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INFLUENCE OF CEMENT AND ADMIXTURE ON AUTOGENOUS SHRINKAGE OF CEMENT PASTE

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ABSTRACT

It has recently been proved that autogenous shrinkage is considerably large for high-strength concrete. In this study influences of cement, chemical admixture, mineral admixture and water-cement ratio on autogenous shrinkage of cement paste were experimentally studied. It was proved that autogenous shrinkage could be estimated form mineral composition of cement. Some admixtures which were able to reduce autogenous shrinkage were found.

Foreword

Autogenous shrinkage is a phenomenon in which cementitious materials shrink at a constant temperature without any change in weight. This phenomenon has long been known as "autogenous volume change" according to wording introduced by H. E. Davis(1). More than 50 years ago, Davis assumed that autogenous volume change would be of great importance for dam concrete, and conducted measurements thereof over an extended period. He reached the conclusion that the autogenous shrinkage of dam concrete is no greater than 50 to 100 x 10^{-6}. Since then, few detailed investigations have been conducted into this subject. The main reason why the autogenous shrinkage was so small is attributable to the large water-cement ratio of concrete at that age. Recent studies have revealed that, in contrast to drying shrinkage, autogenous shrinkage increases as the water-cement ratio decreases and the microstructure of cement becomes denser(2). It therefore becomes more and more significant when higher strength is imparted to concrete by using superplasticizers and silica fume.

Experimental Procedure

Measurement of autogenous shrinkage is basically the same as that of drying shrinkage. The specimens are simply marked and the distances between the marks are measured from time to time. The only difference is that the weight of the specimens for measuring autogenous shrinkage is maintained constant after cement paste is placed in the molds. The method adopted here for this purpose is: [1] to wrap molds sealed with plastic film in a damp cloth up to an age of 24 hr and [2] to seal the specimens with aluminum adhesive tape and seal the joints of marks etc.

with buthyl rubber after demolding at 24 hr. Since autogenous shrinkage may occur immediately after setting, measuring should be commenced at a very early age. Here the author uses foamed polystyrene molds that allow no water absorption, to reduce the rigidity of molds, thereby avoiding restraint of deformation caused by the molds.

Results and Discussions

Effects of water-cement ratio

The absolute amount of autogenous shrinkage tends to increase, and the shrinkage tends to start at earlier ages, as the water-cement ratio decreases. Fig. 1 shows the autogenous shrinkage of ordinary portland cement with the water-cement ratio ranging from 17% to 40%. The symbols denote (type of cement)-(W/C)-(percentage substituted by silica fume)-(superplasticizer dosage)(3). For 17% of W/C, the autogenous shrinkages at 1 day and 14 days are 2500 x 10^{-6} and 4000 x 10^{-6}, respectively, which are fairly large.

Effects of the type of cement

The comparison of the data is shown in Fig. 2 for 30% of W/C. Alumina cement and high-early-strength cement exhibit large early autogenous shrinkage and lead to large ultimate shrinkage. On the other hand, moderate-heat cement and belite-type low-heat cement show small autogenous shrinkage. Blast-furnace slag cement shows large autogenous shrinkage over

