PROPOSAL for EVALUATING THE CURING EFFECT of CONCRETE WITH VARIOUS CURING METHODS USING ELECTRICAL RESISTANCE

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ABSTRACT

In order to ensure surface quality of concrete such as denseness, curing of concrete is important. Construction companies have devised various methods of curing and are carrying out on site. However, there are few knowledge to select what kind of curing method is appropriate when selecting curing method on site. The authors focused on electrical resistance measured by four-probe electrical method and thought to evaluate the curing effect from electrical resistance.

This study evaluates the moisture content of concrete which changes depending on the curing method. First, the effect on electrical resistance of hydration reaction was clarified. The ignition loss test and the measurement of electrical resistance were carried out with the passage of time using cement paste. Second, we evaluated the moisture content at each depth from the surface of the concrete from the electrical resistance measured using the probes. The probes were provided with parts to be energized by being covered with an insulator. Third, the electrical resistance of concrete carried out to various curing was measured.

As a result, the measured electrical resistance was correlated with ignition loss of the cement. The electrical resistance of concrete subjected to various curing was different. It was clarified that the tendency of moisture content for each distance from the surface of concrete can be evaluated by measuring the electrical resistance using the probes. From these results, we propose a method to evaluate the curing effect of various curing method using electrical resistance.

Keywords: four probe electrical method; curing; ignition loss; moisture content; electrical resistance

1. INTRODUCTION

Curing of concrete is important to ensure required strength, durability, cracking resistance, water tightness and performance to protect reinforcing bar. In the standard specifications for concrete structures-2012, materials and construction, methods such as ponding, spray curing, wet mat curing, etc. were written as a curing method to keep the concrete moist. Curing of the concrete is also important to improve the denseness of the surface layer concrete of reinforced concrete structures. Therefore, many construction companies propose various curing methods and carry out curing on sites. In addition, there is also a method of coating a curing compound to concrete after form removed mold. However, there are few methods and knowledge to evaluate the extent and area of moisture content increase due to water supply and water retention of various curing methods. In addition, the constructor has few criteria for selecting curing methods at the site.

The water curing supplies water to concrete. The sealed curing maintains water in concrete. We thought that water supply and water retention effect by curing can be evaluated by measuring moisture content of concrete. In this study, the curing effect is defined as increase and increase area of water content of concrete by water supply and water retention by various curing methods.

The electrical resistance method is an electricalal method for evaluating the corrosivity of reinforcing bar by measuring the electrical resistance of cover concrete. The authors have devised a method to determine the end timing of curing by measuring the electrical resistance of concrete by the four probes electrical method and aim for practical application. In this method, it is possible to measure the electrical resistance for each depth from the concrete surface by using the probes provided with the conducting part. Using this method, water content is evaluated by measuring the electrical resistance of concrete subjected to various curing. We considered evaluating the curing effect from this water content.

In this research, we proposed a method for evaluating the effect of curing by water retention and water supply by various regimens carried out on concrete. First, we clarified the influence of the electrical resistance measured by the DC four probes electrical method on the reduction of water quantity by hydration reaction. Second, the electrical resistance was measured for each depth from the surface of the concrete. The moisture content of each depth from the surface was evaluated from the measured electrical resistance. Finally, using these results, we proposed a method to evaluate the curing effect of water retention and water supply for various curing methods to be performed on concrete.

2. OUTLINE of EXPERIMENT (EFFECT of HYDRATION REACTION)

We measure electrical resistance with cement paste using various cements. From this result, we clarify the influence of hydration reaction on electrical resistance measured.

2.1 Measurement Method of Electrical Resistance

Figure 1 shows the outline for four probes electrical method. The surface of the prob
es were covered with an insulator to provide an energized part of 2 mm. By using these probes, it is possible to measure electrical resistance at any positions from concrete surface by changing energizing depth.

