BLAST FURNACE SLAG'S POTENTIAL ALKALI REACTIVITY AND LONG TERM SERVICE

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ABSTRACT

Air-cooled iron Blast Furnace Slag Aggregate from the works of Broken Hill Proprietary (BHP) Port Kembla has been used in concrete since the early 1950's.

The suitability of this aggregate for use in concrete has been assessed in accordance with the appropriate Australian Standard AS 2758.1 - 1985 Part 1. This assessment included consideration of the potential reactivity of the aggregate to alkalis.

Of recent interest is the accelerated test procedure developed by the CSIRO (Commonwealth Scientific and Industrial Research Organisation of Australia) for the assessment of potential alkali aggregate reaction.

This paper reports the results of testing for potential alkali reactivity using the Australian Standard tests and the CSIRO test of Port Kembla Blast Furnace slag aggregate and the inspection of the performance of concrete made using this aggregate over a period of nearly 40 years.

Keywords: Alkali Reaction, Blast Furnace Slag.

INTRODUCTION

"Satisfactory" concrete can be made from a wide range of aggregates obtained from either natural resources or as by-products of manufacturing processes. The measure of being "satisfactory", until recent years, has been to comply with a specified compressive strength at 28 days.

More recently the focus has been on how the concrete performs in service, that is, its serviceability or durability.

These durability considerations have included such aspects as shrinkage and susceptibility to cracking, ability to prevent corrosion of the reinforcement and possible spalling of the concrete, and the likelihood of alkali aggregate reaction with the subsequent deterioration of the concrete from this action.

This last mentioned phenomena has assumed increasing prominence in very recent times as its occurrence seemingly has become more widespread.

The concern for the likelihood of the occurrence of alkali aggregate reaction understandably has concentrated on concrete made using natural aggregates rather than artificial aggregates because of the greater use of the former materials. However with the move to conserve natural resources and hence to increase the use of aggregates obtained as by-products of manufacturing processes, the possibility of alkali aggregate reaction from the use of artificial aggregates should be considered.

A significant potential source of aggregate for the major construction area of Sydney (Australia), population of approximately five million is blast furnace slag from the Port Kembla Steelworks of BHP, some 80 kms south of Sydney. Approximately 1.2 million tonnes of blast furnace slag is produced at Port Kembla each year. Of this, a certain amount is granulated for use in cement manufacture leaving an appreciable amount of material that is air-cooled and available for use as a concrete aggregate. In keeping with the concern of possible alkali aggregate reaction, it is appropriate to examine air cooled blast furnace slag aggregate as a potential contributor to this problem.

THE FORMATION OF AIR COOLED BLAST FURNACE SLAG

Blast furnace slag is made in the production of iron in a blast furnace. The molten slag being the lighter of the two materials floats on the top of the molten iron. The iron is tapped off to be used in the production of steel while the molten slag is run off and cooled.

In the case of Port Kembla blast furnace slag, the molten slag is either run off into pits and allowed to air cool or cooled quickly with a high volume of water. This latter process causes the slag to form granules that are suitable for the manufacture of slag cement.

The air cooled slag is dug from the cooling pits and transferred to a storage area.

The air cooled slag is then made into concrete aggregate by processing through a crushing and screening plant.

COMPOSITION AND MINERALOGY OF PORT KEMBLA BLAST FURNACE SLAG AGGREGATE

Slag is composed essentially of lime, alumina and silica with variable amounts of magnesia and small amounts of sulphur, alkalis, titania etc.

As will be seen from the mineralogy these compounds do not occur in the slag as single entities but, for the Port Kembla slag, combined mainly as calcium alumino silicate with also other calcium silicates and calcium sulphide.

