Study on the Prediction of Curing Period for meeting required Concrete Durability

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ABSTRACT: In this research, a method for predicting the durability of aged concrete during curing inside the mold was proposed. This method used the specific resistance of concrete, which was evaluated using four electrodes to measure the internal moisture, which changes depending on the degree of cement hydration and the amount of evaporated moisture from the concrete surface. The specific resistance from the surface was also measured. Finally, a relationship between the measured specific resistance and the durability of concrete was proposed under various curing conditions. The results showed that the amount of moisture loss could be measured considering the cement hydration in different kinds of cement and considering the concrete surface area for evaporation. In addition, the relationship between the specific resistance at the end of curing and the durability of concrete was obtained, which then showed which curing method and period could satisfy the required concrete durability.

1. INTRODUCTION

Curing during construction is important for maintaining the required durability of concrete and, if proper curing is not carried out, there will be insufficient water for hydration. This phenomenon is observed to occur at the surface of concrete structures. In addition, degradation factors which cause steel corrosion, such as chloride ions and carbon dioxide, also penetrate from the concrete surface, so it is important to improve the quality of surface concrete in order to enhance the durability of concrete structures.

These days, the quality of surface concrete is verified using non-destructive tests such as the air permeability test (Torrent's Method) or the water permeability test[1,2)]. However, it is necessary to conduct these tests on hardened concrete which has aged over a long period of time and, furthermore, it is known that these tests greatly depend on the amount of moisture in concrete.

In order to have concrete structures in service for a long period, it is necessary to keep good durability. Durability of concrete is affected by the material conditions factors, such as mix proportion and kind of cement, and the factor of setting conditions, such as curing condition, temperature and so on. In recent research, the relationship between concrete durability and curing method and periods has been clarified[3)]. In case of extended curing, such as a long time from casting of concrete to removal, concrete durability is improving. However, in the case of short curing period and not enough curing after removal, it is clear that the concrete durability does not improve and leads to early deterioration of concrete structures.

Furthermore, the compressive strength and durability of concrete are only known after concrete hardens, not in the fresh state. Presently, it is difficult to predict the strength and durability of concrete before hardening of concrete, or during the hardening process.

Curing is important for concrete durability after removal from the molds, and curing periods are different depending on the cement types and curing temperature. The time to removal is set to when concrete strength reaches 5 N/mm^2. This does not consider the durability of concrete. However, deterioration phenomena advance from the surface of concrete, such as carbonation, penetration of chloride ion and also penetrating water and oxygen for leading to steel corrosion. Increasing the life-span of concrete structures requires improving the durability of surface concrete. For that purpose, curing becomes indispensable[4-6)].

This research aims at developing a system that can suggest the end timing of curing using a simple technique. At first, it will clarify the relationship between curing period and durability of concrete. Moreover, it focuses on water content in concrete at the curing period and will measure the decrease in water used for cement hydration and evaporated water from concrete by drying. If both can be separated, we can estimate the hardening process, developing strength and durability with time by this method. Therefore, it was decided to measure the electrical resistance for evaluating the water contents in concrete, by the four-probe electrode method. The electrical resistance is measured continuously from the fresh concrete into the casting. It will be compared with electrical resistance at early age and the durability of concrete after a long time from casting. Finally we will suggest the end timing of curing period from electrical resistance for meeting the durability requirements of concrete structures.

2. EFFECT OF CURING PERIOD ON CARBONATION DEPTH OF SURFACE CONCRETE

2.1 Outline of experiment

Table 1 shows the proportions for the accelerated carbonation test with different types of cement. Figure 1 shows the curing conditions used in this research. Two types of cement were used. Portland cement (N) and the other is Blast-Furnace slag cement type B with 50% replacement with Ground Granulated Blast Furnace slag (BB). Curing conditions were drying for 1 day, in water for 28 days, wetting conditions for 5 and 7 days and Sealed, such as not removed mold, for 5, 7, and 28 days. It means keeping concrete in the mold. Specimen size was 100 *100*400 mm.

