AAR in Chinese Engineering Practices

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Abstract

This paper summarizes studies on AAR in Chinese engineering practices during the last thirty years including, reactive aggregates, inhibiting measures, case histories and a discussion on specifications for construction with reactive aggregate.

Introduction

Since the recognition of AAR, many countries have paid great attention to the deterioration of concrete structures due to AAR. One of the typical cases of affected concrete structures is Prum Afterbay Dam in United States which was pulled down and reconstructed. Idorn's statistics (1) show that throughout the world more than five hundred structures were damaged by AAR.

China took interest in AAR in 1953 and the problem of AAR was submitted to the First Scientific Research conference of the Three Gorge Project in 1958.

From 1959 to 1963 three symposia pertaining to AAR involved in the dam concrete design for the Three Gorge Project were convened to discuss reactive aggregates, reaction mechanism, expansion mechanism and inhibiting measures. After that, a great effort was made to study AAR in concrete structures, especially, those in hydroelectric projects.

After 1964, the number of researchers of AAR decreased and as a result, the research work on AAR for most Chinese hydroelectric and other projects was done in our institute. About fifty projects, including two foreign projects, in which AAR was thought to be involved were investigated.

Reactive Aggregates

The reactive aggregates which have been identified in China are classified as follows.

1 Chert - Various types of chert are more widely distributed in China than any other type of reactive aggregate. Chert is mainly composed of chalcedony and can be divided into several types according to its colour, appearance and, especially, its reactivity.

(1) Gray (or dull yellow) chert - This chert contains more than 90% chalcedony with split - type fracture. Some may contain more than 10% opal and other samples may contain fossil crustaceans. It contains little impurity, and is highly reactive. The Sc and Rc of this chert were determined in accordance with ASTM C289-71 as shown in Table 1.

(2) Black chert - This is a black rock with shell-like fracture. It contains many impurities such as quartz, calcium carbonate etc. It is less reactive than gray chert, some are nonreactive (Table 1).

Table 1. The Reactivity of Reactive Aggregates

Reactive Aggregate	Sc (Millimoles/Liter)	Rc(Millimoles/Liter)
1. Gray(or dull yellow)chert	500.0-844.0	104.0-202.0
Black chert A	70.0-379.0	26.0-204.6
Black chert B	23.8-43.0	55.2-312.9
2. Rhyolite	46.0-76.0	41.0-378.0
3. Tuff A	114.3	88.4
Tuff B	86.9	16.4
Tuff C	13.5-48.3	47.0-110.0
4. Andesite A	269.0	100.3
Andesite B	19.8-33.4	37.4-173.7
5. Dacite A	288.0	178.7
Dacite B	38.7	85.8
6. Siliceous Slate A	157.0-297.0	71.0-91.0
Siliceous Slate B	43.6	85.4
7. Other Siliceous Slate	104.0-112.0	37.0-74.0

(3) Agate and jasper - Agate and jasper are all the varieties of chert, the former has a beautiful colour with a texture of concentric circles, the latter is a form of chert and contains some iron oxide.

2. Rhyolite - Rhyolite with spotted texture is one of the potentially reactive aggregates which is widely distributed in China. A few rhyolites are moderately reactive, most are nonreactive due to devitrification (Table 1).

3. Tuff - Tuff is widely distributed in China. Most tuff is nonreactive, only a few are reactive (Table 1).

4. Andesite - Andesite has a spotted texture and its matrix is cryptocrystalline. It is generally nonreactive, but some exhibit high reactivity (Table 1).

5. Dacite - Dacite is rare in China. It has a spotted texture and its matrix is cryptocrystalline. Some samples exhibit some reactivity, others are nonreactive (Table 1).

6. Siliceous slate - Siliceous slate is widely distributed in China. Cryptocrystalline SiO_2 accounts for 80-90% of the rock. It is reactive, but some are nonreactive (Table 1).

7. Other siliceous rocks identified in China are chiefly composed of cryptocrystalline SiO_2 and are reactive (Table 1).

Inhibiting Measures

AAR and the resulting deleterious expansion depends on a number of factors. Thus, it could be possible to suppress this reaction by controlling these factors.

There are various inhibiting measures and those commonly used in China are:
1. The use of low alkali cement - The alkali content of low alkali cement is specified in China as 0.6% as is commonly adopted by many countries. The alkali content of slag cement is specified as 1.0%. Different alkali contents are specified for different cements, as will be discussed later.

