Evaluation of Curing Effect on Concrete Durability

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ABSTRACT

Concrete is hardening with cement hydration reaction. It is known that the hydration reaction depends greatly on temperature and ambient humidity in circumstances. For the construction of a high-quality concrete structure, curing of concrete after casting is very important. This research is focusing on wet curing expecting curing effected by temperature, we will summarize the influence of wet curing of concrete on durability. After testing the concrete durability with the influence of various curing methods, we experimentally identified the area that curing affects. We also examined the testing method to clarify the durability of concrete using the different curing method. Finally, we developed the system which can evaluate effect of curing with actual structure. As a result, it was found that curing greatly affects about 20 to 30 mm area from the surface of concrete. And it was also found that the initial curing period is important for making good quality of concrete. In order to evaluate the curing of this area, it was shown that it is effective to measure electric resistance. And it is possible to estimate the compressive strength and durability on early and long term using electrical resistance.

1. Introduction_What is curing on concrete?

The hydration reaction occurring in the process of hardening progressing on concrete is largely influenced by the surrounding environment. Since this reaction is a chemical reaction, it can be easily imagined that its hydration reaction rate varies depending on ambient temperature. On the other hand, it is conventionally known that it is also affected by the moisture condition, so it is important that a wetting curing period be provided. Figure 1 shows the result of ignition loss measurement as the progress of hydration in different humidity environments using cement paste. It can be seen that the hydration stops at the initial stage in the environment with low ambient humidity in this figure. In other words, the reason why concrete requires wet curing is not to prevent this hydration reaction. Also, the pore structure is greatly affected by curing conditions. Figure 2 shows the result of measurement of the pore structure of 28 days using a cement paste on various curing by mercury intrusion porosimeater method. When the hydration stops in the drying environment, the pore structure does not change, indicating that large voids remain. It can be easily imagined that this has affected on the strength and the durability of concrete.

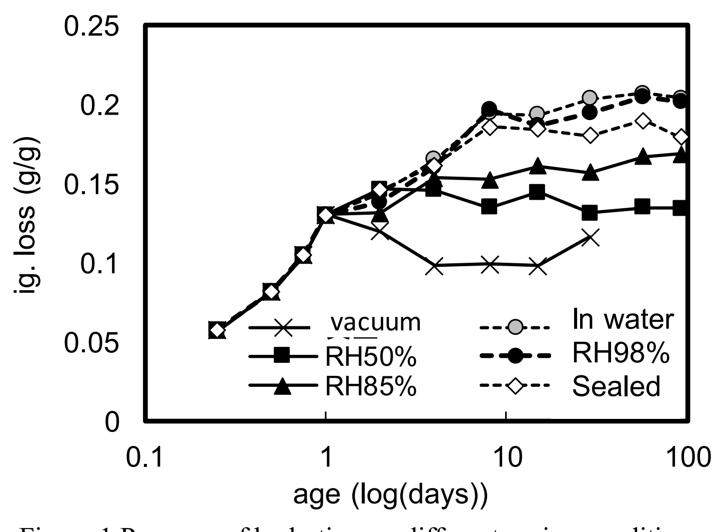

Figure.1 Progress of hydration on different curing conditions

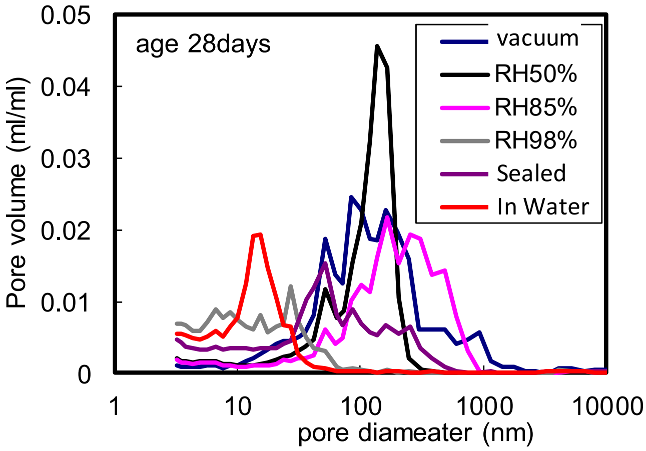

Figure.2 Different pore distribution on different curing conditions

Therefore, here we report the effect of experimental data on the influence of difference in moisture condition during curing on hardened concrete. Also, we evaluate clearly the influenced area of curing from the concrete surface. In addition, we discuss that the evaluation of the influence on curing largely depends on the testing method. Finally, we would like to introduce one of the methods of non-destructively investigating how much performance of concrete after curing can be demonstrated considering the actual structure.

