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Research Paper

COMPARATIVE STUDY OF THE EFFECT OF USING DIFFERENT TYPES OF PORTLAND CEMENT ON ALKALI-SILICA REACTION OF CONCRETE AGGREGATES: A COMPARISON

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Most aggregates are chemically stable in hydraulic cement concrete without deleterious interaction with other concrete constituent materials. However, this is not the case for aggregates containing certain siliceous minerals that react with soluble alkalies in the concrete. 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. Dilution of alkalis by increasing silica content using Portland Pozzolana Cement or Portland Slag Cement or some mineral additives like fly ash, Micro Silica, Metakaolin, etc., retards rate of Alkali silica reaction. The aim of the current study was to determine the effect of using Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) on Alkali silica reaction expansion. The outcome of the study is presented in this paper which is effective in controlling Alkali silica reaction.

Keywords: Accelerated Mortar Bar, Alkali-Aggregate Reactions, Ordinary Portland Cement, Portland Pozzolana Cement, Portland Slag Cement, Gel, Expansion

INTRODUCTION

Ever since T E Stanton (1940) first observed and diagnosed the Alkali Aggregate Reactions (AAR) in concrete, the phenomena have 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. It is observed that reactivity is greatest for a pessimum content of reactive aggregate. The ratio of reactive alkalis

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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. The aim of the current study is to determine the effect of using OPC, PPC and PSC with aggregate on ASR expansion.

When a new aggregate source is developed, the need for the material is immediate. Six to twelve month wait for test results is generally not acceptable. In some cases, concrete already placed may be questioned as to its reactivity. Therefore rapid test is need of the hour to determine whether an aggregate is potentially reactive or not. In study we have used ASTM C 1260/C1567, Standard Test Method for determines the Potential Alkali Reactivity of aggregates (Accelerated Mortar-Bar Test) and to evaluate the efficiency of mitigation using different types of Portland cement.

LITERATURE REVIEW

Portland cement is the main source of the alkalis. Adding fly ash (IS 1489 Part 1, 1991) induces dilution of the alkalis which disrupts ASR. Ensuring sufficient surface area by varying the percentage (BS 3892 Part 1) 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). Laboratory research (Thomas, 1996) and field experience (Thomas, 1996) supports that appropriate use of fly ash can prevent expansion due to ASR in concrete. 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 (Dunstan, 1981; Kleiger, 1987). 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 (Shehata, 1999). Greater proportion of the alkalis is available for ASR in these fly ash (Lee, 1989).

MATERIALS AND METHODS

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.

Different Type of 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 in the study

Type of Cement	Cement Alkalies (Na_2O) equivalent	Water Cement Ratio
OPC	0.62	0.45
PPC	0.88	0.45
PSC	0.75	0.45

METHODOLOGY

Accelerated Mortar-Bar Test (ASTM C 1260 and ASTM C 1567)

The accelerated mortar-bar (AMBT) 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 1 N 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 (Berube *et al.*, 1995; Thomas *et al.*, 1995). The test conditions are more severe than most field service environments. 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 presented in Table 3.

Table 3

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

Petrographical Analysis

Petrographic examination (ASTM C 295) of aggregates is one of the most reliable indicators of the potential for deleterious ASR. Petrographic evaluation provides valuable information about the types and quantities of minerals present in an aggregate. Strained quartz grains in the quartzite and the cracks within the concrete due to Alkali-silica gel is shown in Figures 1, 2 and 3.

Mineralogical Composition of the Aggregate used in study is presented in Table 4.

As per IS 2386 [(Part VII): 1963] aggregate containing more than 20% 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.

