CONCRETE TEST METHOD FOR ALKALI-SILICA REACTION (JCI AAR-3)

Committee on the test method for determination of alkali-aggregate reaction in concrete using concrete specimens (JCI-AAR Committee)

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JCI established an AAR Committee in 1988 to propose a test method for determination of alkali silica reactivity in concrete (Concrete Method).

The concrete method using concrete specimens has the objective of evaluating the reactivity of concrete made using actual mix proportion or any ready mixed concrete.

Since there have been few cases of experiments on concrete test method in the past, the members of committee carried out common tests to resolve problematic points, using a total of 737 test specimens.

The concrete test method specifies the scope of the test, test apparatus, materials, specimens, storage methods, items and methods of measurement, calculation of expansion, judgement, and reporting. Specimen dimensions, storage conditions, alkali content, and judgement standards have been established for the test conditions.

INTRODUCTION

Alkali-aggregate reaction takes place by the interaction between the aggregate and the alkalis in cement and admixtures and also supplied from outside of the concrete, in the presence of moisture. It is known that there are some admixtures which can prevent such a reaction. There is a possibility that the concrete causes expansion under highly alkaline conditions depending on the reactivity of the aggregate even if it is judged as innocuous under some test conditions, while the aggregate judged as reactive can be used without problems with a proper mix proportion. Therefore, in order to determine the alkali-aggregate reactivity of the concrete exactly, a test must be conducted on the concrete made using the actual mix proportion with a combination of the aggregate, cement, and admixtures to be used, or on the ready-mixed concrete to be placed.

In the test of the alkali-aggregate reaction, it is necessary to predict the long-term reaction by means of a relatively short-term laboratory test. The factor of safety for the fluctuation of the quality of the materials should also be taken into account to decide the critical values for the judgment.

The newly proposed concrete method includes an addition of a fixed amount of alkali which accelerates the reaction and accelerated storage conditions, to cope with these subjects. As for the quantity of alkali, an excessive addition of alkali could lead to misjudgment of concrete containing inert aggregate as " deleterious". On the other hand, if the alkali addition is insufficient, the expansion rate could stay below the critical value, causing an assessment as "innocuous", even if the concrete contains reactive aggregate. Thus it has become very important to determine the amount of alkali to be added.

In order to accelerate the alkali-aggregate reaction, the concrete should be stored under the conditions of the optimum temperature and enough relative humidity for the reaction. In this case, it was considered to be important to determine the storage temperature, relative humidity and the proper method to maintain the humidity.

DISCUSSIONS FOR PREPARING THE CONCRETE METHOD

Changes in Physical Properties of Concrete by Alkali Addition

In the concrete method, the tests are conducted using actual concrete or the concrete of the same mix proportion, and an addition of alkali is a prerequisite in order to predict the potential alkali-aggregate reactivity in a short period of time. NaOH is supposed to be adopted as the alkali to be added, since it has been used in a large number of researches. It is necessary, however, to conduct precise examinations as to how the basic properties of concrete change by the addition of NaOH. The influence of the addition of NaOH on the properties of fresh concrete and hardened concrete was examined in the common tests which were conducted by the committee.

The results revealed that the addition of NaOH does not affect the slump or air content of fresh concrete, except for excessive additions (more than 3 kg/m^3) or concrete with an extremely lowered water/cement ratio by addition of air entraining and water reducing agents, and that the concrete can be mixed in the same manner as concrete with no addition of alkali.

For hardened concrete, the addition of NaOH leads to an increase in the amount of small-diameter voids and eventually leads to a substantial decrease in compressive strength (Fig. 1). Although a decrease of the tensile strength is also observed as an increase of NaOH dosage, no such decrease is found in the static modulus of elasticity.

