FLEXURAL STRENGTH AND ELASTIC MODULUS RECOVERY IN SELF-HEALING CONCRETE REPAIRED BY INORGANIC SOLUTIONS

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ABSTRACT

In this research, cementitious hollow tubes were produced by extrusion and used as healing agent containers that were embedded in the mortar matrix to obtain self-healing properties. Based on the results of preliminary mechanical tests, sodium silicate, potassium silicate and Primal (a commercial acrylic resin) were first selected as healing agents. To determine their efficiency, three-point bending test were performed on samples with the different healing agents and load, as well as, stiffness recovery indexes were determined. It was first observed that modulus of rupture and elastic modulus were not affected because of the presence of the capsules inside the samples with respect to plain mortar samples.

1. INTRODUCTION

Natural materials are remarkably efficient because they fulfill the complex requirements posed by the biological functions and they do so using as little material as possible. Most natural materials are complex composites whose mechanical properties are often outstanding, considering the weak constituents from which they are assembled. Moreover, most natural materials are sustainable, recyclable and, when disposal is necessary, biodegradable, making them a model for environmentally conscious engineering. These complex structures, which have risen from hundreds of millions years of evolution, are inspiring Materials Scientists in the design of novel materials.
Most living tissues or organisms can heal themselves, provided the incurred damage is moderate. Most engineered materials are developed on the basis of the damage prevention paradigm and deteriorate with time irreversibly, which limits the life of various components and sometimes causes catastrophic damage. It would be then very desirable to implement the ability of self-healing in inorganic materials.

Concrete is the most widely used construction material over the word because of its high compressive strength and low cost. However, it is sensitive to crack formation because of its limited tensile strength. These cracks endanger the durability of concrete buildings as aggressive liquids and gases may penetrate into the matrix along these cracks and cause further damage. Hence, inspection, maintenance and repair of concrete cracks are all indispensable. It has been estimate that, in United States of America, the annual economic impact is around at $18-21 billion, in Asia at $2 trillion, in Europe, 50% of the annual construction budget is spent on rehabilitation and repair of existing structures, and for United Kingdom, almost 45%. In case of Netherlands, one third of the annual budget is spent [1]. For these reasons, the self-healing ability would be desirable for concrete.

2. MATERIALS

Sodium silicate (Sigma Aldrich, Na_2O 10.6 wt%, SiO_2 26.5 wt%, H_2O 62.9 wt%), Potassium silicate (K_2O 21%, SiO_2 23%, H_2 55%) and Primal B60A+30% H_2O (a commercial acrylic resin) were selected as healing agents. Silicate solutions reacts with calcium cations present in the cement paste, dissolving and crystallizing the silicate to heal the concrete; and Primal is a polymeric resin, and therefore, it helps the mortar being much more flexible without breaking.

The extrusion of the cementitious hollow tubes was used a device to prepare fresh home-made pasta. The nozzle used was a *maccherone* shape, with a diameter of 10 mm and an internal hole of 7.5 mm. Respecting hollow tubes mix design, a low amount of water was used to help maintaining the shape and different compounds were added to the cement paste to reach a good workability.

It was necessary to apply a coating to convert these hollow tubes on a waterproof container for the healing agent. The coating has the purpose to create a homogeneous film to protect the healing agent contained into the tubes from water and moisture, which could stimulate a precocious and undesired spontaneous polymerization reaction of the healing agent, previous to the beginning of cementitious matrix cracking. The coating material used was sodium silicate.

To provided a container for the healing agent the hollow tubes were sealed with wax because its hydrophobicity and its rapid curing time and a good adhesion to cement surfaces.

3. METHODS

To determine the effectiveness and homogeneity of the coating, the morphological characterization was done by means of a Field Emission Scanning Electron Microscope (FE-SEM).

Was evaluate also the durability of the hollow tubes during the mixing process, was performed with the aid of a bottle stirrer (Asal mod. 724, Italy). Ten capsules were added to the conglomerate; subsequently, the fresh mass was mixed. The test was performed for 10 minutes and, at the end of the test, all capsules survived.