2. Influence of wet curing on hardened concrete

2.1 Influence on compressive strength

Figure 3 shows the results of compressive strength on different curing conditions with concrete using different cement type such as OPC and BA, BB, BC (meaning replacement ratio is changed). The curing conditions are in water and no curing (dry curing). When exposed to the dry state from the demolding time, it is understood that moisture shortage for hydration due to evaporating moisture and the strength progress is stopped. The effect is that hydration progresses slowly, because hydration has needed more water. And it was found that it is largely affected on the high volume blast furnace slag contents which required more moisture.

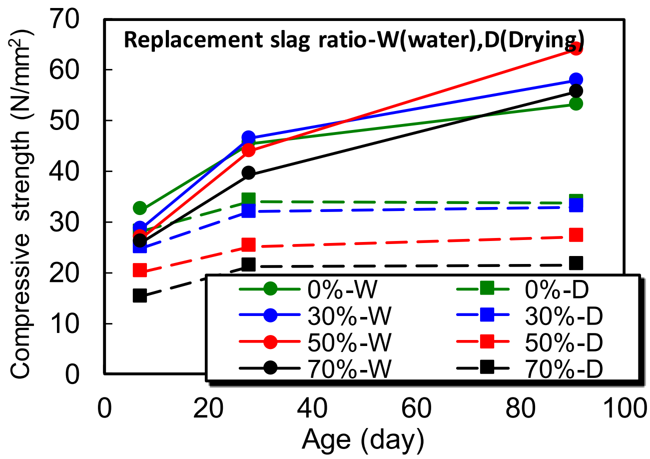

Figure.3 Progress of compressive strength on different replacement ratio of slag and different curing conditions

2.2 Effect on durability

Figure 4 shows the result of permeability coefficient on different curing period. The cement used ordinary Portland cement (N) and blast furnace cement type B (BB). The specimens are demolded at 1 day after casting and sealed curing (S). Here, C indicates drying condition after wet cloth curing, W means underwater curing until curing period, S is sealed (not demolding) curing. The curing period are 3, 5, 7, 28 days. In addition, after completion of curing, symbol D means that it was kept in the dry environment (RH 60%) until the age of 28 days as the test day. The temperature was kept constant at 20 degrees Celsius for all curing.

It was found that the hardened cement has small air permeability coefficient by lengthening the curing period and dense of pore structure. Next, comparison of carbonation rate coefficients is shown in Figure 5. From these results, it can be confirmed that carbonation resistance is improved by continuing curing as well. Likewise, even in the result of the water permeability test, it was markedly reduced unless curing was applied, however it was confirmed that it was improved by curing.

