CRACK SELF-HEALING EFFECT ON PERFORMANCE OF REINFORCED CONCRETE MEMBERS SUBJECTED TO WATER SUPPLY AND CYCLIC LOADING

P. V. Truong [1], T. Kishi [2] and M. Kayondo[1]

[1]*Kishi Laboratory, Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo, Japan – email: phuong80@yahoo.com; email: kayondo@iis.u-tokyo.ac.jp*
[2]*Institute of Industrial Science, the University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo, Japan, – email: kishi@iis.u-tokyo.ac.jp*

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ABSTRACT

Self-healing concrete (SHC) can heal itself from cracks and other minor imperfections and thus prolong the life of the material itself and structure. In plain and reinforced concrete structures, fatigue is one of the major causes of both material and structural failures. Under the moving load due to traffic, it is not only the relatively simple opening and closing action in the transverse direction to the crack plane but also the severe reversed shear displacement along the crack plane. This accelerates the deterioration on the shear transfer mechanism at the crack surface. Although the shear transfer between two cracks accelarates the rupture of crack surface, a lot of crushed powders and fragments are produced in the crack. Even in this severe situation it is expected for self-healing concrete that crushed powders and fragments would bring the healing effect to cracks and then water leakage through cracks would reduce. When cracks form, the release of effective components from the SHA (Self-healing additives) would be promoted. Under cyclic loading, not only opening-closing action,but also reversed shear transfer are repeated and then the release of effective components from SHA would be accelerated. To verify this interesting scenario several SHA were applied to specimens of structural reinforced members subjected to cyclic loading in a series of tests. In this study, flexural fatigue tests were conducted for three different types of Self-healing concrete (SHC) and the effect of self-healing at fracture process zone (FPZ) and cracks area on structural performance is examined. The experimental results indicate that one of SHC shows remarkable effect not only on water sealing in water pass tests but also prolongation of fatigue life in flexural tests.

1. INTRODUCTION

Cracks in concrete may accelerate the rate of chemical deterioration and reinforcement corrosion that affect the durability of infrastructures. Self-healing concrete is one of the modern smart concretes, which can heal the cracks by itself. These are the results of moisture interaction with un-hydrated cement clinker in the crack under some special situations [1].

The man-made self-healing ability of concrete (autonomic healing) which replaces a part of cement or sand by self-healing additives was introduced by many researches [1],[2]. From the water leakage tests of previous studies [1]-[3], the performance of new type self-healing additives showed remarkable decrease in crack width (crack width is smaller than 0.2mm, water passes through the cracks all the time).

In this research, crack self-healing effect on performance of reinforced concrete members subjected to water supply and cyclic loading is studied.

2. EXPERIMENTAL PROGRAM

The materials used in this study included the basic concrete materials (sand, cement aggregates) and self-healing additives that were manufactured in the laboratory, plus other concrete admixtures. Concrete was ready-mix from concrete plant and cast at the same time for all specimens. The mix proportions are shown in Table 1.

For the purpose of investigation, 14 specimen of 100×100×900mm were considered. To avoid the un-hydrated cements inside concrete specimens, which may disturb the result, all the specimens were cured under 40 Celsius degree hot water to make sure almost all the hydration process is finished [4]. After 1 month curing, 3 cracks with crack spacing 110mm were induced in the compressive zone of beam. Holes were induced for crack holding during test. The detail of specimen is shown in Figure 1.
After initial cracks were induced at the top of specimens, cracks were kept open and curing done for two weeks.

