# A Study on Estimation Method of Curing Influence Area for Prediction of Remaining Life on Real Concrete Structures

T. Iyoda[1]*, A. Sugiyama[1], M. Miyawaki[1]

[1]Department of Civil Engineering Shibaura Institute of Technology, 3-7-5 Toyosu Koto-ku Tokyo, JAPAN 1358548
Emails: iyoda@shibaura-it.ac.jp, ah18052@shibaura-it.ac.jp, mh21021@shibaura-it.ac.jp
*Corresponding author

**Abstract**. The life cycle of concrete structures is known to be highly dependent on the manufacturing, construction and the environment of the structure's location. In order to keep the durability of concrete, it is necessary (1) determination of materials and mix proportion on design, (2) keeping the enough compaction and curing period on construction and (3) understanding the environmental effects such as supply of carbon dioxide, chloride ions and water. Therefore, it is important to implement the design with the required performance to satisfy the design service life. On the other hand, in maintenance management, it is necessary to predict the remaining life based on the supplying period and the state of deterioration at that time. In this case, the information at the time of design and construction is often unknown, and it is difficult to estimation. In this study, as a first step to sort out these issues, concrete specimens were prepared using various types of cement, varying the water cement ratio and also varying the curing period. The accelerated carbonation test and vacuum water absorption test were combined to represent the penetration of carbon dioxide and water in the specimens. The area of influence of curing was organized in terms of material and mix proportion conditions. Porosity was also measured to evaluate the relationship between the penetration properties. In addition, wall specimens were also prepared to measure the effect of curing by non-destructive test. As a result, it was confirmed that the larger the water cement ratio, the greater the effect of curing on the surface layer, but the depth of curing effect was about 20 mm. It was also confirmed that the effect of curing and curing area were larger for Low heat Portland cement and high replacement blast furnace slag cement, where the hydration would slower.

**Keywords**: Life cycle; Curing period; Curing effective area; Carbonation; Vacuum water absorption test

## 1. INTRODUCTION

Curing is known to be very important in the construction for concrete structures. Curing is meaning for accelerating the hydration reaction of cement and contributing to the development of concrete strength. If curing is neglected, it is assumed that moisture in the concrete will evaporate from concrete, resulting in a lack of moisture in the concrete. It is known that if the moisture inside the concrete is insufficient, hydration cannot continue, and strength and durability will decrease. Therefore, it is required to establish a standard for the wet curing period and to construct the concrete to satisfy days. However, it is not considered difficult to ensure the concrete strength of the actual structure, since the moisture does not easily dissipate, considering the thickness of the concrete and other factors. On the other hand, the covered concrete, which is considered to be the surface concrete, is easily affected by the curing process, causing hydration to cease and leaving a large number of voids. It can be imagined that the movement of materials will be facilitated. If the cover concrete, which was installed to protect against corrosion of the reinforcing steel bars, has many voids and is prone to mass movement, it will be difficult to protect it from corrosion. In other words, it can be imagined that ensuring the denseness of the cover concrete and ensuring its resistance to mass movement is an important factor in ensuring the durability of the RC structure.

On the other hand, considering the life cycle of concrete structures, it is also necessary to estimate the remaining service life during maintenance. In the diagnosis of structures, it is necessary to accurately determine the current condition and future service life, and repair and reinforcement should be carried out. However, the origin of the structure, concrete materials, and construction information are often unknown at the time of maintenance. In particular, considering the need to ensure the durability of concrete and extend its service life, we believe that understanding the material, construction, and environmental conditions are very important factor. In this study, the first step is to organize basic information to understand the resistance to mass transfer of surface concrete as a function of the number of curing days using concrete with different types of cement and water-cement ratios. We also decided to organize the relationship between the mass transfer resistance of concrete and curing using nondestructive testing based on surface measurements.