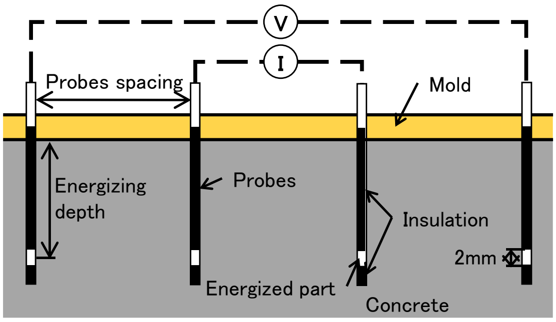

Figure 1. The outline for four probes electrical method

Table 1 shows the measurement conditions of electrical resistance. The reason for using the DC power supply is that the measuring device is smaller and cheaper than the AC power supply. In addition, charging phenomena are prevented by using pulse waves. The applied voltage was 1 V. The probes is aluminum wire.

Table 1. The measurement conditions of electrical resistance

	Mortar tests
Measurement method	Four probes electrical method
Applied voltage	1V
Probes spacing	40mm
Probe diameter	ϕ2.0mm
Energizing depth	30mm
Material of probe	Aluminum

2.2 Mix Proportions and Used Materials

The used materials were ordinary portland cement [OPC] (density 3.16g/cm^3, fineness 3240 cm^2/g) and blast furnace slag [BFS] (density 2.89g/cm^3, fineness 4410 cm^2/g) and fine aggregate (density 2.62 g/cm^3, water absorption rate 1.49%).

Table 2 shows the condition of Mix proportions on mortar. All mix proportions were made with a water cement ratio of 50%, and the content BFS was changed.

Table 2. The condition of Mix proportions on mortar

Cement type	Replacement rate of BFS(%)	W/C(%)	Abbreviation
OPC	0	50	N
	45		B45
	70		B70

2.3 Test Pieces and Curing Method

Figure 2 shows the outline of the test pieces on mortar. The test piece on mortar was a prism of 60 × 60 × 300 mm. In addition, the test piece prevented moisture escape by covering the entire surface of the test pieces with aluminum tape. The test pieces were placed in a constant temperature and humidity chamber (Temperature : 20±1℃, Relative humidity: 60±5%).

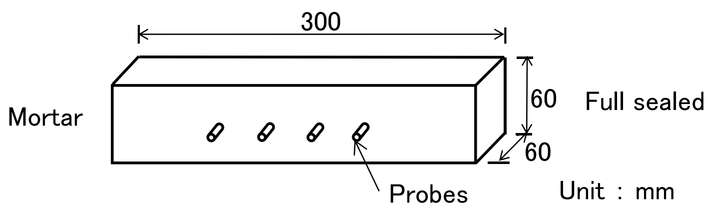

Figure 2. The outline of the test pieces on mortar

2.4 Test Items and Method

Ignition loss test and electrical resistance measurement were carried out using cement paste. The sample was pulverized at each age and the hydration reaction was stopped with acetone. After that, the sample was suction filtered and dried. The heating temperature of sample was 750 ℃. This prevented the oxidation of the glass phase of BFS.

3. EXPERIMENTAL RESULT (EFFECT of HYDRATION REACTION)

Figure 3 shows the change in ignition loss with time. The ignition loss of each age is smaller in the order of N50, B45 and B70. This is thought to be influenced by the replacement rate of BFS. In addition, the electrical resistance after 120 minutes from the water contact of each cement increased with the passage of time.

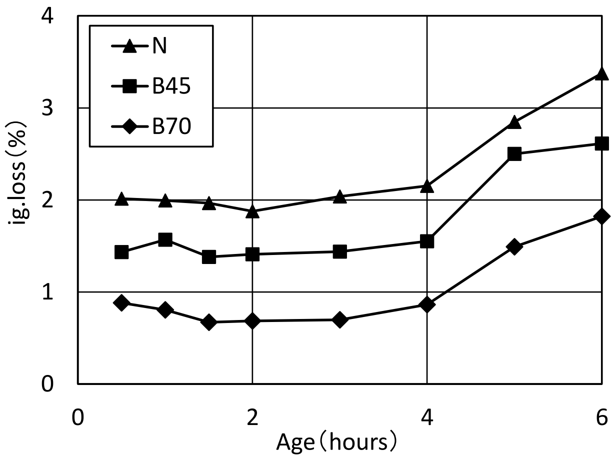

Figure 3. The change in ignition loss with time

Figure 4 shows the measurement results of electrical resistance. The electrical resistance showed a tendency to decrease from the water contact to about 120 minutes. In addition, the electrical resistance after about 120 minutes from the water contact showed an increasing trend. This tendency is the same as the result of the past research which measured the electrical conductivity which is the reciprocal of the electrical resistance.

