EPOXY-COATED REINFORCING BARS

CRSI

ENGINEERING DATA REPORT NUMBER 14

COMPLIMENTS OF CONCRETE REINFORCING STEEL INSTITUTE

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Reinforced concrete is inherently a durable and near maintenance-free construction material under normal conditions. However, contemporary society's demands or harsh environmental conditions can cause deterioration of the material. For example, the "bare-roads" policy in "frostbelt" states requires heavy and continual application of deicing salts during the winter months, resulting in severe and rapid deterioration of bridge decks.* Some reinforced concrete bridge decks with an expected service life of 25 to 50 years, have become so badly deteriorated that they have required replacement after only 5 to 10 years. Deterioration of decks and other bridge elements is not confined to the Northern states. Air-borne salt spray near the coasts of "sunbelt" states such as Florida can also cause deterioration. Depending upon environmental conditions or their function, other types of reinforced concrete structures or elements thereof can be subjected to deterioration.[1]** Some examples are parking garages, port and marine structures, wastewater treatment plants, cooling towers, and other liquid-retention or liquid-conveying structures.

Corrosion mechanism—The process of corrosion in a bridge deck begins with the deicing salt in solution as ice melts, penetrating to the level of the reinforcing bars. Chloride contained in the salt combines with oxygen, and causes rusting of the bars. The rust expands and occupies a greater volume than the original steel and eventually causes cracking of the concrete. General spalling occurs or potholes then form in the bridge deck surface. Once corrosion of the bars has cracked the concrete, more chloride enters to attack the bars, and deterioration of the reinforced concrete bridge deck is accelerated.

Corrosion-protection systems—Various methods to protect bridge decks have been tested or used. The two basic approaches to protection are 1) keep the chloride from getting to the reinforcing bars, and 2) prevent rusting of the bars even if chloride penetrates the concrete. In the first approach, methods include placing a waterproof membrane on the concrete which is then covered by a thin, asphalt wearing course; adding a special, high-quality, concrete topping overlay on a new deck; sealing the deck with linseed oil; or making the concrete watertight by mixing in additives such as wax beads or plastic. Ways to protect the reinforcing bars from chloride attack are to coat the bars with a non-metallic material such as epoxy, or with a metallic coating such as zinc (galvanizing); or neutralize the chloride ions by chemical action or some other process, e.g., concrete admixtures or cathodic protection.

The Federal Highway Administration (FHWA) has done or sponsored research on several of the preceding protection methods. They have also assisted in the construction of experimental projects. The research on epoxy-coated reinforcing bars and bars coated with other non-metallic materials was done by the National Bureau of Standards (NBS) under FHWA's sponsorship.

Epoxy-coated reinforcing bars are a viable and cost-effective corrosion-protection system for reinforced concrete structures. Rapid advancement in technology has been made in the nearly 10-year old industry. Before specifying a corrosion-protection system, the engineer or architect should carefully evaluate the particular structure's requirements for such a system, and the potential benefit-cost ratio thereof. Costs should be considered on the basis of initial cost, maintenance, and rehabilitation or replacement of the structure or its elements.

To serve the construction industry, this Engineering Data Report (EDR) presents basic up-to-date technical information on epoxy-coated reinforcing bars in a question-and-answer format. For owners and the public to gain maximum benefit from a relatively new material, it is essential that all parties involved in the construction industry be aware of the current specification, usage, properties and relative cost of the material.

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* Reinforced concrete bridge decks are mentioned frequently in these introductory remarks, because 1) their deterioration nationwide is such a major concern, and 2) the impetus for research on, and usage of corrosion-protection systems resulted primarily from the bridge deck problems.

** Raised numbers indicate references

Q 1: *When were epoxy-coated reinforcing bars first used in an actual construction project?*

A: During 1973 in a Pennsylvania bridge deck.

Q 2: *Are epoxy-coated bars widely used in the United States?*

A: Yes, and the usage is continually increasing; they are now being specified for new and replacement bridge decks by over 40 of the 50 state highway departments; the bars are also used in other parts of bridge structures, e.g., piers and parapets. In recent years, usage has spread to many other types of reinforced concrete structures such as parking garages, marine structures, wastewater treatment plants, cooling towers and other parts of power plants, and subways.