## 2. OUTLINE OF EXPERIMENT

### 2.1. Outline of Specimen

Ordinary Portland cement (hereafter OPC), blast furnace cement class B (50% replacement of ground granulated blast furnace slag, hereafter BB), and low heat Portland cement (hereafter LPC) and high volumes blast furnace slag containing as 70% replacement cement (hereafter ECM) were used for the concrete. Table 1 shows the listed for kind of cements using in this research. Crushed sand with a density of 2.65 g/cm³ and water absorption of 1.35% was used as fine aggregate and crushed stone with a density of 2.70 g/cm³ and water absorption of 0.26% was used as coarse aggregate. The planned concrete mixes for this study are shown in Table 2. The water-cement ratio was varied from 35%, 45%, 55%, and 65% for the mixes using OPC and BB, and all mixes were deformed the day after placing and cured by seal curing. The curing

Table 1 Cement physical properties

| Cement | Density ($g/cm^3$) | Blaine ($cm^2/g$) | Replacement (%) |
|---|---|---|---|
| OPC | 3.16 | 3080 | - |
| BB | 3.02 | 3500 | 50 |
| LPC | 3.24 | 3780 | - |
| ECM | 2.96 | 3920 | 70 |

Table 2 Mix proportion on this research (different kinds of cements)

| No. | Kinds of cement | W/C (%) | s/a (%) | Unit ($kg/m^3$) | | | |
|---|---|---|---|---|---|---|---|
| | | | | W | C | S | G |
| N35 | OPC | 35 | 44 | 170 | 486 | 788 | 886 |
| N45 | | 45 | 46 | | 378 | 830 | 934 |
| N55 | | 55 | 48 | | 309 | 858 | 965 |
| N65 | | 65 | 50 | | 262 | 876 | 986 |
| BB35 | BB | 35 | 44 | | 486 | 780 | 877 |
| BB45 | | 45 | 46 | | 378 | 824 | 927 |
| BB55 | | 55 | 48 | | 310 | 852 | 959 |
| BB65 | | 65 | 50 | | 262 | 872 | 981 |
| L55 | LPC | 55 | 48 | | 309 | 861 | 969 |
| E55 | ECM | 55 | 48 | | 309 | 850 | 956 |

periods were 1, 3, 5, 7, 10, and 28 days, and in addition to these, specimens cured for 12 and 14 days were prepared only for the formulations using LPC in consideration of the delay in hydration.

### 2.2. Accelerated Carbonation Test

The test was conducted on a prismatic specimen (100 x 100 x 400 mm). After the setting curing period, the specimen was sealed with aluminum tape excepted two sides of the specimen and placed in an accelerating carbonation environment. In this research, we focus on the carbonation ratio effect on curing condition, so that we conducted the pre-treatment for curing period not based on JIS testing method. Carbonation acceleration conditions were 20°C, 60% relative humidity, and 5.0% carbon dioxide concentration based on JIS A 1153:2012. The specimens were split at 50mm intervals during the specified acceleration periods (2 days, 1, 4, 8, and 13 weeks), the cross sections were sprayed with phenolphthalein solution, and the distance to the discoloration boundary was measured at 6 points per surface, 12 points in total, and the average of these measurements was used as the carbonation depth.

### 2.3. Vacuum water absorption test

The vacuum water absorption test currently proposed by the author's group is a simple method for evaluating the mass transfer resistance of concrete and for continuously determining the mass transfer resistance of concrete in the depth direction. A cylindrical specimen (Φ100 × 200 mm) was used in this study. The pretreatment method for this test is shown Figure 1. After the prescribed curing was completed, the sides were sealed with aluminum tape as shown in Figure1, and the specimens were put in an environment of 20°C and 60% relative humidity for 28 days with both ends released to simulate the drying associated with de-framing after curing in the actual construction of the structure. The aluminum tape was then removed and dried in a drying oven at 40°C for 5 days.

