—Paper Test, and the Copper Sulfate Test.

In the Backside Contamination Tape Test, a piece of white tape is burnished onto the bar (Fig. 1) The tape is then removed and compared under magnification to a visual standard to determine the level of “cleanliness” (Fig. 2).

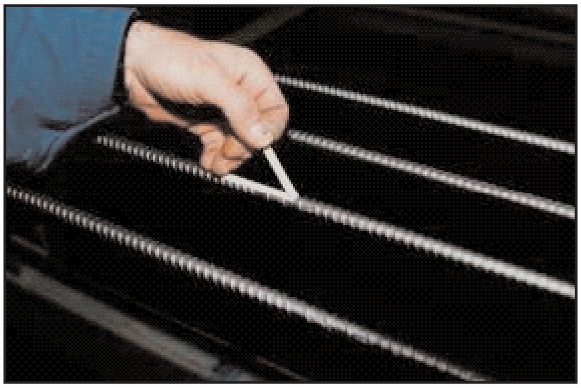

Figure 1—Backside Contamination Tape Test

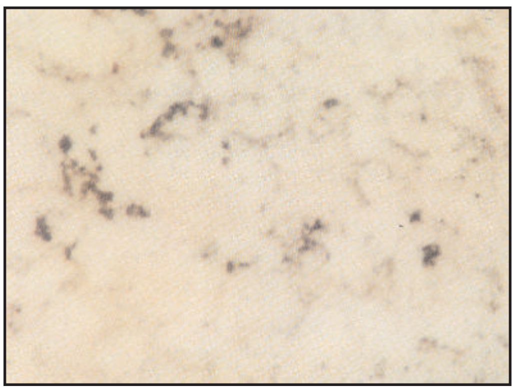

Figure 2—Visual Standard for Backside Contamination

In the Visual Comparison against Cleanliness Standard test, the bar is compared to visual standard to determine if it meets the requirements for SSPC SP10, Near-White Blast Cleaning. A near-white condition means that all visible traces of mill scale or rust have been removed (Fig. 3).

Figure 3—Visual Standard for Near-White Metal

The Detection of Chlorides—Paper Test determines the amount of chlorides on the bar. A small strip of paper that has been saturated with potassium ferricyanide is placed on the bar and moistened with distilled water (Fig. 4). The paper strip will turn varying intensities of blue, depending on the level of chlorides present. The strip is compared against visual standard (Fig. 5) to estimate the amount of chlorides.

