Pfa and fly ash as an addition in concrete – European standards

L K A Sear

United Kingdom Quality Ash Association

ABSTRACT

BS EN206, the European standard for the specification of concrete, has recently been published. The UK complementary standard to BS EN206, BS8500, is currently out for public comment. Both of these standards will come into full force in December 2003. They are the enabling standards for the use of pulverised fuel ash (PFA) and fly ash as an addition in concrete. This paper will review the various options and differences in these materials to the concrete specifier and producer.

There is a long history of use of pulverised fuel ash to BS3892 Part 1 in the UK as an addition. This standard specifies a fine fly ash that has been processed, using air swept classifiers. This processing improves many of the properties of the material, e.g. water demand, strength performance, etc. However, throughout most of the rest of Europe classifying fly ash is virtually unheard of. Therefore, BS EN450 - Fly ash for concrete, permits a wide range of fly ash fineness to be used in concrete. Because of these differences BS EN206 contains some specific rules for using BS EN450 fly ash and yet permits National systems to be adopted. Using the BS EN206 requirements fly ash does not count fully towards the cement content unless it can be shown it has 'equivalent performance' characteristics. These rules and the restrictions within BS EN206 will be explained and how they are applied to both BS3892 Part 1 PFA and BS EN450 fly ash.

BS8500 details the rules specific to the UK. These allow the use of BS3892 Part PFA as an addition in a similar manner to current practice. That is BS3892 Part 1 PFA counts fully towards the cement content. Where it is felt appropriate, BS8500 contains tables that detail the specific requirements for concrete using PFA within the mix parameters, e.g. higher or lower minimum cement contents or water/cement ratios. In addition, BS8500 specifies that EN450 fly ash may adopt the same compliance rules as BS3892 Part 1 and count fully towards the cement content subject to compliance with some additional testing. The requirements of BS8500 and the meaning to both PFA and fly ash as a concrete addition will be reviewed.

Note: The version of BS8500 referred to throughout this paper is the 'Draft for public comment' version of March 2001. The reader should verify the validity of any statements made about this document using the final published version. Changes to the text may invalidate some aspects of the following.

INTRODUCTION

BS EN206: 2001 "Concrete – Part 1: Specification, performance, production and conformity" has recently been published. This document replaces BS5328 as the primary method of specifying concrete within the UK from 1 December 2003. This standard has to be used in conjunction with the complementary standard, BS8500, that

details the durability requirements applicable within the UK. Currently BS8500 is available for public comment.

Within these two standards, the use of materials like pfa and fly ash has changed significantly. However, BS8500 is structured in such a manner to ensure that UK practice will continue is a similar manner as is current. The requirements of these standards in respect of pfa and fly ash in concrete are described.

BS EN206-1: 2001 AND ADDITIONS

The standard recognises two types of additions:

- Type I additions – these are suitable for use in concrete but do not count towards the cement content.
- Type II additions – these are considered to be fully or partially cementitious and count towards the cement content.

Type I additions cannot be counted as contributing towards the cement content of a mix. BS3892 Part 2 PFA is within the category of PFA.

There are two basic concepts for utilising Type II additions are given within BS EN206, firstly the 'k' value concept and secondly, the equivalent performance concept. There are a series of rules for these concepts as follows. However, it should be noted that 'other concepts' for additions are permitted if their suitability is established, that is by an either European Technical Approval or National standard. For the UK, these other concepts are contained in BS8500.

The following is an explanation of the rules in relation to fly ash to EN450.

The 'k' value concept (Clause 5.2.5.2)

The 'k' value concept describes one way of including additions as counting towards the cementitious content. For fly ash conforming to BS EN450 two 'k' values are given for differing Portland cements, CEM I 32.5 where k=0.2 and for CEM I 42.5 where k=0.4. The first restriction is that the maximum amount of fly ash to be taken into account is limited to 0.33 of the cement content. In European standard terms, the cement content is NOT the Portland cement plus the fly ash but just the Portland cement proportion. Effectively only 25% of the total cementitious content can be fly ash and counted towards the cementitious material. The second requirement is the specified minimum cement content, as given in National standards (BS8500 in the UK), may only be reduced by a maximum of k x minimum cement content – 200) kg/m^3. In addition, the total of the mass of cement plus fly ash shall never be less than the minimum cement content. Finally the calculation of water/(cement + k x fly ash) ratio shall not be less than the specified maximum water cement ratio (W/C). These rules are probably best illustrated by example:

BS8500 gives limiting values for exposure class XD2 for which fly ash is a permitted cementitious type:

C25/30 Max. W/C 0.55 Min. cement content=300kg/m^3.