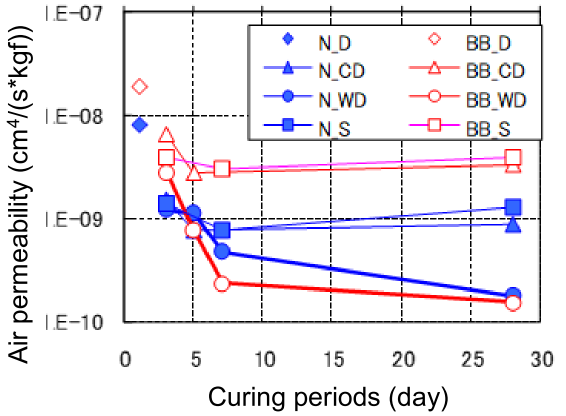

Figure.4 Relationship between curing period and air permeability

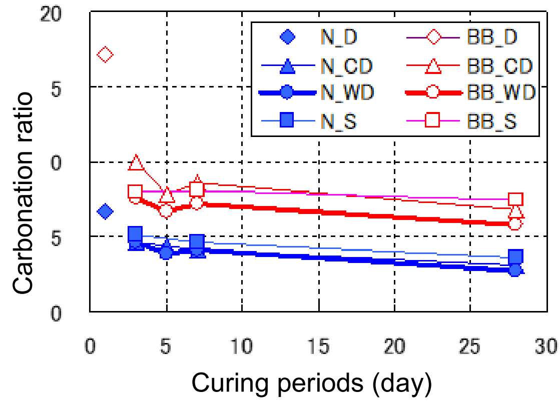

Figure.5 Relationship between curing period and coefficient of carbonation ratio

2.3 Relationship between compressive strength and durability

The improvement of strength and permeability resistance by curing is due to densification of pore structures due to the progress of hydration reaction. Therefore, it clarifies the importance of curing. On the other hand, Figure 6 shows the relationship between compressive strength and permeability and carbonation rate coefficient of concrete with different curing using OPC and BB with different Water cement ratio on the results in 2.2. Although some degree of correlation was found between the compressive strength and each physical property value, however it is difficult to say that the characteristic value is uniquely determined by the compressive strength. This is because the compressive strength test is responsible for the load of the whole specimen, on the other hand the physical property value indicating the permeability from the surface layer of concrete. Therefore, if there is an area where moisture evaporate due to drying curing, permeability resistance may decrease. The area influenced by this curing is limited, and it can be assumed that the portion where the hydration is suppressed and the gap as coarse aggregate such as interfacial tradition zone has also limited area from the surface layered concrete.

2.4 Influence area of curing

As mentioned above, neglecting curing is that water necessary for hydration of cement is deficient as water in the concrete evaporate from the surface layer and performance can not be demonstrated by suppressing hydration. Considering that moisture evaporate occurs only from the concrete surface, it can be imagined that area that is subject to moisture deficiency due to curing becomes a limited part from the surface layer. Therefore, in order to estimate the area, the result of measuring the humidity at different depth positions

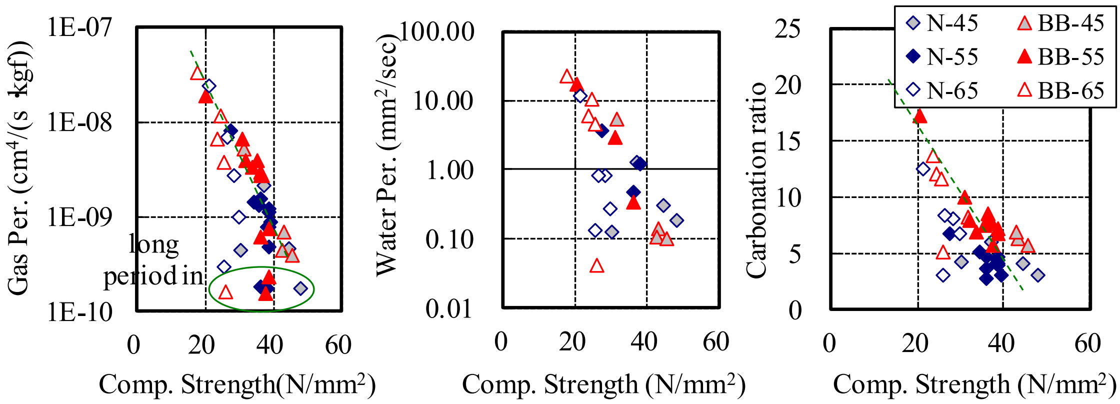

Figure.6 Relationship between compressive strength and other durability indicator such as gas permeability, water permeability and coefficient of carbonation ratio

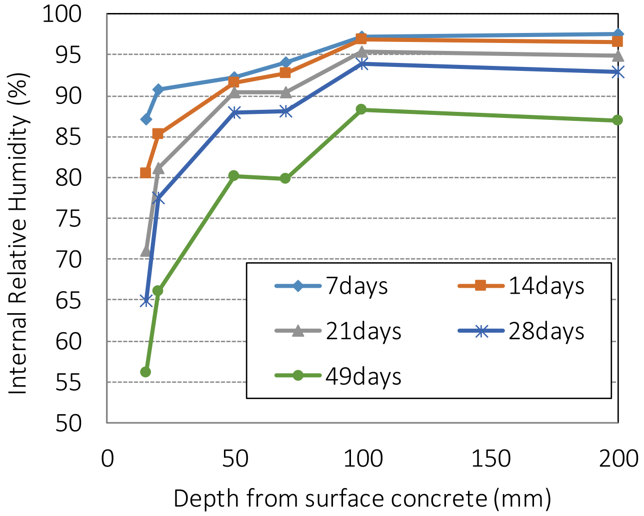

Figure.7 Measurement of internal relative humidity on different depth from surface

