Sixth International Conference on Durability of Concrete Structures **Paper Number TIM10**
18 - 20 July 2018
University of Leeds, Leeds, West Yorkshire, LS2 9JT, United Kingdom

An investigation on moisture and water absorption in cement paste with electrical resistance method

M. Mizoguchi, T. Kitagawa, T. Daungwilailuk, Y. Ogawa and K. Kawai
Department of Civil and Environmental Engineering, Hiroshima University, Hiroshima, JAPAN

ABSTRACT

Moisture in concrete is one of main factors related to degradation and deterioration of concrete structure, and there are various moisture transport phenomena in concrete such as drying and absorbing. There are a lot of previous studies on the drying process of concrete to clarify the mechanisms of creep as well as shrinkage. However, few studies have been reported on the process of water absorption and moisture absorption although carbonation and chloride attack are strongly related to moisture and water absorbing. It is necessary to investigate moisture transfer in concrete in detail. This study investigated the moisture transfer in moisture and water absorbing processes in cement paste by using electrical resistance method to understand how moisture and water transfer into concrete. Cement paste specimens with water-to-cement ratios (W/Cs) of 0.35 and 0.55 were prepared in this study. Stainless steel rods of 0.9 mm in diameter were arranged at an interval of 4 mm in the specimen for measuring the electrical resistance. The specimens for moisture and water absorbing test were cured in water at 20 ºC for 28 days and stored at 20 ºC and a relative humidity of 0% and 70% as reference and the national average of the annual average relative humidity in Japan, respectively. The electrical resistances were measured through the stainless-steel rods and converted to electrical resistivity. The calibration test was also conducted to obtain the relationship between the electrical resistivity and the internal relative humidity (IRH), which was used to know IRH in cement paste specimen. As a result, the rate of moisture transfer in the specimen at initial internal relative humidity (IIRH) of 0% was higher than that at IIRH of 70%. Additionally, the rate of moisture transfer in the specimen at any IIRH depends on the total pore volume in the specimen.

Keywords: cement paste, moisture transfer, electrical resistance, durability

1.0 INTRODUCTION

Concrete has a porous body that stably keeps moisture inside, and the moisture in concrete is closely related to deterioration of concrete structure (Ishida *et al*., 1997). For example, alkali aggregate reaction, which causes cracks and corrosion of steel reinforcements, will not occur without moisture. Moreover, shrinkage of concrete, which can affect adversely structural performance of reinforced concrete, is caused by moisture evaporation and hydration. To maintain concrete structures in good condition, it is necessary to investigate the moisture transfer in concrete. Various studies related to moisture transfer in drying process of concrete have been carried out. However, only few studies have investigated the moisture and water absorbing process.

The performance of concrete structures is strongly affected by weather and relative humidity (RH). For example, the water content in concrete is influenced by surrounding environment. Kashima *et al*. indicated that the rate of water absorption differs by water-to-cement ratio (W/C) and type of cement. Namely, water in concrete involves surrounding environment, materials and mixture proportions of concrete.

For measuring water transfer, two methods can be used; gravimetric determination and electrical resistance measurement. Gravimetric determination is a method that can determine moisture transfer by cutting a specimen and measuring its mass. This is a reliable method because the mass loss of the specimen is directly measured, but a lot of specimens are required (Akita *et al*., 1990). The electrical resistance method is a non-destructive method for concrete and it can be conducted with specific time by using one specimen. This method can be used to measure electrical resistance in concrete by using stainless steel rods embedded in a specimen (Kamada *et al*., 1976). However, the electrical resistance used for measurement of moisture transfer is temperature-dependent (Kamada *et al*., 1976, Kasai *et al*., 1995).

Some studies have been carried out by using electrical resistance method, but there are few studies about the difference of moisture transfer under different atmospheres including temperature and humidity. Therefore, in the present study, moisture and water absorption at different initial internal relative humidity (IIRH) was studied by using electrical resistance method. In this study, the electrical resistance method was used to measure electrical resistance in the hardened cement paste by using stainless steel rods embedded in specimens. The internal relative humidity (IRH) is determined from the measurement of electrical resistance in the specimen based on the calibration test. The pore size distribution measurement is also conducted to investigate the change in moisture transfer due to the pore structure in the specimen.

