

Durability Investigation of Patch-Repaired Reinforced Concrete

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Abstract: Effect of a pre-packaged non-shrinkage cementitious grout on corrosion of patch repaired reinforced concrete was investigated in laboratory and field.

For laboratory study, reinforced concrete specimens were monitored for corrosion, under accelerated and freely corroding conditions. Corrosion activity on freely corroding steel bars in reinforced concrete specimens in the laboratory and corrosion of steel bars in the repaired concrete slabs in the field were monitored by measuring corrosion potential of the steel bars against Cu/CuSO₄ reference electrode. In accelerated corrosion, the steel bar was imposed +4V anodic potential to accelerate the corrosion of the steel bars in the concrete specimens, and corresponding current was plotted against time to determine the time-to-cracking for the specimens.

The results showed that repair materials provided higher protection to steel against corrosion compared to normal concrete. The reinforcing steel within the repaired zone was more cathodic to the rest of steel in the original concrete.

Keywords: Corrosion, Corrosion current, Half-cell potential, Patch repair, Primer, Reinforcement, Repair material.

1. INTRODUCTION

Harsh environmental and service conditions shorten useful service life of reinforced concrete structures in many parts of the world and thus pose a significant challenge to the construction industry. As a consequence, the repair and rehabilitation of deteriorated structures in harsh environments such as Arabian Gulf constitute a major activity of this industry in the coming decade. Timely and economical repair of the deteriorating structures is important to maintain their safety and appearance, and to extend their useful service-life.

Several repair materials are now available in the market. Despite the excellent characteristics of some of these materials, many failures have been reported [1-3] mainly due to property mismatch between the repair material and the parent concrete. Field and laboratory investigations conducted so far on some of the repair materials have been concerned with the total repair of a structural member.

More often, partial repair of the structure, also called patch repair, may be sufficient to restore both the appearance and integrity of a structure. A good matching of the properties of the parent concrete and the repair material is very important in the case of patch repair.

This paper reports the findings of a research carried out to evaluate the effect of pre-packaged non-shrinkage cementitious grout (XRF) on corrosion of reinforcing steel in patch repaired concrete structures.

2. MATERIAL AND METHOD

2.1 Materials

In this study, the repair material tested was a pre-packaged, non-shrinkage cementitious grout, XRF. It is a single component cement based-micro concrete. Its average chloride and sulfate contents were found to be 0.0054 % and 0.121% by weight of concrete, respectively. Both the chloride and sulfate contents are within the limits recommended by standard specifications [4]. The average pH value of the XRF was measured to be 11.64. The pH was highly alkaline, as expected.

As primers, a zinc-rich primer and an ordinary epoxy were used. The zinc-rich anti-corrosion primer is a single-component liquid packed and supplied ready to use. The ordinary epoxy coating is based on solvent-free epoxy resins containing pigment and fine fillers. It is supplied as a two-component material in pre-weighed quantities ready for on-site mix and use. For bond coating modified styrene butadiene rubber emulsion (SBR) was used. It was used with cement slurry as a bond coating in preparation of reinforced concrete slab specimens.

Concrete slabs and cylinders for field and laboratory exposure respectively were prepared using concrete from a local ready mix concrete supplier. The coarse aggregate was 19 mm maximum size crushed limestone, with a bulk specific gravity of 2.5 g/cm³ and an average absorption of 2.45 %. As fine aggregate, dune sand of specific gravity 2.6 g/cm³ and an average absorption of 0.57 percent was used. All aggregates were washed and dried and were free from fine dust, chloride and sulfate contamination.

The reinforcing steel was procured from a local supplier. Nominal composition of the carbon steel used in this study is as follows in percentages: C = 0.38; Si=0.20; Mn=1.53; P=0.020; S=0.016; Cu=0.053; Cr=0.021; Mo=0.009; Ni=0.011; Sn=0.004; V=0.004; Nb=0.005; Fe = Balance.

2.2 Specimen Preparation

Concrete specimens were prepared using Type-I cement at a cement content of 350 kg/m³ and water-to-cement ratio of 0.486. A concrete setting retarder and

super-plasticizer were used to prolong the initial setting time and increase the flowability of fresh concrete respectively. The mix proportions used to prepare the concrete are given in Table 1. The properties of Type-1 cement are given in Table 2. All test specimens were cured under wet burlap for 14 days, followed by 14 days of curing under laboratory conditions.

