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Epoxy-Coated Reinforcement – an Effective Corrosion-Protection System

Armatures recouvertes de résine – une protection efficace contre la corrosion

Epoxy-beschichtete Bewehrung – ein effizienter Korrosionsschutz

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SUMMARY
This paper describes experience in the United States with epoxy-coated reinforcement including coating industry practices, recommended construction practices, and requirements in specifications. Recent laboratory and field research on the corrosion resistance of coated reinforcing bars is cited. Structural performance of concrete members reinforced with coated bars is discussed in terms of bond strength and fire endurance.

RÉSUMÉ
La contribution décrit les expériences faites aux Etats Unis avec les armatures recouvertes de résines, et donne les procédés de fabrication, les recommandations pour la construction et les spécifications requises. On cite les recherches récentes en laboratoire et sur chantier concernant la résistance à la corrosion des armatures enduites de résine. Les performances structurales d'éléments en béton contenant ces armatures sont discutées en ce qui concerne les qualités d'adhérence et la résistance au feu.

ZUSAMMENFASSUNG
Dieser Beitrag beschreibt die in den USA gemachten Erfahrungen mit epoxy-beschichteten Bewehrungen, einschliesslich der Herstellungsverfahren, der Empfehlungen für die Baustelle und der Qualitätsanforderungen. Neuere Labor- und Feldversuche zur Ermittlung der Korrosionsbeständigkeit von beschichteten Bewehrungsstählen werden aufgezeigt. Das Verbundverhalten und der Feuerwiderstand von Bauwerksteilen mit beschichteten Bewehrungen werden diskutiert.

1. INTRODUCTION

In the 1960s, cooperative studies by several state highway agencies, the U.S. Department of Transportation (USDOT), and the Portland Cement Association (PCA) to assess the durability of reinforced concrete bridge decks confirmed that there was a widespread and costly problem of premature deterioration of bridge decks. Corrosion of the reinforcing steel by deicing salts was identified as the main cause of the deterioration. This major problem served as the impetus to accelerate research and develop corrosion-protection methods. The USDOT commissioned the National Bureau of Standards (NBS) to conduct research on the feasibility of using non-metallic coatings on reinforcing bars. NBS evaluated 47 organic coatings [1]. Based on their research, NBS recommended four epoxy powder coatings for use with ribbed bars.

The first application of epoxy-coated bars was a bridge deck in the State of Pennsylvania in 1973. Since 1973, usage in new and replacement bridge decks and in other parts of bridge structures has been continually increasing. Presently, 46 of the 50 state highway agencies use coated bars. States, such as Florida, use coated bars for bridges that are exposed to sea water or salt spray. In recent years, usage has spread to other types of structures, e.g., automobile parking garages, port and marine structures, and wastewater treatment plants. Total usage of epoxy-coated bars in the U.S during 1987 is estimated as 160,000 metric tons.

2. COATING INDUSTRY PRACTICES

For overall economy, the preferred procedure is to coat straight bars and then to fabricate the coated bars. Most of the coating applicators in the U.S. have their equipment arranged to coat straight bars. A few applicators have the capability to coat bent bars. Typically, the coating is applied to bars in a production-line operation which is housed in a plant or factory. Steps in the application process are cleaning of the bars, and application and curing of the coating. Bars are cleaned by abrasive blast cleaning, preheated to about 230°C, and passed through a chamber equipped with electrostatic spray guns that apply the charged dry powder to the grounded bars. The coated bars then pass through a cooling process, typically a water spray bath, to accelerate curing of the coating. The material specification [2] prescribes the requirements for the epoxy powder material, cleanliness of the bars, and the coating application method.

Acceptance tests for thickness, continuity, and adhesion of coating are also prescribed by the material specification. The thickness of the coating after curing must be 0.13 to 0.30 mm. In the continuity test, coated bars are monitored for holidays (pinholes that are not evident to the naked eye) with an electrical detector. 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. Bonding of the coating to the bar is evaluated by the adhesion test -- a bend test, which also serves to demonstrate practical bendability of coated bars.

Properly-applied coatings are tough, flexible, and adhere so well that coated bars can be shop-fabricated just like uncoated bars. Many fabricators bend bars using pins with nylon collars to protect the coating during bending operations. Damaged coating due to fabrication must be repaired before the coated bars are shipped to the site.

