Life-Cycle of Engineering Systems: Emphasis on Sustainable Civil Infrastructure – Bakker, Frangopol & van Breugel (Eds)
© 2017 Taylor & Francis Group, London, ISBN 978-1-138-02847-0

Study on estimation technique of hydration on concrete in the mold by electrical resistance value

Maho OTA
Graduate Student, School of Eng., Shibaura Institute of Technology, Tokyo, Japan
Takeshi IYODA
Associate Professor, Shibaura Institute of Technology, Tokyo, Japan

ABSTRACT: Strength and durability of concrete is important for using long-term structure. In order to obtain enough strength and durability, it is necessary to progress hydration on concrete during the early age. Therefore, it is important to monitor the hydration in the mold. However it is difficult to check the state of concrete in the mold. Then, we focused on the electrical resistance as a method to check hardening concrete for in the non-destructive test. It has been reported that the electric resistance of the hardening concrete has a correlation with compressive strength at remolding time and carbonation ratio. However, it is not measured in the fresh concrete. So, we measured the electrical resistance of fresh concrete in the mold. As a result, the behavior of the electric resistance is very similar to the results of heat of cement hydration measured by the conduction calorimeter. Moreover, the behavior of the electric resistance was correlated with the setting time. Thus, it can be monitored the hydration on concrete from fresh to harden in the mold by using the electrical resistance.

1 INTRODUCTION

Concrete structures are required to build a strength and durability. Moreover, it is also required to economically construct. Therefore, construction management is important. In construction management, we have some test the quality of the concrete at the time of acceptance. Even passes through the test, initial defects such as cold joint occurs. It is defined as that of a point where consolidated fresh concrete did not integrated. Cold joint causes a decrease in the strength and durability.As one of its occurrence factors, it is said that time of placing fresh concrete. Placing on consolidated fresh concrete permissible time in Japan Standard Specification for Concrete Structures, it has only been recommended within 1.5 to 2 hours from mixing. For setting time of the concrete depends on the hydration rate of cement, it is affected such as the cement species are chemical admixtures and temperature. Therefore, the environment and the materials used for each field different, just placing on consolidated fresh concrete permissible time is considered to be difficult to avoid cold joints. By monitoring the concrete structure in real time, which leads to preventing the defective construction in advance. Recently, Trent method and a surface water absorption test has been suggested as a method of inspecting a concrete structure by non-destructive test. However, these tests can only use the concrete after hardening. Therefore, it cannot contribute to prevent initial defect. Thus, the method of evaluating the performance of the structure under construction is necessary for the efficient construction. The authors have proposed to assess the state of the concrete using the four-probe resistance for nondestructive inspection easily. The four-probe is a method of assessing the condition of the concrete from the electrical resistance, which is measured directly electrode is inserted into the concrete. Electric resistance value measured in the hardening. In previous studies has reported that there is a correlation between compressive strength and carbonation rate. However, study of measuring the electrical resistance of the fresh concrete is few, not known electrical resistance value is what kind of behavior. Whereas the electrical conductivity has been research in fresh concrete. Electrical conductivity of the fresh concrete has been reported to be correlated with the setting time[1)]. Accordingly, it has been reported to be an indicator of the cold joint. It is reciprocal of electrical resistance. Therefore, even the electric resistance value of the fresh concrete we thought that there may be related to the setting time. If there is a correlation, it can be proposed that the electric resistance value of the quality of concrete as a means to continuously monitor to hardening from placing. This study was conducted to measure the

Table 1. The Mix proportion applying to fresh concrete test

Kind of cement	W/C(%)	s/a(%)	Unit weight(kg/m^3)			
			W	C	S	G
N	30	48	168	560	755	859
	50			336	843	959
	65			258	873	994

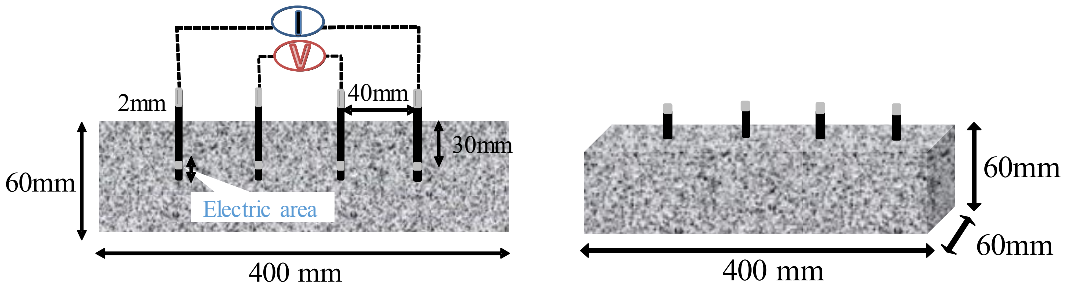

Figure 1. Outline of measurement method for electrical resistance using four-probe

four-electrode method. It was aimed to confirm obtained electric resistance value and set time relationship.

