Durability Enhancement of Concrete Dams by Controlling and Mitigating Aar Problem

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Abstract

Many concrete dams have suffered from heavy deterioration due to Alkali Aggregate Reaction(AAR). The alkali aggregate reaction occurs between the alkalies in cement paste and reactive minerals in the aggregate produces expansive gel resulting in map cracking and low service life of concrete dams. Researches show that a solution for controlling or mitigating this problem is the usage of appropriate supplementary cementing materials in the mixture design of concretes. This paper discusses the effectiveness of various artificial and natural pozzolans as supplementary cementing materials in controlling AAR expansion for various reactive aggregates. Petrographic examination of aggregates was carried out to determine the types of active minerals. Accelerated mortar bar and concrete prism methods were used to evaluate the reactivity of aggregates. Results of the tests show that for each pozzolan there would be an optimum content to be effective in suppressing AAR expansion in accelerated test method. Results of the long-term prism method show that the expansion is not only related to the type and quantity of the supplementary cementing materials but also depends upon the type and the minerals of the aggregates. However, reactivity of some aggregates may be controlled by the optimum content of each pozzolanic materials. It is also concluded that individual evaluation test method may not be suitable for some aggregates and final assessment should be based on different test methods.

Keywords: Alkali Aggregate reaction, concrete Dams, Mitigation, Deterioration, Pozzolans.

1. INTRODUCTION

The alkali-silica reaction (ASR) that occurs between the alkali hydroxides in cement paste and reactive minerals in the aggregate produces expansive gels that cause cracking and displacement in concrete structures. Preventive methods for protecting concrete from the onset of alkali-silica reaction include limiting the use of reactive aggregates, using low-alkali cements, and application of chemical and mineral admixtures. One of the best methods for improving the quality of concrete and controlling deleterious ASR is through the use of supplementary cementing materials. Many different mechanisms have been proposed to explain the effectiveness of supplementary cementing materials against alkali aggregate reactivity, namely higher strength, lower permeability, consequent lower ion mobility, portlandite reduction in the cement paste and alkali reduction in the pore solution are all important factors. The most critical of these factors includes total alkali reduction of the cement matrix and consequent pH decrease in the pore solution as a result of alkali reduction of or entrapping of alkali ions in calcium silicate hydrate [1,2,3]. It is important to note that these materials must be used correctly and in recommended dosages.

Mineral pozzolanic admixtures such as fly ash, silica fume (SF), natural pozzolan, slag, rice husk ash, and highly reactive metakaolin (HRM) have been recommended and used for the mitigation of the deleterious effects of ASR in concrete [4,5] have shown that silica fume (SF) must be used at replacement levels exceeding 10% by mass of cementing materials. Replacement levels in excess of 50% FA or 10% SF may not be acceptable for many construction purposes and this presents a barrier to the wider use of these materials for controlling ASR.

It is generally accepted that the use of natural pozzolans in cement or concrete systems results in low alkali–silica activity [5,6]. In a study carried out by Uzal et al. [7], natural pozzolan has the potential to be used at higher volumes in blended cements for structural concrete applications. They showed that blended cements containing 35%, 45%, and 55% natural pozzolan has excellent performance for suppressing the expansions caused by alkali–silica reaction.

Natural pozzolans are available at limited regions of the world. Chemical properties and the Pozzolanic activities of natural pozzolans vary depending on the region of the source [5]. All natural pozzolans are not equally effective in combating alkali-carbonate and alkali–silica expansions. The importance of using natural pozzolans in the cement industry requires a complete evaluation of their effects on concrete.

Iran is rich in natural pozzolans such as volcanic tuffs (Trass), pumicite (Taftan and Sabalan) and some diatomaceous earths (Mamaghan, Azarshahr) deposits. Some of these natural pozzolans are currently being used to produce blended cements by local cement manufacturers. According to the previous studies[8], Iranian natural pozzolans are competitive with other natural pozzolans in the world because of high amount of active silica and also the high alumina content. The effect of natural Iranian pozzolans on mitigation of alkali-carbonate and alkali-silica reactions has not been well documented; despite the limited works conducted on the use of natural pozzolans as a cement replacement material in concrete. Also the mechanism by which natural pozzolans affect the alkali-carbonate reactions is not yet fully understood.