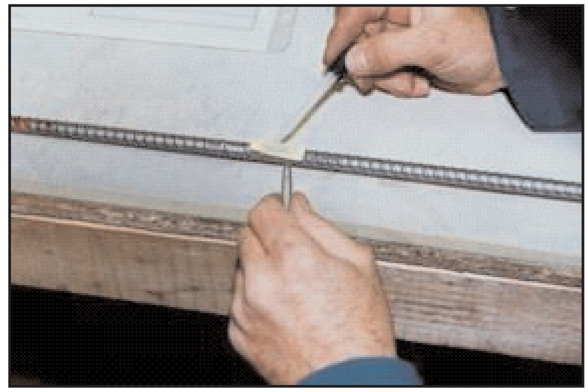

Figure 4—Detection of Chlorides Paper Test

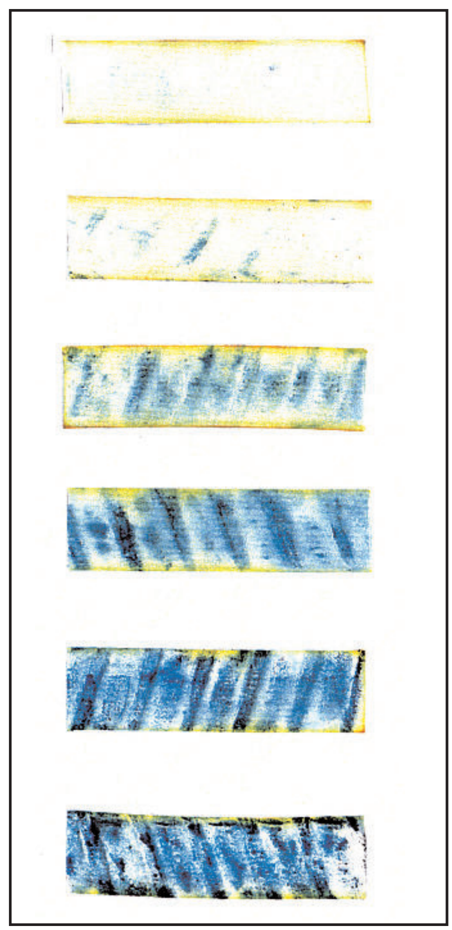

Figure 5—Visual Standard for Chloride-Paper Test

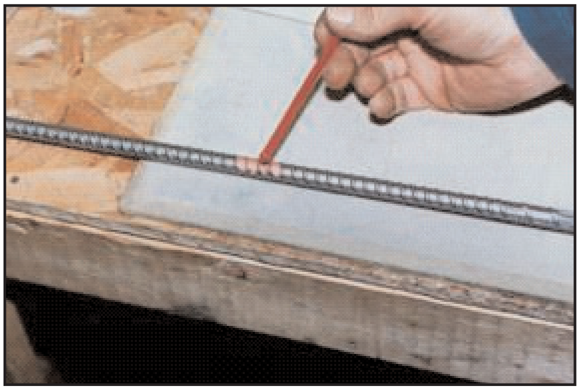

Figure 6—Copper Sulfate Test

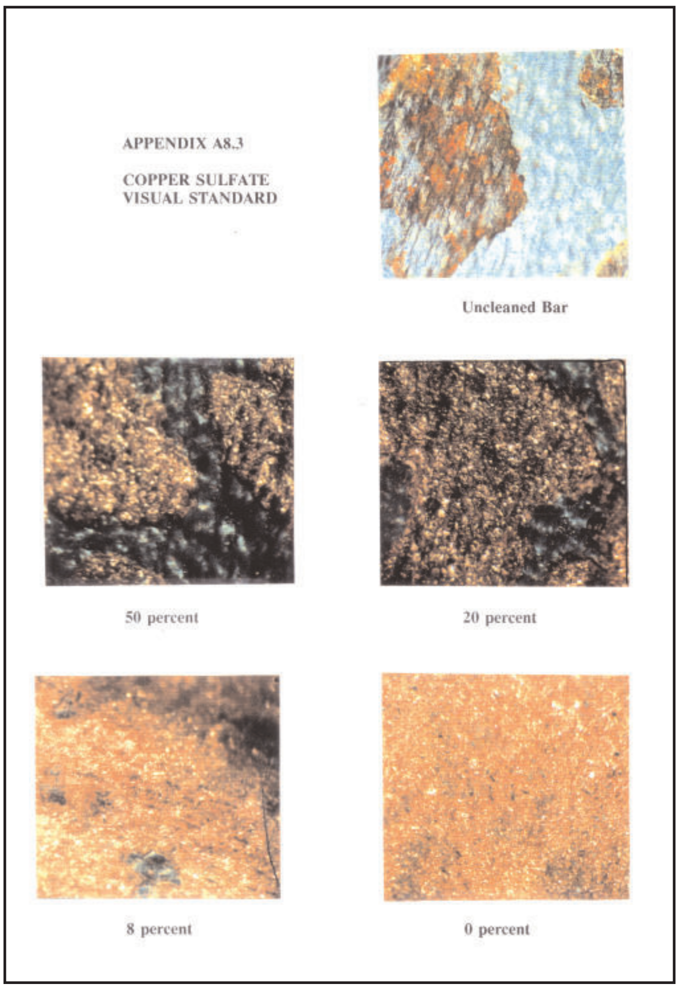

Figure 7—Visual Standard for Copper Sulfate

In the Copper Sulfate Test, a small amount of copper sulfate solution is placed on the bar (Fig. 6). The copper sulfate solution reacts with the iron in steel and turns the steel a copper color; mill scale and other contaminants will prevent the iron from reacting with the copper sulfate. The bar sample is compared to Copper Sulfate Visual Figure 6—Copper Sulfate Test Standard (Fig. 7), to estimate the amount of mill scale.

