PROPOSED CONSTRUCTION SUPPORT SYSTEM FOR ESTIMATION SETTING TIME AND CURING USING THE ELECTRICAL RESISTANCE ON CONSTRUCTION SITE

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ABSTRACT

In order to use longer concrete structure, it is necessary to minimize the failure in construction. Controlling the setting time is essential to consider the timing of finishing. Also, curing is very important on construction site, not only the early strength on removing the formwork time but also keeping the strength and durability of long term. In construction management, if we can clear the hardened state of concrete in the formwork, we will estimate the performance of concrete on long-term management and keeping the construction periods. In this study, we directly measured the electrical resistance of the concrete in the mold. As a result, it was good relationship between the value of electrical resistance in the mold and the setting time, the compressive strength at early age, also long-term strength and the carbonation ratio. Therefore, in order to clear this mechanism, it was added to the analysis on the hydration, the pore structure formation of concrete at early age and elution of ions. Furthermore, we investigated the effect of moisture status in the concrete for the value of electrical resistance.

Keywords: *Electrical resistance, setting, curing, compressive strength, moisture in concrete*

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1. INTRODUCTION

On the construction of good structure, construction is very important. In the construction site, we suggest to the support system for construction. Installation support system for construction is included investigation for the concrete setting, the degree of hardened and curing of concrete.

Curing period in the 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[1][2]. 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) [3][4] or the water permeability test[5]. 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[6-9] , the relationship between concrete durability and curing method and periods has been clarified. 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.

This research aims at developing a system that can suggest the setting time and the end timing of curing using a simple technique. At first, it focuses on water content in concrete at the setting time and curing period. Also it will measure the decrease in water used for cement hydration and evaporated water from concrete by drying[10]. If both can be separated, we can estimate the hardening process, developing strength and durability with time by this method[11]. 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. MESUREMENT METHOD FOR ELECTRICAL RESISTANCE USING FOUR PROBE

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

Figure 1 shows the outline for four-probe electrical method. 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.

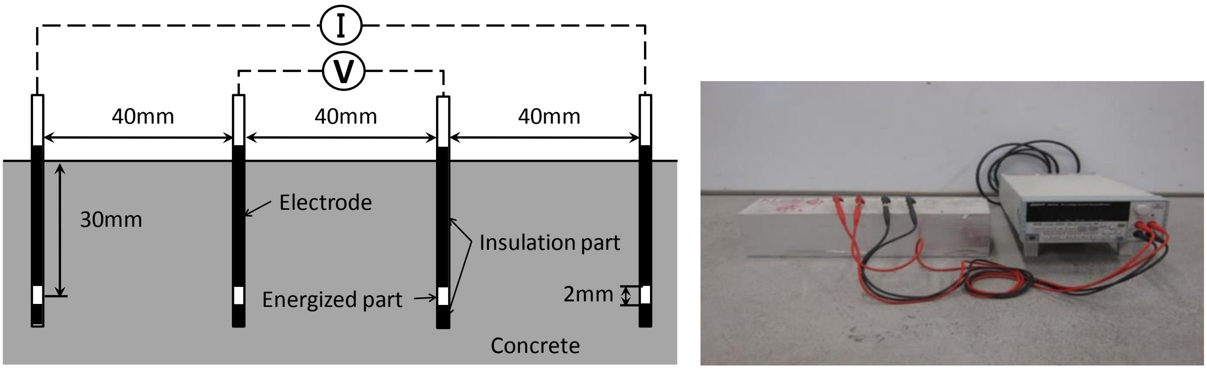


Figure 1. Outline of measurement method for electrical resistance using four-probe

3. APPLY TO FRESH CONCRETE

After concrete is setting into the formwork, concrete gradually is progressed the strength with hydration. On concrete implantation work, it is necessary to determine the timing of finishing of concrete surface. By the measurement of the electrical resistance using the four-electrode method, it was attempted to measure the behaviour on the setting time of fresh concrete. Furthermore, in order to examine the main factors giving the change with time of the electric resistance values were analysed for degree of hydration.

