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EXPERIMENTAL STUDY ON MECHANISM OF AUTOGENOUS SHRINKAGE OF CONCRETE

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ABSTRACT

It was proved that autogenous shrinkage of high-strength concrete could be almost the same as drying shrinkage. For cement paste with low water-cement ratio, shrinkage was observed even in water. Existing composite low evaluated well the restraining effect of aggregate on autogenous shrinkage. Moisture movement caused by capillary condensation was thought to be the cause of flexural strength reduction for sealed specimens.

Foreword

A series of studies on autogenous shrinkage of concrete has been made in our laboratory for the past five years. In this study, some experimental results suggesting the mechanism of autogenous shrinkage are described. From this point of view, effect of aggregate on autogenous shrinkage, the relation between autogenous shrinkage and drying shrinkage, shrinkage of underwater specimens and self stress due to autogenous shrinkage are discussed.

Experimental Procedures

Autogenous shrinkage (20°C) and drying shrinkage (20°C,50%R.H.) of concrete were measured by contact chip method. Volume change under water was also measured for cement paste with different W/C and specimen size. Moisture distribution of sealed cement paste was estimated from electric resistance measurement(100kHz, 1.6V). Self stress on the surface of specimens was predicted by measuring strain due to relieving self stress. Details of experimental procedures were described in the published papers(1,2,3).

Results and Discussions

Effect of aggregate on autogenous shrinkage

Inclusion of aggregate leads to a reduction in autogenous shrinkage, as in the case of drying shrinkage. This is due to the reduction in the cement paste content and to the elastic deformation of aggregate, which partly confines the shrinkage deformation of the paste as such. By assuming a model, these effects can be estimated by a composite rule mathematically. A variety of models have conventionally been proposed. All of these models are confirmed to lead to nearly the same calculated values regarding drying shrinkage(4).

The data of autogenous shrinkage of mortar and concrete containing several types of aggregates with different moduli of elasticity at different volume concentrations(1) is presented as Fig.1. Hobbs's composite rule(4) proposed for drying shrinkage is thus found to be applicable when estimating autogenous shrinkage of concrete (ε_c) from that of paste (ε_p). The broken line in the figure indicates Hobbs' prediction values. The dotted line and the solid lines express the prediction values by the serial and parallel models, respectively. They provide the upper and the lower limits of estimation values, when the modulus of elasticity of the aggregate (E_a) is greater than that of the paste (E_p).

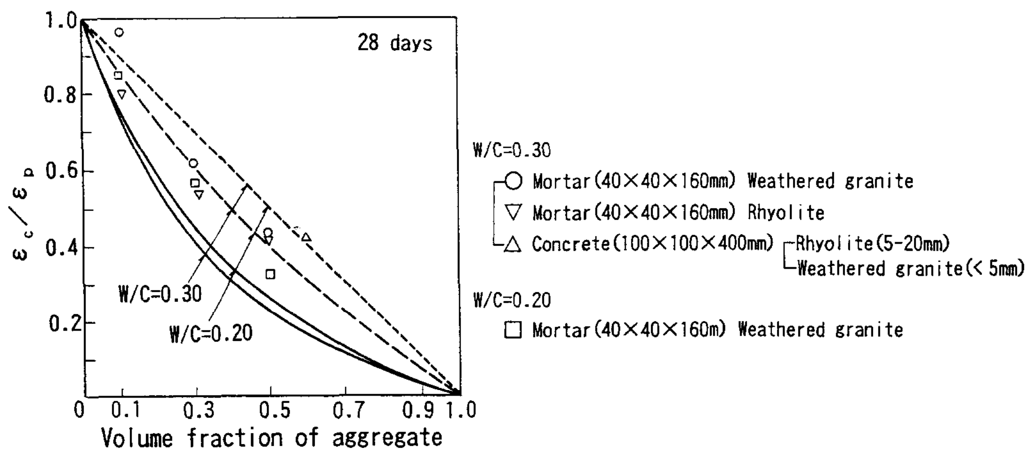

FIG.1
Influence of aggregate concentration on autogenous shrinkage

Relationship between autogenous shrinkage and drying shrinkage

Drying shrinkage and autogenous shrinkage of concretes with extremely low water-cement ratios are nearly the same. In other words, the shrinkage that has been regarded as the result of drying actually occurs independently of drying. Meanwhile, the weight does reduce, indicating that drying does not cause the shrinkage of such concretes with very low W/C. Though the difference between drying shrinkage and autogenous shrinkage increases as the water-cement ratio increases, autogenous shrinkage does not become zero.