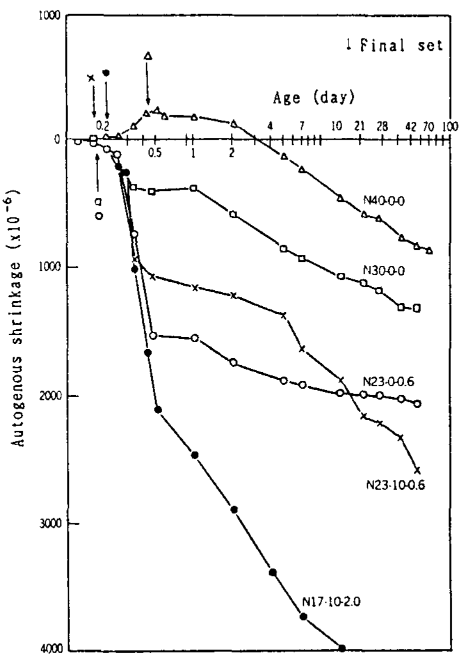

FIG.1
Influence of W/C on autogenous shrinkage

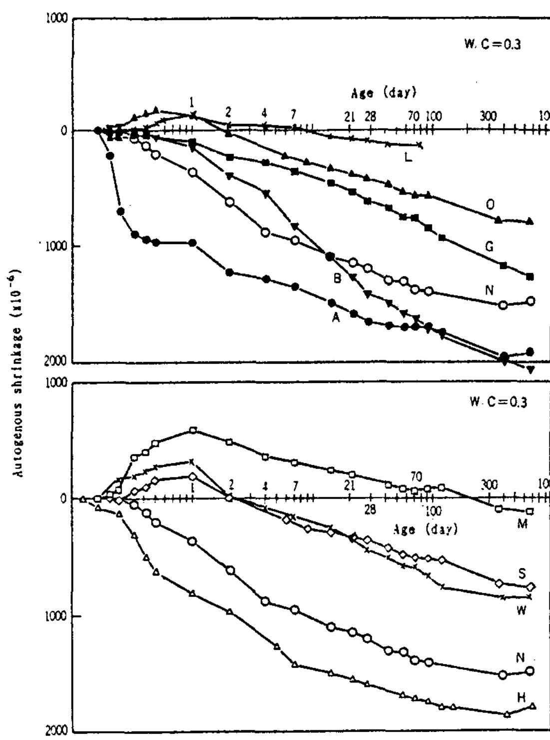

FIG.2
Influence of cement on autogenous shrinkge

a long period. The hardening shrinkages of these cements fall in the range of 8–11% at 28 days, with the exception of 15% plus for alumina cement.

Effects of mineral composition of cement

The mineral compositions of the cements are calculated from the chemical compositions by the Bogue method. Eq. 1 is obtained by multiple regression of these compositions with the autogenous shrinkage measured for respective cements at respective ages. The origin of measuring the autogenous shrinkage is the age at 1 day.

$$\varepsilon_{as}(t) = -0.012\alpha C_3S(t)(\%C_3S) - 0.070\alpha C_2S(t)(\%C_2S) + 2.256\alpha C_3A(t)(\%C_3A) + 0.859\alpha C_4AF(t)(\%C_4AF) \quad \cdots\cdots (1)$$

where $\varepsilon_{as}(t)$ = autogenous shrinkage at age t
$\alpha(t)$ = degree of hydration of mineral at age t
$(\%C_3S)$ = C_3S content, and so forth

The values predicted by Eq. 1 and the measured values are plotted in Fig. 3, showing a close correspondence between them(3). As is obvious from Eq. 1, the absolute values of the coefficients for C_3S and C_2S are as small as 1/10–1/20 of those for C_3A and C_4AF, and have opposite signs. This suggests that autogenous shrinkage greatly depends on the contents and degree of hydration of C_3A and C_4AF.

Effects of mineral admixtures

The autogenous shrinkage of ordinary portland cement containing blast–furnace slag with a fineness of 5680 cm^2/g is shown in Fig.4. The autogenous shrinkage increases as the percentage of cement substituted by slag increases up to 90%. High percentages of substitution lead to large increases in autogenous shrinkage at later ages.

The autogenous shrinkages of portland cement, 10% of which are substituted by 4 types of