2.0 EXPERIMENTAL METHOD

2.1 Specimens

Mixture Proportion
Ordinary Portland cement having a density of 3,160 kg/m³ was used in this study. Cement paste was prepared with water-to-cement ratios (W/Cs) of 0.35 and 0.55.

Preparation
Specimens for moisture transfer test and calibration test were prepared. The size of the specimen for the moisture transfer test is 40x80x35 mm as shown in Fig. 1.

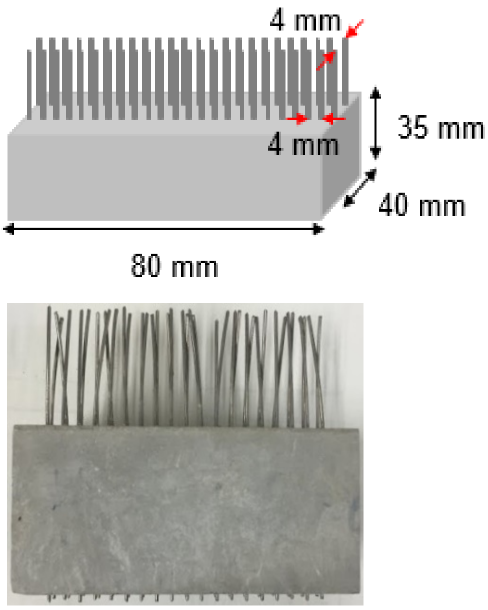

Fig. 1. Specimen configuration for moisture transfer test

The size of the specimen for the calibration test is 40x35x8 mm, obtained by cutting a 40x35x160-mm prismatic specimen as shown in Fig. 2. Stainless-steel rods in the moisture transfer test with a diameter of 0.9 mm were embedded in specimens at an interval of 4 mm. The stainless-steel rods in the calibration test were embedded in specimens at the 8-mm interval as shown in Fig. 2.

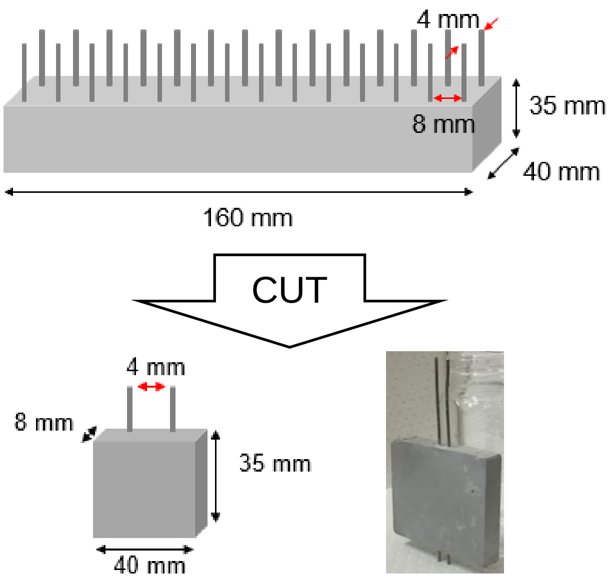

Fig. 2 Specimen configuration for calibration test

After casting, all specimens were covered with plastic wraps on the top surface to prevent water evaporation and stored at 20 ºC and 60 % RH for 24 hours. The specimens were demolded and then cured in water at 20 ºC until the age of 28 days. After curing, the specimens for the moisture transfer and calibration tests were placed at designated initial relative humidity (0% and 70%). The condition of 0% RH was selected for reference and the value of 70% RH is average relative humidity in Japan. The specimen for 0% RH was dried at 100 ºC in an oven until its mass became constant, while the specimen for 70% RH was stored under an atmosphere of 70% RH adjusted by the saturated salt method according to Japanese Industrial Standard (JIS B 7920:2000) as shown in Table. 1 until its mass became constant.