Anchor Profile

In addition to being free from contaminants, the surface of the bar should be slightly roughened to improve the adhesion of the coating. There are various ways of quantifying surface roughness; the Certification Program requires that the plant measure the “anchor profile.” The anchor profile is the overall height (valley depth) of the profile. Bars are to be abrasive blast-cleaned such that the surface of the bar has an anchor profile with a minimum roughness depth of 1.6 mils.

There are two ways to measure the anchor profile. The Electronic Stylus (Profilometer) Measurements of Profile uses a record stylus-like device that measures the depth of the peaks and the number of peaks in a given area. The Surface Profile Measurements Using Replica Tape test uses tape which is burnished onto the bar. The tape is then removed and the depth of the dimples in the tape is measured.

Abrasive Contamination and Gradation

To obtain a satisfactory anchor profile, it is essential that the blasting abrasive have a consistent gradation. The abrasive must also be durable and free from contaminants. Once a plant has determined the composition of the abrasive media required for proper surface preparation, the plant must maintain that mix with as little variation as possible. Unless the proper composition is maintained, particles of the blast media may become embedded in the surface of the steel. If the blast media contains too many fines, a residue which is more likely to be contaminated and may remain on the bars.

Three tests must be performed on the abrasive media. The Sieve Analysis of Blast Abrasive determines the gradation (size distribution) of the media. The Oil Contamination Test involves placing a small amount of abrasive media in a beaker of water and then visually observing the surface of water for any indication of oil. The third test is a chloride test and it verifies that the media is nearly free of chlorides.

Heating the Bars

Before the epoxy powder is applied, the bars must be heated to the temperature recommended by the powder manufacturer, typically around 450 F. The heat melts the powder and initiates the chemical reaction that is required to cure the epoxy. Heating the bar to the proper temperature is critical. If the surface of the bar is too cool, the epoxy may only partially cure and is likely to have poor flexibility and poor adhesion to the bar. If the surface of the bar is too hot, the epoxy coating may exhibit excessive foaming, poor flexibility, lack of adhesion, and blistering.

Proper bar temperature must be monitored by the Temperature Check Using Non-Sulfurous Crayons test. In this test, crayon-like pencils that melt at a specific temperature are applied to the surface of the bar. Most plants also have infrared temperature guns; these allow the surface temperature of the bars to be monitored more easily.

It is also important not to deposit any contaminants on the surface of the bar while heating it, because contaminants will interfere with the adhesion between the coating and the steel surface. Certified applicator plants use induction heaters or gas fired heaters.

Epoxy Powder Application

Oxidation (corrosion) can occur when freshly blast-cleaned steel is exposed to the air. Because the oxides formed may interfere with the adhesion of the coating to the steel, the interval between blast cleaning and application of the epoxy powder should be as short as possible. Although the program limits this interval to 90 minutes, in most plants the powder is applied immediately after blast cleaning.

The epoxy powder is electrostatically charged and then applied to the bars as a fine spray. The air used for this powder spray has to be extremely dry because moisture will cause the powder to clump, resulting in uneven application. Most plants use chillers or a chemical desiccant to remove the moisture from the compressed air.

Curing of the Epoxy

Curing of the epoxy is a chemical process in which the epoxy resin particles melt and cross-link to form a continuous polymer coating. The time from when the epoxy melts to when it stops being a liquid is called the "gel phase." The gel phase is considered to be the first phase of curing and is only a few seconds. During the gel phase, the epoxy flows into the anchor pattern on the bar surface.

