EFFECT OF ADMIXTURES ON THE EXPANSION CHARACTERISTICS OF CONCRETE CONTAINING REACTIVE AGGREGATE

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The influence of various types of chemical admixtures on concrete expansion was studied using concrete specimens which contained alkali silica reactive aggregate and were cured for 24 months at 20°C and 40°C. The effects of the chemical admixtures on air entrainment and reduction of the unit cement content brought about less concrete expansion. Expansion at 20°C curing was greater than at 40°C for long term ages.

INTRODUCTION

This report concerns the results of testing on concrete specimens which were produced at near actual mix-proportions in order to determine the effects of (1) the coarse aggregate type and mixing ratio, (2) the unit cement content, (3) the type of chemical admixture, (4) the air content, (5) the type and total content of alkali, (6) the storage temperature on expansion in concrete specimens, and (7) the leaching of alkalies out of underwater cured specimens. This report has been prepared based on previous reports, [(1) and (2)] and the results of testing performed subsequent to the publication of these reports.

TEST PLAN

Of the various factors which influence the expansion of concrete specimens, we selected the above mentioned factors and examined them as per the plan shown in Table 1.

MATERIALS AND CONCRETE MIX PROPORTION

Materials

The cement was low alkali type ordinary portland cement as stipulated in JIS R 5210, with a Na_2O equivalent (R_2O) of 0.41%. The fine aggregate was refined silica sand from Seto area, judged non-reactive by the chemical test method stipulated in ASTM C 289. Three types of coarse aggregate were used: S, judged to be potentially reactive; T, judged to be reactive; and N, judged to be non-reactive. S aggregate, with R_2O=1.0%, showed 0.1% or less expansion at the age of 6 months, and was judged non-reactive based on mortar bar test method of ASTM C 227.

TABLE 1 - Experimental Design for Expansion Properties

Factor	Level
Aggregate type and mix percentage	S(potentially harmful) N(harmless) S:N=50:50
Unit cement content(kg/m³)	450(plain, AE-agent) 405(AEWR-agent, Superplasticizer)
Alkali type and amount (%)	NaOH (R_2O : Cx1.5%) NaCl (R_2O : Cx1.5%)
Air content (%)	Free, 4.5, 6.0
Admixture type (Standard dosage)	AE-agent :AE-1, -2 AEWR-agent :AEWR-1, -2, -3, -4 Superplasticizer:SP-1, -2
Curing method	A:20℃, R.H.95% B:40℃, R.H.95% C:20℃, underwater(alkali elution experiment)

TABLE 2 - Main Admixture Components and R_2O Amount

Admixture Type	Admixture	Main component	R_2O (wt%) (in the product)
AE-agent	AE-1	Alkylarylsulfonate	2.00
	AE-2	Natural resinate	2.02
AEWR-agent	AEWR-1	Lignosulfonste	0.23
	AEWR-2	Lignosulfonste	0.26
	AEWR-3	Lignosulfonste and Thiocyanate	3.94
	AEWR-4	Organic acid derivatives	4.30
Super plasticizer	SP-1	β-naphtalenesulfonate formalin condensate (Ca salt)	0.40
	SP-2	Melaminesulfonate formalin condensate	2.98

We conducted testing on each course aggregate used alone and used together with N aggregate at equal dosages. Reagent grade NaOH and NaCl were used to control to the alkali content, and were added in the prescribed dosage in 10% aqueous solution to the mixing water.

The types and characteristics of the chemical admixtures used are shown in Table 2. Two different types of AE agent, two standard types of AE water reducing agent, one accelerating and one retarding type agent stipulated in JIS A 6204 "Chemical Admixtures for Concrete", and two different types of superplasticizers stipulated in JASS 5 T 402 "Quality requirements for superplasticizer for concrete", were used.

Concrete mix-proportion

The specilmens were prepared as follows: Target slump: 15cm; air content: free, 4.5%, and 6.0%; unit cement content: 450kg/m^3 for plain concrete and AE agent concrete, and 405 kg/m^3, which is a 10% reduction, for concrete using an AE water reducer, in the interests of practically. The alkali content, based on NaOH, had 1.5% R_2O of cement, and the mixing ratio of the coarse aggregates was S:N=50:50. The AE water reducing agent was used at the standard dosage, and the superplasticizer was used at the dosage which would obtain 10cm slump increasing.

