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EFFECTS ON HYDRATION REACTIONS BY DIFFERENT CURING TEMPERATURES FOR VARIOUS TYPES OF CEMENT

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ABSTRACTS

Cement hardens by hydration reaction. However, it is noted that cement type and curing temperature have an effect on hydration reactions. It is important to understand the effects of materials of concrete and the conditions of the construction environment in order to design concrete that satisfies the required performance such as strength and durability. Therefore, in this study, cement pastes specimens were prepared using various types of cement, curing temperatures, and curing periods. We measured the amount of bound water and organized it according to the accumulated temperature, which is indicated by temperature and time. Then, the degree of hydration was quantitatively evaluated. In order to know the effect on strength and durability, mortar specimens were made by setting the curing period at each curing temperature to achieve the same level of hydration. And we conducted compressive strength test and accelerated carbonation tests. As a result, the effects of temperature on hydration reaction, strength, and mass transfer resistance were evaluated. It was found that a lower curing temperature had a greater effect on the progress of hydration when blast-furnace cement was used. Furthermore, the trend was more significant when the content of blast furnace slag fine powder was high.

Keywords: *Hydration Reaction, Curing Temperature, Curing Period, Bound Water, Accumulated Temperature*

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1. INTRODUCTION

Strength and mass transfer resistance of concrete are developed in the process of hydration reaction between cement and water. Therefore, it is important to prevent dissipation of water during the hydration process, and wet curing is necessary. When designing for concrete, it is assumed that concrete that satisfies the design service life will be produced through material approaches such as type of cement and W/C. However, in addition to the materials used, construction factors such as ambient temperature and curing conditions are also considered to influence the strength and durability in hardened concrete structures. Many studies have been conducted on the effects of curing conditions on hardened cement properties when using various types of cements [1] [2]. On the other hand, in order to design concrete that satisfies the required performance, it is necessary to understand the effects of materials and the curing environment on hydration. In the case of using Ordinary Portland cement, there have been many studies focusing on the curing environment, such as temperature and humidity [3]. It is known that when using blended cements such as blast furnace cement, the initial curing must be ensured. However, there are not many examples of studies on hydration reactions focusing on the curing environment. In recent years, the use of blast-furnace cement with a high percentage of ground granulated blast-furnace slag has been used to reduce the environmental impact, and it is necessary to understand the hydration reactions in different curing environments.

In this study, we focused on the curing temperature as the curing environment when various cements are used, examining it in order to understand the hydration reaction. In addition, the relationship between the hydration reaction and the associated strength and durability was examined.

2. UNDERSTANDING HYDRATION REACTIONS

2.1. Outline of specimen

In this study, the bound water ratio was measured over time with different types of cement and under different curing conditions in order to understand the hydration reaction. Table 1. shows the listed for kind of cements using in this research. Five types of cement were used: Ordinary Portland Cement (OPC), Low-heat Portland Cement (LPC), High-early-strength Portland Cement (HPC), Blast-furnace Cement type B (BB), and type C (BC). BB was 50% replacement of ground granulated blast furnace slag (GGBS). BC was product cement with replacement of about 70% GGBS. W/C = 0.55 and was constant.

Table 1 Cement physical properties

Cement	Density (g/cm^3)	Blaine (cm^2/g)	Replacement (%)
OPC	3.15	3530	-
LPC	3.24	3780	-
HPC	3.14	4330	-
BB	3.03	3780	50
BC	2.96	3860	70

2.2. Outline of experiment

Figure 1 shows an outline of the experiment. Cement paste was poured into a 50×70 mm zippered plastic bag, and a thin specimen of about 50×70×1 mm was casted. To examine the effect of curing temperature, sealed curing was conducted at 5, 20, and 40°C. The number of curing days were 1, 2, 3, 4, 5, 7, 11, 14, 21, 28, 42, and 56 days. After curing was completed, the samples were granulated, and hydration was stopped using a large amount of ethanol as a pretreatment. About 1 g of the granulated sample was measured and firing was conducted at 850°C in an electric furnace. The firing temperature was set at 850°C to prevent mass increase due to oxidation of GGBS.