To study corrosion resistance of the repair material in the laboratory, 12 reinforced concrete cylinders of 75 ϕ x 150mm were cast using Type I cement concrete and the repair material. After curing for 28 days, these specimens were divided into two groups. The first group of specimens was placed in a 5% NaCl solution, and corrosion of the reinforcements was monitored by measuring the corrosion potential and the corrosion current density, at periodic intervals, under freely corroding conditions. Reinforcement corrosion in the second group of specimens was accelerated by impressing a potential of +4V. The relative performance of the repair material in providing an electrochemical protection was evaluated by measuring the time-to-cracking of the specimens.

Concrete slabs were used to evaluate the effect of patch repair on the corrosion of steel in the areas adjacent to the repairs under field exposure condition. Seven reinforced concrete slabs of 1000x1000x100 mm contaminated with 0.8% chloride by weight of cement were prepared using the concrete mix and a 12-mm reinforcing steel bar. The slabs were cast and cured in the field for 28 days. The first readings of corrosion potentials were carried out at the end of 28 days of curing. Then, the concrete of the slabs was removed at the center portion (500x500 mm), about 25 mm beyond the reinforcing steel bars. The steel bars were cleaned of the concrete, treated with two different primers, and the damaged area was repaired using the repair material, XRF. The steel in the patch area was retained in the following condition:

- i. Uncoated
- ii. Coated with the zinc-rich primer, and
- iii. Coated with ordinary epoxy.

Modified styrene butadiene rubber emulsion (SBR) was used as a bond coat in the last two cases. To monitor reinforcement corrosion, the corrosion potentials were measured at repaired locations for a period of six months after the repair.

2.3 Corrosion Monitoring

Corrosion activity in the freely corroding lab specimens and field slabs were monitored by measuring half-cell (corrosion) potential of the steel bars against Cu/CuSO₄ reference electrode (CSE). The “corrosion potential vs time” plots were evaluated to understand the effect of repair material on corrosion of the steel bars. In accelerated corrosion, anodic potential of +4V was imposed to accelerate the corrosion of the steel bars in the concrete specimens, and corresponding current

was measured every four hours by connecting the specimens to a data acquisition system through a resistor. The time-to-cracking of the specimens was obtained from the “current vs time” plots. The accelerated test was continued for 2200 hours or until the specimen cracked whichever occurred first.

3. RESULTS AND DISCUSSIONS

3.1 Free Corrosion

The corrosion potential results of freely corroding reinforced concrete specimens are shown in Figure 1. The free corrosion potential of reinforced concrete specimens, made using the XRF and PCC, were monitored for a duration of 500 days or till they failed. The results showed that the free corrosion potentials of the repair material, XRF, were lower than that of the PCC specimens from the first day of monitoring. Taking the corrosion potential as -270 mV, the PCC specimens were in the corrosion range after about 40 days and the RF specimens after about 220 days.

3.2 Accelerated Corrosion

The variation of current with duration is shown in Figures 2 and 3. As shown in Figure 2, the current of the PCC specimens decreased from about 6.8-7.0 mA to 3.6-4.5 mA in 190 days. At about 190 to 195 hours, all three of the PCC specimens cracked, resulting in the sudden increase in the corrosion current from about 3.6-4.5 mA to 5.0-7.6 mA. Whereas XRH specimens showed cracking after 1500 hrs of testing, Figure 3. The decreasing trend of the current, both before and after the cracking of the specimens, can be explained by a build-up of corrosion products and their decelerating action on the corrosion rate.

3.3 Corrosion of Repaired Reinforced Slabs

The variation of corrosion potential on the reinforcing steel bars in the concrete slabs was monitored for 260 days is shown Figures 4 and 5. The potential variation in the figures is represented in three graphs: potential at unrepaired zone, potential at repaired zone, and potential at the interface zone. Each test point on the graphs is an average of several points.

