Field Application of Self-healing Concrete with Natural Fibres as Linings for Irrigation Canals in Ecuador

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ABSTRACT

This paper describes the first field application of self-healing concrete with alkaliphilic spore-forming bacteria and reinforced with natural fibres. The application took place in the highlands in Ecuador in July 2014. The concrete was cast as linings for an irrigation canal that transports water from glaciers in the Andean mountains to agricultural fields. This canal has been used for over a century by the local farmers. Until not long ago the walls and bottom of the canals were simply made out of compressed soil without any concrete. The yield of the canal was therefore very low: about 70% of the water was lost due to evaporation and infiltration into the soil. In order to improve the functionality of the canal it was then decided to line it with concrete. Unfortunately within one year the concrete cracked so that water was now wasted through the cracks. Self-healing concrete reinforced with natural fibres was proposed as a solution to this problem.

The use of fibres in concrete increases the tensile capacity of concrete and assures a controlled crack width. Abaca fibres were selected due to their mechanical properties and availability as they are a fibre indigenous to Ecuador. Additionally, Abaca fibres have already been studied as reinforcement for mortar to improve the structural behaviour of houses in Ecuador under seismic loads.

The bacteria are included in the concrete in order to seal possible cracks. The mechanical properties of the concrete with fibres and bacteria were first evaluated in the laboratory by means of flexural and compression tests. The compressive strength fulfilled the requirements for the intended application in irrigation canals. The self-healing capacity of the concrete with and without bacteria was studied by monitoring the crack-healing. The concrete was designed to favour the use of locally available materials and following mixing procedure that could be replicate by the local communities.

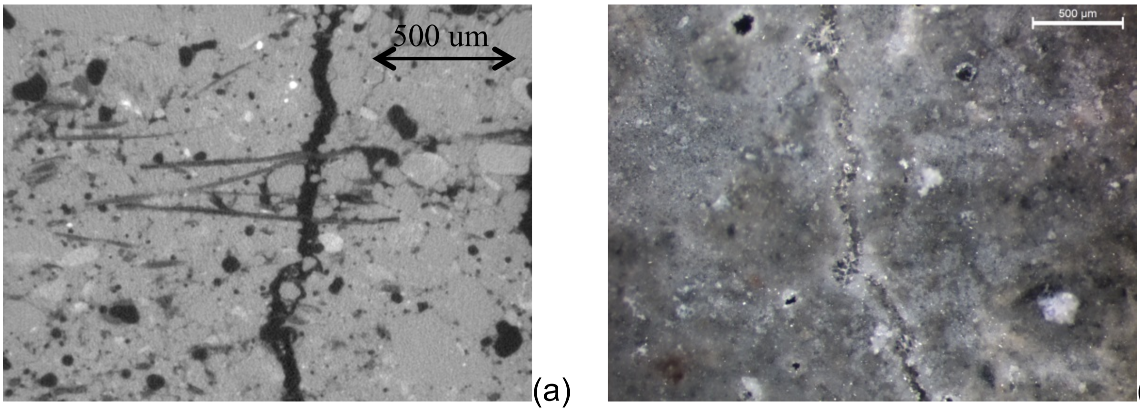
The self-healing concrete was mixed and cast in-place. Following this successful application, new sites in Ecuador are being evaluated by the local authorities for more field applications of this material.

1. INTRODUCTION- PROBLEM STATEMENT

The local economy in the Andean region in Ecuador, South America is based on farming and local consumption. Irrigation canals are needed to assure a constant water supply for the crops. In the province of Tungurahua more than 100 years ago a canal was ditched by the owner of an extensive amount of farmland in order to bring melting water from the Carihuairazo and Chimborazo Mountains to the valleys with crops. In this region the air temperature varies between 5ºC and 20°C with sometimes temperatures below zero. The canal runs from an altitude of 3200 to 2700 meters above sea level. The length of this canal is of approximately 24 kilometres. During the 60's the land was distributed among the farmers who worked it and the canal remain as property of this community. For decades the efficiency of the canal was low since about 70% of the water was loss due to evaporation or infiltration into the soil. To improve the efficiency the farmers together with local authorities casted concrete linings in the canal without any steel reinforcement. Within a year the concrete linings started cracking. The cracks lead to decrease the yield of the canal again. Additionally further cracking may lead to the loss of integrity of this infrastructure. Delft University of Technology, together with Foundation Imagine (NL) and the Catholic University of Santiago de Guayaquil (Ecuador) proposed the use of self-healing concrete reinforced with natural fibres as a viable solution to improve the sustainability and performance of this irrigation system.