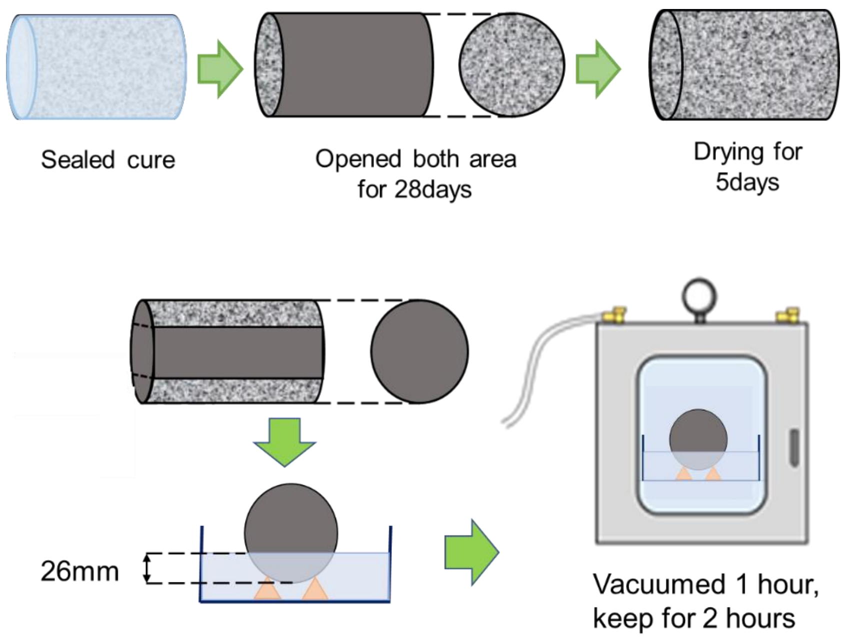


Figure 1 Testing methodology for vacuum absorption test

After pretreatment, the bottom of the cylinder, the casting surface, and part of the side surfaces were sealed with aluminum tape as shown in Figure 1 to prevent water from entering through the side surfaces of the specimen. Next, the butt was filled with water so that the cylindrical specimen was immersed in 26 mm of water and placed in a desiccator. The inside of the desiccator was then vacuumed with a vacuum pump for 1 hour, and the vacuum was kept for 2 hours before the test was conducted. After that, the specimen was split and the height at which water was sucked up was measured at 10 mm intervals in the depth direction for a total of 21 points.

### 2.4. Surface Water Absorption Test (SWAT)

The surface water absorption rate after 10 minutes of water injection was calculated using SWAT, one of the methods to evaluate the surface quality of concrete structures. The test specimens of 150 x 150 x 260 mm were prepared and demolded the day after casting, and the excepting test surfaces were covered with aluminum tape to prevent water loss except for the test surface. The curing sheets were sealed and cured with commercially available curing sheets with water retention properties. After curing, the specimens were dried in the same environment for a specified period (7, 14, 28, 56 days), and then measured. Equations are left-justified and numbered in Arabic numerals.