Another important parameter with respect to curing is the "time-to-support." Time to support is the time from when the powder is applied to the bar to the time the coated bar can contact the first roller without damaging the coating. Although the coating is not fully cured at this point, the coated bar can be transported by wetted, non-metallic rollers. Depending on the ambient temperature and bar size, coated bars are often water-quenched once the coating is fully cured to facilitate inspection and handling of the coated bars.

Continuity of the Coating

Coated bars must be continuously monitored for holidays. Holidays are defined as discontinuities in the coating that are not discernible to a person with normal or corrected vision. ASTM A775/A775M limits the maximum number of holidays to an average of one per foot over the length of the bar. Any void, crack, thin spot, inclusion, or contamination that lowers the dielectric strength of the coating to less than 80,000 ohms is counted as a holiday. Continuous monitoring is done with in-line holiday detectors on each coating line (Fig. 8) and is supplemented with spot-checks using hand-held detectors (Fig. 9).

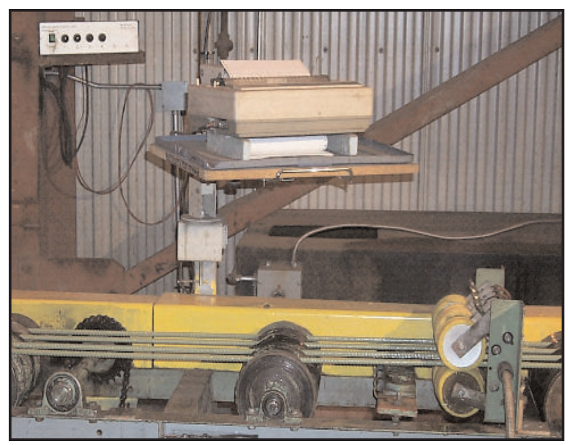

Figure 8—In-line Holiday Detector

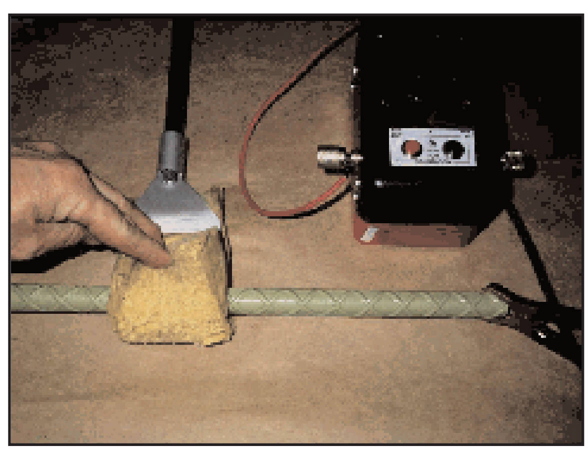

Figure 9—Hand-Held Holiday Detector

Coating thickness

Coating thickness has a significant impact on coating quality and performance. If the coating is too thin, there is a greater likelihood of holidays and damage. If the coating is too thick, the bar deformations will be less effective; this may affect the bond strength between the coated bars and the concrete. Unless specified otherwise by the purchaser, the epoxy coating thickness is required to meet ASTM A775 / A 775 M. The ASTM specification requires the coating thickness to be between 7 and 16 mils. The coating thickness is to be measured with magnetic gauges.

Coating Flexibility

The coating flexibility test assesses the coating's ability to resist cracking, tearing, disbonding, and other mechanical damage as a result of bending. The test also provides an indication of the adequacy of surface preparation and cleanliness, degree of coating cure, application temperature, and powder quality.

Coating stresses are a function of the rate of bending; the quicker a bar is bent, the greater the stress at the coating-to-steel interface. The flexibility of the coating is evaluated by bending coated bars around a mandrel of a specified diameter and within a certain amount of time, based on the bar size. The coating at the bend is then inspected for evidence of cracking or disbondment (Fig. 10). The plant is required to retain test specimens for 30 days.

