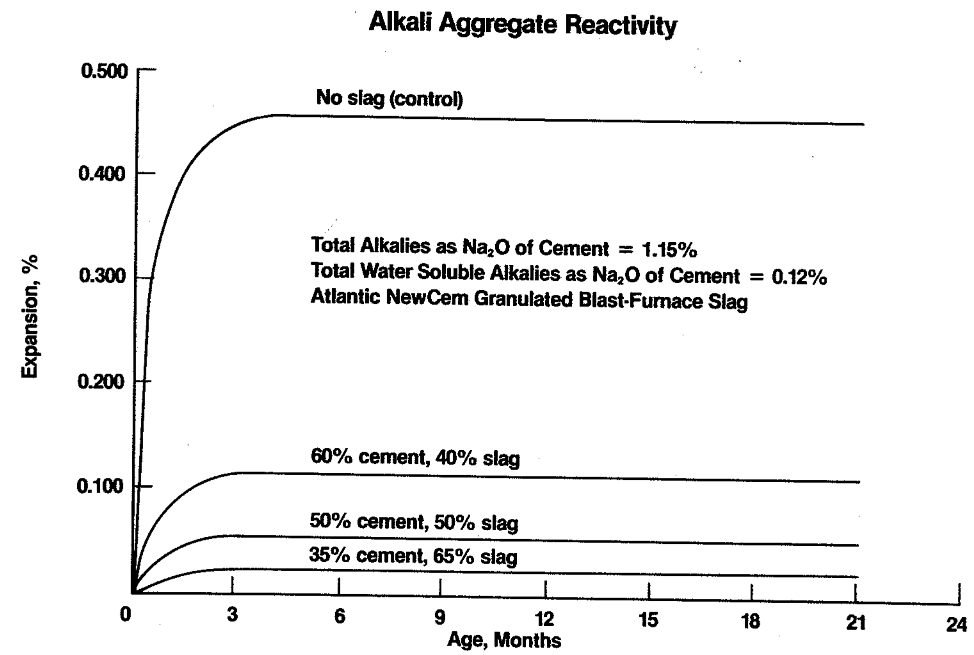

Figure 1.

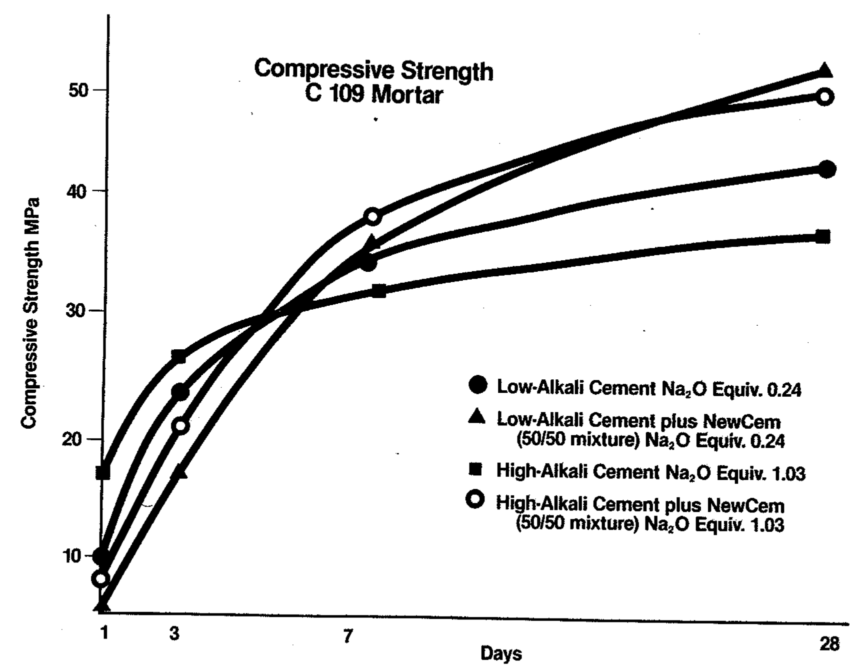

Figure 2.

THE EFFECTIVENESS OF FLYASHES AND GRANULATED BLASTFURNACE SLAGS IN PREVENTING AAR

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1. ABSTRACT

The effectiveness of slags and flyashes in preventing AAR causing damaging expansion of mortars and concretes has been assessed at BRE in a number of ways. Mortar bar expansion tests have been used with pyrex glass, beltane opal or crushed chert rock as the reactive aggregate and tests have also been carried out using concrete prisms containing a flint fine aggregate. All the tests showed that expansions were considerably reduced if sufficient flyash was used to replace the Portland cement. When beltane opal was used as the aggregate the alkali level of the ash was important and small replacement levels of high alkali ashes could increase the expansion of some mixes. The expansion of concretes containing flint aggregates may not be so sensitive to the alkali in the ash however. The more limited information on the effects of slags suggests that with UK materials a 50% replacement level is sufficient to prevent damage from AAR.

