

DEVELOPMENT OF SELF-HEALING GRANULES HAVING SEMI-CAPSULATION EFFECT BY USING CEMENT COMPOUND, CHEMICAL/MINERAL ADMIXTURES & ITS WATERTIGHT PERFORMANCE THROUGH CRACK

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ABSTRACT

Granulation technique, introducing the self-healing ability to concrete, was developed by Koide, 2010 [1] based on the capsulation technology in the food/medicine industry. In this research, self-healing granules, containing cement compounds, chemical and mineral admixtures, were fabricated by a proposed granulation process and the capability of crack-self healing concretes incorporating granules was investigated.

Self-healing granules, which were manufactured in advance by a roller mixer in the laboratory, were added to the concrete mixture as partial sand replacement, at a dosage of 70 kg/m³ concrete.

In order to examine the self-healing performance of the concrete, a water passing test, in which a constant water head of eight centimeters flowing through a static crack of 0.2-0.4mm in width, was conducted for two months. Three different regimes of cured conditions i.e regime one (cured in water at 40°C for one month-short term range), regime two (cured in air at 20°C, relative humidity of 60% for twelve months-long term range) and regime three (cured in water at 40°C for nine months and then in air at 20°C, relative humidity of 60% for three months-long term range) were applied to investigate the self-healing capacity of concrete.

In this study, the capability of crack self-healing concrete was assessed by observing the reduction of water leakage over time, the closing process of surface crack and chemical analysis of deposit products in the crack.

Based on the experimental results, the performance of self-healing concrete, improved by selecting the ingredients of granule and developing suitable method for granulation, will be discussed.

1. INTRODUCTION

One of recent approaches to introduce the self-healing ability to concrete at a normal water/cement ratio was proposed by Ahn and Kishi, 2010 [2]. Some specific mineral and chemical admixtures were added to concrete mixture in form of powder as partial cement replacement. Even though the self-healing performance was promising, there were some disadvantages in this approach, such as the reduction in the workability of fresh concrete and the self-healing efficiency of hardened one. To overcome the

above mentioned drawbacks, the self-healing granules, in which the inner materials containing Portland cements and other additives were coated by cement compound, were used by partial sand replacement in this study.

2. MATERIALS

Self-healing granules were introduced with a target of long term preservation of self-healing capacity in normal water/cement ratio concrete. In this study, the crack self-healing capacity of concrete was attributed by the combined effects of cement hydration reaction, calcite formation and swelling/expansion of cementitious matrix. Apart from the granulation technology to maintain self-healing property for long term, a specific retarder material, which refrained the hydration process of embedded cement during casting concrete, were also investigated (Table 1). After fabrication in the laboratory, the granules were transported to a ready-mixed concrete plant for casting the cylindrical concrete specimen (100mm diameter x 200mm height). Concrete was cast with a water/cement ratio of 49.6% and self-healing granules were incorporated as partial sand replacement at a dosage of 70 kg/m³ concrete (Table 2). After casting, concrete specimens were cured under three different regimes i.e regime one (cured in water at 40°C for one month-short term range), regime two (cured in air at 20°C, relative humidity of 60% for twelve months-long term range) and regime three (cured in water at 40°C for nine months and then in air at 20°C, relative humidity of 60% for three months-long term range).

Table 1 : Ingredients of self-healing granules

Ingredients	Portland cement	Admixtures	Retarder	Water
Percentage (%)	53.8	16.1	21.5	8.6

Table 2 : Mix proportion of concrete

W/C (%)	s/a (%)	G _{max} (mm)	Air (%)	Water	Cement	SH Granule kg/m ³	Sand	Gravel
49.6	51.3	20	4.5	175	353	70	830	869

3. METHODS

After curing, a penetrating crack was induced to the concrete specimen by tensile splitting test. The internal crack was controlled to around 0.2mm by the thickness of Teflon sheet, while the surface crack width was measured by Microscope at three different spots. The average value of those spots was adopted as the surface crack width, ranging from 0.2-0.4mm. In this experiment, a continuous water supply was conducted until 56 days to stimulate the chemical and other reactions in the crack. It was assumed that once crack occurred, the embedded granules were broken. And when water flowed through a crack, not only did the self-healing materials were diffused into crack surface but also the cement hydration products were dissolved in flowing water. Over time, the crack in concrete was healed & the water leakage was stopped, mainly due to the formation of new products by the above mentioned mechanisms.