We will presume the specifier states a preference for a mix containing BS EN450 fly ash at either 25% or 30% of total cementitious using CEM I 42.5 as the Portland cement. Therefore, 'k' is 0.40.

The adjusted minimum cement content is:

300 + (0.4 x 300 – 200) = 220 kg/m^3. (NB: This is the Portland cement element only)

For a 25% fly ash content in the total cementitious the minimum total cementitious content would be:

220 / 0.75 = 293 kg/m^3 – as this is less than the original 300kg/m^3 the latter figure would apply.

However, 30% fly ash in the total cementitious has been specified. Therefore the minimum total cementitious content would be

220 / 0.70 = 314.3 kg/m^3

The adjusted W/C ratio is calculated using the formula water/(cement + k x fly ash) – again only 0.33 of the cement content can be used. Assuming a water demand of 150l/m^3 the calculations would be:

For 25% fly ash of the total cementitious there would be 225kg/m3 of CEM I and 75kg/m3 of fly ash. 225 x 0.33 = 74 kg/m3 – the maximum fly ash that can be used in the calculation. Therefore, the adjusted W/C ratio to use to compare against the maximum W/C ratio would be:

150 / (225 + 0.4 x 225 x 0.33) = 0.59

For a mix with 30% fly ash the calculation would be:

150 / (220.5 + 0.4 x 220.5 x 0.33) = 0.60

Both these mixes fail to comply with the maximum W/C ratio requirements the cementitious content would have to adjusted to compensate, e.g. increased by a factor of 0.59/0.55 for the 25% fly ash version and 0.60/0.55 for 30% fly ash version. This results in mixes containing 321kg/m^3 total cementitious for 25% fly ash and 344kg/m^3 for 30% fly ash. In general terms these formula always increase the effective minimum cementitious content of a concrete mix. This would appear to prejudice the use of water reducing plasticisers as little technical of commercial benefits are likely to be achieved.

Within the same clauses k-values are given for silica fume complying with prEN13263: 1998 and similar calculations for minimum cement content are required. However, the k-values assigned with BS EN206 are considerably higher (2.0 and 1.0 where W/C >0.45 and for exposure class XC and XF) and, additionally, there is no adjusted W/C ratio values to calculate.

As is seen from the above the circuitous calculations involved are time consuming and fail to take into account much of the addition in the mix design. Alternatively, the ‘equivalent concrete performance concept’ may be used.

The equivalent concrete performance concept (Clause 5.2.5.3)

This is a generalised approach to using fly ash within concrete. The clause simply states that amendments to the minimum cement content and max. W/C ratios may be made for clearly defined and sourced additions. It has to be proven that the resulting concrete has equivalent performance both environmentally and from durability aspects in relation to concrete in accordance with the exposure requirements. Reference is made to Annex E is made that indicates the general requirements for such equivalence testing.

BS8500 adopts this equivalence approach in respect of the requirements for PFA and fly ash.

BS 8500: COMPLEMENTARY STANDARD TO BS EN206-1 AND PFA TO BS3892 PART 1 AND FLY ASH TO EN450

As will be seen above the European standards approach to fly ash is very different to the well established practice within the UK. The UK and Ireland are the only two countries within Europe that classify fly ash to improve the reactivity and reduce water demands. Classified fly ash for concrete is produced under BS3892 Part 1 and will be retained for the foreseeable future through BS8500. It is useful to compare these standards for PFA and fly ash to understand the differences in specification.

BS3892 Part 1: Specification for pulverised fuel ash for use with Portland cement.

