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Effectiveness of Pakistan Steel's Slag in Controlling Alkali-Silica

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EFFCTIVENESS OF PAKISTAN STEEL'S SLAG IN CONTROLLING ALKALI–SILICA REACTION

By

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SYNOPSIS

Several siliceous rocks and minerals have been recognised in concrete aggregates which react with cement alkalies and can damage the concrete. This deleterious reaction, known as alkali-silica reaction (ASR), can be controlled by certain methods. The use of blast-furnace slag as partial replacement of cement is one of the metholds adopted in preventing ASR. This paper descrbes the effectiveness of Pakistan Steel's slag in controlling ASR. It is concluded that ASR could be controlled by partial replacement of cement with Pakistan Steel's slag at the cost of a slight decrease in compressive strenghth of concrete/mortar.

Introduction

Concrete aggregates may contain reactive constituents that would react with the alkalies of cement causing damage to the concrete. The aim of this paper is to evaluate the effectiveness of the slag produced in the Pakistan Steel Mill Karachi, in controlling the reaction which is called the alkali-silica reaction (ASR). Briefly described herein are also the ASR, various methods of controlling it, and the effect of Pakistan Steel's slag on properties of cement paste, mortar and conrete. The test data presented and discussed is based on the studies conducted for a dam project in Pakistan. .

Alkali-silica reaction (ASR)

Aggregates are the major constituents in concrete and their optimum use is the main consideration in producing economical and durable concrete. The aggregates for concrete are normally considered suitable if they have requisite properties such as gradation, abrasion, soundness, specific gravity, water absorption and permitted amount of deleterious materials. However, in some parts of the world extensive cracking of concrete works have been observed although these structures were constructed with aggregates of excellent physical properties, for example, Buck hydroelectric Plant of the New River Virginia, Parker Dam (California) and the Jinnah barrage on the Indus river in Pakistan constructed with sound and good quality gravels have shown cracks in the concrete structure due to the ASR.

During the hardening of concrete, hydration of cement occurs and the alkalies of the cement (Na_2O & K_2O), if present in high proportion, say greater than 0.60 percent as Na_2O, react with the

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siliceous constituents of aggregates. This reaction produces an expandable alkali silicate gel causing internal pressure, leading to damage of the concrete structures, loss of strength, durability and in some cases complete disintegration and decomposition of concrete. The ASR depends on time, temperature, particle size as well as silica in hydrous or amorphous form. Not all siliceous aggregates are reactive. The reactive siliceous aggregates which cause ASR are given in table I. In addition argillites, graywackes, phyllites, quartzites, schists, fractured and strained quartz are also recognised as reactive. Granite, gneisses, metamorphosed subgraywackes and some quartz and quartzite gravels also have the potential to slowly react with cement alkalies.

Identification of ASR potential

The ASR potential can be identified by:

a. Field performance record of the aggregates if these have been used with high alkali cement.

b. Identification of reactive aggregates by petrographic examination as recommended by American Society for Testing and Material (ASTM) Designation ASTM C-295.

c. Chemical determination of the potential reactivity of aggregates (ASTM Test C-289). The reactivity is measured by the amount of reaction during 24 hours at 80^{o}C between NaOH solution and the pulverized aggregates.

d. Mortar bars expansion tests (ASTM C–227 & C-342). In these tests the potential reactivity of the aggregates is indicated by measuring the increase in length of (25mm x 25mm x 285mm) mortar bars cast with particular aggregates and subjected to different water saturation and temperature conditions for one to three years. The limiting values for these tests are given in ASTM C-33.

