

EFFECTIVENESS OF GGBS IN PREVENTING ASR

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Expansion measurements are being carried out on concrete prisms containing a natural reactive aggregate (Thames Valley sand), with specimens stored at both 20° and 38°C. The expansion behaviour at 20° has been found to mirror closely that observed at 38°C, though over a longer time-scale. With increasing ggbs %, the specimens tolerate increasing alkali contents without expansion. The results are being used to test various rules which have been proposed to take into account the effectiveness of ggbs in preventing ASR; conclusions are drawn on their applicability.

INTRODUCTION

The ability of ground granulated blastfurnace slag to reduce the risk of damage due to Alkali-silica reaction is recognised worldwide and has been reviewed by Hogan (1). There have been numerous investigations which almost without exception have confirmed a capacity to significantly reduce the deleterious expansion caused by ASR; in general, the tendency for expansion reduces with increasing ggbs content. The mitigating mechanism is not fully understood nor fully quantified, but Bakker (2) has suggested that the low permeability of ggbs concrete to alkali ions is an important factor.

In the UK, it is generally agreed that the use of a minimum of 50% ggbs can be a suitable preventative measure against ASR provided that alkalis are not contributed by sources other than the cementitious materials. When this is not appropriate, an alternative approach is to limit the reactive alkali content in the concrete to less than a nominal 3.0 kg/m<sup>3</sup> which is the procedure for Portland cement concrete; this is calculated on the average alkali content of the Portland cement and accords to an effective maximum of about 3.5 kg/m<sup>3</sup>. However, in the case of concrete containing ggbs, there is some disagreement on the value to use for the reactive alkali 'contribution' from the ggbs. A Concrete Society Technical Report (3) recommends that the water-soluble alkali content of the ggbs is the value which should be taken as the reactive alkali contribution. The water-soluble alkali in ggbs is normally very small, typically less than 0.05%, and the calculated contribution from this is of little significance. However, Building Research Establishment Digest 330 (4) recommends that the contribution should be taken as one half of the acid-soluble alkali content of the ggbs. The acid-soluble alkali content of ggbs is essentially the total alkali content, and the calculated contribution as one half of this is significant (typically 0.3%).

The present programme of research was designed to try to resolve this conflict of advice. Expansion measurements are being carried out on concrete prisms containing natural UK aggregates. The aggregates for the prisms were a combination of flint-bearing sand and crushed limestone coarse aggregate; these were selected because ASR damage in UK structures has occasionally resulted when high-alkali Portland cement has been used with such a combination. The following parameters have been varied:

- |                                      |  |
|--------------------------------------|--|
| 1) cementitious content              | (420 kg/m <sup>3</sup> to 1000 kg/m <sup>3</sup> ) |
| 2) percentage ggbs                   | (0% to 70%)  |
| 3) alkali content of Portland cement | (0.60% to 1.20%)                                   |
| 4) alkali content of ggbs            | (0.45% and 0.87%)                                  |
| 5) added alkali                      | (0 to 3.7 kg/m <sup>3</sup> )                      |
| 6) storage temperature               | (20°C and 38°C)                                    |

Over three hundred specimens, corresponding to 158 different combinations of the above are being monitored.

Since a primary aim of the programme is to test the hypothesis that ggbs contributes one half of its total acid-soluble alkali to the alkali silica reaction, the matrix of mix designs was based on this assumption. However, a sufficiently wide range of mix designs was included to enable alternative hypotheses to be tested.

#### METHOD OF TEST

The test methods, test conditions and mix designs were selected following detailed consultation with the Concrete Society Technical Sub committee on ASR. Expansion testing followed the method given in draft BS 812:Part 123 'Alkali Silica Reactivity, Concrete Prism Method' (5), with the following exceptions and additions:

Two pairs of specimens were cast from each combination; one pair was stored at 20 +/- 2°C and the other at 38 +/- 2°C.

The specimens were wrapped in towelling or cloth, and then placed inside 500 gauge poly tubing which was sealed at each end; this was then placed into poly net and the specimens were stored horizontally.

The specimens were measured and weighed following the method given in draft BS 812:Part 123 at 1 and 28 days. Thereafter the 38°C specimens were measured at monthly intervals and the 20°C specimens at 3 monthly intervals.