Table 4

Quarry	Strained quartz (%)	Undulatory extinction angle (in degree)	Name of Rock type
A	50-60	28°- 36°	quartzite
B	47-52	31°-41°	quartzite
C	45-50	31°-35°	quartzite
D	31-35	24°-26°	quartzite
E	35-40	25°-30°	quartzite
F	18-21	17°-21°	quartzite

Figure 1: Strained Quartz Grains in the Quartzite

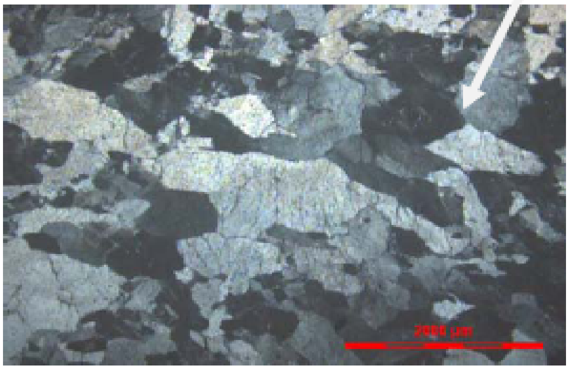


Figure 2: Alkali-silica gel extruded into cracks within the concrete

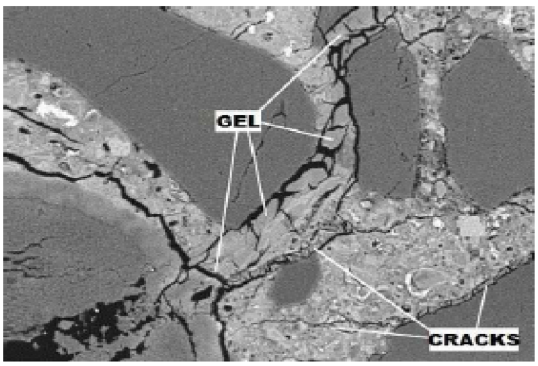
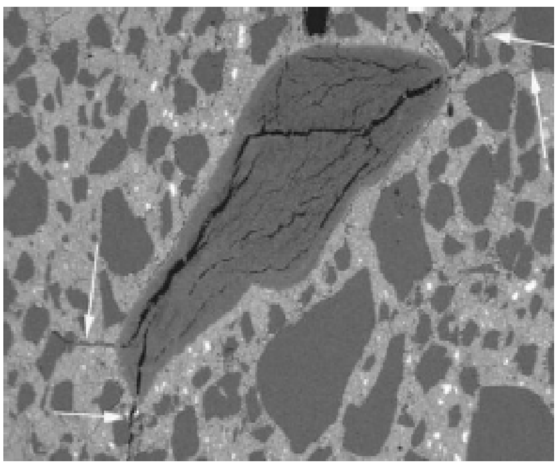


Figure 3: Aggregate particle with extending internal cracks due to ASR



RESULTS AND DISCUSSION

The reactivity of these aggregate with different types of cement have been measured by accelerated mortar bar test method. The reactivity of aggregate has been graphically presented in terms of observed expansion in Figure 4 to 9. Based on 14 days expansion the cement-aggregate combination is classified in different zone of reactivity (Table 5).

