CLARIFICATION OF PORE MODIFICATION MECHANISM IN CONCRETE BY C-S-H TYPE ACCELERATOR

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ABSTRACT

Hardening accelerators are used to reduce concrete demolding time during the winter and in concrete products. In recent years, the C-S-H type accelerator have been developed to improve the workability and productivity of concrete. This is affected by the nanoparticles of calcium silicate hydrate (C-S-H), and it is believed that the hydration product fills the pores efficiently. However, the mechanism of which C-S-H nanoparticles densify pores in concrete is unclear. The purpose of this research is to understand the influence of the C-S-H type accelerator on the durability of concrete due to the difference in addition rate, and to elucidate the mechanism of densifying pores. In addition, measuring the pore size distribution by a mercury intrusion method. It was also carried out air permeability test in order to understand the relationship between durability and addition rate. Furthermore, in order to evaluate the effect of the C-S-H type accelerator on the pores at the aggregate interface, an air permeability test was performed from different directions. As a result, it was found that the air permeability coefficient was improved by the addition of the C-S-H type accelerator. In addition, it is suggested that the space to be densified may be different depending on the addition ratio of the C-S-H type accelerator.

Keywords: Air permeability test, C-S-H type accelerator, Mercury intrusion method

1. INTRODUCTION

Hardening accelerators which are chemical admixtures, are used to reduce concrete demolding time during the winter constructions and in concrete products factories.
A ordinary nitrite-based hardening accelerator promotes the hydration of cement because it promote the elution of ions from cement particles. So it accelerates the development of strength. On the other hand, the C-S-H type accelerator developed in recent years is mainly composed of calcium silicate hydrate (C-S-H) nanoparticles, and these particles are introduced as seed crystals of C-S-H in the liquid phase of concrete. C-S-H grow and hydration is boosted. According to previous researches [1], the C-S-H type accelerator, like the other hardening accelerators, increases initial strength. In addition, since it does not help the hydration reaction of cement, it is thought that it does not affect the strength at long age.

In recent research, the C-S-H type accelerator is effective in the durability of concrete. A possible reason is because the hydration product efficiently fills the pores in concrete due to the hydration reaction that proceeds even in a position apart from the cement particles by the nanoparticles. However, the mechanism by which C-S-H nanoparticles densify pores in concrete is not clear. The purpose of this research is to understand the effect of the C-S-H type accelerator on the durability of concrete by the addition rate and to clarify the mechanism of densifying the pores. For that purpose we carried out two experiments. (A) Confirmation of densification of pores in concrete due to difference in addition rate. (B) Which pores in the concrete were densified by the C-S-H type accelerator.

2. MATERIALS / MIXPROPORTION

2.1 Materials

Table 1 Mix Proportion

<table>
<tr><th colspan="2">Experiment</th><th rowspan="2">W/C (%)</th><th rowspan="2">s/a (%)</th><th rowspan="2">air (%)</th><th colspan="4">Unit[kg/m³]</th><th colspan="2">ACX</th></tr>
<tr><th>(A)</th><th>(B)</th><th>W</th><th>C</th><th>S</th><th>G</th><th>Addition rate [W×%]</th><th>Addition amount [kg]</th></tr>
<tr><td>○</td><td>○</td><td rowspan="7">60</td><td rowspan="7">48</td><td rowspan="7">4.5</td><td rowspan="5">170</td><td rowspan="5">283</td><td rowspan="5">874</td><td rowspan="5">976</td><td>0</td><td>0.0</td></tr>
<tr><td>○</td><td></td><td>3</td><td>5.1</td></tr>
<tr><td>○</td><td>○</td><td>5</td><td>8.5</td></tr>
<tr><td>○</td><td></td><td>7</td><td>11.9</td></tr>
<tr><td>○</td><td></td><td>10</td><td>17.0</td></tr>
<tr><td></td><td>○</td><td rowspan="2">200</td><td rowspan="2">333</td><td rowspan="2">817</td><td rowspan="2">912</td><td>0</td><td>0.0</td></tr>
<tr><td></td><td>○</td><td>5</td><td>10.0</td></tr>
</table>

The cement was ordinary Portland cement (OPC). As fine aggregate, it was Crushed sand (S). The coarse aggregate was Limestone (G). Hardening accelerator was the C-S-H type accelerator. It was used air entraining agent and water reducing agents as other admixtures.