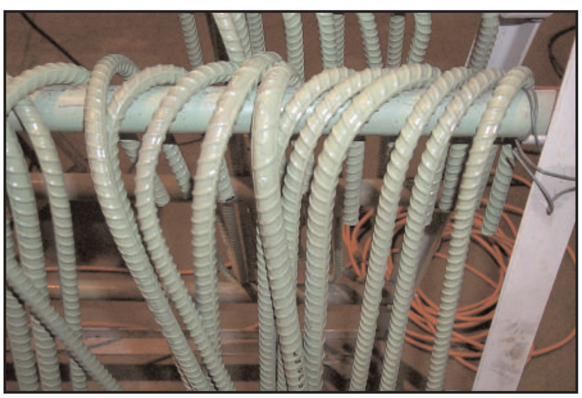

Figure 10—Coating Flexibility Test

Cathodic Disbondment

Although cathodic disbondment test results do not directly correlate to corrosion resistance of epoxy-coated steel reinforcing in reinforced concrete, they do reflect the overall consistency of the coating production line. Accepted practice is that the moving average of the test results should be evaluated, rather than single test values. A change in the moving average of the test results often indicates that a change has occurred in the prodution process and that the process should be reviewed.

The test is done on a short length of coated bar that has a small diameter hole drilled through the coating, into the steel (Fig. 11). The bar is placed in a salt solution and subjected to an electrical current for 168 hours. The bar is then removed and the coating adjacent to the hole is peeled back with a knife. The amount of epoxy coating that can be peeled off is a reflection of the coating's ability to resist the effects of the salt solution ions electrical current. The cross axis of the exposed area is measured and the radius of disbondment (Fig. 12) is determined.

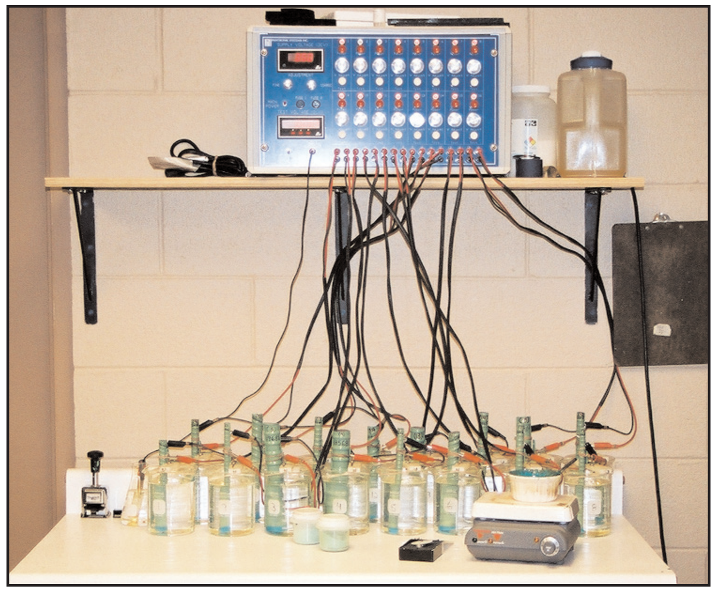

Figure 11—Cathodic Disbondment Test

Figure 12—Radius of Disbondment

Storage and Handling of Epoxy Powder

Because epoxy powder can start to cure prematurely if stored at elevated temperatures, plants are required to monitor the temperature of the storage area to ensure that it does not exceed the temperature specified by the powder manufacturer. Use of a continuously recording thermometer is encouraged.

Powder is to be stored in the unopened manufacturer's containers and must be kept dry at all times; plants are prohibited from using powder that has exceeded the manufacturer's specified expiration date. The Program also requires that the plant maintain documentation on the epoxy manufacturer's prequalification tests. The pre-qualification tests determine the acceptability of a specific epoxy powder with respect to chemical and abrasion resistance, resistance to applied voltage and impact, chloride permeability, adhesion, flexibility, bond strength to concrete, and hardness. Unless specified otherwise by the purchaser, epoxy powder must meet the requirements of ASTM A775/A775M, Annex A1, Requirements for Organic Coatings for Steel Reinforcing Bars.

