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Improving durability of SHCC under imposed strain by water repellent treatment

Zhang Peng
School of Civil Engineering, Qingdao Technological University, Qingdao, China, zhp0221@163.com

Wittmann Folker H.
Aedificat Institute Freiburg, Freiburg, Germany, wittmann@aedificat.de

Wang Penggang
School of Civil Engineering, Qingdao Technological University, Qingdao, China

Zhao Tiejun
School of Civil Engineering, Qingdao Technological University, Qingdao, China

SUMMARY: Strain Hardening Cementitious Composite (SHCC) is used to take advantage of its high strain capacity, which can reach up to 5 % under tensile stress. If durability is an issue, however, the ultimate strain allowed at the multi-crcaking state is very limited. In this contribution, the process of water penetration into neat SHCC specimens before and after a certain level of tensile strain has been investigated by means of neutron digital imaging. The results indicate that even at relatively modest imposed strain when cracks were formed, water quickly penetrated into the materials via the cracks. To reduce water penetration into cracked SHCC, two approaches were used. Samples of SHCC were prepared with an integral water repellent or water repellent surface impregnation was applied to plain SHCC samples. The effectiveness of both approaches is studied in detail. It is shown that integral water repellency could reduce water penetration significantly. But there is still a small amount of moisture that could enter the matrix via cracks. As an alternative method, surface impregnation with silane gel is more promising to protect SHCC from water penetration when multi-cracks formed.

KEY-WORDS: Water penetration; Integral water repellent; Surface impregnation; Strain Hardening Cementitous Composite (SHCC); Neutron digital imaging.

INTRODUCTION

As a brittle material, concrete can easily crack thereby allowing water, chlorides and other aggressive ions to penetrate easily into the materials and result in its deterioration. Therefore, it is necessary to find ways to improve the ductility of concrete. In the history of concrete technology many attempts have been made to improve this property. However, recent high modulus and high strength polymer fibers changed the situation significantly [1-3]. With this new material, Strain Hardening Cementitous Composite (SHCC) is prepared which is also called ECC (Engineered Cementitious Composites) in America [3]. The ultimate strain of SHCC can reach up to 5% under tensile stress which is more than 300 times the ultimate strain of conventional cement-based materials. If such a material is applied under protection, without exposure to water or salt solutions the full strain capacity can be exploited. However, if SHCC reached a certain amount of tensile stain which leads to multi-cracks, in cases where the material is exposed to natural environment, as for instance in contact with seawater, durability becomes an important issue and service life of a structure may be seriously reduced by crack formation. In this case, the huge strain capacity can only be used in part.

For this reason, water repellent treatments are often applied to reduce capillary suction of cement-based materials [4-7]. The effect of addition of a water repellent agent to SHCC on water absorption has been studied by Martinola et al. [4] and Sahmaran et al. [5]. However, the effectiveness of water repellent treatment(s) with regard to water penetration when SHCC is exposed to different level of tensile strain, has not been investigated systematically. Neutron digital imaging has been shown to be a particularly powerful method to view water penetration into porous materials such as concrete, and in particular, into its cracks. The major aim of this study was to evaluate the influence of integral water repellent SCHH as well as surface impregnation of plain SHCC on water penetration into the fine cracks that were formed under imposed strain.

EXPERIMENTAL

The composition of SHCC used in this project was the following: 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 fibres with a diameter of 40 µm produced by Kuraray Company were added. In addition, a second batch was prepared to which 2.0 % (related to the mass of binder) of an alkyl silane emulsion (Protectosil MH50, produced and sold by Evonik, Germany) was added to the fresh mix to obtain the integral water repellent SHCC, henceforth IWR-SHCC.

After compaction in steel forms, all specimens were allowed to harden in the laboratory under wet burlap for 24 hours. Then the steel form was removed and the specimens were stored for 21 days in a moist curing room (20 °C, 95% RH).

In this project, dumbbell shaped specimens with a thickness of 30 mm and an overall length of 330 mm were cast in steel moulds. The width at both ends is 90 mm and the centre part with a length of 120 mm has a width of 60 mm as shown in Fig. 1. The centre part, which was subsequently subjected to a uniform tensile stress, had the following size: 120×60×30 mm. To determine capillary absorption of water by means of neutron digital imaging, the centre part has been cut out of the specimen after a certain tensile strain had been applied.

