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MOISTURE MIGRATION AND DRYING PROPERTIES OF HARDENED CEMENT PASTE AND MORTAR

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1. INTRODUCTION

Moisture content and movement have a significant influence on mechanical properties of concrete. Therefore, many studies have been done on the migration or loss of water in concrete mostly without any external loads. Concrete in actual structures, however, is usually under stresses. As the microstructure of concrete is changed by the load, the observed moisture movement phenomena may be changed. Hence it is necessary to study the moisture migration in concrete under compressive stress in order to estimate rationally the mechanical behavior such as creep and shrinkage in actual concrete structures.

In this paper, the influence of compressive stress on moisture migration and water loss of hardened cement paste were studied experimentally and analytically. Furthermore, comparing them with the results of mortar specimens, the influence of containing aggregates was also discussed.

2. METHODS OF EXPERIMENTS

2.1 SPECIMENS AND MIX PROPORTION

In this experiment, thin wall cylindrical specimens of hardened cement paste with the thickness of about 1.0 mm, the outside diameter of 15 mm and the length of 100 mm were used to avoid hygral gradient in the section. In the case of mortar specimen, the length and the outside diameter were 100 mm and 20 mm, respectively. These specimens were manufactured with normal Portland cement paste and mortar of which water-cement ratio and sand-cement ratio were 0.4. To study the influence of containing aggregates, three ranges of sand diameter that were under 0.15mm, 0.25mm - 0.30mm and 0.40mm - 0.60 mm were used for mortar.

2.2 TEST SERIES

In this paper, two test series were carried out as follows:
[TEST-1] In order to study the influence of compressive stress or aggregate on water loss of the specimens, the process of water loss were measured. Fig. 1 shows the equipment for the test. The specimens were loaded in the range of 0 MPa and 11 MPa by screwing up the spring at the top of the equipment. Load cell was set at the bottom of the specimen to measure the stress, and loading levels were modulated at a certain intervals to cope with the relaxation caused by drying shrinkage and creep. The specimens were set in the chamber (20 C, 55% RH) and the water loss of specimens was measured by weighing the total mass of the specimen and the equipment.

[TEST-2] Water migration through the thin wall of the specimen loaded under different compressive stresses was studied. The specimens were dried until the moisture in the specimen reached at an equilibrium condition with the ambient air of the chamber. After the condition was obtained, a saturated chloride was arranged at the inside of specimens as shown in Fig.2. Then the specimens were set in the chamber and the weight change of saturated chloride with the specimen was measured.

In these tests, thin wall specimens of mortar were also tested to discussed the difference between hardened cement paste and mortar at the condition without any loads.

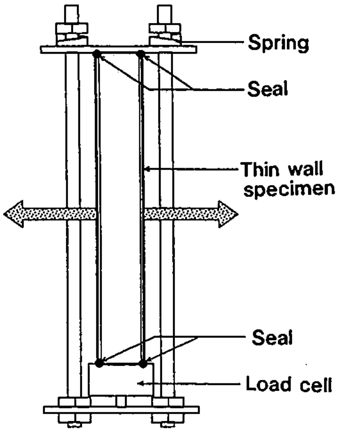

Fig.1 Test equipment of water loss

3. EXPERIMENTAL RESULTS AND DISCUSSION

As the results of TEST-1, Fig. 3 shows the water diffusion process of hardened cement paste during the drying test for each load levels, and Fig.4 shows the results of mortar specimens for each sand diameter range. In the case of specimen under compressive stress, the rate of water loss is higher than that of the unloaded specimen. Especially, this tendency becomes more clearly for the specimen loaded over 9.0 MPa. Furthermore, the total amount of water loss from the loaded specimen is slightly larger than that from the unloaded specimens.

Figs. 5 and 6 show the results of TEST-2. In these figures, moisture migration of hardened cement paste specimens for each stress level and of mortar specimens for each sand diameter are shown. To distinctly illustrate these results, Fig. 7 shows the relationship between compressive stress and rate of moisture migration which was calculated from the differential of the curves in Figs. 5 and 6.

