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Application of neutron radiography in observing and quantifying the time-dependent moisture distributions in multi-cracked cement-based composites

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ABSTRACT

Significant tensile strain capacity of SHCC under tensile stress can be reached by multi-crack formation, while the cracks remain bridged by fibres. Ductility of SHCC is due to this multi-crack formation. Cracks are preferential pathways for ingress of water and salt solutions into the material. In this contribution neutron radiography has been successfully applied to visualize the process of water penetration into cracked SHCC and to quantify the corresponding time-dependent moisture distributions in cracked SHCC. Results indicate that in uncracked SHCC, less water can be found. Once cracked, however, both the amount of water and the penetration depth increased with increasing of crack density and the wider crack pattern when higher tensile strain was applied. Even at comparatively modest imposed strain when micro-cracks were formed, water penetrated into the specimens along the cracks of 30 μm–50 μm immediately and then water migrated further into the surrounding matrix from water filled cracks. Water then moved into the matrix adjacent to the cracks which was mechanically damaged by direct tension. Therefore, if durability of SHCC is an issue for application, a maximum strain may not be exceeded. In order to prevent penetration of water or salt solutions into cracked SHCC, two approaches were used. Integral water repellent SHCC was prepared by adding silane emulsion to the fresh mortar. Compared with neat SHCC, the integral water repellent SHCC with multi-cracks absorbed much less water after imposed to the same tensile strain. Notice that there was still a small amount of moisture that could enter the matrix of integral water repellent SHCC via cracks when the tensile strain was over 1.5% in this study. As an alternative method, surface impregnation with silane gel was a more promising approach to protect cracked SHCC from water or salt solution penetration into the material when multi-cracks formed.

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1. Introduction

Nowadays, it is generally accepted that service life of many reinforced and pre-stressed concrete structures is frequently not sufficient. The cost for early repair measures is often significantly higher than the cost for new construction. The major origin of these problems of maintenance and repair costs and poor serviceability is a lack of durability of reinforced concrete structures [1]. One reason for durability problems is the limited strain capacity of cement-based materials under imposed tensile stress. 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 meet this challenge. More recently high modulus and high strength polymer fibres changed the situation significantly. With this type of fibre Strain Hardening Cement-based Composite (SHCC) is prepared which is also called ECC (Engineered Cementitious Composites) in America [2–5]. The ultimate strain capacity of SHCC can reach up to 5% under tensile stress which is more than 500 times the ultimate strain capacity of conventional concrete [2]. This

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significant tensile strain capacity of SHCC is reached by multiple crack formation while the cracks are bridged by fibres. This is beneficial with respect to durability only if the multi-crack formation in SHCC does not lead to significantly increased penetration of water and aggressive ions. However, if SHCC reached a certain amount of tensile strain which leads to multi-cracks, in cases where the material is exposed to natural environment and to contact with seawater for instance, the durability becomes an important issue and service life of a structure may be seriously reduced. Wittmann et al. [6] reported that with approximately 3.5% of tensile strain, in which case the width of multiple cracks of the materials was around 60 μm–140 μm, water penetrated into SHCC quickly through the cracks. Similar phenomena have been found by Schroefl [7] in the cracked RC/SHCC slabs recently. On the other hand, Lepech et al. [8] and Yang et al. [9] found that micro-cracks in SHCC under moist conditions were closed again by self-healing. Both mechanical properties and permeability were re-established in this way.

However, the time-dependent moisture distributions in SHCC, especially after multi-crack formation due to different level of imposed tensile strain, has not been measured directly nor has it been quantified spatially so far. In this contribution, neutron radiography, a powerful non-destructive testing method was utilized to observe and quantify the process of water penetration into multi-cracked SHCC after a certain level of tensile strain. One major aim was to study how water penetrates into SHCC via multiple fine cracks, which were formed under different levels of imposed strain. In addition, water repellent treatment of cement-based material is proved an effective method to reduce water or ions penetration into material. So, another major aim of the project was to study the influence of integral water repellent treatment and surface impregnation on water penetration into these multiple cracks, which were formed under imposed tensile strain. This will be an economical and effective way to take advantage of the strain capacity of SHCC in severe environment. Results will be discussed in particular with respect to durability.