2. The use of pozzolanic admixture - The effectiveness of pozzolanic admixtures in reducing expansion is due to their much greater surface area compared to that of reactive aggregates. They can therefore react quickly with alkali, so that the alkali is soon consumed. Therefore, various types of admixtures are used as partial replacements in the cement to suppress adverse AAR.

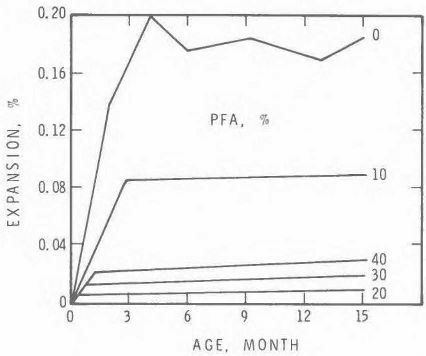

FIGURE 1. Influence of fly ash on expansion due to AAR

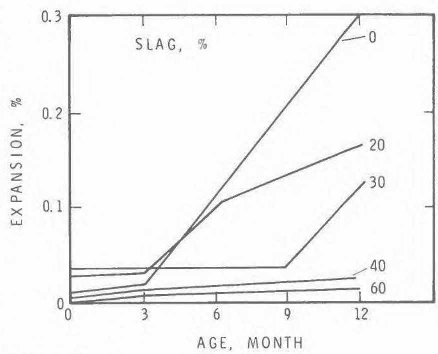

FIGURE 2. Influence of slag on expansion due to AAR

The admixtures commonly used in China are as follows:

(1) Flyash - Flyash is widely used to suppress AAR. Low calcium flyash is used in China. The content of CaO is less than 5%. Flyash from different sources could be used to suppress AAR, if its quality is up to the standard. But the typical curves of Fig. 1 show that if its replacement level is too small, it is not effective in preventing damaging expansion. The lowest replacement level of flyash used as an inhibiting material is specified as 20% in China.

(2) Blast furnace slag - Slag is also used to suppress AAR, but it must be added in greater quantities (Fig. 2). In order to suppress AAR the slag content of cement is generally specified as 40 - 50% in China.

(3) Burnt clay - Burnt clay, including kaolinite, montmorillonite etc., exhibits reactivity after calcining at 600-700°C (Fig. 3). It is a pozzolanic material and can be found everywhere in China. Its replacement level is 20-30% when used as inhibiting material; it is seldom used.

(4) Reactive aggregate powder - Powdered reactive aggregate is a good admixture and can be used to suppress adverse AAR. For use in construction diatomaceous earth, perlite etc. are tested in the laboratory. All these are effective in preventing deleterious expansion (Fig. 4).

3. Other measures - AAR may be deleterious or not depending on the combination of the type, grain size and quantity of reactive aggregates, the quantity of cement and the total alkali content (including alkali content of cement and the cement content of concrete). By varying one factor or several factors, it is possible to suppress the adverse AAR. For example, the total alkali content could be reduced to the safe alkali content by controlling alkali content of cement or the quantity of cement, or both. If the total alkali content in concrete is constant, we may vary the grain size and quantity of reactive aggregates. On the other hand, if the type, grain size and quantity of reactive aggregate are constant, we may reduce the total alkali content with the measures mentioned above.

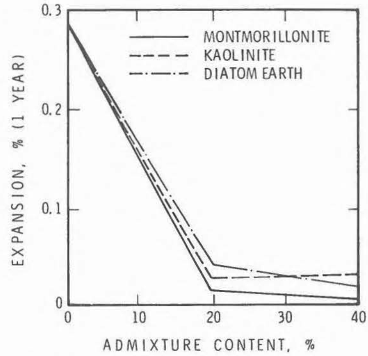

FIGURE 3.
Influence of burnt clay and diatomaceous earth on expansion due to AAR

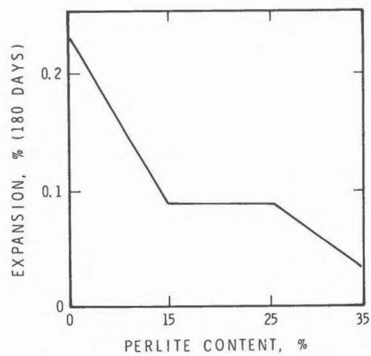

FIGURE 4.
Influence of perlite on expansion due to AAR.