3.1. Experimental outline

Three kinds of concrete was used as shown in Table 1. The formwork is obtained the 60 * 60 * 300mm in order to eliminate the influence of bleeding. The electrode position was a depth of 30mm from the surface of concrete. It was measured the value of electrical resistance by the four-electrode method. Using voltages were 1V and 10V.

Table 1. The Mix proportion of applying to fresh concrete test

Kind of cement	W/C(%)	s/a(%)	Unit weight (kg/m^3)			
			W	C	S	G
OPC	30	48	168	560	755	869
	50			336	843	959
	65			258	873	994

3.2. Results of experiment

Figure 2 is a representation of the measurement results of the electrical resistance of the fresh concrete. Thus, the applied voltage even 1V and 10V, it can be seen that the resistance value at about 100 minutes of contact with water is the smallest. After 100minites, the resistance value gradually increases. This trend can be see finely the more of 1V is compared to 10V. On the other hand, when the past 100 minutes resistance increases, it is easy to grasp of indicating a large resistance using 10V.

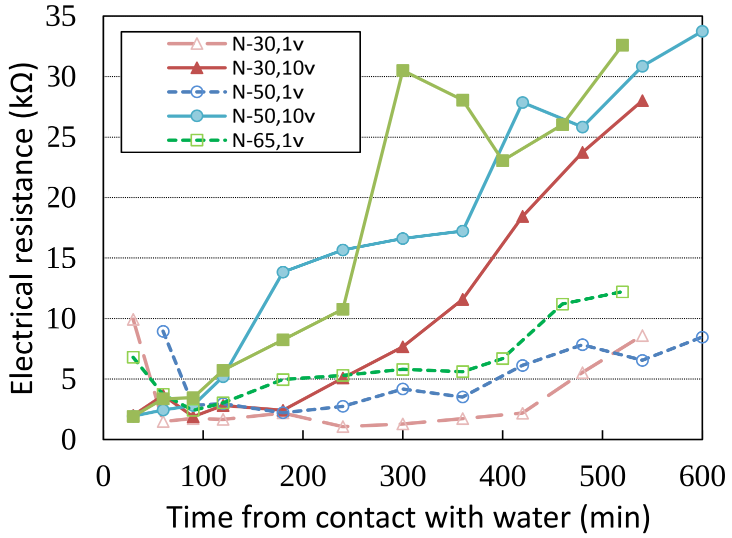


Figure 2. The results of electrical resistance on fresh concrete

3.3. Investigation for these causes

It is necessary to clear why indicates the minimum value at 100 minutes from contact with water. So, it was decided to explore the cause by using a cement paste. At first, using a cement paste (1) Measurement of degree of hydration by loss on ignition, (2) Measurement for the rate of heat liberation on hydration by calorimeter, followed by (3) Measurement of Calcium ions by ion chromatography. As a result, Figure 3 shows the results on the rate of heat liberation by calorimeter. I found that the reaction at 100 minutes is activated. Also Figure 4 shows the measurement result of the electrical resistance from four probe method and the calcium ions by measuring ion chromatography of cement paste. Thus, calcium ions was found that in turn decreasing the time indicating the minimum value of electrical resistance. Thus, to measure the electric resistance value at the fresh concrete, it has captured the hydration reaction.