3. CONSTRUCTION PRACTICES

All parties involved with a new construction material should be apprised of the material's characteristics, limitations, special requirements, etc. An effort has been made to disseminate information about epoxy-coated bars to structural engineers, contractors, and inspectors [3, 4, 5]. Engineers should include requirements in their project specifications to cover job site operations concerning coated bars [6, 7]. The epoxy coating on a bar is hard and relatively duraable, but a contractor has to realize that all construction operations must be performed in a manner to minimize damage to the coating. Simply stated, more care must be exercised with coated bars than with uncoated bars. Since requirements in project specifications and recommended construction practices are closely related, these items are discussed together here.

Repair of damaged coating - specify limits on permissible coating damage due to construction operations, and when required, the repair of damaged coating. Current practice permits individual damaged spots up to a certain area or size without requiring repair, the limit is usually in the order of 40 sq mm. Individual damaged spots larger than this limit have to be repaired. Current practice also limits the maximum amount of total coating damage to 2% of the total surface area per metre of the coated bar, i.e., the repaired and unrepaired areas. The patching or touch-up material for repairing damaged coating should conform to the coated bar specification; and the repair work should be done in strict accordance with the patching material manufacturer's instructions.

Handling and placing - specify requirements to minimize coating damage, i.e., handling equipment should have protected contact areas; bundles of coated bars should be lifted at multiple pick-up points to minimize bar-to-bar abrasion from sags in the bundles; coated bars or bundles of coated bars should not be dropped or dragged; and coated bars should be stored on protective cribbing.

Bar supports and tying - bar supports should be made of dielectric material, or wire bar supports should be coated with dielectric material. When reinforcing bars are used as support bars, the bars should be epoxy-coated. Coated tie wire should be specified. Suitable coatings for tie wire are vinyl or epoxy.

Splices - for mechanical connections and welded splices, there will be damaged coating on the bars in the vicinity of the splices. The damaged coating should be repaired. After installation of mechanical couplers or completion of welding, all parts of the connections should be coated with patching material. Adequate ventilation should be provided when welding coated bars.

Field cutting - cutting of uncoated or coated bars, should be done only if permitted by the engineer. Patching material should be applied to the cut ends of coated bars. Coating damage and field touch-up can be reduced by saw cutting bars rather than flame cutting.

Field bending or straightening - include any special requirements for bending or straightening coated bars which are partially embedded in hardened concrete. Damaged coating on the bars should be repaired. If heat is used, adequate ventilation should be provided.

4. PERFORMANCE - CORROSION RESISTANCE

4.1 Laboratory Tests

Several accelerated corrosion laboratory tests have been conducted since the NBS research. In many of the tests, the concrete specimens reinforced with epoxy-coated bars are subjected to cyclic saltwater exposure and drying conditions. Typically, the specimens in laboratory time-to-corrosion tests are not loaded. The performance of coated bars in these types of tests has been very good [8].

Accelerated corrosion tests on precracked, loaded concrete slab specimens also show good performance by epoxy-coated bars [9]. The researchers observed that the coating had chipped off the bar ribs at crack locations and light surface corrosion of the bar was evident. It was the researchers' opinion that the corrosion should be very localized, because the coating should remain intact on a bar away from the cracks, and no cathodes can form to sustain the corrosion process.

4.2 Longer-term field performance

Many practicing engineers would probably agree that it is encouraging that further laboratory tests are confirming the high degree of corrosion-resistance provided by epoxy-coated bars, but an important and practical question is: how are the bars performing in actual structures? Since the use of epoxy-coated bars in bridge decks began only 15 years ago, relatively little published data are available now on their performance in actual structures. A field study of 22 bridge decks in Pennsylvania indicates good performance [10]. The decks were in service for about 10 years. None of the 11 decks with epoxy-coated bars showed any visual signs of deterioration. Four of the 11 decks with uncoated bars exhibited deterioration of the concrete caused by corrosion of the reinforcement.

5. STRUCTURAL BEHAVIOR AND PERFORMANCE

5.1 Bond strength

The question raised most often regarding structural behavior and performance of epoxy-coated bars is: what about their bond strength? That is certainly an appropriate question. The coating on a ribbed bar has a very smooth surface. It is quite comfortable to the touch as compared to uncoated bars. The smooth coating leads, intuitively, to the bond strength question. In the NBS research, bond strength was evaluated by making pull-out tests on 20-mm diameter coated bars. The NBS researchers concluded that the bond strength of coated bars was acceptable if the coating thickness did not exceed 0.25 mm. It should be noted that the NBS research focused on the bridge deck deterioration problem, i.e., the use of relatively small diameter bars in slab elements.