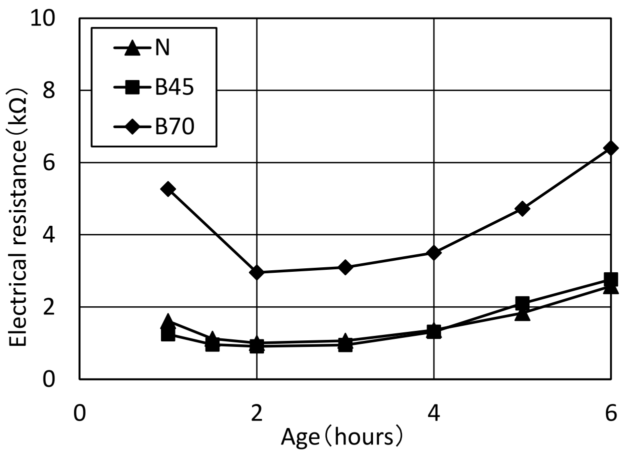

Figure 4. The measurement results of electrical resistance

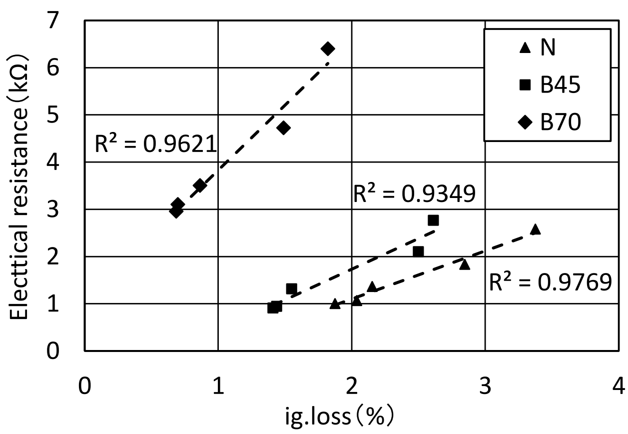

Figure 5. The relationship between electrical resistance and ignition loss

Figure 5 shows the relationship between electrical resistance and ignition loss after 120 minutes from contacting water. There is a correlation between electrical resistance and ignition loss.

From previous studies, the decreasing tendency of the electrical resistance from the water contact to about 120 minutes was thought to be the influence that the electricity flows easily by elution of ions from cement to water.

Furthermore, it is considered that an increase in electrical resistance after about 120 minutes from water contact is influenced by generation of a cement hardened body which is a nonconductor and difficult electricity to flow. From the result, it is possible to estimate the hydration progress rate by measuring the electrical resistance of concrete on sealed curing. By evaluating the magnitude of the electrical resistance with reference to this electrical resistance, it is considered that changes in moisture content due to water supply and drying of various curing can be evaluated.

4. OUTLINE of EXPERIMENT (EFFECT AREA of CURING AND CURING EFFECT)

We measured the electrical resistance for each distance from the concrete surface. From the measurement result, water content of each depth from concrete surface is evaluated. Furthermore we made concrete with various curing and measured electrical resistance. From this result, the curing effect by various curing is evaluated from the measured electrical resistance.

4.1 Measurement Method of Electrical Resistance

Table 3 shows the measurement conditions of electrical resistance. The applied voltage was 10 V. In case 1, the energized depth was changed from 5 to 70 mm. The electrical resistance of each depth from the concrete surface was measured by this measurement. The probes is iron wire.

Table 3. The measurement conditions of electrical resistance

	Case 1	Case 2
Measurement method	Four probes electrical method	
Applied voltage	10V	
Probes spacing	40mm	
Probe diameter	φ2.0mm	
Energizing depth	5,10,20,30,50,70mm	30mm
Material of probe	Iron	

4.2 Mix Proportions and Used Materials

The used materials were the same as mortar tests. The density of the coarse aggregate was 2.70 g/cm^3, and the water absorption rate was 0.34%.

