Alkali-Silica Reaction (ASR) Control in Concrete by using different Portland Cement

Ravi Agarwal, Nisheeth Agnihotri, U S Vidyarthi

***Abstract*— Alkali-silica reaction (ASR) is the chemical reaction that occurs between alkali cations and hydroxyl ions in the pore solution of hydrated cement paste and certain reactive silica phases present in the aggregates used in concrete. Most aggregates are chemically stable in hydraulic cement concrete without deleterious interaction with other concrete constituent materials. Alkali silica reaction is potentially a very disruptive reaction within concrete in which silica reacts with alkalis to form a gel which expands and disrupts its mechanical properties. The aim of the current study was to determine the effect of using Ordinary Portland Cement, Portland Pozzolana Cement and Portland Slag Cement on Alkali silica reaction expansion. The outcome of the study is presented in this paper which is effective in controlling Alkali silica reaction.**

***Keywords*— Alkali-Aggregate Reactions, Accelerated Mortar Bar, Aggregate OPC, PPC, PSC, Gel, Expansion.**

I. Introduction

The Alkali Aggregate Reactions (AAR) in concrete, the phenomenon has been subject to a great deal of research and has been recognized as a growing problem in many areas of the world. Alkali silica reaction (ASR) is potentially a very disruptive reaction within concrete. *The ASR forms a gel that swells as it draws water from the surrounding cement paste (has great affinity to moisture). In absorbing water, these gels can induce pressure, expansion, and cracking of the aggregate and the surrounding paste.* Presence of pore fluid, alkalis and ASR reactive aggregate in concrete will initiate such process of deterioration.

The three criteria required to initiate expansive ASR are:

1. Presence of reactive siliceous component(s) in aggregate;
2. Liquid medium with sufficient pH and alkalis; and
3. Sufficient moisture.

If any of these criteria are not met, then ASR will not occur.

The ratio of reactive alkalis to reactive silica surface area is crucial in ASR. However, dilution of alkalis by increasing silica content by using Portland Pozzolana Cement (PPC), Portland Slag Cement (PSC), Silica Fume (SF) etc retard the rate of ASR.

II. LITERATURE REVIEW

Portland cement is the main source of the alkalis. Ensuring sufficient surface area by varying the percentage (BS 3892 Part1) and type of fly ash provides an efficient method to prevent ASR. Small quantities of fine fly ash with low-reactivity aggregates and sufficient alkalis may be more susceptible to ASR, if the pessimum silica alkali ratio is approached. Even when total alkalis within the concrete are as high as 5 kg/m^3, fly ash has been found effective in preventing ASR (Alasali and Malhotra, 1991). The addition of fly ash reduces the pH of the pore solution to below 13 which prevents ASR. Researchers have categorized fly ash for usage for arresting ASR (Fournier and Malhotra, 1997). It is however suggested that to restrict ASR fly ash must comply with ASTM C618 (ACI *Manual of Concrete Practice*, 1994). Fly ash from bituminous coal sources (ASTM Class F) which is characterized by relatively low calcium contents (i.e. <10% CaO) is most effective in controlling expansion instead of those obtained from sub-bituminous or lignite coals [1–2]. The inferior performance of fly ash with calcium contents in excess of 25% may be largely ascribed to the pore solution chemistry. Such fly ash is not as effective in reducing the pore solution alkalinity of cement paste systems [3].

III. MATERIALS AND METHODS

A. Materials

1. Aggregates:

Coarse aggregate samples have been obtained from different quarries identified for the project. The project site is located near the Silli village in southern Bhutan. These coarse aggregate samples have been reduced to crushed sand sizes.

2. Cements

Three different types of cements viz. Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) have been used with aggregate for studying ASR. Alkali Content and Water Cement Ratio of these cements are presented in Table 1.

Table 1: Alkali Content and Water Cement Ratio of the Cements used

Type of Cement	**Cement Alkalies (Na_2O) equivalent**	**Water Cement Ratio**
OPC	0.60	0.40
PPC	0.85	0.40
PSC	0.73	0.40

B. Methodology

1. *Accelerated Mortar-Bar Test (AMBT):*

The accelerated mortar-bar test is quick, reliable and can characterize the potential reactivity of slow as well as fast reactive aggregates. Aggregates are crushed to sand sizes for mortar-bar expansion test. The mortar bars are stored in a 1N NaOH solution to provide an immediate source of sodium and hydroxyl ions to the bars. Temperature is maintained at 80°C to accelerate the ASR. Comparator readings are taken over a period of 14 and 28 days [4, 5]. Categorized the aggregate based on 14 days expansion observation in AMBT is presented in Table 2

Table 2: Categorized the aggregate based on 14 days expansion

Average Expansion at 14 days	Reactivity
Less than or equal to 0.10%	innocuous
Greater than 0.20 %	deleteriously
Greater than 0.10% but Less than 0.20%	susceptible to reactive

Test Conducted

The study has been carried out using different types of cements. The details of the test and material combination used are shown in Table 3.