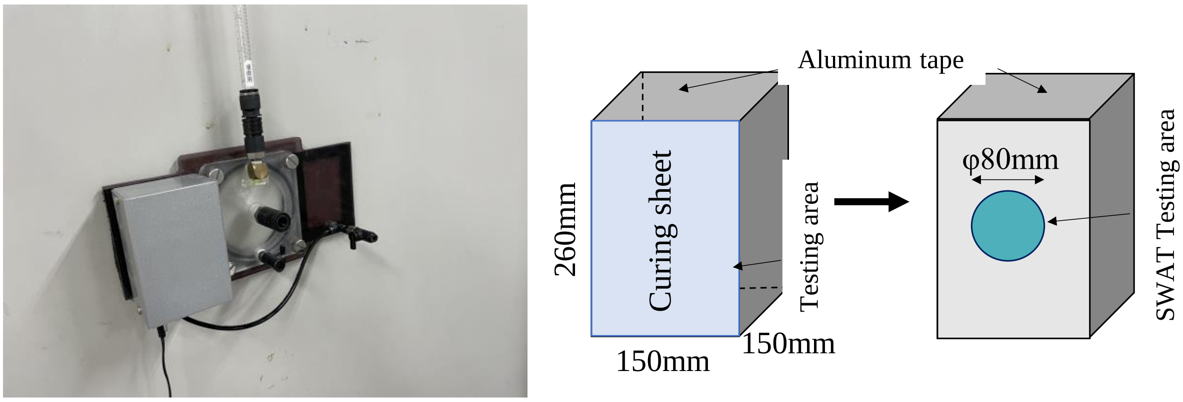


Figure 2 system for SWAT and outline of specimen

# 3 RESULTS OF TESTS

## 3.1 Accelerated Carbonation test

(1) Relationship between curing periods and coefficient of carbonation rate

Figure 3 shows the relationship between the curing periods and the coefficient of carbonation rate, based on the results of the accelerated carbonation test for the mix proportions using OPC and BB and LPC and ECM. Regardless of the water-cement ratio and cement type, the longer the curing period, the lower the coefficient of carbonation rate, but the BB and LPC and ECM mix proportions show a greater decrease in the coefficient of carbonation rate with extended curing. Therefore, it can be said that a longer curing period is necessary to obtain the original mass transfer resistance of concrete when using slow-hydrating cement, and this is also the reason why BB has a longer curing period than OPC in the standard wet curing period described in the JSCE Standard Specifications for Construction [Construction Edition]. In addition, it was confirmed that the decrease in the depth of carbonation tends to reach a ceiling after a certain period of curing. In the case of compressive strength, it is known that the strength continues to increase with wet curing up to about 28 days, but the decrease in the coefficient of carbonation rate stagnates after curing up to about 7 days for the OPC-based mix proportion and up to about 10 days for the BB-based mix proportion, indicating that the decrease in the coefficient of carbonation rate is not significant at the initial stage of curing. It is considered that the voids that contribute to mass transport resistance are filled by the progress of hydration reactions at the age of the hydration products. Therefore, it is considered that the majority of the mass transfer resistance potential of the concrete mix can be realized if the initial curing period is conducted properly.

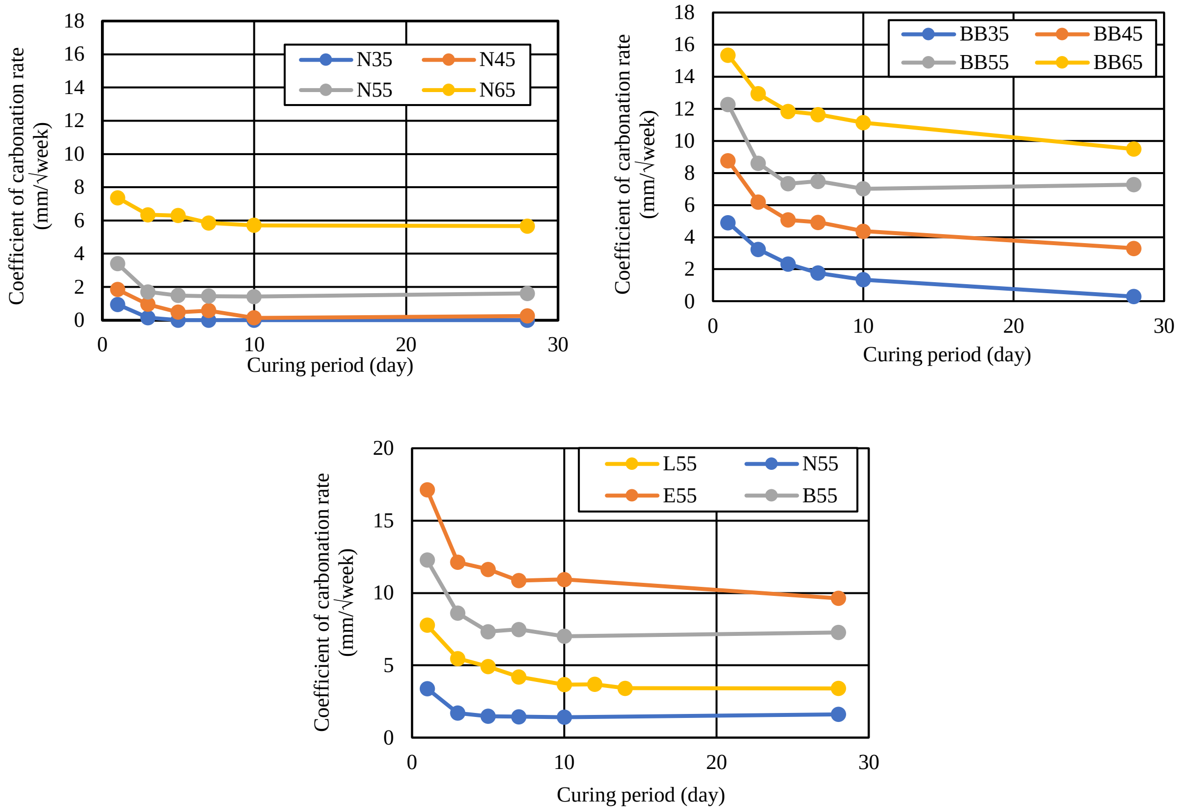


Figure 3 The results for coefficient of carbonation rate on different cements and W/C