Table 1. Relative humidity of the air in equilibrium with each saturated salt

Type of salt	Relative humidity (%)
K_2SO_4	97.6
KCl	85.1
NaCl	75.5
KI	69.9
NaBr	59.1
K_2CO_3	43.2
$MgCl_2$	33.1
CH_3COOK	23.1
LiCl	11.3
LiBr	6.6

2.2 Measurement of the Electrical Resistance

Direct current (DC) and alternating current (AC) can be used to measure small electrical resistance. However, the electrical resistance on DC cannot be measured stably because of polarization (Kimata *et al*., 1996). In addition, it is difficult to measure the electrical resistance using small voltage in the specimen with low water content. Therefore, in this study the power supply of AC was used according to the previous studies (Kitagawa *et al*., 2017, Bui *et al*., 2016) at 1 kHz AC and 1 V to prevent the polarization.

The electrical resistance in a specimen was measured by a LCR meter shown in Fig. 3.

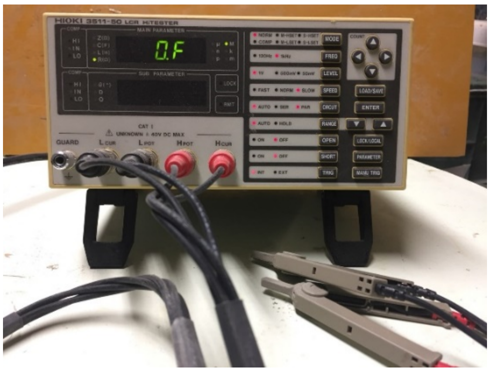

Fig. 3. LCR meter

Measured electrical resistances were converted to specific resistances by using Eq. [1] (Kamada *et al*., 1976).

$$\mathrm{R} = \{\log(d/a)/(\pi \times l)\} \times \rho = Sf \times \rho \qquad (1)$$

where R: electrical resistance (kΩ), d: interval of stainless-steel bar (m), a: radius of stainless steel rods (m), l: length of current-carrying part (m), ρ: specific resistance (kΩ·m), and Sf: geometrical factor (In this study, it was calculated as 8.63.)

2.3 Moisture Transfer Test

All surfaces other than the exposed surface (35x40 mm) of specimens for the moisture transfer test were coated with epoxy resin. The specimens for the moisture absorbing test were placed in a box at 98% RH as shown in Fig. 4.

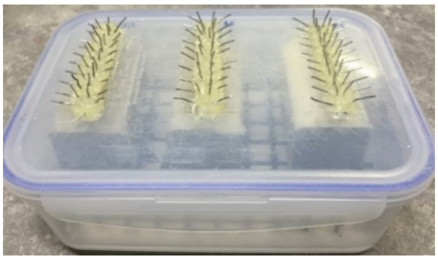

Fig. 4. Moisture absorbing test

2.4 Calibration Test

The electrical resistance of the calibration test specimen stored at different relative humidity shown in Table 1, was measured to obtain the relationship between the electrical resistance and IRH of the specimens. The IRH of the specimen in the moisture transfer test can be evaluated by applying its relationship to the electrical resistance of the specimen.

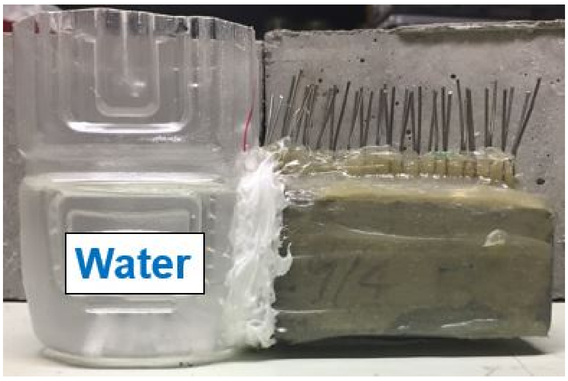

Fig. 5. Water absorbing test

Each calibration test specimen for 0% RH and 70 % RH was prepared. After 28 days of curing, the specimens were moved and stored at 0% and 70% of IIRH until the mass became constant. After that, the specimens at the IIRH of 0% were stored at various RHs shown in Table 1 and the specimens at the IIRH of 70% were stored at various RHs ranging from 70% to 98%.