The chemical composition of the currently produced Port Kembla blast furnace slag aggregate is shown in Table 1 (Australian Steel Mill Services, 1994)

Table 1 Chemical composition of Port Kembla blast furnace slag aggregate

Constituent	Percentage
CaO	41.1 - 41.6
SiO_2	33.7 - 34.3
Al_2O_3	14.1 - 14.7
MgO	6.5 - 7.1
MnO	0.39 - 0.48
S	0.7 - 0.8

It is emphasised, with particular reference to the silica content, that these compounds do not exist in blast furnace slag as "free" or single compounds.
It has been established that a petrological examination is necessary if a considered judgement on the presence of reactive silica is to be made (Nurse *et al.* 1951).

Bauman (1959), speaking of blast furnace slags in general, stated that very little, if any, free silica existed in slag. Concerning Port Kembla blast furnace slag, Hensel (1995) reported no free silica in slag from this source.

TESTING FOR POTENTIAL ALKALI REACTIVITY

Australian Standard 2758.1 - 1985 (Standards Australia 1985) refers to three test procedures that could be used to assess the potential alkali reactivity of an aggregate:

- ASTM 295 (American Society for Testing and Materials 1994) a method of petrographic examination for analysis of types of minerals present.
- Australian Standard 1141 Section 39 (Standards Australia 1974a), a chemical test relating the reaction of the aggregate with sodium hydroxide in terms of amount of silica dissolved and the reduction in alkalinity of the solution - expressed in terms of the potential of the aggregate to react with alkali.
- Australian Standard 1141 Section 38 (Standards Australia 1974b) where reactivity of the aggregate is assessed from the expansion of mortar bars made using the aggregate, the bars being cured for up to six months.

Dissatisfaction with these methods has led to the development of other tests including two Australian test methods -

- the CSIRO accelerated mortar bar method (Shayan *et al.* 1988)
- the Queensland Department of Transport accelerated cured concrete prisms (Carse *et al.* 1990).

The Port Kembla air cooled blast furnace slag aggregate is regularly tested for potential alkali reactivity using the test method of AS 1141 Section 39 and by petrographic examination.

Testing of the Port Kembla slag aggregate to Section 39 gives typical results for reduction in alkalinity and silica concentration of 65.0 and 3.0 millimoles/litre respectively. These results classify the Port Kembla slag aggregate as "innocuous" as far as potential alkali reactivity is concerned.

The petrographic examination typically shows the Port Kembla blast furnace slag aggregate to be predominantly melilite with no free silica. (Table 2).

Table 2 Typical petrographic description of Port Kembla blast furnace slag aggregate

Constituent	Percentage
Melilite	55
Larmite	4
Opaque oxides	Less than 1
Unidentified Ca Silicates	1
Glass	1
Interstitial Material	13
Voids	25
Carbonate	Less than 1
Others	-

The Port Kembla blast furnace slag aggregate has also been tested for potential alkali reactivity using the CSIRO accelerated mortar bar method. Testing to this method has shown the Port Kembla material to be non-reactive.

EXAMINATION OF OLD CONCRETE CONTAINING PORT KEMBLA BLAST FURNACE SLAG AGGREGATE

In April 1995 a survey was made of a number of concrete structures within the steelworks of Broken Hill Proprietary (BHP) at Port Kembla to detect the occurrence of alkali aggregate reaction in the concrete.

The structures inspected were specially selected for the following considerations:

- Concrete age in excess of 30 years.
- Exposure conditions conducive to alkali aggregate reaction.
- No supplementary cementitious materials used in the concrete.

At the time of selection of the structures it was appreciated that other factors such as the cement content of the concrete and the alkali content of the cement used can have an effect on the occurrence of alkali aggregate reaction. However it was decided to defer consideration of the possible influence of these factors until the final analysis.

Supplementary cementitious material was first used in concrete for the BHP Port Kembla works, then operating as Australian Iron and Steel Pty Ltd, in 1966. The material used was ground granulated blast furnace slag (Visek. 1969). Although flyash was available in the area in 1965 it was not used in concrete supplied to Australian Iron and Steel Pty Ltd at Port Kembla until 1967 some time after the introduction of the use of ground granulated blase furnace slag in concrete supplied to that company. (Visek .1969)

The survey was restricted to concrete placed before 1966 to ensure that no supplementary cementitious materials had been used in the concrete.

