- Technical Paper -

ELECTRICAL RESISTANCE MEASUREMENT TO ASSESS MOISTURE TRANSFER IN CEMENT-BASED MORTAR THROUGH WATER ABSORBING AND DRYING PROCESSES

Phuong Trinh BUI[*1], Yuko OGAWA[*2], Kenichiro NAKARAI[*3] and Kenji KAWAI[*4]

ABSTRACT

Based on calibration specimens, internal relative humidity (IRH) and moisture transfer (MT) in mortar through water absorbing and drying processes were assessed by measuring electrical resistance using stainless steel rods placed at intervals of 4 mm in the specimens. As a result, for mortar exposed to water, the initial change in IRH could be mainly caused by the penetration of liquid water and then, IRH increased gradually due to diffusion of water vapor in the later stage. Meanwhile, IRH of mortar exposed to drying condition decreased gradually with time.

Keywords: internal relative humidity, moisture transfer, electrical resistance, cement-based mortar

1. INTRODUCTION

Sustainable issues in construction have been currently the major concerns in the world. One of them is the durability design for concrete structures to achieve durable service life performance [1]. It is known that the durability is commonly related to moisture in concrete which is one of main factors causing the degradation and deterioration of concrete structures [2, 3]. Moisture in concrete is not uniformed and moisture transfer within concrete varies with the exposure time, depending on the porosity of concrete correlated to the water to cement ratio (W/C), temperature and relative humidity of surrounding environment [4, 5]. It was found that the higher the W/C, the higher the porosity, the easier the penetrations of aggressive ions (such as Cl^- ion) and moisture from the environment into concrete as well as the faster the moisture transfer within the concrete or from the concrete to the environment [6, 7]. Therefore, an assessment of moisture and moisture transfer in the concrete is required in order to evaluate its durability as well as predict the service life of concrete structures.

Several methods to measure the concrete moisture have been suggested, such as gravimetric determination, electrical resistivity and so on [8, 9, 10]. The method based on gravimetric determination is the simple method to measure the concrete moisture through the ratio of mass to completely dried mass of specimens. In order to determine moisture transfer within concrete in this method, sawing and taking measurements for the different depths of the specimens have to be done, resulting in the large number of specimens as well as the inaccuracy determination of moisture transfer in specimen with time [8]. Meanwhile, the method based on electrical resistivity is not a direct measure of the moisture in concrete. However, electrical resistance or electrical resistivity is the parameter which is mostly relevant to moisture transfer in concrete and even to the dominant stages (including the initiation period of chloride penetration and the propagation period characterized by significant corrosion rate) in the service life of a concrete structure [9, 10]. Additionally, this method can be used at different depths of concrete specimens with time because it is a method of nondestructive testing. Consequently, a lot of studies have used this method for monitoring the moisture transfer in concrete exposed to drying-wetting cycles or only drying [11, 12]. There are only a few studies on moisture transfer in mortar exposed to water absorbing by measuring electrical resistance [13].

In the present study, electrical resistance was measured using stainless steel rods placed at intervals of 4 mm in the cement-based mortar specimens with W/Cs of 0.35, 0.45, and 0.55 in order to assess internal relative humidity and moisture transfer in specimens through water absorbing process. In addition, these mortar specimens through drying process were also investigated for comparison. In order to assess moisture transfer in mortar specimens accurately, electrical resistance of calibration specimens through the water absorbing and drying processes was also measured using saturated salt solutions.

2. EXPERIMENTS

2.1 Materials and mixture proportions

Ordinary Portland cement and silica sand (No. 6 and No.7 grade) were used as cement and fine

*1 Special Appointed Assistant Prof., Institute of Engineering, Hiroshima University, JCI Member
*2 Assistant Prof., Institute of Engineering, Hiroshima University, JCI Member
*3 Associate Prof., Institute of Engineering, Hiroshima University, JCI Member
*4 Professor, Institute of Engineering, Hiroshima University, JCI Member

aggregate, respectively for making cement-based mortar. The physical properties of these materials are shown in Table 1. Mortar specimens with W/Cs of 0.35, 0.45, and 0.55 were prepared in this study to investigate the electrical resistivity and moisture transfer in mortar in the wide range of W/C. The amount of fine aggregate was kept constant in order to eliminate the effect of aggregate on electrical resistance. Mixture proportions of mortar specimens are shown in Table 2. Besides, superplasticizer was added 0.6% by mass of cement only in the case of W/C of 0.35 in order to get the same mortar flow of 200 ± 5 mm as the case of W/C of 0.45 or 0.55 as well as to compact the mortar appropriately among the stainless rods arranged closely.