Many test methods and guidelines for the prevention of alkali aggregate reaction in new concrete structures have been adopted by various national and international organizations around the world [9]. Most of these standards and guidelines are dealing with alkali-silica reaction. The tests are usually carried out by a number of accelerated and long term laboratory methods. Prior to mortar bar and concrete prism tests, petrography examination, chemical tests are carried out. They have given satisfactory results for some aggregates, while in a number of cases and for aggregates in different parts of the world test results were not reliable [10].

A large number of concrete dams and other concrete structures in the world are suffering from deterioration induced by AAR reaction that impair the durability, serviceability, and also endanger the safety of the structures in future. Most of the aggregates used for the construction of these structures and those for dams to be constructed in the future are reactive aggregates.

The aim of this investigation is to study the effectiveness of natural pozzolans to control the alkali-silica reaction of some reactive aggregates from different sources, which have been considered as concrete aggregates for construction of dams. petrographic examination, accelerated mortar bar test, and concrete prism test were used throughout this investigation.

The use of natural pozzolans as a reasonable method to control the expansion of concretes as a result of ASR has been studied in accordance with ASTM C 1293 and ASTM C 1260, however the accelerated mortar bar test method (ASTM C 1260) has been recognized not to be suitable to determine the effect of cement replacement materials and also it is recommended to measure the expansion of concrete prisms at least for two years [11,12]

2. Test Results and Discussion

Results of the expansion of mortar bar specimens containing various aggregates are illustrated in Figs.1 and2. The length changes of at least two specimens for each aggregate are shown in these figures. It can be seen that the expansion of mortar bars containing fine and coarse aggregates have exceeded 0.25 percent after 14 days. Thus from the results of the mortar bar accelerated test, three aggregates were classified as highly reactive.

In order to investigate the effect of natural pozzolans on mitigation of alkali aggregate reaction, mortar bar test was carried out on specimens containing pozzolanic cements at 15 and 30 percent replacement level. Test results are depicted in Figs.3 and4. From the results it is obvious that significant reduction in expansion can be obtained in all concrete mixtures containing natural pozzolans. Mortar mixtures containing natural pozzolans at the 15% replacement level have shown expansion higher than 0.1 percent limitation after 35 days. However, in mortar mixtures containing higher amounts of natural pozzolans (30%), the expansion is below 0.1 percent which indicates the ability of pozzolans to control ASR in accelerated mortar bar test.

