

Use of epoxy-coated reinforcing steel for increasing the service life of FDPC deck panels

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INTRODUCTION

Use of epoxy coated steel reinforcement (ECR) backs to late nineteenth's century to reduce the annual maintenance costs due to steel corrosion. After developing epoxy-coated reinforcement In the early 1970s, the construction market initiated utilizing ECR as the preferred method of corrosion protection in different structures especially highway bridges. Although use of ECR reduced the amount corrosion, still, there were a lot of corrosion issues on bridges located in marine environmental and the first evidence of defects in ECR, announced in 1986 in bridges in the Florida Keys. Since 1990, several field investigations revealed the good performance for ECR, but still examples of corrosion of coated reinforcement were reported [1].

In 1993, a study on 20 Florida keys bridges showed that the most of corroded bridges with ECR had constructed with relatively high permeable concrete [2]. Later, in 2009 an investigation assigned by FDOT to evaluate the present condition of ECR in the structure of marine bridges built starting backs to 1970 to 1990. The University of South Florida conducted this study to develop predictive corrosion performance models for estimating the repair and maintenance needs over the remaining

service life of bridges [3]. Meanwhile, lots of modifications have been mad to increase the adhesion of coatings and decrease the number of defects associated with ECR. As the sufficient conditions for long-term performance field performance have not been defined, the effective service life of epoxy-coated reinforcement is still uncertain.

This report combines a brief history of epoxy-coated reinforcing steel in bridge industry with a summary of studies evaluating the corrosion performance of epoxy-coated reinforcements to investigate the effectiveness of ECR in increasing the total service life of full-depth precast concrete (FDPC) deck panels which is an accelerated bridge construction method.

FDPC SYSTEM AS ACCELERATED BRIDGE CONSTRUCTION METHOD

FDPC deck panels have been heavily used in bridge construction since the 1960s. While they are primarily used to accelerate construction, other major advantages of FDPC deck panel systems highlighted by previous researchers include high-quality plant production under tight tolerances, low maintenance cost, low permeability, reduced volume changes due to shrinkage and temperature effects during initial curing [4]. In a recent investigation conducted by Shahrokhinasab et al. in Florida international university, the total FDPC bridges in the US determined through a comprehensive survey between all DOTs. Total 281 FDPC bridges were studied to evaluate their long term performance [5], [6]. Results showed that at the best condition the FDPC deck panels have service life equal to those similar bridges constructed

with cast in place concrete. Therefore, some modification will be crucial to increase the service life of the FDPC system. Different components of the FDPC deck panel system are shown in Figure 1.

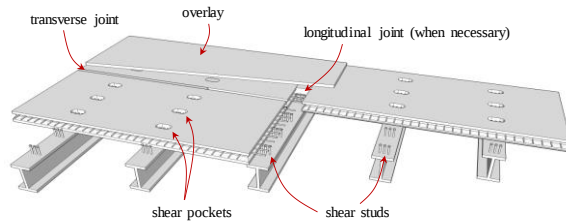


Figure 1: Components of the FDPC deck panel deck system[7], [8]

One major defect observed in the FDPC system is corrosion of steel bars especially around transverse joints where two FDPC panels connect each other. By decreasing the defects in these areas, the service life of the FDPC system will improve significantly. The primary solution in this regard is using the epoxy coated reinforcement in the FDPC system to make a barrier for chloride ions especially in the location of transverse and longitudinal joints.

LONG-TERM PERFORMANCE OF EPOXY-COATED REINFORCEMENT

Since 1970, structure owners have used epoxy-coated reinforcement (ECR) as a mean to protect the structures from corrosion. Typically, ECR is covered in a protective layer of epoxy for protection the steel core from corrosion. If the coating is applied correctly and without any defect, it will protect the steel from corrosion appropriately. Laboratory studies have indicated that epoxy-coated reinforcement performs better than uncoated reinforcement but has certain limitations [9]. Epoxy-coated reinforcing steel is not lonely enough to corrosion problems, and there is room for

improvement in this product. Several important factors like environmental condition, concrete permeability, concrete cover, presence of aggressive ions like chloride and sulfate and also the level of maintenance, all affect the long performance of epoxy-coated reinforcement in reinforced concrete structures.

