C-1-2 Influence of water repellent surface impregnation of SHCC on corrosion of steel reinforcement

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ABSTRACT: Fiber reinforcement of SHCC leads to formation of many fine cracks instead of few wider cracks under imposed strain. In this way ductility is increased but water and chloride dissolved in water may still penetrate into micro-cracks quickly and deep by capillary action. As a consequence, corrosion of steel reinforcement can be initiated at an early stage. In this contribution, multiple cracked SHCC specimens with and without water repellent surface impregnation were prepared and tested. Corrosion of steel reinforcement in multi-cracked SHCC was monitored by measuring the electric potential of the steel reinforcement during wetting and drying cycles with salt solutions. Based on the results obtained, it can be concluded that steel reinforcement corrosion can be reduced significantly by water repellent surface impregnation, even in the cracked state. In this way service life of steel reinforced SHCC elements exposed to aggressive environment can be extended substantially.

KEY-WORDS: Multiple crack formation, strain hardening cementitious composites (SHCC), surface impregnation, steel reinforcement corrosion.

INTRODUCTION

Strain hardening cement-based composites (SHCC) exhibit pseudo-strain hardening characteristics and multiple crack characteristics, this means many fine cracks are created when the materials are subjected to bending or direct tensile stress [1-3]. This comparatively new material was initially called ECC (Engineered Cementitious Composites) [3]. Strain capacity of SHCC under tension ranges from 3 % to more than 5 %. This means that strain capacity of SHCC is about two orders of magnitude higher than that of conventional concrete. This enormous ductility is obtained by formation of many micro-cracks, which are stabilized by fibers, instead of few wide cracks as observed in normal concrete. Because of the typical crack width of values below 100 µm it was thought initially that transport of aggressive substances in these fine cracks can be stopped or at least limited and thus a more durable material in aggressive environment may be obtained.

Corrosion of steel embedded in concrete is one of the major deterioration mechanisms in reinforced concrete structures. This process shortens service life of conventional structures considerably. Necessary maintenance and repair measures are very expensive and are an increasing ecological load for the environment. Steel reinforcement in young concrete is initially protected by a passive layer, which is formed on the surface in an alkaline environment, which is provided by hydration products of Portland cement. But this protective layer may be destroyed by carbonation of the concrete cover or by chloride ingress. Then the electrochemical process of steel corrosion may begin, which leads to dissolution of iron and formation of iron hydroxide (FeO(OH)). Iron hydroxide has roughly three times the volume of the original steel. The multiple cracks created in SHCC by an applied mechanical load may serve as pathways for water and chloride ions. For this reason, water repellent treatment may be applied as a protective measure [4-6].

Multiple cracked SHCC specimens with and without water repellent surface impregnation have been prepared by three point bending. Corrosion of the steel reinforcement in SHCC has been followed by measuring the electrical potential between corroding steel and stainless steel and the corrosion rate during wetting-drying cycles with a salt solution. The effect of water repellent surface impregnation on the protection the steel reinforcement has been investigated in particular. Results will be presented and discussed in detail in what follows.

EXPERIMENTAL

Preparation of test specimens

The composition of SHCC used in this project was as follows: 550 kg/m^3 ordinary Portland cement Type 42.5; 650 kg/m^3 local fly ash; 550 kg/m^3 sand with a maximum grain size of 0.3 mm, and 395 kg/m^3 water. To the fresh mix 26 kg/m^3 of PVA fibers with a diameter of 40 µm produced by Kuraray Company, Japan, were added. Prismatic specimens with the following dimensions were cast in steel molds: 40 × 25 × 160 mm. The specimens were reinforced with two cylindrical steel bars. The upper bar was made of stainless steel with a diameter of 4 mm, while the lower one was made of plain carbon steel with a diameter of 8 mm. This arrangement is shown in Fig. 1. The fresh mix was cast into steel forms. After hardening for 24 hours under wet burlap the forms were removed and the specimens were then placed in a humid room (T = 20 °C and RH = 95 %). At an age of 28 days SHCC specimens were loaded by three-point bending to induce cracks.

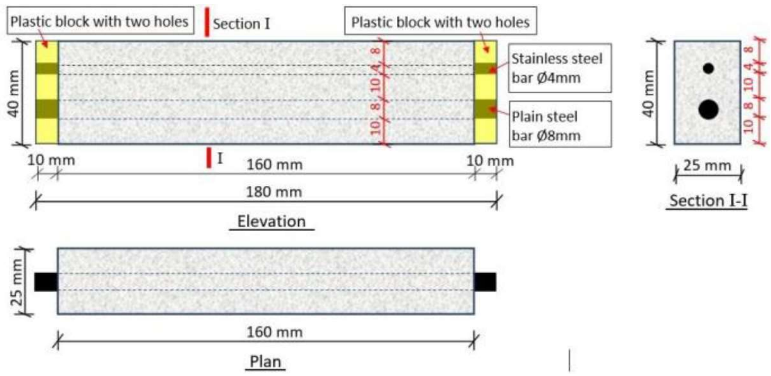

Fig.1. Shape and size of the prismatic specimens used in this project and the positions of the steel reinforcement and the stainless steel bar embedded in these specimens.