Q 3: *Were epoxy coatings originally designed for reinforcing bar protection?*

A: Epoxy coatings that were tested and originally specified for use on reinforcing bars were materials designed and used to protect pipelines. It was not until 1976 that a fusion-bonded coating specifically designed for reinforcing bars reached the market.

Q 4: *What is a fusion-bonded epoxy coating?*

A: Fusion bonded means that the coating achieves adhesion as a result of a heat-catalyzed chemical reaction. In addition to the chemical adhesion, there is also a physical adhesion of the coating to the bar which results from developing an anchor pattern on the bar with the abrasive used in the cleaning process.

Q 5: *Why is adhesion of the coating so important?*

A: The main purpose of course is that the coating will not disbond when the reinforcing bar is subject to stresses during fabrication, handling, placing and in service. The coating also must be able to resist abrasion and impact forces to prevent damage. Fusion bonding produces a "tough" coating which has these characteristics.

Q 6: *Is there a specification covering epoxy-coated reinforcing bars?*

A: In 1981, the American Society for Testing and Materials (ASTM) issued "Standard Specification for Epoxy-Coated Reinforcing Steel Bars (A775-81)."[2] The Concrete Reinforcing Steel Institute recommends the use of A775-81 in user project specifications.

Q 7: *Briefly, what provisions are included in the A775 specification?*

A: There are requirements for the chemical, corrosion-resistive and physical properties of the epoxy powder material; cleaniness of the bars to be coated; method of application of the coating; limits on thickness of the coating; acceptance testing of the coated bars; and permissible coating damage and repair.

Q 8: *Please elaborate on the cleanliness requirements of the bars?*

A: The bars are cleaned by abrasive blasting with steel shot or steel grit to a near-white metal finish.

Q 9: *How is the epoxy powder applied to the clean bars?*

A: A775 requires the coating to be applied by an electrostatic spray method.

Q 10: *Briefly, what is involved in this method of application?*

A: The clean bars are preheated to about 450°F and pass through a chamber equipped with electrostatic spray guns that apply the charged dry powder to the bars; the coated bars then pass through a cooling process, typically a water quench bath.

Q 11: *Have other methods of coating application been used?*

A: Yes, even in the NBS laboratory tests[3] liquid epoxies were applied by brushing and dipping, and epoxy powder was also applied in a fluidized bed. It is more difficult to control the coating thickness using these methods. The NBS concluded that the electrostatic spray method is the most effective application method in producing thin films free of defects.

Q 12: *What thickness of coating is required by A775?*

A: The thickness of the coating after curing must be 5 to 12 mils; the maximum thickness does not apply to repair of small spots of coating damage (touch-up).

Q 13: *Are there any potential problems with bond of the epoxy-coated bars in concrete?*

A: No potential problems concerning bond have been identified. In the NBS research[3] bars with average film thicknesses of 5 to 11 mils had acceptable bond strengths based on pullout tests. The researchers state in Reference 4 that a previous study of uncoated reinforcing bars indicated the average bond strength of pullout specimens was 75% of the average value for beam specimens. This conclusion indicates that pullout tests are a conservative measure of bond strength. For production application of the coating per A775, the maximum thickness was raised to 12 mils to permit, in those isolated cases, coverage of reinforcing bars with certain surface imperfections that are inherent in making the bars. A thickness of 12 mils is a practical upper limit at which there is no appreciable loss of bond of the coated bars in concrete. Considering bond strength, flexibility, creep characteristics, and minimum corrosion protection requirements, the NBS laboratory tests showed that the optimum coating thickness is 5 to 9 mils. From a cost standpoint, a coating applicator will strive to keep the coating thickness near the minimum of 5 mils, perhaps about 7 mils. In addition to assuring satisfactory structural performance of the coated bars in concrete, the maximum thickness in A775 was also established on the basis of fabrication. Thicker coatings are more susceptible to cracking during fabrication.