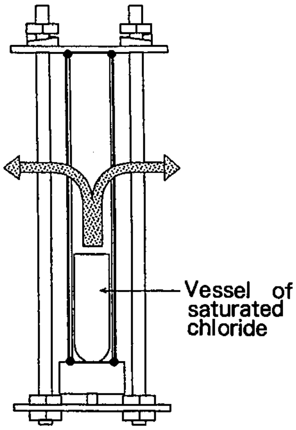

Fig.2 Test equipment of water migration

These results of TEST-1 and TEST-2 show that compressive stress have a significant influence on water loss and moisture migration in cement matrix. These tendencies are explained as follows: microstructures of the hardened cement paste were strained and water in the pores are squeezed out by the compressive stress. Accordingly, the higher the specimen is stressed, the more water the specimen loses at the early stage when the specimen contains sufficient water. This tendency becomes more clearly when the load is over 20% of compressive strength that was 46 MPa in this case. On the other hand, the moisture migration through the thin wall of specimens was reduced because the microstructure becomes more tight due to the compressive stress. However, microcracks caused by the stress may grow up when the compressive stress becomes over 20% of compressive strength. Since moisture migration takes a shortcut through these cracks, the rate of moisture migration increases at the stress levels over 9 MPa.

Figs.4 and 6 shows that water loss and moisture migration were accelerated by containing aggregates. Furthermore, the rate of water loss at the early stage of drying test becomes higher as the specimen contains larger aggregates. In the case of the moisture migration, this tendency slightly changes. Figs.6 and 7 show that the rate of the moisture migration of the specimen containing aggregates of 0.25 mm - 0.3 mm is lower than that of other two mortar specimens. Fig.8 shows the pore volume distribution and the