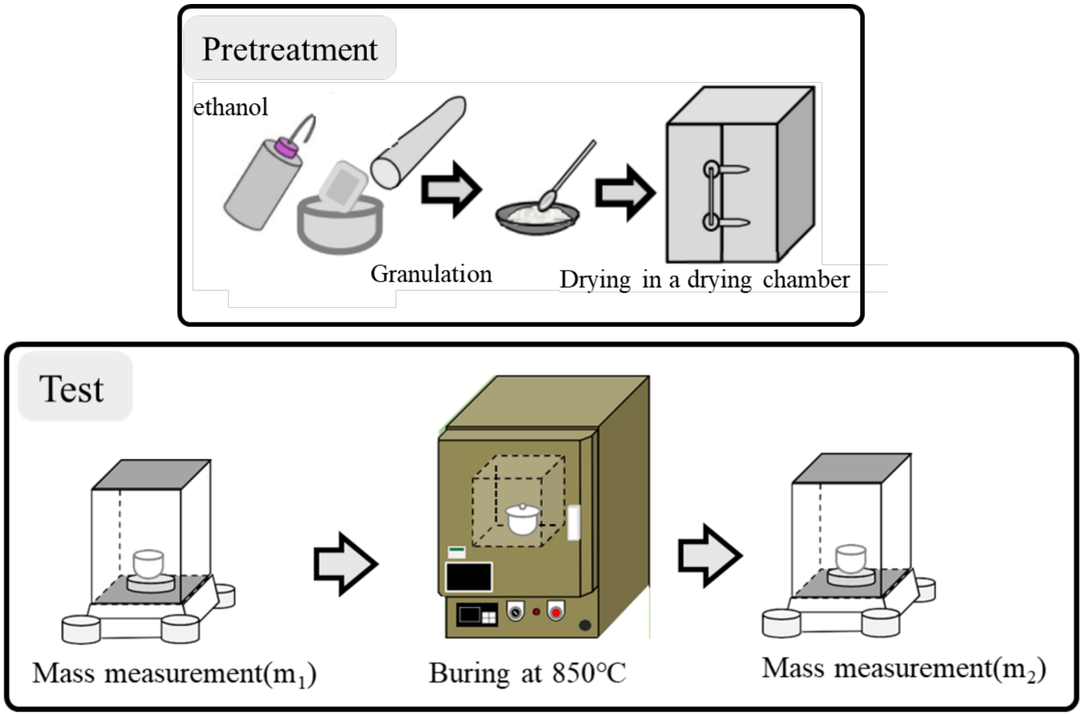

Figure 1. Outline of the experiment

The sample mass was measured before and after buring, and the bound water ratio was calculated using Equation (1).

$$\text{Bound water ratio}(\%)=\frac{m_1\text{-}m_2}{m_2}\times 100 \tag{1}$$

Where m_1 is the mass of before firring, m_2 is the mass of after firing

2.3. Results and discussion

2.3.1. Relationship between curing days and bound water ratio

Figure 2 and Figure 3 show the relationship between the number of curing days and the bound water ratio for each curing temperature about OPC and BB. It was found that the bound water ratio increased significantly when the curing period was short, and that the increase slowed down as the curing period was extended for all cement types. BB shows a slower increase in bound water ratio in the initial period of curing when cured at 5°C compared to OPC.

Focusing on the curing temperature, the higher the temperature, the larger the bound water ratio in the initial stage of curing. However, when curing was conducted at 40°C for a long period of time, the increase in bound water ratio stagnated, and at 56 days of curing, it was shown that the bound water ratio was almost the same regardless of the temperature.