In term of long term durability, two different approaches should be noticed; how fast, aggressive ions can get close to the surface of ECR and second one is that how long ECR can resist against the chloride ions as the main reason of corrosion in reinforced concrete structures. Moreover, the presence of intact epoxy coated reinforcement is another important factor in this regard. Unfortunately, damage can occur during transportation, storing, handling, deforming and casting of the ECR, causing defects such as chips and cracks in the coating. Therefore, this vulnerability requires special considerations during all procedure after manufacturing.

RESULTS OF PAST STUDIES ON THE LONG-TERM PERFORMANCE OF ECR

Since 1986, after revealing some corrosion evidence of epoxy-coated reinforcement, several studies conducted to evaluate the long –term performance of ECR and find the root of corrosion in corroded ECR samples.

Erdogdu and Bremner (1993) evaluated the performance of epoxy-coated rebars using lab and field tests data for two years. Results showed that for two years ECR performed very well and just minor corrosion observed in the imperfection spots on the surface of ECR [10].

In the same period, McKenzie researched at the Transport Research Laboratory in the UK to evaluate the influence of imperfections on ECR on their long-term durability. He found out that after two years, corrosion propagated from the defects on the epoxy coated rebars, but the amount of corrosion was still less than that uncoated steel rebars[11].

Smith et al. (1993), investigated the corrosion of epoxy coated rebar in the marine environment. Results showed the disbondment of epoxy coating from the rebar occurs after about 3 to 5 years of service even in the absence of chloride ions. So by losing the bond, the protection characteristics were diminished. Results of this study convinced the Florida Department of Transportation that epoxy coated rebar doesn't perform very well at least in environmental conditions [2]. Extreme disbanding is shown in Figure 2 during this research.

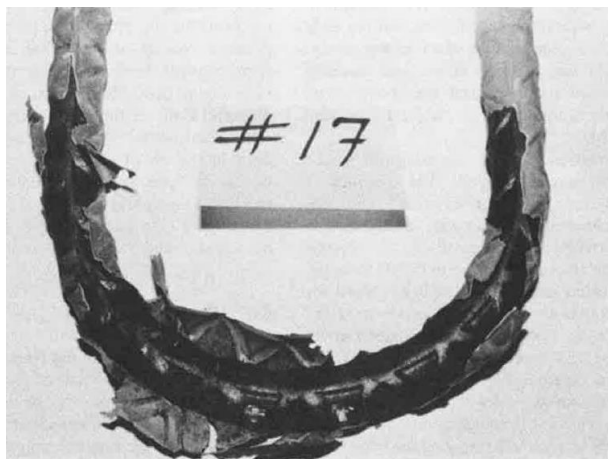


Figure 2: Extreme disbanding, localized and general corrosion after[12]

Sagues et al. (1996) investigated 28 bridges with ages 3 to 12 years to evaluate the amount of disbondment in ECR structures. In this regard, several samples extracted from bridge substructures and field knife test had been utilized for evaluating the amount of disbondment. Results showed that 82% of bridges had severe disbondment (23 of 28 bridges), 10% had partial disbondment and only had not any disbondment (2 bridges with less than five years old). Results also showed that after average four years under construction, all the extracted samples from bridge substructures had shown disbondment consistency even in absence chloride ion contamination [13].

Wolf and Sarcinella (1997) conducted seven-year research to evaluate the durability of epoxy coated reinforcement in bridge structures in Texas. They considered different condition for their evaluation including the use of Type II cement, epoxy-coated reinforcing steel, increasing the concrete cover, making the concrete less permeable and also cathodic protection systems. Results showed that epoxy coated generally are more durable than uncoated steel bars but still for getting the maximum service life, a multilateral approach including several considerations appears to offer the best protection [9].

Lau (2009) conducted a comprehensive study at the University of South Florida on 18 bridges with over 15 years under service to develop an estimation model for the corrosion of epoxy-coated reinforcement. The bridges were studied in 4 groups with different amount of corrosion as follow:

Group1: bridges with sever early ECR corrosion from 1991 to 1993

Group2: bridges not showing ECR corrosion from 1991 to 1993 but had shown the high potential of ECR corrosion

Group3: bridges with low to very low chloride diffusivity with some narrow cracks

Group4: bridges with intermediate chloride diffusivity with a chance of ECR corrosion

A corrosion model developed for this purpose considering chlorid exposure, concrete permeability, concrete rebar cover and extent of ECR coating imperfections [3].

