The effect of pfa upon alkali–aggregate reaction*

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In their paper on the effect of pfa upon expansion caused by the alkali–silica reaction (ASR), Mr Gaze and Dr Nixon found, in their first series of tests, very little expansion due to ASR when 20 or 30% pfa was present as cementitious material. This was when the alkali contributed by the Portland cement plus added alkali, expressed as equivalent Na_2O , was approximately 6 kg/m^3 . In the second series of tests, pfa was not included in the mix and little expansion due to ASR was observed when the alkali contributed by the Portland cement plus added alkali content was approximately 5.0 kg/m^3 .

These 'threshold alkali levels' are appreciably higher than those deduced from data published by other investigators. In the case of OPC mortars for example, Stanton⁽¹⁾, Sprung⁽²⁾ and Hobbs⁽³⁾ observed damage due to ASR at alkali levels as low as 3.5 kg/m^3 , whilst for OPC-pfa mortars several investigators have observed deleterious expansion when the

alkali contributed by the Portland cement component was approximately 3.5 kg/m^3 (see Table I). Is it possible that the test curing regime used by Mr Gaze and Dr Nixon was not as adverse as those used by other investigators and could this explain why damage due to ASR was not observed when 30% of the cement was replaced by pfa?

At the C&CA we have found that the effectiveness of pfas in preventing damage due to ASR varies quite widely and that 30% replacement of a high-alkali-content cement in mortars with water/cement ratios of 0.41 and 0.53 and aggregate/cement ratios of 2.75 and 3.5 respectively is rarely sufficient to prevent damage due to ASR when the alkali content of the cement is approximately 1%⁽⁴⁾. The total alkali content of the pfas we have used to date ranged from 1.4 to 3.6% and was therefore higher in every case than that of the pfa tested by Mr Gaze and Dr Nixon.

Some results obtained at the C&CA on mortars with 30% replacement of a high-alkali-content cement by pfa are shown in Figures I and II. The pfa

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TABLE I: Expansion of OPC-pfa mortars.

Authors	Portland cement content (kg/m^3)	Alkalis contributed by Portland cement as Na_2O (kg/m^3)	$\frac{F}{c+F}$ (%)	Number of pfas tested	Test temperature ($^{\circ}\text{C}$)	Expansion* (%)
Hobbs ⁽⁴⁾	310	3.2	30	7	20	0.02 ⁺ , 0.23 ⁺ , 0.57 ⁺ , 0.62, 0.73, 0.75 ⁺ , 0.76 at 200 days
Lenzer and Ludwig ⁽⁵⁾	380	3.5	20	1	25	0.45 at 1 year
Porter ⁽⁶⁾	540	3.2	18	1	38	0.15 at 2 years

⁺pfa complied with BS 3892: Part 1.

*Cracks are often visible at an expansion of 0.05%.

Figure I: Influence of pfa upon the relationship between expansion at 200 days and Beltane opal content, $F/(c+F) = 0.3$.

Figure II: Influence of pfa upon the relationship between expansion and age when Beltane opal content is 8%. (The high variation shown is not untypical for specimens containing high reactive aggregate contents.)

had a total alkali content of 3.6% equivalent Na_2O , a residue of 7.4% on a $45 \mu\text{m}$ sieve and a fineness of $330 \text{ m}^2/\text{kg}$. It can be seen that large expansions still occur when 30% of a cement is replaced by pfa and that expansion can even be increased in the presence of pfa.

Reply by the authors

We thank Dr Hobbs for his interest in our paper. We do not, however, feel that the data that Dr Hobbs has contributed conflict with our findings. Our purpose in this work was to investigate whether or not pulverized-fuel ashes have an effect upon alkali-aggregate reaction other than that of a diluent. The results which we have presented seem to show that, at a storage temperature of 38°C , the particular ash tested (which had a low alkali content) did indeed have a specific effect in reducing expansion even when the alkali level in the mix was kept constant. We are, however, as stated in the paper, carrying out further tests at 20°C and the results so far corroborate those at 38°C .

The expansive characteristics of mortars containing Beltane opal are indeed complicated and have to be interpreted with great care. The results shown by Dr Hobbs in Figure II refer to mixes at the very edge of the opal expansion range and such mixes often seem to produce inconsistent results. We note that one of the mortar specimens containing pfa expanded to a very much greater extent than the other. We have ourselves noted that it is not unusual in such mixes for one specimen to expand and the other not. This

makes interpretation of results for mortars with opal contents at either the extreme low or high ends of the expansion range difficult and we do not consider that too much significance should be read into small differences between such specimens.

Dr Hobbs wonders whether the test curing regime used in our investigation was sufficiently 'adverse'. In so far as our experiments were conducted at 38°C , at which temperature, as we noted in our paper, the reaction of pozzolanic materials is relatively favoured, this is fair comment. As explained above, we do not consider that this invalidates our conclusions. However, it is worth noting that mortar specimens stored at 20°C and made with a high alkali cement and opal contents at the high end of the expansion range, but otherwise to the same mix design as those described in our paper, were still expanding strongly at age 1 year (see Figure III). These results have been reported⁽⁷⁾. It could be argued that, since ostensibly similar specimens are shown in Dr Hobbs's Figure II to have completed their expansion by about 50 days, the test regime to which our specimens are exposed is (setting aside the storage temperature) a rigorous one.

Figure III: Expansion of mortar bars containing high-alkali OPC and Beltane opal aggregate with replacement by high-alkali pfa. Specimens stored at 20°C.

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