Before the repair, the potential was low, -0.63 V. The steel bars were under corroding conditions. In the presence of chloride ions, the steel bars can develop protective ferric oxide (γ -Fe₂O₃) on their surface, and they start corroding right from the casting of chloride contaminated concrete slabs, in spite of highly alkaline conditions in the concrete slabs [5]. After the repair, the repaired, unrepaired, and interface zones exhibited different potentials. The potential value at the repaired zone was higher than the potential values at both the interface and unrepaired zones. The potential values at the unrepaired zone were the lowest throughout the monitoring period. As the monitoring continued, the potential values at the three

zones increased and converged. At the end of the monitoring period of 260 days, the potentials were about -0.32V. The potentials indicated an uncertainty of corrosion (less than -0.35V) on the steel bars. Generally, the potential values at all the zones monitored on the concrete slabs showed a similar increasing and converging trend as long as the environment remained under drying conditions. When there was wetting of the slabs due to rain, in most cases, the potentials decreased, indicating an increased corrosion activity. This is seen very clearly in Figure 4, from the 150th to 210th day of monitoring. Generally, the potential on the unrepaired zone was the lowest at all points and at all times, except on the control slab where the potential was the highest on the unrepaired or undisturbed zone. The potential values at the interface and the repaired zones were respectively higher than those on the unrepaired zone. The highest potentials were measured on the repaired zone in all the slabs. On the control slab, however, the potentials were higher at the interface and repaired zones. This indicates that the steel bars in the repaired zones become better protected after the repair due to applied primer, superior quality of the repair material, or both. The corrosion on the steel bars in this zone therefore became less active (cathodic) compared to the corrosion activity on the steel bars in other (unrepaired) part of the slabs. Similar results in repaired concrete were also reported by others [6]. David [6] reported that steel bars in the repaired area, with or without inhibitor, attained more passive potential than the steel bars in the contaminated original concrete.

The study showed that XRF with the zinc-rich primer performed better than PCC with the epoxy, control slab. Steel primers ideally are expected to protect steel bar from corrosion and have good bond to steel surface and the repair material [7]. Mortar slurries were reported to offer good protection due to high alkalinity but they were found to accelerate corrosion on the surrounding steel. Published data indicate that polymer-modified slurries containing rust inhibitors, silica fume, and sand can give good results and are not subject to undercutting [8]. McCurrich et al [8] reported that an active zinc-rich primer conforming to BS 4652, Type 2, was found to offer excellent protection to the steel in both the repair zone and the surrounding concrete. With this system the zinc coating allows electrical contact between the bar and the active zinc. The zinc can then act as an anode protecting the steel sacrificially.

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusion can be drawn from the results of this study.

1. The free corrosion tests showed that corrosion potential of 270mV vs CSE was reached after 40 and 220 days in the control and XRF specimens, respectively. The XRF specimens performed 5.5 times better.

2. The accelerated corrosion results showed that, the average cracking time for PCC (control) and repair material, XRF, specimens was 193 and 1200 hours respectively. The RF had almost 6 times longer cracking time than the PCC.
3. In the field slabs also, the corrosion potentials showed that XRF performed better than PCC. The repair systems with zinc-rich primer performed slightly better than the system with epoxy. The steel bars in the repaired area of the slabs remained more cathodic than the steel bars in the other parts of the slabs throughout the monitoring period.
4. It can be recommended that XRF can be used as repair material together with a zinc-rich or an epoxy primer.

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Table 1. Concrete mix proportions per m³.

Mix Parameters	Quantities
Cement Type V	350 kg
Water	170 liters
Water /Cement Ratio	0.486
Aggregate, 20mm	690 kg
Aggregate, 10mm	1050 kg
Sand	1800 kg
Retardar,	1.70 liters
Super-plasticizer	1.6 liters

Table 2. Chemical composition of Type-I cement.

Constituent	Type I cement
SiO ₂	20.0
Al ₂ O ₃	6.0
Fe ₂ O ₃	3.7
CaO	65.9
MgO	0.7
SO ₃	2.1
C ₃ S	64.6
C ₂ S	8.89
C ₃ A	9.65
C ₄ AF	11.24