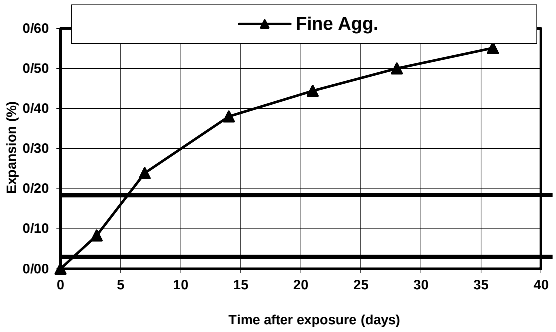

Figure 1. Expansion of mortar bars made with Fine Agg

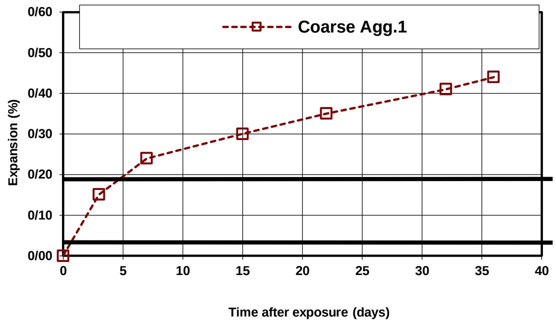

Figure 2. Expansion of mortar bars made with Coarse Agg.1

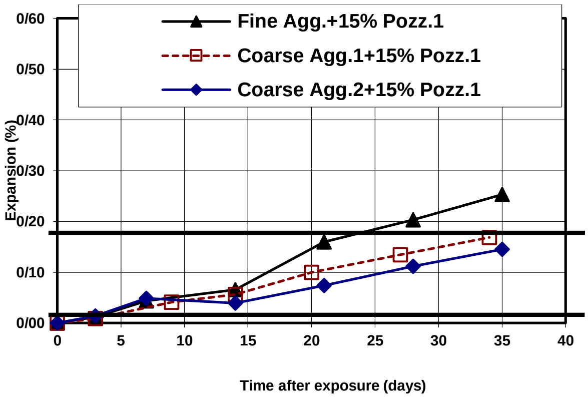

Figure 3. Expansion of mortar bars made with 15% pozzolan

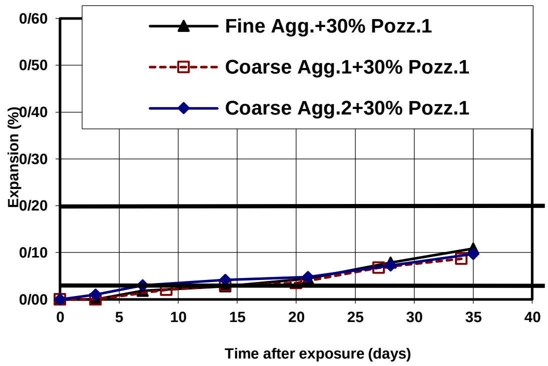

Figure 4. Expansion of mortar bars made with 30% pozzolan

Results of expansion of concrete prisms incorporating reactive sand with and without natural pozzolans at various ages up to 270 days are illustrated in Figs.5 and6. In specimens containing natural pozzolans, 30 percent pozz-1 natural pozzolan was replaced with cement. It is clearly seen that in concrete mixtures containing 30 percent natural pozzolans, expansions of all specimens are less than 0.04 percent at this age. However, expansions after one and two years will show how pozzolans can control the ASR.

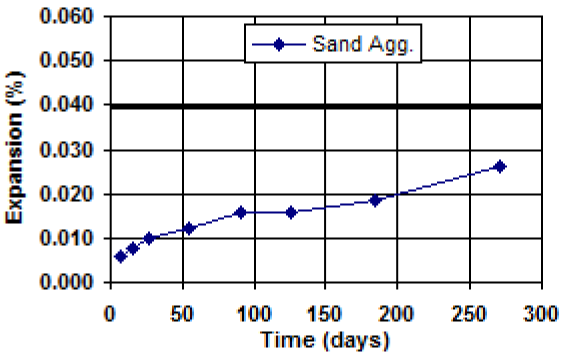

Figure 5. Expansion of prisms made with sand

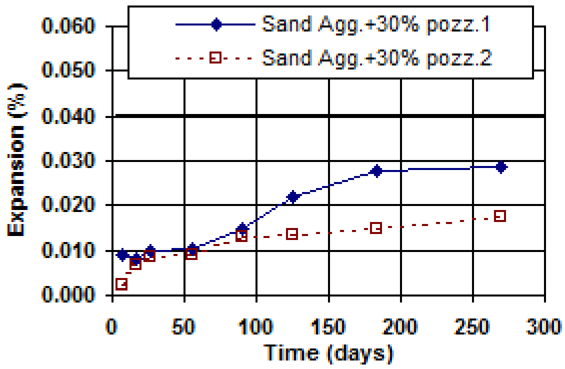

Figure 6. Expansion of prisms made with 30%pozzolan

In another research, results of 56-day mortar bar expansion of specimens containing various amounts of natural pozzolan and a reactive carbonate aggregate are presented in Fig 7.