Handling and Storage of Epoxy-Coated Reinforcing Bars

The program requires that coated bars be handled in a manner that minimizes the likelihood of damage to the coating. This means that exposed metal surfaces and edges should be padded or covered with plastic, nylon slings should be used when lifting the bars, and bars should be stored off the ground on wooden cribbing. If metal strapping is used to bundle the bars, it should be padded so that there is no direct contact with the bars (Fig. 13).

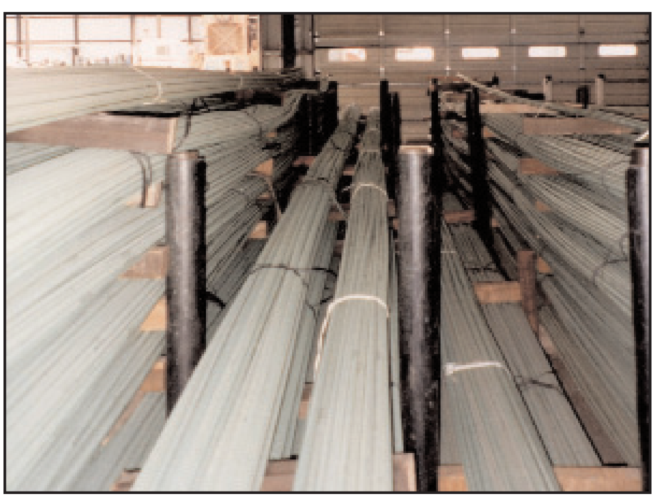

Figure 13—Storage

Bar Identification and Rejected Material

The program also requires that bar identification be maintained throughout the coating process, to the point of shipment. The coating applicator must be able to identify the reinforcing steel used (the mill and heat number), the date and time that the coating was applied, and the applicable specification (ASTM A775/A775M or as specified by the purchaser). Coated bars and other materials that have been rejected must be clearly identified so that they are not intermingled with acceptable material.

Summary

CRSI's Plant Certification Program is a voluntary, industry-sponsored program, based on an independent third-party inspection. It should be emphasized, however, that it is a process certification, not a product quality guarantee. It is not intended to replace acceptance testing of the materials.

The overriding goal of the program is to assist coating applicator plants in maintaining a high level of excellence in both their plant operations and the products they produce. In achieving this goal, the program helps to ensure that the epoxy-coated reinforcing bars delivered to a job-site meet the current high industry standards.

Four Tenets of Fabrication and Field Handling of Epoxy Coated Steel Reinforcing Bars

1. **Repair:** Material used to patch ends and damaged portions of the coated bars is to be compatible with the epoxy coating and capable of providing an acceptable level of protection from corrosion. In practice, this means that patch material is applied in accordance with manufacturer's instructions.

2. **Fabrication:** Contact areas of the fabrication equipment are to be covered with material such that coating damage is minimized. Practically, this means that drive rolls, mandrel, and back-up barrel are covered with high density plastic.

3. **Handling:** Coated bars are to be handled in a manner that minimizes the likelihood of damage. For handling this means that contact points are to be padded, and that coated bars are bundled in such a manner that the strapping will not damage or cut the coating. In addition, coated bars and bundles are to be lifted in a manner that minimizes bar-to-bar abrasion, and they are not dropped or dragged.

4. **Storage:** Coated bars are to be stored in a manner that minimizes the likelihood of damage. This means that coated bars and bundles are to be stored above ground on wooden or other padded supports with timbers placed between bundles, coated and uncoated steel reinforcing bars are stored separately, long-term storage is avoided, and material delivery scheduled to suit construction progress. If cumulative out of door exposure, including previous uncovered storage time is greater than two months, coated bars are covered with opaque polyethylene, or other suitable ultra-violet light protective material and provisions are made to minimize condensation under the cover.

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