Crack formation and measurements

The specimens were loaded by three-point bending under controlled conditions to induce micro-cracks, as shown in Fig. 2. The specimens can be considered to be small size beams with a span of 150 mm between the two supports. A typical crack pattern as observed on the bottom and side surfaces of one SHCC sample is shown in Fig. 3. After crack formation the opening of the cracks on the bottom surface of the specimens was measured, by means of a high resolution digital microscopic device. In this way, the average value of four individual measurements on each crack was determined. For each cracked SHCC specimen, the essential information including the number of micro-cracks, the minimum and maximum crack width, the average crack width and the standard deviation are listed in Table 1. From these specimens, two samples were selected. The surface of these samples was impregnated with silane gel. Sample "SHCC11" was surface impregnated with 200 g/m^2 silane gel. The bottom surface of the second sample "SHCC12" was impregnated with 400 g/m^2 silane gel.

Fig. 2. Three point bending test

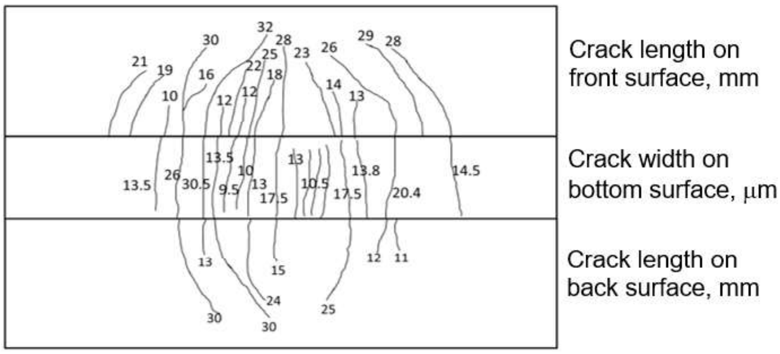

Fig. 3. Typical crack pattern as formed under three-point bending: multiple cracks on the bottom surface and cracks on the two side surfaces as observed on a SHCC sample.

Table 3: Measured data as obtained from the digital crack analysis before exposure to wetting-drying cycles. Minimum, maximum and average crack width, standard deviation (SD) and imposed strain measured near the centre of the beam.

	No. of cracks	Min. µm	Max. µm	Avg. µm	SD µm	Strain, %
SHCC1	No crack					
SHCC2	No crack					
SHCC3	8	7.0	27.8	16.2	7.5	1.14
SHCC4	11	9.5	18.5	14.0	2.7	1.36
SHCC5	7	20.0	36.5	27.5	7.2	1.73
SHCC6	16	9.5	40.3	16.6	8.1	2.08
SHCC7	17	8.8	55.3	20.8	13.5	2.60
SHCC8	20	7.3	30.0	17.9	6.0	2.82
SHCC9-200	13	10.5	42.5	20.4	9.4	1.97
SHCC10-400	13	10.3	27.5	19.6	4.4	2.60

Measurement of the steel reinforcement corrosion

After crack formation, all four side surfaces of the specimens were covered with aluminum foil, leaving the bottom and top surfaces open. Then the specimens were exposed to wetting-drying cycles. The bottom surface was put in contact with the salt solution. Each wetting period lasted 6 h in contact with 5 % NaCl solution and the following drying process lasted 18 h in an environment with 60 % RH. During the wetting-drying cycles, the electrical potential difference between the stainless steel and the plain steel in SHCC samples was measured after five cycles at the beginning and after 10 cycles when 100 cycles were reached.

RESULTS AND DISCUSSION

The evolution of corrosion of the steel reinforcement in multi-cracked SHCC has been followed by measuring the electric potential between the stainless steel and the reinforcement steel during wetting and drying cycles with salt solutions. Results are shown in Fig. 4. It can be seen from these results that in un-cracked SHCC specimens even after 200 cycles no corrosion can be observed. This indicates that SHCC is a very dense material and chloride penetration is very slow. SHCC can also be applied as a protective layer to protect conventional reinforced concrete from early corrosion. However, once SHCC specimens are cracked, the plain steel started to corrode soon after few wetting-drying cycles. There is no obvious difference of the beginning of corrosion in cracked specimens, which were exposed to different stain (1.14 % ~ 2.82 %) and which have shown different total crack widths (129.2 µm ~ 357 µm).