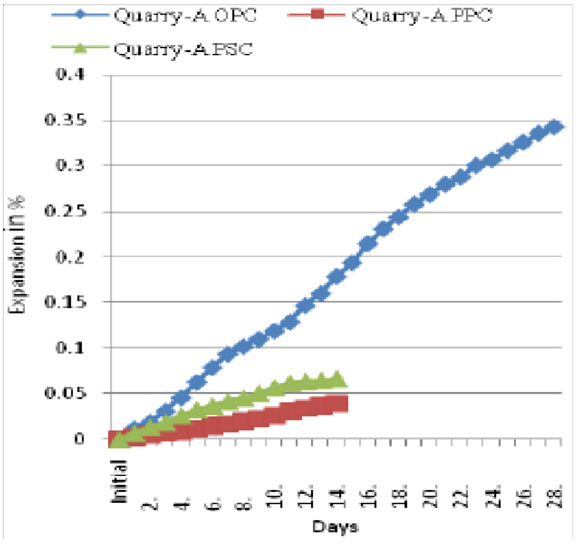
Table 5

Quarry	Material Combination	% expansion after 14 days	Classification
A	Agg.+OPC	0.179	susceptible to reactive
	Agg.+PPC	0.040	innocuous
	Agg.+PSC	0.067	innocuous
B	Agg.+OPC	0.163	susceptible to reactive
	Agg.+PPC	0.046	innocuous
	Agg.+PSC	0.061	innocuous
C	Agg.+OPC	0.141	susceptible to reactive
	Agg.+PPC	0.029	innocuous
	Agg.+PSC	0.074	innocuous
D	Agg.+OPC	0.141	susceptible to reactive
	Agg.+PPC	0.050	innocuous
	Agg.+PSC	0.070	innocuous
E	Agg.+OPC	0.141	susceptible to reactive
	Agg.+PPC	0.046	innocuous
	Agg.+PSC	0.074	innocuous
F	Agg.+OPC	0.125	susceptible to reactive
	Agg.+PPC	0.027	innocuous
	Agg.+PSC	0.063	innocuous

Quarry A

Based on 14 days expansion, the aggregate is indicative of both innocuous and deleterious with OPC while indicative of innocuous with both PPC and PSC. However use of PPC restricts the expansion due to ASR more than 24% in comparison to PSC at 14 days (Figure 4).

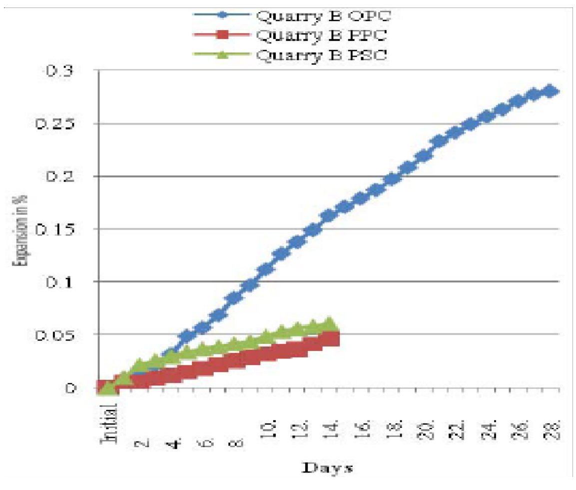
Figure 4



Quarry B

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

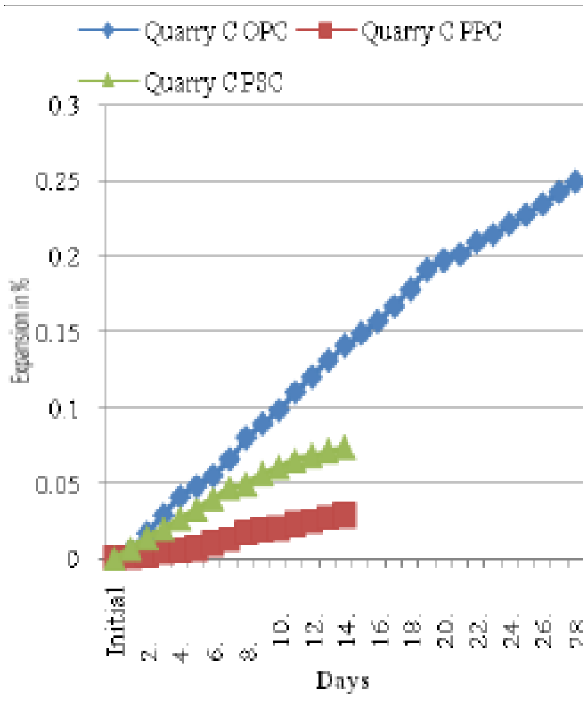
Figure 5



Quarry C

Based on 14 days expansion, the aggregate is indicative of both innocuous and deleterious with OPC while indicative of innocuous with both PPC and PSC. However use of PPC restricts the expansion due to ASR more than 67% in comparison to PSC at 14 days (Figure 6).