(2) Effects of insufficient curing

Figure 4 shows the results of accelerated carbonation tests for B55 at 1, 3, and 28 days of curing. This figure shows that the depth of carbonation is proportional to the square root of the curing period for the 28day curing period, but not for the 1day and 3day for curing periods. This can be attributed to the stagnation of hydration of the surface concrete due to water dissipation caused by insufficient curing. Compared to the latter half of the acceleration period, the speed of increase in carbonation depth with respect to the acceleration period is almost the same regardless of the number of curing days, indicating that the interior concrete, which is not affected by curing, has almost the same resistance to mass transfer regardless of the curing period. Therefore, the usual fitting is done by the root t rule, but to see the effect of curing, an approximate line passing through the origin was created, and a two-line approximation was considered.

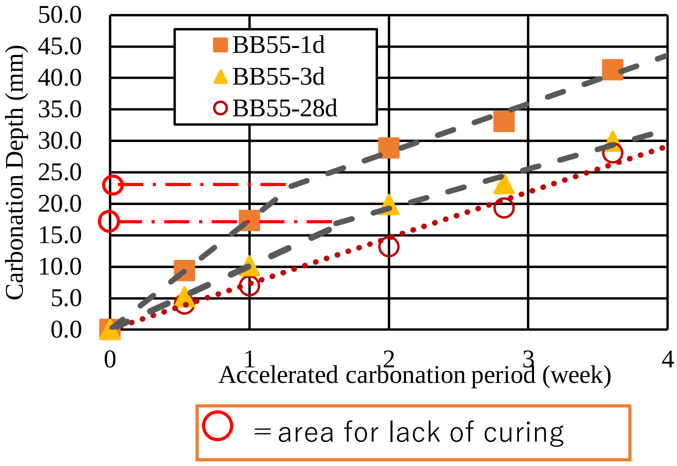


Figure 4 Carbonation Depth on accelerated carbonation periods on different curing period

### 3.2 Vacuum water absorption test

The test results of N55, BB55, L55, and E55 are shown in Figure 5 as representative mixes. The bottom surface is shown on the left, and the casting surface is on the right. Both graphs show a large suction uplift on the casting side, which may be due to moisture loss in the 24 hours before demolding and bleeding effects. On the other hand, the bottom side is considered to be unaffected by these factors and thus reflects only the effects of curing. Therefore, this study focused on the bottom side. The results of the vacuum water absorption test also showed that, as in the carbonation acceleration test, the effect of the test tended to reach a ceiling after a certain curing period, and that the mix proportions using BB and LPC were susceptible to insufficient curing due to the slow rate of hydration and required a longer curing period. In addition, the short curing period of L55 also resulted in a greater water absorption depth in the interior concrete, which is considered to be unaffected by curing, indicating that more attention should be paid to curing.