After ending these curing or demolding the specimen, the carbonation test was presented with these specimens. It means that the beginning the carbonation test was different on each cuing conditions. The accelerated carbonation test conformed to JIS (Japanese Industrial standard). Temperature was 20 degree Celsius,

Table 1 Mix proportions

cement type	W/C (%)	s/a (%)	Unit weight (kg/m^3)					Fresh		
			W	C		S	G	SL (cm)	Air(%)	C.T.(℃)
				N	BFS					
N	55	50	174	316	0	906	923	12.5	5.1	23.3
B B	55	51	174	158	158	920	900	14.0	4.0	22.5

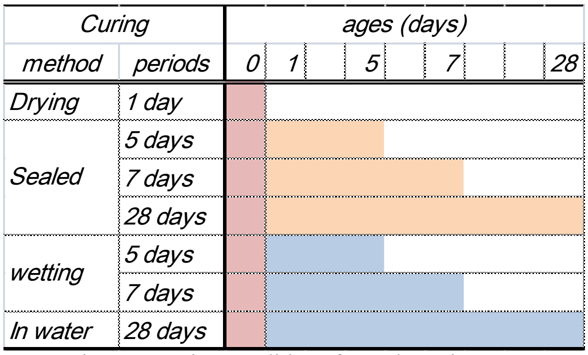


Figure 1 Curing conditions for carbonation test

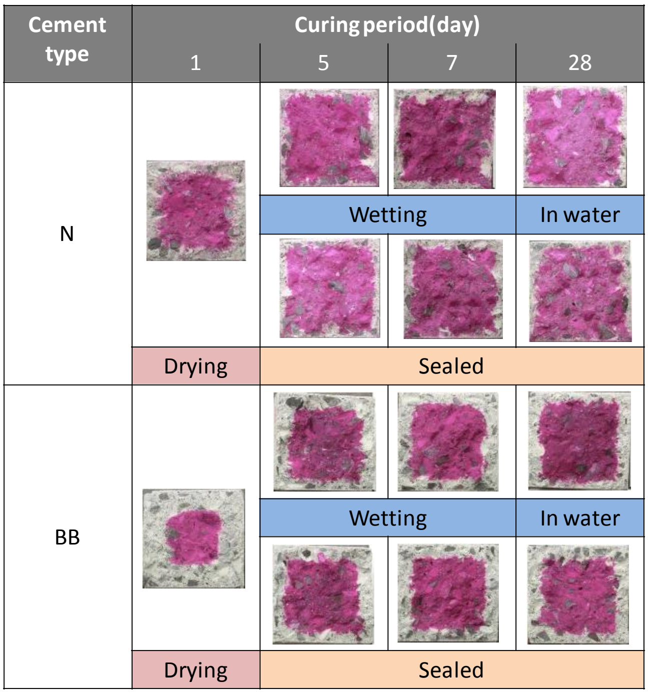


Photo 1 Result for accelerated carbonation test under different curing conditions

relative humidity was 60% and concentration of CO_2 was 5%.

2.2 Result of carbonation test

Photo 1 shows the result for carbonation depth under different curing conditions for 6 weeks of accelerated carbonation. Where there was a lack of curing, such as drying condition from 1 day, the carbonation rate is much faster than the other curing conditions.

Figure 2 shows the result of carbonation depth under different curing conditions, and Table 2 shows the carbonation rate under different curing conditions.

3. MEASUREMENT OF ELECTRICAL RESISTANCE OF CONCRETE

3.1 Outline of experiment

In this research, the specific electrical resistance inside concrete was measured by the four-probe electrode method with direct current (DC). Generally, alternating current (AC) is used for this method. However, an AC power supply requires the large size machine and it is difficult for transporting to the construction site. The DC power supply is small and lightweight as compared to the AC power supply, and measurement on a construction site is possible. In addition, it is possible that the AC power machine is the power supply generating and measurement in one set. On the other hand, it is difficult to both electrify and measure using DC, as the value of specific electrical resistance is not stabilized. Therefore, the