The mixes were designed to produce nominal total alkali contents generally either 5, 6, 7 or 8 kg/m<sup>3</sup>, using 3 combinations of OPC alkali contents and 2 ggbs alkali contents. It was assumed for the purpose of calculation that 50% of the acid-soluble alkali in the ggbs was available for reaction. Details of the materials are given in table 1 and the concrete mix designs in table 2. Mixes that required in excess of 1000 kg/m<sup>3</sup> of cement were recalculated using a total cement content of 1000 kg/m<sup>3</sup> cement, and potassium sulphate was added to bring the total alkali to the required level.

In all the mixes, 25% of the flint-bearing sand (ex Thames Valley) was included by volume of the total aggregate based on a mix with a cement content of  $700 \text{ kg/m}^3$ . The combination of aggregates chosen has a wide 'pessimum' and it has been reported by Sims and Higgins (6) that comparable expansions are obtained with between 20 and 40% Thames Valley sand. Thomas et al (7) found comparable expansions with between 15 and 35% Thames Valley sand.

The expansion measurements are given in Table 3. The programme of testing is not yet complete and monitoring is continuing.

## DISCUSSION

### Effect of Temperature

Testing at  $38^\circ\text{C}$  accelerates ASR expansion and this is advantageous for obtaining results within a realistic timescale in the laboratory. However, it is necessary to determine how the results at elevated temperature relate to what would happen at normal ambient temperature.

Figure 1 shows the age at which specimens achieve an expansion of 0.1%; it plots this age for  $38^\circ\text{C}$  storage, against the age for  $20^\circ\text{C}$  storage (for each of the mixes which have expanded). Those points with an arrow are mixes where expansion has reached 0.1% at  $38^\circ\text{C}$  but not yet reached it at  $20^\circ\text{C}$ . It can be seen that there is very good correlation between  $20^\circ\text{C}$  and  $38^\circ\text{C}$ , with the specimens at  $20^\circ\text{C}$  taking about four times longer to reach 0.1% expansion than those at  $38^\circ\text{C}$ . The specimens which have not expanded at  $38^\circ\text{C}$  have not expanded at  $20^\circ\text{C}$ .

### Effective Alkali Contribution

Figure 2 assumes that the reactive alkali contribution from the ggbs is one half of its acid-soluble alkali content. On this basis, the reactive alkali content in the concrete is plotted against the percentage ggbs; specimens which have expanded (expansion greater than 0.05% at an age of one year at  $38^\circ\text{C}$ ) are differentiated from those which have not expanded. If the reactive alkali contribution of the ggbs is actually 'one half' then it should be possible to draw a horizontal line on this graph separating those specimens which have expanded from those which have not. However, the line of separation is not horizontal but veers upwards as the ggbs percentage increases. This indicates that 'one half' is an over-estimation of the alkali contribution from the ggbs. Hence the 'one half' recommendation in BRE Digest 330 is overly conservative in assessing the benefits of ggbs.

Figure 3 is a similar graph but in this case it is assumed the ggbs contributes no reactive alkali whatsoever. If the ggbs contribution is 'zero', then it should be possible to draw a horizontal line of separation. In this case the line of separation starts off horizontally but after 25% ggbs it once again veers sharply upwards. This could be interpreted as implying that at 25% ggbs the contribution is zero and at higher levels it is negative. On this basis, any contribution greater than zero (e.g. water-soluble alkali), is overly conservative in assessing the benefits of ggbs, particularly at replacement levels greater than 25%.

Figure 4 is a similar graph but in this case the full alkali content of the ggbs is included in the reactive alkali content of the concrete. This is more scientifically justifiable than the previous assumptions since ggbs in concrete will hydrate in similar fashion to the Portland cement component and as it does so, its alkalis will be released into the concrete where they will be indistinguishable from those released by the Portland cement. In Germany, Smolczyk (8) has suggested that the effective alkali contribution from blastfurnace cements can be computed as:

$$A \left( 1 - \left( \frac{H}{H_0} \right)^2 \right)$$

where A = total alkali content of the blastfurnace cement (including the slag)

H = slag component in % by weight

H<sub>0</sub> = experimental constant which was found to be 72%

The line on Figure 4 is deduced from this formula, assuming a critical alkali content for Portland cement concrete (H = 0%) of 5.0 kg/m<sup>2</sup>, and it can be seen that the results are compatible with the formula.

It would appear that as the slag percentage increases, so the alkali present is less effective at causing expansion. This could alternatively be expressed by saying that with increasing slag percentage, the concrete is able to tolerate increasing alkali contents without expanding.