BS 3892 Part 1 main requirements can be summarised as:

- The fineness of the PFA shall be less than 12% retained on the 45μm sieve.
- The water requirement for mortars of the same workability made in standard prisms containing 30% PFA and 70% Portland cement shall not be greater than 95% of a Portland cement alone reference mortar.
- The ratio of strengths from the mortar prism test described above, the strength factor, shall be a maximum of 0.80.

In addition the PFA must be classified, that is processed to remove the coarser fractions of the fly ash being produced by the power station. This is normally done using air swept classifiers. Loss on ignition (LOI) of up to 7.0% is permitted.

BS EN450: Fly ash for concrete – Definitions, requirements and quality control.

BS EN450 main requirements can be summarised as:

- The fineness of the fly ash shall be less than 40% retained on the 45μm sieve.
- The fineness shall not vary by more than ±10% of the mean value declared by the manufacturer.
- The ratio of mortar prism strengths for the same W/C ratio (0.50) shall not be greater than 75% at 28 days and 85% at 90 days.

LOI is limited to 5.0%, though 7.0% is permitted on a National basis. It is clear from above that BS EN450 permits a wider range of fineness and the performance tests are at fixed W/C ratio rather than equal workability. In addition, there is no requirement for any water reduction.

In a project carried out by the UK Quality Ash Association it was found the water demand differences between BS EN450 fly ash and BS 3892 Part 1 PFA were marked. Part 1 PFA, being a finer ash, gave considerable water reductions for a given workability and greater reactivity/strength performance, see figure 1. In addition, the differences between sources, in the main, are removed as the UK suppliers of PFA adjust the classification process to produce a demonstratively similar material. In fact the Quality Scheme for Readymixed Concrete and the British Standards Institute third party quality assurance schemes for readymixed concrete both accept that PFA to BS3892 Part 1 from many sources are demonstratively similar.

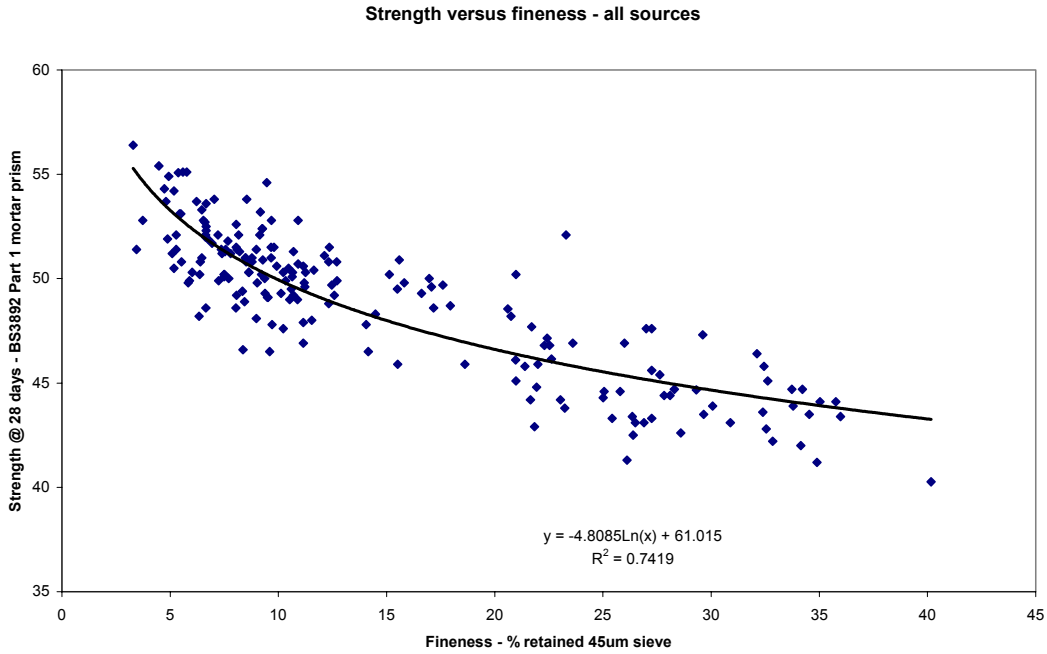

Figure 1 - Strength of mortar prisms (made to BS3892 Part 1 requirements) with PFA/fly ash fineness.