PREPERATION AND STORAGE OF THE SPECIMENS

Expansion testing

Concrete was placed in 10x10x40cm steel molds, and stored in a constant temp. room at 20±3°C and 95% relative humidity. At 24 hrs. after placement, the molds were released, and the initial lengths were determined. Type B specimens (accelerated storage) were then placed in a tank at 40°C and 95% relative humidity.

The specimens were placed on holders so as not to touch each other, and were stood on end. At the time of 24 hrs. before measuring, the specimens were moved into a special sealed container, which was located in a constant temp. and humidity room at 20±3°C and relative humidity 80%. The length change, weight, and modulus of elasticity were determined at the ages of 2 and 4 weeks, 2, 3, 4, 5, 6, 9, 12, 18, and 24 months. Depending on the length change, other ages were also measured.

Type A specimens (standard storage) were stored in a moist room at 20±3°C and 95% relative humidity after the initial length was determined, and were covered with a plastic sheet to protect from water drops from the ceiling. Other items were determined by the same process as the type B specimens. The A specimens, however, were stored horizontally.

Alkali leaching testing

Concrete was placed in 15x15x15cm steel molds and stored in a constant temp. and humidity room at 20±3°C and 95% relative humidity. At the age of 24 hrs., the molds were released and the specimens were stored sealed for 14 days. The specimens were soaked in a 30 liter plastic sealed container filled with 20 liters of distilled water, which was stored in a constant temp. room at 20°C until the prescribed ages.

MEASURING OF THE LEACHED COMPONENT

The solution in which the concrete specimens were soaked was stirred to be homogeneous, whereupon 20ml was removed for chemical analysis. Na^+ and K^+ were analyzed with an atomic absorption spectrophotometer, and Cl^- and SO_4^{2-} by ion chromatography. The pH was determined with a glass electrode pH meter.

TEST RESULTS AND CONSIDERATIONS

Effect of the aggregate type and the mixing ratio

Results are shown in Fig. 1. There was no significant difference in the expansion with T aggregate when used alone or when used 50:50 with N aggregate, showing basically the same expansion as the age increased. The expansion of S aggregate when used alone, was small, approx. 0.1% at the age of 12 months. When S and N were mixed equally, the expansion was greater than that of T aggregate, approx. 1.3 times as great at the age of 6 months. It is considered that there is a pessimum in the mixing ratio of S aggregate.

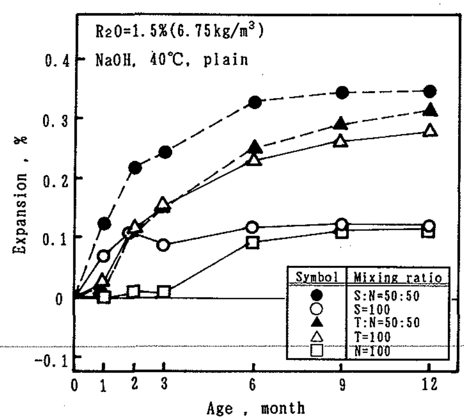

Figure 1 Effect of the aggregate type and the mixing ratio

Effect of the unit cement content

As shown in Fig. 2, plain concrete with a unit cement content of 350kg/m^3 (R_2O=5.25kg/m^3) showed 0.1% or more expansion at the age of 6 months for both S and T aggregate.

No significant difference was seen in the expansion of S aggregate between unit cement content of 450kg/m^3 and 550kg/m^3. With T aggregate, the expansion of specimens with the greater unit cement content of 550kg/m^3 became greater as the age increased.

Compared to the plain specimens, the specimens with an AE agent generally showed less overall expansion, which is probably to due to the air entrainment, with expansion increasing with increases in unit cement content. The specimens with an AE water reducing agent had 10% less unit cement content than the plain specimens, 315kg/m^3 (R_2O=4.72kg/m^3), and thus reduced unit alkali content, and did not show significant expansion even to the age of 12 months. However, with a unit cement content of 405kg/m^3 (R_2O=6.08kg/m^3), expansion exceeded 0.1% at the age of 6 months. NaCl showed greater expansion than NaOH at the same cement, and alkali contents.