#### CONCLUSIONS

- 1) There is good correlation in expansion behaviour between specimens stored at 38°C and those stored at 20°C. At 20°C, expansion takes place more slowly and the timescale is about 4 times longer than at 38°C.
- 2) The experimental results are not compatible with either the UK Concrete Society or UK Building Research Establishment recommendations for the use of ggbs to combat ASR and suggest that both these recommendations underestimate the advantages of ggbs in combatting ASR, particularly at higher replacement levels.
- 3) The results are however compatible with a rule proposed in Germany for the effective alkali contribution of blastfurnace cement.

REFERENCES

1. Hogan, F.J., 1983, "Cement Concrete and Aggregates", Vol 7, No 2, pp 100-107.
2. Bakker, R.F.M., 1981, "Proceedings of the Fifth International Conference on Alkali-aggregate reaction in concrete", Cape Town, Paper S 252/29.
3. Concrete Society, 1987, "Technical Report No.30".
4. Building Research Establishment, 1988, "Digest 330".
5. British Standards Institution, 1988, "Draft for public comment", 88/11922DC.
6. Sims, I., and Higgins, D.D., 1992, "Proceedings of the Ninth International Conference on Alkali-aggregate reaction in concrete".
7. Thomas, M.D.A., et al., 1992, *ibid.*
8. Smolczyk, H.G., 1974, "The Sixth International congress on the chemistry of cement", section 111-2.

**Table 1 - ALKALI CONTENT OF CEMENTITIOUS MATERIALS**

		equivalent sodium oxide content ( $\text{Na}_2\text{O} + 0.658 \text{K}_2\text{O}$ )
Portland cement	'H'	1.20%
Portland cement	'M'	0.87%
Portland cement	'L'	0.60%
GGBS	'h'	0.87%
GGBS	'l'	0.45%

(Values supplied by providers of materials)

**TABLE 2 - CONCRETE MIXES**

Mix	PC	g gbs	% g gbs	total cementitious (kg/m <sup>3</sup> )	alkali from K <sub>2</sub> SO <sub>4</sub> (kg/m <sup>3</sup> )	total alkali (Kg/m <sup>3</sup> )	alkali from PC + alkali from K <sub>2</sub> SO <sub>4</sub> + 1/2(alkali from g gbs) (Kg/m <sup>3</sup> )
5H0	H	-	0	417	0	5.0	5.0
5Hh25	H	h	25	496	0	5.6	5.0
5HL25	H	l	25	523	0	5.3	5.0
5Hh50	H	h	50	612	0	6.4	5.0
5HL50	H	l	50	702	0	5.8	5.0
5Hh70	H	h	70	752	0	7.3	5.0
5HL70	H	l	70	966	0	6.5	5.0
6H0	H	-	0	500	0	6.0	6.0
6Hh25	H	h	25	595	0	6.7	6.0
6HL25	H	l	25	627	0	6.3	6.0
6Hh50	H	h	50	734	0	7.6	6.0
6HL50	H	l	50	842	0	7.0	6.0
6Hh70	H	h	70	903	0	8.8	6.0
6HL70	H	l	70	1000	0.8	7.6	6.0
7H0	H	-	0	583	0	7.0	7.0
7Hh25	H	h	25	694	0	7.7	7.0
7HL25	H	l	25	732	0	7.4	7.0
7Hh50	H	h	50	856	0	8.8	7.0
7HL50	H	l	50	982	0	8.1	7.0
7Hh70	H	h	70	1000	0.4	10.1	7.0
7HL70	H	l	70	1000	1.8	8.6	7.0
8H0	H	-	0	667	0	8.0	8.0
8Hh25	H	h	25	793	0	8.8	8.0
8HL25	H	l	25	837	0	8.4	8.0
8Hh50	H	h	50	979	0	10.2	8.0
8HL50	H	l	50	1000	0.9	9.2	8.0
8Hh70	H	h	70	1000	1.4	11.1	8.0
8HL70	H	l	70	1000	2.8	9.6	8.0
5M0	M	-	0	575	0	5.0	5.0
5Mh25	M	h	25	657	0	5.7	5.0
5ML25	M	l	25	705	0	5.4	5.0
5Mh50	M	h	50	766	0	6.6	5.0
5ML50	M	l	50	913	0	6.1	5.0
5Mh70	M	h	70	884	0	7.7	5.0
5ML70	M	l	70	1000	0.8	6.6	5.0
6M0	M	-	0	690	0	6.0	6.0
6Mh25	M	h	25	788	0	6.8	6.0
6ML25	M	l	25	847	0	6.5	6.0
6Mh50	M	h	50	920	0	8.0	6.0
6ML50	M	l	50	1000	0.5	7.2	6.0
6Mh70	M	h	70	1000	0.3	9.0	6.0
6ML70	M	l	70	1000	1.8	7.5	6.0