Methods of Controlling ASR

The alkali-silica-reaction can be controlled or reduced to an acceptable level in the following ways:

a. Avoid the use of reactive aggregates if non-reactive aggregates are available within economical distance.

b. Blending or dilution of reactive aggregates with non reactive aggregates.

c. Using low alkali cement.

d. Partial replacement of Ordinary Portland Cement (OPC) with Pozzolan or slag. This paper deals with the last method of controlling ASR and studies the possible use of Pakistan Steel's slag in preventing ASR'

Pakistan Steel's Slag:–

According to ASTM C-989, slag is defined as, "a non-metallic product, consisting essentially of silicates and aluminosilicates of calcium and of other bases, that is developed in a molten condition simultaneously with iron in a blast furnace." The granular slag, which is used for controlling ASR is the glassy granular material formed when molten blast furnace slag is rapidly chilled. Pakistan Steel Mill near Karachi is the only source of slag in Pakistan. The full design capacity of slag from Pakistan Steel is 270,000 tons annualy.

ASTM have recommended series of tests to check the effectiveness of slag in preventing ASR. Some of the test properties of the slag produced at Pakistan Steel are as under:

Chemical properties:—

Iron ores used by Pakistan Steel are imported from various countries with different chemical composition but these are blended in such proportions to produce a mix of uniform chemical composition and the constituents of the slag are kept fairly constant. ASTM chemical and physical specified requirements for slag are given in table 2. ASTM have also recommended chemical limits for the slag in a special technical paper (ASTM STP-169-B). The ASTM recommednded limits and chemical test values of the slag are as follows:

Constituents (%)	ASTM Recommended Limits (%)	Test values of Pakistan Steel Slag (%)
SiO_2	30 — 40	35 — 37
Al_2O_3	8 — 18	15 — 17
Fe_2O_3	0 — 1	0.57 — 0.90
CaO	40 — 50	36 — 38
MgO	0 — 8	7.75 - 8.50
Mn_2O_3	0 — 2	0.9 — 2.0
S	0 — 2	0.5 — 1.5
Alkalies as Na_2O	No Limit	0.53 — 0.68

It is observed that the slag meets ASTM mandatory requirments given in table 2, but as per foregoing recommended limits, the lime content is low and magnesia is slightly high. The low lime reduces the cementitious properties of slag. The high magnesia causes expansion by the formation of magnesium hydroxide crystals. The magnesia is not harmful provided it does not exceed 7 percent in the slag cement.

Glass Content of Slag:—

The effectiveness of slag in controlling ASR and its strength development properties depends on the glass content or non-crystalline state of slag. The average glass content of the slag is about 91%. Although no limit is specified by ASTM, the published data indicates that this glass content is sufficient in reducing ASR and for manufacturing concrete of desired strength.

Slag Activity Index (ASTM Test C-989):—

The compressive strengths of both OPC and corresponding mortars with 50-50 weight combination of the slag and OPC were determined. Slag activity index at 7 days was 70% and it was measured as 83% at 28 days. The test values meet the ASTM requirements of slag grade 80.

Effect of Slag on ASR

The effectiveness of slag in controlling ASR is determined by performing mortar bar expansion test (ASTM C-441). In this test Pyrex glass is used as aggregate with high alkali cement. Pyrex glass brand No. 7740 specified for the test by ASTM contains about 80 percent silica in amorphous form and is highly reactive. By using high alkali cement alone control mortar bars are cast and test bars are made by replacing the cement with different percentages of slag. To be considered satisfactory the high alkali cement by partial replacement of slag should produce an expansion less than 0.02 percent at 14 days.

The Pakistan Steel's slag, ground to a fineness of 3000 cm^2/gram (Blaine value) when tested with high alkali cement (0. 82% as Na_2O) showed that about 40 percent slag is required to prevent alkali-silica reaction. The results are presented on Fig. 1. Further tests indicate that the slag content can be reduced to 30% if it is ground to a fineness of 4000 cm^2/gram. However more testing is required to study the effect of increase in fineness on the quantity of slag required for controlling ASR.

Limited tests on commercially produced Thatta slag cement (30% slag 70% OPC) revealed that commercially produced Thatta slag cement is also effective in congrolling ASR althought the alkalies of the clinker used in the manufacturing of slag cement were not known. Some additional tests are needed to draw some definite conclusions.