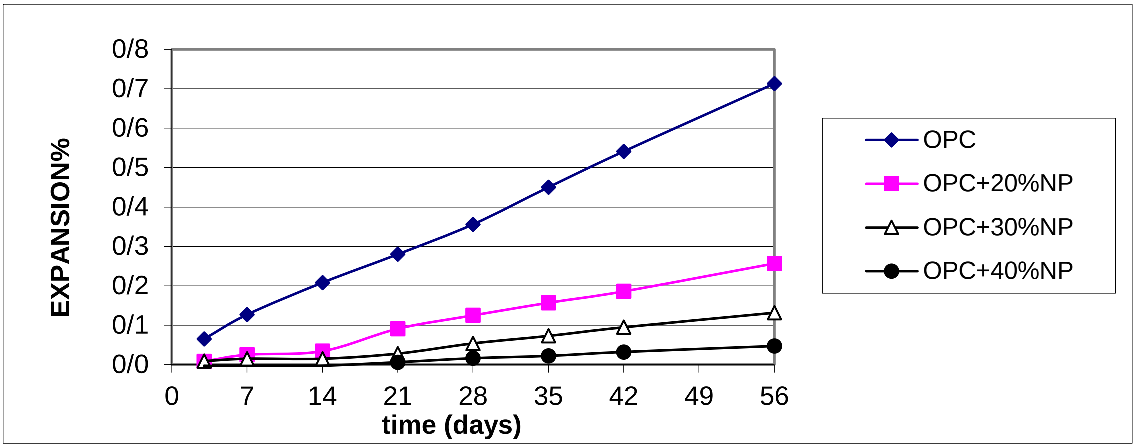

Figure7. Results of accelerated mortar bar tests containing natural pozzolan

As seen in Fig 7, the expansion rate of the control sample is about 0.21% for 14 days which is categorized as extremely reactive aggregates based on ASTM C1260 standard. This sample expands about 0.71% at 56 days and will expand more at longer ages.

Mortar bars containing natural pozzolan have lower expansion at all ages and show a reduction of 64%, 79% and 93% for pozzolan's content of 20%, 30% and 40% respectively after 56 days under ASTM C1260 standard. This reduction in expansion is about 84%, 89% and 99% after 14 days respectively. The results of one-year test based on ASTM C1293 shows that natural pozzolan has marginally reduced the expansion (see Fig.8).

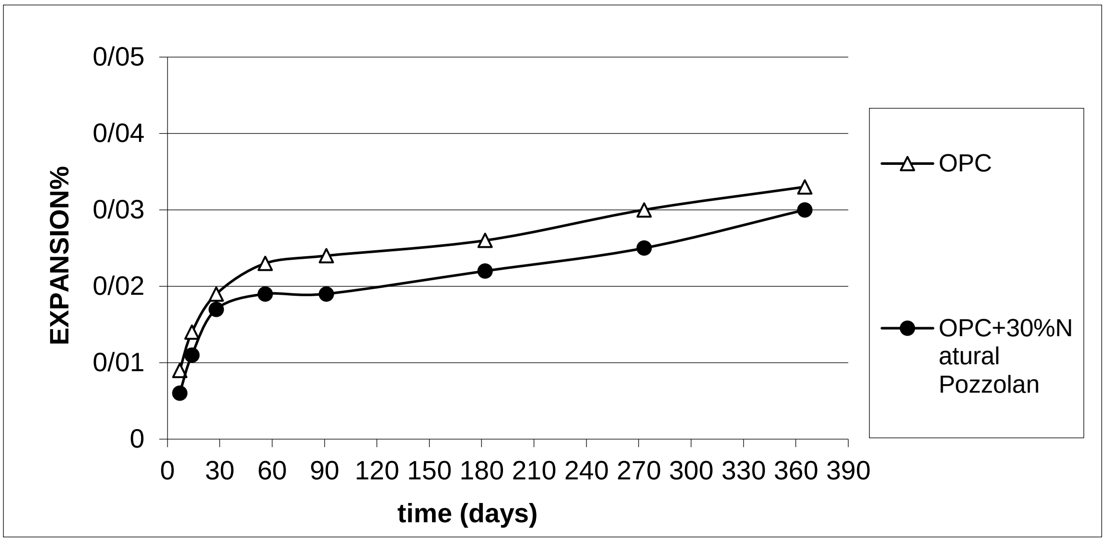

Figure 8. Results of long term expansion of specimens containing natural pozzolan

In an investigation the results of concrete prism test indicate that the expansion of specimens can be controlled by addition of trass as a natural pozzolans at 20 and 30 percent replacement [66]. This is clearly seen in Figure 9.In general, the effect of natural pozzolans to suppress alkali silica reaction depends on the reactivity of aggregate, the level of natural pozzolan replacement, the equivalent alkali content of cementitious composition and the activity index of natural pozzolan. The maximum reduction of concrete prism expansion compared with control sample increases with an increase in activity index of natural pozzolan. It was also concluded that the expansion of specimens is declined by increase of natural pozzolan replacement level, while in some cases a pessimum amount in natural pozzolan replacement level exists.