2 EXPERIMENTAL OUTLINE AND RESULT

2.1 *Measurement 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 DC power machine is the power supply generating and measurement in one set. However, DC is susceptible to charge compared to AC. Therefore, the influence of electrification was made as small as possible by using a DC. Figure 1 shows the outline for four-probe electrical method. The formwork is obtained the 60×60×300mm in order to eliminate the influence of bleeding. The electrode position was depth of 30mm from the surface of concrete.

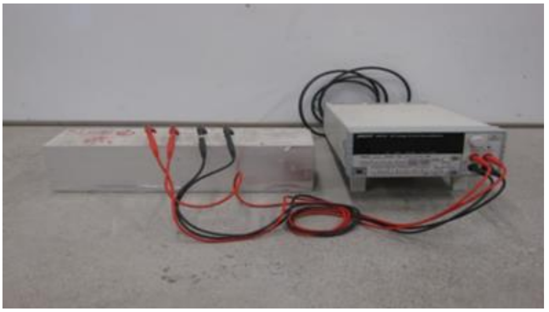

Photo 1. Electrical resistance using four-probe

The terminal used for measurement of specific resistance is an aluminum wire, and the distance installation interval was set at 40mm. Further Electrodes were fixed in position for passing current by winding an insulator. Using voltages were 1V and 10V. Three different W/C of concrete was used as shown in Table 1. Electrical resistance value in order to receive the effects of temperature, specimen after placing, it was immediately allowed to place in the room of humidity of 60% at a temperature of 20 degrees Celsius.

2.2 *Electrical resistance measurement results*

Figure 2 shows the measurement results of the electrical resistance. Behavior of the electric resistance value showed a tendency different from the behavior after hardening. Electrical resistance showed behavior that firstly the electrical resistance is decreased quickly at cement contacting water, and after then it is increased slowly. That was regardless of the water cement ratio. To capture the decreasing behavior finely was able better 1V than 10V. We consider that overvoltage in the measurement of 10v in fresh concrete.

2.3 *Relationship of the electrical resistance and the electrical conductivity*

Behavior of electrical conductivity correlates with setting time .Thus, if the correlation to the behavior of the electrical resistance and the electrical conductivity, even in the electric resistance value is considered to be correlated with setting time. The measurement of electrical conductivity, typically those used in water quality testing was used it embed into the concrete. The probe used for the measurement is shown in the photo 2. Specimen of the electrical conductivity were used φ100 × 200mm. Electrical conductivity meter was placed from the surface to the 30mm position. It specimen after placing, it was immediately allowed to place in the room of humidity of 60% at a temperature of 20 degree Celsius. It is shown in Figure 3 the results of measurement of electrical conductivity in the fresh concrete. Behavior of the electrical conductivity is opposite to the electric resistance value, which is increased to decrease. In addition, the trend was similar regardless of the water cement ratio. It is shown in Figure 4 relationships of the electrical resistance and the electrical conductivity in N 50%. After contacting water, the electric resistance value decreases, the conductivity began to increase. The time behavior is changed, the electrical conductivity and the electrical resistance values were generally consistent. Therefore, it confirmed the relationship of the behavior of the electric resistance value and electrical conductivity.

2.4 *Setting time and electric resistance*

Since the time change of behavior the electrical conductivity and the electrical resistance value was the same. Accordingly, since the setting time and the electrical conductivity in previous studies are related, even in the electric resistance value was thought that there may be correlated with the setting time. In order to confirm the setting time of the relationship with the electrical resistance value, it was carried out Penetration resistance method. It was carried out in the Table 1. Until the end of the condensation comes, we continued to measure the penetration resistance value.

