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VOLUME CHANGE OF HIGH-STRENGTH CONCRETE IN MOIST CONDITIONS

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ABSTRACT

This paper reports results of length change over time of high-strength cement paste, mortar, and concrete in moist conditions. The effect of specimen size, water-to-cement ratio and type and size of aggregate on the water absorption and length change were also investigated. Water permeation depth was calculated based on the increase in mass of the specimen and on the theoretical chemical shrinkage.

Introduction

Autogenous volume change is defined as the macroscopic volume reduction that is not caused by evaporation or temperature change, but by self-desiccation due to chemical reactions. Until recently it was assumed that autogenous volume change of ordinary concrete is so small as to be ignored in the estimation and control of cracking (1). Recent research, however, has demonstrated that autogenous shrinkage of high-strength concrete can be quite large (2,3), and it should be considered in the control of cracking (4–7).

Experimental data have shown large decrease in length of cement paste specimens containing low water-to-cement ratio, when they were kept under water (3). The volume change of specimens kept under water can be affected by the moisture permeation from the exposed surfaces and by self-desiccation within the specimen. The study of the concrete volume change is more complex due to the presence of aggregates. This research reports results of length change over time of high-strength cement paste, mortar, and concrete in moist conditions. The effect of specimen size, water-to-cement ratio, and type and size of aggregate on the water absorption and length change were also investigated.

Experimental Procedure

The chemical composition and physical properties of ASTM type I portland cement used in this investigation are shown in Tables 1 and 2, respectively. The physical properties and the grading

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TABLE 1

Chemical Composition of Cement (%)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	R_2O	Total
22.12	4.07	3.40	63.86	2.05	2.41	0.28	0.51	0.61	99.73

of aggregates are shown in Table 3. Surface moisture of the fine aggregates ranged from 0.5 to 0.6%, and the coarse aggregate was in SSD condition. The aggregate volume fraction was 0.50 for all mortar and concrete mixtures and water-cementitious material ratio ranged from 0.23 and 0.30. A high-range water-reducing admixture(HRWRA) was used for mixtures with w/c = 0.30, and silica fume (sf) and HRWRA were used for mixtures with w/(c + sf) = 0.23. The HRWRA dosage was 2% by mass of the cementitious material for the 0.23 w/c mixtures and 0.25% by mass of the cement for the 0.3 w/c mixtures. The mortar and concrete mixture proportions are shown in Table 4.

After casting, the specimens were covered with plastic film and stored at 22°C in the fog room for 24 hours, after that they were demolded and stored in the fog room. Cement paste beams were cast in the following dimensions: 0.5 × 1.0 × 11 in. (13 × 25 × 279 mm), 1.0 × 1.0 × 11 in. (25 × 25 × 279 mm), 1.5 × 1.5 × 11 in. (38 × 38 × 279 mm), 3.0 × 3.0 × 11 in. (76 × 76 × 279 mm) and 4.0 × 4.0 × 11 in. (102 × 102 × 279 mm). Mortar and concrete beams had dimensions of 4.0 × 4.0 × 11 in. (102 × 102 × 279 mm). Both surfaces perpendicular to the axis of specimen were sealed to allow two-dimensional moisture flow into the specimen. Length and mass were measured at specific intervals up to 56 days.

Results and Discussions

Effect of Specimen Size. The 0.30 w/c cement paste specimens that were smaller than 1.5 × 1.5 × 11 in. (38 × 38 × 279 mm), increased in length continuously in moist conditions, while the larger specimens decreased in length during the first two weeks, as shown in Fig. 1. The larger specimens decreased in length as much as 140 × 10^{-6} linear strain and thereafter they gradually increased in volume. Due to the low permeability of the specimen, the curing water only permeated the surface layer of the specimens, while the inside of the specimen was subjected to self-desiccation. This explains the discrepancies in length changes that occur in different-sized specimens subjected to moist conditions.