Q 14: *What acceptance tests are included in A775?*

A: There are requirements for measuring the thickness of the coating; continuity of coating; and adhesion of coating.

Q 15: *What is the "continuity of coating" test, and what is its purpose?*

A: After the coated bars have passed through the cooling process, the coating is checked for holidays (pinholes that are not evident to the naked eye) with an electric detector. A775 limits the maximum number of holidays on the coated bars. The purpose of the test is to assure that the coating has been properly applied to the bars, and that there are a minimum number of tiny cracks or pinholes in the coating.

Q 16: *What is the "adhesion of coating" test?*

A: As the word "adhesion" implies, the test is to determine how well the coating is bonding to the bars. Adhesion is evaluated by making 120° bend tests around mandrels of specified diameters. No cracking or disbonding of the coating visible to the naked eye on the outside radius of the bent bar is permitted. This test also serves to demonstrate practical bendability of coated bars.

Q 17: *Do the colors of the coatings vary?*

A: Yes, depending on the particular pigments used by the epoxy powder manufacturer. Some colors will fade in field use when exposed to sunlight over a period of time. This fading does not harm the coating.

Q 18: *When is shop fabrication of the bars done—before or after the coating is applied?*

A: For overall economy, the preferred procedure is to coat straight bars and then to fabricate the coated bars. Typically, several straight bars are coated at the same time. Coating bent bars or bars with hooks slows down the operation. It would necessitate separating the fabricator's bundles into straights and bent, and require the coating applicator to preserve identification tags and re-bundle.

Q 19: *It was mentioned previously that the coated bars must pass bend tests (adhesion of coating). But can the epoxy coating on straight bars routinely withstand shop bending?*

A: Yes, the properly-applied coating is so tough, flexible and adheres so well to the bars that coated rebars can be shop-fabricated into the standard hooks and typical bends that are used for uncoated bars. The A775 specification permits some coating damage due to fabrication and handling. When damaged areas exceed the specified limits, they must be touched-up with patching material compatible with the coating material and inert in concrete. Many fabricators bend bars using pins protected with nylon collars to protect the coating during bending.

Q 20: *Does the A775 specification contain any provisions for the coated bars at the construction site?*

A: A775 is patterned after the other ASTM specifications for steel reinforcement. These are product standards and their provisions cover the product to the point of shipment. In addition, the A775 specification is intended to be used for procurement of epoxy-coated reinforcing bars for a wide variety of structures by various agencies, A-E firms, constructors, etc. From a practical standpoint, provisions for the coated bars beyond the point of shipment should be included in the project specifications.

Q 21: ***What are some of the recommended practices to minimize damage to the coating during handling, transporting and placing (field installation) the coated bars?***

A: All handling and hoisting should be done carefully; nylon lifting slings should be used, or wire rope slings should be padded; bundles of bars should be lifted to prevent bar-to-bar abrasion; spreader bars should be used for lifting bundles, or the bundles should be lifted at the third points with nylon or padded slings. Bundling bands should be padded or made of nylon. Coated bars should be stored on padded or wooden cribbing. Bars or bundles of bars should not be dragged over the ground or over other bars. After the bars are placed, walking on the bars by workmen should be held to a minimum, and workmen should be careful not to drop tools or other heavy construction materials on the bars in place. Recommendations on how to handle, store and place epoxy-coated reinforcing bars are available from fabricators.

Q 22: ***Are there any special precautions required during concrete placement?***

A: Really, only common-sense type considerations. Care should be exercised so that concrete conveying and placement equipment does not bang on the coated bars. Runways for concrete buggies, hoses for pumping, etc., should be set up, supported and moved carefully to minimize damage to the coating and not knock the bars out of their intended position.

Q 23: ***Is the intent of the preceding comments to emphasize care in handling, transportation and installation of coated bars?***

A: Yes. The coating is applied under shop-controlled conditions and stringent acceptance testing must be followed to assure that the coated bars meet the specification. However, more care must be used in transporting, handling, and placing coated bars than is required for uncoated bars. It is more productive and economical to exercise care in handling and placing coated bars rather than having to repair extensive damage. Experience has shown that with normal common-sense considerations, field touch-up is usually minimal.