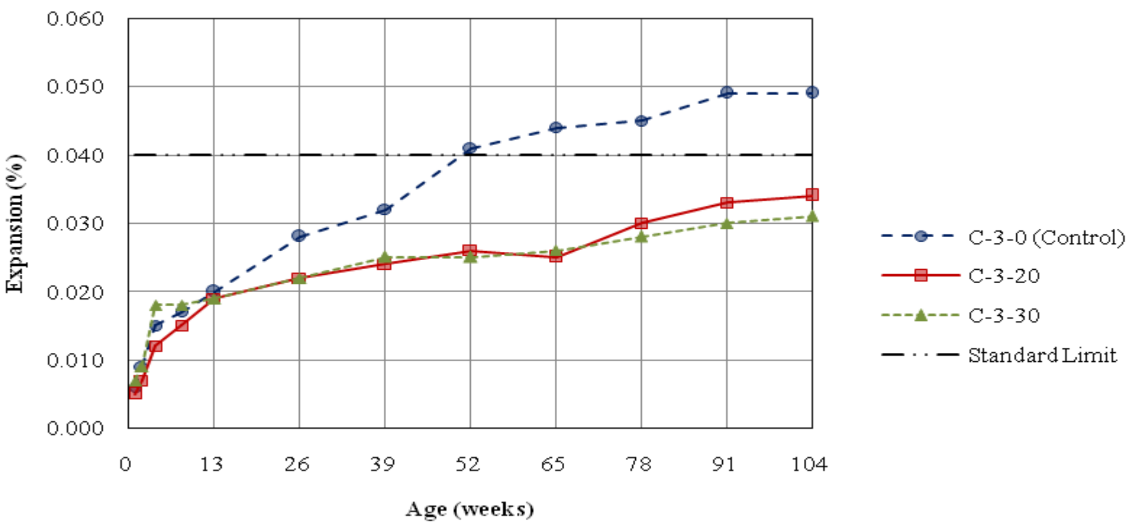

Figure 9. Effect of a natural pozzolan on expansion reduction of concrete prisms up to 2 years

3. CONCLUSIONS

From the test results obtained in this investigation, the following conclusion can be drawn:

1. For the assessment of alkali silica reaction of siliceous aggregates, the application of the ASTM C 289 chemical test method should be followed by the accelerated mortar bar and concrete prism tests.

2. Incorporating natural pozzolans in the mixes can reduce the expansion of mortar specimens containing highly reactive aggregates.

3. The use of 15% natural pozzolans in the mixtures seems to be not sufficient to control the expansion of mortar bars in accelerated tests.

4. When using highly reactive aggregates, it is recommended to incorporate 30 percent or more natural pozzolans in concrete mixtures to control the alkali silica reaction.

5. The results of accelerated mortar bar test method are approximately the same for a constant natural pozzolan replacement with an individual aggregate. It means that this test method is not an appropriate method to assess the influence of natural pozzolans replacement on expansion due to ASR. Nevertheless, the AMBT method is a suitable accelerated method to distinguish reactive aggregates.

6. The results of concrete prism test indicates that the expansion of specimens does not cease at 52 weeks. The growth of expansions, however, is declined significantly at the age of 104 weeks. Therefore it is recommended to measure the expansion of concrete prisms which contain natural pozzolans as a part of their cementitious composition up to two years.

7. In general, the effect of natural pozzolans to suppress alkali silica reaction depends on the reactivity of aggregate, the level of natural pozzolan replacement, the equivalent alkali content of cementitious composition and the activity index of natural pozzolan.

8. The maximum reduction of concrete prism expansion increases with an increase in activity index of natural pozzolan.

9. The expansion of specimens is declined by increase of natural pozzolan replacement level, while in some cases a pessimum amount in natural pozzolan replacement level exists.

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