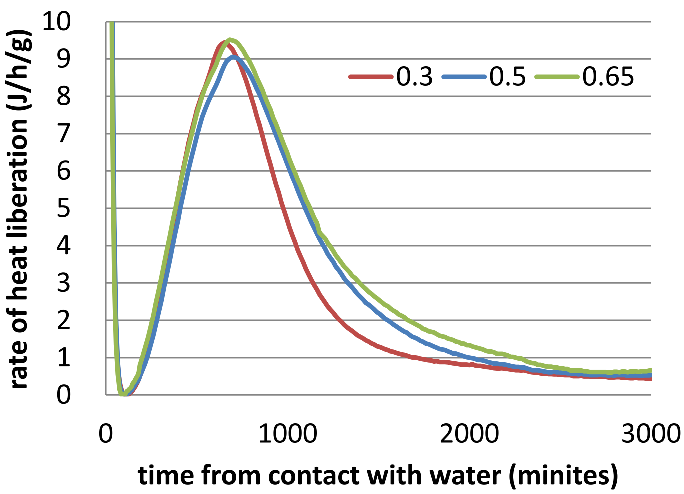


Figure 3. The results of rate of heat liberation

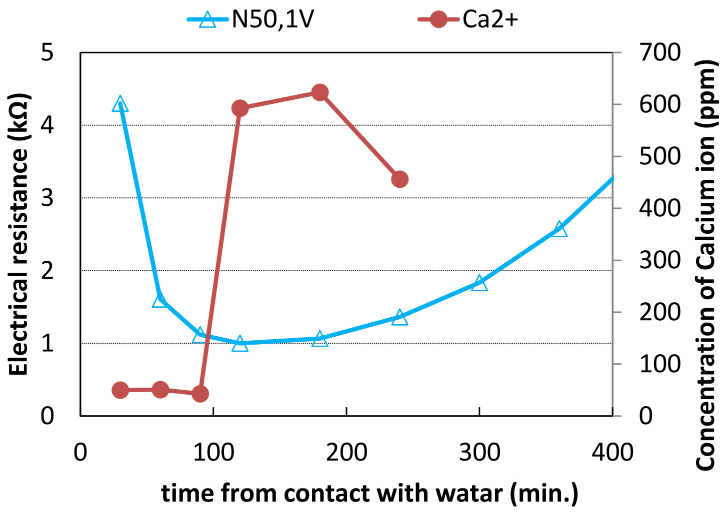


Figure 4. Result of electrical resistance and concentration of Calcium ion

4. APPLY TO CONCRETE DURING CURING PERIODS

4.1. Outline of experiment

Here, we consider the effect of measurement on depth from surface of concrete and curing periods. The measurement depths were 5, 10, 20, 30, 50, and 70 mm from the concrete surface. The concrete mix proportion was table 2 shown. The specimen size is shown in Figure 5, 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”.

Table 2. The mix proportion of applying concrete test

cement type	W/C (%)	s/a (%)	Unit weight (kg/m³)					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

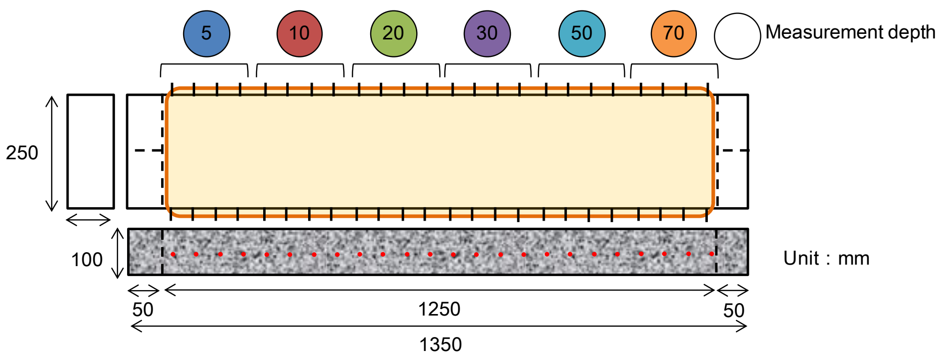


Figure 5. The specimen size

Table 3. Curing conditions

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									

4.2. Result of experiment

4.2.1. Effect of measurement depth from concrete surface

Figure 6 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 7 shows the result for curing period of 7 days using BB concrete. The result was similar for concrete using BB cement.