Results showed that the corrosion of group 1 has continued to develop steadily with no indication of a slowdown. The interesting outcome of this study was that no corrosion of ECR observed when the bar had a thick cover of sound and concrete had very low permeability but still the evidence of disbonding observed which could facilitate the corrosion in future. Samples with evidence of ECR corrosion are shown in Figure 3 and Figure 4.

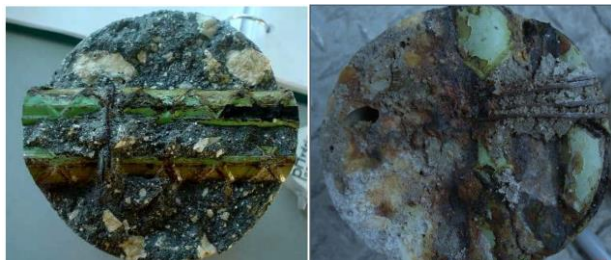


Figure 3: Severe ECR corrosion in Group 2 bridges[3]



Figure 4: Extensive corrosion damage[3]

Calvo et al. (2013) researched to investigate the performance of ECR in cracked concrete. Six types of epoxy coatings embedded in concrete slabs with a 0.4mm wide preformed crack intersecting the reinforcing steel at right angles were tested [14]. The properties of the six types of epoxy coated summarized in Table 1.

Table 1: Six types of epoxy coatings embedded in concrete [14]

Coating ID	Epoxy type	Pretreatment	Fabrication details	Epoxy color
T1	Fusion bonded epoxy coating (Flexible)	No primer	Post-fabricated	Green
T1p	Fusion bonded epoxy coating (Flexible)	Proprietary chromate primer	Post-fabricated	Green
T2p	Powder coating (Flexible)	Proprietary chromate primer	Post-fabricated	Green
T3	Plain bar (Uncoated)	—	—	Black bar (uncoated)
T4	Fusion bonded epoxy coating (Inflexible)	No primer	Prefabricated	Violet
T5	Powder coating (Inflexible)	No primer	Prefabricated	Olive green
T6p	Powder coating (Inflexible)	Proprietary chromate primer	Prefabricated	Blue
T6pn			Prefabricated but not cast in concrete	

p = chromate primer, n = not cast in concrete, post-fabricated bars were coated and then bent, prefabricated bars were bent and then coated.

Results of corrosion potentials, corrosion current density, coating adhesion tests, chloride content, and visual examination after 68 months of exposure to a simulated

marine environment were reported. Results revealed that under the studied conditions the ECR did not provide total protection of steel reinforcement in cracked concrete. Their use, however, tended to reduce significantly the damage caused by the chloride-induced corrosion when compared with the uncoated bars embedded in concrete with similar characteristics.

Based on the electrochemical testing results, the order of performance could be established as follow: T6p $\approx$ T4 > T2p > T1p > T1 > T5 > T3 (Uncoated) [14].

Results of the visual inspection and dry-adhesion testing revealed that inflexible epoxy coatings, with and without chromate treatment, showed the best performance in cracked concrete specimens with no signs of corrosion damage on or underneath the coating after more than five years of accelerated testing. The order of performance can be given as follow: T4 > T6p $\approx$ T2p > T1p > T1 > T5 > T3 (Uncoated). The damages after the adhesion test on different rebars are shown in Figure 5.

It can be also concluded that pretreatment of the steel bar surface before the coating application enhanced the effectiveness of epoxy coatings, either by creating a more resistant coating to the breakage or by maintaining good adhesion between the epoxy-coating and the metal substrate which limits the spread of corrosion [14].

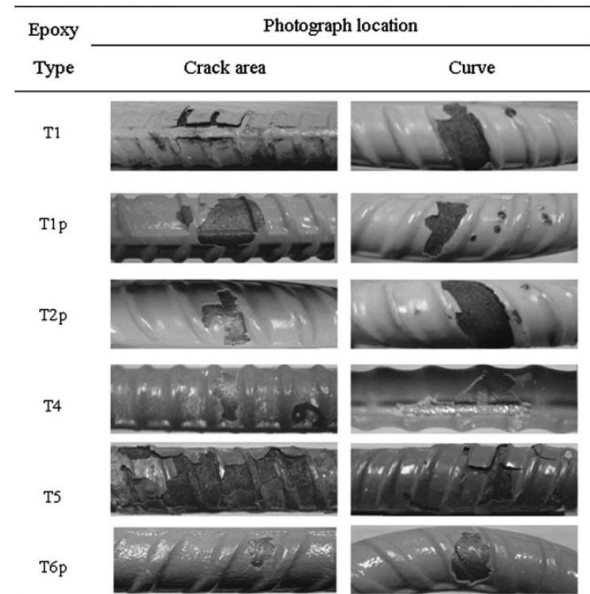


Figure 5: Damage on different epoxy coating types after 68-month exposure(after the adhesion test)[14]