Effect of admixtures

Fig. 3 shows the test results of the admixtures using a mixture of coarse aggregate (S:N=50:50). NaOH was added to the plain specimens and the specimens with an AE agent in order to control the R_2O content per 1m^3 concrete to 6.75kg, and with the specimens with AE water reducing agent was controled the R_2O content per 1m^3 concrete to 6.075kg. NaCl was added to the specimens with plasticizer to control the R_2O content to 6.075kg.

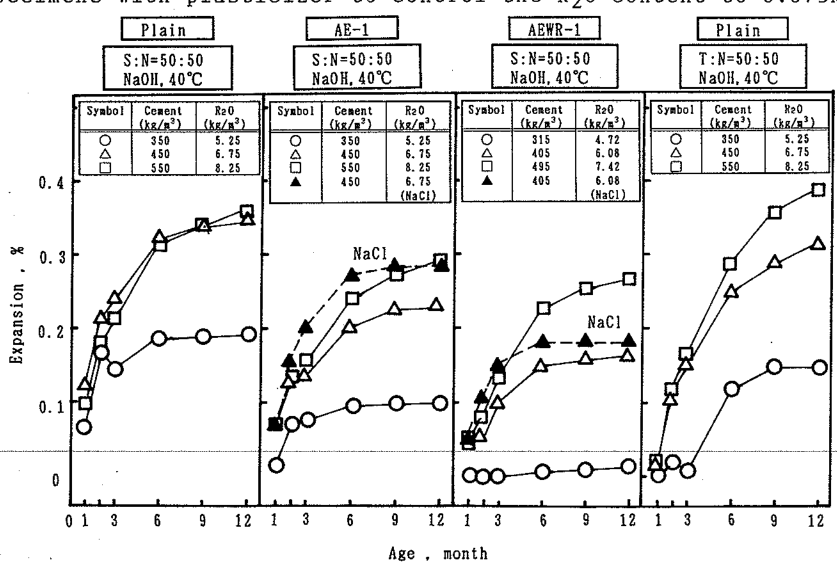

Figure 2 Effect of the unit cement content

Plain and AE agent specimens. In 40°C storage, the expansion of plain concrete specimens already exceeded 0.1% at the age of 1 month, increased almost linearly until the age of 6 months, and increased slightly thereafter until the age of 24 months, at which time the expansion was 0.36%.

The specimens with an AE agent showed similar expansion to the plain specimens, not increasing much after the age of 6 months. The expansion was less than the plain specimens at all ages, and there was no difference between the AE agents at the age of 24 months, AE-1: 0.24% and AE-2: 0.24%.

In 20°C storage, the start of expansion of both plain specimens and specimens with an AE agent was retarded, with plain specimens starting at the age of 5 months and the specimens with an AE agent starting at the age of 6 months. Once expansion started, it was roughly the same as with specimens stored at 40°C, expanding significantly even at the age of 24 months. Specimens with an AE agent and cured at 20°C showed greater expansion at the ages of 18 to 20 months than specimens stored at 40°C.