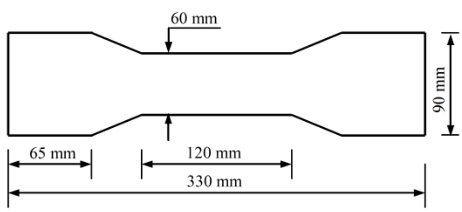

Figure 1**.** Geometry and dimensions of the dumbbell specimens used in this project.

After curing for 21 days, the specimens were fixed in a stiff steel frame so that direct tension tests. at different strain levels, could be imposed [8]. In this project, 0.5 % and 1.5 %

of tensile strains were been applied to both control and integral water repellent SHCC samples. After unloading the specimens, some of the stressed control samples were surface impregnated with 400 g/m^2 of silane gel (StoCryl HG200 distributed by STO, with about 85%) of an alkyl alkoxy silane in ethanol) henceworth SSG-SHCC. In this way, the surface zone of these samples was hydrophobic.

Subsequently, both the control, the SSG-SHCC, and the IWR-SHCC specimens were put in contact with water. Together with the set-up for water absorption test, they were put in front of the neutron beam. The first neutron images were taken from the dry samples and once water capillary suction started, neutron images were taken serially to follow the process of water penetration into SHCC. Further details can be found elsewhere [9, 10].

RESULTS AND DISCUSSION

Water penetration into control SHCC

The process of water penetration into the control SHCC exposed to different levels of tensile strain can be visualized by neutron digital imaging. Selected images taken at 5, 15 and 90 minutes of capillary absorption are shown in Fig. 2. As expected SHCC specimens which were not subjected to tensile stress absorbed very little water even after contact with the liquid for 90 minutes. A quantitative analysis shows that only a small amount of water penetrates into the porous material nevertheless as shown in Fig. 3.

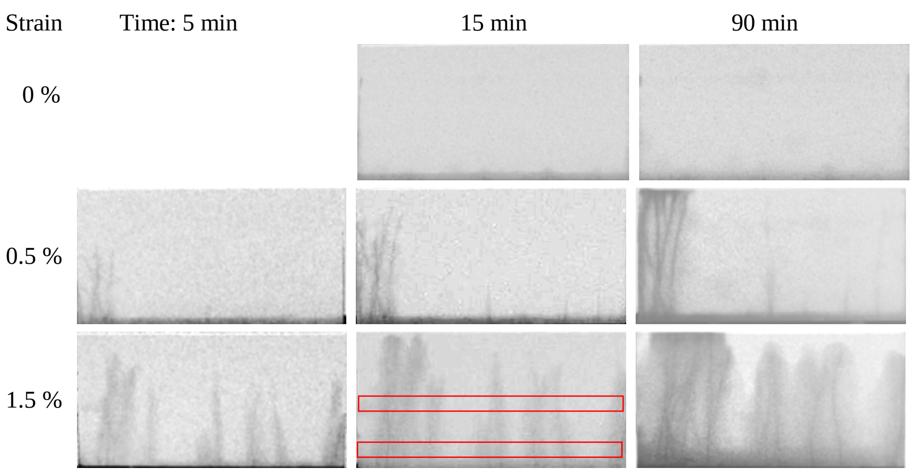

Figure 2. Neutron images of water penetration into control SHCC before and after subjecting it to 0.5% and 1.5% of tensile strain.

Upon exposure to a 0.5% tensile strength, the type of SHCC prepared for this project developed a few cracks. For wide cracks, water fills them up to the height of the specimen within 15 minutes. Only after this time, do the finer cracks become visible. The moisture distribution in SHCC in contact with water was quantitatively determined after 15 and 90 minutes in the two rectangular areas marked in Fig. 2 and are shown in Fig, 4. The graphs show the case water profiles obtained after 15 and 90 minutes of capillary absorption on specimens exposed to a tensile strain of either 0.5 % or 1.5 %. Obviously the lower part absorbed more water than the center of the specimen. The wide cracks, which reach the upper surface, soon contain significantly more water than the fine cracks. The profiles show that the sample subjected to a 1.5% tensile stress, had more and wider cracks that absorb more water. In addition, since the regions near the cracks is also gradually damaged under this strain, the samples absorb far more water than those that were subjected to a 0.5% tensile stress.