2.2 Preparation of mortar specimens

The mortars were mixed in a mechanical mixer and were cast in the moulds of 20x20x80 mm. The stainless steel rods of 0.9 mm in diameter were arranged at intervals of 4 mm in the mortar specimens for both calibration and measurement as shown in Fig. 1. All samples were demolded 24 hours after casting and cured in water at 20°C for 28 days. Thereafter, mortar specimens for calibration and measurement were prepared as shown in Figs. 2 and 3, respectively.

As shown in Fig. 2, for calibration, mortar specimens measuring 20x20x8 mm made from prism specimens measuring 20x20x80 mm (as shown in Fig. 1 (a)) were exposed to different humidity boxes at 20°C according to JIS B 7920:2000 (Hygrometers - Test method) in order to obtain the relationship between internal relative humidity and electrical resistivity, assuming that the relative humidity in the specimens reaches the same humidity as a state of equilibrium in the box. Table 3 shows the types of saturated salt solutions used for creation of specified humidity conditions so that the specimens were allowed to desorb or absorb moisture until the mass became constant and the equilibrium relative humidity were obtained. The exposing time to reach the equilibrium relative humidity for both drying and moisture absorbing processes were 53, 39 and 25 days in the case of W/Cs of 0.35, 0.45 and 0.55, respectively. In the case of moisture absorbing process, the specimens were dried at 100°C in an oven for 1 day when their mass became constant before placing in the different humidity boxes as shown in Fig. 2 (b). As shown in Fig. 3, for measurement, mortar specimens measuring 20x20x80 mm were sealed with epoxy resin, except for one surface which is exposed to water or drying condition at 20°C and 60% R.H. Similar to calibration, the mortar specimens through water absorbing process were dried at 100°C in an oven for 1 day before one surface was exposed to water as shown in Fig. 3 (b).

2.3 Measurement of electrical resistance

An LCR meter was used in this study to measure the electrical resistance through two stainless steel rods placed at intervals of 4 mm in the specimens. The power supply of AC was used according to the previous study [14]. For calibration, this measurement was carried out when the relative humidity in the specimens

Table 1 Physical property of materials

Property	Cement	Sand (saturated surface-dry)	
		No. 6	No. 7
Density (g/cm^3)	3.16	2.64	2.63
Blaine specific surface area (cm^2/g)	3360	-	-
Water absorption (%)	-	0.18	0.16
Size range (mm)	-	0.075-0.6	0.053-0.3

Table 2 Mixture proportions

W/C	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	
			No. 6	No. 7
0.35	987	345	361	541
0.45	858	386	361	541
0.55	759	417	361	541

Table 3 Types of saturated salt solutions creating specified humidity conditions

Relative humidity (%)	Saturated salt solution
98	Potassium sulfate
85	Potassium chloride
75	Sodium chloride
70	Potassium iodide
60	Sodium bromide
43	Potassium carbonate
33	Magnesium chloride
23	Potassium acetate
12	Lithium chloride
6	Lithium bromide

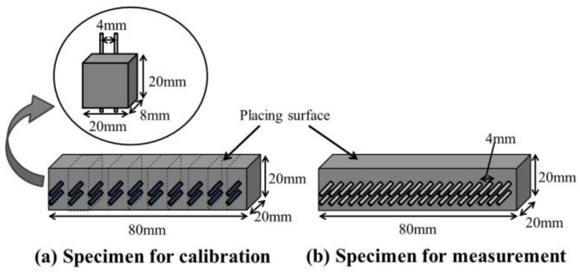

Fig.1 Preparation of specimen for (a) calibration and (b) measurement

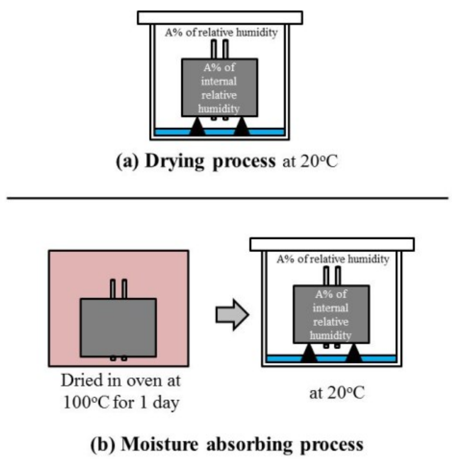

Fig.2 Preparation of calibration specimens through (a) drying and (b) moisture absorbing processes, after 28-day curing in water