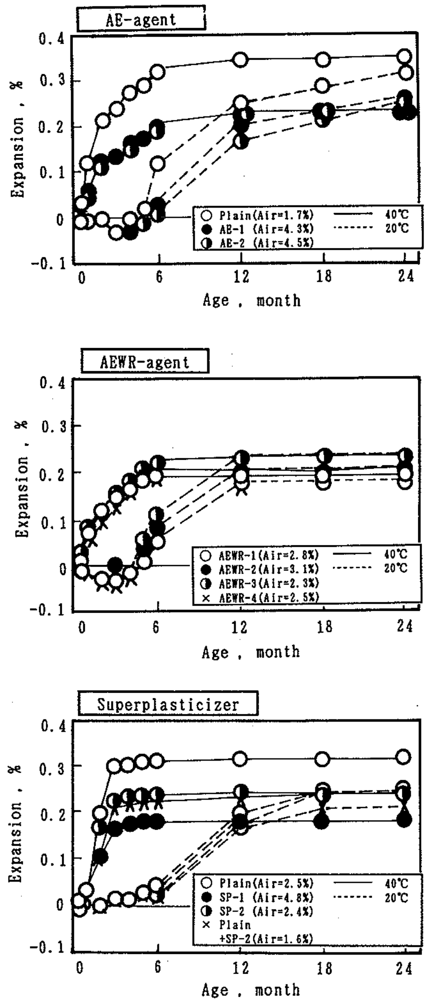

Figure 3 Effect of curing method on expansion properties

AE water reducing agent speci-mens. The expansion of specimens with an AE water reducing agent was smaller than for plain specimens due to the reduced unit cement content. Of all admixtures, expansion was the greatest with accelerating type AEWR-3 at both 20°C and 40°C storage. The alkali (R_2O) content in concrete introduced by AEWR-3 at the standard dosage was 0.170kg/m^3, while that from the other admixtures was only 0.013 to 0.035kg/m^3. We assume that this difference in alkali content influenced the expansion of the concrete specimens.

Specimens with an AE water reducer at 20°C storage started expanding later than that at 40°C storage, and showed slightly greater expansion even at the age of 12 months.

Superplasticizer specimens. Test results of specimens with the simultaneous addition of a superplasticizer are shown in Fig. 3. For comparison, the results of 9cm slump plain concrete to which SP-2, a melamine sulfonate formaldehyde condensate type admixture, was later added, attaining 19.0cm slump, are also shown.

With regard to simultaneous addition at 40°C storage, SP-2 showed greater expansion at all ages than SP-1. This is due to the difference in air entrainment, and to the fact that SP-2 introduced a greater alkali content, $R_2O=0.136kg/m^3$, than SP-1, $R_2O=0.006kg/m^3$. In 20°C storage, however, there is no significant difference in expansion between SP-1 and SP-2. This is probably due to the fact that the expansion is not completed as of 24 months, and the difference may become greater at greater ages.

Effect of the air content

With AE-1 specimens in 40°C storage in Fig. 4, the relationship between the air content and expansion was similar at 6, 12, and 24 months, being almost a linear relationship in the air content range of 1.7%-6.4%. With R_2O=1.5%, the expansion compared to plain specimens at the age of 6 months was reduced by 40% for an air content of 4.5% and by 75% with an air content of 6.0%. In 20°C storage, as was the case in Fig. 3, expansion is still continuing at the ages of 12 and 24 months, and the relationship between the air content and expansion is not clear.

Effect of the type of alkali

As shown in Fig. 5, NaCl caused greater expansion at all ages with both AE agents and AE water reducers. As seen with NaOH specimens, NaCl specimens showed greater expansion at the age of 24 months at 40°C storage than at 20°C storage, after which expansion continued to occur.

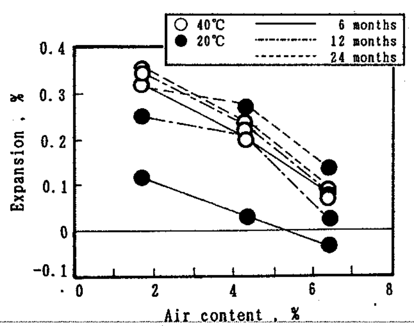

Figure 4 Effect of the air content

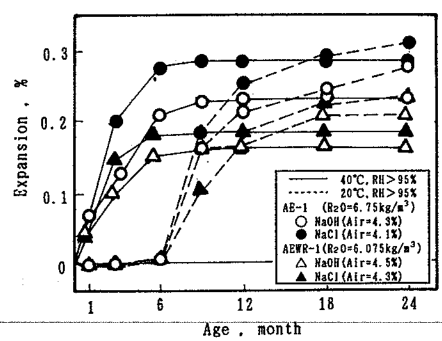

Figure 5 Effect of type of alkali

Effect of the total alkali content

As shown in Fig. 6, as with increases in the unit cement content, increases in the total alkali content caused increased expansion. When the R_2O content in concrete exceeded approximately 5 kg/m^3, the expansion exceeded 0.1%.