Case Histories

Case I - The concrete of Danjiangkou Dam contains some highly reactive gray chert and less reactive black chert. Fig. 5 shows that deleterious expansion will be caused, when the alkali content of cement is above certain values. But, there is no evidence of AAR in the dam after over twenty years because slag cement and low alkali cement were used in the interior and outer parts of the concrete dam respectively. It is demonstrated that such two types of cement can be used as inhibiting materials.

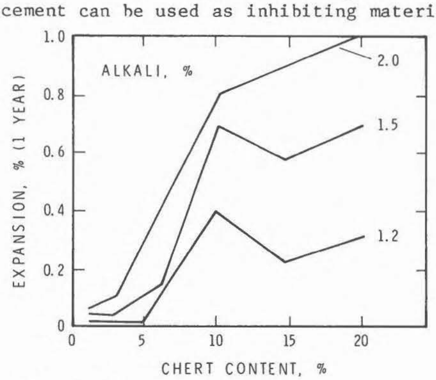

FIGURE 5.
Effect of DanJiang Kou chert on mortar expansion

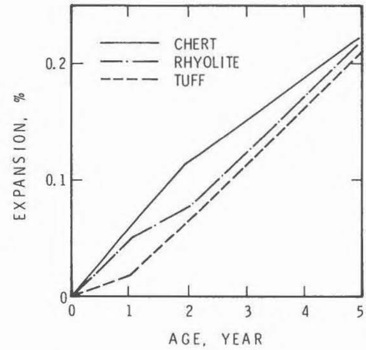

FIGURE 6.
Dangerous long term expansion of mortar.

Case II - The concrete of San Men Xia Dam also contains some reactive aggregates. Flyash was used as 40% replacement in the cement. There is no evidence of AAR after the dam has operated for thirty years. It may be concluded that flyash is an inhibiting material.

Case III - The concrete of Zhe Xi Dam contains chert aggregate. The dam was constructed in 1958. But there is no evidence of AAR. It is due to the addition of 20-30% burnt clay pozzolan to the concrete.

Case V - When Xiao Feng Man Dam was heightened, significant pattern cracking developed. It was guessed that the cracking was caused by AAR, as coarse aggregates contain up to 25% of rhyolite, tuff and dacite. Several field investigations have been made on the dam, but no reaction products of AAR are evident. Chemical method and bar tests show that the aggregates are not reactive. Cores (a total length of 173 meters) were examined. No evidence of AAR was found, except that the white matter contained in several voids in one part consists of silicon ions and sodium ions and one grain of sand has reaction rim. Consequently, it was concluded that the pattern cracking at the crest of the dam is not due to AAR.

In the four cases mentioned above, the first three cases show that the inhibiting measures taken in China are effective, while the fourth indicates the AAR problems are considered seriously in Chinese engineering practice.

Problem with Mortar Bar Test

The mortar bar test, ASTM C227, is the most widely used method of evaluating the potential alkali reactivity of aggregates. The criteria for evaluation of the results of the mortar bar test are given in ASTM C33-76a. According to ASTM C33-76a expansions should not exceed 0.1% at six months.

According to the engineering practice in China, the criteria are applicable, but with some exceptions. Mortar tests show (Fig. 6) that expansion does not exceed 0.1% at six months or even at one year, but expansion is increasing with age and greatly exceeds 0.1% afterwards. Bending cracking, white secretion etc. may appear as evidence of AAR. Consequently, if the concrete of the structure in the field is similar to that in laboratory experiments, deleterious AAR might occur in the structure.

Conclusions

1. From the viewpoint of chemical reactivity, reactive aggregates found in China are of the alkali-silica type. These aggregates include chert, rhyolite, tuff, andesite, dacite, siliceous slate and other siliceous rocks.

2. Deleterious AAR can be suppressed by use of low alkali cement (alkali content less than 0.6%), by use of slag cement containing not less than 40% slag with an alkali content of less than 1.0% or pozzolanic admixtures such as flyash, slag, burnt clay or powdered highly reactive aggregates in suitable amounts.

3. Deleterious AAR has not occurred in concrete structures in China. The reason is that reactive aggregates are identified before construction is started and then inhibiting measures are taken to prevent expansion.

4. The criteria for evaluating the potential alkali reactivity of aggregates given in ASTM C33-76a are not applicable to all Chinese aggregates.

Reference

(1) G.M. Idorn 1977. Translation of G.M. Idorn's Papers, Nanjing Institute of Chemical Technology, 1983.