# Durability and development of epoxy-coated reinforcement

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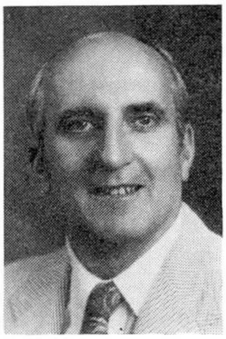
# Durability and Development of Epoxy-Coated Reinforcement

Durabilité et longueur d'ancrage de barres d'armature protégées par une couche d'époxy

Dauerhaftigheit und Verankerungslänge von mit Epoxydharz beschichter Bewehrung



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## SUMMARY
Epoxy-coated reinforcement is being widely used in the USA to improve the durability of bridge decks, parking garage decks, and other structural elements exposed to salt water or de-icing salts. Recent tests reported in this article indicate that the epoxy coating provides substantial corrosion protection. However, the coating reduces the development lengths of reinforcement particularly in applications where splitting is significant such as in tensile lap splices. Longer splices and development lengths must be used to develop the yield strength of the coated bars.

## RÉSUMÉ
Des barres d'armature protégées par une couche d'époxy sont utilisées couramment aux États-Unis pour améliorer la durabilité des dalles de ponts, de garages et d'autres structures en béton armé exposées au sel ou à l'eau salée. De récents tests, présentés dans cet article, indiquent que la couche d'époxy fournit une protection substantielle contre la corrosion. L'époxy réduit cependant l'adhérence des barres. Dans certains cas, comme les zones de recouvrement en tension, des longueurs de recouvrement et d'ancrage plus grandes sont nécessaires pour développer la limite d'écoulement des barres.

## ZUSAMMENFASSUNG
Die Verwendung von mit Epoxidharz beschichteter Bewehrung für die Erhöhnung der Dauerhaftigkeit von Brückenfahrbahnen, Decken über Tiefgaragen und anderen Elementen, welche Salzwasser oder Salz zur Verhinderung der Frostbildung ausgesetzt sind, ist in den USA verbreitet. Neueste Versuche zeigen, dass die Beschichtung die Haftfestigkeit vermindert, insbesondere beim Ueberlappungsstoss in der Zugzone. Grössere Ueberlappungen und Verankerungslängen sind notwendig, um im Bruchzustand die Fliessgrenze in den Bewehrungsstäben zu erreichen.

## 1. INTRODUCTION

It has been estimated that over 500 million U.S. dollars are spent annually for repair of bridge and parking garage decks which suffer from deterioration. The major cause of damage is galvanic corrosion of reinforcing steel induced by exposure to chlorides from deicers and salt water spray. Dissolved salts seep into bridge decks primarily at crack locations and cause steel corrosion which sets up splitting forces because of the volumetric expansion. These forces eventually break the concrete apart.

There are many recommended procedures for improving the durability of such concrete decks. The use of waterproofing membranes and hardened surfaces such as with polymer concrete have sometimes proven effective. Improved concrete quality, limitations on water-cement ratios, and increased cover will greatly restrict the chloride penetration in uncracked concretes. However, when structural cracking occurs, even these improved concretes can be penetrated by chlorides which make the reinforcement susceptible to corrosion when moisture and oxygen are present.

A widely used technique in the USA for electrochemically isolating reinforcing steel is the use of epoxy coatings. Ordinary low carbon steel deformed reinforcing bars have a fusion-bonded epoxy coating applied. The ASTM Specification [1] requires the coating to have a minimum thickness of 5 mils (0.13 mm) and a maximum thickness of 12 mils (0.30 mm). Current federal requirements mandate the use of such coated reinforcement in unprotected bridge decks in aggressive environments. When the epoxy-coated reinforcement was introduced, substantial electrochemical corrosion and other durability-related research was conducted but relatively little structural member testing and evaluation was undertaken [2,3]. The usage of such coated reinforcement is growing rapidly. It is estimated that in 1986, over 250,000 tons (227,000 Mg) of such coated reinforcement was used in the USA.

This paper reports on recent tests run on relatively large structural members to assess both the durability effectiveness and the structural action of typical epoxy coated reinforcement.

