# STUDY ON PREVENTIVE CONDITIONS OF ALKALI-SILICA REACTION

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The study was carried out an examine on effective condition to prevent damages caused by ASR under 40℃ and humid atmosphere. Influential two factors were adopted type of cement, sodium chloride content in fine aggregate.
The results obtained ① Low alkali and sulfate resistant cement, blast furnace slag cement(slag content 45, 65%), flyash cement(flyash content 28 %) are effective to prevent ASR. ② The influence of alkali contained in admixtures(slag, flyash) on expansion is very small. ③ The expansion by sodium chloride in fine aggregate will increase proportionally with the total alkali in cement plus the sodium chloride in fine aggregate.

## INTRODUCTION

From 1985, 6 kinds of typical alkali-silica reactive coarse aggregates produced in Japan were collected and the influence of different factors on concrete alkali-silica expansion was studied by changing (1) total alkali of cement, (2) cement content in concrete, (3) percentage of reactive aggregates.

From these studies, it was concluded that (1) concrete alkali-silica expansion is influenced by the total alkali in concrete, (2) expansion will not occur when total alkali is less than 3kg/m$^3$ under pessimum mixture of rather large alkali-silica expansion reactive aggregate.

This report, based on the above conclusion, summarizes the study on effective methods to prevent damages caused by alkali-silica reaction by using 2 kinds of alkali-silica reactive coarse aggregates(andesite, chert), commonly used JIS cements, then changing sodium chloride content in fine aggregate and cement content.

## EXPERIMENTAL METHOD

### Method

Experiment was conducted by measuring alkali-silica expansion under condition of 2 kinds of alkali-silica reactive coarse aggregates(andesite, chert), 10 different cements (ordinary, low alkali, high-early-strength, sulfate resistant, blast-furnace slag A, B, C (slag content 25, 45, 65%), flyash A, B, C (flyash content 8, 18, 28%)), fine aggregate of 5 different sodium chloride content(0.00, 0.01, 0.10, 0.20, 0.40%), cement content(450, 600kg/m$^3$) under 40℃ and humid atmosphere (Table 1).

## Materials

Cement. Chemical composition of the 10 different cements is shown in Table 2. The low alkali portland cement with a total alkali content of 0.56% is prepared by mixing ordinary portland cement with total alkali content 0.93% and 0.36%.

BA, BB, BC are cement with 25, 45 and 65% of blast furnace slag blended respectively to ordinary portland cement.
FA, FB, FC are cement with 8, 18 and 28% of flyash blended respectively to ordinary portland cement.

TABLE 1 – Causes and conditions

| Causes | Conditions | |
|---|---|---|
| 1 Type of reactive aggregate | 2types(B(andesite), F(chert)) | |
| 2 Type of cement | [type] | [Symbol] |
| | Ordinary portland cement ($R_2O$=0.93%) | N |
| | Low alkali portland cement ($R_2O$=0.56%) | NL |
| | High-early-strength portland cement ($R_2O$=0.80%) | H |
| | Sulfate resistant portland cement ($R_2O$=0.51%) | SR |
| | Blast furnace slag cement A (slag content 25%) | BA |
| | Blast furnace slag cement B (slag content 45%) | BB |
| | Blast furnace slag cement C (slag content 65%) | BC |
| | Flyash cement A (flyash content 8%) | FA |
| | Flyash cement B (flyash content 18%) | FB |
| | Flyash cement C (flyash content 28%) | FC |
| 3 Sodium chloride content in fine aggregate (sea sand) | 5levels(0.00,0.04,0.10,0.20,0.40%) | |
| 4 Cement content in concrete | 2levels(450,600kg/m$^3$) | |

