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A comparative study of corrosion resistance of different coatings for mortar–embedded steel plates

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HIGHLIGHTS

- Performance of three types of coatings for steel plates against corrosion is evaluated.
- Three experimental techniques related to chloride-induced corrosion were used in the study.
- The results show that epoxy coating performed the best against chloride-induced corrosion.

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ABSTRACT

In view of corrosion problem encountered in mortar–embedded steel plates used in joints of precast concrete cylinder pipes, an experimental study was undertaken at the initiative of the manufacture of the pipes to evaluate the relative performance of three chosen types of commercial coatings namely, red oxide, zinc primer, and epoxy coatings for protection of mortar–embedded steel plates against chloride-induced corrosion. Three different types of experiments were planned for this comparative performance evaluation: natural corrosion, accelerated corrosion and chloride exposure test. Test specimens were prepared using cement–sand mortar with cement–sand ratio of 0.5 (ASTM type I cement) and water–cement ratio of 0.5, using an embedded steel plate at the mid-depth. For natural corrosion, specimens admixed with 12% NaCl solution were placed in humidity and temperature controlled chamber to promote corrosion in hot–humid environment. In accelerated corrosion test, the weight loss and corrosion current densities were measured. Chloride penetration and corrosion initiation time were measured in specimens subjected to ponding with 10% NaCl solution. The results of all three tests convincingly showed that epoxy-coating, out of the three tested, performed as the best corrosion protection coating for mortar–embedded steel plates against chloride-induced corrosion.

1. Introduction

Locally produced precast concrete cylindrical pipes, made of thin steel shell lining helically reinforced with steel bar wrapping and a protective outer lining of cement mortar, are used extensively in Saudi Arabia to transport water across the cities. The pipes are assembled at site with a ‘bell and spigot’ joint with a mild steel strip which is protected from corrosion by a coating and an encapsulating outer layer of lean concrete mortar. Instances of chloride-induced corrosion at the joints prompted the manufacturer to seek a better coating for the steel plate as one of the options for improved corrosion protection. A study was undertaken to evaluate, on a comparative basis, the corrosion performance of three different coatings for steel plates embedded in sand–cement mortar.

The aim of applying coatings is to get smother surface and to protect the metals from chemical attack. In general, the description of the coatings can be based on their appearance, e.g. clear, metallic, and by their function like corrosion protective [1]. Coatings can also be classified as organic and inorganic coatings. The organic coatings develop protection either by a barrier action from the layer or from active corrosion inhibition provided by pigments in the coatings. In real life, the barrier properties are limited because all the organic coatings are permeable to water and oxygen to some extent [2]. The coating systems are also described by generic type of binder or resin, and grouped according to the curing or hardening mechanism of that generic type. Paints are mostly classified as primers and topcoats. Primers are applied directly to the metal surface. They contain pigments of zinc and perform the

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main job of corrosion protection. Topcoats are applied over the primer, mainly for the sake of manifestation. However, they provide diffusion barrier and close the pores in the primary coat [2]. For protection of steel against corrosion, various types of surface coatings are used. Coatings on steel whose performance against chloride-induced corrosion are widely reported in literature include: zinc, tin, lead, nickel–phosphorus, mill-scaled, polished, brown-rusted, black-rusted, polyaniline–nylon, silane, copper-clad and epoxy coatings [3–14].

Maldonado and Pech-Canul [3] have reported the performance of galvanized reinforcement (hot-dip zinc-coated steel rebars) embedded in concrete exposed to tropical humid marine environments. They found that the zinc-coated rebars remained passive for a study period of two years in cases of concretes with water/cement ratio of less than 0.6. However, the zinc-coated rebars embedded in concrete with water/cement of 0.7 showed signs of corrosion initiation in 14 months. Bellezze et al. [4], in their study on the corrosion performance of three differently galvanized steel rebars (Zn–Pb; Zn–Ni–Bi; and Zn–Ni–Sn–Bi baths) embedded in concrete, have found that the bars galvanized in the Zn–Ni–Sn–Bi bath have no corrosion resistance for high alkaline concrete matrix while they showed a good corrosion performance in concrete with low alkalinity and high chloride content. On contrary the bars galvanized in the Zn–Pb and Zn–Ni–Bi baths were performed better in concrete with high alkalinity than concrete with low alkalinity and high chloride content.

The study on corrosion performance of electroless nickel–phosphorus (ENP) alloy coatings applied on steel rebars embedded in concrete subjected to chloride-induced corrosion, conducted by Singh and Ghosh [6], has indicated a high degree of protection against corrosion of ENP alloy coatings. Singh and Ghosh [6] found that the ENP coatings with a phosphorous content of about 8% are more effective in comparison to coating with a high phosphorous content of 16%. Excellent corrosion performance of polyaniline/nylon composites coating on steel was found by Ansari and Alikhani [7]. They found that the polyaniline/nylon coating can provide an anodic protection to steel against corrosive environments with corrosion rate 10–15 times lower than the bare steel. Lin et al. [8] have reported excellent performance of coating of steel with silane coupling agent and rare earth salt against chloride-induced corrosion. Copper-clad steel coating has been reported to have corrosion performance better than zinc coating [9].