But, when cracked SHCC specimens were surface impregnated with 400 g/m^2 silane gel, the electric potential remained constant. This indicates that no corrosion took place even after 200 wetting-drying cycles. If 200 g/m^2 silane gel was applied on the cracked surface, the steel reinforcement was protected until 45 cycles. Then the electrical potential decreased significantly. But the corrosion risk is still lower than the risk in cracked SHCC without surface impregnation.

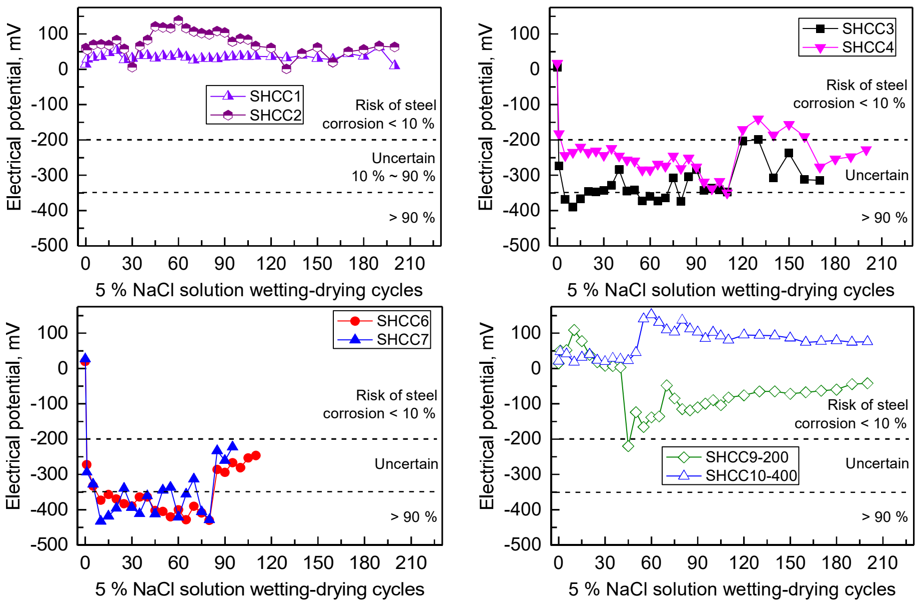

Fig.4. Electric potential of the steel reinforcement in un-cracked, cracked and surface impregnated SHCC samples as function of the number of wetting-drying cycles.

Electrochemical impedance spectroscopy (EIS) data were further analyzed with ZsimpWin software. The instantaneous corrosion rate of the rebar in SHCC specimens was obtained from the polarization resistance via the Stern-Geary Equation [8]. Results are shown in Fig. 5. The current density of the rebar in un-cracked SHCC could not be measured, this fact indicates that there was not corrosion under these conditions. The current density in cracked SHCC without surface impregnation is 0.13 ~ 0.34 μA/cm^2, corresponding to low and up to medium rate of corrosion. Surface imprenantion with 200 g/m^2 silane gel can reduce the corrosion rate significantly. While after efficient surface impregnation, i.e. with 400 g/m^2 silane gel, the steel rebar showed no corrosion.

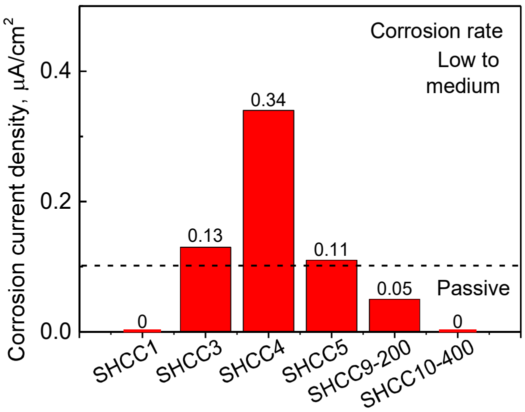

Fig.5. The corrosion current density of the rebar in un-cracked, cracked and surface impregnated SHCC samples measured after 140 wetting-drying cycles.

CONCLUSIONS

Steel reinforced SHCC may be a useful material for many applications if it is not exposed to aggressive environment. In the un-cracked state steel reinforced SHCC may have a comparatively high service life because the cover is rather dense. In the cracked state, however, corrosion will start early as the cracks allow chloride to penetrate deep into the material very quickly. Service life of reinforced SHCC elements exposed to aggressive environment can be extended considerably by surface impregnation with a water repellent agent. SHCC can also be applied as a protective layer on conventional reinforced concrete.

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