Experimental Study of the Effect of Different Crack Widths on CO₂ ingress into Concrete with Repair Patch

Islam Md. SHAFIQUL*, Tsugio NISHIMURA**, Taketo UOMOTO***

1. Introduction

Reinforcing steel is protected by high alkaline environment that forms passive ferric oxide film around steel. However due to CO₂ penetration into concrete, the alkalinity is reduced and passive film becomes unstable, corrosion starts, volume of steel is increased and causes tremendous pressure on concrete, finally cover concrete spall off.

When concrete spall off, particular destroyed section requires repair. Drying shrinkage within that new repair material results crack at the interface of patching material and the base concrete. Once these crack take place, the transport properties of material drastically change and it is no longer reasonable to assume that durability life span based on uncracked properties will hold.

Cracks in concrete become a cause of reduction of durability due to reinforcement corrosion, deterioration in functions such as water tightness and air tightness, large deformations, impairment of appearance, etc.

From practical point of view, cracks or defects exist in concrete structures. And from maintenance viewpoint, repair and maintenance is significantly increased during the last decades. So, when deal with cracked repaired concrete this study will be important.

2. Outline of Experiment

2.1 Materials and mix proportion

The cement used was ordinary portland cement (SSD specific gravity: 3.15); the coarse aggregate was crushed stone (SSD specific gravity: 2.7); and the fine aggregate was river sand (SSD specific gravity: 2.63; FM: 2.90).

Polymer modified cementitious mortar was used as repair patch named Emaco S98P. Emaco S98P is a ready to use polymer modified cementitious mortar mixed with cement, standard various powder polymer.

Table 1: Mix proportion of concrete

<table>
<thead>
<tr>
<th>Gmax</th>
<th>W/C</th>
<th>s/a (%)</th>
<th>Air entraining agent (kg)</th>
<th>Slump (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>55</td>
<td>45.5</td>
<td>2.083</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cement</th>
<th>Water</th>
<th>Coarse aggregate</th>
<th>Fine aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>320.53</td>
<td>176.3</td>
<td>988.84</td>
<td>804.15</td>
</tr>
</tbody>
</table>

Table 2: Mixing quantity of Emaco S98P

<table>
<thead>
<tr>
<th>Emaco S98P (kg)</th>
<th>Water (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>4</td>
</tr>
</tbody>
</table>

Mixing of concrete was done by large mixer and Emaco was mixed with water using small mixer of our laboratory.

2.2 Specimen geometry

Fig:1 shows the geometry of the specimen. The specimen had a square cross section of 100 mm (W) X 100 mm (H) X 376 mm (L). One deformed steel bar of 10 mm in diameter was embedded longitudinally with cover depth 20 mm from exposed surface.

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2.3 Curing period

Five specimens were casted only with concrete and were allowed to set in mould for 1 day. After demolding it was cured in water controlled at 200 C for 6 days. Emaco was added to the specimen after 7 days of concrete casting. Specimens were further air cured for 21 days. Cracks were introduced 28 days after casting. Primer and chloride-carbonation resistant epoxy were coated to all faces leaving one surface (Fig. 1) uncovered. Exposure was allowed after 34 days of concrete casting. Temperature 20 °C and humidity 60% were maintained throughout the exposure.

2.4 Introduction of crack

<table>
<thead>
<tr>
<th>Target crack width (mm)</th>
<th>Introduced crack width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.025</td>
<td>0.024</td>
</tr>
<tr>
<td>0.05</td>
<td>0.053</td>
</tr>
<tr>
<td>0.075</td>
<td>0.077</td>
</tr>
<tr>
<td>0.2</td>
<td>0.197</td>
</tr>
<tr>
<td>1.0</td>
<td>1.002</td>
</tr>
</tbody>
</table>

The specimens were subjected to 3-point loading to generate a flexural crack at centre.

Crack widths were measured at three points on crack by (PI-5-50) displacement transducer and average was taken.

2.5 Carbonation test

The specimens were splitted into two halves longitudinally by compression, which were immediately sprayed with 1% of phenolphthalein solution. Uncolored area was taken as carbonated. Measurements were done by caliper at positions as in fig (4). Splitted specimen further splitted at the crack portion and the carbonated depths were measured in the same way at crack face.

3. Experimental results and discussion

3.1 Carbonation depth

Fig (5) shows the result for carbonation depth according to distance from crack to both concrete and emaco parts. Crack width has no effect on the ingress of CO₂ from exposed surface for 4 weeks duration. The depths at each point are almost equal. But just at the crack CO₂ go through a long distance. It indicates that crack acts as an open door for CO₂ movement.

Carbonation depth just after spraying phenolphthalein solution is shown in Fig (6).
Fig (7) shows the relationship between crack width and CO₂ penetration depth at crack face. It correlates well. This can be used for practical application. CO₂ did not penetrate inwards from crack face due to high moisture content inside.

![CO₂ penetration depth at crack face](image)

**Fig 7: Penetration of CO₂ inside crack**

### 3.2 Half cell potential

Fig (8) shows the half cell potential value for specimens having different crack widths. With the increasing value of crack width the potential tends to go further negative. That means increased crack width allow the corrosion probability to increase.

![HCP for different crack widths at 4 weeks](image)

**Fig 8: Half cell potential for different location**

### 3.3 Corrosion area of steel

Percentage of rust area for concrete and emaco is shown in fig (9). Rust was generated more in the case of repair part than that of concrete. Due to mixing of emaco by mixer some air voids may exists inside repair material.

Fig (10) shows the diagrams of corrosion pattern. For higher crack width more rust was produced near the crack. In case of carbonation if crack width is increased, it develops macro cell and corrosion is localized.

![Percent of rust area](image)

**Fig 9: Rust area of concrete and repair material**

![Corrosion diagrams](image)

**Fig 10: Corrosion diagrams**
4. Conclusion

This paper shows the carbonation tests carried out with the specimens having five different crack widths. From the results the conclusion attained here are as follows.

1. Within limited 4 weeks exposure duration the crack width does not have any significant influence on the penetration of CO₂ from exposed surface.
2. Crack is similar to exposed boundary since CO₂ was found on the crack face.
3. The penetration depth of CO₂ inside crack correlates well with the crack width.
4. With the increase of crack width corrosion is localized near crack.
5. CO₂ did not penetrate inside the concrete or emaco from the crack surface.

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