These results underline the fact that SHCC has an extreme strain capacity. If the mechanical properties are of main interest in a given application, then one can take full advantage of the strain capacity. If durability is an issue, however, the ultimate strain that may be allowed is very limited.

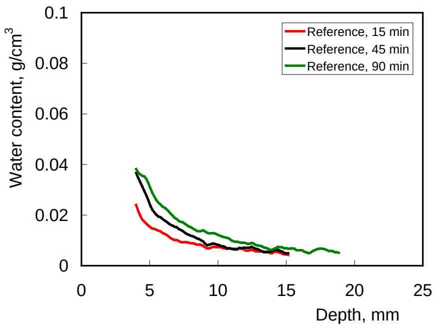

Figure 3. **A**mount of water absorbed by capillarity in unstrained SHCC after 15, 45 and 90 minutes of contact with water.

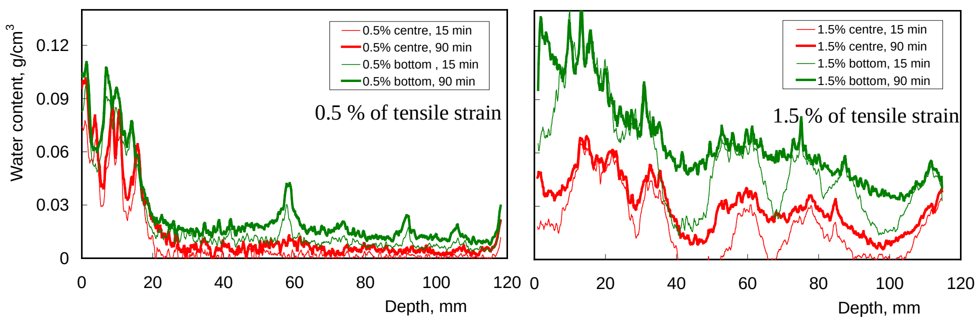

Figure 4. Horizontal quantitative water profiles in the center and at the bottom of cracked SHCC after imposed tensile strain of 0.5% (left) and 1.5 % (right).

Water penetration into integral water repellent SHCC

Addition of a silane emulsion to the fresh mix of SHCC results in an integral water repellent cementitious matrix (IWG-SHCC) and water penetration into the cracks formed under tensile strain should be reduced. Typical results are shown in Fig. 5. The specimens that were not exposed to strain practically do not absorb any water after 90 minutes of contact with water. Even after application of 0.5 % strain, only a small quantity of water can be observed in the cracks. However, when a strain of 1.5 % is imposed, cracks begin to absorb more water and, as the width of cracks is wide enough, water penetration cannot be prevented by this water repellent treatment alone.

The moisture profiles for the IWG-SHCC after strains of 0.5 % and 1.5 % were imposed are shown in Fig. 6. Compared with results shown in Fig, 4, far less water enters the crack-free zones and fewer cracks absorb water. However, water can enter the cracks and into the matrix. This means that integral water repellent treatment is effective in protecting IWR-SHCC from penetration of water and aqueous salt solutions as long as there are no cracks. But once micro-cracks are formed under a certain level of imposed tensile strain, as those tested in this study, water can still penetrate into the matrix of the IWR-SHCC. This emphasizes the point that high strain capacity of IWG-SHCC is beneficial mainly under mild conditions and not appropriate for an aggressive environment.