The slag was also subjected to long term mortar bar expansion tests with moderately reactive Indus river aggregates for about three years. The mortar bars cast with OPC indicated considerable expansion, however, the mortar bars cast by replacing 30, 40 and 50 percent slag with OPC showed insignificant or no expansion.

Effect of the Slag on Cement Paste, Mortar and Concrete

Effect on Cement Paste:–

a. Normal Consistency:–

Normal consistency of the cement is the percentage of water required to made a cement paste of standard consistency. Two different brands of cement when replaced with various percentages of slag showed decrease in normal consistency but the effect was not very significant.

b. Setting Time:–

The partial replacement of OPC with the slag delayed the initial and final setting time but both remained within the limits of blended as well as OPC cements.

c. Autoclave and Le-Chatelier Expansion:–

A considerable decrease in expansion was noted when several slag samples were tested by both the tests. The expansion test values were well below the maximum specified limits.

d. Heat of Hydration:–

Heat of hydration is useful for winter concreting but is harmful for mass concrete and during hot weather. About 65 percent decrease in heat of hydration was noted at 7 days by replacing OPC with 40 percent slag. The test values of slag cement (30 to 40% slag) of several samples meet the ASTM requirement of low heat of hydration cements.

Effect on Mortar:–

The ground slag samples were tested with two brands of OPC for unconfined compressive strengths by using 1 cement:3 sand:0.40 water to cement ratio. The test results of various blends of the slag and cement are presented onFig.2 to 4. It is seen that the ultimate compressive strengths measured at 3, 7, 28, 90 & 180 days of slag cement are less than the strengths of OPC alone at all ages. The low strengths are probably caused by the marginal quality of slag. However, these values are well within the limits specified by ASTM.