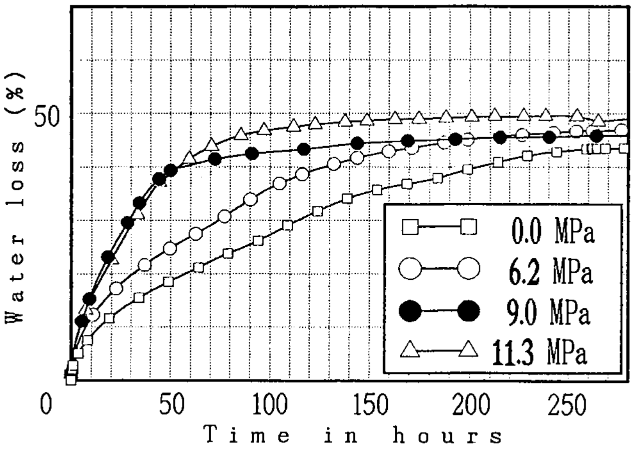

Fig.3 Water loss of paste specimen for each stress level

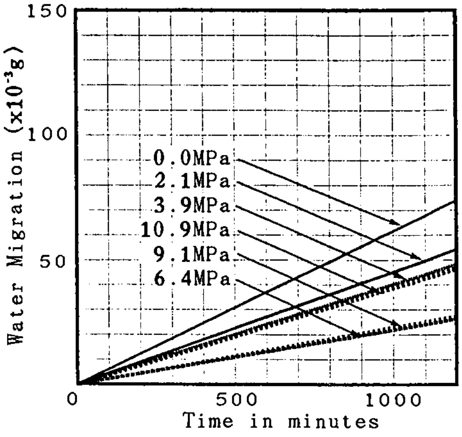

Fig.5 Moisture migration of paste specimen for each stress level

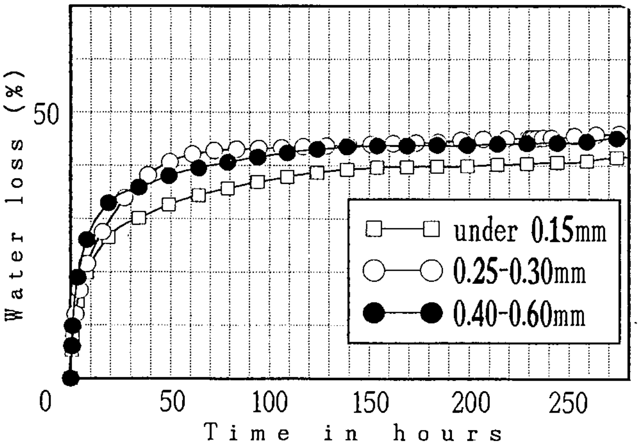

Fig.4 Water loss of mortar specimen for each diameter of aggregates

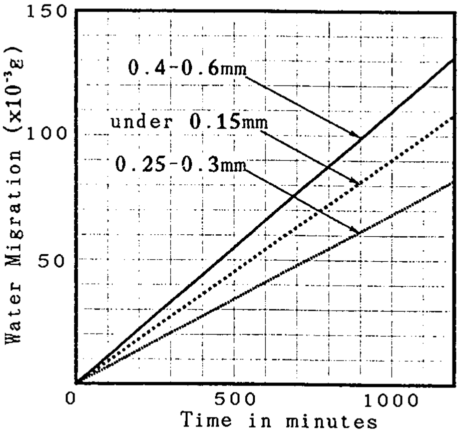

Fig.6 Moisture migration of mortar specimen for each diameter of aggregates

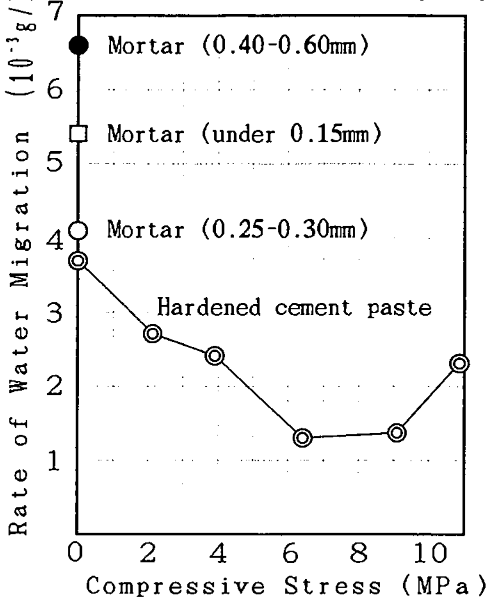

Fig.7 Compressive stress vs. rate of moisture migration

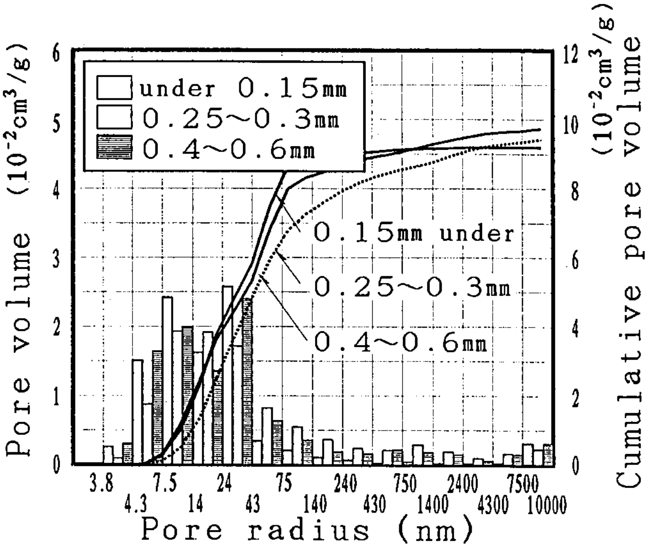

Fig.8 Pore volume distribution and cumulative pore volume of mortar specimen

cumulative pore volume of each mortar specimens measured by a mercury porosimeter. Although the total pore volume of the specimens becomes larger as the diameter of the aggregates increases, the cumulative pore volume of the specimen containing aggregates of 0.25 mm- 0.3 mm in the range of pore radius of 7.5 nm - 2400 nm is smaller than that of other specimens. It might be the reason why the rate of moisture migration of the specimen became lower than others.