2.5 Pore Size Distribution Test

Pore size distribution test was conducted to examine the difference in pore structure of the specimens with different W/Cs. Pore volume depends on W/C, material, curing method and the age of concrete. Specimens for the pore size distribution test were cured under the same curing condition as moisture transfer test specimens. After curing, the specimens were stored at 0% and 70% RH. The samples ranging 2.5 - 5.0 mm in size were obtained by crushing at the age when the moisture transfer test was started. They were soaked in acetone for 24 hours to stop the further hydration and dried in a vacuum desiccator for another 24 hours prior to the test. After drying, the pore volume was measured by using a mercury intrusion porosimetry (MIP). The measurement range was $3\text{x}10^{-6}$ m - 10^{-3} m in this study.

3.0 RESULTS AND DISCUSSIONS

3.1 Pore Volume of Specimen

Figure 6 shows the pore volume of all specimens stored at the IIRH of 0% and 70% at the beginning of the moisture transfer test.

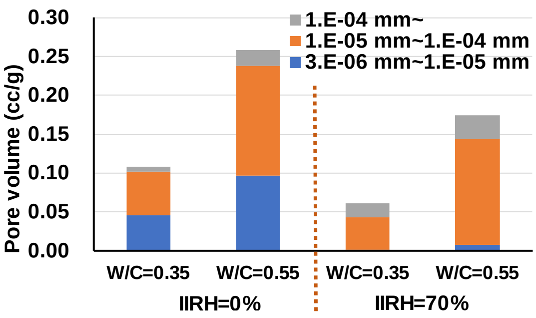

Fig. 6. Pore volume in each specimen

The pore volume of the specimen with W/C of 0.35 is lower than that with W/C of 0.55 regardless of the IIRH.

The total pore volume of the specimens with W/Cs of 0.35 and 0.55 in the case of IIRH=70% was lower than that for IIRH=0% by approximately 40% and 30%, respectively. The hydration reaction in the case of IIRH=0% could be stopped by drying in the oven after water curing. Meanwhile, the hydration reaction in the case of IIRH=70% can continue even after water curing.

The results are consistent with the fact that hardened cement with a high W/C has a high pore volume.

3.2 Specific Resistance in Water Absorption Test

Figs. 7 and 8 show the changes in the specific resistance of the specimens in the water absorbing process stored at IIRH=0% for W/Cs of 0.35 and 0.55, respectively. In the case of W/C=0.35, it took a longer time to increase the internal relative humidity toward the inside of the specimen due to the diffusion of water vapor when compared with that for W/C=0.55.

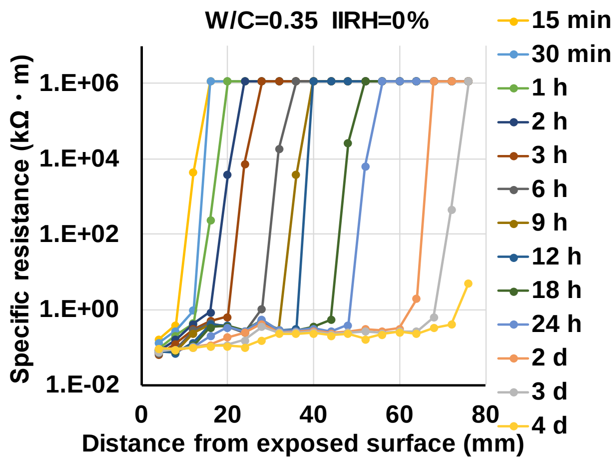

Fig. 7. Change in specific resistance of specimen (W/C=0.35, stored at IIRH=0%) in water absorbing process

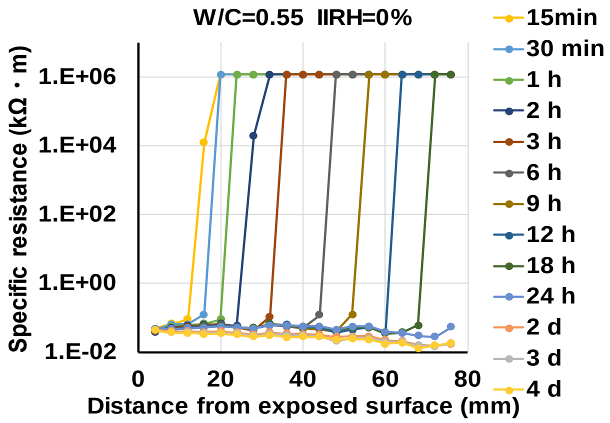

Fig. 8. Change in specific resistance of specimen (W/C=0.55, stored at IIRH=0%) in water absorbing process

Figure 9 shows the relationship between the elapsed time and moisture transfer distance in the water absorbing process.