Q 24: ***Should particular types of bar supports be used to support epoxy-coated reinforcing bars in a structure?***

A: Yes, portions of wire bar supports should be coated or the bar supports should be made of other materials. The purpose of particular types of bar supports is to minimize damage to the coated bars during field placing operations and not introduce a potential source of corrosion at or near the coated rebars.

Q 25: ***Should project specifications specify the types of bar supports?***

A: Yes, by all means. We have found in general that project specifications, even those of state highway agencies, are somewhat vague on the requirements for the bar supports. Problems and misunderstandings in furnishing bar supports for coated bars have resulted because of the lack of specifications.

Q 26: ***Does the Concrete Reinforcing Steel Institute have a recommendation for the bar supports?***

A: Where users require protection at, and in close proximity to the point of contact with the epoxy-coated bars, we recommend that: "Bar supports should be manufactured from a dielectric material or wire bar supports should be coated with dielectric material such as epoxy or vinyl compatible with concrete, for a minimum distance of 2 inches from the point of contact with the epoxy-coated reinforcing bars."

Q 27: ***Should a particular type of tie wire be used in tying assemblages of coated bars?***

A: Yes, some type of coated wire should be used to minimize damage or cutting into the bar coating. Epoxy- or plastic-coated tie wire has been used; however, these kinds of coated wire tend to slip. A nylon-coated tie wire is available and has less tendency to slip.

Q 28: ***Do all the bars in a bridge have to be coated?***

A: In "frostbelt" states using deicing salts, current practice is to coat the top mat of bars only (top two orthogonal layers of bars). This practice is mainly responsible for the cost-effective advantage of using epoxy-coated rebars as a corrosion-protection system in a bridge deck. In a salt-water sea coast location, all of the bars in the deck, as well as those in the other parts of the bridge, might have to be epoxy-coated.

Q 29: ***Is there any published information on the approximate difference in cost between uncoated and coated bars in bridge decks?***

A: FHWA's notice[5] included some costs from late 1975 construction contracts. Total additional in-place cost of coated bars was 25 to 30¢ per pound. Keep in mind the cost figures are during the infancy of the industry. As expected with practically any new product or material, an increase in volume, competition among more suppliers, and progress on the "learning curve" by all parties involved tend to reduce the cost difference of coated vs. uncoated bars.

Q 30: ***Are there any more up-to-date published costs on coated and uncoated bars for bridge decks?***

A: A bid analysis of a bridge in Colorado in a recent issue of *Engineering News-Record*[6] shows the additional in-place cost of epoxy-coated bars at 10¢ per pound. The two contractors included in the analysis both bid the cost of uncoated bars at 40¢ per pound or $800 per ton; epoxy-coated bars were bid at 50¢ per pound or $1,000 per ton.

Q 31: ***Are there any published costs on epoxy-coated bars for other types of structures?***

A: Reference 7 reports costs for a new parking garage in the Minneapolis-St. Paul area. The supplier of the coated bars is quoted as saying the coated bars cost approximately $300 to $350 per ton over the cost of uncoated rebars for that type of project; uncoated bars would cost about $510 to $560 per ton. An interesting point in the article, based upon the total floor area of the garage, is that the additional cost of the coated bars was figured at approximately 40¢ per square foot or only 3.6% of the total cost.

Q 32: ***How does the cost of epoxy-coated coated rebars compare to galvanized rebars?***

A: Epoxy-coated rebars are competitive with galvanized rebars.

Q 33: ***What are some design tips that an engineer-architect can use to help hold the cost of epoxy-coated reinforcing bars?***

A: Basically the same considerations as for uncoated bars: maximize the use of straight bars in a design; based upon anchorage (bond) considerations, maximum spacings, and distribution of flexural reinforcement, use the largest bar sizes possible; and use or specify the fewest possible bar sizes for a project. On projects where uncoated and coated bars are used, be precise in identifying those bars which are to be coated.