TABLE 2 - CONTINUED

Mix	PC	ggbs	% ggbs	total cementitious (Kg/m <sup>3</sup> )	alkali from K <sub>2</sub> SO <sub>4</sub> (Kg/m <sup>3</sup> )	total alkali (Kg/m <sup>3</sup> )	alkali from PC + alkali from K <sub>2</sub> SO <sub>4</sub> + 1/2(alkali from ggbs) (Kg/m <sup>3</sup> )
7M0	M	-	0	805	0	7.0	7.0
7Mh25	M	h	25	920	0	8.0	7.0
7Ml25	M	l	25	988	0	7.5	7.0
7Mh50	M	h	50	1000	0.5	9.3	7.0
7Ml50	M	l	50	1000	1.5	8.2	7.0
7Mh70	M	h	70	1000	1.3	10.0	7.0
7Ml70	M	l	70	1000	2.8	8.5	7.0
8M0	M	-	0	920	0	8.0	8.0
8Mh25	M	h	25	1000	0.4	9.1	8.0
8Ml25	M	l	25	1000	0.9	8.5	8.0
8Mh50	M	h	50	1000	1.5	10.3	8.0
8Ml50	M	l	50	1000	2.5	9.2	8.0
8Mh70	M	h	70	1000	2.3	11.0	8.0
8Ml70	M	l	70	1000	3.8	9.6	8.0
5L0	L	-	0	833	0	5.0	5.0
5Lh50	L	h	50	966	0	7.1	5.0
6L0	L	-	0	1000	0	6.0	6.0
6Lh50	L	h	50	1000	0.8	8.2	6.0
7L0	L	-	0	1000	1.0	7.0	7.0
7Lh25	L	h	25	1000	1.4	8.1	7.0
7Lh50	L	h	50	1000	1.8	9.2	7.0
7Lh70	L	h	70	1000	2.2	10.1	7.0
5.5H0	H	-	0	458	0	5.5	5.5
5.75H0	H	-	0	479	0	5.75	5.75
5.5Hh25	H	h	25	545	0	6.1	5.5
6Hh35	H	h	35	644	0	7.0	6.0

**TABLE 3 - EXPANSION MEASUREMENTS - RESULTS FOR MIXES WHICH ARE ONE YEAR OR MORE OLD AT TIME OF PREPARATION OF PAPER**

Mix	Expansion(percent)							
	Storage at 38°C				Storage at 20°C			
	0.5 year	1.0 year	1.5 years	2.0 years	0.5 year	1.0 year	1.5 years	2.0 years
5H0	0.01	0.02	-	-	0.00	0.00	-	-
5Hh25	0.01	0.01	-	-	0.02	0.01	-	-
5HL25	0.01	0.00	-	-	0.01	0.01	-	-
5Hh50	0.02	0.02	-	-	0.01	0.02	-	-
6H0	0.31	0.32	0.34	-	0.01	0.07	0.12	-
6Hh25	0.16	0.20	0.22	-	0.01	0.00	0.01	-
6HL25	0.02	0.07	-	-	0.00	0.00	-	-
6Hh50	0.01	0.02	-	-	0.00	0.00	-	-
6Hh70	0.00	0.01	-	-	0.01	0.01	-	-
7H0	0.37	0.38	0.37	0.38	0.05	0.09	0.17	0.20
7Hh25	0.23	0.35	0.36	0.37	0.02	0.04	0.09	0.15
7HL25	0.21	0.33	0.32	0.33	0.02	0.04	0.09	0.13
7Hh50	0.01	0.03	0.04	0.03	0.02	0.01	0.02	0.02
7HL50	0.03	0.04	0.04	0.05	0.01	0.01	0.01	0.02
7Hh70	0.01	0.02	-	-	0.02	0.00	-	-
8H0	0.39	0.40	0.40	-	0.03	0.12	0.23	-
8Hh25	0.18	0.34	0.35	-	0.03	0.04	0.11	-
8HL25	0.12	0.22	-	-	0.01	0.01	-	-
8Hh50	0.02	0.03	0.05	0.11	0.00	0.02	0.02	0.02
8HL50	0.00	0.02	-	-	0.01	0.01	-	-
8HL70	0.00	0.01	-	-	0.00	0.00	-	-
5M0	0.10	- *	-	-	0.00	-	-	-
6M0	0.31	0.37	-	-	0.01	0.08	-	-
6Mh25	0.02	0.13	-	-	0.00	0.01	-	-
6ML25	0.05	0.19	-	-	0.01	0.02	-	-
6Mh70	0.00	0.02	-	-	0.01	0.02	-	-
7M0	0.50	0.52	0.51	0.50	0.06	0.20	0.36	0.40
7Mh25	0.18	0.36	0.45	0.48	0.04	0.05	0.09	0.10
7ML25	0.11	0.22	0.35	-	0.02	0.02	0.04	-
7ML50	0.00	0.03	-	-	0.01	0.02	-	-
7Mh70	0.00	0.01	-	-	0.01	0.00	-	-
8M0	0.43	0.53	0.53	0.57	0.05	0.12	0.23	0.23
8Mh25	0.08	0.25	-	-	0.01	0.02	-	-
8ML25	0.08	0.15	-	-	0.00	0.01	-	-
8ML50	0.00	0.04	-	-	0.00	0.01	-	-
5.5H0	0.12	-	-	-	0.00	-	-	-
5.75H0	0.19	-	-	-	0.00	-	-	-