reached the same humidity as a state of equilibrium in the box as shown in Fig. 2. For measurement, the electrical resistances between two stainless steel rods arranged at the same depth from the surface exposed to water or drying condition were measured at designated periods as shown in Fig. 4.

2.4 Determination of resistivity, internal relative humidity and relative water content

The resistivity of specimens was calculated from Equation (1) according to a study of Kasai and Matsui [15].

$$\rho = \frac{R}{Sf} = \frac{\pi \times l}{\log\left(\frac{d}{a}\right)} \times R \tag{1}$$

where,
ρ: resistivity (kΩ · cm)
R: resistance (kΩ)
l: depth of electrode (cm)
d: interval of electrode (cm)
a: electrode radius (cm)

Based on the results of resistivity of calibration specimens, relationships between the resistivity and internal relative humidity of mortar specimens under each condition (W/Cs of 0.35, 0.45, and 0.55, and through the moisture absorbing and drying processes) should be obtained. From these relationships, internal relative humidity of specimens under each condition was determined. Besides, the relative water content in calibration specimens was calculated according to Equation (2) based on method of gravimetric determination:

$$RWC = \frac{M_i - M_d}{M_{saturated} - M_d} \tag{2}$$

where,
RWC: relative water content (%)
M_i: mass of specimen under the equilibrium condition (g)
M_d: mass of oven-dried specimen (g)
$M_{saturated}$: mass of saturated specimen (g)

3. RESULTS AND DISCUSSIONS

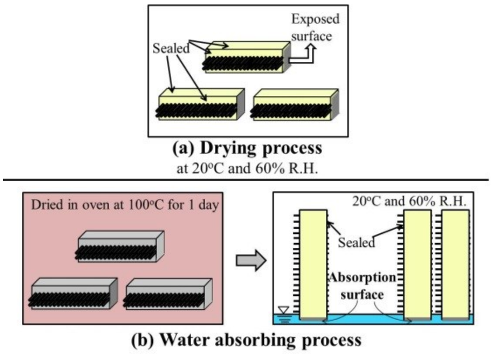

Fig.3 Preparation of specimens for measurement through (a) drying and (b) water absorbing processes, after 28-day curing in water

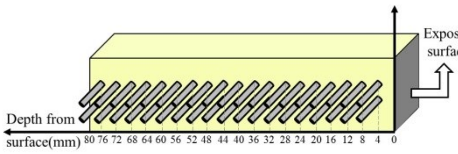

Fig.4 Measurement method of electrical resistances of specimen at same depths from the exposed surface

3.1 Resistivity and relative water content of calibration specimens

(1) Influence of internal relative humidity on resistivity

Influences of internal relative humidity on resistivity of calibration specimens through moisture absorbing and drying processes are shown in Fig. 5. It can be said that the resistivity of mortar specimens increased with the decrease in internal relative humidity in both absorbing and drying processes regardless of W/C. It indicates the measurement of electrical resistance using two stainless steel rods placed at intervals of 4 mm in the specimen enables to determine the internal relative humidity of mortar through moisture absorbing and drying processes. From the negative correlation between the electrical resistivity and internal relative humidity of calibration specimens as shown in Fig. 5, the equations (3), (4), (5), (6), (7), and (8) obtained in order to determine the internal relative humidity of mortar specimens are also shown in Fig. 5. However, the equations (6), (7), and (8) were