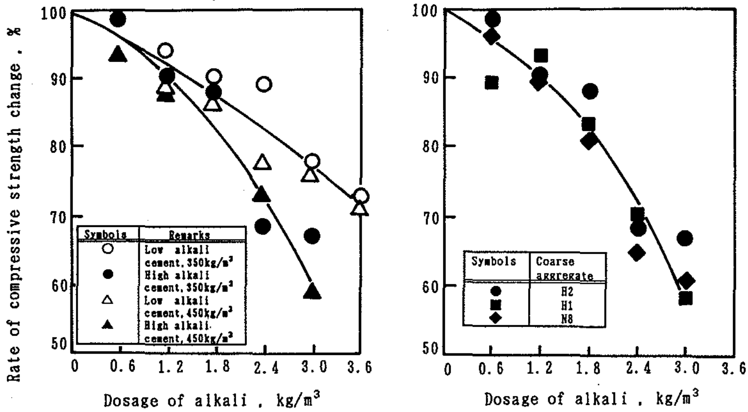


Fig. 1 The Reduction of Compressive Strength Accompanied by an Addition of Alkali

Alkali Dosage

Expansion of concrete containing reactive aggregate is closely related to the total alkali amount (unit alkali content) that the concrete contains. Test results of concrete specimens made with a variety of alkali dosages reveal that the concrete does not expand with unit alkali content less than a certain value, but it starts to expand when alkali content exceeds the value, in proportion to the alkali content.

Fig. 2 shows the relationship between the expansion of concrete and the dosage of alkali (increased with interval of $0.6kg/m^3$), and Fig. 3 shows the relationship between unit alkali content and those expansion after 6 months under the accelerated storage conditions.

It is apparent from Fig. 2 that the dosage of alkali which is required to cause obvious expansion is low when the alkali content in cement is high, and it is high when the alkali content in cement is low. On the other hand, Fig. 3 shows that obvious expansion is observed at the same level of unit alkali content of concrete irrespective of alkali contents in cement. Therefore, for the testing purpose, the key figure is the difference between the alkali content originally contained in the concrete to be tested and the total alkali amount (unit alkali content) of the concrete to which the required amount of alkali for obvious expansion is added. That is, the bigger this difference is, the lower the reactivity of the concrete to be tested, and vice versa. In other words, the amount of alkali added corresponds to the magnitude of the safety.

Various common tests were carried out in order to determine the magnitude of this difference from which the concrete to be tested can be judged as non-reactive, namely to determine the dosage of alkali from which the re-activity of concrete can be judged without fault. As a result, an alkali dosage of 2.40kg/m^3 was adopted.

Storage Conditions

Common tests were carried out by the committee under the accelerated storage conditions, at 40°C and 20°C, and 100% relative humidity, and under exposure condition to compare the expansion of each specimen of concrete.

The tests gave the following results: 1) A comparative test using two kinds of reactive aggregate which had shown an obvious difference in the development of expansion under the exposure condition was carried out under the accelerated conditions at 40°C and 20°C. The same trend as the test result under the exposure condition was observed at 20°C.

2) In the tests with extremely high alkali quantity (6.75kg/m^3 in total alkali content), no expansion was observed for about 5 months at 20°C, while the same concrete started to expand greatly at the age of one or two months and shifted to the moderate expansion at around 6 months at 40°C.

3) The progress of expansion was promoted under the accelerated condition, at 40°C and 100% relative humidity, as compared with the results of the exposure test under natural condition, in which expansion was also observed but started at around the age of one year.

From these results, while there is some argument on the adoption of the extremely high temperature condition which differs from the actual one, the temperature condition of 20°C cannot satisfy the purpose of early assessment. Eventually it was decided to adopt 40°C, as the storage temperature, which can accelerate the reaction. Successive common tests using this

