Construction and Building Materials 178 (2018) 372–383

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

The effects of PE and PVA fiber and water cement ratio on chloride penetration and rebar corrosion protection performance of cracked SHCC

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HIGHLIGHTS

- Rebar corrosion protection performances of cracked SHCCs were investigated.
- Chloride penetration through cracks into SHCC was affected by the number of cracks.
- It was also affected by W/C of mortar matrix.
- The corrosion prevention performances of PE-SHCC and PVA-SHCC were comparable.
- Even SHCC with low ductility can enhance the durability of RC structures.

ARTICLE INFO

Article history:
Received 4 November 2017
Received in revised form 8 May 2018
Accepted 21 May 2018
Available online 26 May 2018

Keywords:
SHCC
Crack
Fiber
Chloride penetration
Rebar corrosion

ABSTRACT

SHCC mixtures with various water cement ratios and different types of fiber (PVA and PE) were tested with an aim to clarify the properties of cracked SHCC. After examining the mechanical performances of the composites, chloride penetration and rebar corrosion tests were conducted on cracked SHCC specimens.

PE fiber, PVA fiber, and a mixture of PE and PVA were added in SHCC. Part of the cement was replaced with limestone powder in some mixtures to vary the water cement ratio of the mortar matrix. For SHCC mixtures containing PVA fiber, which has lower strength and Young's modulus, the water cement ratio had to be increased to obtain a strain hardening property. The chloride penetration test revealed that chloride could penetrate into SHCC through fine cracks and that the width of the fine cracks had no bearing on the amount of chloride accumulated in the crack fracture surfaces. On the other hand, chloride penetration through cracks into the mortar matrix was affected by the number of cracks and water cement ratio. As a result, the corrosion area on rebar in cracked SHCC was also largely dependent on the number of cracks and water cement ratio. However, the corrosion area was smaller than that of ordinary mortar. When the strain is in a small range, the corrosion prevention performances of PE-SHCC and PVA-SHCC were more or less the same.

1. Introduction

Reinforced concrete (RC) exhibits superior mechanical performance thanks to the complementary combination of high compressive strength of concrete and excellent tensile strength of steel bars. RC is also highly durable because the corrosion-prone steel is embedded in high-alkaline concrete and prevented from corrosion. However, inadequate design and construction may allow ingress of aggressive agents such as chloride, carbon dioxide, water, and oxygen through cover concrete to the reinforcement and let corrosion occur on the steel surface. In particular, chloride-induced deterioration caused by chloride attack progresses at high rate. Deterioration of RC infrastructure, a large proportion of which suffers chloride attack, has been causing great economic losses in Japan.

RC member is designed to allow formation of bending cracks. As these cracks provide paths for aggressive agents to penetrate into the cover concrete, deterioration is further accelerated. A great

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https://doi.org/10.1016/j.conbuildmat.2018.05.163

number of researches have been conducted on the influences of cracks on reinforcement corrosion, in association with parameters such as crack width, cover depth, water cement ratio of concrete, and so on [1–6]. Since these tests were conducted under different conditions including the deteriorating environmental conditions, some of the results contradict each other. The general understanding, however, is that the smaller the crack width, the smaller the corrosion degree, as long as the crack width is less than about 0.1 mm.

Strain-hardening cement composite (hereafter, SHCC) is a material that exhibits pseudo strain-hardening characteristics, and develops numerous fine cracks with widths of several tens of microns under tensile stress. SHCC with cracks has higher corrosion protection performance than cracked ordinary concrete thanks to the fineness of the cracks [7–13], and is used for enhancing the durability of concrete structures [14,15]. Having said that, it has been reported that water can penetrate into SHCC within several hours by capillary action even when the cracks are minute [16–18]. According to Paul et al, chloride that has penetrated through fine cracks into SHCC causes corrosion of rebar [19]. The progress of corrosion is dependent on crack properties such as width, numbers, and so on [20], and affected by the mixture proportions of the mortar matrix [21]. Another important factor that may influence the corrosion protection performance of SHCC is the type of fiber used. The fiber volume and mix proportion of mortar matrix are determined in consideration of the properties of fiber such as its strength, elastic modulus, bonding characteristics with the mortar matrix, and so on, so that the SHCC can exhibit superior tensile ductility and excellent crack dispersity. If SHCC is to be used as a repair material for the purpose of enhancing structural durability based on the relationship between fine cracks and material permeability, the effects of different types of fiber, which govern the crack properties, on the durability and permeability should also be clarified.