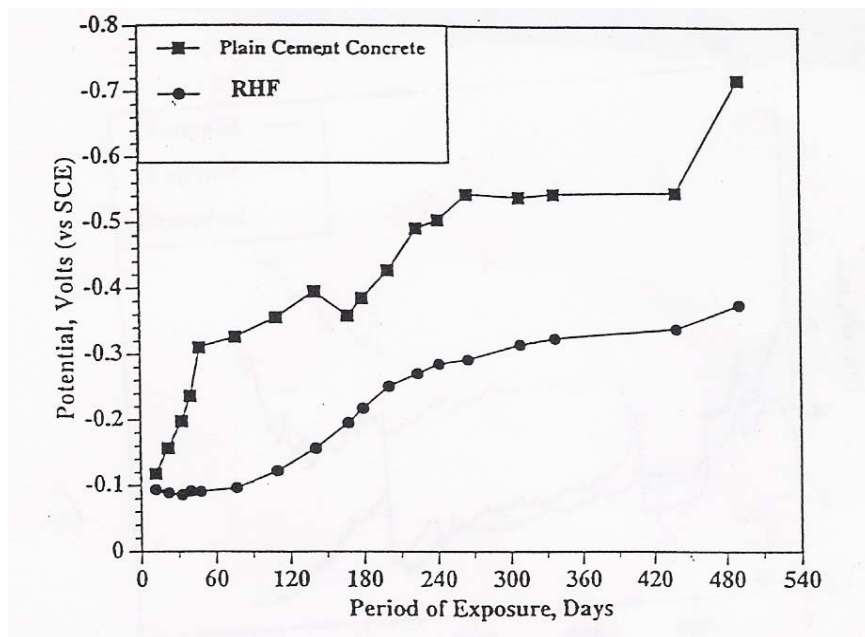


Figure 1. Average corrosion potential of freely corroding specimens.

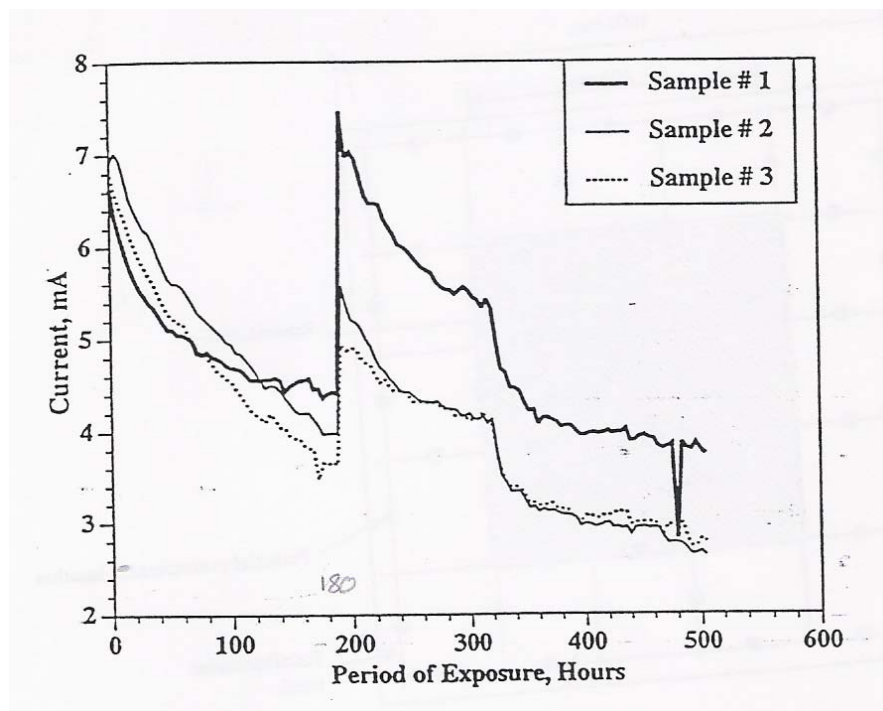


Figure 2. Variation of current with time in PCC specimens.

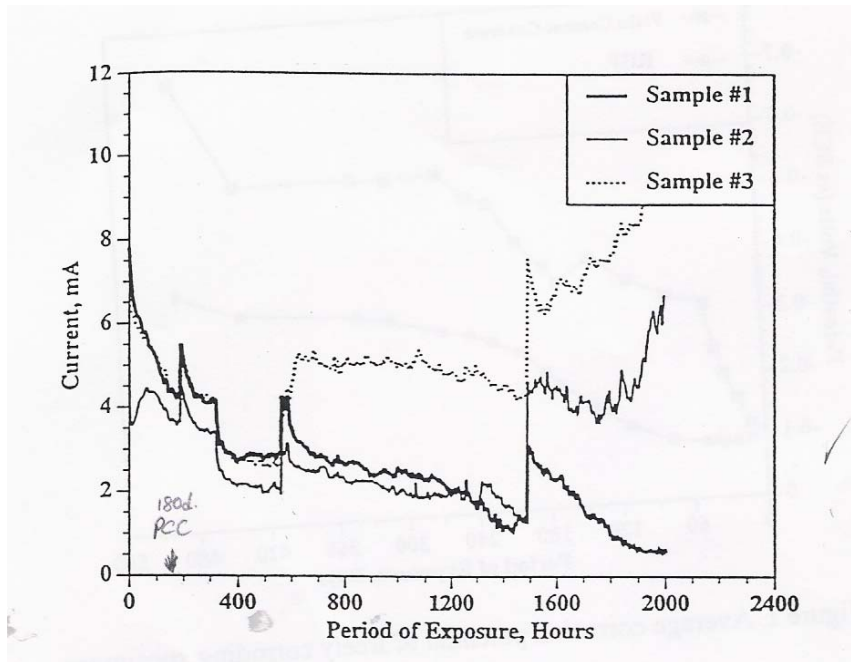


Figure 3. Variation of current with time in XRF specimens.