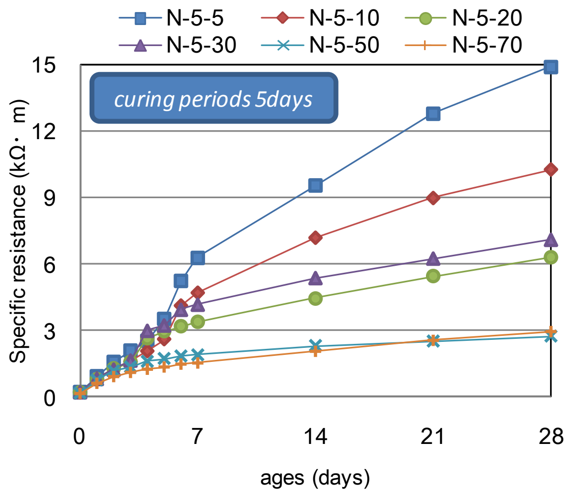


Figure 6. Result of electrical resistance using N

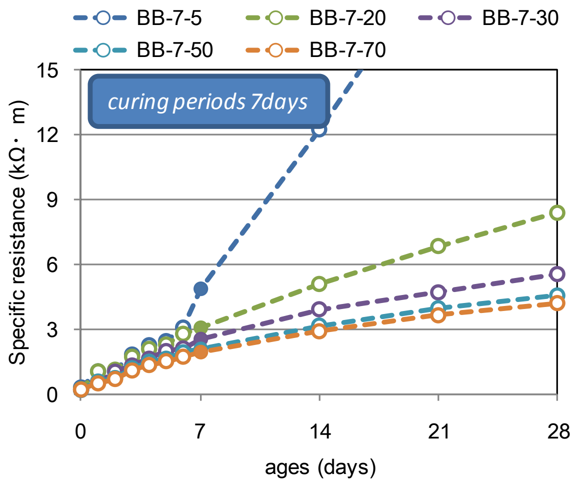


Figure 7. Result of electrical resistance using BB

4.2.2. Effect of cement type

Figure 8 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.

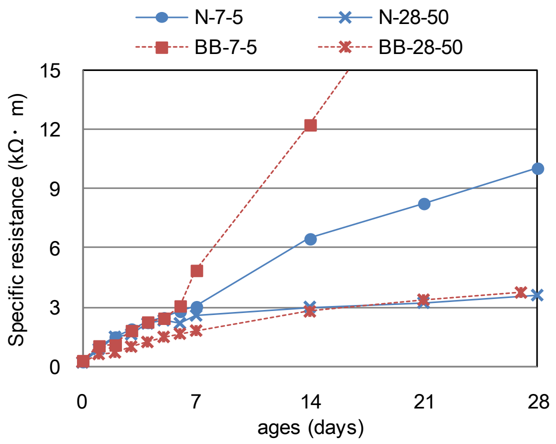


Figure 8. Result of electrical resistance on different cement type

4.2.3. Effect of curing periods

Figure 9 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.

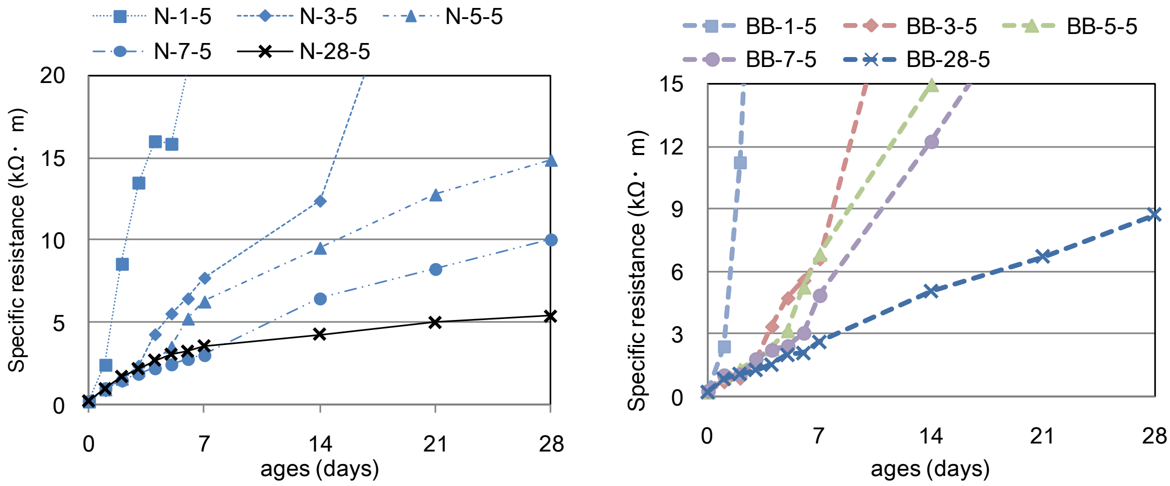


Figure 9. Result of electrical resistance on different curing periods

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.

