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Deleterious expansion of concrete due to alkali-silica reaction: influence of pfa and slag*

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The author is to be congratulated on undertaking such an extensive and informative review of the existing literature on ASR.

In his discussion of alkali release from pfa and slag, Dr Hobbs uses as a point of reference "the annual average works alkali levels of British ordinary Portland cements" which are quoted as being "*normally* (my emphasis) in the range 0.4 to 1.0% expressed as equivalent sodium oxide . . .". No mention is made of the abnormal cements. If all OPC's complied with the quoted average works alkali levels, there would be little need for research on ASR. These values are then compared with the total alkali contents of 26 British pfa's ranging from 0.75 to at least 4.6% by mass. No attempt is made to discriminate between the sources tested by Smith and Halliwell and sources fit for use in structural concrete in terms of BS 5328: Part 1. Recourse to the source material (Ref. 43 of Dr Hobbs' paper) reveals that the ashes "were selected to give as wide a variation as possible in chemical composition, particularly loss-on-ignition, and physical characteristics; they include a number of ashes which are clearly unsuitable for use in concrete". "The distribution of properties in the BRE samples is probably distorted towards those of ashes produced in smaller peak-load stations and is therefore unlikely to be representative

of what the Central Electricity Generating Board or the South of Scotland Electricity Board would consider supplying for use in concrete". Hardly a suitable reference for a fair appraisal.

In fact, all but one of the potential sources of BS 5328: Part 1 pfa in England have a total alkali level (as Na_2O) in the range $3.4 \pm 0.3\%$. The 'odd man out' is Ironbridge at about 2.55%. Whilst both pfa and slag can have alkali contents markedly higher than Portland cement, the alkali from the cement is always reactive, whereas that in pfa may not be so. The important question is how much of this alkali is significant in the ASR situation and does it vary from source to source.

Because pfa is used as a direct replacement for Portland cement in the tests reported in Table 2, Dr Hobbs claims that "the pfa's are being treated in a more favourable manner than would be the case with designed mixes". This is not necessarily so. While the use of pfa as an addition-replacement may increase the alkali content of the concrete, it also reduces the permeability. Ho and Lewis⁽¹⁾ have shown the relative difficulty of re-wetting concrete containing fly ash. It must be remembered that ASR is not a problem in dry concrete.

In testing for potential ASR, investigators strive to use the pessimum amount of reactive aggregate, but do not necessarily seek or adopt the optimum amount

*Pages 191 to 205 of MCR 137.

of cement replacement material. As a result, the predictions from the laboratory data will tend to be pessimistic. A further concern is the sensitivity of test results to the fine detail of the laboratory procedures and to the nature of the reactive aggregate used. Beltane opal is a heterogeneous material and pyrex glass has been reported to vary in reactivity from batch to batch. When it comes to predicting field

performance from laboratory tests, the level of confidence cannot be high.

Unfortunately, the sources of cement, pfa and slag are not given so that, from the published data, it is not possible to decide which material sources are desirable and which are potentially harmful. However, this should not be taken as a criticism of Dr Hobbs or his paper.

Reply by the author

I would like to thank Mr Butler for comments on my paper. I will deal with his various comments in the same order as they were raised.

The annual average works acid-soluble alkali levels of British Portland cements have, over the past decade, been in the range 0.3 to 1.0% expressed as equivalent sodium oxide content by mass. The certified average acid-soluble alkali content of cements currently in production in the UK also ranges from 0.3 to 1.0% by mass. This certified average is an up-to-date running mean of 25 daily test results. Some variation in acid-soluble alkali level is inevitable in the production of cement and this may occasionally amount to $\pm 0.15\%$ about the certified average, giving a maximum alkali level of 1.15%. However, the highest alkali level of any batch of UK cement which has been delivered to the C & CA over the past 5 years is 1.05% by mass, so the abnormal cements mentioned by Mr Butler are not produced.

I referred to the paper by Smith and Halliwell because it was the only reference I was aware of which reported test data for a range of UK pfa's. Whilst I agree that the pfa's should not be taken to be representative of the pfa's used in concrete, the range of total acid-soluble alkali contents reported by Smith and Halliwell is similar to that of the pfa's tested at C & CA which conform with BS3892: Part 1. Some examples are given below. Most UK pfa's, as Mr Butler points out, have total acid-soluble alkali contents in the range 3.0 to 3.8% by mass.

Pfa source	Total acid-soluble alkali content (% by mass)
Longannet	0.94, 1.30
Ironbridge	2.35, 2.40
Fiddlers Ferry	3.28, 3.45
Eggborough	3.32, 3.67
Barford	4.03, 4.50

Mr Butler implies that the addition-replacement method of using pfa may reduce the risk of cracking due to a reduced permeability of the concrete. This may well be so if alkalis are entering the concrete from an external source, but it is not so if the alkalis are already present in the concrete. This is illustrated in

Figure 1: Expansion data for OPC concrete and concretes in which the pfa has been used as an addition-replacement (moist cured at 20°C, opaline silica aggregate).

Figure 1, where expansion data are plotted for concretes of high binder content. The use of pfa as an addition-replacement has, in this example, increased expansion due to ASR.

In my paper I attempted to give guidance to assist in minimizing the risk of cracking due to ASR in new construction when a reactive aggregate was to be used. Although I would accept that under field conditions, higher available alkali levels are probably necessary for cracking to occur than for comparable concretes stored in the laboratory under controlled conditions, I do not accept that the one-sixth rule overestimates the alkali contribution made by pfa's under field conditions.

REFERENCE

- HO, D. W. S. and LEWIS, R. K. *The effects of fly ash and water-reducing agents on the durability of concrete*. Melbourne, CSIRO, Division of Building Research, 1981. Research Report.

Corrigendum to the original paper

The percentages by mass of Na_2O and K_2O in slag B were 0.31 and 0.40% respectively, giving an equivalent acid-soluble Na_2O content of 0.57% by mass.