2. MATERIALS AND PRELIMINARY LABORATORY INVESTIGATION

A concrete mix was designed taking into account the materials available and the building practice in the highlands in Ecuador as well as the strength and performance demands for the concrete linings. The concrete mix included gravel with maximum size of 10 mm, sand, cement, lightweight aggregates (LWA) containing the healing agent and natural fibres. Samples were prepared with LWA with healing agent as well as control samples with LWA without healing agent.
The healing agent consisted of a mixture spores of alkali-resistant bacteria and a food source for the bacteria: Calcium lactate- (80 g/l) and yeast extract- (1 g/l). The healing agent was impregnated into lightweight aggregates (LWA) (expanded clay particles Liapor R 2–4 mm, Liapor GmbH Germany). The bacteria used in this study are capable of healing cracks by direct and indirect calcium carbonate ($CaCO_3$) formation [1,2].
The use of fibres in concrete increases the tensile capacity and assures a controlled crack width [3]. Since the linings in the canals has no steel reinforcement, the addition of fibres will assure a higher tensile capacity of the concrete. Additionally, cracks with a controlled width will be easier to heal (Figure 1a). A fibre indigenous to Ecuador, Abaca, was chosen since this fibre has been successfully studied in Ecuador as reinforcement for mortar to improve the structural behaviour of houses under seismic loads [4].
The compressive strength, as tested in the laboratory, was 30 MPa for the mix with healing agent and 26 MP for the mix without healing agent [5]. To evaluate the self-healing capacity, a crack of about 140 μm was produced in several concrete samples by means of the three-point bending test. The samples were then placed to heal with the cracked surface in contact with water simulating the condition of the concrete in the bottom and slopes of the irrigation canals [5]. Observations of the cracks under the microscope after 6 weeks already indicate crack sealing (Figure 1b).



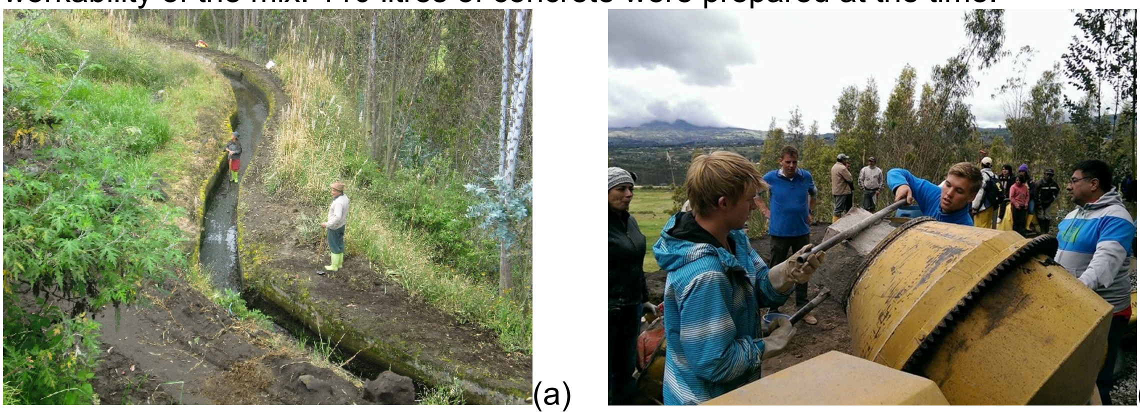
(a) (b)

Figure 1: (a) CT image showing Abaca fibres bridging the crack, (b) Crack sealing.

3. FIELD APPLICATION IN ECUADOR

The casting took place at about 2900 meters above sea level. During the mixing and casting the temperature was around 5°C. The water flow in the canals was stopped and deviated so that the community could clean the canal from vegetation and residues. This activity takes place twice a year. After cleaning the section of canal that was chosen for casting, the wood formwork was placed. The canal has a square cross section of 100 x 100 cm and a wall and bottom thickness of 10 cm. Three linear meters of concrete linings with bacteria were casted and three linear meters of control concrete without bacteria.

The mixing sequence and the mix design were adapted to the properties of the materials available in the site. The materials for the concrete were measured per volume. The local farmers, owners of the canal, provided sand and gravel from local extraction. The water for the impregnating solution for the LWA as well as for mixing the concrete was gathered from the water transported by the canal. Prior to mixing and casting, the LWA were impregnated with the solution containing bacteria and the food source. The Abaca fibres were cut to a length of about 2 cm. During the concrete mixing and due to the presence of natural fibres a superplasticiser was added to the fresh mix to assure the even distribution of the fibres and the proper workability of the mix. 110 litres of concrete were prepared at the time.



(a) (b)

Figure 2: (a) Farmers cleaning the canal upstream, (b) Dutch students helping during casting of self-healing concrete.


(a)

(b)

Figure 3: (a) Canal section 24 h after casting, (b) Five months after.

The formwork was taken out 3 days after casting. There were no signs of segregation of the LWA (Figure 3a). Two days later the water flow was reopened. During the last inspection, five months after casting, the concrete linings show no signs of cracking or deterioration, as can be seen in figure 3b.

4. CONCLUSIONS

Self-healing concrete with bacteria and natural fibres were successfully applied as linings for an irrigation canal in the highlands in Ecuador. Five months after the applications the concrete, with and without bacteria, shows no signs of cracking and therefore its healing capacity has not yet been being assessed. In the laboratory, six months after cracking and curing the samples showed crack sealing. Local farmers and government authorities in Ecuador are looking forward to more applications of this novel material.

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