5. RELATIONSHIP BETWEEN ELECTRICAL RESISTANCE AND CHARACTERISTICS OF HARDENED COCNRETE

5.1. Outline of experiment

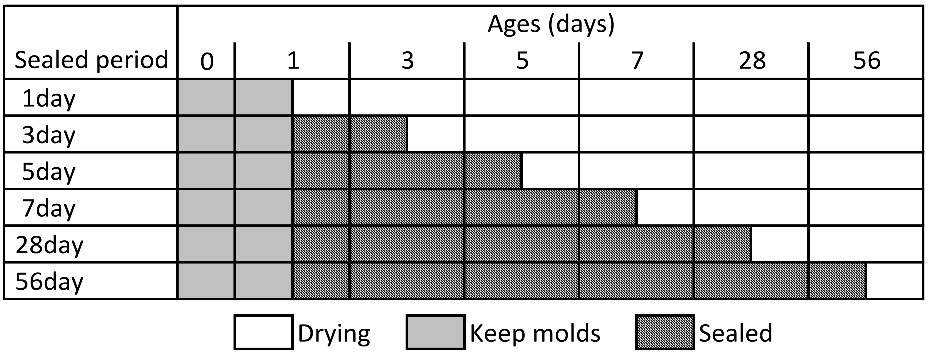
The concrete mix proportion was in Table 4 shown. It used some kinds of cement type, such as Ordinary Portland cement, Blast Furnace slag cement type B (content BFS is 45% replacement as OPC) and type C (content BFS is 65% replacement as OPC), Fly ash cement type B (content Fly ash is 20% replacement as OPC). And water cement ratio is changed as 45, 55, 65 % on Normal cement. Unit water is constant as 172 kg/m^3.

The periods when drying began after the end of curing, were 1, 3, 5, 7, 28, 56days as shown in Table 2. The molds were removed after 1 day of casting, then all surface put on the wrap for protecting the evaporating water from surface. Specific electrical resistance was continuously measured. And cylinder for compressive test and cubic spacemen for carbonation test were demolded at the same time as measuring the electrical resistance. Specimen size was shown Figure 10. Compressive strength and carbonation test were done based on JIS.

Table 4. Mix proportion for relationship between electrical resistance and characteristics

Cement Type	W/C (%)	s/a (%)	Weight Unit (kg/m^3)						Add.	AE
			W	C	BFS	FA	S	G		
N	45	46	172	382	0	0	808	971	0.20×C	2.00A
	55	48		313			869	968	0.25×C	2.00A
	65	50		265			928	949	0.25×C	2.00A
BB	55	48		313	125		869	965	0.20×C	3.25A
BC		50		313	219		903	927	0.25×C	2.00A
FC		50		250	0	63	896	919	0.20×C	6.00A

Table 5. Curing conditions



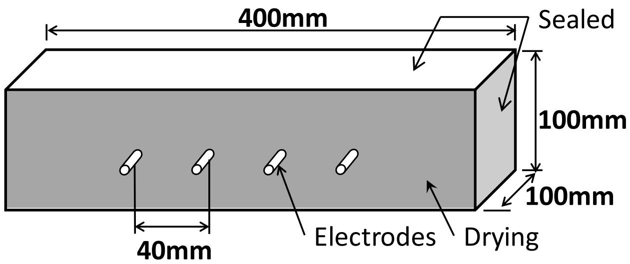


Figure 10. Specimen size

5.2. RESULT OF EXPERIMENTS

5.2.1. Compressive Strength on demolding age

Figure 11 shows the progress of compressive strength at demolding age on different water cement ratio and different cement type. Compressive strength becomes high, so that water cement ratio is small. The compressive strength at the early age becomes small so that the amount of admixture increases, but the growth of long age strength is large.