As shown in Fig. 2, the autogenous shrinkage accounts for 50% and 40% of the shrinkage of concretes with W/C at 30% and 40%, respectively. For 17% of W/C, the autogenous shrinkage accounts for 100% of length change at constant temperature and has no virtual difference from drying shrinkage(2). Data plotted in Fig. 2 are taken from gauges buried in the center of concrete beams 10 x 10 x 120 cm in size. Comparison of the percentages of the stresses due to autogenous and drying shrinkages when confined by reinforcing bars leads to similar results.

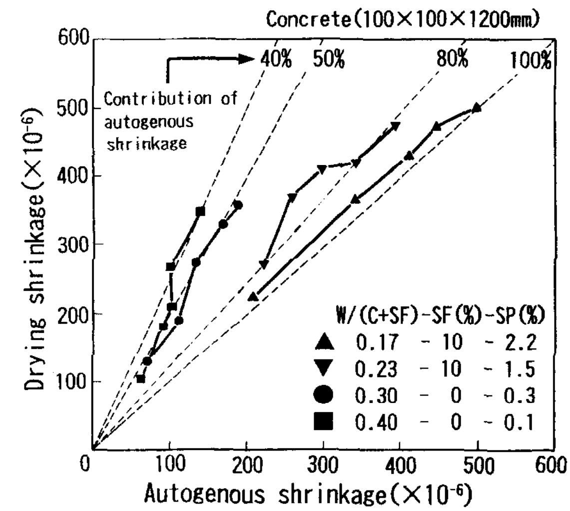

FIG.2
Relation between W/C and contribution of autogenous shrinkage

Autogenous shrinkage of hardened cement occurring underwater

The underwater changes in weight and length of cement specimens 4 x 4 x 16 cm in size and with W/C at 17–30% is shown in Fig.3, those of cement specimens of different sizes with W/C

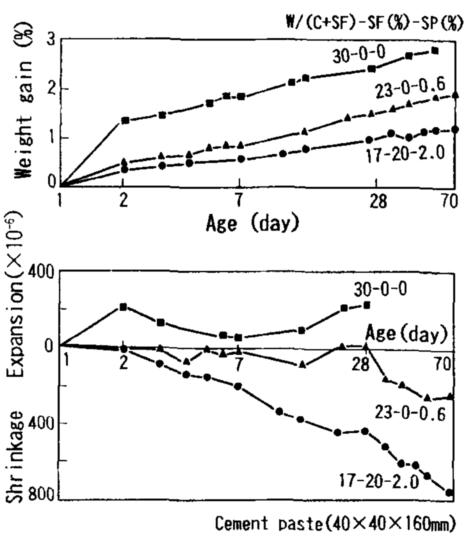

FIG.3
Absorption and length change under water(Effect of W/C)

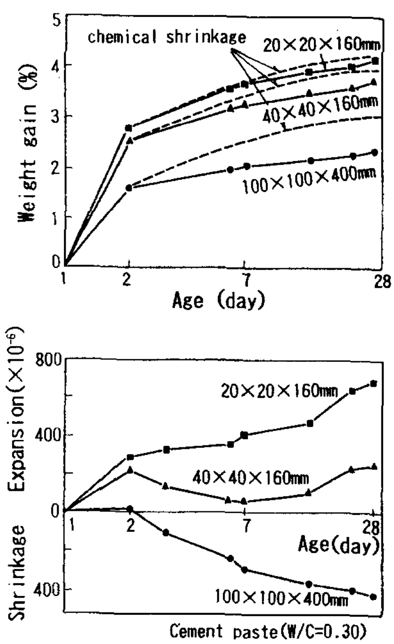

FIG.4
Absorption and length change under water (Effect of specimen size)

at 30% is shown in Fig.4. The paste with 17% of W/C in Fig. 3 as well as the 10 x 10 x 40 cm specimen in Fig. 4 show shrinkage underwater while their weights increase. These are considered to exhibit the same phenomenon resulting from the internal autogenous shrinkage exceeding the expansion due to the water absorption near the surfaces(3). All voids including those produced by chemical shrinkage are filled with water near the surfaces. The internal distribution of the water content, however, is supposed to be as shown in Fig. 5, due to the internal self-desiccation and also due to the inward transfer of capillary water(5).