The self-healing performance of concrete was evaluated by the water passing test, in which the water leakage through a crack under pressure of approximately eight centimeters water head was measured periodically, the crack closing process

observed by microscope, and Thermogravimetry-Differential Thermal Analysis (TG-DTA) of healing product precipitated at the crack.

In order to observe the time dependent permeability of a cracked concrete, the water flow rate was measured and calculated by the formula (1), on the specific days until 56 days subjected to continuous water flow.

$$FR_i = \frac{V_{5min,i}}{t} \tag{1}$$

where: FR_i -water flow rate on i days [cm^3/sec]; $V_{5min,i}$ -volume of water flowing through a crack in five minutes on i days [cm^3]; t -period of testing, in this test $t=300sec$.

Moreover, to assess quantitatively the decreasing flow rate with time, flow relative to initial flow was introduced as in formula (2):

$$RFR_i = \frac{FR_i}{FR_0} \tag{2}$$

where: RFR_i - relative flow rate on i days [%]; FR_i - water flow rate on i days [cm^3/sec]; FR_0 - initial water flow rate on starting day of testing [cm^3/sec].

4. RESULTS

The results showed that there was no significant difference of healing capacity among three curing regimes. The same tendency of reduction in water leakage and healing products deposit on the surface crack was observed with time even though the initial flow rate was relatively different (Figure 1). It could be seen that the water leakage after one day exposed to water flow was just about 10% of initial water flow and then after one week exposure, the water flow was almost stopped during the permeability test as clearly seen in Figure 2.

Moreover, it was found that the crack closing process was mainly observed at the bottom of testing specimen by the substantial amount of white residue forming at crack mouth (Figure 3). A possible reason was that under the effect of flowing water, there was a higher concentration of both calcium and carbonate ions at this area so that facilitating the precipitation of calcite. The findings mentioned above were verified by analyzing the healing products deposited on the surface crack by TG-DTA test. The result showed that the healing products were mainly composed of calcite.

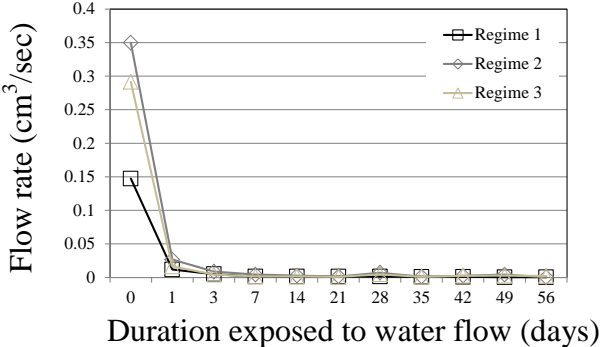


Figure 1: Change of water flow rate with time.

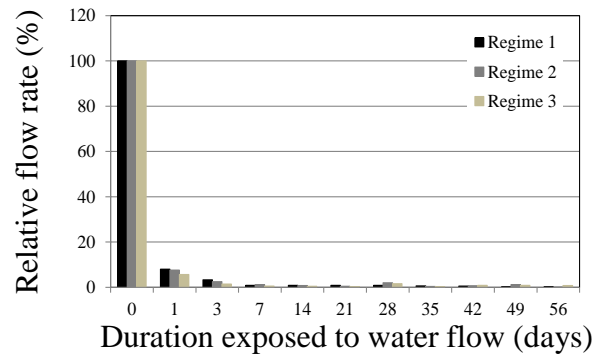


Figure 2: Change of relative flow rate with time.

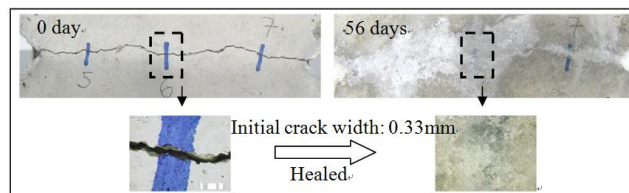


Figure 3: Crack closing process in a typical specimen of regime 1.

5. CONCLUSIONS

Under certain laboratory conditions (static crack of 0.2-0.4mm, continuous water supply), the granulation approach may look promising to maintain the self-healing ability of concrete, with respect to recovery of transport properties, for both short term and long term exposure. Crystalline healing products were gradually formed on the crack surface and thus significantly reduced or completely stopped the water leakage with time. This approach may be suitable for self-healing of underground or water retaining structures where continuous water supply may be expected.

REFERENCES

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