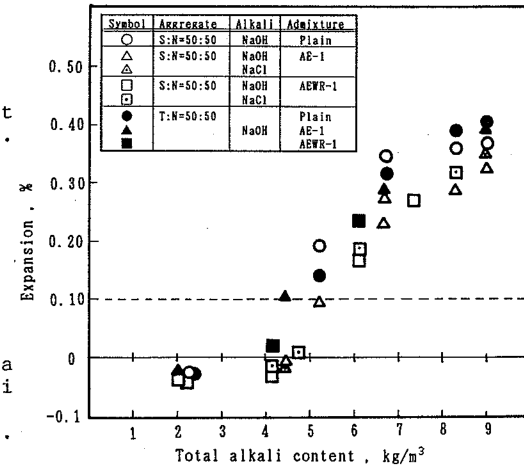

Figure 6 Effect of the total alkali content

Leaching of alkalies

The specimens used in the testing used S and N coarse aggregate mixed at a 50:50 ratio, and the alkali content was adjusted to R_2O=6.075kg/m^3, using NaCl. The admixture was an AE water reducer, AEWR-1, used at standard dosage. The expansion of 10x10x40cm concrete specimens produced at the same time and under the same conditions and stored at 20°C was 0.06% at the age of 6 months, and 0.1% at the age of 9 months.

From Fig. 7, the pH of the solution is obserbed to have already reached 12.1 by the age of 1 month, where it remained fairly stable to the age of 9 months. Cl^- and K^+ leached at a fairly constant rate until the age of 6 months. SO_4^{2-} leached at the constant rate of 1-4.3 mg/liter.

The leaching of Na^+ increased with age, reaching 180mg/liter at 6 months and 210 mg/ltr at 9 months.The degrees of leaching of Na^+ at the ages of 6 and 9 months were 27.5% and 32.1% to the amount of Na^+ when the concrete specimens were prepared. The leaching of K^+ was 39 mg/liter at 6 months and 43 mg/liter at 9 months, equivalent to 19.5% and 21.5%. The degree of expansion and cracking of specimens immersed in water was not determined in this experiment, but based on the expansion in 10x10x40cm concrete specimens prepared at the same time and cured at 20°C, 95% or more relative humidity, these specimens immersed in water are expected to crack between the age of 6-9 months, leading to greater leaching of alkalies.

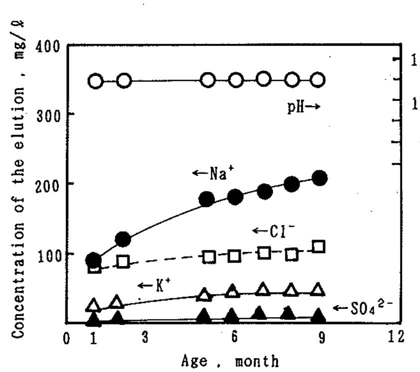

Figure 7 Change in eluent from concrete specimens over time

CONCLUSION

The 12 and 24 month test results on the expansion in concrete specimens containing chemical admixtures and reactive aggregates can be summarized as follows:

1) S aggregate, judged potentially reactive by ASTM C 289 testing, showed significant expansion when mixed with non-reactive aggregate.

2) Increases in the unit cement content of plain, AE agent, and AE water reducing agent specimens resulted in increases in the alkali content, and increases in expansion. Within the range of this experiment, when the alkali content in concrete exceeded approximately $5kg/m^3$, the expansion increased 0.1%.

3) AE agent specimens showed less expansion than plain concrete, due to the entrained air. The expansion is approx. 40% less than plain concrete when the air content is 4.5%.

4) When an AE water reducer is used, the cement content can be reduced over plain concrete and reduce expansion. There is little effect on expansion, due to the composition of the admixture, but the more alkali content that is introduced from the admixture, the greater the expansion.

5) There is no significant difference in expansion between the simultaneous addition and the later addition of the superplasticizer.

6) With accelerated storage at 40°C and 95% relative humidity, expansion was mostly completed by the age of 6 months, with little or no increase thereafter to the age of 24 months. With storage at 20°C and 95% relative humidity, no expansion was seen until the age of 6 months, but once expansion begins, the rate increases to near that of the accelerated storage at 40°C. Expansion continued past the age of 24 months, in some cases showing greater expansion than with accelerated storage at 40°C.

7) Concrete to which NaCl was added showed greater expansion than concrete to which NaOH was added.

8) When the concrete was immersed in water at 20°C, Na^+ showed 32.1% leaching and K^+ showed 21.5% leaching at the age of 9 months.

REFERENCE

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2. Nakajima M., et. al, 1990, "Effect of Admixtures on Expansion Characteristics of Concrete Containing Reactive Aggregate", Proceedings of the Japan Concrete Institute, Vol. 12, No. 1,, pp. 815-820.