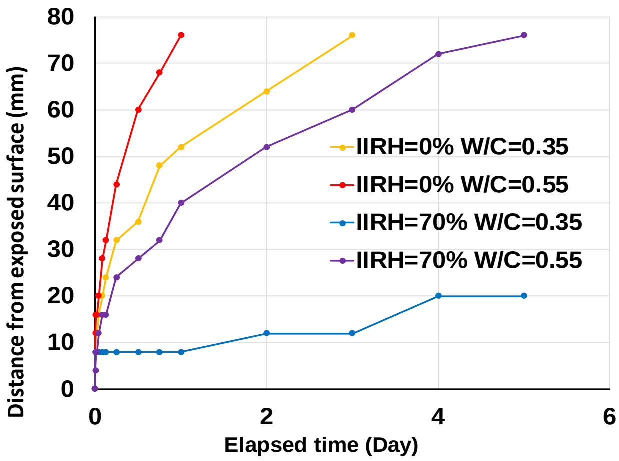

Fig. 9. Relationship between the distance of moisture transfer and elapsed time

The rate of water absorption in the case of W/C=0.55 was higher than that of for W/C=0.35 since a higher pore volume can absorb water more easily.

3.3 Specific Resistance in Moisture Absorption

Figures 10 and 11 show the changes in the specific resistance of the specimens stored at IIRH=0% and 70% in the moisture absorbing process, respectively. The specific resistance of the specimen with W/C of 0.35 for IIRH=0% at the age of 7 days was higher than that with W/C of 0.55 because high total pore volume can easily transfer moisture into the specimen. This tendency agreed with the previous study (Kashima *et al.*, 1999). However, for IIRH=70%, the specific resistance of the specimen with W/C of 0.35 was lower than that with W/C of 0.55 at the ages of both 0 minute and 7 days.

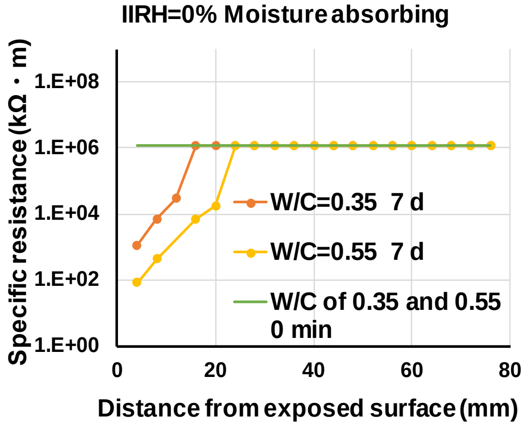

Fig. 10. Change in specific resistance in moisture absorbing process IIRH=0%

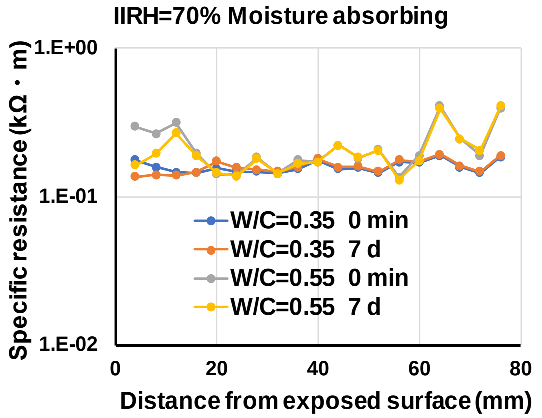

Fig. 11. Change in specific resistance in moisture absorbing process, IIRH=70%

In the case of W/C=0.55, the depth affected by moisture absorbing for 0% and 70% of IIRH were 24 mm and 16 mm, respectively. McCarter *et al.* reported that Moisture measurement is occurring due to capillary suction and/or vapor diffusion and is dependent on initial moisture state (McCarter *et al.*, 1995). Therefore, the specimens stored at lower IIRH can absorb moisture more easily. The larger difference in RH between inside of specimen and its surrounding environment results in easier moisture absorption, similarly to water absorption.