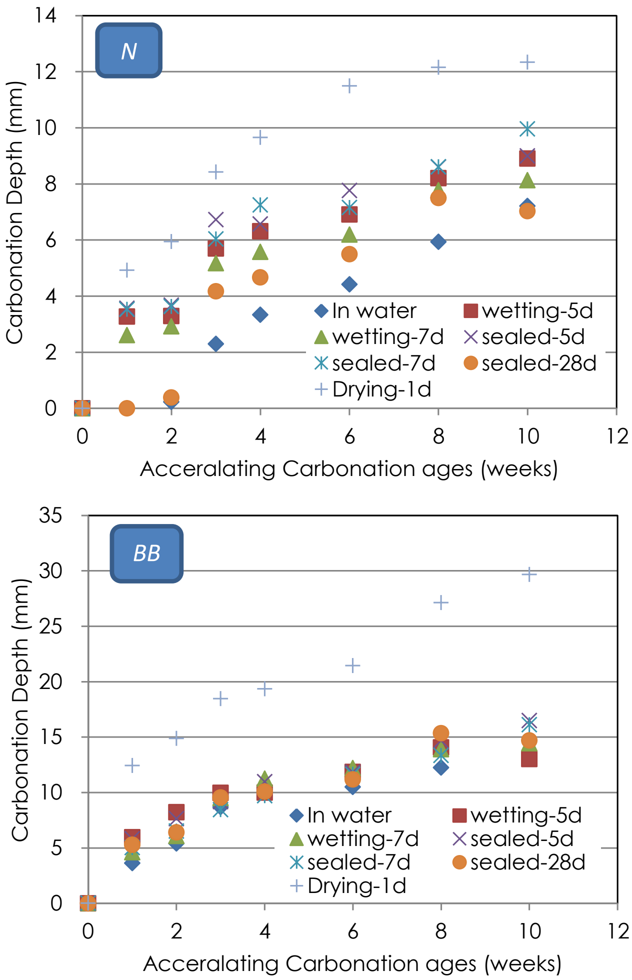


Figure 2 Result for accelerated carbonation test

Table 2 Result for coefficient of carbonation rate(mm/√ year)

Cement type	Curing periods (days) 1	5	7	28
N	4.57	2.94	2.67	1.61
		Wetting		In water
		3.20	3.15	2.16
	Drying	Sealed		
BB	9.71	5.15	5.05	4.45
		Wetting		In water
		5.19	4.76	5.08
	Drying	Sealed		

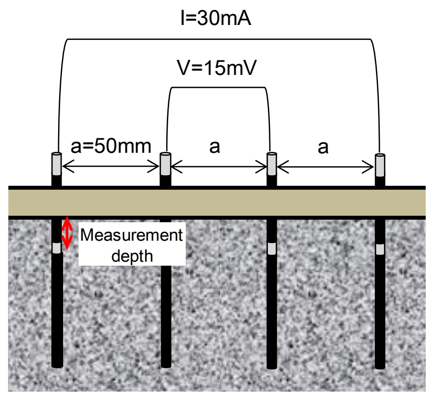


Figure 3 Outline of four-probe electrical method

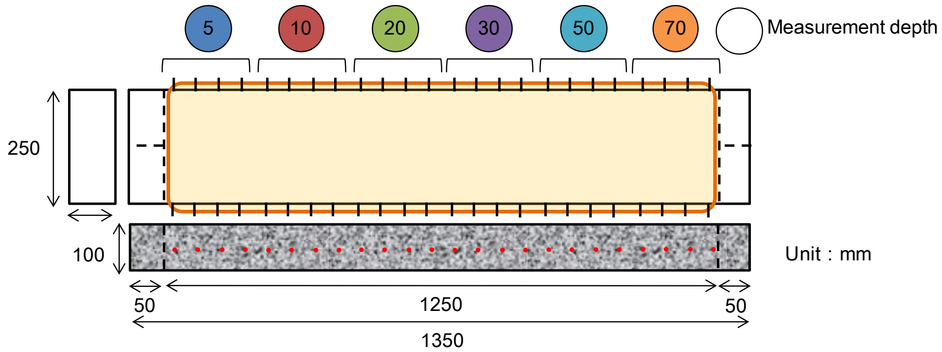


Figure 4 Outline of samples for measurement

Table 3 Curing condition for electrical resistance test

Curing		ages (days)								
method	periods	1		3	5	7				28
Drying	1 day									
Sealed	3 days					20 ℃				
	5 days					RH 60%				
	7 days									
	28 days									

influence of electrification was made as small as possible by using a DC pulse wave.