It was observed that gain in mass occurred as the specimen absorbed water into capillary voids. Figure 2 shows the gain in mass for the cement paste samples. It is noted that the gain in mass decreased with increasing specimen size. The maximum gain in mass curve as a function of time can be theoretically estimated from the chemical equations of cement hydration (7,8). This curve is shown in Fig. 2. Assuming that the capillary pores were successively sat-

TABLE 2

Physical Properties of Cement

Blaine fineness (cm^2/g)	Compressive strength (MPa)			
	1 day	3 days	7 days	28 days
3524	10.4	19.9	27.6	39.4

TABLE 3

Physical Properties and Grading of Aggregate

	River sand	Gravel	Crushed diabase	Crushed limestone
Specific gravity	2.67	2.69	2.84	2.71
Absorption (%)	1.2	1.3	1.5	0.4
	Cumulative percent retained (%)			
25.0 mm(1 in)	0	0	0	0
19.0 mm(3/4 in)	0	19	8	15
12.5 mm(1/2 in)	0	65	57	75
9.5 mm(3/5 in)	0	85	94	93
4.75 mm(No.4)	1	99	99	100
2.36 mm(No.8)	20	100	100	100
1.18 mm(No.16)	45	-	-	-
600 μm(No.30)	65	-	-	-
300 μm(No.50)	84	-	-	-
150 μm(No.100)	94	-	-	-
75 μm(No.200)	98	-	-	-
Fineness Modulus	3.09	7.03	7.02	7.07

urated from the surface layer as the curing water permeated, the average thickness of absorbed water can be calculated from both observed and theoretical gain in mass. The calculated thickness of absorbed water is shown in Fig. 3. The thickness increases with the specimen size for the smaller specimens, but it does not increase significantly for the larger specimens. The ratio of observed gain in mass to the theoretical one is also shown in Fig. 3. This value decreases with the specimen size. This suggests that degree of self-desiccation increases with specimen size.

As shown in Fig. 4, the ratio of observed gain in mass to the theoretical one and the strain of the specimen have a well-defined relationship, with decrease in length occurring if the ratio is less than 0.5. This relationship is different for different mixtures.

Effect of Aggregate. The permeability of concrete depends not only on the permeability of the cement paste and of the aggregate, but also on the characteristics of the transition zone between the aggregate and the cement paste. The gain in mass of mortar and concrete per unit cement paste content is larger than that of cement paste itself, as shown in Figs. 5 and 6. This suggests that the permeability of transition zone is larger than that of bulk cement paste. Gain in mass of mortar is less than that of the 0.23 w/c concrete, suggesting that permeability of transition

TABLE 4

Mixture Proportion of Mortar and Concrete

	W/C	Mass, kg/m^3					HRWRA (g/m^3)
		W	C	SF	S	G	
Concrete	0.23	205	802	89	401	942-994	17,800
Mortar	0.23	205	802	89	1335	0	17,800
Concrete	0.30	243	810	0	401	942-994	2,000
Mortar	0.30	243	810	0	1335	0	2,000

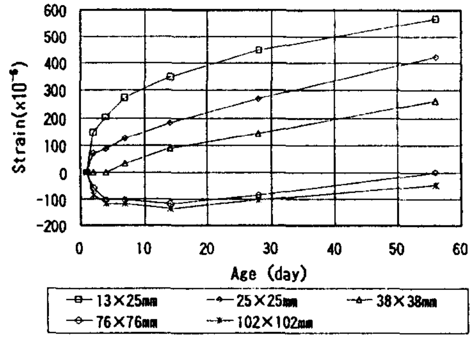

FIG. 1.
Length change of cement paste (w/c = 0.30).

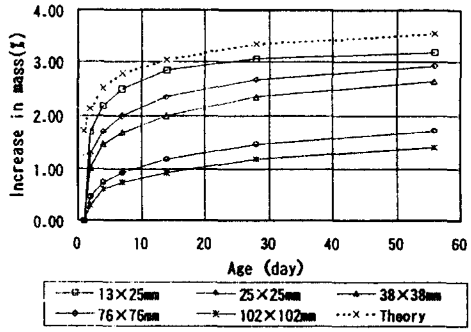

FIG. 2.
Gain in mass of cement paste (w/c = 0.30).

zone increases with increasing aggregate size. This difference did not occur for the specimens with a 0.30 water-cement ratio.

Decrease in length was observed in high-strength concretes in moist conditions, as shown in Figs. 7 and 8. The decrease in length of 0.23 w/c concrete was larger than that of the 0.30 w/c concrete. The maximum decrease in length observed for the 4 × 4 × 11 in. (102 × 102 × 279 mm) specimen was 80 × 10^{-6} for the 0.30 w/c concrete samples and 150 × 10^{-6} for the 0.23 w/c concrete samples. The 0.30 w/c concrete samples decreased in length during the first two weeks, then increased in length; while for the 0.23 w/c concrete samples, minimal length increase occurred during the 2-months testing period. Decrease in length of mortar and concretes was lower than that of the cement paste for the 0.30 w/c mixture, but the result was different for the 0.23 w/c mixture. This suggests that the influence of aggregate on the length change of the specimen in moist conditions is different for different mixtures.

