XV International Conference on Durability of Building Materials and Components
DBMC 2020, Barcelona
C. Serrat, J.R. Casas and V. Gibert (Eds)

Durability Based Service Life Estimation for Chloride Exposed Cracked and Self-Healed Concrete

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Keywords: *Steel Corrosion, Durability, Cracking, Self-Healing Concrete, Service Life Prediction.*

1 Introduction

Cracks in reinforced concrete structures form preferential pathways for chlorides or carbon dioxide to penetrate the concrete and rapidly reach the steel reinforcement. This will increase the risk for initiation and possibly further propagation of steel reinforcement corrosion. Therefore, the idea of providing the concrete with the ability of restoring cracks by itself without any human interference grew during the last few decades. In this research, self-healing through the use of polymeric healing agents in brittle capsules, was investigated for its efficiency to reduce the ingress of chlorides and to improve the corrosion resistance of reinforced concrete.

2 Materials and Methods

A reference concrete as described in Van den Heede (2014) was used as a representative mixture for concrete in exposure class XS2, i.e. submerged reinforced concrete in contact with chlorides from seawater. The mixture had a water-to-binder ratio of 0.41, a fly ash-to-binder ratio of 15%, and a compressive strength at 28 days of 65.2 ± 2.0 MPa. Steel reinforced concrete prisms with dimensions of 120 mm x 120 mm x 500 mm were made with a reinforcement scheme that was adapted after earlier experiments (Van Belleghem *et al.*, 2018) (Figure 1). The steel reinforcement consisted of an anodic and a cathodic part which were electrically separated from each other. Both parts were connected at the exterior by means of an insulated copper wire. Four types of specimens were prepared: uncracked, cracked but not healed specimens, and self-healing specimens containing two layers of 6 capsules filled with high (6700 mPas) or low (200 mPas) viscosity polyurethane. An Ag/AgCl internal reference electrode was fixed to the anodic rebar. After casting, the prisms were stored at 20°C and a relative humidity above 95%, demolded after 24 hours and stored at the same conditions until 28 days.

At 28 days, a flexural crack of about 300 μm was created in the concrete prisms by means of a three-point bending test. After crack creation, all samples were stored at 20 ± 2°C and a relative humidity of 60% for 48 hours to allow the polyurethane to cure inside the crack. The top (cracked) surface of the samples was exposed during 44 weeks to 1 d wetting and 6 d drying cycles. During the wet period, the central compartment was filled with a 33 g/l NaCl solution, while the outer compartments were filled with a 1.15 g/l $Ca(OH)_2$ solution. The chloride ingress was determined in an area of 10 mm x 30 mm around the crack.

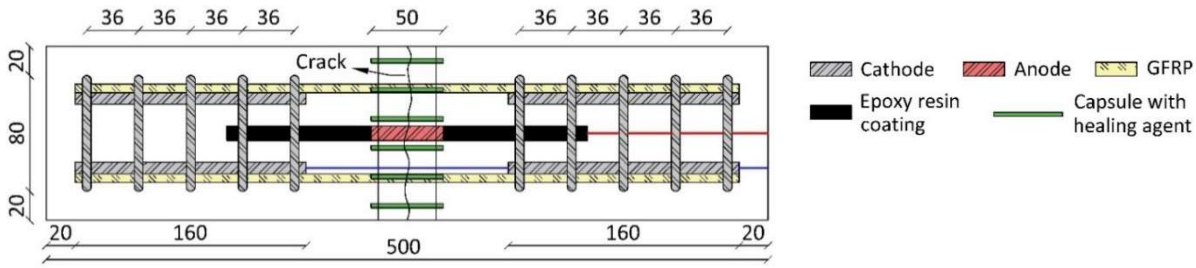

Figure 1. Reinforcement scheme and capsule positions in the concrete prisms (dimensions in mm) – top view.

3 Results of Corrosion Experiments

The uncracked samples showed a non-active state of corrosion along the whole exposure period. The mean chloride concentration at the surface amounted to 3.43 ± 0.05 m%/binder and then dropped fast to nearly zero at a depth of 18 mm into the concrete matrix. The cracked samples showed clear evidence of corrosion initiation within the first three weeks: a steep rise in the macrocell corrosion current and a concurrent drop of the corrosion potential down to -200 to -400 mV. The macro-cell corrosion current showed a decreasing trend during the first twenty weeks and remained relatively constant between 20 to 44 weeks (20 to 60 μA). A volume loss of 6.36 to 15.45 mm³ was calculated for the initial 20 weeks, followed by a period with volume loss of 0.55 to 0.72 mm³/week. A simplified pitting model predicted that 50% of the rebar cross-section (diameter 10 mm) would be lost after 9 to 20 years. Chloride profiles at the end of the experiment showed a chloride concentration which dropped steeply from up to 6 m%/binder near the surface to the second layer and then decreased gradually. At depths larger than 20 mm, the chloride concentration remained almost constant at about 1.3 to 1.5 m%/binder. For the self-healing samples, crack formation led to rupture of the capsules and release of healing agent in the crack The corrosion behaviour of the self-healing samples with high viscosity PU was very similar to the corrosion behaviour of the cracked samples. However, the self-healing samples with low viscosity PU showed negligible macro-cell corrosion current and a driving potential comparable to the values found for the uncracked samples. After an initial volume loss of 1.65-10.34 mm³, the mean steel loss rate amounted to 0.042 mm³/week only. At the end of the experiment the rebars showed no or very limited signs of corrosion. At the level of the reinforcement the chloride concentration was only about 0.26 m%/binder. A 50% reduction in steel cross-section was estimated to take more than 100 years, using a simplified pitting model.

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