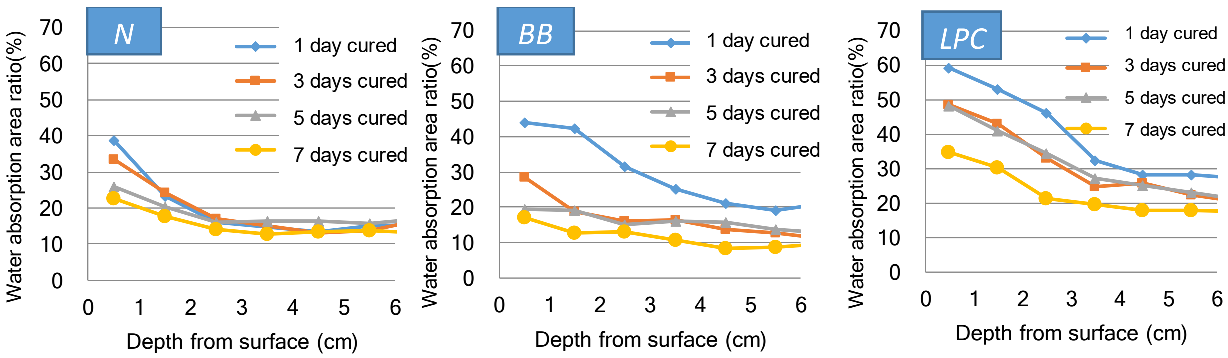

Figure.8 Results of water absorption area ratio on different kind of cement

inside the concrete, as shown in Figure 7. The area was about 30 mm from the surface layer of concrete. Similarly, in order to ascertain the pore condition inside the concrete whose curing period was changed, the permeability moisture test under the vacuum state was carried out, and as a result it depended on the type of cement as shown in Figure 8. It was found the effective area of 20 to 30 mm from surface on curing. Of course, it is also necessary to take into consideration that the end of curing at the age of 1 day in a cement with a slow hydration like BB and LPC has the effect of drying to a remarkably deep position and that coarse voids remain.

In this way, curing changed the moisture state in the area of several mm from the surface layer, it became clear that the stagnation of the hydration reaction made a pore structure, which affected the strength and durability. However, when the cover concrete can be set large like a civil engineering structure, it is possible to ensure the performance of concrete deeper than the range where curing has an influence, and there is a possibility that the influence by curing is not great. On the other hand, due to factors such as insufficient strength, the influence on the occurrence of cracks and peeling off of surface layer concrete can not be denied. In addition, considering that the permeability resistance in that area becomes considerably small, it can be said that it is important to apply appropriate curing.

3. Test method on carbonation and penetration of chloride ion to evaluate on the influence of curing

3.1 Test for carbonation

Generally, the accelerated carbonation test is carried out in a drying environment such as RH 60%. When moist curing is insufficient, the internal moisture evaporate and the hydration reaction can not be carried out. Therefore, as a result of the carbonation test with different curing conditions, as shown in Figure 9, the influence of curing remarkably appears, and the shorter the curing, the faster the progress of carbonation. By promoting carbonation in this manner, the importance of curing can be recognized.

However, in general circumstances it is assumed that moisture will be supplied even after curing. And in that case, the hydration reaction may also cause rehydration. In addition, since the progress of carbonation is remarkably suppressed by the moisture condition, it is also assumed that it is difficult to clearly evaluate the influence of curing in the general environment. It can be said that discussion is necessary enough to judge the durability of concrete structures by accelerated test.

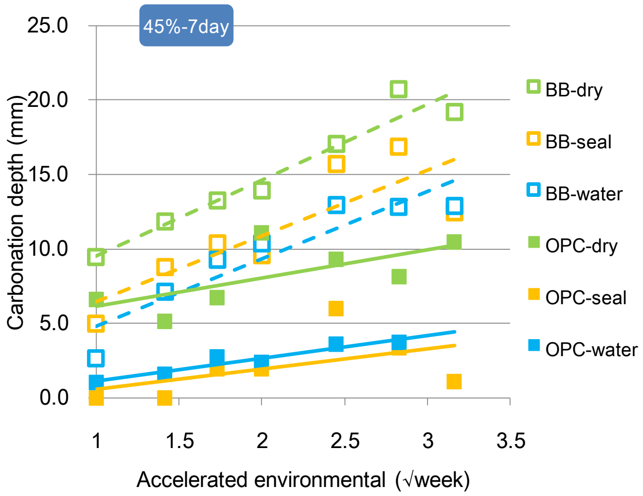

Figure.9 Relationship between accelerated period and carbonation depth on different curing conditions