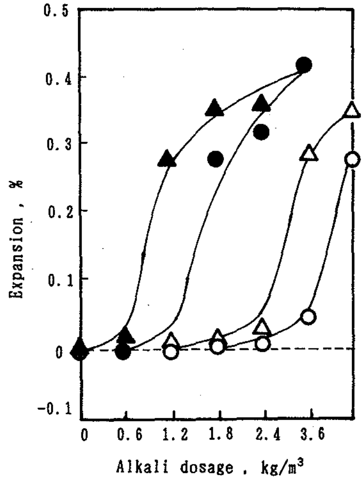


Fig. 2 Relationship between Expansion and Alkali Dosage

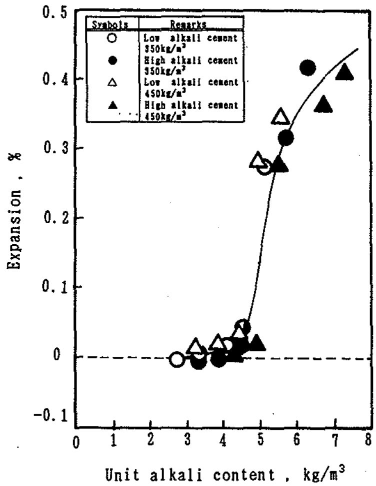


Fig. 3 Relationship between Expansion and Unit Alkali Content

storage condition revealed that the test results fluctuated widely depending on the moisture for the storage. Therefore, the moisture condition for the storage was examined next.

Underwater storage such as water curing would be the most suitable for keeping test specimens in a stable moisture condition. However, it was found from the results of experiments that the quantity of alkali which was leached out during the water storage was not negligible. Therefore, during accelerated testing, it is undesirable to keep specimens under the condition in which dew condensation water always falls in drops as well as under the dry condition. It was thus decided to adopt the following storage method in order to keep the moisture condition strictly constant: the specimens are wrapped with wet cloth containing the given amount of water and put in sealed containers and then the containers are kept at 40°C. It was also decided to name it "the wet-cloth-sealing method".

Dimensions of Test Specimens

Data showing the influence of the size of specimens on the expansion of concrete induced by alkali-aggregate reaction have often been reported.

In the committee, a difference in the magnitude of expansion between two different sizes of specimens, 75x75x400mm and 100x100x400mm, was examined using the same mix proportion of concrete. As a result, it was judged that there is no big difference beyond measuring error between the two sizes of the specimens, as long as the temperature and humidity conditions were strictly controlled. No significant difference was observed in the fluctuation of expansion of each specimen. From these results, it was decided that either size of 75x75x400mm or 100x100x400mm could be used for the concrete method. It was also pointed out that the specimens of sectional size 75x75mm are remarkably easier to handle on measuring because of the light weight of the specimens, and the total amount of the concrete and the size of the storage vessel can be substantially smaller.

Criteria for Reactivity

When the expansion of concrete from the alkali-aggregate reaction is adopted as the criterion of concrete deterioration, not only the expansion but also cracking caused by the expansion must be brought into question. Namely, it is necessary to define the relationship of the expansion and cracking. The results of the common tests showed that the first crack was observed with the rate of expansion between 0.05% and 0.10 % in many cases, but the fluctuation of the rate was considerably wide, depending on the individual person who carried out the tests or because of the long intervals (1 month) of measurement in those cases where the rate of the expansion is high. Since the expansion tends to make considerably rapid progress once it starts, the probability of observing the rate of expansion between 0.05% and 0.10% is low at measuring intervals of one month. There is, therefore, no big difference whether 0.05% or 0.10% were settled as the criterion of expansion rate to evaluate concrete deterioration from cracking.

For the test method proposed here, in which the reaction is accelerated by the alkali addition, it is desirable to adopt a criterion of the expansion which can judge the occurrence of expansion clearly and correctly. The committee thus adopted 0.10% after 6 months as the critical value for the judgment.

FUTURE SUBJECTS

The followings are the subjects to be considered in the future with brief explanations:

Relationship between Alkali Dosage and Expansion Rate

It is generally known that the rate of expansion increases as the alkali dosage or total alkali content in concrete increases. However, it must be borne in mind that there may be a pessimum phenomenon, in which the rate of expansion decreases instead of increasing as the alkali content in concrete increases. Actually, this alkali pessimum was recognized in one case of a total of 474 types of concrete tested in the committee.