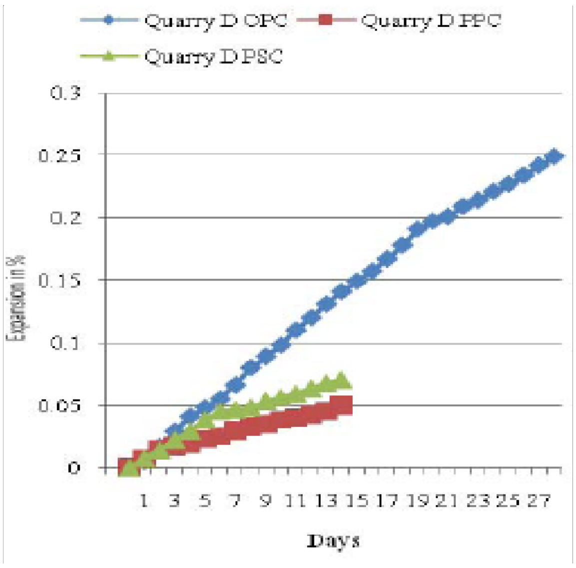
Figure 6



Quarry D

Based on 14 days expansion, the aggregate is indicative of both innocuous and deleterious with OPC while indicative of innocuous with both PPC and PSC. However use of PPC restricts the expansion due to ASR more than 28% in comparison to PSC at 14 days (Figure 7).

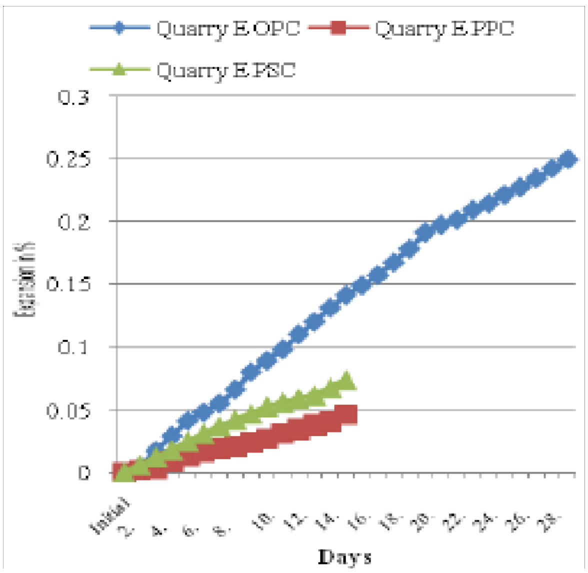
Figure 7



Quarry E

Based on 14 days expansion, the aggregate is indicative of both innocuous and deleterious with OPC while indicative of innocuous with both PPC and PSC. However use of PPC restricts the expansion due to ASR more than 41% in comparison to PSC at 14 days (Figure 8).

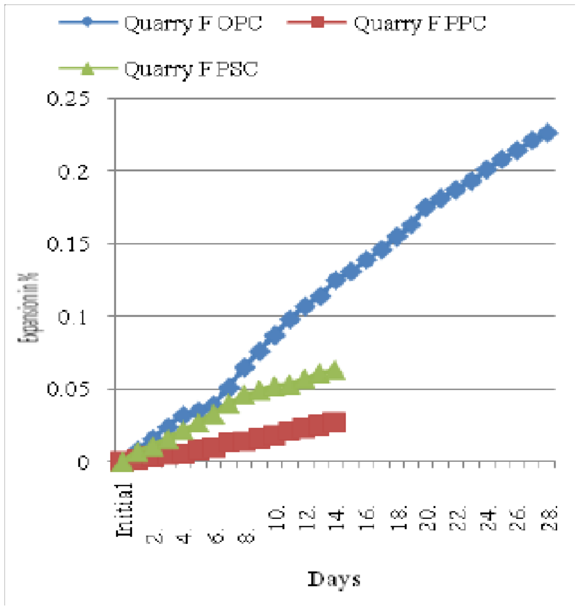
Figure 8



Quarry F

Based on 14 days expansion, the aggregate is indicative of both innocuous and deleterious with OPC while indicative of innocuous with both PPC and PSC. However use of PPC restricts the expansion due to ASR more than 58% in comparison to PSC at 14 days (Figure 9).

Figure 9



CONCLUSION

Reactivity of these aggregates and effect of using OPC, PPC and PSC on the reactivity of these aggregate have been measured experimentally with the help of accelerated mortar bar test 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 test results clearly show that PPC is better in controlling expansion due to ASR in comparison to PSC.

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