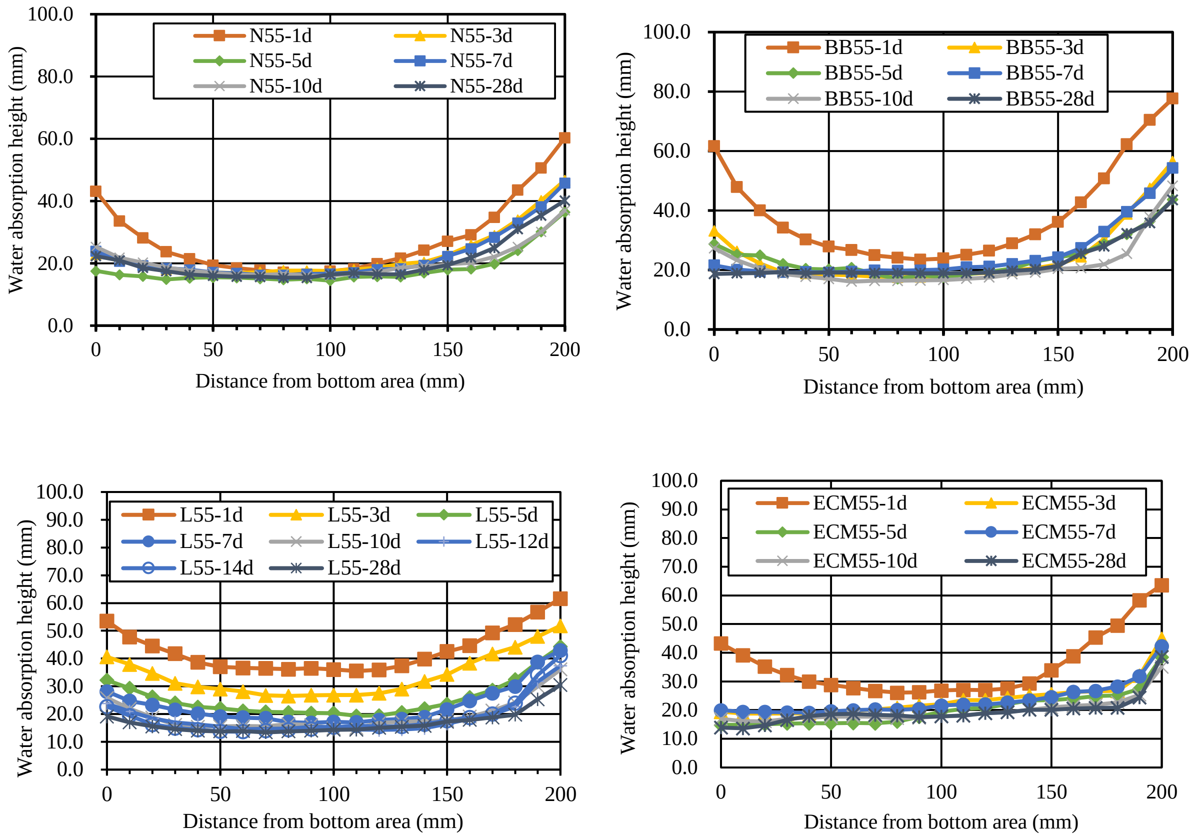


Figure 5 The results for water absorption test in vacuum conditions

### 3.3 Surface Water Absorption Test Results

Figure 6 shows the surface water absorption rate of concrete with different cement types after 56 days of curing for each of the different curing days. For all cements, the water absorption rate decreased as the curing period increased. The improvement in surface quality was N<B<E=L. This indicates that concrete using E and L, which delay the hydration reaction, is more susceptible to the effects of curing.

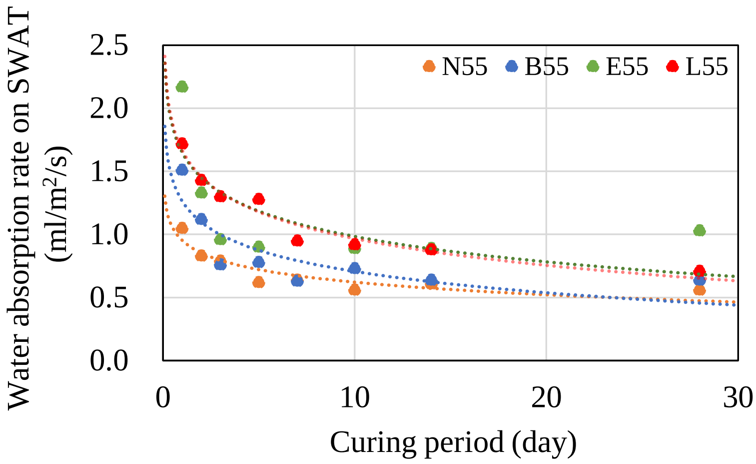


Figure 6 The results of water absorption rate in SWAT on different cement

Figure 7 shows the water absorption rate of different W/C after 56 days of curing. For low W/C, the improvement effect on the surface layer is small even if the number of curing days is increased. On the other hand, for high W/C, the improvement effect of the surface layer quality by prolonging the curing period is high. This indicates that the hydration reaction needs to occur for a long period of time to fill the voids in high W/C where the cement ratio in the space is small.