Table 4 shows the mix proportions of concrete. Concrete using AE water reducing agent. The water cement ratio was 55%.

Table 4. The mix proportions of concrete

	Cement type	W/C (%)	s/a (%)	kg/m³			
				W	C	S	G
Case 1	OPC	55	50	174	316	906	923
Case 2			48	175	318	851	960

4.3 Test Pieces and Curing Method

Figure 6 shows the outline of the test piece on concrete. The test piece using concrete in case 1 was a large specimen of 100 × 250 × 1350. In case 2, a prism test piece of 100 × 100 × 400 mm was used. The test pieces covered the surface of the test piece other than the probes setting surface. The test pieces of case 1 was placed in a constant temperature and humidity chamber (Temperature：20±1℃, Relative humidity: 60±5%).

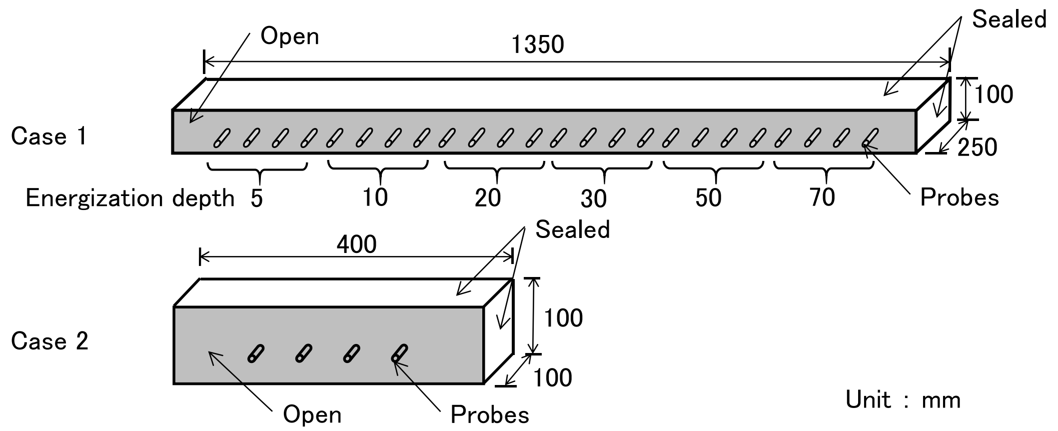

Figure 6. The outline of the test pieces on concrete

Table 5 shows the curing method. The curing method was a relative humidity of 60%, a relative humidity of 80%, Sealed, Water, and Membrane. The membrane was applied after demolding at 1 day. This membrane agent is mainly composed of organic-inorganic composite type polymer.

Table 5. The curing method

	Age			
	0day	1day	・・・	28days
RH60%	Placing	Demolding	RH60%	
RH80%			RH80%	
Sealed			Sealed	
Water			Water curing	
Membrane		Application of membrane agent	RH60%	

5. EXPERIMENTAL RESULT (EVAPORATION AREA AND CURING EFFECT)

5.1 Influence of Energizing Depth on Electrical Resistance (Case 1)

Figure 7 shows the measurement results of the electrical resistance of the test pieces removed from mold release in 1 day. The legend shows the current supply depth. The electrical resistance before removed mold shows the same value regardless of the energizing depth. However, the electrical resistance after removed mold increased with decreasing energizing depth. In addition, the electrical resistance near to the surface of the 5 mm deep energization depth much increased immediately after removed mold. Furthermore, the electrical resistance of 50 mm and 70 mm of the energization depth has no change due to removed mold.