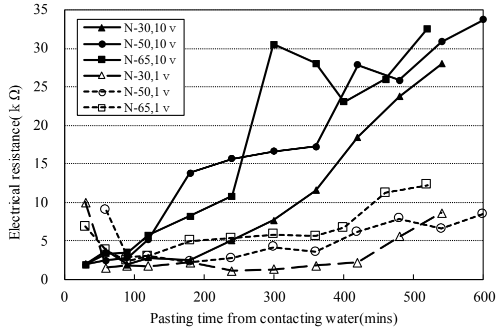

Figure 2. Measurement of electrical resistance in concrete

Photo 2. Electrical conductivity

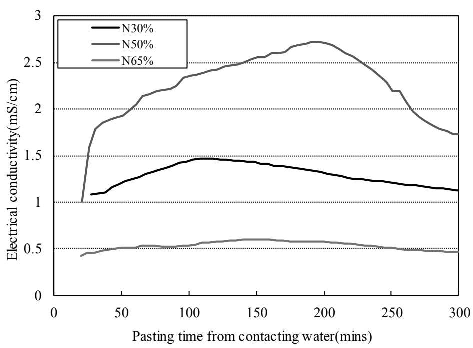

Figure 3. Measurement of electrical conductivity

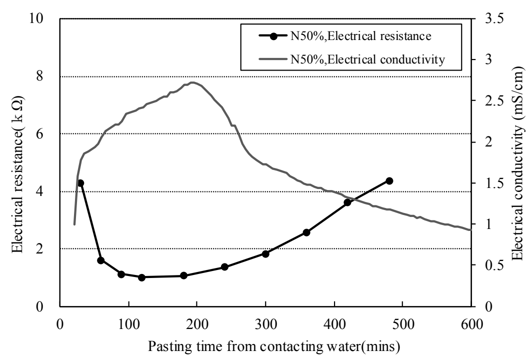

Figure 4.Relationship of the electrical resistance and the electrical conductivity

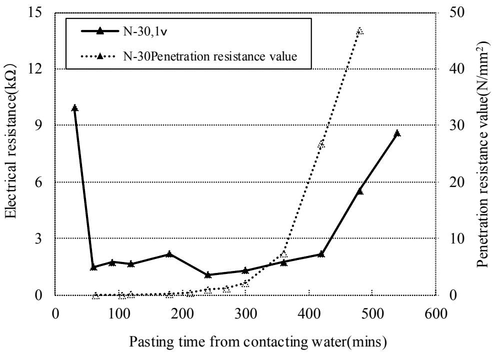

Figure 5. N30 relationship between the electrical resistance value and penetration resistance value

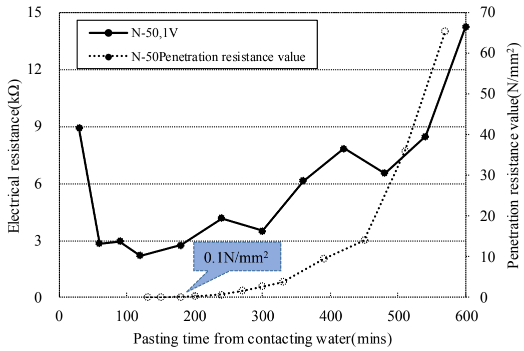

Figure 6. N50 relationship between the electrical resistance value and penetration resistance value

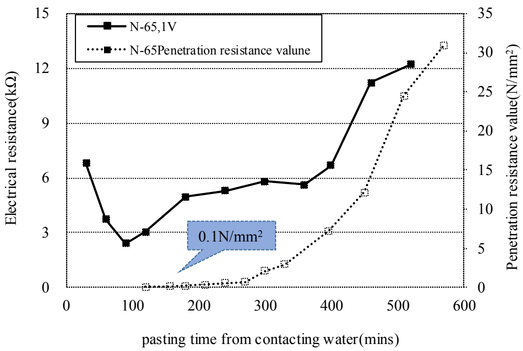

Figure 7. N65 relationship between the electrical resistance value and penetration resistance value