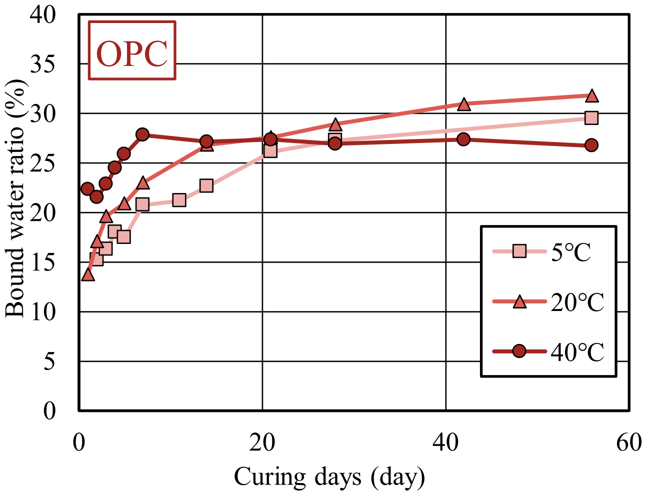

Figure 2. Result of bound water ratio (OPC)

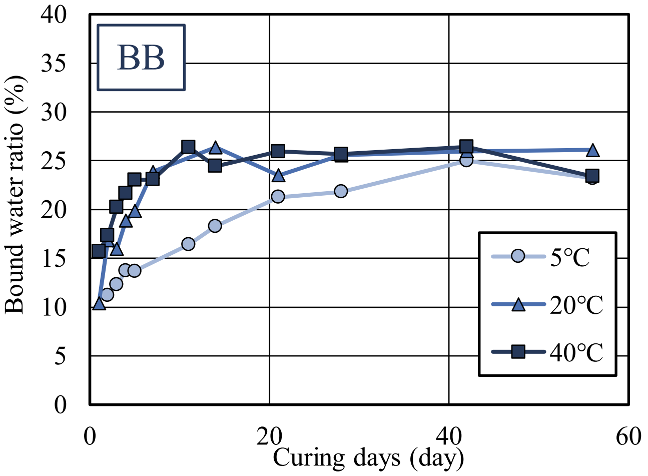

Figure 3. Result of bound water ratio (BB)

2.3.2. Relationship between accumulated temperature and bound water ratio

The relationship between the bound water ratio and the accumulated temperature calculated by Equation 2 is organized.

$$M = \Sigma(\theta + 10) \cdot \Delta t \tag{2}$$

Where M is accumulated temperature(° D･D), θ is curing temperature(℃), Δt is curing periods(day).

The accumulated temperature ranges up to about 400° D･D, which is the period of initial curing. Figure 4 - Figure 7 show the results for OPC, LPC, and HPC. OPC, LPC, and HPC, which are Portland cement-based cements, showed similar bound water ratio at the same accumulated temperature, regardless of the curing temperature. Among them, focusing on the cement type, it was found that the overall bound water ratio was smaller in LPC compared to OPC, and that in HPC, the bound water ratio increased rapidly up to about 100◦ D･D. This may represent differences in the reactivity of the cement minerals contained in each cement.

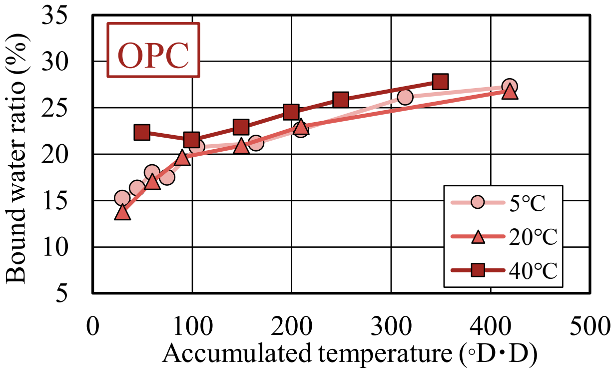

Figure 4. Relationship between accumulated temperature and bound water ratio (OPC)