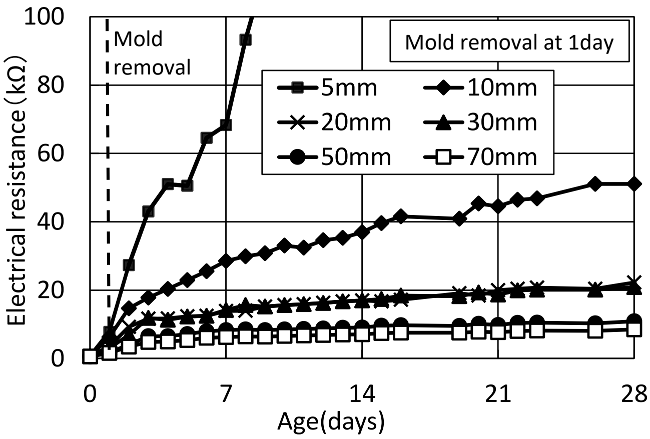

Figure 7. The measurement results of the electrical resistance (Removed mold at 1day)

Figure 8 shows the electrical resistance of test pieces from removed mold at 5days. As compared with figure 7, the increase amount of the electrical resistance after removed mold is small. This tendency seems to be due to the fact that the cement hardened body structure densifies as the age progresses and the rate at which moisture escapes becomes slow.

It is thought that the electrical resistance of concrete with different energizing depth is influenced by change of moisture condition due to escape of moisture after demolding.

By using this method it is possible to estimate the moisture content for each distance from the concrete surface. In addition, the depth at which the water content of the concrete decreases by drying was about 30 mm from the surface.

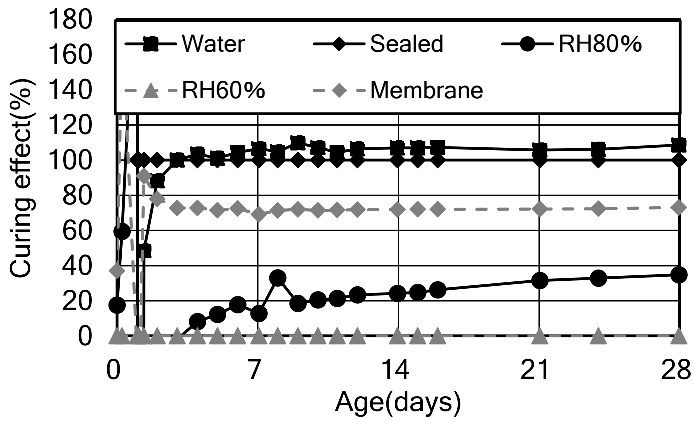

Figure 8. The measurement results of the electrical resistance (Removed mold at 5days)

5.2 Comparison of Curing Effect by Each Curing Method (Case 2)

As mentioned above, the electrical resistance of concrete correlates with the ignition loss. In addition, it is considered that the electrical resistance of the concrete which changes the energizing depth of the probes evaluates the moisture condition of the concrete at energizing depth. Based on these results, we thought that we can evaluate the curing effect by various curing methods by measuring electrical resistance.

Figure 9 shows the rate of change in mass of test pieces subjected to various curing. Membrane reduces the mass increase after coating. The rate of mass change of the test pieces with various curing is different. Mass change rate decreased in order of water, sealed, membrane, RH 80% and RH 60%. Water has increased mass change rate due to water absorption. This result is due to the difference in moisture escape situation depending on the curing environment. The membrane is exposed to the same environment as RH 60%. However, membrane has mass change rate of 3% less than RH 60%. Membrane can confirm the curing effect.