TABLE 2 – Chemical composition of cement

(%)

| Typeof Cement | ig. loss | insol. | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $Na_2O$ | $K_2O$ | S | $R_2O$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 0.5 | 0.1 | 21.8 | 5.0 | 3.2 | 64.0 | 1.6 | 2.1 | 0.59 | 0.51 | – | 0.93 |
| NL | 0.6 | 0.1 | 22.2 | 5.4 | 2.9 | 63.1 | 2.3 | 1.9 | 0.30 | 0.40 | – | 0.56 |
| H | 1.5 | 0.1 | 20.1 | 4.7 | 2.4 | 64.7 | 1.6 | 3.2 | 0.41 | 0.60 | – | 0.80 |
| SR | 0.6 | 0.1 | 21.7 | 3.5 | 4.4 | 64.9 | 1.2 | 2.0 | 0.17 | 0.52 | – | 0.51 |
| BA | 0.8 | 0.3 | 24.2 | 7.0 | 2.6 | 58.4 | 2.9 | 1.6 | 0.51 | 0.50 | 0.2 | 0.84 |
| BB | 0.7 | 0.4 | 26.6 | 8.8 | 2.0 | 54.1 | 3.8 | 1.2 | 0.46 | 0.43 | 0.4 | 0.74 |
| BC | 0.9 | 0.6 | 28.6 | 10.3 | 1.5 | 49.8 | 4.8 | 0.8 | 0.36 | 0.38 | 0.5 | 0.61 |
| FA | 0.8 | 5.5 | 21.0 | 5.0 | 3.0 | 59.3 | 1.5 | 2.0 | 0.58 | 0.53 | – | 0.93 |
| FB | 1.2 | 12.5 | 19.8 | 5.1 | 3.0 | 53.4 | 1.5 | 1.9 | 0.54 | 0.47 | – | 0.85 |
| FC | 1.4 | 19.5 | 18.6 | 5.2 | 2.8 | 47.7 | 1.4 | 1.7 | 0.51 | 0.44 | – | 0.80 |

Note: $R_2O=Na_2O+0.658\times K_2O$

Aggregate. For non reactive fine aggregate, sea dredged sand (specific gravity; 2.56, sodium choride content; 0.003%) was used to prepare the sand with sodium chloride content of 0.00, 0.04, 0.10, 0.20, 0.40% in order to study the influence of chloride contained in sea sand. For reactive coarse aggregate, andesite (specific gravity ; 2.73, absorption ; 2.20%) and chert(specific gravity ; 2.67, absorption ; 0.86%) according to the previous report(8th International Conference (1)) were used.

The potential alkali reactivity of aggregates evaluated by chemical method(CAJS I-33-1986(Chemical Method)) is shown in Fig.1 and Table 3.

TABLE 3 — Potential alkali reactivity test of aggregate

| Classification | Type | Mineral | Potential alkali reactivity test | | |
|---|---|---|---|---|---|
| | | | Rc (m mol/ℓ) | Sc (m mol/ℓ) | Rc/Sc |
| Reactive coarse aggregate | B | Augite·Hypersthene·Andesite | 124.6 | 541.7 | 0.23 |
| | F | Slate(50%),Chert (45%),Sandstone(5%) | 51.7 | 99.5 | 0.52 |
| Fine aggregate | - | Quartz·Potasium feld spar·Plagioclase | 66.1 | 29.0 | 2.28 |

Mix Proportion of Concrete. Mix proportions of concrete were the 2 mixes shown in Table 4. The mixes were determined by absolute volume in order to keep the absolute volume of reactive aggregate constant to equalize the influence of reactive aggregate.

TABLE 4 — Mix proportion of concrete

| Water cement ratio (%) | Fine aggregate ratio (%) | Cement content | Water content | Fine aggregate | Coarse aggregate |
|---|---|---|---|---|---|
| | | (kg/m³) | | Absolute volume (ℓ/m³) | |
| 44.4 | 40.4 | 450 | 200 | 258 | 380 |
| 36.7 | 33.3 | 600 | 220 | 190 | 380 |

Test Method. Expansion was measured on 10×9.5×9.5cm specimen. The specimen was demolded at 1 day and after cured for 1 week under sealed condition, the initial length was measured and then exposed in 40℃ humid enviroment. Measurement was conducted under 1 month cycle.

## RESULTS AND DISCUSSION

The expansion test of concrete showed that development of expansion saturates at age of about 12 months, therefore the influence of kinds of cement, specific cement content, sodium chloride content contained in fine aggregate was verified by measurements taken at age of 18 months when expansion had completely saturated.

### Kinds of Cement

Expansion for different kinds of cement is shown in Fig.2 for different cement content. In case of concrete with a specific cement content of 450kg/m³, expansion of 0.035 and 0.030% was observed respectively for cement N and FA while no expansion was observed for other cement.