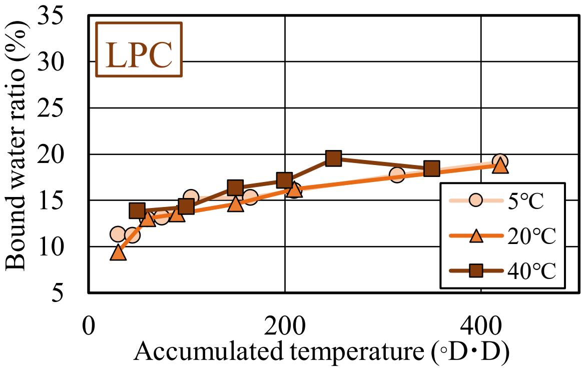

Figure 5. Relationship between accumulated temperature and bound water ratio (LPC)

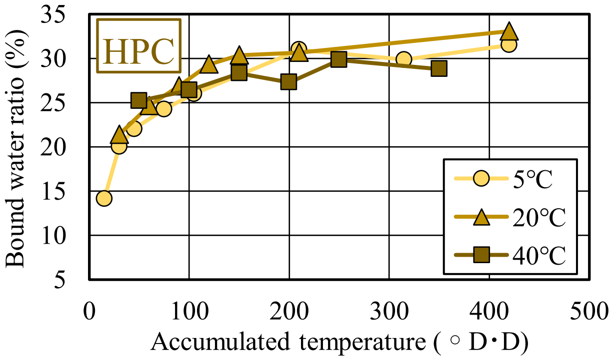

Figure 6. Relationship between accumulated temperature and bound water ratio (HPC)

Figures 7 and 8 show the results for BB and BC. While the bound water ratio of BB and BC, which are blast furnace cements, is similar at 20°C and 40°C, the bound water ratio tends to be smaller in relation to the accumulated temperature only in the case of 5°C curing. This shows that the temperature dependence is high for a blast furnace cement type, and the effect is particularly large at low temperatures.

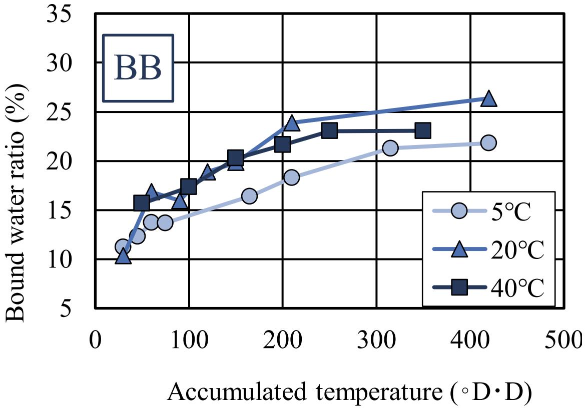

Figure 7. Relationship between accumulated temperature and bound water ratio (BB)

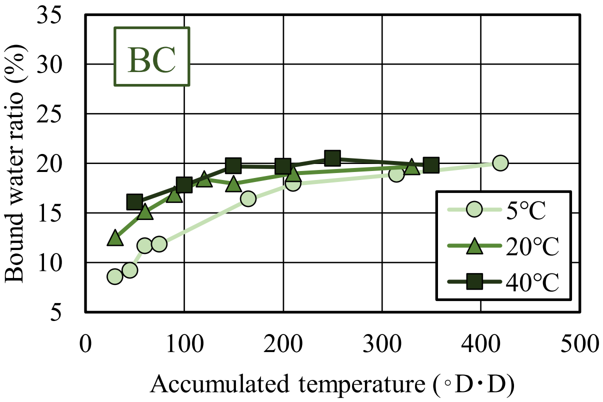

Figure 8. Relationship between accumulated temperature and bound water ratio (BC)

3. DETERMINATION OF HARDENED CEMENT PROPERTIES AT THE SAME BOUND WATER RATIO

3.1. Outline of experiment

To evaluate the relationship between the bound water ratio and hardened cement properties, strength and durability were examined at each curing temperature with the same bound water ratio. Tests were conducted with OPC, LPC, and BC. The mortar was tested with W/B = 0.55 and the mass ratio of cement to fine aggregate was kept constant at 1:3. Compressive strength tests were conducted at the ages shown in Table 2.