Figure 3 shows the outline for four-probe electrical method and Figure 4 shows the outline of samples for measurement.

The terminal used for measurement of specific resistance is an iron wire, and the distance between measurements was set at 40 mm. For the purpose of measuring the affected areas from the concrete surface during drying and curing, the specific resistance measurement depth in concrete was varied. The sealing of the electrode was carried out so that only the necessary measurement depth position might turn on electricity. The measurement depths were 5, 10, 20, 30, 50, and 70 mm from the concrete surface. The concrete mix proportion was the same as the accelerated carbonation test (2.1). The specimen size is shown in Figure 3, and the molds were removed on two sides. The periods when drying began after the end of curing, were 1, 3, 5, 7, 28 days as shown in Table 3. The molds on the side of specimens were removed after the end of curing. Specific electrical resistance was continuously measured, during both curing periods and after removal of the molds. In addition, the mark of the test result shows "cement types – curing period – measurement depth".

3.2 Result of experiment

3.2.1 Effect of measurement depth from concrete surface

Figure 5 shows the experimental result for curing period of 5 days using N concrete as an example. In addition, these signatures mean the followings.

N-7-5 : cement type – curing periods – measurement depth

The result is given in terms of the specific electrical resistance at different depths from the surface of concrete. The measurement result showed the equivalent value in every depth position during the curing period – that is, within 5 days. However, after the end of curing, after removal from the mold, it turns out that the specific electrical resistance is rapidly increased near the concrete surface. This is believed to depend on the moisture in concrete having evaporated water due to drying. On the other hand, the value of specific electrical resistance at 50 and 70 mm from the concrete surface gradually increased. As for this change, the moisture in concrete is consumed by the cement hydration progress. From this result, it is thought that the depths of 50 and 70 mm from surface are not affected by the evaporation of water from the surface due to drying. Figure 6 shows the result for curing period of 7 days using BB concrete. The result was similar for concrete using BB cement.