Table 1: Mix proportions

Series	W/C	S/A	Fiber	Water	Cement	SHA	other	Sand	Gravel
	(%)	(%)	(kg/m^3)						
NC	49.6	51.3	0.65	175	353	-	-	900	869
SH30-LRA	49.6	51.3	0.65	175	353	240	60	600	869
SH10-G-S	49.6	51.3	0.65	175	353	123	-	777	869
SH27-LC	49.6	51.3	0.65	175	353	SHS 865.78		SHG 799.8	
Remarks	SH: self-healing; LRA: low reaction activation; LC: low heat cement;30 is 30% of aggregate is replaced by self-healing additives; S: Swelling material based; SHS; SHG: self-healing additives + sand and gravel								

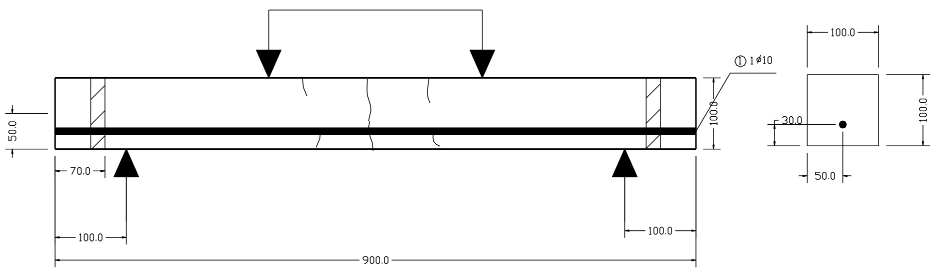


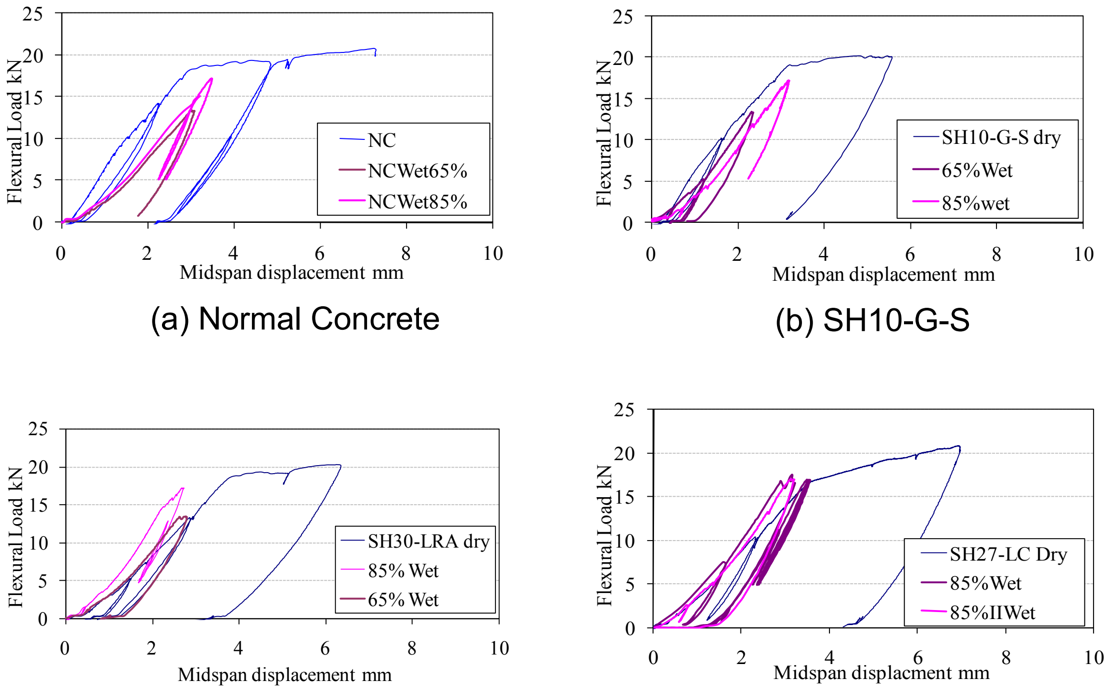
Figure 1: Profile of specimens

To investigate the degradation of flexural stiffness of concrete, a low reinforcement ratio was designed to ensure the failure stage is the same in all specimens. Ultimate capacity of the four types of concretes is the same; value 20kN is taken as the ultimate load. Mid span displacement of 4 mm was taken as the service criteria to quantify the life span of concrete member subjected to flexural loading in stress level 65% and 85% of ultimate capacity