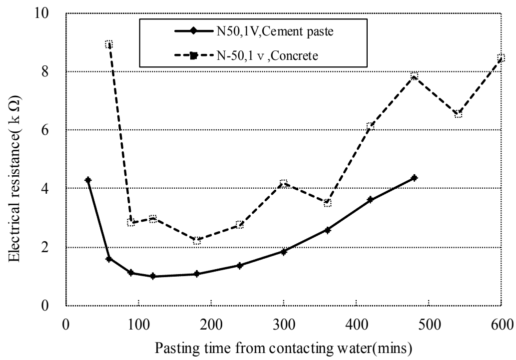

Figure8. Relationship of the electrical resistance of the concrete and cement paste

2.5 *Penetration resistance value and the electric resistance value*

The relationship between the penetration resistance value and the electric resistance value it is shown in Figure -5, 6, 7. Electric resistance value was also increased when the Proctor penetration resistance value started to increase. There was no relationship to the initial setting time and final setting time. However, the water cement ratio 50, 65, penetration resistance value when the electric resistance value begins to increase showed 0.1N / mm^2. This value is a lower limit occurs timing of the cold joint from previous studies[1]. Electrical resistance of fresh concrete is related to setting time, in other words it can be said to be an index time of placing on consolidated fresh concrete. Behavior of the electric resistance was associated with the setting time from the results from above. However, the reason why there was a correlation is not known. Therefore, we aimed to clarify the factors that the electrical resistance correlated with setting. Progress of the setting time is that is the progress of the hydration. Progress of the hydration affects the setting. Therefore, it was decided to confirm the relation between the hydration and the electrical resistance value for clarify of the behavior factors. To measure the heat of hydration using a conduction calorimeter in order to observe the progress of the hydration. However, the test of conduction calorimeter carried out in the cement paste. So, we carried out to confirm the behavior of the electrical resistance value by the cement paste. In addition, it was decided to check the effect of the aggregate of the electrical resistance value from cement paste results. Specimens used in the cement paste were the same as those used for concrete.

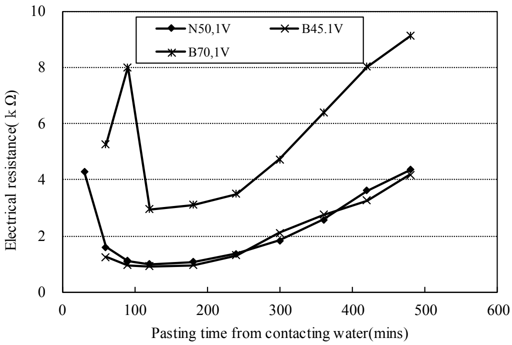

Figure 9. Electrical resistance of different cement species

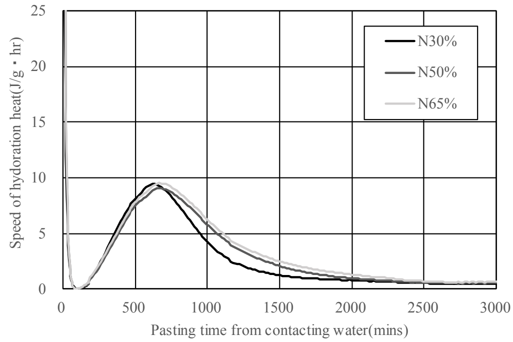

Figure10. Hydration heat generation rate in different W / C

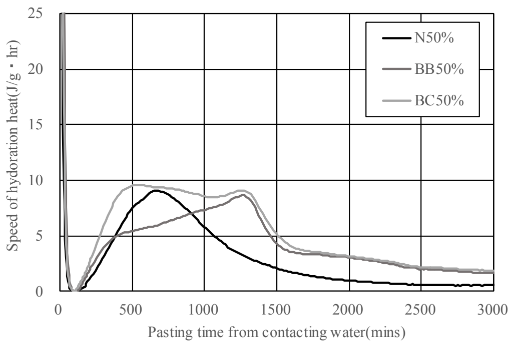

Figure11. Hydration heat generation rate in different cement species

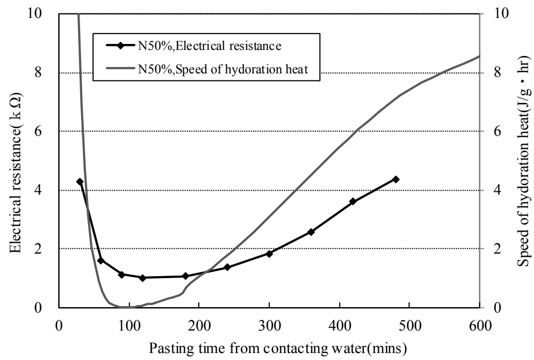

Figure12. Relationship between the electrical resistance values and hydration heat generation rate in N50