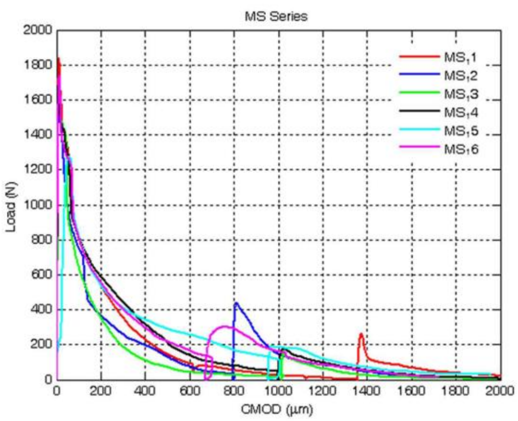
To test the self-healing potential was made a mortar specimens measuring 140 mm x 40 mm x 40 mm, and one capsule was placed approximately at the center of the prism, 32 specimens were produced: two plain mortar specimens, two specimens with capsule filled with sand, six specimens with Primal, 14 specimens with Sodium silicate, and 8 with Potassium Silicate. To these specimens were realized a three-point-bending tests in Crack Mouth Opening Displacement (CMOD) control mode, with the aid of a 25 kN closed-loop servo-controlled MTS hydraulic press.

The specimens were unloaded when the crack opening reached a value between 0.80 and 1.3 mm, regardless of the residual load. The crack was maintained open for 5 minutes at the maximum opening before unloading. The specimens were removed from the loading frame upon unloading and always stored in a moist environment for 2 days. Then, they were kept in indoor environment at room conditions for a variable period before the repetition of the test. These periods to some specimens were 1 month and to other of 6 months. After these periods of time necessary for the self-healing reactions to be established, to evaluate their possible performance recovery: they were subjected to a re-loading stage with the same test velocity as in the preloading stage, up to failure.

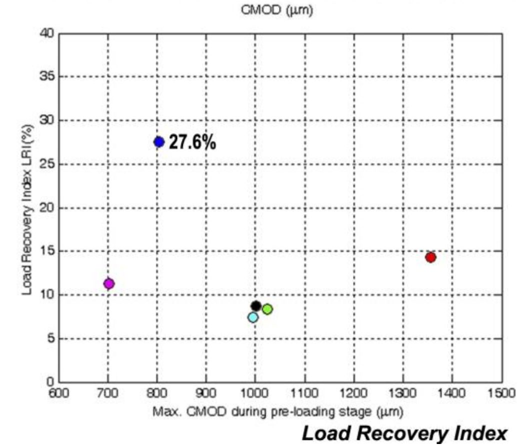
The self-healing effect was evaluate through, Load Recovery Index (LRI) and a Stiffness Recovery Index (SRI).

4. RESULTS AND DISCUSSION

With the end to give answer to the objectives of this research, it is report the best results achieved respecting to flexural strength and elastic modulus recovery, was obtained with Sodium Silicate solution.



In the Figure 1, there are results to Sodium silicate solution with one month after damaging the samples, in this case the specimens were broken with different breaking opening, and in this way determined the best opening to output of the healing agent was 800µm. The best recovery of the 6 samples was to $MS_1 1$ and $MS_1 2$.



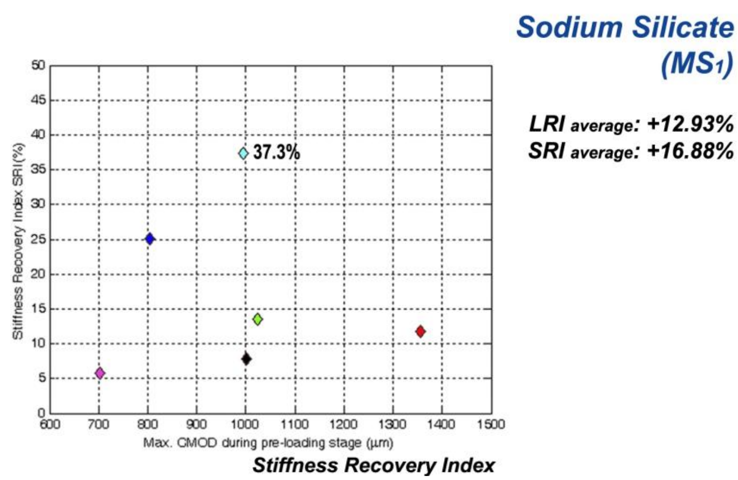
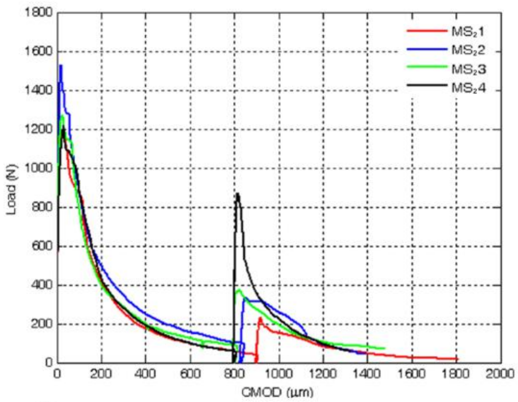