As to avoid the misjudgment due to the alkali pessimum phenomenon, a test with a few levels of alkali dosage is desirable.

Late Expansion

When alkali-aggregate reaction of concrete is judged by the accelerated test method, it is desirable to confirm the relation between the expansion at the standard age and the expansion after long term storage. It is especially important for the concrete using aggregates which cause drastic expansion after the standard age. These are called "late expansion aggregates" (there are some late expansion aggregates mainly in cherts). It is necessary to examine carefully whether the reaction of the concrete using late expansion aggregate can also be accelerated by the addition of alkali.

Test Frequency

If the concrete method proposed here is applied in all concrete actually used (for instance concrete produced at ready mixed concrete plants in conformity with JIS A 5308), a huge number of test specimens would have to be prepared. In this case, when the same kind of aggregate is used and the mix proportion is within the small modification, if the deleterious expansion is recognized in the concrete with a certain unit cement and a certain quantity of alkali addition, the concrete with more cement and larger amount of alkali addition can be considered as "reactive". Thus, the number of concrete types to be tested will be limited, as a matter of course.

PROPOSED CONCRETE MEHTOD

As a conclusion of the two year activity of the committee, "CONCRETE TEST METHOD FOR ALKALI-SILICA REACTION (DRAFT)- CONCRETE METHOD (JCI AAR - 3)" was reported as a proposed method at the symposium of JCI AAR-committee in March, 1991.

CONCRETE TEST METHOD FOR ALKALI-SILICA REACTION (DRAFT) - CONCRETE METHOD (JCI AAR-3)

1. Scope

This test method covers the determination of the alkali-silica reactivity of the concrete with any mix proportion by measuring the length changes of concrete specimens. The alkali-silica reactivity of concrete means the probability of deleterious expansion or cracking due to alkali-silica reaction which will occur in the concrete in the future.

Note - In order to determine the alkali-silica reactivity of concrete correctly, it is desirable to accomplish the determination tests on the concrete specimens made using the same materials and mix proportion as actual concrete. The concrete method proposed here is a test method to determine the alkali-silica reactivity of concrete of any mix proportion. In this method an accelerated condition including an addition of alkali and the storage of specimens at the temperature of 40°C and the relative humidity of 100% was adopted in order to obtain the test results as early as possible.

2. Apparatus

2.1 Molds - Molds for test specimens shall provide for 100 mm by 100 mm by 400 mm prisms or 74 mm by 75 mm by 400 mm prisms. Each end plate of the molds shall have holes for fixing the gauge plugs to be embedded in prisms which are used for measuring the length change of concrete.

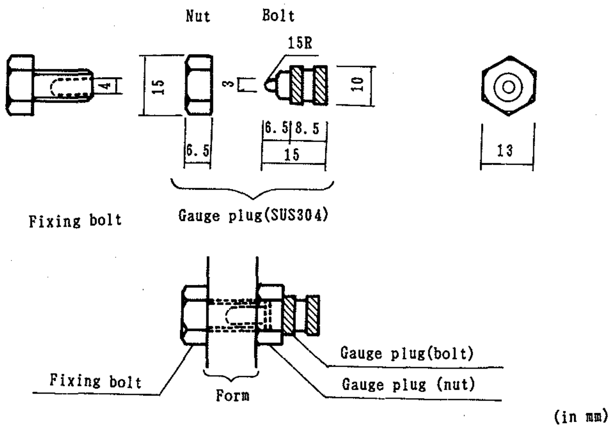
2.2 Length Comparator - The procedure for measuring length changes of specimens shall follow the dial gauge method prescribed by JIS A 1129. The comparator shall provide the dial gauge graduated to read in 0.01 mm units, accurate within 0.01 mm, specified by JIS B 7503.