It concluded that under the studied conditions, the ECR does not provide total protection of steel reinforcement in cracked concrete; their use, however, tended to reduce significantly the damage caused by the chloride-induced corrosion when compared with the uncoated bars embedded in concrete with similar characteristics.

In 2014, Pincheira et al. studied four bridge decks built in the 1970s by in situ inspections and laboratory tests. Proof of high corrosion observed in every one of the four decks transverse and longitudinal joints, cracks, and delaminated or spalled areas high concentration of chloride ions (5 lb/cy or more), however after around 30 years of service, the decks were all in great condition and indicated light cracking and few delaminated regions [15].

Loss of coating adherence and softening was found in both corroded and noncorroded bars and the presence of low and high chloride ion concentrations. Therefore, disbondment and softening of the coating

cannot be solely attributed to corrosion activity and high chloride ion concentrations. HCP field surveys agreed well with the observed bar corrosion level. Therefore, Half-Cell Potential Surveys (HCP) measurements as conducted in this study can be used as reliable tools to identify corrosion activity in bridge decks with ECRs [15].

SERVICE LIFE OF FDPC DECK PANELS UTILIZING ECR

The use of full-depth precast concrete (FDPC) deck panels allows for accelerated construction and repair of bridge superstructures, and in some cases decreased overall project costs.

By a recent study which has been conducted by Florida International University, it revealed that the performance of the FDPC deck panels in best condition is equal to cast in place traditional deck. The results are summarized in Table 2. So improving the service life of this innovative system is a must. As the most deterioration of FDPC deck panels are observed around the transverse and longitudinal joints where decks connect each other, improving the service life of these components is necessary.

Table 2: Overall average performance of bridges with FDPC deck panel decks and CIP decks

Deck Type	FDPC	CIP
<i>n</i>bridges	206	178
<i>Avg. n</i>inspections per bridge	12.6	13.0
<i>Avg. Year of 1st Inspection</i>	2004	2005
<i>Deterioration Rate</i>	-0.12	-0.09
<i>Estimated Service Life (year)</i>	33	35

Most of the defect is due to penetrating salt and chloride through the prevalent cracks in joints. So the first economic solution for improving the service life of FDPC deck panels is using epoxy-coated reinforcement instead of uncoated steel.

CONCLUSION

ECR is an economic solution for protecting structures against corrosion. There have been several studies that evaluated the long-term durability of this rebars. Investigations in this regards showed that ECRs could not provide the total desire protection and their performance depends on several factors including the type of epoxy, environmental condition, regular maintenance, concrete cover and also permeability and quality of concrete. It revealed that disbondment of coating is prevalent after 5 to 7 years of service and it may be due to change in chemical properties but is not due to chloride ions because this phenomenon also observed in are with very low chloride content. The best type of coat for ECR are inflexible powder coating or inflexible fusion bonded epoxy coating.

With the high demand of future transportation, FDPC deck panels are the best solution for saving the construction time and lowering the traffic impact, so protecting this system against corrosion and increasing the service life of this system is mandatory for future need. Using epoxy coated for constructing the FDPC deck panels can increase up to 50% the service life of FDPC. Future lab and field study should be conducted to evaluate the influence of using ECRs in the FDPC deck panel.

FUTURE RESEARCH

As the FDPC database for all bridges in the US is available, for the first step, a survey can be done through the different DOTs around the United States to get information about any use of ECRs in FDPC bridges that had been constructed in the past. Then as the service life of FDPC bridges are estimated during a most recent study by FIU, it just needs to determine those that have been used ECRs in their structures and compare tier service life with those with uncoated steel rebars.

For the next step, if the results showed require improvement in long-term durability and also cost analysis proved utilizing ECR, it can be used on at least one new project for extra evaluations.

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