KEY WORDS - FLYASH, SLAG, AAR

2. INTRODUCTION

Since the discovery in the UK in the late 70's of deterioration due to alkali aggregate reaction there has been much interest in and debate about the possible benefits and dangers of using flyashes and granulated blastfurnace slags to reduce the possibility of damaging AAR developing in new construction.

At BRE we have assessed the effectiveness of slags and flyashes in reducing the expansion caused by AAR in a number of ways; mortar bar tests in which the reactive aggregate was pyrex glass, beltane opal or crushed chert rock and tests using concrete prisms containing flint fine aggregate. In this paper we summarise this work, concentrating on the results of the work with beltane opal and the concrete prisms which have not been presented before, and we comment on the different methods of assessment.

3. TESTS USING MORTAR BARS

In these tests 275 x 25 x 25 mm mortar bars were stored in a water saturated atmosphere at temperatures of either 38, 20 or 5°C. Length measurements recorded are the mean of two bars.

3.1 Mortar bars containing pyrex glass as reactive aggregate

The results of these tests were reported at the Cape Town conference in 1981(1). Eleven flyashes and a granulated blastfurnace slag were tested broadly according to ASTM C441 using storage temperatures of 38, 20 and 5°C. The eleven flyashes covered a wide spectrum of properties, from good to poor pozzolanas and with total alkali contents up to 4.57% equivalent Na_2O. When used as partial replacements for a high alkali (1.06% equiv. Na_2O) Portland cement all the flyashes and the slag were found to produce significant reductions in expansion of the mortar bars compared with bars containing the Portland cement only and the extent of the reduction increased as the replacement level increased. At a storage temperature of 38°C 20% of any of the ashes or 50% of the slag reduced the expansion to a level below that produced by a low alkali (0.58% equiv. Na_2O) Portland cement. The effectiveness of the flyashes at this storage temperature was therefore greater than would be produced by an equivalent dilution of the Portland cement alkalis. The effects of the different ashes were not greatly different. Such differences as there were correlated best with a measure of pozzolanic activity and the alkali content of the ash had only a secondary effect.

3.2 Mortar bars containing chert aggregate

The main reactive component of the aggregates in concrete affected by AAR in the UK has been found to be chert. It has only been possible, however, to produce damaging expansion of mortar bars containing chert aggregates by increasing the total alkali level over and above that produced by a high alkali cement(2). The effects of partially replacing this high alkali cement plus alkali by 20, 30 or 40% of a low alkali flyash or 70% slag were also reported at Cape Town(1). Significant reductions in expansion of mortar bars stored at 38°C were produced by both the flyash and slag and 30 or 40% ash or 70% slag reduced the expansion to negligible levels.

3.3 Mortar bars containing beltane opal aggregate

In these tests the reactive aggregate was Beltane opal, a porous opaline rock from the Beltane quarry, California, which is distributed as a standard alkali reactive material by Purdue University, USA. It was used in the 150 to 300 micron fraction of the aggregate which was otherwise composed of inert basalt. The water/cement ratio of the mortars was 0.43 and the aggregate/cement ratio 2.75.

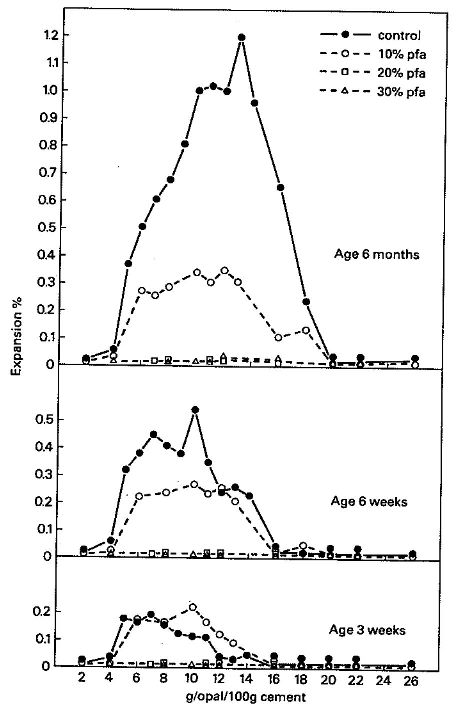

Figure 1 Mortar bars containing high alkali opc/high alkali flyash with beltane opal aggregate. 38°C