Epoxy-coated reinforcing bars embedded in concrete are reported to have excellent corrosion performance in chloride-laden marine environments [10]. Cui et al. [10] observed that the epoxy-coated steel rebar's have resistance against corrosion up to a chloride concentration of 0.079% (by weight of concrete). However, corrosion was observed in case of epoxy-coated steel bars with significant coating damage (5%). Shin and Shon [11] and Lawler et al. [12] have also reported the better corrosion performance of epoxy-coated steel. Internal and external coatings of the steel water and wastewater pipelines using liquid epoxy are recommended [13,14].

It is observed from the review of literature that different surface coatings are available for protection of steel against corrosion depending on the local availability of the coating materials and methods and also on corrosivity of the exposure conditions. The primary aim of this paper is to present a comparative assessment and evaluation of corrosion resistance of three different types of commercially available coatings namely, epoxy, zinc primer and red-oxide coatings, selected by the manufacturer as the preferred coatings for steel plates embedded in sand–cement mortar. Natural corrosion under aggressive chloride-bearing environment, accelerated corrosion, and chloride penetration were used as experimental techniques for evaluation.

2. Experimental program

The experimental program consisted of three different types of tests [15]: (i) natural corrosion tests, (ii) accelerated corrosion test and (iii) chloride exposure test. In the first one, the values of the corrosion current densities at different time intervals were determined by linear polarization resistance method. In the accelerated corrosion test, the specimens were subjected to accelerated corrosion through impressed current and the weight loss of metal was calculated. In the third test, specimens were ponded with NaCl solution and the chloride penetration at the level of metal was determined. The test data from the three different tests allowed capturing a comparative performance of the three coatings.

2.1. Materials

For preparation of specimens for corrosion tests, the mix design with cement/sand ratio of 0.5 (by mass) and water/cement ratio of 0.5 (by mass) as used by the manufacturer in joint assembly was adopted. Type I cement conforming to ASTM C150 [16], dune sand (specific gravity of 2.66, fineness modulus of 2.11 and water absorption of 0.6%) and potable water for mixing and curing were used in preparation of all test specimens. The steel strips used were of grade ASTM A36 steel plate, which is a low carbon steel having good strength and formability, and can be galvanized to provide increased corrosion resistance. Three different coating materials, namely commercial epoxy paint, red oxide, and zinc primer, were applied on the surface of the steel strips for improving the resistance against corrosion.

2.2. Specimens

All test specimens were prepared using a single embedded steel strip of 20×8 mm thick uncoated (to serve as control specimens) and coated with the three types of surface coatings: epoxy paint, red oxide and zinc primer, applied to the plates following manufacturer's recommendation. Fig. 1 shows the details of test specimen. The specimens for natural and accelerated corrosion tests were of size 75×150 with thickness of 58.0 mm ($W = 75$ mm and $L = 150$ mm) and those used in chloride exposure test were of size $300 \times 300 \times 58$ mm ($L = W = 300$ mm). In all specimens, the steel plate was positioned at the mid-height of a specimen (Fig. 1).

To speed up the natural corrosion, 12% sodium chloride (by mass of mortar) was admixed into the mortar. For the specimens targeted for accelerated corrosion test using impressed current, 3% sodium chloride (by mass of mortar) was admixed. In chloride exposure test, chloride-free specimens were subjected to ponding over a face with 10% NaCl solution. The designations and the number of test specimens used are given in Table 1. All the specimens were water-cured for 10 days before subjecting them to tests.

2.3. Inducing and monitoring corrosion in naturally corroded and ponded specimens

Eight specimens for natural corrosion, after curing for 10 days, were placed in a purpose-built humidity chamber fitted with temperature and humidity controls (Fig. 2), maintaining 80% relative humidity and 40–45 °C temperature. This combination of hot and humid environment was maintained to stimulate aggressive corrosion environment of the coastal belts of Saudi Arabia.

Corrosion current densities, I_{corr}, were measured using linear polarization resistance method (LPRM) at different times of exposure. LPRM is a reliable, non-destructive technique for corrosion measurements [17]. In LPRM, the reinforcing steel is polarized by a small amount of potential from its equilibrium potential either potentiostatically or galvanostatically. In this study, the steel reinforcing

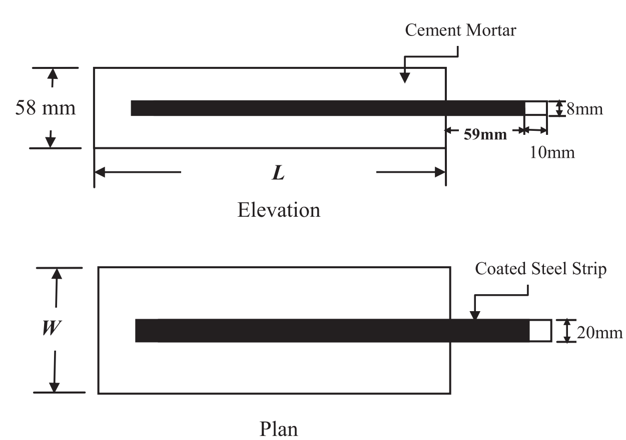

Fig. 1. Details of specimens.