Accordingly, this study aims at clarifying the effects of types of fiber used in SHCC and mixture proportions of mortar matrix on the rebar corrosion protection performance by a wet/dry cycle test with chloride solution. SHCC specimens with different types of fiber and varying cement proportions were prepared, and their mechanical performance and crack properties were examined. Other specimens were subjected to a wet/dry cycle test with chloride solution to examine penetration of chloride into cracked SHCC and the corrosion protection performance of cracked SHCC.

2. Influences of types of fiber and mix design on crack properties of SHCC

First, a uniaxial tensile test was conducted on SHCCs with different types of fiber and mortar matrix mixtures to examine the influences of types of fiber and mortar mixtures on the crack properties of SHCC under tensile stress.

2.1. Materials and mixtures

Table 1 shows the physical properties of fibers used in this study. Two types of fiber were used: High strength polyethylene (PE) fiber and high strength vinylon (PVA) fiber. For the matrix mortar, Ordinary Portland cement, silicate sand with a diameter ranging from 0.08 to 0.4 mm, fine limestone powder, a polycarboxylic acid super plasticizer, and a viscosity enhancing agent of cellulose ether were used.

Table 2 shows the mix proportions of SHCCs. A total of 9 SHCC mixtures, three each for three series, were prepared: 1) SHCC with PE fiber (series PE), 2) SHCC with PVA fiber (series PVA), and 3) SHCC with both PE and PVA (series PEPV). The fiber volume ratios of series PE and series PVA were 1.5 percent and 2.0 percent, respectively. These ratios were selected so that the SHCC mixtures could exhibit sufficient ductility despite the very low w/c ratio, as well as retain good flowability in a fresh state. While all the mixtures had a water powder ratio of 0.3, the w/c ratio was varied to investigate its effect: One of three mixtures in each series had its powder content entirely consisting of cement, and two other mixtures respectively had 300 kg/m^3 and 600 kg/m^3 of limestone powder. The amount of super plasticizer in each mixture was adjusted to achieve a mortar flow of 170 ± 10 mm.

2.2. Experimental procedure

Ten dumbbell-shaped specimens shown in Fig. 1 were prepared for each mixture according to the JSCE standards [22]. The specimens were demolded one day after the placement and cured in water at 20 °C until they reached the age ready for the tensile test. At the age of 1 month and 3 months, a uni-axial tensile test was carried out. Each time when the strain reached 0.25, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0 and 5.0%, the number and width of cracks within a 80 mm length gauge span were measured with the use of a ×50 magnification microscope (Keyence VH-5000). The minimum detectable crack width was 0.010 mm. The position of each crack was recorded in order to calculate average crack spacing.

2.3. Experimental results on crack properties

Figs. 2 and 3 show the stress-strain relationships under tensile stress at the age of 1 and 3 months, respectively. Table 3 shows the first cracking stress, tensile strength and ultimate tensile strain [22]. When the water cement ratio was high, the crack initiation strength and ultimate strain tend to be large. The tendency was most evident in PVA series. Only PVA-600 with the highest water cement ratio showed clear strain hardening, and PVA-0 and PVA-300 both had a very low ductility. This is because PVA fiber has lower tensile strength as compared to PE fiber, and when the crack initiation strength is high, PVA fiber cannot withstand the tensile force transferred from the mortar matrix at the moment of cracking, and rupture instantly in PVA-0, so that the fiber showed no reinforcement effect at all. Meanwhile, some with larger water cement ratio showed higher ultimate strains. All the mixtures showed a decrease in ultimate tensile strain as they aged, due to the increase in mortar matrix strength resulting from the advanced cement hydration.

Figs. 4–7 show the relationships between the strain and the average crack width, maximum crack width, number of cracks, and average crack spacing at the age of 1 and 3 months. As can be seen in Fig. 4, the average crack width of PVA-600, which was the only one PVA mixture that showed strain-hardening, was twice as large as that of other mixtures. This is because PVA fiber has a Young's modulus that is almost half of that of PE fiber and elongation of fiber was large at the cracks.

Table 1
Mechanical and geometrical properties of PE fiber.

Fiber	Diameter (mm)	Length (mm)	Density (g/cm^3)	Tensile strength (GPa)	Young's modulus (GPa)
PE	0.012	12	0.97	2.58	88
PVA	0.040	12	1.30	1.60	40