DETAILS OF CONCRETE MIX USED

The typical mix design for the concrete supplied to all of the structures inspected was as follows:

Type A Ordinary Portland Cement	290 kg/cu.m
20mm air cooled blast furnace slag aggregate	1185 kg/cu.m
6mm air cooled blast furnace slag aggregate	145 kg/cu.m
Dune sand	565 kg/cu.m
Water (approximate)	170 litres/cu.m

RESULTS OF THE INSPECTIONS OF OLD CONCRETE STRUCTURES AT BHP STEELWORKS, PORT KEMBLA

Number 1 salt water lift pump station

This structure was built in 1958. It is in tidal seawater with parts of the structure in the splash zone. Seawater temperatures range from 13 to 22°C throughout the year.

No supplementary cementitious materials were used in the concrete.

From the records that are available it would seem that cement contents used in these times were not high. (Murrie *et al.* 1968)

A thorough visual examination of this structure showed no cracking or distress that could be attributed to the occurrence of alkali-aggregate reaction. In fact, this structure is notable for the lack of cracking of the concrete.

Number 2 - 3500mm plate mill scale pits

The concrete in this structure at the time of inspection was 32 years old. The concrete is exposed to wetting and drying in a water environment. In addition the operation of a clam shell bucket removing mill scale from the bottom of the pit would provide mechanical impact as well as abrasion and attrition from the mill scale particles in the water.

Steel sections have been set into the surface of the concrete as a means of protection from the impact of the clam shell. However it is believed that such inclusions of steel could aggravate deterioration of the concrete by differential expansion and contraction due to thermal effects. The concrete in this situation would be subjected to fairly high stresses from a number of different influences.

These stresses, it is suggested, would aggravate any potential for alkali aggregate reaction.

When this concrete was examined, some 32 years after placement it showed no sign of cracking or other distress.

Number 3 - Coolant basement of cold rolled steel mill

The concrete for this structure was placed in 1961. The conditions in the basement are humid, warm to hot still air with the presence of high electrical activity due to the presence of continuously operating electrical motors.

The concrete was closely examined for signs of alkali aggregate deterioration. No deterioration of the concrete that could be attributed to alkali aggregate reaction was detected.

Number 4 - Walls, and beams of the Oil Cellars and De-scaling Pump-house

This structure was built in 1963. The adverse conditions are heat and humidity. No deterioration of the concrete was observed when inspected on 6 April 1995.

Discussion

The conditions to which the old concrete has been subjected and the length of time the concrete has experienced these conditions are considered to be conducive for the occurrence of alkali aggregate reactivity.

The examination of the various old concrete structures however has shown no signs that this reaction has occurred.

Other factors influencing the occurrence of AAR have been considered. It has been reported that no supplementary cementitious materials were available for use in the concrete for these structures (Visek 1969). Also the cement content of the concrete would not have been particularly high (Murrie *et al.* 1968). The typical mix design of the concrete confirms this. Concerning the available alkalis from the cement used, it would seem that the alkali content of the cement supplied by Southern Portland Cement during the time these structures were built was fairly low (Na_2O 0.04%, K_2O 0.20%) (Schott 1995).

The most definite and influential factor that has been established in examining the lack of evidence of alkali aggregate reaction is the innocuous nature of the blast furnace slag aggregate. It is maintained that this is the single most important factor in the non-occurence of alkali aggregate reaction in the concrete structures examined.

Conclusion

Concrete structures ranging in age from 32 to 37 years subjected to conditions considered conducive to alkali aggregate reactivity were examined and found to show no signs of this phenomenon.

From reports of the various materials used in the concretes, particularly mineralogical examinations and potential alkali reactivity testing of the blast furnace slag aggregate, the most important factor in the non-occurrence of alkali aggregate reaction seems to be that the aggregate is not reactive with alkalis.

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