With EN450 fly ash the differences in mean fineness between differing power stations was noticeable, see figure 2. While all UK fly ashes are pozzolanic, these fineness differences are such that concrete consistency will be source dependent. However, it is interesting to note that the inherent variation in fineness for EN450 fly ash does not induce high variability in the concrete, as in figure 3. Once a particular source has been adopted this would have to be retained unless the concrete mix designs are adjusted to compensate should another fly ash source be used. In addition, some of the coarser fly ash may not give any water reductions found with Part 1 PFA.

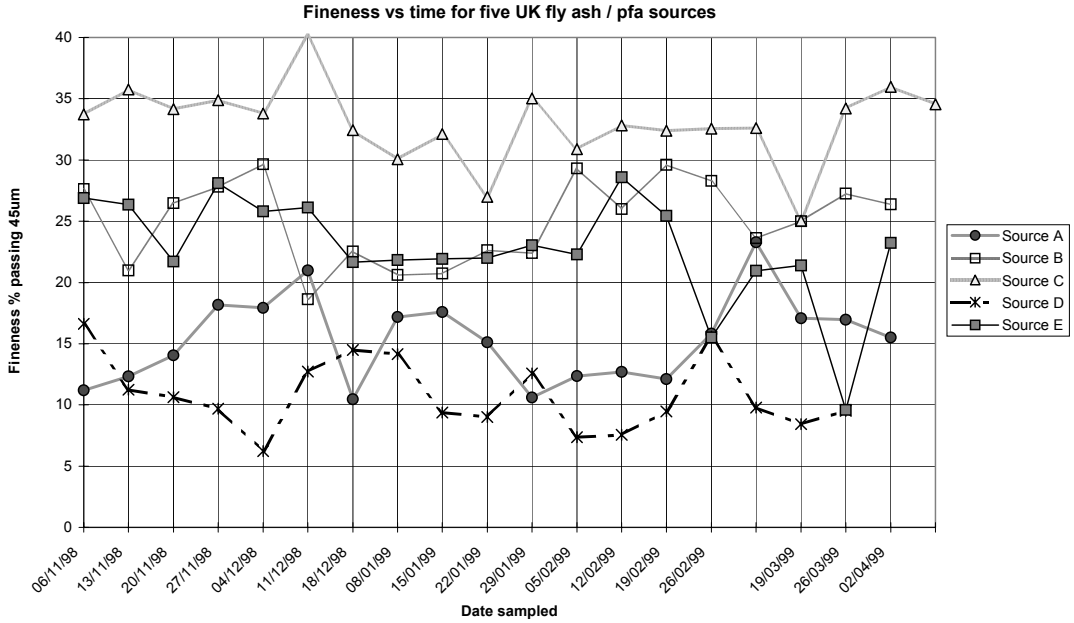

Figure 2 - EN450 fly ash has a wide range of finenesses

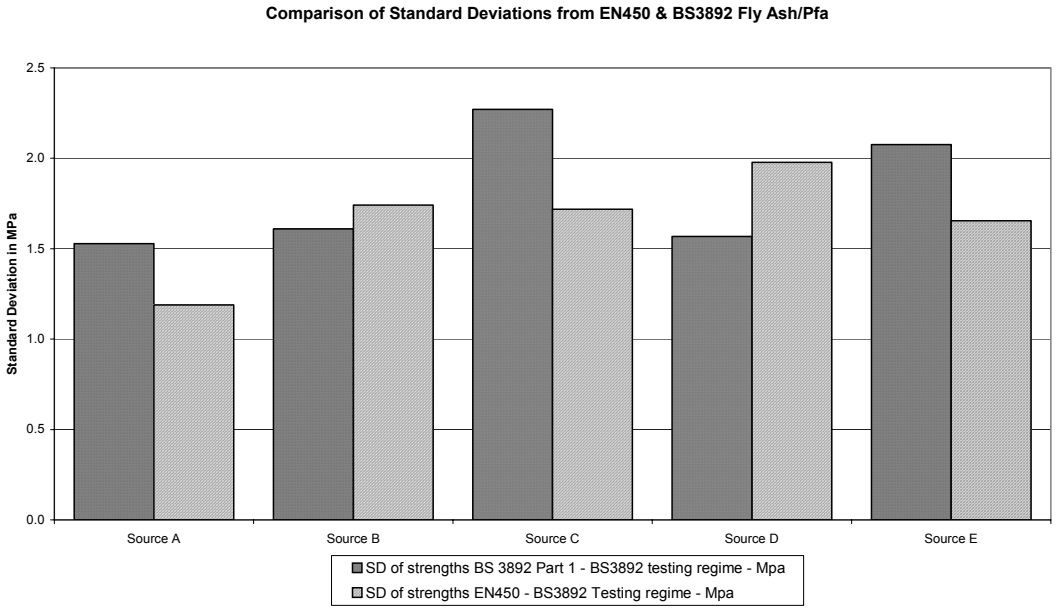

Figure 3 - EN450 fly ash is not excessively variable

Requirements of BS8500

'Combinations' is the term for blends of Portland cement (CEM I) and additions mixed in the mixer used throughout BS8500. Clause 5.1.2 'Cement and combinations' establishes suitability for some cements not covered by European standards including Pozzolanic pulverised fuel ash cement conforming to BS6610. Combinations conforming to Annex C are also given established suitability.

Clause 5.1.6 – 'Additions (including mineral fillers and pigments)' of BS8500 Part 1 firstly limits the LOI for EN450 fly ash to 7.0%. This statement is to account for the revision of EN450, due out by December 2003, which will have categories of LOI up to 9.0%. The UK does not feel such high LOIs are relevant in the UK and the traditional 7.0% limit has been confirmed. BS3892 Part 1 PFA is given the status of 'established suitability' as a type II addition and BS3892 Part II as a type I addition in this section.

Further requirements for additions are given in clause 5.2.3 'Use of additions'. Both BS 3892 Part 1 PFA and BS EN450 fly ash are allowed to be taken fully into account in respect of W/C ratio and cement content when tested in accordance with Annex C. This option, permitted under the equivalent concrete performance rules of EN206, is an alternative to the k-value concept approach. However, it must be made clear it does not stop the use of the k-value approach or other methods of assessing equivalent concrete performance as defined in BS EN206-1. A British Standard cannot circumnavigate the requirements of a European standard, as this would form a barrier to trade.