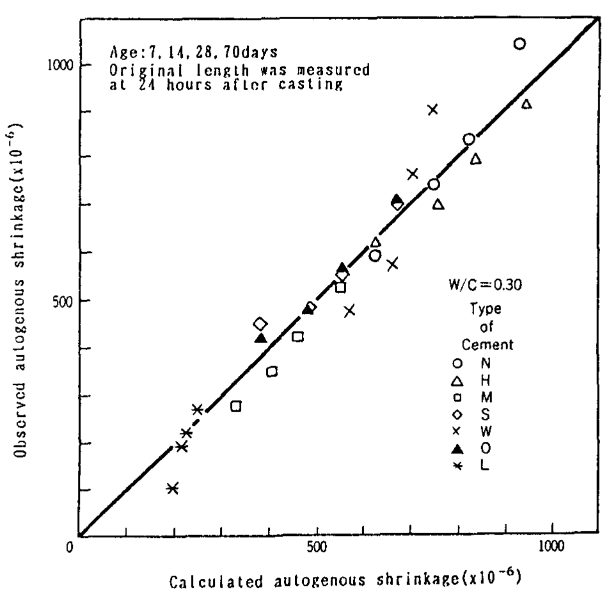

FIG.3
Comparison between calculated and observed autogenous shrinkage

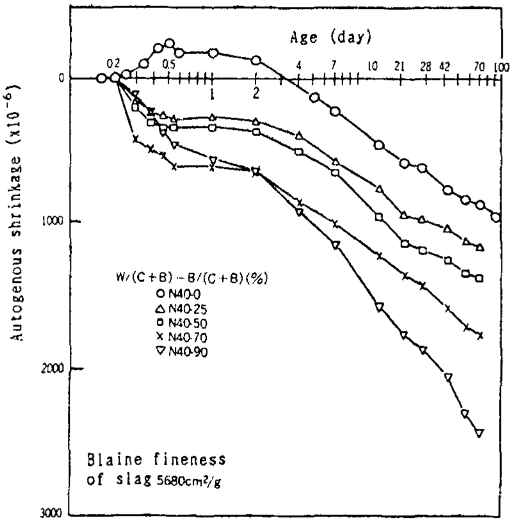

FIG.4
Influence of blast furnace slag on autogenous shrinkage

commercial expansive agent, is shown in Fig.5. W/C is 30%. Autogenous shrinkage is also observed with cements containing an expansive agent. Shrinkage occurs even when no drying occurs. A calcarious type agent E_3, leads to small autogenous shrinkage.

Inclusion of silica fume causes an increase in autogenous shrinkage (Fig. 6). The cement is ordinary portland cement, and the superplasticizer is a naphthalene derivative. Autogenous shrinkage increases as W/C decreases, but this phenomenon has limits. Silica fume causes this W/C range of increasing the shrinkage to extend. As seen from the figure, the autogenous shrinkage shows increases even with W/C at 23%.

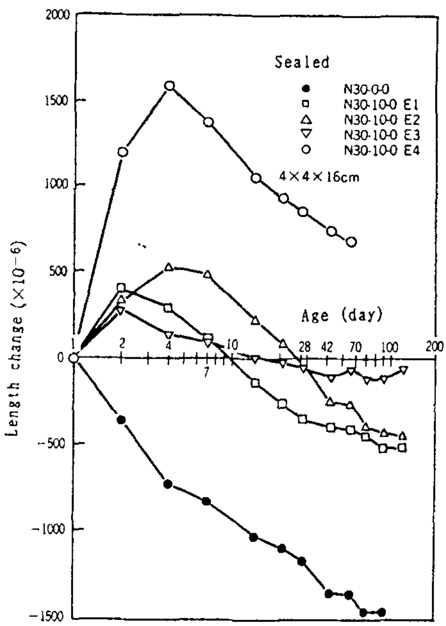

FIG.5
Influence of expansive admixture

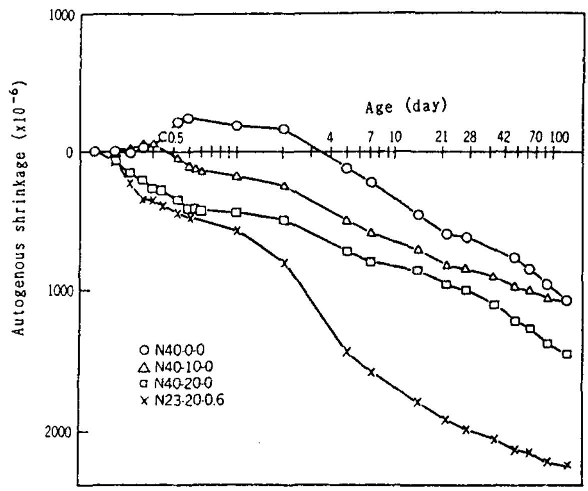

FIG.6
Influence of silica fume

When part of cement is substituted by a water repellent–treated powder, the autogenous shrinkage drastically decreases. The effects of water repellent–treated metakaolin and siliceous powder are shown in Fig. 7 (a) and (b), respectively. Whereas metakaolin's effect of reducing autogenous shrinkage diminishes at later ages, siliceous powder sustains the effect for longer periods. A content of about 10% is sufficient for the effect. These effects may be attributable to the increased contact angle between the solid phase and pore water, which reduces the negative pressure in pore water.