## 2. DURABILITY STUDIES

### 2.1 Test Program

As part of a study on the possible application of transverse prestressing to bridge decks, a series of rectangular reinforced and prestressed concrete specimens (Fig. 1) were used to simulate components of a bridge deck. Specimens had various combinations of stressed or unstressed prestressing tendons and uncoated or epoxy-coated deformed reinforcement. Mean 28-day concrete cylinder strength was 35 MPa. Concrete clear cover over the deformed reinforcement was 50 mm or 75 mm. Water-cement ratio was 0.44 with 5 percent air content. The typical 200 mm thick bridge deck specimens were loaded to simulate the behavior of a slab over a girder in a slab-girder bridge. A 10-15 mm deep, 3.5 percent salt solution was ponded on the specimen top surface every fourteenth day. On the next day specimens were subjected to five repeated loading cycles to produce a crack of predetermined width. Top surface crack widths of 0.05 mm and 0.38 mm were used to represent both prestressed and nonprestressed service load conditions. The 0.38 mm level is slightly greater than the generally specified crack width limits for environmental exposure in the USA. The specimens were allowed to dry until the beginning of the next exposure cycle. On the ninth day five additional load cycles were applied to provide an oxygen path to the reinforcement via the cracks. The entire exposure cycle was repeated after the fourteenth day. These cycles were repeated from eight to fourteen times which was felt adequate to judge relative corrosion damage in the vicinity of cracks. Visual observations, half-cell potential and crack measurements were made during exposure testing. After testing, a complete post-mortem was run, including chloride content determination in both cracked and uncracked zones as well as visual inspection of all reinforcement, prestressing strands and anchorages. A complete report is available in Ref. 4.

## 2.2 Test Results

Fig. 2 indicates that heavy corrosion was observed on a majority of the uncoated specimens. The corrosion often extended along the bar for 6 to 10 diameters. The classifications "heavy" or "very heavy" corrosion include evidence of severe pitting. Fig. 3 indicates that the epoxy-coated reinforcement showed very little evidence of corrosion. In a few cases the epoxy coating had chipped off the bar deformations at the cracks resulting in very light surface corrosion with no evidence of pitting. Fig. 4 indicates that the epoxy-coated reinforcement was extremely beneficial for crack widths of 0.38 mm. At crack widths of 0.05 mm where there was still some corrosion of uncoated reinforcement the coating was completely effective. The half-cell potential readings for the uncoated bars correctly predicted that corrosion was occurring. However, with coated bars, the half-cell potential readings frequently suggested corrosion activity, but when the post-mortem was carried out visual inspection indicated no corrosion.

# 3. DEVELOPMENT STUDIES

## 3.1 Test Program

Twenty-one beam specimens were tested to determine the bond strength of epoxy-coated bars [5]. The beams contained three bars which were spliced in the constant moment region. There was no transverse reinforcement in the splice region. The splices were intentionally designed to fail before the steel yielded. Nominal coating thicknesses were 0.5 and 12 mils (0.13 and 0.30 mm). The specimens were cast and tested in nine series with only the coating thickness varied in any series. The variables between series include:

- --Bar size - 19 mm (#6) and 36 mm (#11)
- --Concrete strength - 30, 55, and 80 Mpa
- --Casting position - bottom and top cast (more than 300 mm of concrete cast below the bar)

The cover over the 19 mm bars was 20 mm and 50 mm over the 36 mm bars. The spacing between bars was 100 mm with a 50 mm side cover.

## 3.2 Test Results

Epoxy-coated bars developed approximately 65 percent of the bond of uncoated bars. Based on specimens with an average coating thickness greater than 5 mils, the mean bond ratio between coated and uncoated bars was 0.65 with a standard deviation of 0.06. The reduction in comparison with theoretical bond strength [6] was nearly identical to the measured results. The mean ratio of measured bond strength to theoretical bond strength (bond efficiency) for the uncoated bar specimens was 0.996 with a standard deviation of 0.13. The mean bond efficiency of the coated bar specimens was 0.58 with a standard deviation of 0.065. The bond efficiency of the coated and uncoated bars is shown in Fig. 5.

A distinguishing feature of the coated-bar failures is the total lack of adhesion between the bar surface and the concrete. Fig. 6 shows the surfaces after failure for coated and uncoated bars. Note the shiny surface of the concrete and coated bar. The thickness of the coating did not influence the strength. In any case, coating thicknesses are not uniform. Fig. 7 shows a histogram of measured coating thickness. While the average is near the specified thickness, there was considerable variation.

The results indicate virtually no difference in bond between the top- and bottom-cast conditions; however, low slump concrete was used in casting the specimens. It is likely that there is some reduction in bond strength in the top cast position, but the effect is probably not as great as for uncoated bars.

These tests indicate that development or splice length must be increased when using epoxy-coated reinforcing bars. The increase is dependent on the type of bond failure likely to occur. All tests in the current study resulted in a splitting failure. Previous studies on epoxy-coated bars showed that reduction in bond is much less for a pullout failure. In a previous study [2] using stub-beam specimens, epoxy-coated bars developed about 85 percent of the bond of uncoated bars. However, splitting was restrained by uncoated transverse reinforcement. Comparisons of critical bond strengths in pullout tests [3] showed that epoxy-coated bars developed 94 percent of the bond of uncoated bars. In both studies, only specimens failing in bond before the bars yielded were considered. A 15 percent increase in the development length of epoxy-coated bars was recommended. Tests at the University of Texas indicate the increase in development length needed for a case where splitting failure may occur is greater than 15 percent. Using the measured average bond ratio (0.65), the development length should be increased by a factor of about 1.5 for epoxy-coated bars where a splitting mode of failure is likely.