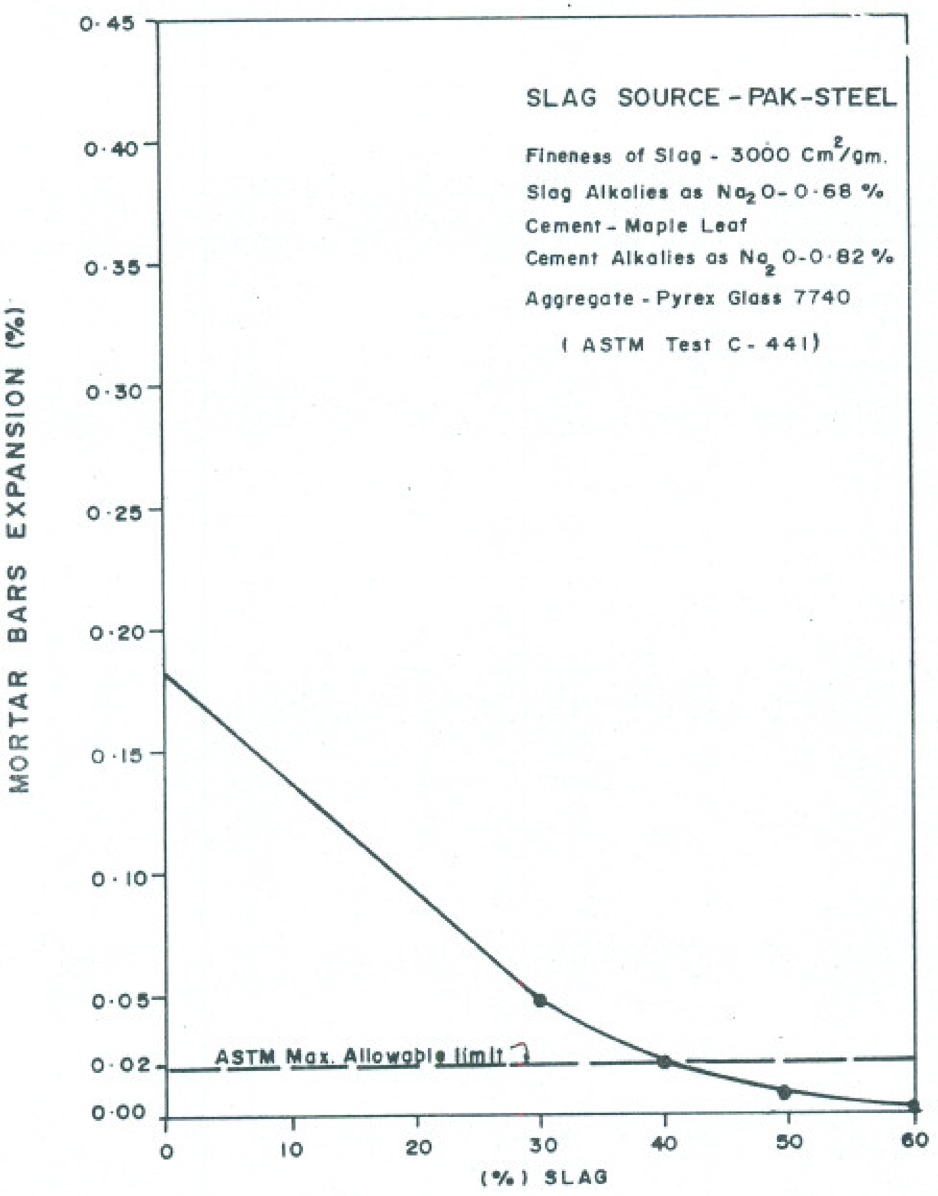
Effect on Concrete;-

The effect of slag on compressive strength of concrete was studied by laboratory concrete trial mixes. By replacing 40% OPC with slag, the strength gain at 28 days was about 95% of the concrete made with cement alone and by using 60% slag the strength gain was 75%.

Conclusions:

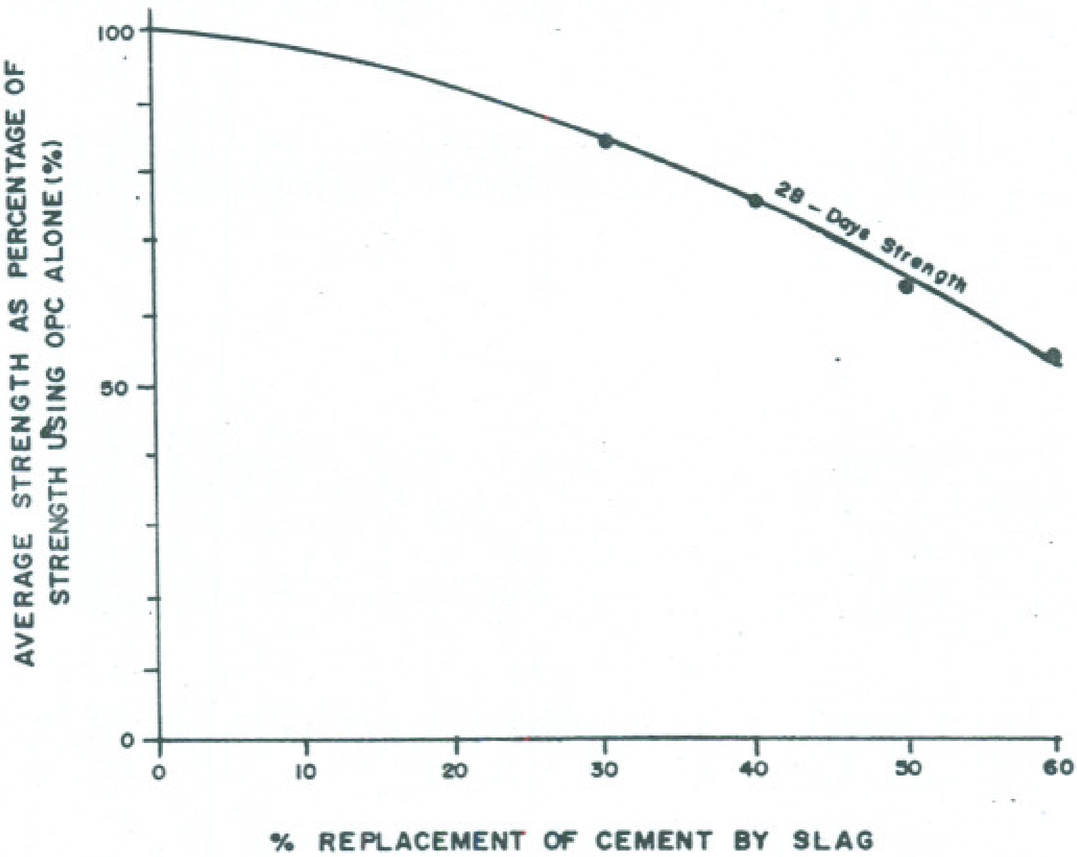
1. Pakistan Steel's slag can be used to prevent alkali-silica reaction (ASR)
2. About 30 to 40% slag is needed to achieve safe acceptable expansion.
3. By using Indus river gravels with OPC, the moratar bars showed considerable expansion but there was insignificant or no expansion by using 30, 40 and 50 percent slag when tested over a period of three years.
4. The partial replacement of OPC with slag reduces concrete expansion and heat of hydration however, it delays setting time of concrete.
5. The use of slag causes reduction in compressive strengths of mortar/concrete at all tested ages but these compressive strength values are within the specified limits of ASTM.