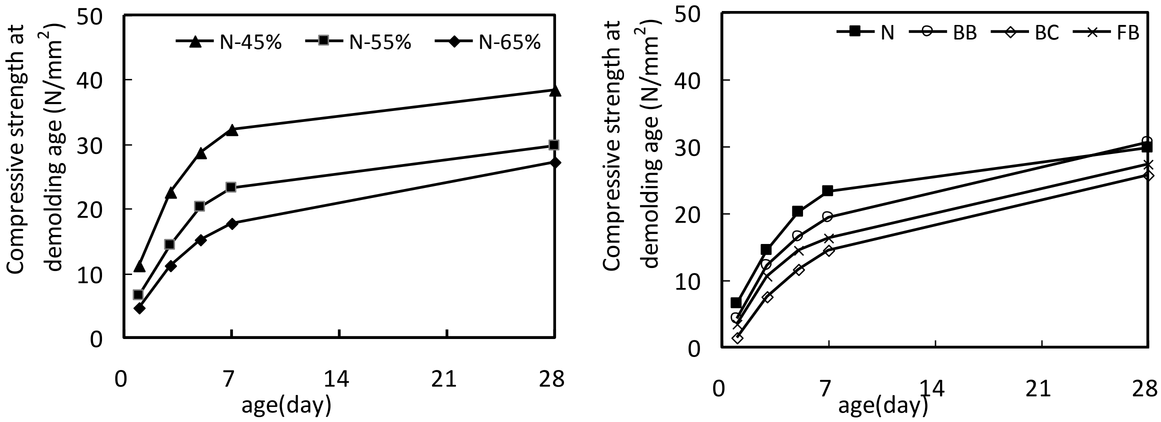


Figure 11. Result of compressive strength on demolding age

5.2.2. Electrical resistance affected on mix proportions

Figure 12 shows the electrical resistance at the different water cement ratio. The values of electrical resistance on each water cement ratio are same at age of 3 days, however, the electrical resistance increases as the water cement ratio, with the passage of age. In the case of a constant of unit water, if the water cement ratio is small, the amount of cement increases. The water used for hydration increased in case of a large amount of cement. Therefore, it is considered that the amount of water except the used by hydration in the concrete is decreased.

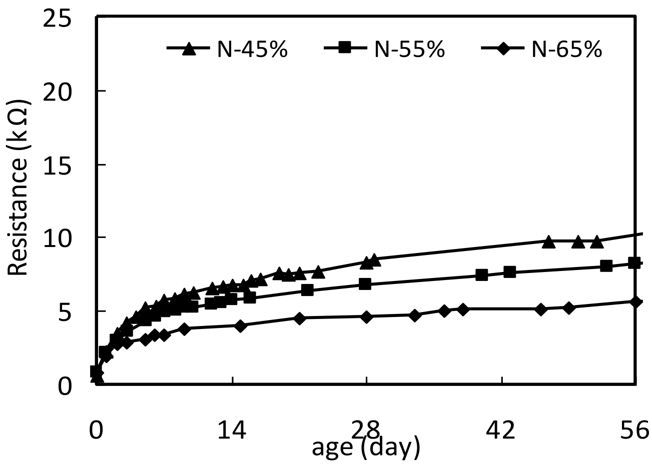


Figure 12. Electrical resistance on different water cement ratio

Figure 13 shows that the replacement ratio of admixtures on binder affected the electrical resistance. Each spacemen of water cement ratio is same as 55 %. At the early age from contacting water, such as

4 days, they have not difference on resistance of all spacemen. However with progress age, resistance on concrete of replacement on Blast Furnace slag are larger than normal concrete with progress age. And it is clear that resistance is large with high replacement ratio. On the other hand, the electrical resistance of concrete using fly ash is smaller than it of concrete using ordinary Portland cement. However the value is same at 56 days. It means the effective of cement into amount of admixtures.