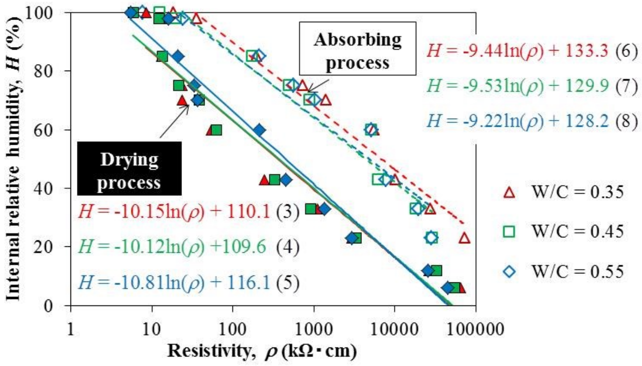

Fig.5 Influence of internal relative humidity on resistivity of calibration specimens through moisture absorbing and drying processes

only used to determine the range of internal relative humidity of 23% - 100% due to the limitation of measurement under the equilibrium relative humidity of 12% and 6% through moisture absorbing process. Meanwhile, for drying process, the equations (3), (4), and (5) were used to determine that of 6% - 100%.

Briefly, electrical resistivity measurement using stainless steel rods placed at intervals of 4 mm in the mortar specimens could determine internal relative humidity of specimens regardless of W/C in the further discussion.

(2) Influences of moisture absorbing and drying processes on resistivity and relative water content

Fig. 5 also shows the influences of moisture absorbing and drying processes on the resistivity of calibration specimens. For the same internal relative humidity, specimens through moisture absorbing process had the higher resistivity than those through drying process regardless of W/C. Fig. 6 shows the influence of moisture absorbing and drying processes on relative water content in calibration specimens determined according to Equation (2). For the same internal relative humidity, specimens through moisture absorbing process had the smaller relative water content than those through drying process regardless of W/C. This phenomenon should be due to the so-called ink-bottle effect of water in pores [16].

(3) Relationship between resistivity and relative water content

Relationship between resistivity measured by electrical resistance method and relative water content is shown in Fig. 7. It can be seen that the resistivity of mortar specimens decreased with the increase in relative water content in both moisture absorbing and drying processes.

In brief, there was a negative correlation between electrical resistivity and internal relative humidity as well as between electrical resistivity and relative water content in calibration specimens through moisture absorbing and drying processes.

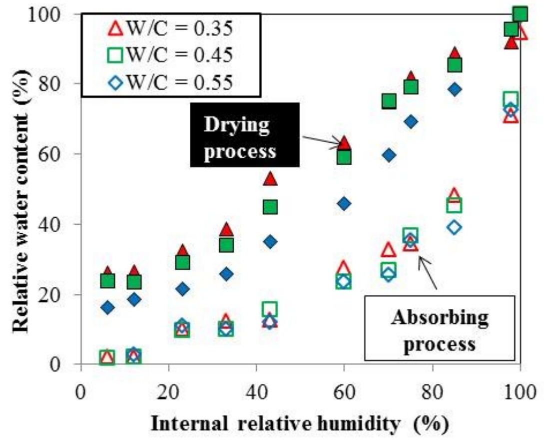

Fig.6 Influence of internal relative humidity on relative water content of calibration specimens through moisture absorbing and drying processes

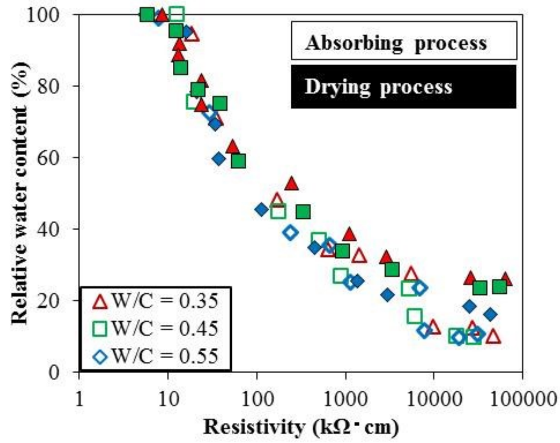

Fig.7 Relationship between resistivity and relative water content of calibration specimens through moisture absorbing and drying processes

3.2 Moisture transfer in mortar

(1) Drying process

The resistivity of mortar specimens was determined from the electrical resistances between two stainless steel rods at the same depths from the surface exposed to dry condition at designated times according to Equation (1). Using Equations (3), (4), and (5), internal relative humidity of specimens with W/Cs of 0.35, 0.45, and 0.55 is shown in Figs. 8, 9, and 10, respectively. It appears that internal relative humidity at all depths from the surface of mortar specimens exposed to dry condition decreased homogeneously with time, especially significantly in specimens with low W/C as shown in Figs. 8 and 9. It may be due to the effect of self-desiccation, lowering internal relative humidity in mortar specimens having W/Cs of 0.35 and 0.45.