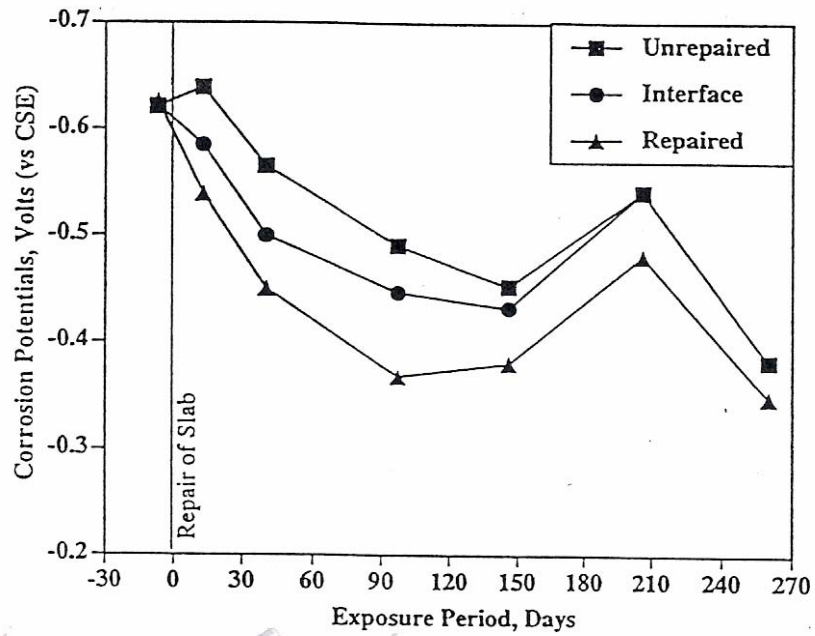


Figure 4. Average corrosion potentials on repaired concrete slabs for 260 days.
Primer: Zn-rich epoxy; Bond : SBR with cement slurry; Repair Material: XRF.

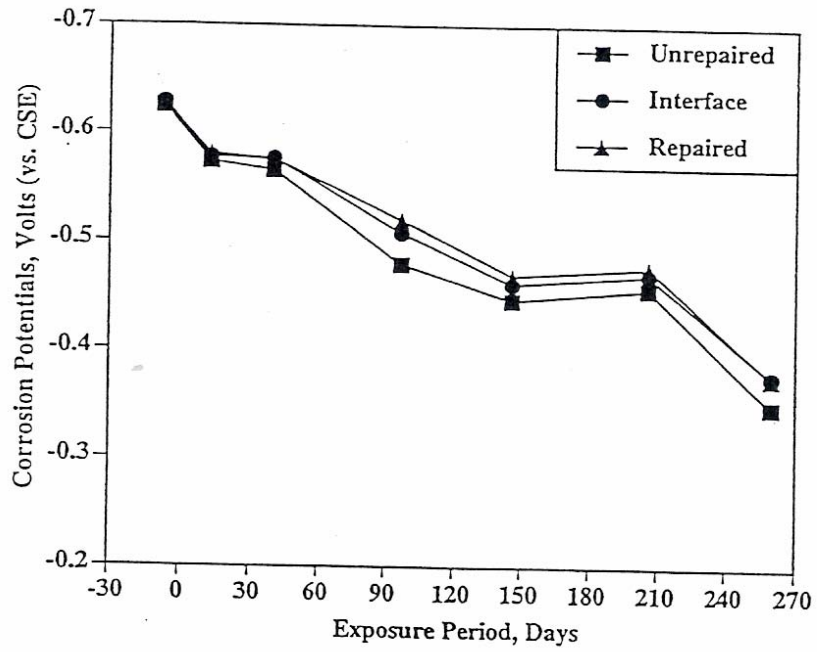


Figure 5. Average corrosion potentials on control concrete slabs for 260 days.