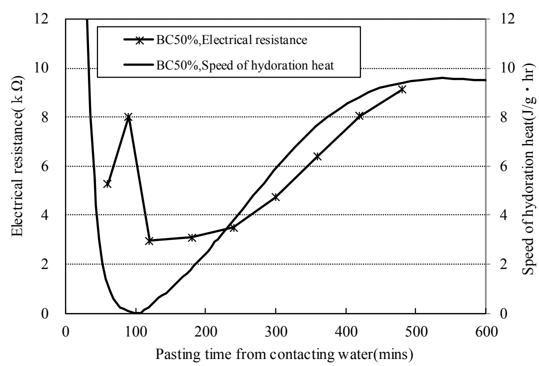

Figure13. Relationship between the electrical resistance values and hydration heat generation rate in BC50

2.6 *Electrical resistance of the cement paste results*

Shown in Figure 8 the measurement result in the cement paste. Electrical resistance was decreased and increased after contacting water without depending on the water cement ratio as well as the concrete. Compared with the measurement result of the concrete, the time that the electric resistance began to increase does not change regardless of the water cement ratio. But electric resistance is shown a small value, it can be said to be influenced by the aggregate.

2.7 *Effect on the electrical resistance value due to the cement kinds*

Hydration reaction is due to the cement ratio, also affect the cement species. To determine the relationship the heat of hydration and the electrical resistance value, we decided to also make sure the relationship between the different cement species of electrical resistance value and hydration reaction. Therefore, the measurement of the electrical resistance of the different cement types were measured using a cement paste. Cement used was to replace the BFS to OPC. Replacement ratio of BFS used was of 45, 70%. The BB was replaced 45 percent of the BFS. The BC was replaced 70% BFS. Figure 9 to show the electric resistance values were measured using a cement paste in different cement types. Regardless of the replacement rate of the BFS, the behavior of the electrical resistance did not change.