(2) Water absorbing process

Similar to drying process, internal relative humidity of specimens with W/Cs of 0.35, 0.45, and 0.55 calculated by using Equations (6), (7), and (8) is shown in Figs. 11, 12, and 13, respectively. Each lowest value of internal relative humidity as shown in Figs. 11, 12, and 13 was not real value of internal relative humidity of specimens due to the limitation of measurement. It can be seen that the internal relative humidity of mortar exposed to water increased quickly with the value up to 100% at the near-surface depths in early times. However, the increase in internal relative humidity became slow at the far-surface depths after 24h. This phenomenon observed in this study could not be controlled by diffusion of water as shown in the previous study [17]. It could be said that the internal relative humidity increased gradually due to the diffusion of water vapor, following the transfer of liquid water from oven-dried condition was observed significantly. Additionally, for specimen with W/C of 0.35, liquid was penetrated highly, possibly due to the use of superplasticizer and the micro-cracks in the specimen caused by drying in oven.

(3) Diffusion of water vapor

The experimental results in water absorbing process could suggest that the initial change in internal relative humidity could be mainly caused by the penetration of liquid water into a limitation depth,

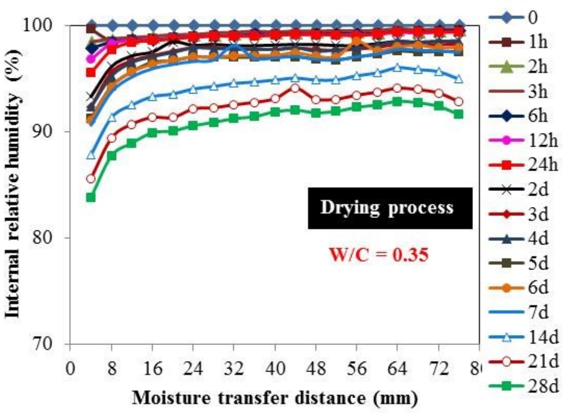

Fig.8 Moisture transfer in mortar specimen with W/C of 0.35 through drying process

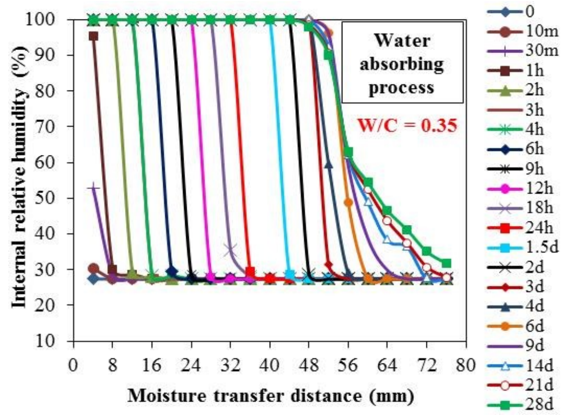

Fig.11 Moisture transfer in mortar specimen with W/C of 0.35 through water absorbing process

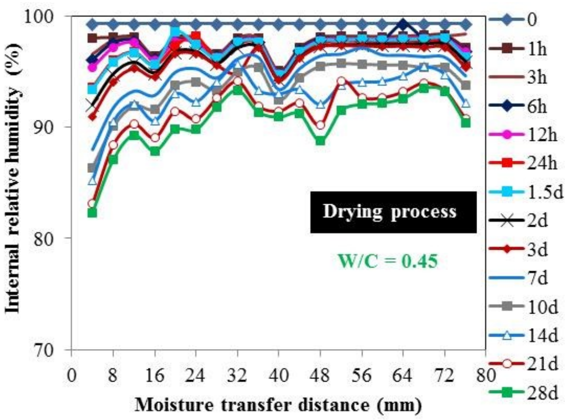

Fig.9 Moisture transfer in mortar specimen with W/C of 0.45 through drying process