McCarter *et al.* also reported that unlike RH measurement using humidity probe, electrical measurement responded instantaneously to changes in level of void saturation (McCarter *et al.*, 2001). Therefore IIRH=0% can more easily than IIRH=70% for moisture absorbing.

3.4 Relationship between Specific Resistance and Internal Relative Humidity in Calibration Test

Figure 12 shows the relationship between the IRH and specific resistance of cement paste in the calibration test. The relationship between the IRH and the logarithm of the specific resistance can be linearly approximated.

For each IIRH, the specific resistance of the specimens with both W/Cs was almost the same at any internal relative humidity. In the case of IIRH=70%, the specific resistance at IRH= 70% was approximately 0.19-0.40 kΩ·m, whereas in the case of IIRH=0%, the specific resistance at IRH=70% was approximately 20 kΩ·m and higher than that in the case of IIRH=70%. Moreover, the specific resistance in the case of IIRH=0% more widely varied with changes in the IRH when compared with IIRH=70%.

Generally, concrete conductivity is correlated with water content. In this study, it could be implied that the specific resistance in all specimens was affected by absorbed water and the specimen for IIRH=0% was prominently affected.

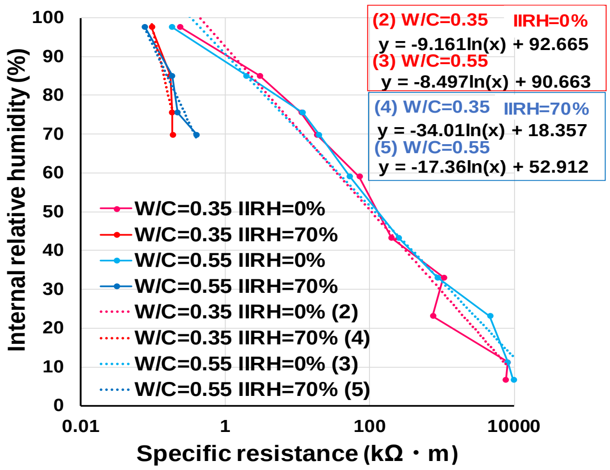

Fig. 12. Relationship between internal relative humidity and specific resistance in calibration test

3.5 Internal Relative Humidity in Moisture Absorbing Process

By using equations (2) and (3) shown in Fig. 12, the IRH of specimens with W/Cs of 0.35 and 0.55 in the case of IIRH=0% was obtained as shown in Fig. 13.

At the depth of 4 mm from the exposed surface, the IRH for the specimens with W/C=0.35 and W/C=0.55 reached 28% and 53%, respectively. Generally, the moisture absorption rate depends on the pore volume. It indicated that the specimen with higher W/C, which has higher total pore volume, can absorb moisture more easily.

The IRH of specimens with W/Cs of 0.35 and 0.55 in the case of IIRH=70% was calculated by using equations (4) and (5), and was shown in Fig. 14. The IRH of the specimen at the beginning was not 70%. It is because the approximation equations cannot accurately express the IRH. The increment of IRH for 7 days in the case the relationships. Further investigation will be needed to quantitatively evaluate of IIRH=70% for W/C of 0.35 and 0.55 was 8.8% and 10.3% respectively. The increment for W/C of 0.55 was higher than that for W/C of 0.35. This is similar with the case of IIRH=0% .