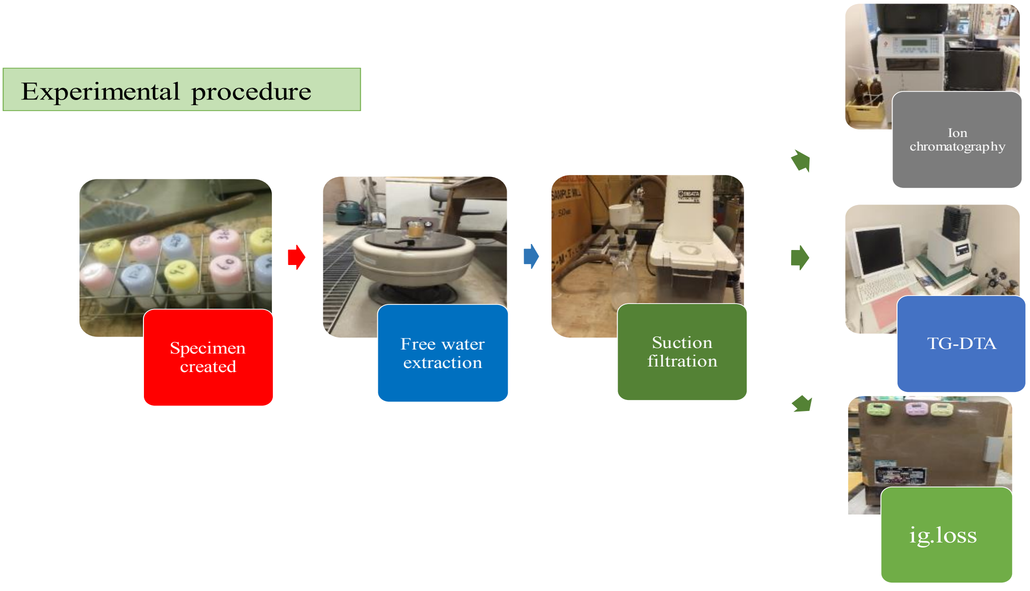

Figure 14 Specimen preparation method

2.8 *Hydration heat and the electric resistance value*

Hydration heat obtained from the conduction calorimeter to change the behavior. In this study it was measured from stirred for 1 minute after water contact. Figure 10 shows the measurement result of the heat of hydration. Hydration heat generated regardless of the water cement ratio, 120 minutes per after water contact, showed a behavior that increases after the decrease. In addition from 2.6, we measured the hydration heat generation in order to see the relationship with the electrical resistance values of the different cement species. Figure11 shows the measurement result of hydration heat in different cement kinds. It is shown in Figure 12 the relationship between the electrical resistance value and the hydration heat generation rate in N 50%. Regardless of the water cement ratio, generally the same time that the behavior of the heat of hydration and the electrical resistance value changes. It is shown in Figure13 the relationship of hydration heat and the electrical resistance value in BC. Regardless of the replacement rate of BFS, time electrical resistance value decreases and the hydration heat generation of time to decrease was generally same.

Behavior of decreasing hydration heat generation rate it is to show the elution of ions. Therefore, the behavior of the electric resistance value is considered that captures the timing of the elution starting calcium ions. C3S in the cement reacts with water, it is known to elute calcium ions. In this study, we focused on high conductivity calcium ion. The change in calcium ion concentration was measured by ion chromatography, and then confirm the relationship between the electrical resistance value. Also, the cement with the progress of the hydration for producing hydrated product. To generate a hydrate with the progress of the hydration reaction. Therefore, to confirm the relationship between the electrical resistance and the hydration product using ignition loss test and TG-DTA test.

2.9 *Measurement of hydration*

Samples used for the ion chromatography, ignition loss and TG-DTA were taken on the basis of the method shown in Figure 14. Placing the cement paste to the plastic-made bottle, and allowed to stand in the room of humidity of 60% at a temperature of 20 degree Celsius. Removed from the room of humidity of 60% at a temperature of 20 degree Celsius in 5 minutes before the measurement, and extracted with the free water in the cement paste by using a centrifuge. The resulting the free water was suction filtered using a filter paper, and the next ones diluted 100-fold as a sample for ion chromatography, and finally to measure the calcium ion concentration. The remaining cement paste is to extract the free water, immediately hydrated stopped with acetone, and subsequently measured ignition loss at 1000 degree Celsius. Further, by using the same as ignition loss test samples were measured the amount of calcium hydroxide carried out a TG-DTA test.

2.9.1 *Ion chromatography*

It is shown in Figure 15, 16 the measurement results in N50%, BB50%. The free water that 240 minutes

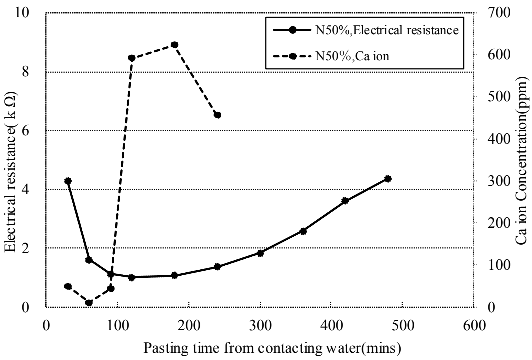

Figure 15 Relationship of calcium ions and the electrical resistance value in N50

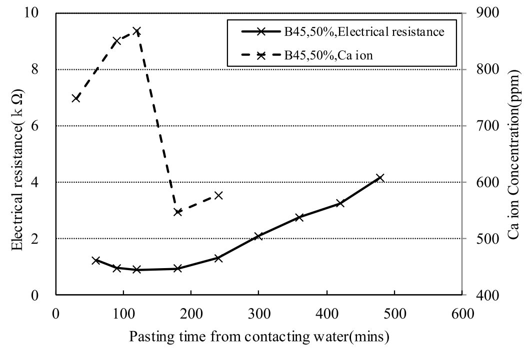

Figure 16 Relationship of calcium ions and the electrical resistance value in BB45