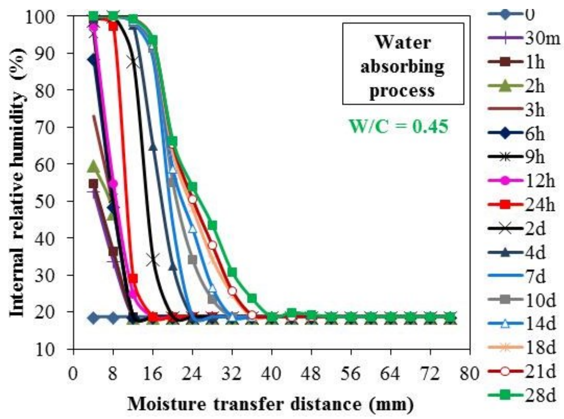

Fig.12 Moisture transfer in mortar specimen with W/C of 0.45 through water absorbing process

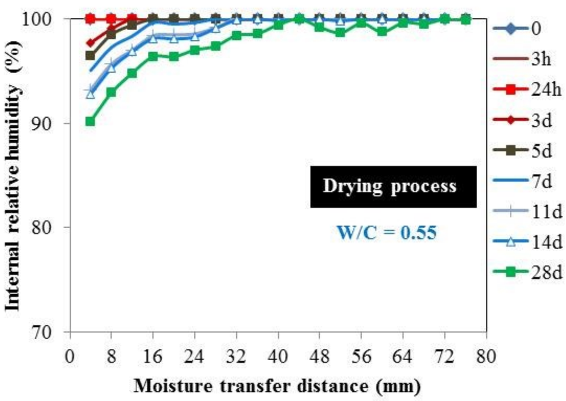

Fig.10 Moisture transfer in mortar specimen with W/C of 0.55 through drying process

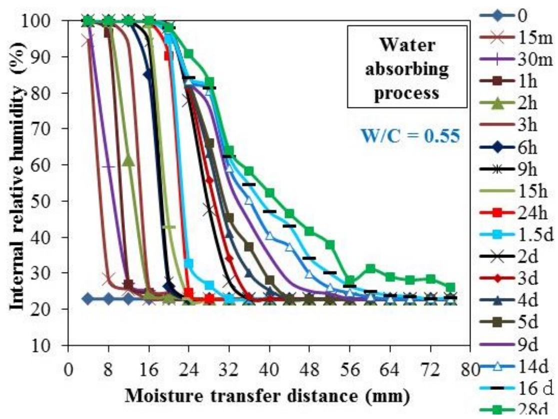

Fig.13 Moisture transfer in mortar specimen with W/C of 0.55 through water absorbing process

and internal relative humidity increased gradually due to the diffusion of water vapor. Therefore, on the assumption that internal relative humidity 1 day after starting of absorption was changed due to diffusions of water vapor, internal relative humidity was calculated according to Equation (9) where the diffusion coefficient was obtained from Fig. 13. As shown in Fig. 14, it can be seen that the measured and calculated values at 2d and later nearly matched. It indicates that the present method, which can assess the change in the distribution of internal relative humidity with time, can obtain the moisture transfer with considering the liquid penetration and diffusion of water vapor, while the conventional laboratory methods can only assess the movement of gas phase as a nonlinear diffusion. Briefly, the moisture transfer in specimens through the divided moisture transfer of the liquid phase-gas phase from the change in internal relative humidity with time could be considered in this study.

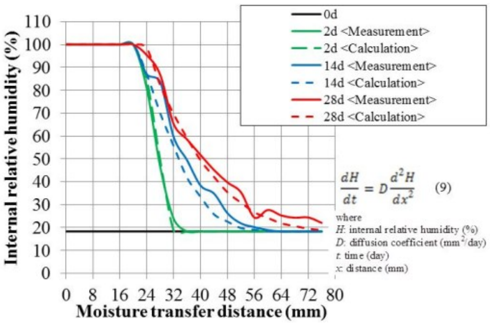

Fig.14 Analysis result of diffusion of water vapor for specimen with W/C of 0.55

4. CONCLUSIONS

(1) Electrical resistance measurement using stainless steel rods placed at intervals of 4 mm in the specimens could determine internal relative humidity through a negative correlation between electrical resistivity and internal relative humidity.

(2) Internal relative humidity of mortar specimens exposed to dry condition decreased gradually with time due to evaporation. For the specimens with low water to cement ratio, the internal relative humidity at the far-surface depth decreased significantly due to self-desiccation.