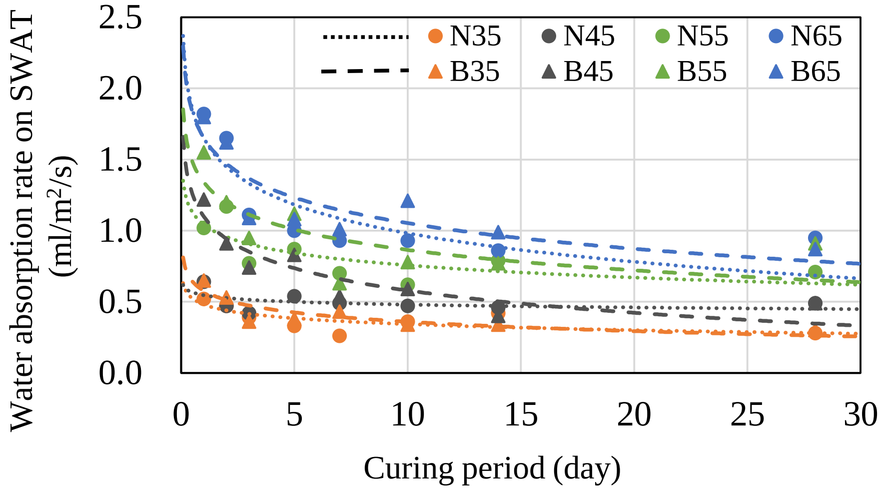


Figure 7 The results of water absorption rate in SWAT on different W/C

## 4 CONCLUSIONS

In order to estimate the degree of curing during construction of structures and during maintenance, to evaluate the importance of curing during construction, the duration of curing and the quality of surface concrete in various cements were evaluated in this study. Accelerated carbonation test and vacuum water absorption test were applied to evaluate surface concrete. In addition, a non-destructive water absorption test was performed to determine the degree of influence of each concrete quality. As a result, it was understood that the quality of concrete improves with an extended curing period. However, the effect was found to be small for concrete made with ordinary Portland cement, larger for blast furnace slag cement and cement with high blast furnace slag content, and very large for low heat Portland cement. It was also found that for low W/C, the effect was small, but for high W/C, the effect was large. All of these are considered to be dependent on the hydration of the cement. We believe that the fact that we were able to quantitatively sort out the effects of curing in this way is a certain achievement. In the future, we plan to consider how to reflect these results in specifications and how to use them to set environmental conditions in maintenance and management.

## REFERENCES

Takeshi Iyoda, Shinichiro Matsuzaki (2010), New method for evaluation of concrete durability in different curing condition, The 4th ACF International conference

E. Toyomura, K. Aoyama, T. Iyoda (2012), Effect of different curing conditions on the degradation process, The 5th ACF International conference

T. Iyoda (2018), Evaluation of Curing Effect on Concrete Durability, The 8th International Conference of Asia Concrete Federation, pp.241-248

K. Hayashi, A Hosoda (2013), Fundamental study on evaluation method of covercrete quality of concrete structures by surface water absorption test, Journal of JSCE, Vol.69, No.1, pp.82-97

JSCE (2013), Standard Specifications for concrete Structures

Okazaki, S. , Yagi,T., Kishi, and T., Yajima, T .(2006), Difference of sensitivity due to curing condition on strength and permeability" Cement Science and concrete Techonogy,No.60

Takeshi IYODA, Taketo UOMOTO (2003), Effect of Drying at Early Age on the Microstructures and the Physical Properties, Proceedings of the ninth east Asia-pacific conference on structural engineering and construction, CMT-6 with including CD-ROM

Takeshi IYODA, Yasuhiro DAN, Yasutaka SAGAWA and Hidenori HAMADA (2008), THE EFFECT OF CURING PERIOD ON CONCRETE DURABILITY USING BLAST-FURNACE SLAG CEMENT, 3rd ACF International Conference, ACF/VCA