The same high alkali (1.06 equiv. Na_2O) Portland cement used in the tests with pyrex and chert aggregates was used here. In the main series of tests it was partially replaced by either 10, 20 or 30% by weight of flyash 178 (Table 1) which has a high alkali level (both total and available) and is classed as a good pozzolana. We have not yet carried out any tests in which the Portland cement is replaced by granulated blastfurnace slags in mortars with beltane opal. It was known that the expansion of mortar bars containing beltane opal varied markedly with the proportion of opal (the 'pessimum' effect) so in order to obtain a clear interpretation of the effects of the flyash a series of mixes containing different proportions of opal was made for the control Portland cement and each of the replacement levels. The results for a storage temperature of 38°C are shown in Figure 1 at ages of 3 weeks, 6 weeks and 6 months by which time expansion was effectively complete. It can be seen that at this storage temperature replacement of the high alkali cement by 20 or 30% of the ash reduces the expansion to negligible levels at any proportion of opal. With only 10% ash the mortars containing the higher proportions of opal expand more than the control at early ages but after 6 weeks storage the control expansion is greater for all amounts of opal. Overall there is a less marked pessimum for the mixes containing pfa. It can also be noticed that the control mixes containing the higher proportions of opal expand more slowly so with time the pessimum moves to higher amounts of opal.

TABLE 1 PROPERTIES OF THE FLYASHES USED

Flyash	Pozzolanicity by Lea Test(5) Strength difference MN/m^2 20-50°C 30% ash	Rating	45 µm residue	Specific surface area (m^2/kg)	Total alkalis 1)K_2O 2)Na_2O
178	17.6	Good	3.77	386	3.84 0.82
233	18	Good	5.4		3.71 0.96
237	17.4	Good	12.5	423	0.87 0.18
185	7.9	Poor	27.36	258	3.81 1.48
198	7.5	Poor	25.88	584	1.0 0.13

The expansions at 8 weeks, 3 months, and 1 year at a storage temperature of 20°C are illustrated in Figure 2. Features noticed at 38°C are now more exaggerated. The mixes containing the lower proportions of opal expand much sooner so the apparent pessimum of the control moves from 12 g opal/100 g cement at 3 months to 18 g, and as the higher opal mixes are still expanding it may move to higher values yet. Some of the lower opal content mixes containing 10 and 20% flyash expand more quickly than the control so that at ages up to 6 months they may have equal or greater expansions to the control mixes but in most cases the control mixes then overtake them. At the lowest end of the pessimum curve however the mixes with 10 or 20% flyash equal or exceed the expansion of the control even at age 1 year. The pessimum moves to lower proportions of opal as the amounts of flyash increase; 12 g opal/100 g cement for 10% flyash and 8-12 g for 20% flyash compared with the 18 g of the control.