Q 34: ***Will there be more usage in the future?***

A: We anticipate increased usage of epoxy-coated reinforcing bars in the future. The volume should increase in bridge work when more funds become available to the states. There is also a large potential increase in usage in the other types of structures mentioned earlier.

Q 35: ***Any additional comments on the industry?***

A: The coating application process, the fabrication of epoxy-coated reinforcing bars, and other facets of the industry have become well-established in about 10 years. The industry is fully capable of supplying a high-quality product to serve as an effective corrosion-protection system. Improvements in the epoxy-powders and coating application and overall experience in the industry have virtually eliminated the early problems of cracked coatings and reduced field handling damage requiring excessive touch-up.

Q 36: ***Are there other sources of information?***

A: We have tried to cover the main points on epoxy-coated reinforcing bars and cite major references in this EDR. For further information, the reader is urged to contact the:

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REFERENCES

Cited references

1. "Steel Corrosion Damage on Vertical Concrete Surfaces," *Concrete Construction,* February 1981, Part I, pp. 91-93 and Part II, pp. 97-101.
2. "Standard Specification for Epoxy-Coated Reinforcing Steel Bars (A775-81)," Part 4 of *1982 Annual Book of ASTM Standards,* American Society for Testing and Materials, Philadelphia, pp. 859-864.
3. "Nonmetallic Coatings for Concrete Reinforcing Bars," by J. R. Clifton, H. F. Beeghly and R. G. Mathey, Report No. FHWA-RD-74-18, February 1974; available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.
4. "Bond of Coated Reinforcing Bars in Concrete," by R. G. Mathey and J. R. Clifton, *Journal of the Structural Division,* ASCE, Vol. 102, No. ST1 Proc. Paper 11855, January 1976, pp. 215-229.
5. "Interim Report No. 2, NEEP No. 16 Coating Reinforcing Steel for Bridge Decks," FHWA Notice N5080.48, Federal Highway Administration, March 1976.
6. "Colorado Bridge Draws Nine," *Engineering News-Record,* May 20, 1982, p. 49.
7. "Fusion-Bonded Epoxy-Coated Rebars," *Concrete Construction,* August 1980, pp. 587-591.

General reference

"Epoxy Coatings for Corrosion Protection of Reinforcement Steel," by W. P. Kilareski, *Chloride Corrosion of Steel in Concrete,* ASTM STP 629, 1977, pp. 82-88.

ENGINEERING DATA REPORT was formerly called Product Services & Information (PSI).
Complete set of 16 reports available at $16.00 from Concrete Reinforcing Steel Institute. Subjects include:

• Serviceability Requirements with Grade 60 Bars – ACI 318-71 (Bulletin 7603A) • Splicing Reinforcing Bars – Welding and Splice Devices (Bulletin 7604A) • Reinforcing Bars Required – Minimum vs Maximum (Grade 60) (Bulletin 7701A) • Saving Steel in Columns (Bulletin 7702A) • New Maximum Column Capacities – 1977 ACI Building Code (Bulletin 7703A) • Implication of Recent Tests upon "Standard" Details, Part 1 of 2 (Bulletin 7801A) Part 2 of 2 (Bulletin 7802A) • Combined Strength-Slenderness One-Step Design for Columns in Ordinary Structures (Bulletin 7803A) • Grade 60 Bars in Sanitary Structures (Bulletin 7804A) • Selection of (Open) Stirrups/(Closed) Ties in Flexural Members for Economy (Bulletin 7901A) • Update on ASTM Specification for Reinforcing Bars (Bulletin 7902A) • Evaluation of Reinforcing Steel in Old Reinforced Concrete Structures (EDR Number 11) • Field Corrections to Rebars Partially Embedded in Concrete (EDR Number 12) • Preliminary Design for Tied Columns (EDR Number 13) • Epoxy-Coated Reinforcing Bars (EDR Number 14) • Orientation of Bars in Round Columns (EDR Number 15) • Limitations Upon Use of Lap Splices in Columns (EDR Number 16)

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