3.2 Penetration teat for chloride ion

Chloride penetration test is generally conducted by salt water immersion test. Here, Figure 10 shows the results of saltwater immersion test of concrete prepared with different curing. As it is clear from this, it can be seen that salt penetrates into the specimen in the drying curing, which is deficient in curing at the beginning of the measurement. However, when the specimen is subjected to long-term exposure, the difference in curing is hardly seen. It is assumed that this is caused by rehydration of cement by dipping in salt water, which causes densification of pores and it is difficult to penetrate chloride ions into concrete. Under such circumstances it is difficult to judge the difference in curing. Therefore, Figure 11 shows the non-steady state electrophoresis test conducted on concrete prepared under different curing conditions. In this case, we can see the difference on curing clearly. Here, in the non-steady state electrophoresis test, since the test is carried out at an early stage from the anode side to the detection of the chloride ion, the influence such as rehydration can be eliminated and the influence of curing is evaluated that it is a possible way. On the other hand, in real structures, it is necessary to discuss how much the effect of this curing is expected.

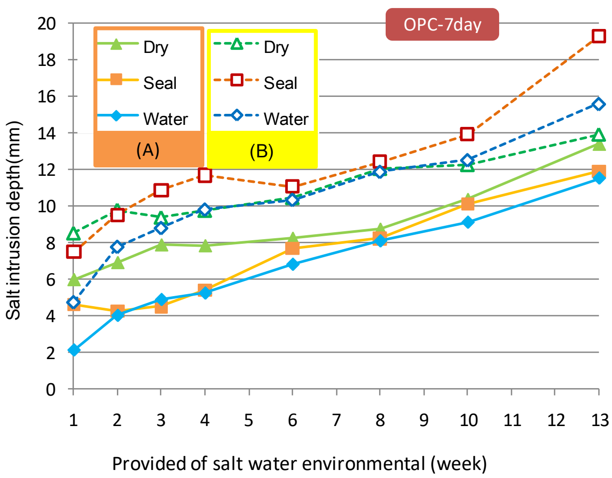

Figure.10 Relationship between accelerated period and penetration depth of chloride ion on different curing conditions

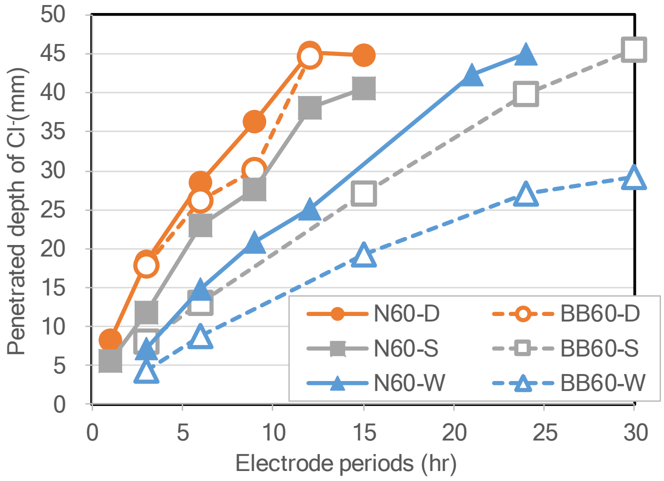

Figure.11 Results of penetration depth of Chloride ion on non-steady state electrophoresis test on different curing conditions

4. Evaluation of curing using electrical resistance - Inference of characteristic values of concrete

It is necessary for curing not to disturb the progression of hydration by preventing moisture evaporation from the concrete surface, and its influence can be said to be 20-30mm from the surface layer. Here, if there is a method that can confirm the degree of curing on surface layer concrete, it is possible to estimate the performance of concrete even in the actual structure to improve concrete performance by curing.

Furthermore, if it becomes possible to predict the end timing of curing, there is a possibility of shortening the construction period and streamlining the construction. Therefore, in this section, we will introduce a case where evaluation of curing was attempted by focusing on water content in concrete and also electric resistance in concrete.