2.2 Mix proportion

Table 1 shows mix proportion used in the experiments. For experiment A, it was conducted at a unit water volume of 170kg/m^3 and, experiment of B, 170kg/m^3 and 200kg/m^3. The amount of aggregate was changed to evaluate the porosity at the aggregate interface. The pore in the lower surface of the aggregate can be multipled by increasing the amount of water trapped in the lower surface of the aggregate. In this study, the C-S-H type accelerator was added over the unit of water volume. It was considered to be important for its concentration to be relative to the unit of water content, because C-S-H nanoparticles are present in concrete as core for the reaction of C-S-H [2]. So the C-S-H type accelerator was changed by the addition rate to the unit water volume.

3. OUTLINE OF EXPERIMENT

3.1 (A)Confirmation of densification of pores in concrete due to difference in addition rate

3.1.1 Air permeability test

An air permeability test was conducted to understand the substance permeability of the concrete containing C-S-H type accelerator. The cylindrical sample of φ100 × 50 mm were prepared and sealed for 7 days in a constant temperature and humidity chamber. The sample was dried in a 40°C oven until the mass becomes constant, air was allowed to permeate at a pressure of 0.2 MPa, and the amount was measured using a measuring cylinder by water displacement method. From the test results, the air permeability coefficient was calculated using the equation number (1).

$$K = \frac{2LP_1}{(P_1^2 - P_2^2)} \cdot \frac{Q}{A} \qquad (1)$$

Where:
K: Air permeability coefficient (cm ^{4}/N·s)
L: Sample thickness (cm)
P1: Loading pressure (N/cm^2)
P2: Outflow side pressure (N / cm^2)
Q: Air permeability (cm^3/s)
A: Air permeability area (cm^2)
P2: Atmospheric pressure 0.1 (N / cm^2)

3.1.2 Porosity test

A porosity test was conducted to understand the amount of pores in the concrete. After measuring the dry mass, vacuum saturation treatment was performed, and the saturated mass and the water immersed mass were measured. The porosity was calculated from the Archimedes method using dry mass, saturated mass and water submerged mass. The density of the object was obtained by the equation number (2). The porosity was calculated by equation number (3).

$$\rho = \frac{\rho_1 \times W}{(W - W')} \qquad (2)$$

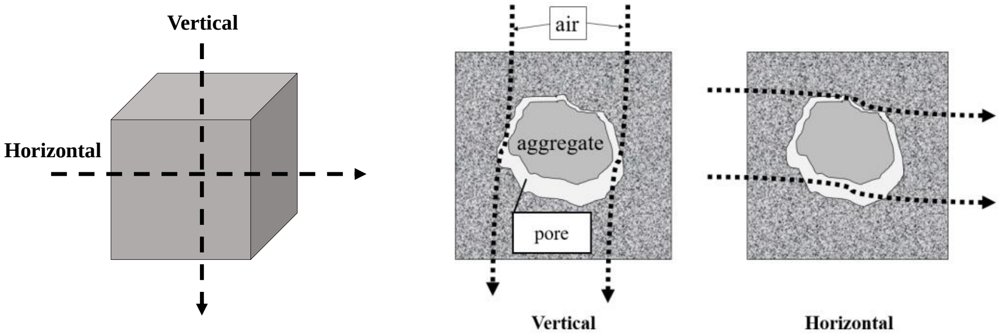

Figure 1 Core removal from different directions

ρ: Density of the object (kg/m^3)
W: Weight in air (kg·m/s^2)
W ': Weight in water (kg·m/s^2)
ρ_1: Density of water (kg/m^3)

$$\text{Porosity} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Wet weight} - \text{Immersed weight}} \times 100 \qquad (3)$$

3.1.3 Pore size distribution measurement

Mercury intrusion test was conducted to understand the pore size distribution in concrete. The sample used for the mercury penetration test was a cube of about 5mm. First, a 100×100×400 mm square specimen was prepared, and a cubic cutter of about 5mm side, including aggregate, was collected using a concrete cutter. The sample was dried in a drying oven at 40°C, and then dipped in acetone and dried again in the oven at 40°C.