4. METHOD OF NUMERICAL ANALYSIS

In this paper, a thin wall cylindrical specimen with infinite length as shown in Fig. 9 was analyzed on the assumption that the moisture movement in cement matrix is described as a changing process of pore humidity and that the moisture content is linearly related with the pore humidity. In this case the moisture diffusion process may be governed by the following equation.

$$\frac{\partial h}{\partial t} - \frac{1}{r} \cdot \frac{\partial}{\partial r} \cdot \left(D \cdot r \cdot \frac{\partial h}{\partial r} \right) = 0 \qquad (1)$$

The above equation is highly nonlinear because the diffusion coefficient is strongly dependent on pore humidity and temperature. The diffusion coefficient was assumed as the following function:

$$D(T, h) = D_1 \cdot f_1(h) \cdot f_2(T) \cdot f_3(T) \qquad (2)$$

$$f_1(h) = a_0 + (1 - a_0) \left(1 + \left\{ \frac{(1-h)}{1-hc)} \right\}^n \right)^{-1} \qquad (2.1)$$

$$f_2(T) = \left(\frac{T}{T_0} \right)^{n_{T1}} \exp \left\{ \frac{U}{R} \left(\frac{1}{T_0} - \frac{1}{T} \right) \right\} \qquad (2.2)$$

$$f_3(T) = \exp \left(\left\{ \frac{(T-273)}{90} \right\}^{n_{T2}} \right) \qquad (2.3)$$

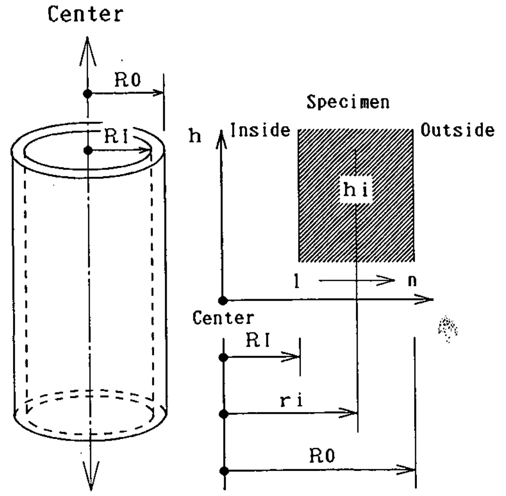

Fig.9 Model for analysis of water loss

where D_1 is the diffusivity in case of h = 1.0 at a reference temperature, T is absolute temperature, U is activation energy and R is the gas constant; T_0=293 K is the reference temperature; a_0,n, n_{T1}, n_{T2} are material constants.

In this test, function f_2 and f_3 which describe the effect of temperature is constant because the experiment was carried out at a constant temperature(20 C). Parameters involved in function f_1 which describes the effect of pore humidity on the diffusivity were discussed.

Furthermore, as the boundary condition of the moisture, a boundary layer with a constant thickness d was simply added to the inside and the outside surface of the cylindrical specimen.

In this analysis, experimental results of TEST-1 were chosen as objects for the analysis.

5. ANALYTICAL RESULTS AND DISCUSSIONS

Comparison of the calculated results with the experimental results is shown in Figs.10 and 11. Drying processes of thin wall specimens are shown in Fig.10 for two stress levels, 0 MPa and 11.3 MPa, of hardened cement paste specimens and in Fig.11 for two diameter types, under 0.15mm and 0.4 - 0.6mm of aggregates in mortar specimens, respectively. These figures show that calculated values agree well with the experimental values. As the results of data fitting, the parameters which constitutes the function f1 in equation (2.2), was obtained as shown in Table-1. Figs. 12 and 13 show clearly the relationship between pore humidity and diffusion coefficient ratio D/D_1.