\* 0.14 at 8 months



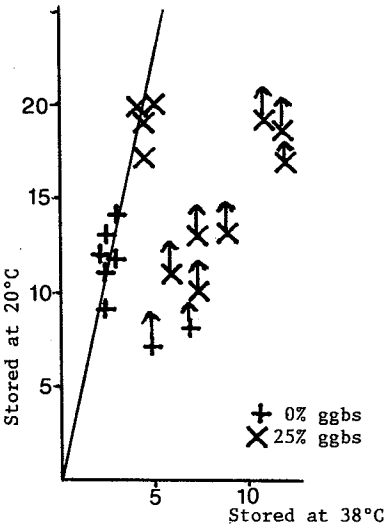


Figure 1 Months to 0.1% expansion

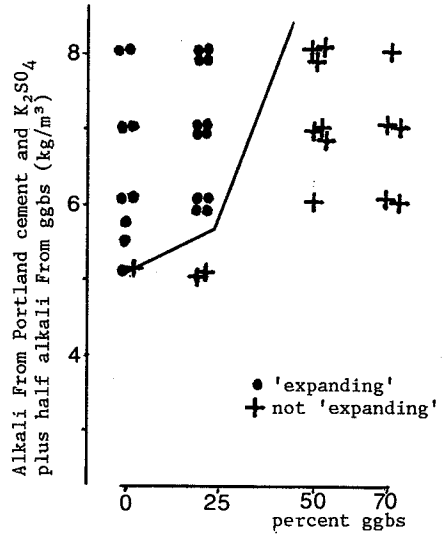


Figure 2 Half contribution From ggbs

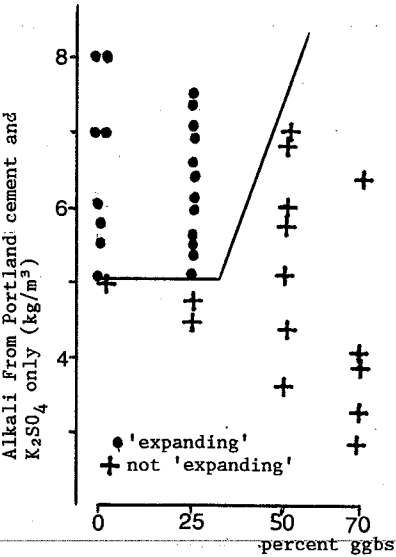


Figure 3 No contribution from ggbs

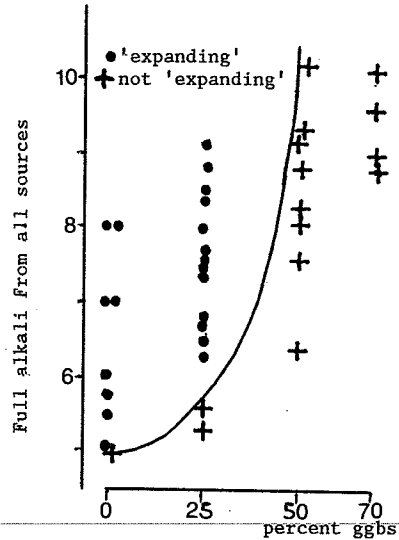


Figure 4 Full contribution from ggbs