With the increasing usage of coated bars including larger sizes and applications in many other types of structures besides bridge decks, and coupled with the frequently raised questions regarding bond strength, it became apparent that more research was needed. A research project was initiated in 1985 to determine if there is a difference in bond strength between epoxy-coated and uncoated bars, and if so, how much. Beam specimens, with lap-spliced coated or uncoated Grade 400 bars, were load tested [11]. Performance of the lap splices served as the basis for evaluating bond strength. Variables included coating thickness, bar size, concrete strength, and casting position. The coated bars developed approximately 66% of the bond strength of the uncoated bars. All failure mechanisms were splitting of the concrete cover at the splices. Bond strength was essentially the same for the different coating thicknesses. The epoxy coating, whatever its thickness, is essentially a bond breaker of the adhesion bond. The tests showed that adhesion bond is a very important component of total bond strength of ribbed bars in concrete.

Based upon the test results, provisions for tension development length of epoxy-coated bars are being formulated for the 1989 ACI Building Code, i.e., a 50% increase when concrete cover is less than 3 bar diameters or clear spacing between bars is less than 6 bar diameters to control potential splitting fail-through the cover or splitting between bars in a layer; a 20% increase for all other conditions of cover and spacing; and the combined factor for top bar effect and epoxy coating does not have to exceed 1.7. Since the splice failures in the tests were splitting of the concrete cover, more research will be undertaken to assess the beneficial effect of transverse reinforcement (stirrups or ties) on the bond strength of coated bars.

5.2 Fire endurance

Another question about structural behavior and performance deals with fire endurance. Coated bars are being used in parking garages -- in new construction as well as in the repair and rehabilitation of existing structures. Statutory building codes usually impose a fire rating requirement on enclosed parking garages, particularly on those which comprise the lower levels of commercial or residential buildings. Structural designers' concerns focus on the heating of the epoxy coating and its subsequent effect on bond strength, i.e., when the coating on the bars softens or melts, due to heating, do the bars lose their bond with the concrete? In response to the issue, the Construction Technologies Laboratories (CTL), a Division of PCA, has fire-tested a large two-way slab reinforced with coated Grade 400 bars. The objectives of the fire test were to determine the slab's fire endurance, and compare the slab's structural performance and fire endurance to a companion slab, reinforced with uncoated Grade 400 bars, that had been fire tested previously. The slab with the coated bars performed very well in the fire test. Its fire endurance was about 4½ hours -- comparable to that of the companion slab, and more than satisfactory for use in parking garages where regulations generally require a 1½ to 3-hour fire rating. CTL plans to fire test beams, reinforced with coated bars, in the next phase of the research project.

6. EPOXY-COATED WELDED WIRE FABRIC

It was a natural progression to extend the technology of coated bars to the coating of welded wire fabric. The procedure of coating sheets of fabric parallels the processing of bars with regard to cleaning of the fabric and application of the epoxy powder coating. Coated fabric was first used in an actual construction project about five years ago. Coated fabric is being used in precast prestressed members, in topping slabs and overlays, and in bridge decks. Coated fabric is also used in reinforced earth construction, such as mechanically-stabilized embankments. ASTM is currently preparing a specification for epoxy-coated wire and welded wire fabric.

7. EPOXY-COATED STRAND

Epoxy-coated prestressing strands have been developed [12]. Two basic types of corrosion-resistant strands are commercially available. One type is intended for post-tensioning applications where bond with concrete is not required. The other type is intended for use where bond is an important consideration. The latter type has grit embedded in the outer surface of the coating which provides the coated strand with bond transfer and development length properties equivalent to or better than those of uncoated strand.

Unlike coated bars and welded wire fabric, coated strands are manufactured by a proprietary process. The company, which began development of the coated strands in 1981, will grant licenses to other firms. The strands are coated with epoxy using the electrostatic fusion-bonded process similar to bar and fabric coatings. The coating thickness on strands is nominally 0.76 mm ± 0.13 mm -- much thicker than bar coatings. This greater thickness completely bridges the interstices of the strand and provides a virtually holiday-free coating. The strand coating is considerably more flexible than bar coatings to permit stretching to large strains during tensioning operations without the formation of holidays. Epoxy-coated strands have been used in a wide variety of prestressed concrete applications and in other corrosive environments, e.g., piles, fender piles, bridge decks and girders, replacement tendons in parking structures, ground anchors (tiebacks), and stay cables.

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