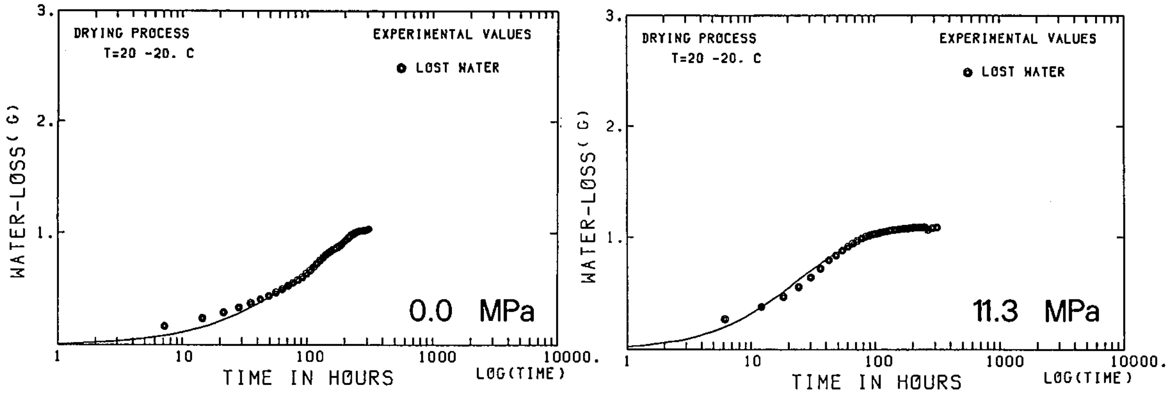

Fig.10 Drying process of paste specimen (0 MPa, 11.3 MPa)

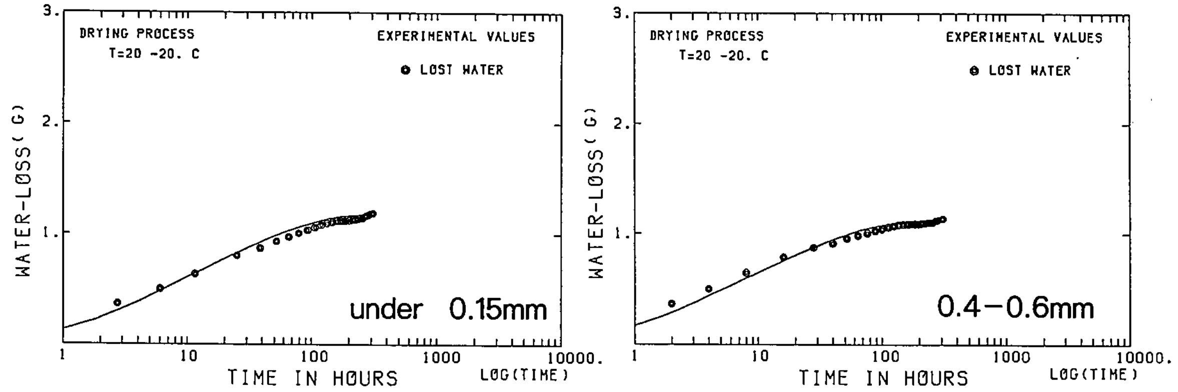

Fig.11 Drying process of mortar specimen (under 0.15mm, 0.4 - 0.6 mm)

Table 1. Analytical Results of Parameters

	Stress/ Diameter	D_1 ($\times 10^{-5} mm^2/s$)	a_0	hc	n	n_{T1}	n_{T2}	d
Hardened cement paste	0.0 MPa	5.00	0.03	0.88	6.0	3.0	1.0	0.55
	6.2 MPa	4.90	0.03	0.79	6.0	3.0	1.0	0.55
	9.0 MPa	0.95	0.03	0.59	6.0	3.0	1.0	0.55
	11.3 MPa	0.80	0.03	0.48	6.0	3.0	1.0	0.55
mortar	under 0.15 mm	5.30	0.03	0.77	6.0	3.0	1.0	0.55
	0.25-0.30 mm	6.50	0.03	0.75	6.0	3.0	1.0	0.55
	0.40-0.60 mm	7.00	0.03	0.75	6.0	3.0	1.0	0.55