In moist conditions, concrete containing 20-mm coarse aggregate decreased in length more than mortar with the same aggregate volume fraction, as shown in Figs. 7 and 8, suggesting that self-desiccation may not occur uniformly in the cement paste matrix. Concrete containing gravel decrease in length more than those containing crushed aggregate. Characteristics of the transition zone may be influenced by the type of aggregate (9), therefore the permeability and the

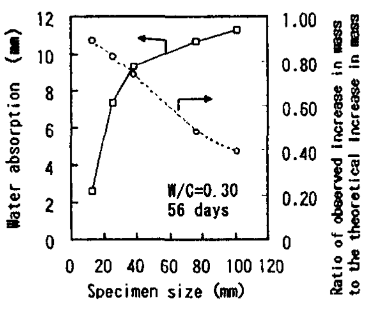

FIG. 3.
Water absorption in cement paste (w/c = 0.30).

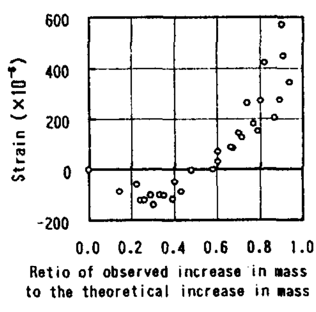

FIG. 4.
Water absorption and strain of cement paste specimen (w/c = 0.30).

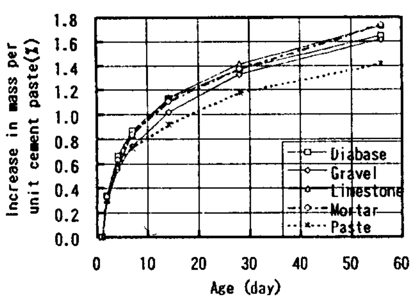

FIG. 5.
Gain in mass of specimens in moist conditions (w/c = 0.30).

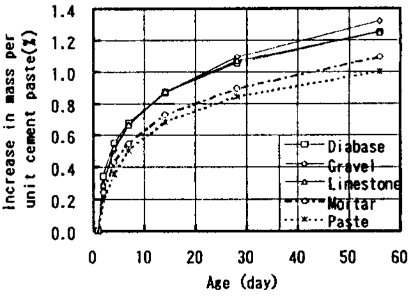

FIG. 6.
Gain in mass of specimens in moist conditions (w/c = 0.23).

restraining effect may be different for different aggregate types. These experimental results show that various factors have influence on the length change of high-strength concrete in moist conditions.

Concluding Remarks

The experimental results indicate that increase in volume occurred in small cement paste specimens in moist conditions while larger specimens decreased in volume during the first two weeks of testing. Because the curing water can only permeate the surface layer of the specimen, the inside of the specimen is subjected to self-desiccation, thus leading to a size effect in the prediction of length change.

High-strength concrete samples in moist conditions had a higher decrease in volume than the mortar samples containing the same aggregate volume fraction. This difference is attributed to the higher porosity in the transition zone between the aggregate and cement paste. The self-stress caused by restrained autogenous volume change can be large, and should be taken into account when designing high-strength concrete structures.

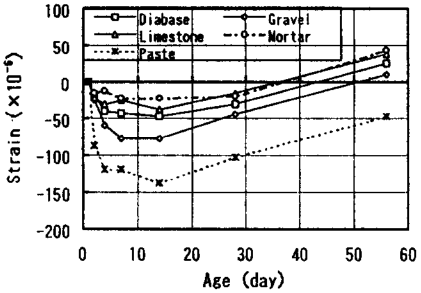

FIG. 7.
Length change of specimens in moist conditions (w/c = 0.30).

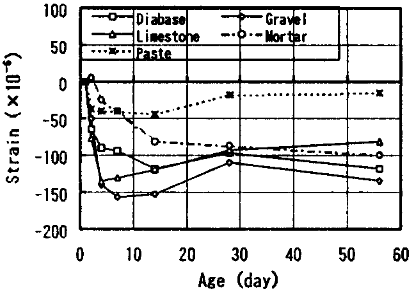

FIG. 8.
Length change of specimens in moist conditions (w/c = 0.23).

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