A mortar specimen of 40 × 40 × 160 mm was used. Also, accelerated carbonation tests were conducted using specimens of the same size. After curing, the specimens were placed in an accelerated carbonation chamber at 20°C, 60% RH, and 5% CO2 concentration, with one 40×40 mm face released, and carbonation was performed for 7 days. The specimens were split and sprayed with phenolphthalein solution. The distance to the coloring zone was measured as the carbonation depth.

Table 2. The age of motor and accumulated temperature at the same bound water ratio

Cement Type	OPC			LPC			BC		
Curing temperature(°C)	5	20	40	5	20	40	5	20	40
Age (day)	14	6.8	1.7	28	14	5.6	12	2.7	1
Accumulated temperature (∘D･D)	210	205	86	413	421	277	184	81	50

3.2. Results and discussion

Figure 4 shows the compressive strength and Figure 5 shows the carbonation depth at 7 days of acceleration; OPC and LPC showed similar compressive strength and carbonation depth at the same bound water ratio regardless of curing temperature. On the other hand, for BC, curing at 5°C resulted in lower strength and greater carbonation depth compared to other curing temperatures. If the bound water ratio is the same, the hydration progress is also expected to be the same, and the hardened cement properties like compressive strength and carbonation depth are expected to show similar results; however, it was found that the 5°C curing of BC did not fully express the performance of the product. In a previous study [4] , it was reported that hydration products were different depending on the curing temperature when blast-furnace cement was used, and it is thought that the difference in the H/S ratio of the C-S-H is hydrate may have affected the strength when the bound water ratio was the same, but further studies such as qualitative analysis of hydrates are needed in the future. These results indicate that a sufficient curing period is necessary when blast-furnace cement is used in low-temperature environments.

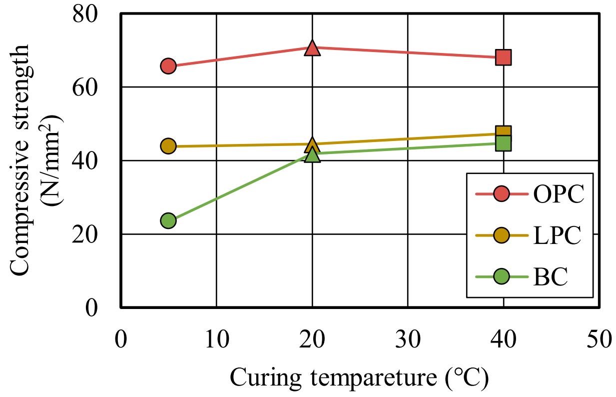

Figure 9 Compressive strength

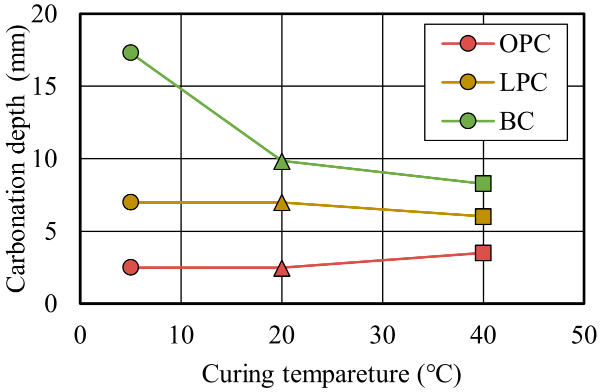

Figure 10 Carbonation Depth

4. CONCLUSIONS

1) It was shown that the bound water ratio of Portland cements such as OPC, LPC, and HPC can be sorted out according to the accumulated temperature. Also, it was suggested that the same level of strength and durability could be obtained by setting the wet curing period according to the bound water ratio. In other words, it is thought that the accumulated temperature can be used to set the wet curing period independent of the curing temperature.
2) Blast-furnace cement is easily affected by curing temperature at low temperatures. It was shown that even if the accumulation temperatures are equivalent, the bound water ratio is lower. Even if the bound water ratio is the same, the cement exhibits low strength and durability, suggesting that it is necessary to set a sufficient wet curing period when used in a low-temperature environment. Further studies, such as qualitative analysis of hydrates, are needed in the future.

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