Fig.12 shows that the point at which the diffusion coefficient abruptly decreases shifts to a range of lower humidity and the decreasing rate becomes more moderate as the stress increases, and that the diffusivity D_1 decreases as shown in Table 1. These tendency becomes more clearly when the compressive stress is over 9 MPa. These results are explain as follows: since the compressive stress squeezed out water from micropores and deforms the microstructures, the pore volume was reduced. Therefore the moisture condition in the pore may be not so much changed though the total pore humidity decreases apparently as the water loss progresses. For this reason, a rapid decreasing

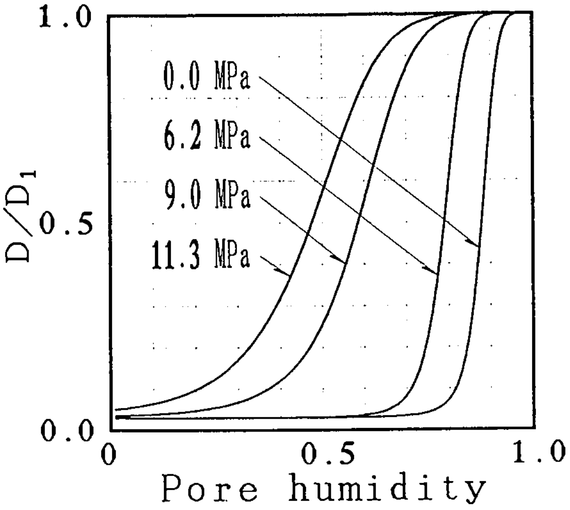

Fig.12 Pore humidity vs. D/D_1 of paste specimen

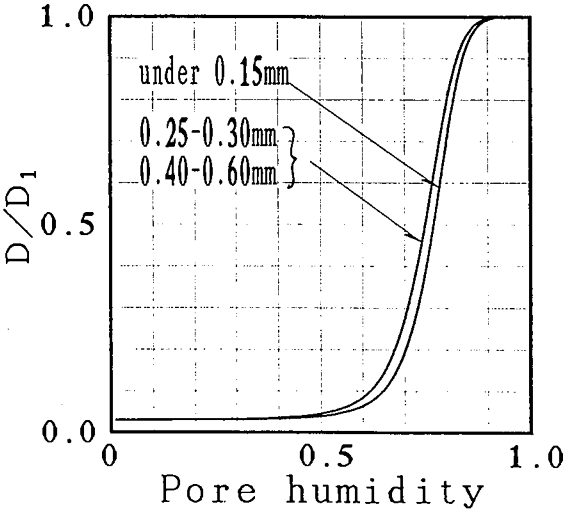

Fig.13 Pore humidity vs. D/D_1 of mortar specimen

point of diffusion coefficient shifts to a range of lower humidity and the decreasing rate becomes more moderate. Furthermore, the diffusivity D_1 decreases as the compressive stress increases because the microstructure becomes tight by the stress.

On the other hand, the diffusivity D_1 of mortar increases as the diameter of aggregates increases. This tendency indicates that aggregates have an influence on water loss and that water in the specimen loses more easily when larger aggregates were contained.

6. CONCLUSION

The following results were obtained in these experimental and analytical studies.

(1)Compressive stress and containing aggregates have significant influences on water loss and moisture migration in concrete.

(2)Since water in the cement matrix is squeezed out by the compressive stress, rate of water loss increases as the stress increases.

(3)Water loss and moisture migration were accelerated by containing aggregates. The larger aggregates contained in the specimen, the higher the rate of water loss and moisture migration become.

(4)The effects of the compressive stress and containing aggregates on these phenomena are also interpreted by the analytical studies.

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