In case of concrete with a specific cement content of 600kg/$m^3$, concrete expansion was large for cement N, FA and H using aggregate B, also expansion was observed for cement FB and BA. Expansion of FA was 0.33% which is larger than that of N and H. When the percentage of admixture differred, expansion was observed for FA, FB and BA, but expansion was not observed for FC, BB and BC.

Expansion was hardly observed for low alkali cement NL and expansion was not observed for SR which had lower total alkali content.

As described above, it was found that even in concrete with high specific cement content and using highly reactive alkali-silica aggregate, expansion due to alkali reactive aggregate can be effectively prevented by using cement with low total alkali content such as NL or SR, also blended cement BB, BC or FC.

With regards to percentage of admixture content, higher admixture percentage generally show better expansion prevention, but small admixture percentage does not generally show higher expansion preventive effect as can be seen in small flyash content FA which shows a higher expansion than ordinary cement N.

Therefore, when using blended cement for the purpose of preventing expansion caused by alkali-silica reaction, it is necessary to select suitable admixture and suitable admixture percentage.

Total Alkali Content

The relation between total alkali in concrete and expansion for different aggregates is shown in Fig.3. When observing the overall picture of cement quantity and type of cement, it is observed that above a certain total alkali content, an abrupt expansion is observed. However, the expansion characteristic differs with the type of cement even when the total alkali content was the same, and the expansion distribution was as shown in the figure.

In case of aggregate B, when total alkali is about 5kg/$m^3$, expansion for H, FB, BA and FC was respectively 0.3, 0.1, 0.05 and 0%. This is believed to be due to the different degree of influence on alkali-silica reaction arising from alkali coming from slag and flyash and alkali coming from cement clinker.

When all alkali related to alkali-silica reaction is assumed to come from cement clinker, the relation between the calculated total alkali contained in concrete and expansion is as shown in Fig.4.

In case of blended cement, alkali related to alkali-silica reaction in actual practice is believed to come only from cement clinker and the effect of admixture such as slag and flyash is to dilute the alkali contained in cement clinker. Since the upper limit of total alkali content contained in current ordinary portland cement clinker is about 0.7%, the influence of alkali-silica reaction of such ordinary portland cement may be expected to be similar to that in case of BA or FC in this experiment.

## Sodium Chloride Content in Fine Aggregate

In case of sodium chloride contained in fine aggregate in concrete made from cement N which is most higly influenced by sodium chloride in fine aggregate, the relation between total alkali with the addition of alkali coming from sodium chloride in fine aggregate and expansion is shown in Fig.5. In the figure, the relation given in the previous report (8th International Conference) is also shown.

The relation between total alkali and expansion differs with the kind of aggregate, but expansion in case of same aggregate, it is believed that alkali from sodium chloride contained in fine aggregate is equivalent to alkali in cement.

When the total alkali for alkali from cement and alkali from sodium chloride contained in fine aggregate is more than 4.0~5.0kg/$m^3$ than total alkali in cement, expansion will increase proportionately with total alkali in concrete.

## SUMMARY

Prevention measures on alkali-silica reaction were carried out by studying the influence and effect on concrete expansion of factors including type of cement, specific cement content, sodium chloride in fine aggregate with two typical alkali-silica reactive aggregates(andesite, chert). The main results are summarized in the following paragraphs.

1) Portland cement with low total alkali content such as low alkali portland cement, sulfate resistant portland cement, blended cement with high percentage of admixture; blast furnace slag cement B(slag content 45%), C(slag content 65%); flyash cement C(flyash content 28%) are effective to prevent alkali-silica reaction.

2) When blended cements are used, the alkalis contained in admixtures were not worth due consideration as alkali in total alkali because the influence of alkali contained in admixtures(slag, flyash) on expansion is very small.

3) The influence of sodium chloride contained in fine aggregate is the same as that of alkali contained in ordinary portland cement. In other words, expansion will increase proportionally with the total alkali in cement plus the sodium chloride in fine aggregate.