FIG. 1



EFFECT OF SLAG IN CONTROLLING ASR

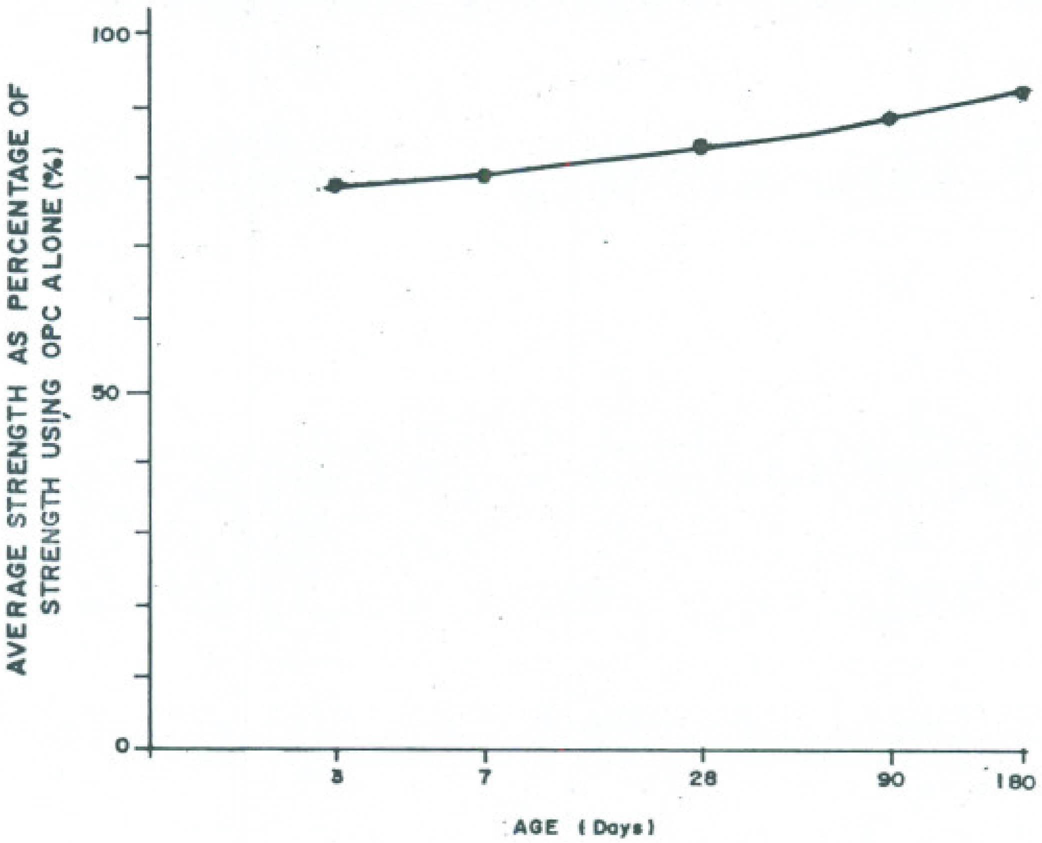
FIG. 2



NOTE:

1. Based on results of 5 No. tests on mortar cubes with slag.

FIG. 3

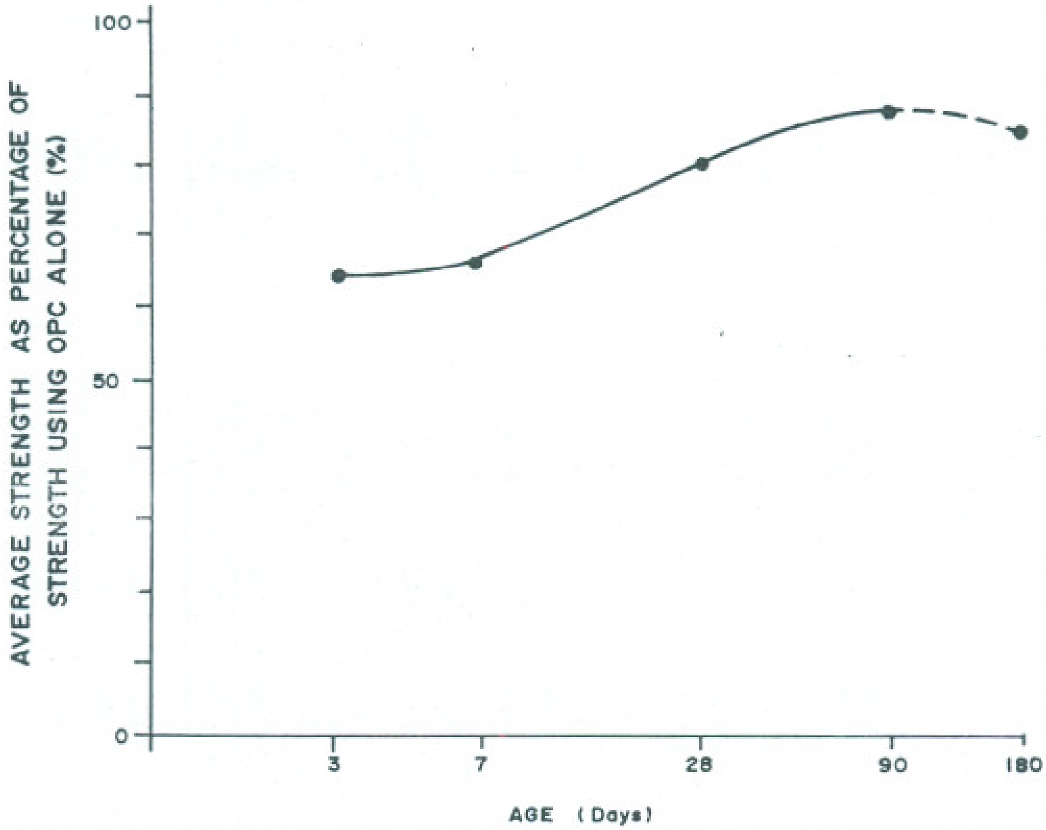


FOR 30 % REPLACEMENT OF CEMENT BY SLAG

NOTE:

1. Based on results of 19 No. tests on mortar cubes with slag.

FIG. 4



FOR 40 % REPLACEMENT OF CEMENT BY SLAG

NOTE:

1. Based on results of 19 No. tests on mortar cubes with slag, one Test at 180 days.