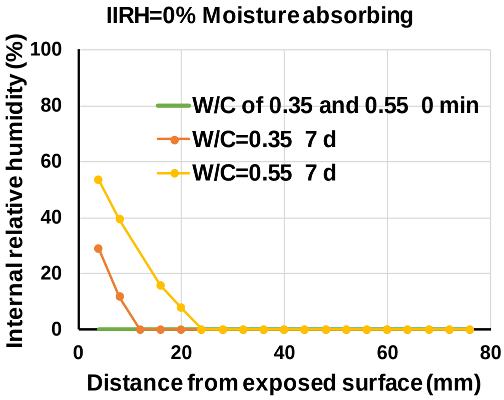

Fig. 13. Change in internal relative humidity in moisture absorbing process, IIRH=0%

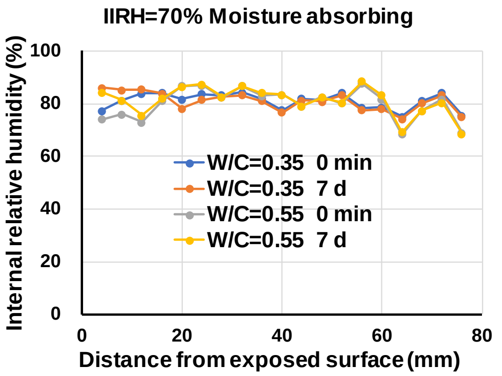

Fig. 14. Change in internal relative humidity in moisture absorbing process, IIRH=70%

4.0 CONCLUSION

The conclusions from the experimental results obtained in this study are as follows:

1) The specific resistance of the specimens with W/Cs of 0.35 and 0.55 was almost the same at any internal relative humidity regardless of the IIRH. However, the specific resistance for different IIRH was different at any internal relative humidity.
2) In the case of moisture absorbing process, moisture was able to transfer more easily into specimens stored at IIRH=0% than at IIRH=70%.
3) The moisture transfer into specimens stored at both IIRH=0% and 70% depends on the total pore volume of the specimen and moisture content inside the pore. The moisture behavior can be observed by using electrical resistance method.

In this study, the temperature condition was kept constant. In actual situation, however, surrounding temperature can be changed by weather and will affect conductivity measurement (i.e. the specific resistance). Further study about the effect of temperature on the specific resistance will be needed.

References

Akita, H., Fujiwara, T., Ozaka, Y., 1990. Water movement within mortar due to drying and wetting, Proceedings of Japan Society of Civil Engineers, 13(420):61-69.

Bui, P. T., Ogawa, Y., Nakarai, K., Kawai, K., 2016. Electrical resistance measurement to assess moisture transfer in cement-based mortar through water absorbing and drying processes. Proceedings of the Japan Concrete Institute, 38(1):813-818.

Ishida, T., Chaube, R. P., Kishi, T., and Maekawa, K., 1997. Modeling of pore water content in concrete under generic drying wetting conditions, Proceedings of Japan Society of Civil Engineers, 35(564):199-209.

Kamada, E., Tabata, M., Nakano. Y., 1976. The measurement of the water content in the concrete, Sement Gijutsu Nenpo, 30:288-290.

Kasai, Y., Matsui, I., Yuasa, N., Satoh, H., 1995. Testing method of moisture content in concrete with a small stainless steel electrodes. Proceedings of the Japan Concrete Institute, 17(1):671-676.

Kashima, T., Kawano, H., Watanabe, H., and TANAKA, Y., 1999. Fundamental study on electrical resistance for assessing durability of concrete. Proceedings of the Japan Concrete Institute, 21(2):895-900.

Katsura, O., Yoshino, T., Tabata, M., Kamada, E., 1994. Estimation of water content in concrete by resistivity and temperature. Proceedings of the Japan Concrete Institute, 16(1), pp.735-740.

Kimata, H., Ishikawa, Y., Ohshita, H., Tanabe, T., 1996. 1093 An experimental study on the water migration in nonsaturated mortar. Proceedings of Japan Society of Civil Engineers, 18(1):591-596.

Kitagawa, T., Daungwilailuk, T., Bui, P. T., Ogawa, Y., Kawai, K., 2017. A study on moisture transfer in hardened cement in a drying process using electrical resistance method. Proceedings of Japan Society of Civil Engineers, 472:943-944.

McCarter, W. J., Emerson, M., Ezirim, H., 1995. Properties of concrete in the cover-zone: developments in monitoring techniques. Magazine of Concrete Research, 47(172):243-251.

McCarter, W. J., Watson, D. W., Chrisp, T. M., 2001. Surface zone concrete: Drying, absorption, and moisture distribution. Journal of Materials in Civil Engineering, 13(1):49-57.