## 4. CONCLUSIONS

Based on the limited test series reported herein, it was concluded:

(1) The epoxy-coated reinforcement greatly reduces the incidence and extent of corrosion in cracked structural members.

(2) The repeated loading of epoxy-coated reinforcement in concrete specimens can result in minor chipping and flaking of the epoxy coating on the deformations. This can provide a path for minor corrosion.

(3) The development length of coated bars needs to be increased about 50 percent in cases where a splitting failure may occur.

## ACKNOWLEDGMENTS

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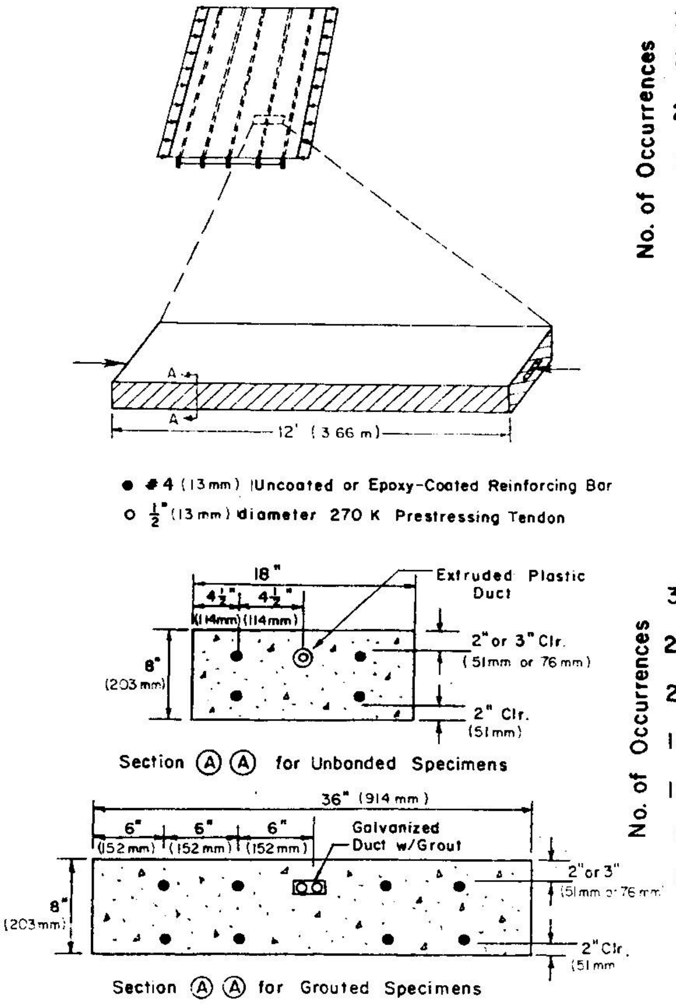