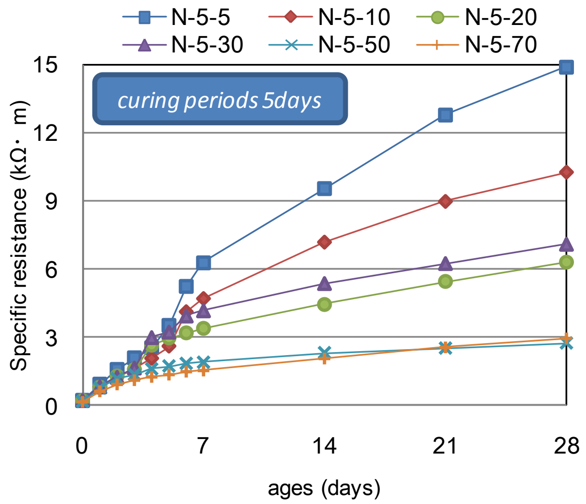


Figure 5 Result for specific resistance on N cement

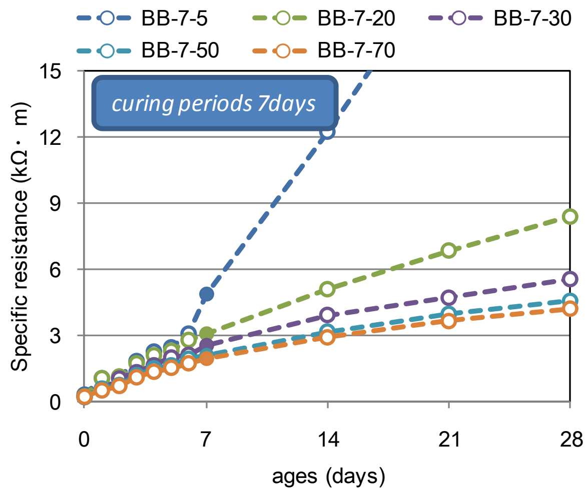


Figure 6 Result for specific resistance on BB cement

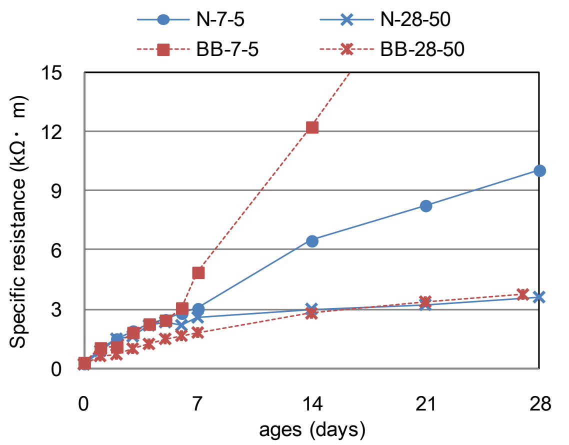


Figure 7 Result for specific resistance on different cement

3.2.2 Effect of cement type

Figure 7 shows the result of specific electrical resistance comparing different kinds of cement for curing periods of 7 and 28 days. At first, the results for specific electrical resistance in N and BB concrete are equivalent at the depth of 50 mm from surface and curing condition of 28 days. However, at the depth of 5 mm from surface, the measurement result of BB cement is notably affected by the drying condition compared to N cement. This shows that BB concrete dries more easily.

3.2.3 Effect of curing period

Figure 8 shows the result of specific electrical resistance for different curing periods at 5 mm from concrete surface. The specific electrical resistance value increased rapidly immediately after the end of curing. This tendency was so remarkable that the end of curing was early for short curing periods. On the other hand, even if the curing periods were different, the specific electrical resistance value within the mold was almost the same. It turns out that the specific electrical resistance value of concrete within the mold shows a fixed value in concrete for the same mix proportions.

From these results, it is thought that the measurement of specific electrical resistance of concrete in the mold can evaluate the degree of cement hydration progress. Furthermore, the measurement of the specific electrical resistance by depth in concrete can evaluate the influence of drying from the concrete surface.

4. RELATIONSHIP BETWEEN DURABILITY AND SPECIFIC ELECTRICAL RESITANCE

First, we consider the relationship between the specific electrical resistance in concrete and durability using the results obtained in 2.2 and 3.2. In the discussion, we used a specific electrical resistance value at 50 mm depth from the concrete surface immediately after demolding from 3.2 and the accelerated carbonation depth at 6 weeks from 2.2. Figure 9 shows the relationship between the specific electrical resistance and carbonation depth at 6 weeks. Within the scope of this research, both of these have a good relationship. It is possible to estimate the curing period required for a chosen carbonation depth. In real structures, it is possible to measure the specific electrical resistance by placement in the mold, and we would then be able to estimate the curing period required for durability in the structures as was suggested. By placing an electrode at each depth, it is possible to identify how the surrounding environment affects the concrete at various depths from the concrete surface, and by applying the proposed method here it may be possible to estimate the durability at each depth position.

5. CONCLUSION

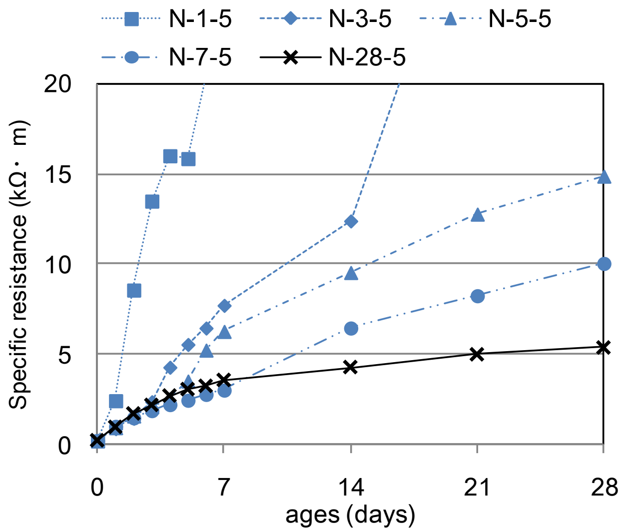
The following results were obtained by this research.

(1) Carbonation progress of concrete is greatly affected by the curing method and curing period. For carbonation progress by the accelerated carbonation test, the effect of curing conditions is larger for N concrete than for BB concrete.

(2) It is possible to evaluate the effects of drying received from the surrounding concrete by measuring the specific electrical resistance. The effect of drying at depths more than 50 mm from surface of concrete appears small.