Table 3

Tests	Ingredient Materials
ASR	Aggregate +OPC
ASR	Aggregate +PPC
ASR	Aggregate +PSC

2. *Petrographical Analysis*

Petrographic examination of aggregates is the important parameter for deleterious ASR. Petrographic evaluation provides important information about the types and quantities of minerals present in an aggregate.

Mineralogical Composition of Aggregate in table 4.

Table 4

Quarry	Strained quartz (%)	Undulatory extinction angle (in degree)	Name of Rock type/Mineral
A	45-50	31°-35°	quartzite
B	47-52	31°-41°	quartzite
C	35-40	25°-30°	quartzite
D	31-35	24°-26°	quartzite

As per IS 2386 [(Part VII) : 1963] aggregate containing more than 20 percent strained quartz and undulatory extinction angle greater than 15° causing deleterious reaction. From the mineralogical composition of the aggregate (Table 4) it reflects that the strained quartz percentage and the undulatory extinction angle exceed the critical limits. The ASR test results of aggregates with the OPC also confirm the samples falling in deleterious zone.

Figure 1. Alkali-silica gel extruded into cracks within the concrete

IV. RESULTS AND DISCUSSIONS

The reactivity of tested aggregate with different types of Portland cement have been measured by accelerated mortar bar test method. The reactivity of aggregate has been shown graphically in terms of observed expansion in figure 2 to 5. Based on 14 days expansion the cement-aggregate combination is classified in different zone of reactivity (Table 5).

Table 5

Quarry	Material Combination	% expansion after 14 days	Classification
A	Agg.+OPC	0.176	susceptible to reactive
	Agg.+PPC	0.042	innocuous
	Agg.+PSC	0.068	innocuous
B	Agg.+OPC	0.165	susceptible to reactive
	Agg.+PPC	0.045	innocuous
	Agg.+PSC	0.060	innocuous
C	Agg.+OPC	0.142	susceptible to reactive
	Agg.+PPC	0.030	innocuous
	Agg.+PSC	0.072	innocuous
D	Agg.+OPC	0.142	susceptible to reactive
	Agg.+PPC	0.052	innocuous
	Agg.+PSC	0.072	innocuous

1. *Quarry A*

The aggregate is indicative of both innocuous and deleterious with OPC while innocuous with both PPC and PSC. However PPC restricts the expansion due to ASR more than 25% in comparison to PSC at 14 days (Figure:2)

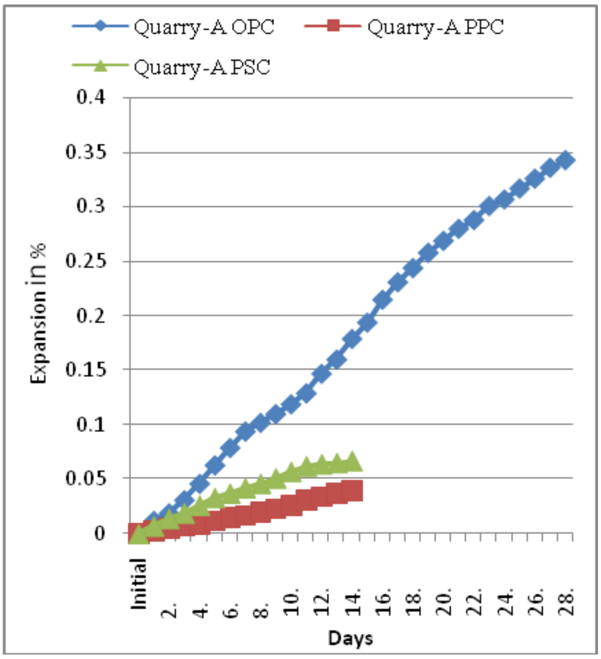

Figure: 2

2. *Quarry B*

The aggregate is indicative of both innocuous and deleterious with OPC while innocuous with both PPC and PSC. However PPC restricts the expansion due to ASR more than 15% in comparison to PSC at 14 days (Figure: 3)