Figure 1: Results of Sodium Silicate solution with one month

The LRI were all positive, ranging from +8.3% to +27.6%; to $MS_1 1$ reach of +14.3% and to $MS_1 2$ reach until +27.6%. Similarly, the SRI ranged from +5.8% to +37.3%; to $MS_1 1$

reach of +11.8% and to MS_12 reach until +25.0%. These results are showed, when the peaks of the re-loading stages are verticals, demonstrating the recovery of the stiffness of the samples. This is only visible in samples MS_11 and MS_12.



In the Figure 2, there are results to Sodium silicate solution with six months after damaging the samples. It is possible to see, the high stiffness recovery of the samples because the peaks of the re-loading stages are verticals. The best recovery of the 4 samples of MS_2 were to MS_23 and MS_24. The LRI was always positive, ranging from +17.1% to +70.9%; the MS_23 reach of +24.5% and MS_24 reaches until +70.9%.

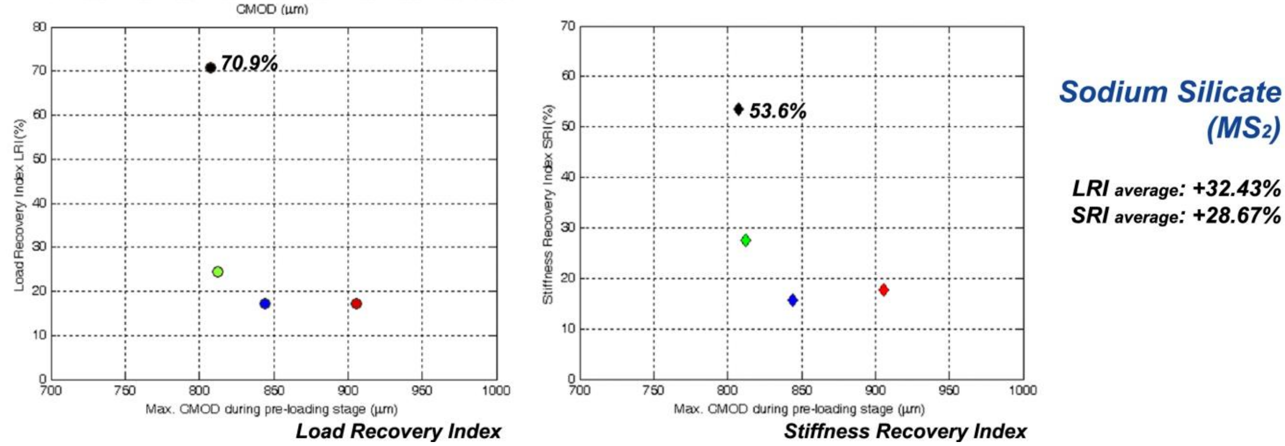


Figure 2: Results of Sodium Silicate solution with six months

Similarly, the SRI ranged from +15.7% to +53.6%; the MS_23 reaches of +27.6% and the MS_24 reaches until +53.6%.

5. CONCLUSION

It is concluded that the use of Sodium Silicate solution work as healing agent during six months after damaging was obtained even 70.9% of flexural strength recovery, and 53.6% of elastic modulus recovery, being these much satisfactory values.

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