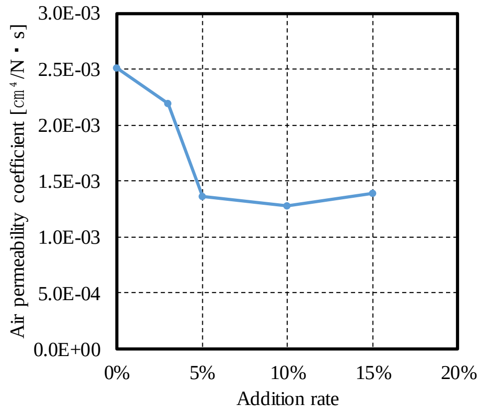

Figure 2 Air permeability test

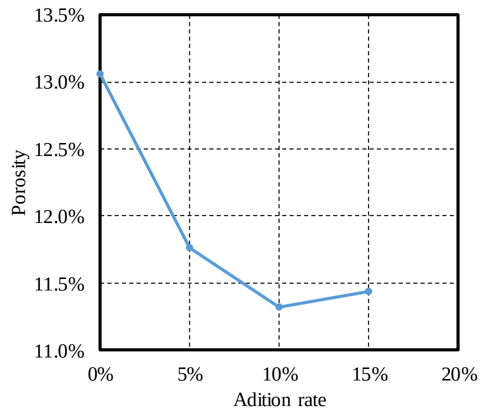

Figure 3 Porosity test results

3.2 (B)Analyse of densification of the pores in concrete by using C-S-H type accelerator

Permeability test from different directions

Figure 1 is a schematic illustration of the test. An air permeability test, from different directions, was conducted to understand the influence of the C-S-H type accelerator on the aggregate interface [3]. Usually, the air permeability test is often performed from the vertical direction. In this case, we wanted to measure the pores on the lower surface of the aggregate, thus we conducted an air permeability test from the horizontal direction. For the test it was produced concrete samples using a 150×150×150 mm steel formwork. After, the specimens were sealed in a constant temperature and humidity chamber for 7 days. The cores were collected in order to provide a cylinder with the φ100 mm perpendicularly to the installation surface, and was cut with a concrete cutter with a size of φ100 × 50 mm. After that, this sample was tested as shown in Figure 3.1.1 to calculate the air permeability coefficient.