(3) There was good correlation between the carbonation depth and specific electrical resistance. By using the specific resistance, it is possible to estimate the necessary curing period for a required durability.

Future work will consider different mix proportions in concrete and application methods for concrete structures. And also, not only carbonation resistance but relationship with other durability is due to be examined.



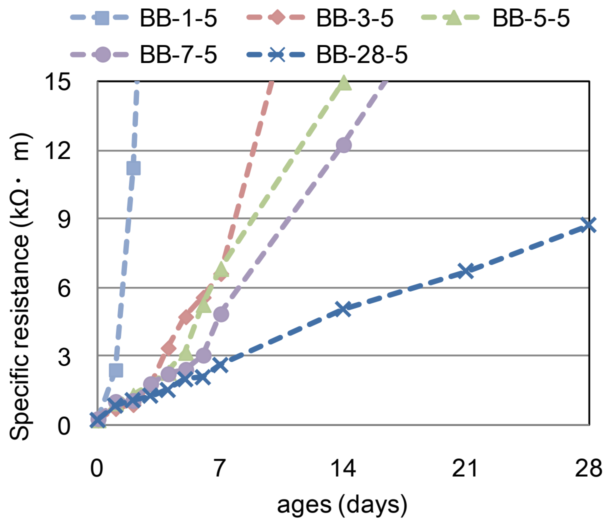


Figure 8 Result of specific resistance on different curing period

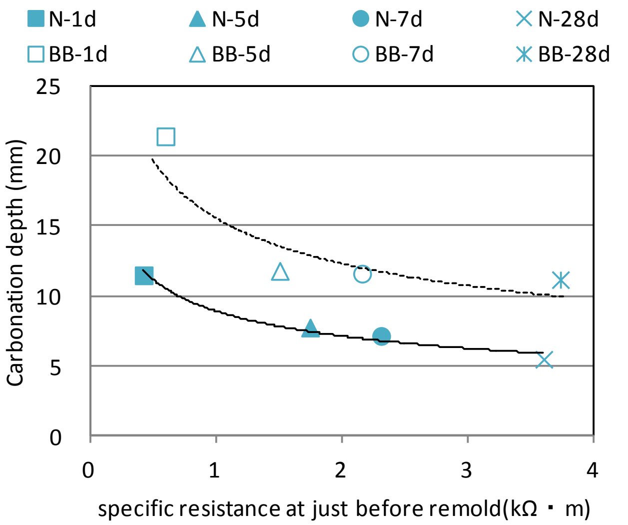


Figure 9 Relationship between specific resistance and carbonation depth

References

1) K. Nakarai, I. Kurashige and T. Kishi : Completion Inspection Method to Check Impermeability of Cover Concrete – Recommendations in Switzerland -, Concrete Journal, Vol. 49, No.3, pp.3~6, 2011 (In Japanese)

2) U. Akmal, A. Hosoda, K. Hayashi and K. Suhara : EVALUATION OF COVERCRETE OF EXPANSIVE CONCRETE WITH EXTERNAL RESTRAINT BY

SURFACE WATER ABSORPTION TEST, Proceedings of the Japan Concrete Institute, Vol.34, No.1, 2012

3) S. Okazaki, T. Yagi, T. Kishi and T. Yajima : Difference of sensitivity due to curing condition on strength and permeability, Cement Science and Concrete Technology, NO.60, 227-234, Japan Cement Association, 2006 (In Japanese)

4) K. Inokuchi and T. Iyoda : Effect of Curing Conditions and Exposure Conditions on Drying Shrinkage of Concrete, Proceedings of 4th ACF International Conference, 2010

5) Y. Dan, T. Iyoda, Y. Ohtsuka, Y. Sagawa, H. Hamada, The relationship between curing condition and durability on concrete using blast-furnace slag cement, Journal of the Japan Society of Civil Engineers E, Vol.65 No.4, 431-441, Japan, 2009 (In Japanese)

6) T. Iyoda, Y. Dan, Y. Sagawa, H. Hamada, 2008, The effect of curing period on the durability of concrete using Blast-furnace sag blended cement, The 3rd ACF International Conference-ACF/VCA 2008