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Because all the specimens are cured under hot water, it is assumed that almost all the hydration process in concrete is completed. Response of normal concrete in dry and wet condition under static flexural tests is shown in Figure 2a. The response of specimens in wet condition showed smaller flexural stiffness than normal concrete in dry condition. This can be explained as the reduction of compressive and tensile strength of concrete when it is wet.

The static flexural responses of SHC are shown in Figures 2 (b, c and d). Flexural stiffness recovery of SHC was found after curing. In case SH30-LRA and SH27-LC, the flexural stiffness of specimens under wet test was even larger than the specimen under dry test. It can be explained as the process of curing; the specimens were put up side down and bended on opposite direction to keep the crack open during curing period by bolt anchors.



(a) Normal Concrete

(b) SH10-G-S

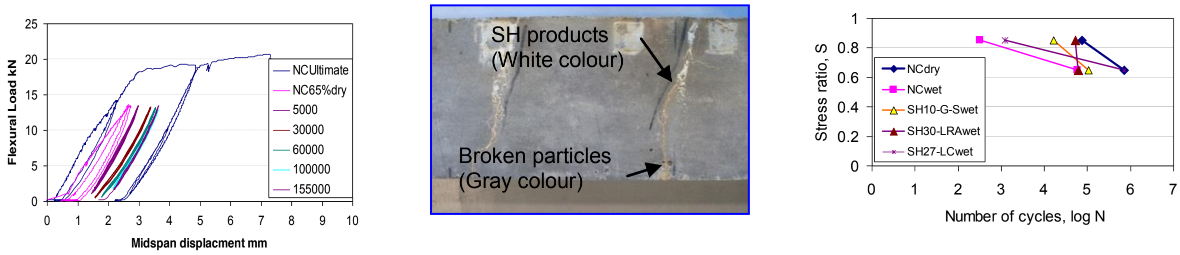
(c) SH30-LRA

(d) SH27-LC

Figure 2: Response of concrete specimens in dry and wet condition

When the crack is opened, the SH products are activated and fill the cracks and harden after two weeks. After the bolt anchors on both sides of specimens were released, due to the existence of SH products on the cracks, the cracks could not close completely. In dry conditions, the damage was large in first stage due to the appearance of new cracks. It was observed from experimental results that from cycle 60000, the degeneration of stiffness was almost stopped (Figure 3a). The possible change was the plastic deformation of steel bar. Figure 3b shows the broken particles flushed out after test. The initial crack induced before tests are nearby the ink line. After the test, the initial cracks penetrated to the bottom of the specimens, gray color indicated the broken particles of concrete which was washed out by water. White color may be the self-healing products that formed after curing and one part of them were washed out by water. Therefore, SHC is expected to reduce the effect of water

into RC members by creating a self-healing solid layer; reducing the smoothness of crack surface, and then prolong the flexural fatigue endurance of RC structures. The results of the fatigue test are generally expressed in terms of S-N curves. The linear regression of specimens is shown in Figure 3c. SHC shows different level of improvement in comparison with normal concrete in wet condition. SH27-LC showed longer and stable flexural fatigue endurance than normal concrete.
The relationship between load and mid span displacement is shown in Figure 3a.



(a) (b) (c)

Figure 3: Cyclic load result, flushing effect and S-N curves

4. CONCLUSIONS

- Water is found to accelerate the degradation of concrete under flexural fatigue loading. Washing out of crushed particles was observed.
- The increase of flexural stiffness of SH30-LRA and SH27-LC were observed at the first cycle after curing.
- Self-healing additives may make flexural fatigue endurance of concrete member become longer than that of normal concrete in wet condition.

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