2.3 Gauge Plugs - Gauge plugs shall be embedded at both ends of the longitudinal axis of test specimens. The gauge plugs shall be made of corrosion-resistant metal.

Note - Many gauge plugs shapes have been proposed and improved by various research institutes. Among those gauge plugs, the type illustrated below is recommended; it does not protruded from the end surface of the specimen and so results in no damage to the plug for duration of the testing period; it can be screwed firmly to the forms to allow for the dense placement of concrete around the plug by compaction using vibrators.

2.4 Covering Materials - The paper for covering test specimens shall be of high water retention, big enough to cover the entire surface of the specimen, and of the quality which does not deteriorate with alkalis during storage. The net bag for wrapping the specimens covered by the paper shall be elastic and non-corrodible by alkali. The polyethylene bag for preventing water evaporation from the specimens wrapped by the paper and net bag shall be thick enough to stand the weight of specimens and big enough to cover and seal the entire specimens.

Note - For the material to keep the surface of specimens wet, high water-retentive sheets or non-woven fabric of 100% polypropylene is desirable.



An Example of a Gauge Plug

3. Materials

3.1 Concrete - Ready mixed concrete or concrete made using the same materials as those of concrete to be tested shall be used.

3.2 Sodium hydroxide - Sodium hydroxide reagent complying with Specification JIS K 8576 shall be used.

4. Test Specimens

4.1 Mix Proportion of Concrete - Mix proportion shall follow the same mix proportion of the ready mixed concrete or the concrete to be tested. The alkali to be added to the concrete shall be sodium hydroxide. The dosage of sodium hydroxide shall be 2.4kg Na_2O equivalent per 1 m^3 of concrete for each batch.

Note - In general the more alkali content is in concrete, the greater the magnitude of the expansion due to alkali-silica reaction. However, in the concrete using aggregates which give the alkali pessimum phenomenon, the rate of expansion inversely decreases as the alkali dosage increases in the alkali content level exceeding the pessimum area. It is therefore necessary to examine with various alkali dosages in order to check the relationship between the alkali dosage and the rate of expansion.

From the results of the common tests for the concrete method, it was found that misjudgment for the alkali-silica reaction rarely happens with the alkali dosage of 2.40kg/m^3. On the other hand, in the concrete using reactive aggregate, the deleterious expansion appeared with a total alkali content exceeding 3 to 4 kg/m^3 Na_2O equivalent. Accordingly, it was decided to adopt 2.40kg/m^3 Na_2O equivalent of alkali dosage, which slightly exceeds the critical value, for determining whether the concrete causes deleterious reaction or not.

4.2 Procedure of Making Concrete Specimens - Although the method shall follow the same manner as making the concrete te be tested, in general it shall follow the method prescribed by JIS A 1138 and JIS A 1132.

The standard specimens shall be 100 mm by 100 mm or 75 mm by 75 mm in cross section and the length shall be 400 mm. The number of specimens for each individual test condition shall be three.

4.3 Procedure for Alkali Addition - Alkali addition shall follow either of the following two methods:

(1) All-in Method: Sodium hydroxide shall be added in the mixing water and concrete shall be mixed using this sodium hydroxide solution.

(2) Post Addition Method: Fine sodium hydroxide grain shall be added to the fresh concrete to be tested and the mixture shall be remixed in conformity with JIS A 1138.

Note - The post addition method can be applied for ready mixed concrete. For making specimens of 75mm by 75mm by 400mm using this method, measure 7 liters of fresh concrete with the container specified by JIS A 1128 and transfer it to a mixing plate in the first place. Then sprinkle 21.7g of fine grain of sodium hydroxide (2.40kg/m^3 Na_2O equivalent) over the concrete and quickly mix with a scoop to get the uniform mix for casting test specimens in molds. For making specimens of 100mm by 100mm by 400mm, measure the fresh concrete twice with the same container mentioned above.