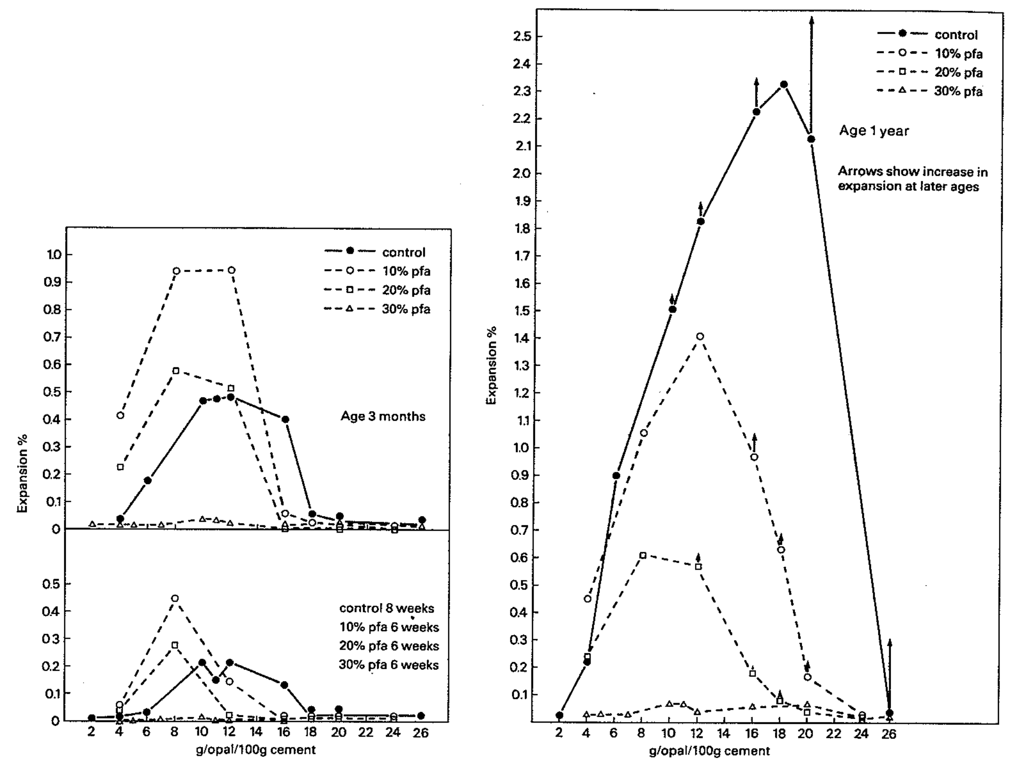

Figure 2 Mortar bars containing high alkali opc/high alkali flyash with beltane opal aggregate. 20°C

With 30% ash the expansions are small (less than 0.1% at 1 year) but definite. There is no sharp pessimum, however, and all the mixes between 10 and 20 g opal 100 g cement have similar small expansions.

The effect of the alkali level in the ash and its pozzolanicity were also investigated using three other ashes at the 20 and 30% replacement level in the mix containing 12 g opal/100 g cement. A storage temperature of 20°C was used. The properties of the ashes are given in Table 1 and the results in Figure 3.

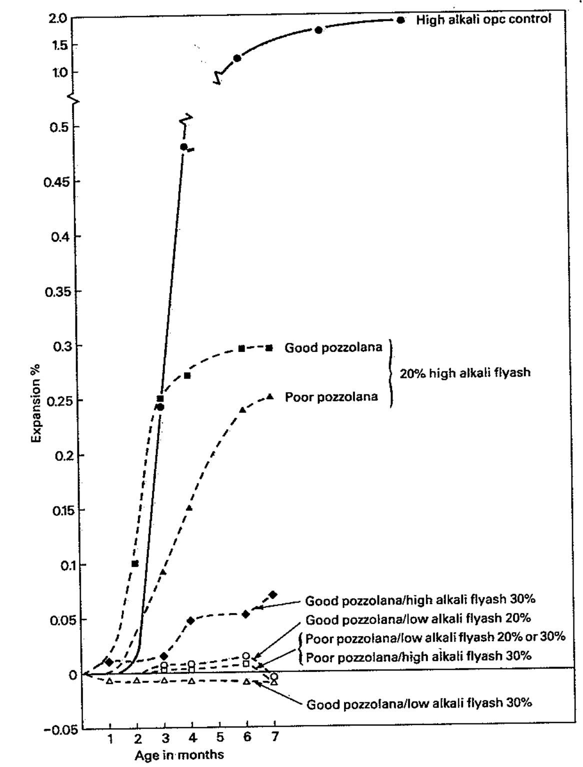

Figure 3 Effect of flyash properties on expansion of mortar bars containing 12 g opal/100 g cement. 20°C

At the 30% replacement level only the bars containing the high alkali ash 178 have expanded significantly by 7 months. Those containing the highly pozzolanic, low alkali ash 237 have shown a consistent shrinkage.

At the 20% replacement level the bars containing the high alkali ashes have expanded whereas the expansion of the bars with the low alkali ashes is insignificant.

In mortars containing beltane opal therefore, the alkali content of the flyash does seem to have a significant influence on the effectiveness of the ash in reducing expansion.

4. TESTS USING CONCRETE PRISMS

A series of experiments is in progress in which the expansion of 75 x 75 x 200 mm concrete prisms stored at 38°C either in water or in a saturated atmosphere is being used to study the reactivity of British aggregates(2). Cracking and expansion has been produced within a few months in prisms containing 20, 30 or 40% Thames Valley sand as a proportion of the total aggregate and a high content (740 kg/m^3) of the same high alkali cement (1.06 equiv. Na_2O) used in the mortar bar tests. The reactive material in this sand is flint in the coarser size fractions, the rest being mainly quartz

5, 20 and 30% of this Portland cement have been replaced by a flyash in a set of prisms containing 30% of the Thames Valley sand. For each mix duplicate prisms were made. The flyash (233) is from the same power station as ash 178 used in the mortar bar tests and similarly has a high alkali content and is a good pozzolana. A further duplicate set of prisms has been made with 600

kg/m^3 of the Portland cement giving an alkali level (from the Portland cement) equivalent to dilution of the 740 kg/m^3 mix by 20% flyash.