Autogenous drying near the surfaces during seal curing

The water content distribution as shown in Fig. 5 has been confirmed by several sets of data measured on seal-cured specimens. References 6 and 7 give the data of directly measured capillary water content of samples taken from the surfaces and centers of specimens. The capillary water content is determined from the weight reductions of the samples ground in advance when they are dried to a constant weight in a room at 20°C and 50% R.H. According to this data, the capillary water content near the surfaces is reduced to approximately 40% of that near the center.

Another measurement example is shown in Fig. 6. Cement paste is placed between 2 polyethylene plates and two sides and the bottom were sealed, and top surface was either sealed or dried. The electrical resistance of the cement changes as shown in the figure, revealing that self-desiccation is occurring in the periphery portion of the specimen(8).

Flexural strength loss due to self-desiccation

Due to the self-desiccation near the surfaces as described above, autogenous shrinkage may slant along the cross-section. Reductions in flexural strength of specimens were observed even during seal curing(9).

The self-strain of the specimens in which the surface strain is partly relieved by notches is observed either as compressive strain, when the expansion due to water absorption is confined, or as tensile strain, when the autogenous shrinkage is internally confined near the surfaces (Fig. 7(6).

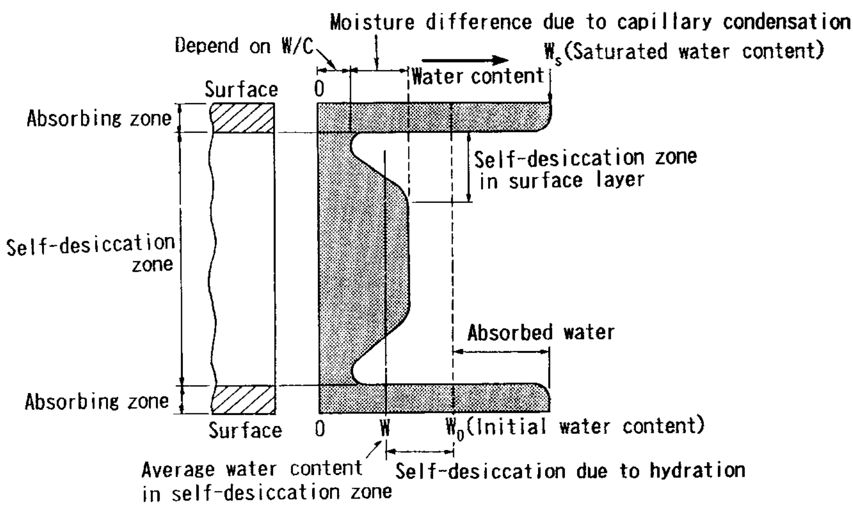

FIG.5
Moisture distribution of underwater specimen

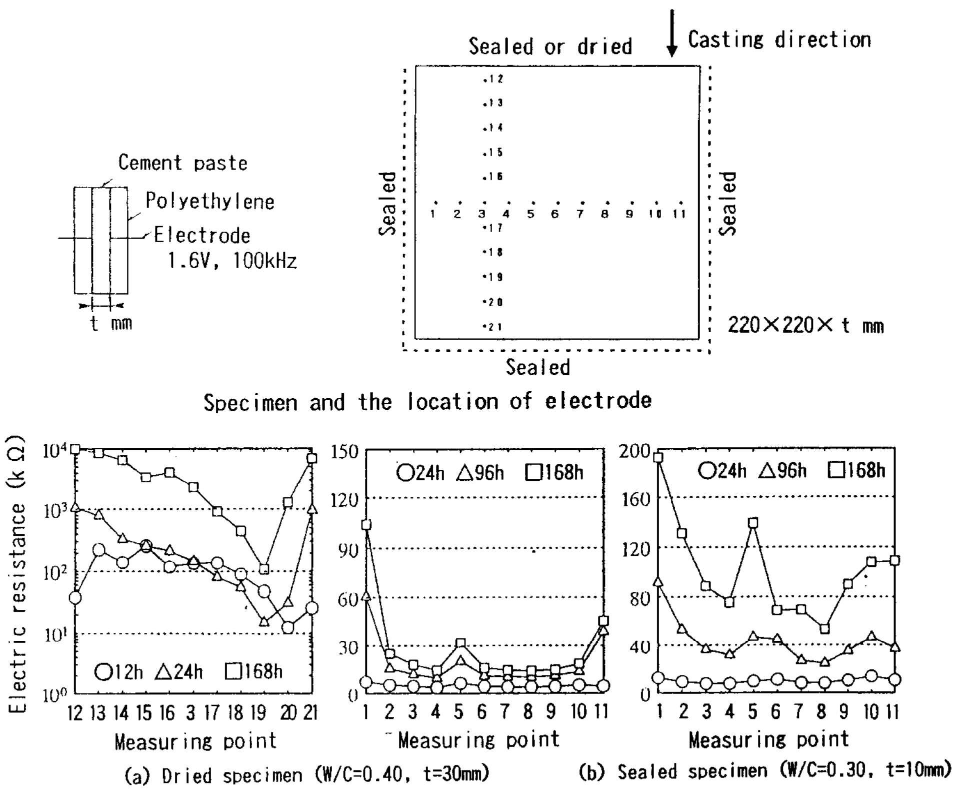

FIG.6
Electric resistance of cement paste

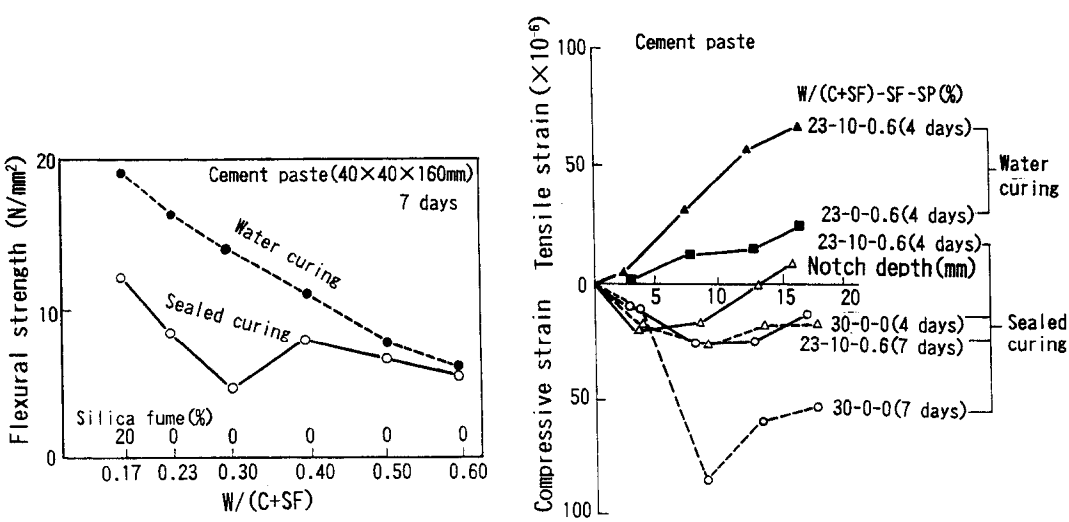

FIG.7
Flexural strength and self strain of sealed and underwater specimens

Size effects of autogenous shrinkage

Size effects do not seem to be negligible on autogenous shrinkage as well(7). The effects are appreciable not only with the water-cured specimens described above, but also with the specimens sealed immediately after placing(10). In addition, the values obtained from several experiments show a lack of consistency. This phenomenon may not be independent to the complexity related to the continuity of capillary water.

It is conceivable that a very low water-cement ratio tends to lead to discontinuous capillary water. This is, however, a problem of balance between the volume of water transferred by capillary tension and the absolute volume shrinkage due to hydration. A number of factors affect as regard to the estimation when and where the capillary water is discontinued under what conditions. This may be one of the problems to be solved in the future.

Concluding Remarks

The beginning of autogenous shrinkage becomes earlier as W/C decreases. Meanwhile the cracks due to thermal stress and plastic shrinkage can hardly be independent of autogenous shrinkage. It is hoped that these problems will be clarified by future study on autogenous shrinkage.

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