2. Materials and methods

2.1. Materials and preparation of test specimens

The composition of SHCC used in this project is as follows: 550 kg/m^3 ordinary Portland cement Type 42.5, 650 kg/m^3 local class F fly ash, 550 kg/m^3 sand with a maximum grain size of 0.3 mm, and 395 kg/m^3 water. Twenty six kg/m^3 of PVA fibres (Kuraray Company, Japan) with diameter of 40 μm were added into the fresh mix. In order to improve the workability a small amount of super plasticizer was added. For this test series dumbbell specimens have been prepared. The geometry and the dimensions are given in Fig. 1. The fresh mix was cast into steel forms. After hardening for 24 h under wet burlap the forms were removed and the specimens were placed in a humid room (T = 20 °C and RH > 95%). At an age of 21 days the specimens were fixed in a stiff steel frame in which different strain levels could be imposed via direct tension test, as shown in Fig. 2.

In order to characterize the mechanical properties of the SHCC under investigation in this project, stress-strain diagrams were prepared from measured load-deformation responses. The typical results are shown in Fig. 3. The average first cracking stress of this type of SHCC was approximately 2.05 MPa with variation of 0.05 MPa and the average ultimate tensile strain was approximately 3.86% with variation of 0.13%. It is acknowledged that the characteristic behavior of SHCC in tension under monotonic, quasi-static loading would be changed significantly when considering the cyclic loading condition [10]. In this project, however, the effect of cyclic loading was not considered. It shall be taken into consideration in future works.

After a selected tensile strain had been reached between 0.5% and 2%, the central part of the dumbbell specimens with dimension of 120 mm × 60 mm × 30 mm was cut off with a diamond saw. Then these small samples were dried in the oven at 50 °C until equilibrium. After that four of the surfaces of the samples were covered by aluminum self-adhesive foils with the exception of the two opposite surfaces with dimension of 100 mm × 30 mm.

In addition, integral water repellent SHCC had been produced by adding 2.0% (wt. % related to cement) of silane emulsion to the fresh mix of SHCC. Then the process was repeated to get the small samples after different tensile strain for capillary absorption as mentioned above. At the same time, a selected SHCC sample after exposed to tensile strain of 2.0%, was impregnated with 400 g/m^2 of

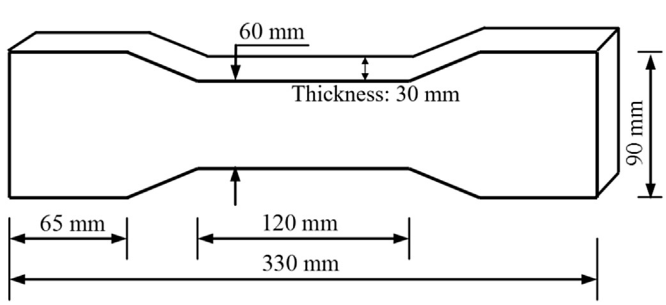

Fig. 1. Geometry and dimensions of the dumbbell specimens.

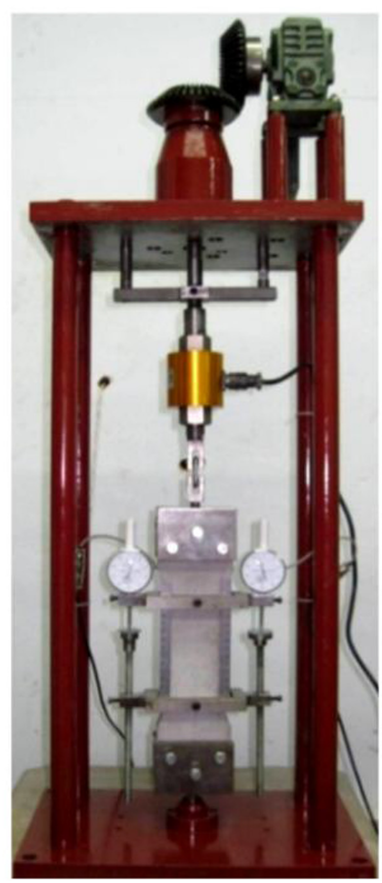

Fig. 2. Direct tension test imposed on the specimens to create multiple cracks under different levels of tensile strain.

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