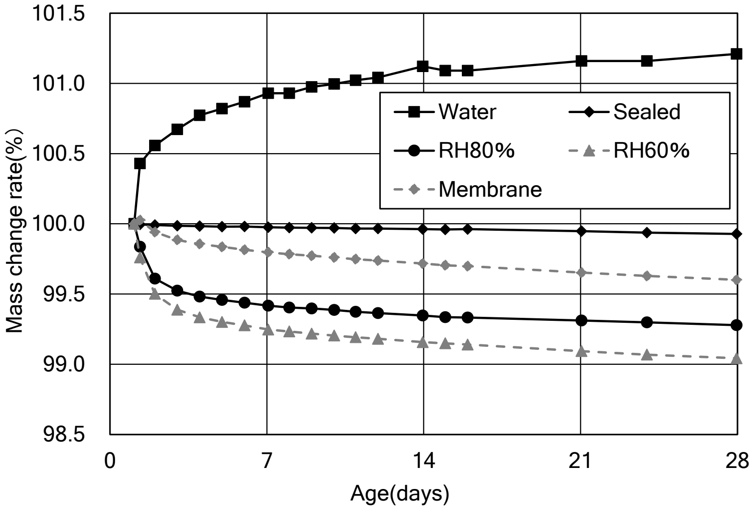

Figure 9. The rate of change in mass of test pieces subjected to various curing

Figure 10 shows the measurement results of the electrical resistance of test pieces subjected to various curing. The energizing depth is 30 mm. The electrical resistance to be measured evaluates the moisture content of concrete of 30 mm part from the surface. There is no difference the electrical resistance of concrete subjected to various curing until removed mold at 1 day. However, the electrical resistance of concrete subjected to various curing showed a different tendency as time passed after removed mold. The electrical resistance at 28 days was increased in order of water, sealed, membrane, RH 80% and RH 60%. This tendency seems to be evaluating evaporation and water supply of moisture by various curing. As a result of mass change rate, an increase in mass due to water supply could be confirmed. However, in the measurement result of electrical resistance, the electrical resistance of water curing shows the smallest value, but there was no big difference from the value of sealed electrical resistance.

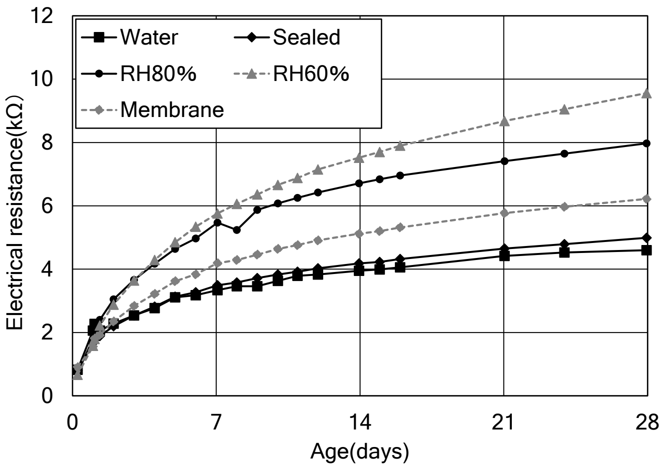

Figure 10.The measurement results of the electrical resistance

The cause was considered that, the measurement part of electrical resistance is evaluating the moisture condition at 30 mm from the surface of the concrete. It is considered that the supplied water mainly penetrates only the surface layer concrete, and no clear difference in the electrical resistance at the part of 30mm from the surface concrete.

By measuring the electrical resistance with the energized depth varied in this manner, it is possible to obtain the area of water supply and water supply by various curing.

Figure 11 shows the relationship between the difference of electrical resistance of various curing and sealed curing and the mass change rate. Correlation was found between the difference of electrical resistance and the mass change rate. Therefore, it is possible to estimate the mass change rate by measuring the electrical resistance of concrete.

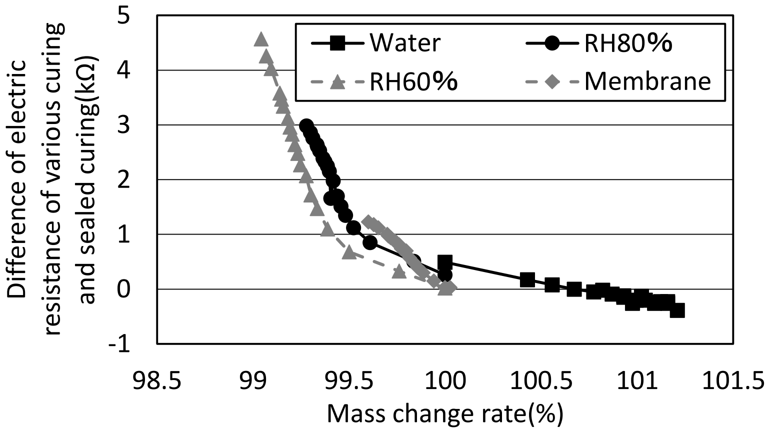

Figure 11. The relationship between the difference of electrical resistance of various curing and sealed curing and the mass change rate

Figure 12 shows the change with time of the curing effect. The curing effect was thought to evaluate other curing methods by setting Sealed curing to 100% and relative humidity 60% to 0%. The curing effect of water curing increased with water supply after removed mold at 1 day and became to maximum at 7 days. RH 80% curing showed the same curing effect as RH 60% curing to 3 days. However, the curing effect of RH 80% was increasing even after 3 days.