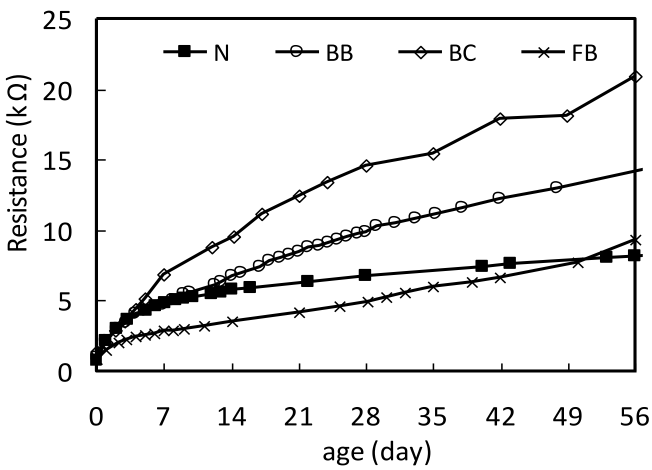
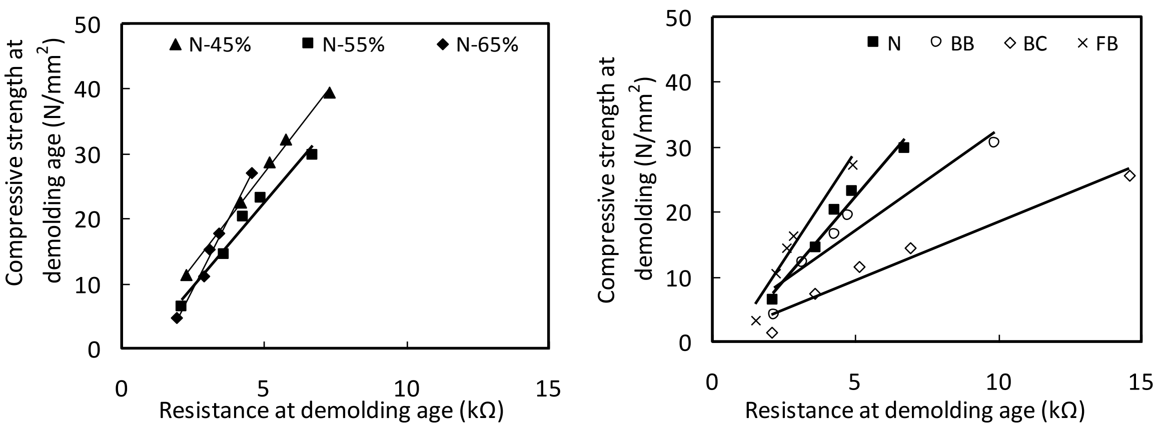


Figure 13. Electrical resistance on different replacement ratio of admixtures

5.2.3. Relationship between compressive strength at demolding age and electrical resistance

Figure 14(a) shows the relationship between compressive strength at demolding age and electrical resistance on different water cement ratio. With the increase of the electrical resistance, the compressive strength at demolding age is increased. The relationship ratio were almost same at 45 and 55% of W/C, however it was increased in 65% of W/C. Thus, the compressive strength at the time can be predicted the electrical resistance value from immediate demolding.

Figure 14(b) shows the relationship on the replacement ratio of ground granulated blast furnace slag. The higher the replacement ratio of BFS, it was observed that the slope of line was decreased. Since the rate of hydration is slower, is that the delayed strength progress is shown.



(a) Different water cement ratio (b) Different replacement ratio of admixtures

Figure 14. Relationship between electrical resistance and compressive strength at demolding age

5.2.4. Relationship between carbonation depth and electrical resistance

Figure 15 shows the relationship between carbonation depth at 4 weeks on accelerated carbonation test and electrical resistance on different water cement ratio and used BB cement. With the increase in the electrical resistance value, the carbonation depth showed the tendency which becomes small. It had good relationship between the electrical resistance value at the demolding age and the carbonation depth on for 4 week as an accelerated age. Even if it was the case with same electrical resistance value at the demolding age, the difference with the large carbonation depth was seen by different water cement ratio and kind of cement.