## REFERENCE

1. K.NAKANO, et all., 1989, "Study on Expansion Properties of Alkali Reactive Aggregate", Proc. 8th ICAAR, Kyoto, Japan.

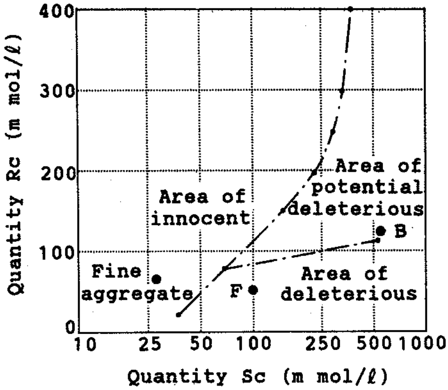


Figure 1 Result of evaluation in accordance with ASTM evaluation method

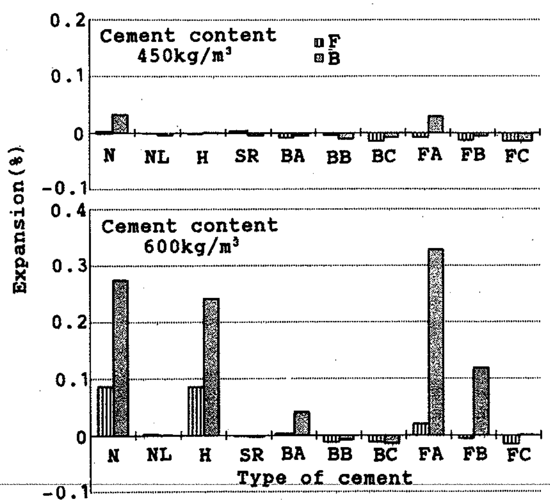


Figure 2 Relation between type of cement and expansion

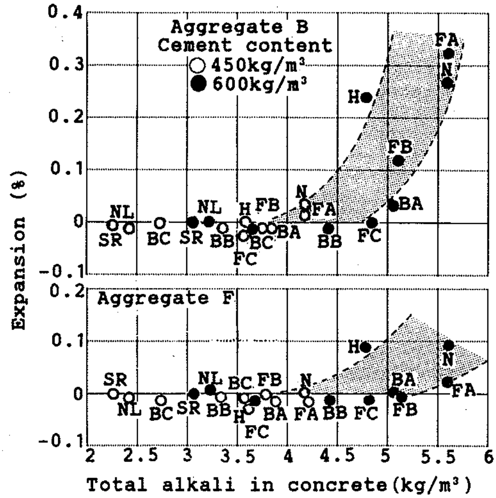


Figure 3 Relation between total alkali in concrete and expansion

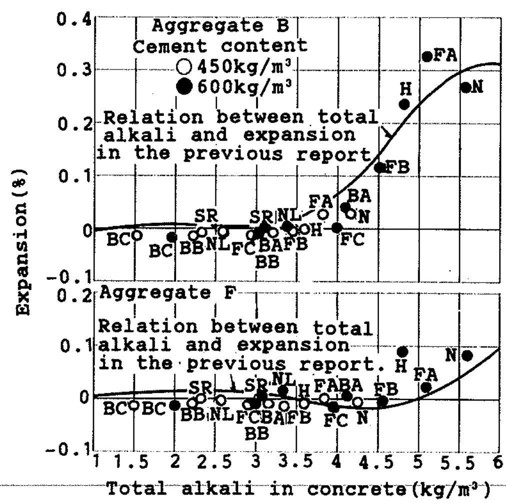


Figure 4 Relation between total alkali in concrete and expansion (Alkali in slag and flyash of blended cement is assumed to be"0")

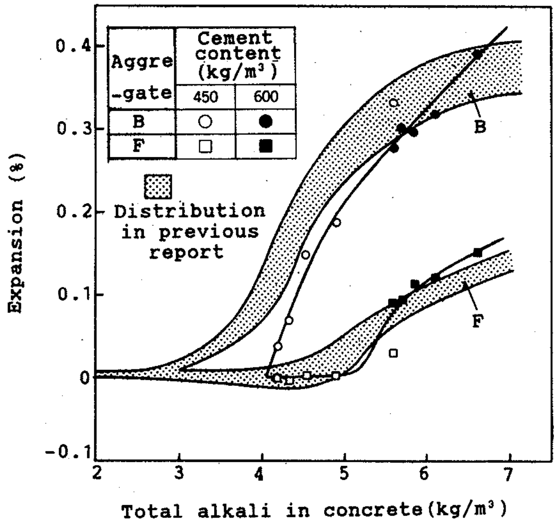


Figure 5 Relation between total alkali in concrete and expansion