Annex C – Conformity procedure for combinations.

Annex C details a complex test procedure to establish strength classes for combinations of CEM I and additions. This system is familiar to the UK as the system common to both BS3892 Part 1 PFA and BS6699 for ggbs for concrete. This establishes relationships between the addition, e.g. PFA, and the maximum replacement level for various strength classes for a given source of material. These classes, which are characteristic strengths, are similar to those for within EN197-1 for common cements, e.g. 32.5, 42.5 and 52.5N/mm^2. The basic relationships are established on a two yearly basis with monthly testing required ensuring that the material being supplied still falls within the established criteria. Certificates of declaration of conformity shall issued on a monthly basis based on these test results. It is also indicated that third party certification of conformity is desirable.

Both BS 3892 Part 1 and EN450 fly ash, as can other additions, can be tested to this Annex C regime. This allows them to count fully towards the cement contents and maximum W/C ratios described in the various durability tables throughout BS8500. Through this route, the complexity of the 'k-value' concept can be avoided within the UK.

CONCLUSIONS

BS EN206 has a number of routes through which PFA and fly ash can be used. The 'k' value route is not the preferred route within the UK. BS8500, the UK complementary standard to BS EN206, provides differing routes of using these additions requiring additional testing in Annex C to establish equivalent strengths as used with cements.

BS 3892 Part 1 PFA can continue to be used through this route, maintaining existing UK practice. Similarly EN450 fly ash can be tested to the Annex C regimes enabling fly ash to count fully towards the cement content of a mix.

BS 3892 Part 1 PFA is classified to remove the coarser fractions of the fly ash from a power station. This guarantees the PFA reduces the water demand for a given workability and increases reactivity. Classification improves the consistency between sources allowing many PFAs to be defined as demonstratively similar.

EN450 fly ash normally would not be classified. The inherent differences in fineness and reactivity between different power stations means fly ash is source dependant.

ACKNOWLEDGEMENTS

REFERENCES