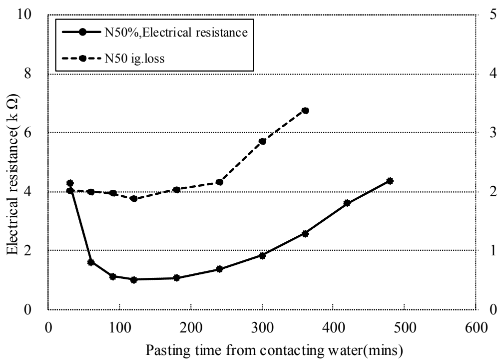

Figure 17 Amount of bound water and the electrical resistance value in N50

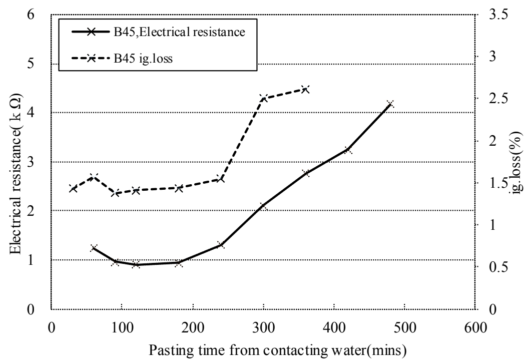

Figure 18 Amount of bound water and the electrical resistance value in BB45

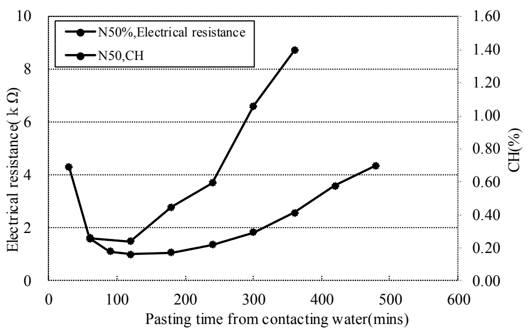

Figure 19 CH and the electrical resistance value in N50

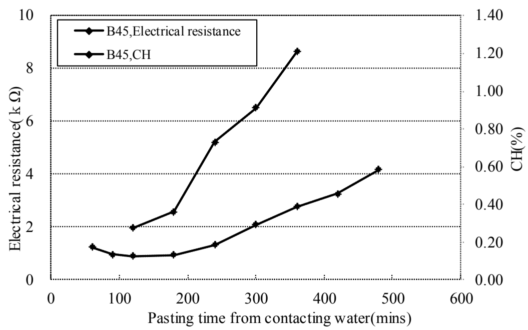

Figure 20 CH and the electrical resistance value in BB45

from the contact water, it was not possible to obtain the free water. Calcium ion concentration behaved differently in comparison to electrical resistance. It was behavior decreases to increase after contacting water. The time to change this behavior was generally consistent with the time the behavior of the electrical resistance value changes. However, the electric resistance value is that of the high replacement rate did not correlate with the dissolution of the calcium ion.

2.9.2 *Ignition loss test*

It is shown in Fig 17 the relationship between the electrical resistance values and the amount of combined water in N50%. It is shown in Fig 18 the relationship between the electrical resistance values and the amount of bound water in BB50%. Water cement ratio and regardless of the substitution rate of BFS, there is almost no change while decreasing the electrical resistance. But, suddenly combined water volume increased when the electric resistance start increased.

2.9.3 *TG-DTA test*

It is shown in Figure 19, 20 the relationship of calcium hydroxide amount and the electrical resistance value in N50%, BB50%. At the start of the behavior of electrical resistance value increases we were able to measure the amount of production of calcium hydroxide. From the results of the ignition loss test and TG-DTA test, the reason that the electric resistance value increased is that water was consumed when generating the hydrate.

3 CONCLUSION

It is summarized the results obtained in this research as follows

1) The electrical resistance is decreased quickly at cement contacting water, and after then it is increased slowly.
2) Electrical resistance value will affect the aggregate.
3) The behavior of the electric resistance value is correlated with the setting time.
4) The behavior of the electric resistance value is correlated with the hydration reaction.
5) The behavior of the electric resistance decreases was correlated with the elution of calcium ions, the behavior of the electric resistance increases was correlated with the water consumption.

REFERENCES

- *Murakami.H and Abo.T and Iyoda.T,(2011),Effectiveness of setting management method by specific electric conductivity, The 11th JSMS (in Japanese)*
- *JapanSocietyof Civil Engineers,(2013),Standard Specifications for Concrete Structures-2012 Materials and Construction, Japan*
- *Misaka.T and Iyoda.T (2013).Study on curing of concrete by the end time judgment of the DC specific resistance,SCMT3*
- *Iyoda.T and Ota.M and Misaka.T (2013). Proposed construction support system for estimation setting time and curing using the electrical resistance on construction site,CONMAT'15*