Healing of dynamic concrete cracks using acrylate-endcapped polymer precursors

M. Araújo¹,², P. Dubruel², S. Van Vlierberghe² and N. De Belie¹

¹ Magnel Laboratory for Concrete Research, Ghent University, Ghent, Belgium; e-mail: adelaide.araujo@ugent.be; nele.debelie@ugent.be
² Polymer Chemistry and Biomaterials Group, Ghent University, Ghent, Belgium; e-mail: sandra.vanvlierberghe@ugent.be; peter.dubruel@ugent.be

Keywords: concrete, self-healing, acrylate-endcapped polymer precursors, dynamic cracks.

ABSTRACT

The occurrence of cracks in concrete is inevitable due to its limited tensile strength. Up to now, several approaches have been used to design concrete with self-healing properties. Depending on the type of damage, different healing agents can be used. In case of dynamic cracks in structures exposed to cyclic loads, elastic healing materials can be used to cope with the crack opening and closing movement.

In this study, we aimed at determining the most suitable polymer backbone to be applied for the healing of dynamic cracks. For this purpose, different polymeric precursors including siloxane- (PDMS), polypropylene glycol/urethane- (PPG), epoxy- and polyester-based (PE) have been evaluated. The healing capacity was evaluated by determining the regain in water tightness of the healed cracks using water flow tests. The strain capacity of the polymers was assessed after widening of the healed cracks in a stepwise fashion. Comparison of the sealing properties before and after each stepwise elongation shows that a strain of at least 50% could be achieved for epoxy and PDMS-based healing agents. For polyester and PPG-based precursors failure occurred due to polymer detachment.

The effect of high alkalinity on the degradation of the polymerized healing agents has been also evaluated with the PPG-based precursor showing the best performance in terms of degradation. and PE the highest mass loss percentage after incubation in concrete pore solution.
1. INTRODUCTION

In the past few decades, many researchers have focused on the development of concrete that can repair cracks by itself. Self-healing concrete can be obtained by incorporation of different healing agents such as bacteria, hydrogels or encapsulated polymers [1].

In this work, various acrylate endcapped precursors (polyester-, epoxy-, polydimethysiloxane- and urethane-based) have been combined with a tetrathiol cross-linker and applied in mortar cracks in order to determine the most suitable polymer backbone to be applied for the healing of cracks of dynamic nature.

2. MATERIALS

2.1. Healing agents

The healing agent mixtures consisted of an acrylate precursor (polyester, epoxy, PDMS or urethane) and a tetrathiol cross-linker. The viscosity of the mixtures was adjusted by adding a certain amount of chloroform (1 g precursor / ml solvent). Polyester acrylate and epoxy acrylate were provided by Arkema-Sartomer Division. PDMS acrylate was obtained from abcr GmbH. Urethane acrylate was in-house synthesized [2]. Tetrathiol (pentaerythritol tetrakis (3-mercaptopropionate)) was purchased from Sigma-Aldrich.

<table>
<thead>
<tr>
<th>Healing agent</th>
<th>Acrylate-endcapped backbone</th>
<th>Viscosity (Pa.s) (^1)</th>
<th>Swelling in demi water (%)</th>
<th>Moisture uptake @ 90% RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE</td>
<td>Polyester</td>
<td>0.16</td>
<td>4.31</td>
<td>2.07</td>
</tr>
<tr>
<td>Epoxy</td>
<td>Epoxy</td>
<td>1.07</td>
<td>3.00</td>
<td>1.91</td>
</tr>
<tr>
<td>PDMS</td>
<td>Poly(dimethylsiloxane)</td>
<td>0.16</td>
<td>17.32</td>
<td>9.77</td>
</tr>
<tr>
<td>PPG</td>
<td>Polypropylene glycol/urethane</td>
<td>0.60</td>
<td>6.26</td>
<td>5.74</td>
</tr>
</tbody>
</table>

\(^1\) measured at 20 °C for a shear rate of 3000 s\(^{-1}\)

3. METHODS

The healing agents were exposed to pore solution (pH~13) to assess their resistance to the alkalinity characteristic for concrete. Pore solution was obtained after mixing 100 g of cement (CEM I 52.5N) with 1 liter of water during 3 h. Then, the cement particles were removed and the pore solution was collected. Polymer discs were incubated in this solution and the resistance to high pH was measured as percentage of mass loss.

Mortar specimens (40 x 40 x 160 mm\(^3\)) with a water to cement ratio of 0.5 and a sand to cement ratio of 3 were made. Each specimen contained two steel reinforcement bars with a diameter of approximately 2 mm. At the age of 21 days, controlled cracks were created using a 3-point-bending test and manually healed with the various healing agents. As comparison, three additional specimens were cracked and left untreated (Ref_cracked). To assess the strain capacity of the polymers, the healed cracks were widening in a stepwise fashion, 3 days after injection. Images of the
polymers in the healed cracks were recorded after each stepwise elongation. Before and after each stepwise elongation, a water flow test [3] was performed on the healed mortar samples in order to evaluate their sealing capacity.

4. RESULTS

The resistance of the polymers to the high alkaline environment characteristic for concrete was evaluated by exposing cross-linked polymer discs to pore concrete solution. The polymer weight change as a function of the incubation time in pore solution is shown in Figure 1. The results show that the PE-based polymer showed the highest weight loss (27%) after one month incubation while for PPG, no weight loss was noticed.

![Figure 1: Percentage weight loss as a function of incubation time in pore concrete solution.](image)

The polymer strain capacity was determined after widening of the healed cracks by means of visual analysis and water flow tests. Images of the healed cracks recorded before and after each stepwise elongation allowed to detect polymer detachment from the concrete walls and whether or not polymer rupture had occurred. Based on visual examination, it was found that a strain capacity of at least 100% and 50% was obtained for epoxy- and PDMS-based healing agent respectively. For PE and PPG failure occurred due to detachment of the polymer from the crack walls. In the case of PPG, however, the detachment was limited to local spots. Figure 2 shows, as an example, failure of the PE polymer due to detachment after widening by 50%.

![Figure 2: Detachment of the PE polymer after widening by 50%](image)

The water flow values obtained for each test series are presented in Figure 3.
It can be concluded that a strain capacity between 0 and 50% was obtained for the PE-based healing agent since the water flow increased considerably after 50% elongation. For PPG, a significant increase was noticed, however, the value obtained is still 82% lower if compared with cracked not healed samples (ref_cracked, before reloading). For PDMS polymer, the crack remained sealed after widening by 50%. Samples healed by the epoxy-based healing agent showed an increase (from 0.18g/min to 6.18g/min) in the water flow after reloading to 100%. The water flow test after 100% elongation was only performed on the series that did not show (after visual analysis) debonding or rupture of the polymer.

5. CONCLUSIONS

It was found that all acrylate-endcapped precursors could be used to seal concrete cracks. However, if one considers dynamic cracks, the epoxy-based healing agent seems to be the most suitable as it showed the ability to bridge cracks of increasing width (up to 100%).

ACKNOWLEDGEMENTS

Financial support from the Agency for Innovation by Science and Technology (IWT) under the project “Encapsulation of polymeric healing agents in self-healing concrete: Capsule design” is gratefully acknowledged.

REFERENCES