(3) Internal relative humidity of mortar with one surface exposed to water increased quickly at the near-surface depths in early times and slowly at the far-surface depths after 24h. It indicates that the initial change in internal relative humidity could be mainly caused by the penetration of liquid water into a limitation depth, and internal relative humidity increased gradually due to the diffusion of water vapor. In brief, the moisture transfer in specimens through the divided moisture transfer of the liquid phase-gas phase from the change in internal relative humidity with time could be considered in this study.

ACKNOWLEDGEMENT

The authors wish to thank Mr. Satoshi Fujioka, master student of Hiroshima University, for his help in doing some of the experiments.

REFERENCES

[1] Swamy, R. N., "Sustainable concrete for the 21st century concept of strength through durability," JSCE, Concrete Committee Newsletter, Vol. 13, 2008, 28 pages.

[2] Liu, P., Song, L. and Yu, Z., "Quantitative moisture model of interior concrete in structures exposed to natural weather," Constr. Build. Mater., Vol. 102, 2016, pp. 76-83.

[3] Enevoldsen, J. N., Hansson, C. M. and Hope, B. B., "The influence of internal relative humidity on the rate of corrosion of steel embedded in concrete and mortar," Cem. Concr, Res., Vol. 24, 1994, pp. 1373-1382.

[4] Chari, M. N., Shekarchi, M., Sobhani, J. and Chari, M. N., "The effect of temperature on the moisture transfer coefficient of cement-based mortars: an experimental investigation," Constr. Build. Mater., Vol. 102, 2016, pp. 306-317.

[5] Norris, A., Saafi, M. and Romine, P., "Temperature and moisture monitoring in concrete structures using embedded nanotechnology/microelectromechanical systems (MEMS) sensors," Constr. Build. Mater., Vol. 22, 2008, pp. 111-120.

[6] Baroghel-Bouny, M. M., Lassabatere, T. and Coussy, O., "Characterization and identification of equilibrium and transfer moisture properties of ordinary and high-performance cementitious materials," Cem. Concr. Res., Vol. 29, 1999, pp. 1225-1238.

[7] Kurumisawa, K. and Tanaka, K., "Three-dimensional visualization of pore structure in hardened cement paste by the gallium intrusion technique," Cem. Concr. Res., Vol. 36, 2006, pp. 330-336.

[8] Selih, J., Sousa, A. C. M. and Bremner, T. W., "Moisture transport in initially fully saturated concrete during drying," Transport in Porous Media, Vol. 24, 1996, pp. 81-106.

[9] Pacheco, J., Savija, B., Schlangen, E. and Polder, R. B., "Assessment of cracks in reinforced concrete by means of electrical resistance and image analysis," Constr. Build. Mater., Vol. 65, 2014, pp. 417-426.

[10] Polder, R. B., "Test methods for on site measurement of resistivity of concrete – a RILEM TC-154 technical recommendation," Constr. Build. Mater., Vol. 15, 2001, pp. 125-131.

[11] Osterminski, K., Polder, R. B. and Schiebl, P., "Long term behavior of the resistivity of concrete," HERON, Vol. 57, 2012, pp. 211-230.

[12] Polder, R. B. and Peelen, W. H. A., "Characterisation of chloride transport and reinforcement corrosion in concrete under cyclic wetting and drying by electrical resistivity," Cem. Concr. Compos., Vol. 24, 2002, pp. 427-435.

[13] Fujioka, S., Kawai, K., Nakarai, K. and Hayashi, A., "Measurement of moisture transfer using stainless steel in a water absorption process," Proc. of the 12th International Conference on Civil and Enviromental Engineering (ICCEE), 2013, pp. 222-224.

[14] Kashima, T., Kawano, H., Watanabe, H. and Tanaka, Y., "Fundamental study on electrical resistance for assessing durability of concrete", Proc. of JCI, Vol. 21, 1999, pp. 895-900.

[15] Kasai, Y. and Matsui, I., "Measuring moisture content using thin stainless steel rods," Proc. of JCI, Vol. 17, 1995, pp. 671-676.

[16] Maekawa, K., Ishida, T. and Kishi, T., "Multi-scale modeling of structural concrete," Taylor & Francis, 2009, p. 134.

[17] Krus, M., Hansen, K. K. and Kunzel, H. M., "Porosity and liquid absorption of cement paste," Mater. Struc., Vol. 30, 1997, pp. 394-398.