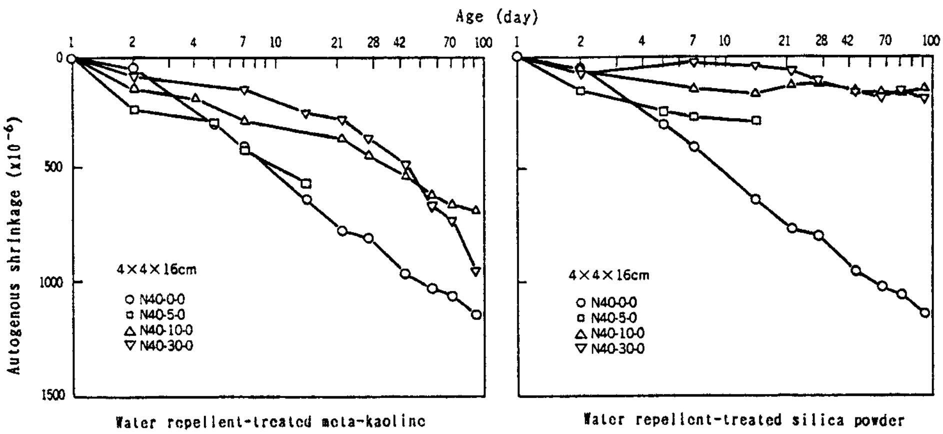

FIG.7
Influence of water repellent–treated powder on autogenous shrinkage

Effects of chemical admixtures

The results of using 5 types of superplasticizers are shown in Fig. 8. The effects of the type of the superplasticizers(4) and the effects of the dosage of SP(5) are shown in (a) and (b), respectively. Autogenous shrinkage is slightly reduced by superplasticizers, but the differences by the type of superplasticizer are small. The effects of the dosage are also small. These reductions in the shrinkage may be due to the slight effects of superplasticizers on the rate of hydration.

Drying shrinkage inhibitors are also effective in reducing autogenous shrinkage (Fig. 9). This suggests that the mechanism of autogenous shrinkage is essentially identical to that of drying shrinkage. Measurements of the surface tension of an aqueous solution of the alkylene oxide type (D_2) revealed that the percentage of decrease in the autogenous shrinkage nearly corresponds to the percentage of decrease in the surface tension.

Effects of fineness

The autogenous shrinkage of cements with Blaine finenesses of 3390–7430 cm^2/g is shown in Fig.10. Finer grain of cement leads to greater shrinkage starting at an earlier age. A cement with a fineness of 5570 cm^2/g or higher undergoes an autogenous shrinkage of 1000 to 1200 x 10^{-6} at an age of 24 hr.

Fineness of blast–furnace slag also affects the autogenous shrinkage (Fig. 11). When the Blaine fineness of the slag is 4000 cm^2/g or higher, the autogenous shrinkage of cement containing the slag at 120 days increases with the percentage of substitution up to 70%, whereas it does not increase when a slag with a Blaine fineness of 3000 cm^2/g is used(6).