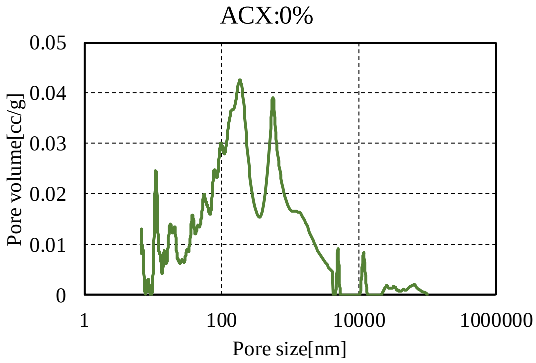

Figure 4 Addition rate: 0%

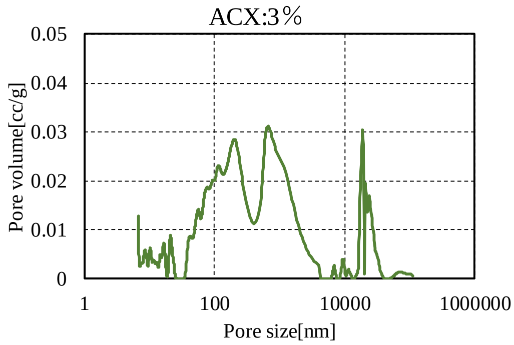

Figure 5 Addition rate: 3%

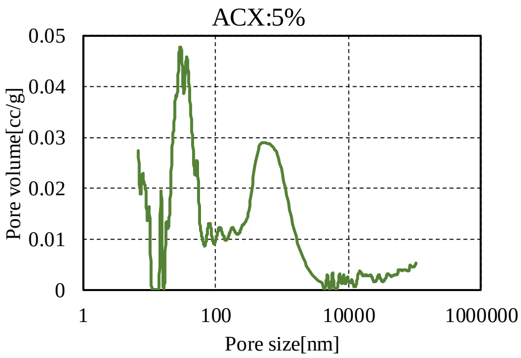

Figure 6 Addition rate: 5%

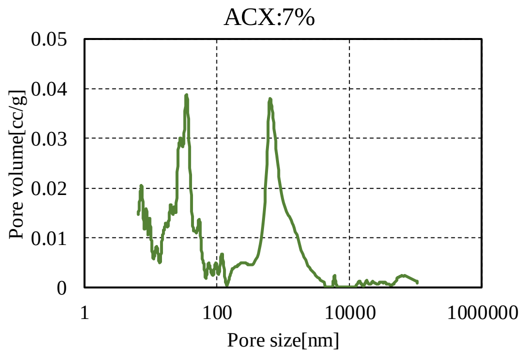

Figure 7 Addition rate: 7%

4. TEST RESULTS

4.1 (A)Confirmation of densification of pores in concrete due to difference in addition rate

4.1.1 Air permeability test results

Figure 2 shows the relationship between the air permeability coefficient and the addition rate at 7 days. It can be seen that the permeability coefficient decreases as the addition rate of the C-S-H type accelerator is increased. In particular, the air permeability coefficient was greatly reduced at the addition rate of 3% to 5%, and almost no change was observed in the air permeability coefficient even when added more than that. From this, it is considered that the permeability coefficient is improved when the C-S-H type accelerator is added to make the pores in the concrete dense.

4.1.2 Porosity test results

Figure 3 shows the relationship between the porosity and the addition rate. When the C-S-H type accelerator was added, the porosity decreased at any addition rate as compared with

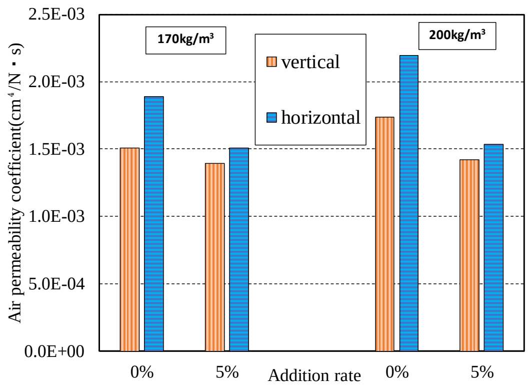

Figure 8 Air permeability test from different directions

the non-addition. In particular, when the addition rate was 5%, the porosity was significantly reduced when compared with the non-addition. Moreover, even if the addition rate was increased to 10% and 15%, the difference was less than 1% compared to the case of the addition rate of 5%.

4.1.3 Porosity test results

Figure 4 to 7 show the pore size distribution at each addition rate. Two large peaks can be confirmed from the results of any addition rate.