Fig. 1 Durability specimen details

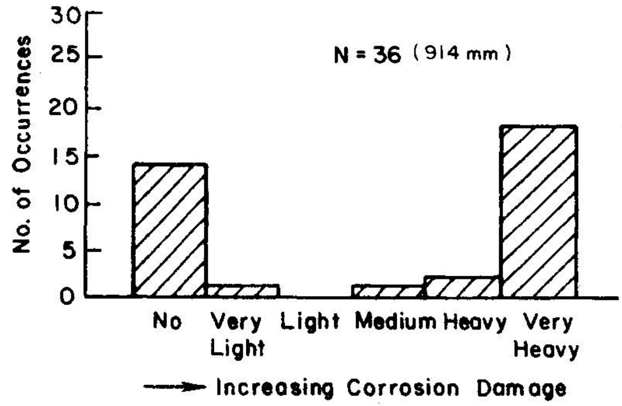



Fig. 2 Histogram of corrosion of uncoated reinforcement

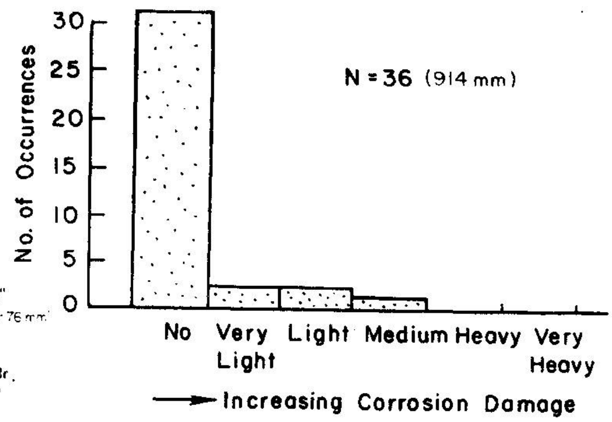



Fig. 3 Histogram of corrosion of epoxy-coated reinforcement

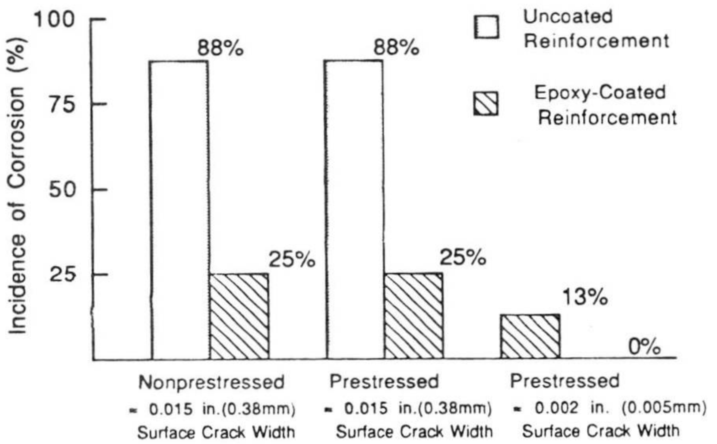
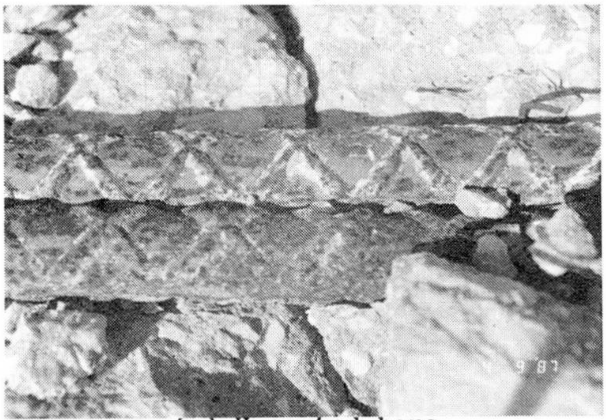



Fig. 4 Comparison of incidence of corrosion of reinforcement in nonprestressed and prestressed specimens



(a) Uncoated bars

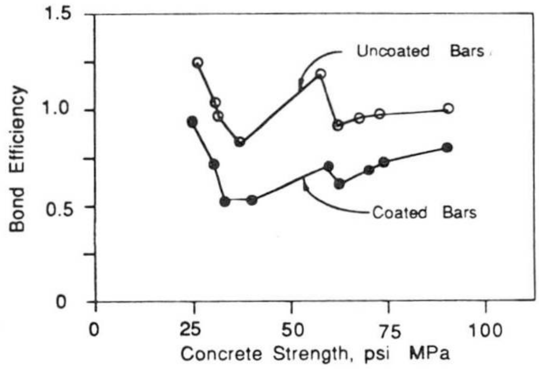
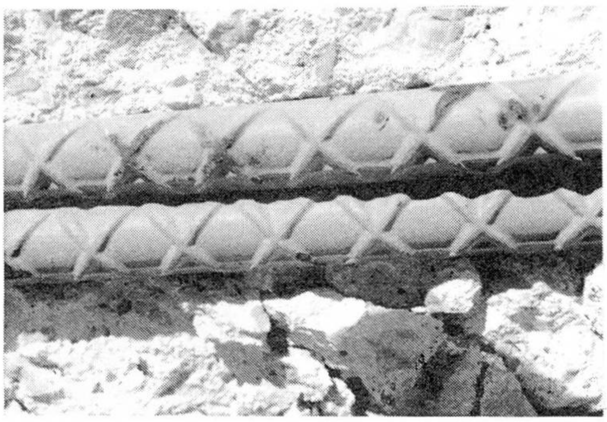



Fig. 5 Bond efficiency vs concrete strength



(b) Epoxy-coated bars

Fig. 6 Visual appearance of bar and concrete surfaces after test

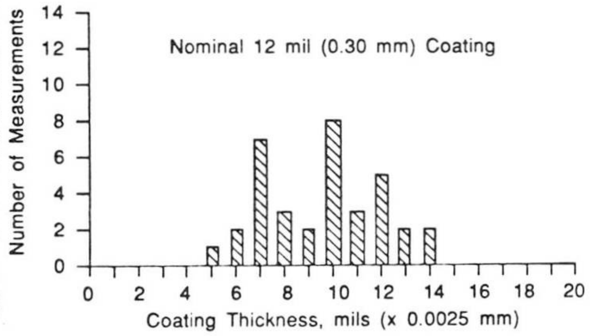



Fig. 7 Variation in coating thickness 36 mm bars