Figure 12 shows the electrical resistance measurement system developed by the four electrode method. The electrodes (four wires) which are embedded in the formwork and the position to be measured was left, so as to be able to measure only the specific depth position from the formwork, and seal the rest of the part. Voltage is applied to the two outer electrodes, current is measured by the inner two electrodes, and the resistance value is measured. Figure 13 shows the time-dependent change in resistance at the position 5

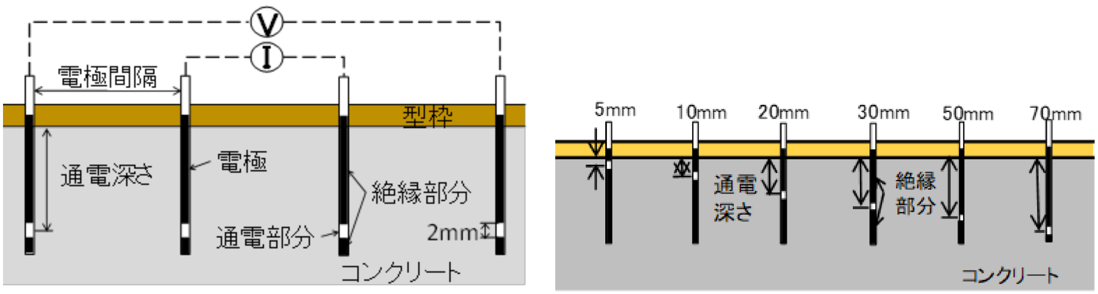

Figure.12 Methdology of four probe electrical restance measurement system

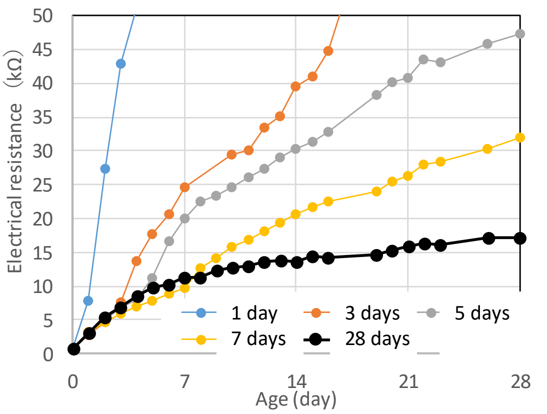

Figure.13 Result of electrical resistance on different curing periods

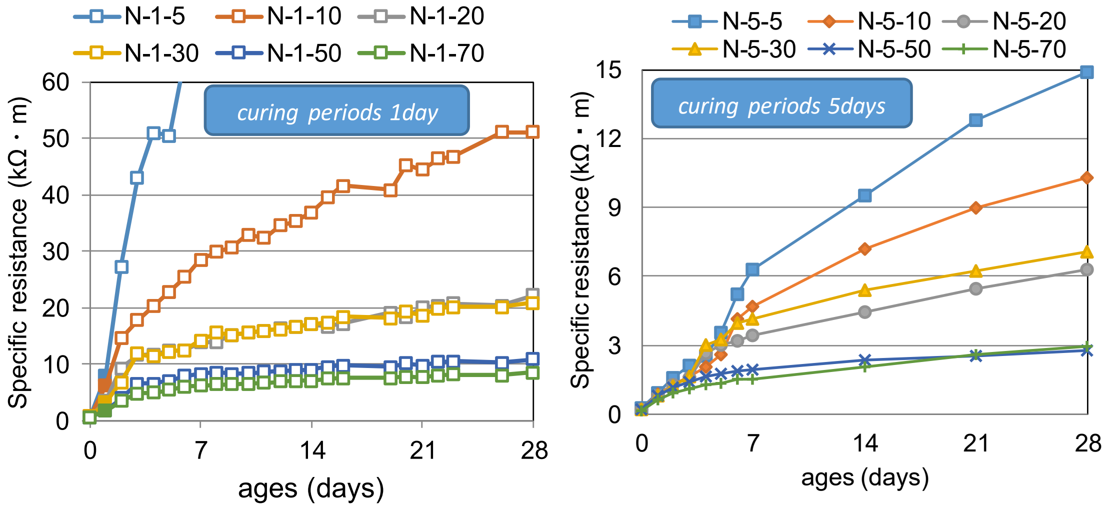

Figure. 14 Results of electrical resistance on different measurement depth

mm from the surface with different formwork duration. From this result, it can be confirmed that the resistance value decreases as moisture is kept as the form-in-residence period is lengthened. This indicates that as the hydration progresses, the pores are densified together with the decrease in water content in the concrete by hydration. It is evident that the resistance value increases as a result of moisture escaping, but the influence becomes smaller as the formwork holding period becomes longer.
Next, Figure 14 shows the measurement result under the drying condition that the measurement position is different from the surface layer by 5, 10, 20, 30, 50, 70 mm. From this result, the resistance at the surface layer remarkably rises from the 5th day sealed curing means the formwork is removed at age 5days, whereas the resistance value only gradually increases under the depth of 20-30 mm. On the other hand, resistance value is not changed at 50 mm or more from surface. Since the resistance increases as the amount of moisture decreases due to the hydration progress, the increase in resistance at this depth position shows mainly the decrease in moisture used for hydration. However, it is thought that the remarkable increase in the resistance value on the surface concrete shows moisture evaporated.