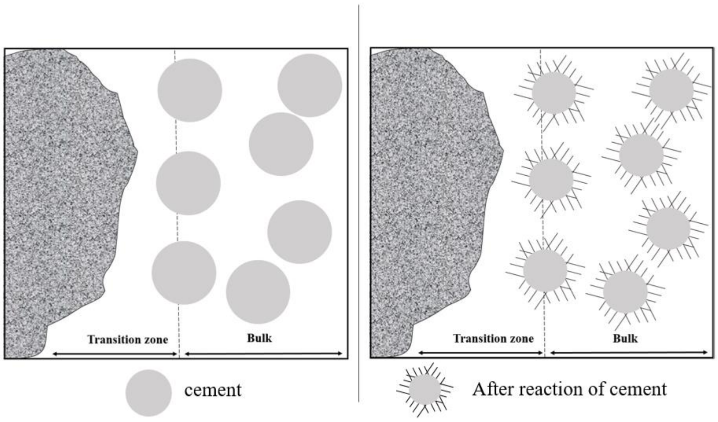

Figure 9 The hydration reaction of cement

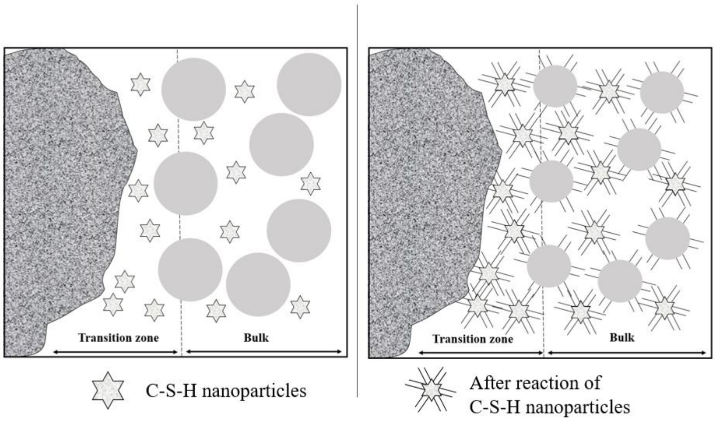

Figure 10 The function of C-S-H type accelerator

In addition, focusing on the pore size for each addition rate, it can be seen that the pore size distribution with addition rates of 0% and 3% of C-S-H type accelerator has peaks around 800 nm and 200 nm. On the other hand, when the C-S-H type accelerator was added at 5% or more, the peak at 800 nm could be seen, but the peak at 200 nm could not be confirmed. Instead, a peak appeared at a small diameter of about 30 nm. From this result, it is understood that when 5% or more of C-S-H type accelerator is added, the pores in the concrete are densified.

4.2 (B)Analyse of densification of the pores in concrete by using C-S-H type accelerator

Permeability test from different directions results

Figure 8 shows the results of air permeability test from different directions. In the case the C-S-H type accelerator was not added, it was found that the permeability coefficient in the horizontal direction was larger than that in the vertical direction for both unit water amounts of concrete. It is considered that this is due to the pore in the lower surface of the aggregate. On the other hand, the air permeability coefficient of the concrete using 5% of C-S-H type accelerator was improved in the vertical and horizontal direction. In particular, the improvement of the permeability coefficient in the horizontal direction was a great result. In addition, in both unit water contents, when 5% of C-S-H type accelerator was added, there was almost no difference between the vertical and horizontal air permeability coefficients.

5. CONSIDERATION AND CONCLUSIONS

Figure 9 and 10 shows an image of the pores density when the C-S-H type accelerator is added and when it is not. The improvement of the permeability coefficient has been confirmed by the addition of the C-S-H type accelerator. In addition, it is suggested from the measurement results of pore size distribution, that the pores to be densified may differ depending on the addition rate. Since the C-S-H nanoparticles are small particles of several tens to several hundreds of nano-meters, they are considered to enter in pores of concrete. It is thought that the pores of concrete are densified by generating hydrates in side them. And when 5% or more of the C-S-H type accelerator is added, it is considered that the pores in the interfacial transition zone interface are also densified.

6. FUTURE WORKS

In this study, it was shown that the C-S-H type accelerator may act in the transition zone. The C-S-H type accelerator has an effect of suppressing bleeding. Adjust the bleeding amount and check if the same effect can be obtained. In addition, it is necessary to introduce particles in the same size as the C-S-H nanoparticles into concrete and to carry out comparison to confirm that the transition zone is densified by hydration reaction caused by C-S-H nanoparticles.

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