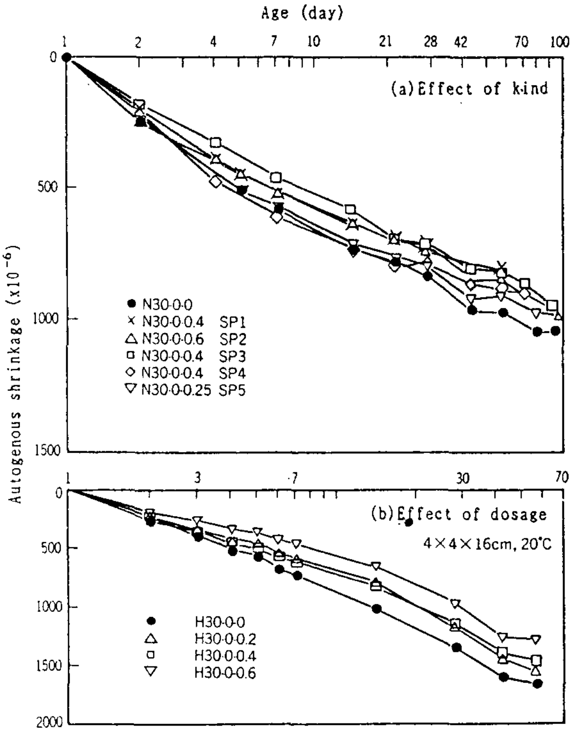

FIG.8
Influence of superplasticizer

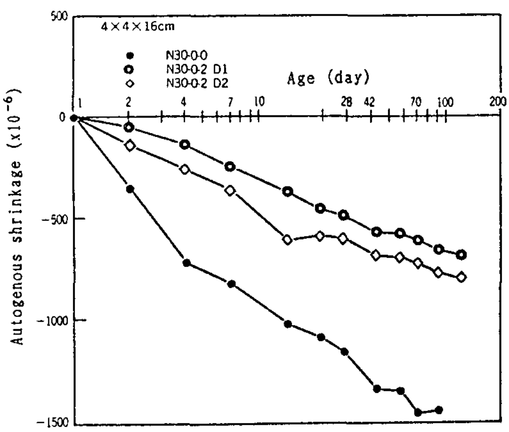

FIG.9
Influence of drying shrinkage inhibitors

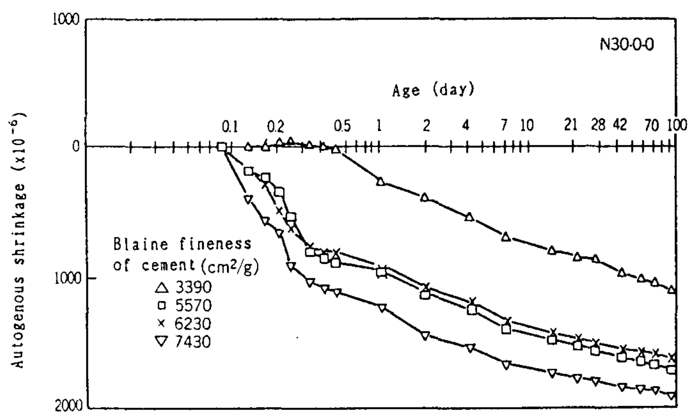

FIG.10
Influence of fineness of portland cement

Concluding Remarks

Autogenous shrinkage has been introduced here, mainly regarding the phenomenology based on experimental data. The simple fact that autogenous shrinkage increases as W/C decreases indicates that it is a phenomenon totally different from drying shrinkage. Part of normal drying shrinkage is understood as autogenous shrinkage.

Though autogenous shrinkage is directly triggered by hydration, it is not correlated with the amount of hardening shrinkage at all. As pointed out above, it seems to be strongly related with the hydration of aluminate phase. This is quite suggestive. In this connection, it should be remembered that the importance of C_3A was pointed out with regard to the amount of drying shrinkage(7,8). The beginning of autogenous shrinkage becomes earlier as W/C decreases. Mean while, 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.

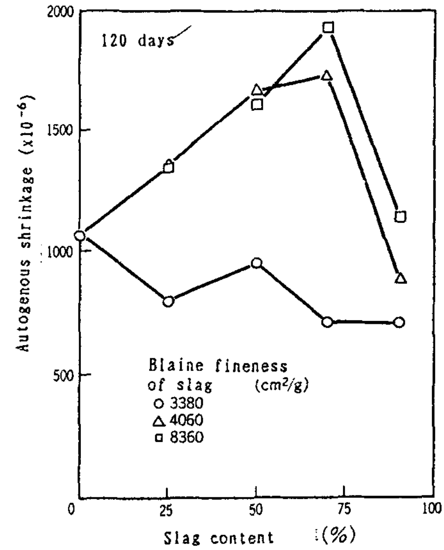

FIG.11
Influence of blast furnace slag

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