Next, the electric resistance was measured in a sealed state with the formwork embedded with the electrode placed at the position of 30 mm in depth at age of 1, 3, 5, 7, and 28 days. And also the compressive strength is measured at same age. Figure 15 shows the relationship with compressive strength and the electric resistance at that time. It is concrete using ordinary Portland cement, but it was different water cement ratio. It can be said that the compressive strength of the concrete inside the formwork can be estimated by measuring the electric resistance. And it was also good relationship obtained with compressive strength and coefficient of carbonation rate and electrical resistance at 28 days after demolding and exposure to the dry environment. It can be estimated the compressive strength in the formwork and the 28 days strength and durability such as carbonation after exposed to environment with different formwork duration of concrete. By using this, it is possible to estimate the performance of concrete to some extent at the time of finishing curing at the site as shown in Figure 16. We are suggesting that it is possible to a system for construction that can predict the curing end time in real time according to the required performance.

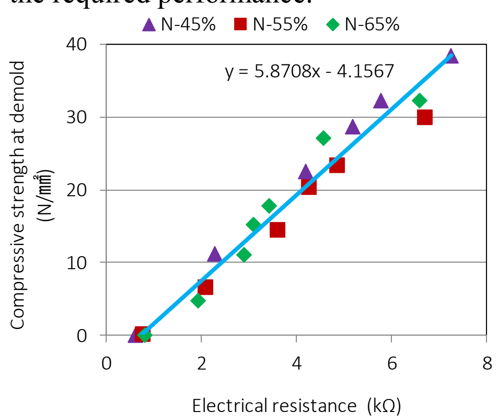

Figure. 15 Relationship between electrical resistance and compressive strength at demolding time

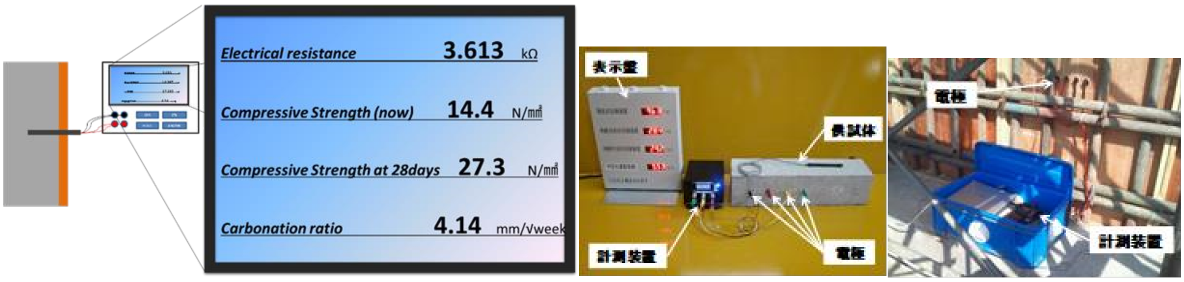

Figure.16 System for prediction of concrete properties in formwork using electrical resistance

5. Conclusion

Curing is an indispensable act to encourage the cement hydration and develop strength and durability. The reason is that it is important to prevent evaporate of water necessary for hydration reaction of cement and to form a dense pore structure. On the other hand, moisture escaping due to poor curing is about 20 - 30 mm from the surface layer. Considering the mass transfer characteristics, it is extremely important to ensure the quality of concrete in the cover concrete part. However, securing excessive curing days and supplying moisture may cause troubles in processes and cost required for construction. We believe that it is important to ensure adequate curing period according to materials used and required performance and to improve concrete performance.

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