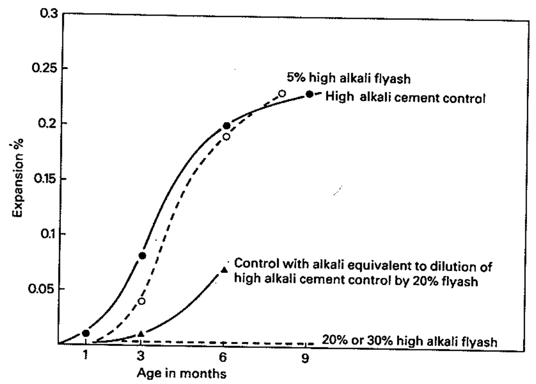

Figure 4 Concrete prisms containing high alkali opc/high alkali flyash with 30% flint/quartz fine aggregate. 38°C

It can be seen from Figure 4 that 5% replacement by flyash had little effect on the expansion but 20 and 30% replacement suppressed the expansion completely. It can also be seen that the effect of the flyash is more than is produced by an equivalent reduction in the alkali level in the concrete.

5. DISCUSSION

Comparison of the results of the different test methods described reveals both important similarities and differences. All the test methods show that expansion is reduced very significantly if a sufficient quantity of the flyash is used and where tests were carried out at both 38°C and 20°C those at 38°C show the flyashes to be more effective in reducing expansion. Tests carried out at 38°C on mortars containing beltane opal(3) or pyrex or on concrete prisms containing the Thames Valley sand show that the reductions are greater than would be produced by dilution of the cement alkalis. It may be that the pozzolanic action of the flyash which is favoured by the high storage temperature and moist conditions is playing a part in combating the alkali aggregate rection under these conditions.

The effectiveness of granulated blastfurnace slags has so far only been assessed by us using mortar bars made with either pyrex or crushed chert aggregate. The reductions in expansion seem to be approximately equivalent to the dilution of the Portland cement alkalis and with British Portland cements and slags, 50% replacement is therefore sufficient to reduce expansion to negligible levels.

The use of beltane opal in mortars produces two important results. Firstly there are some mixes, at the lowest end of the pessimum, where the replacement of the high alkali Portland cement control by 10 or 20% of the high alkali flyash results in a greater expansion. Secondly the amount of alkali in the ash seems to be important in determining the relative effectiveness of different ashes in reducing the expansion. This suggests that for the most effective control of alkali aggregate reaction involving opaline aggregates some limit should be placed on the alkali level of the

ash. It should however be noted that this result was not obtained with mortars containing pyrex aggregate.

Interpreting the results of the mortar bar tests, especially those with pyrex and beltane opal as reactive aggregates and flyash as the cement replacement, in terms of appropriate specifications for concrete is not straightforward. Mortars containing those aggregates expand by amounts which can produce cracking in concrete prisms (more than about 0.05%) inspite of quite large amounts of flyash. If the aggregate in the concrete contains an opaline or other highly reactive constituent then these results from mortars may be directly applicable to concrete. It may then be necessary to regard the ash as simply a diluent to the alkalis from the Portland cement and to restrict the alkalis in the concrete to less than 3 kg of equivalent Na_2O per cubic metre even if ash is used. If the total alkali level of the ash is restricted, however, the results suggest that 20% replacement by ash will be an adequate safeguard against AAR even with an opaline aggregate.

In the case of the aggregates such as those containing chert which have reacted in the UK however, the tests with concrete prisms show that 20 or 30% of even a high alkali ash suppressed the expansion completely. For such aggregates therefore it seems more sensible to take note of the very considerable reductions in expansion in both mortars and concrete compared with the opc controls produced by the use of flyash.

6. CONCLUSIONS

1 In all the test methods expansions caused by alkali aggregate reaction were reduced very significantly if sufficient flyash (about 30%) was used to replace the Portland cement.

2 When beltane opal is used as the reactive aggregate in mortars there are some mixes where 10 or 20% replacement by a high alkali flyash produces greater expansion than the control. Low alkali ashes were much more effective and 20% of low alkali ash suppressed expansion to negligible levels.

3 The expansion of concrete containing chert aggregate is effectively suppressed by 20% of a high alkali flyash. It may not therefore be necessary to consider the alkali level of the flyash for its use in suppressing AAR in concrete in the UK but this is being investigated further.

4 The limited amount of informtion on the effects of granulated blastfurnace slags on AAR suggests that with British Portland cements and slags a 50% replacement level is sufficient to prevent damage from AAR. More information on the effects of the alkali level in the slag on the effectiveness of the slag in preventing damaging AAR expansion is needed however.

7. ACKNOWLEDGMENT

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