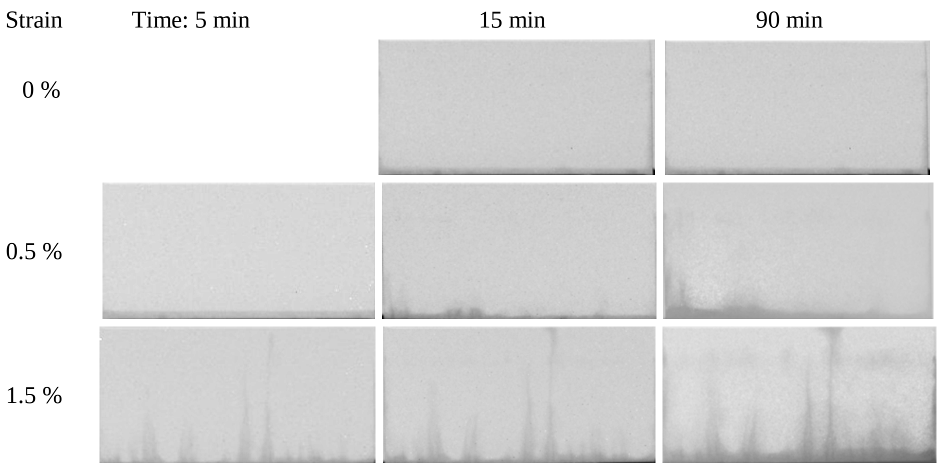

Figure 5. Neutron images of water penetration into integral water repellent SHCC before and after imposed tensile strain of 0.5 % and 1.5 %

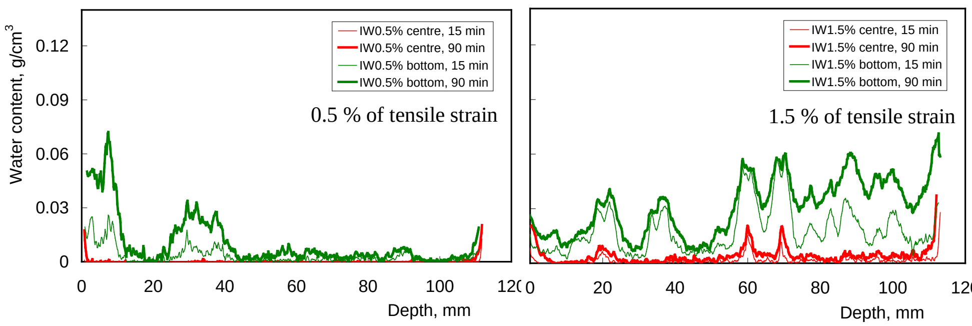

Figure 6. Horizontal quantitative water profiles in the center and at the bottom of integral water repellent SHCC after imposed tensile strain of 0.5 % (left) and 1.5 % (right).

Water penetration into hydrophobized stressed SHHC

The pre-stressed samples of control SHHC that had been surface impregnated with a silane gel, were also immersed in water, following the same protocol as for the other samples. The neutron images obtained for the water absorption by these samples are shown in Fig. 7. It can be clearly seen that no water can penetrate into the cracked zone after surface impregnation. This is clear evidence that surface impregnation after crack formation is most efficient to avoid penetration of water or aqueous salt solutions into SHCC.

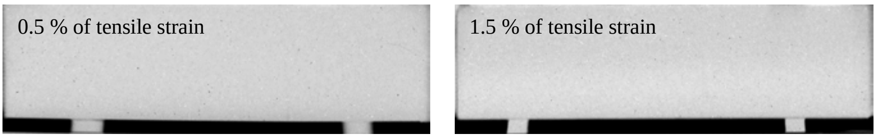

Figure 7. Neutron images of water penetration (after 24 h immersion) into pre-stressed SHCC samples (0.5% left, and 1.5% right) that were surface impregnated with a silane gel.

CONCLUSIONS

The following conclusions can be drawn from this study:

- Neutron digital imaging is a powerful tool to observe and quantify the process of water penetration into SHCC. A small amount of water penetrates unstrained SHCC as compared to ordinary concrete. But if a tensile strain of around 0.5 % is applied, the induced micro-cracks are quickly filled with water. It the strain imposed is 1.5%, more and wider cracks will result that allow far more water to penetrate into them, allowing the water to migrates into the neighboring material.
- Less water penetrates into integral water repellent SHCC. But under increasing imposed strain more and wider cracks will still form and although less water will enter as a result of its hydrophobic nature, some water will penetrate.
- Surface impregnation with silane gel after crack formation due to imposed strain has proved to be an efficient protection of SHCC in contact with water or aqueous salt solutions.

Therefore, if the structure is in an aggressive environment, the best protection is provided by surface impregnation with silane gel, rather than using an integral water repellent SHCC. Or, a combination of both.

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