5. Initial Length

The specimens shall be removed from the molds after at least 20 hours and within 24 hours and measured immediately for the initial length in conformity with JIS A 1129.

6. Storage of Specimens

6.1 Covering of Specimens - After the initial dial gauge reading, the surface of the specimens shall be covered with wetting paper containing water and then entirely wrapped with an elastic net so as to ensure close contact of the paper with the surface of specimens. Then the specimens shall be sealed in polyethylene bags to prevent the evaporation of moisture.

Note - Soak the wetting paper in water beforehand and squeeze loosely before use (It is desirable that each sheet of paper contains 100g of water.)

6.2 Procedure for Storage of Specimens - The specimens covered as above shall be stored in a storage vessel or thermostatic chamber where the temperature can be kept at 40±2°C. During storage, the specimens shall be kept so as not to touch one another and put on proper holders so as not to load the weight on the gauge plugs.

7. Measuring Items and Procedure

7.1 Measuring Items - Length changes of specimens shall be measured at the given ages. At the same time, the surface of the specimens shall be observed to see whether cracking or leaching of gel appears and the ages of their first appearance shall be recorded.

7.2 Measuring Procedure - Length changes shall be measured in a thermostatic room controlled at 20±3°C in conformity with JIS A 1129.

The specimens shall be taken out of the storage condition and cooled down without removing the covers in the measuring room for 24 hours before measuring in order to bring the temperature of specimens close to the temperature of the room.

7.3 Ages for Measurement - Dial gauge readings of each specimen after periods of storage of 1, 2, 3, 4, 5, and 6 months as well as initial reading shall be recorded to obtain the length change.

8. Calculation of Expansion Ratio

Based on the dial gauge readings, the rate of expansion shall be calculated to 0.001% according to the following equation:

$$\text{Expansion Rate } (\%) = \frac{(X_i - sX_i) - (X_{ini} - sX_{ini})}{L} \times 100$$

X_i : Dial gauge reading of the specimen after a period of storage i
sX_i : Dial gauge reading of standard scale at age i
X_{ini} : Dial gauge reading of the specimen when demolded
sX_{ini} : Dial gauge reading of standard scale when the specimen was demolded
L : Effective gauge length (distance between both ends inside the plugs)
(Units of X_i, sX_i, X_{ini}, sX_{ini}, and L shall be the same.)

9. Determination

When the average expansion rate of 3 specimens after 6 months is less than 0.100%, the concrete considered shall be determined "innocuous". When it is equal to or more than that, the concrete shall be determined "reactive".

Note - The critical rate of expansion used for the determination of alkali-silica reactivity was laid down at 0.10% in consideration of the following items:

a) The rate of expansion is to be big enough to cause identifiable cracks.
b) The rate of expansion is to be big enough to get reliable results taking the accuracy into account.
c) The concrete in which alkali-silica reaction is realized in actual structures is to be determined as "reactive" by this rate of expansion.
d) The concrete made using aggregate which does not contain any alkali-reactive mineral and was judged as "innocuous" in the chemical method and/or the mortar bar method is to be determined as "non-reactive" by this rate of expansion.

10. Accuracy

The rate of expansion of an age must not be lower than that of the former age. However, the result is considered to satisfy the tolerance of accuracy if the gap is less than 0.010%.

11. Report

The report shall include the following:
(1) Date of measurement.
(2) Name of the person who carried out the test.
(3) Sources and rock groups of fine and coarse aggregate.
(4) The test results and judgment of the chemical method (JCI AAR-1), the mortar bar method (JCI AAR-2), etc.
(5) Types of cement and admixtures and their alkali content.
(6) Mix proportion of the concrete.
(7) Dimensions of concrete specimens.
(8) Method of alkali addition (All-in method or post addition method).
(9) Rates of expansion and their average values of specimens of each age, and judgments.
(10) Important matters obtained from the observation of specimens during and after the test.
(11) Chart of relationship between the rate of expansion and storage time.