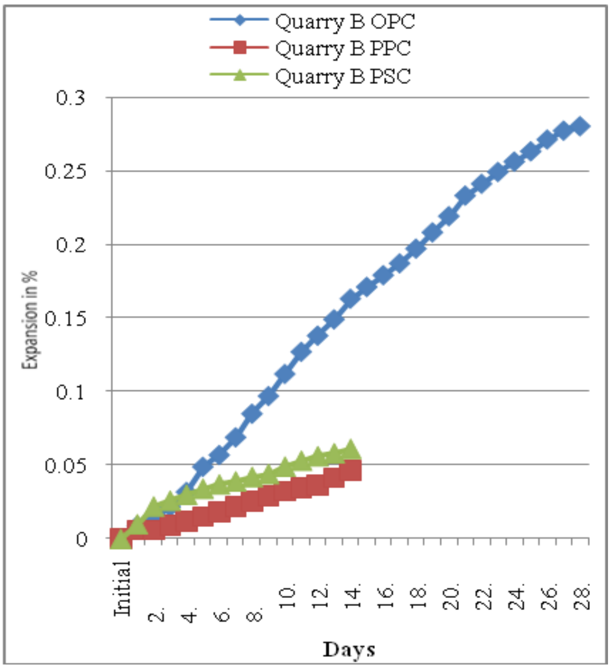

Figure: 3

3. *Quarry C*

The aggregate is indicative of both innocuous and deleterious with OPC while innocuous with both PPC and PSC. However PPC restricts the expansion due to ASR more than 68% in comparison to PSC at 14 days (Figure:4)

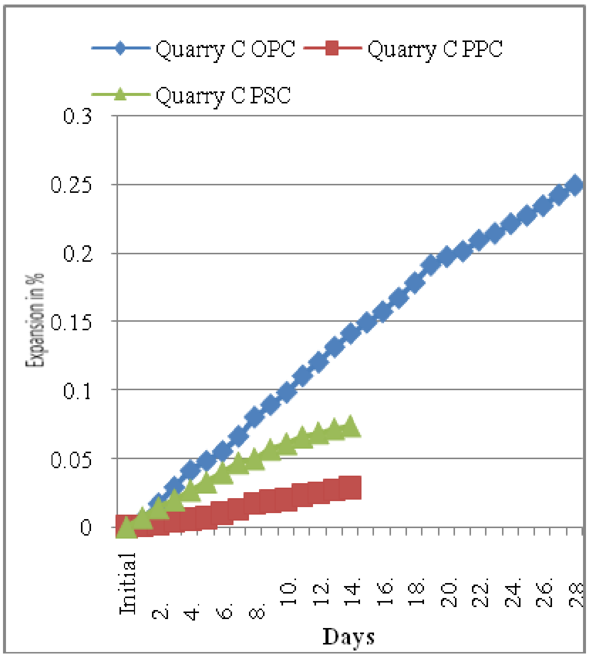

Figure: 4

4. *Quarry D*

The aggregate is indicative of both innocuous and deleterious with OPC while innocuous with both PPC and PSC. However PPC restricts the expansion due to ASR more than 29% in comparison to PSC at 14 days (Figure: 5)

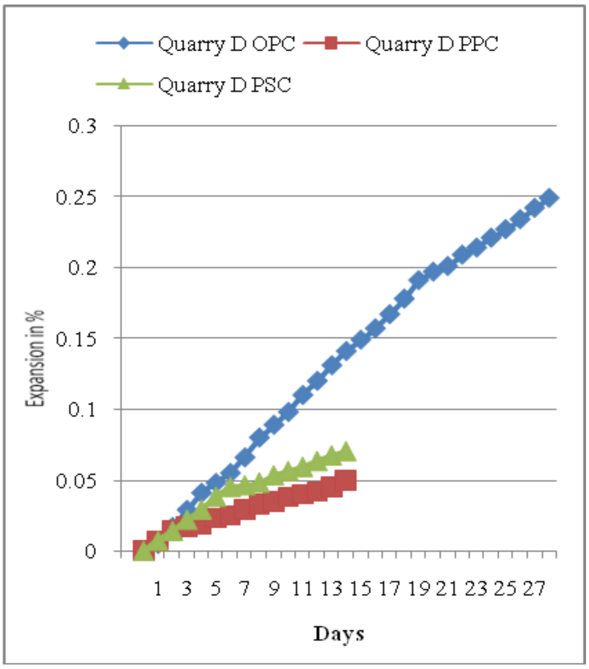

Figure: 5

V. CONCLUSION

Reactivity of these aggregate have been measured experimentally with the help of accelerated mortar bar test (AMBT) method as per *ASTM C 1260 & ASTM C 1567* and petrographical analysis as per ASTM C 295. The OPC-aggregate combination is found to be susceptible to reactive while the PPC is better in controlling expansion due to ASR in comparison to PSC.

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Ravi Agarwal[1], Nisheeth Agnihotri[2], U S Vidyarthi[3]

1,2,3 Central Soil and Materials Research Station, New Delhi, India