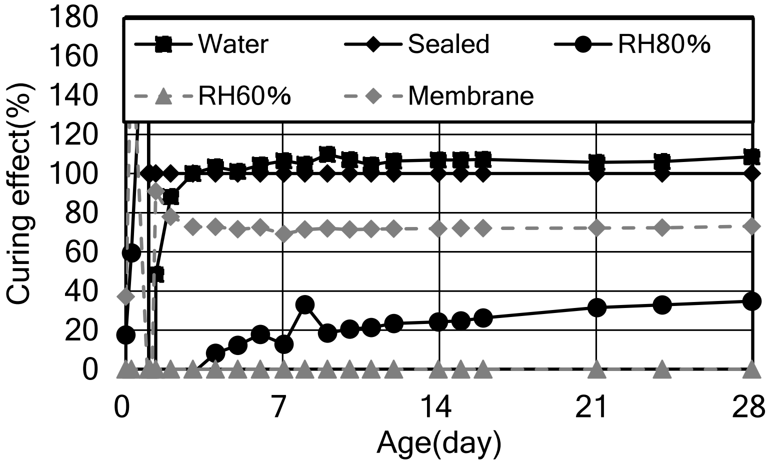

Figure 12. The change with time of the curing effect

Figure 13 shows the curing effect at 28 days. The curing effect of water curing is 108%, and can be confirmed when compared with Sealed curing the curing effect by water supply. The curing effect of membrane curing was about 70%, and there was a curing effect. Previous studies have reported that the hydration reaction stops at curing conditions with a relative humidity of 80% or less, and the amount of pores increases. RH 80% is thought that moisture was supplied by the humidity of the curing environment up to the energized depth of 30 mm.

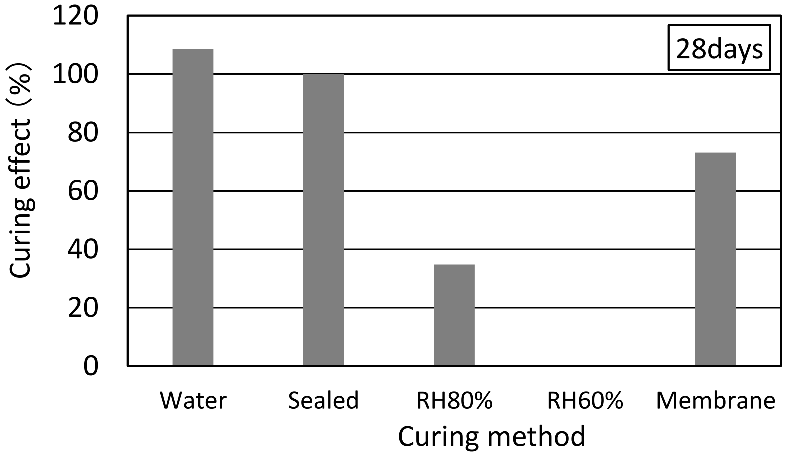

Figure 13. The curing effect at 28 days

6. CONCLUSION

1) It was possible to estimate the ignition loss by measuring the electrical resistance of the concrete of sealed curing. Also, by measuring electrical resistance, the progress of hydration reaction can be evaluated.
2) The electrical resistance of concrete evaluates the change of water content by evaporation after removed mold. It was possible to estimate the moisture content of each depth from the surface using the probes with energized part.
3) It was possible to estimate the mass change rate due to evaporation by measuring the electrical resistance of concrete.
4) It was possible to investigate the water supply and water retention effect and the influence area by various curing by measuring the electrical resistance using the four probes electrical method with energized parts.

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