By using the above results, it is possible that the compressive strength and durability can be guessed within a curing period or period of concrete in a mold by measuring the electrical resistance value before demolding age.

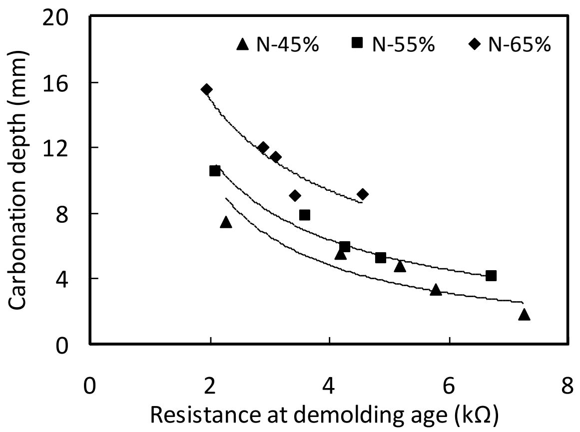


Figure 15. Relationship between electrical resistance and carbonation depth

6. APPLY FOR STRUCTURES ON CONSTRUCTION SITE

Based on the above results obtained, it was investigated how to apply the actual construction. The ready-mixed concrete is implanting to formwork which installing the electrodes. It was continuously measured on electrical resistance of concrete into formwork, it is possible to measure the timing of the setting time and curing. It had already make the calibration curve (it means the relationship between electrical resistance and strength, durability), it will be estimating the strength and durability of concrete in real time to allow monitoring the state of the concrete in the formwork, as shown in Figure 16. We are aimed to measurable system on constructed in the actual structure. In the future, it is assumed to make a system that can monitor the status of the concrete curing by management data using wirelessly connection in real time at a different location.

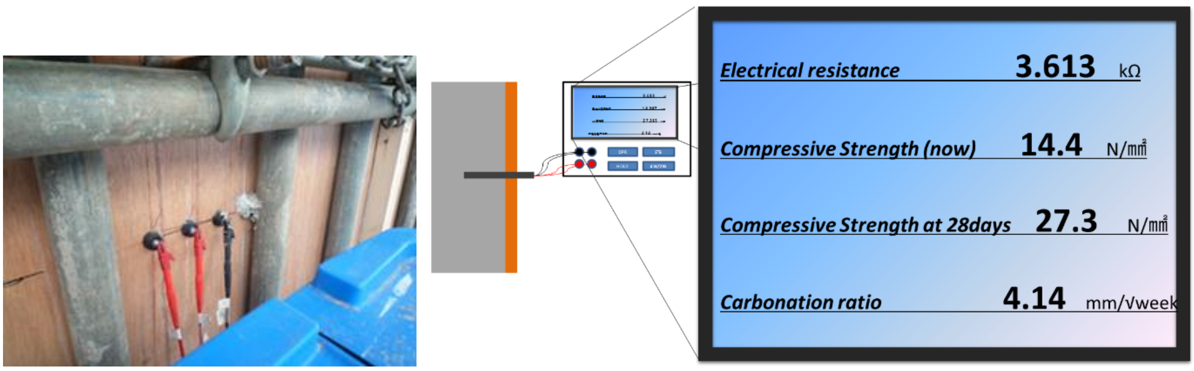


Figure 16. The images of the supporting system of construction site

7. CONCLUSION

It is summarized the results obtained in this research as follows.

1) Electrical resistance by four probe electrode method is related the condensation of fresh concrete.
2) Electric resistance value by four probe electrode method is able to catch the curing state of the hardened concrete.
3) Electrical resistance values obtained four probe electrode method can be used to estimate the strength and durability of the cured concrete is in the formwork.
4) It showed the potential to be applied to the construction site of electrical resistance measured by the four probe method.

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