UK PRACTICE – A REVIEW OF FLY ASHES FOR USE IN CONCRETE

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ABSTRACT

Within the UK there is a long history of the use of classified fly ash from coal fired power stations, in concrete. This fly ash is known as pulverised fuel ash (PFA). UK knowledge is based predominantly upon a standard called BS3892 Part 1. EN450 'Fly ash for concrete' adopts a very different approach to the specification of fly ash than that within BS3892 Part 1. There are many differing views on the benefits and drawbacks to the concrete producer of both these fly ashes. From this basis, this paper will attempt to explain:

- The history behind the classification of fly ash within the UK.
- Why was this form of fly ash adopted as the preferred one?
- The details and logic behind the UK specification for PFA to BS8392 Part 1.
- To review the research works that have been carried out over the years on concrete durability supporting BS3892 Part 1 PFA.

With the adoption of EN450 in 1995, the UK Quality Ash Association carried out an extensive test programme to determine the differences between the various test methods. In addition, the project looked at whether UK fly ashes would comply with EN450 and the effects of classification on the performance of fly ash. A number of research works are been carried out, by various UK bodies, on the use of EN450 fly ash and its influence on concrete durability. This paper will review the results of the UKQAA test programme, plus the various durability research projects, and outline the differences between the two forms of fly ash. From this, a discussion on the necessity for continued co-existence of both EN450 and BS3892 Part 1 will be carried out.

THE HISTORY BEHIND THE CLASSIFCATION OF FLY ASH

It was the introduction of modern steam raising plant in the UK in the late 1940's that saw the growth of research into the use of fly ash. In particular the example of using fly ash in mass concrete dams was considered, and, following research at the University of Glasgow[1], the practice was adopted for construction of the Lednock[2], Clatworthy and Lubreoch Dams in Scotland. Lednock involved some 82,000 cu yards (62,500 m^3) of concrete saving some 3,000 tons of Portland cement.

There followed, in the period 1954-58, examples of the use of fly ash as cement replacement in structural concrete at the Fleet Telephone Exchange, Newman Spinney Power Station[3] and the High Marnham sub-station[4]. By the mid 1970's fly ash was regularly being used in concrete, as an addition at the concrete plant, within many structures and public works[5]. Such usage was always on a basis of close monitoring by the site and within large construction projects. It was around this time within the UK that fly ash from coal combustion became known as Pulverised Fuel Ash (PFA) to differentiate it from fly ashes derived from other processes.

Although the use of fly ash in concrete was accepted by British Standards it was not until 1965 when the first edition of BS3892[6] was published that there was a standard for the PFA for use in concrete. PFA was treated as a fine aggregate having three classes of fineness based on the specific surface area. During this period, acceptance in the readymixed concrete market was not being achieved. During the 1970's, readymixed concrete suppliers were producing ever more technically demanding concretes of higher strength and lower water cement ratios. It was perceived that the variability in quality and the supply problems of fly ash when taken directly from the power station were unacceptable.

Within the UK, the solution was found when, in 1975, Pozzolan Ltd. introduced the concept of supplying controlled fineness material. Controlling the PFA to a tightly controlled fineness involved either classifying the ash, to remove the coarse fractions, or selection of the finer material by continual monitoring of the ash production. In general, classification enhances the pozzolanicity whilst reducing the water demand for a given workability. An Agrèment Board Certificate[7] was obtained for classified fly ash, or PFA, in 1975. These changes were reflected within BS3892[8] in 1982 with the various parts of the standard indicating the uses and quality of PFA. Classified PFA to BS3892: Part 1 was accepted as counting fully towards the cement content of a mix, whereas the use of 'run of station' ashes is at the discretion of the site engineer. Run of station ash was usually considered as inert filler and are covered by BS3892: Part 2: 1984. Before 1985, interground Portland fly ash cement had been produced by Blue Circle in the North of England, under an Agrément Certificate.

Classified PFA was increasingly accepted for use within concrete both on technical and economic grounds. Currently the use of classified PFA is widespread within the UK readymixed and precast concrete industries. Some 25% of the readymixed concrete produced in the UK contain a binder that consists of, typically, 30% PFA and 70% Portland cement. Currently some 500,000 tonnes per annum of classified PFA are used in readymixed and precast concrete. With European harmonisation, BS EN450[9] 1995 was introduced. With the exception of the UK and Ireland, no other European countries routinely classify fly ash for use in concrete. EN450 reflects this differing approach and allows a wider range of fineness for use in concrete than BS3892 Part 1[10]. The enabling standard for EN450 fly ash, EN 206[11], has taken a number of years to finalise and consequently the use of EN450 fly ash is restricted in the UK to date. This will change in 2003 when EN206 is fully adopted.

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, known as 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) in the UK 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 water/cement ratio (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.

WHY CLASSIFY?

The reasons for the predominance of classified fly ash in the UK are mainly technical. They are cited as greater consistency, improved water reduction and consequently better strength performance. With the introduction of EN450 within the UK a research project to assess UK fly ashes when tested to both the European and British standard test methods was instigated. This project was carried out by NUSTONE[12] for 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.

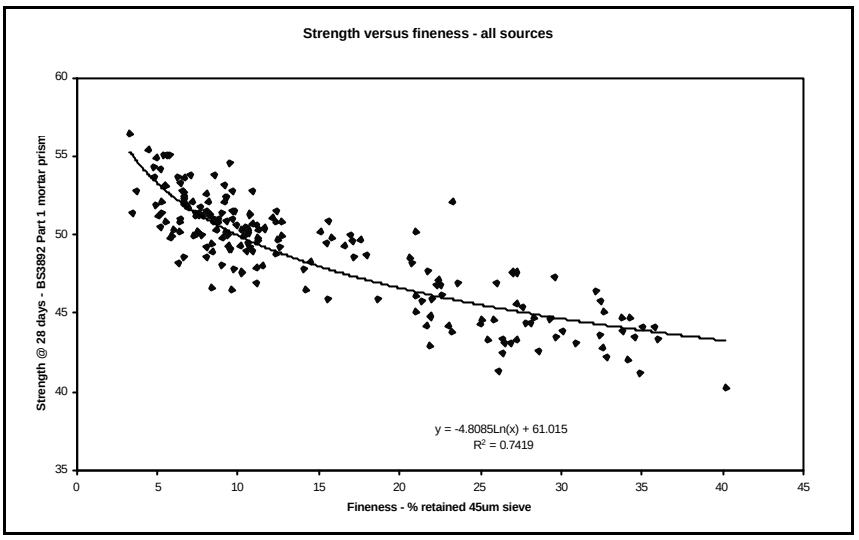

Figure 1 - Strength at 28 days - MPa from EN197-1 mortar prisms (made to BS3892 Part 1 requirements) with a range of PFA/fly ash fineness.

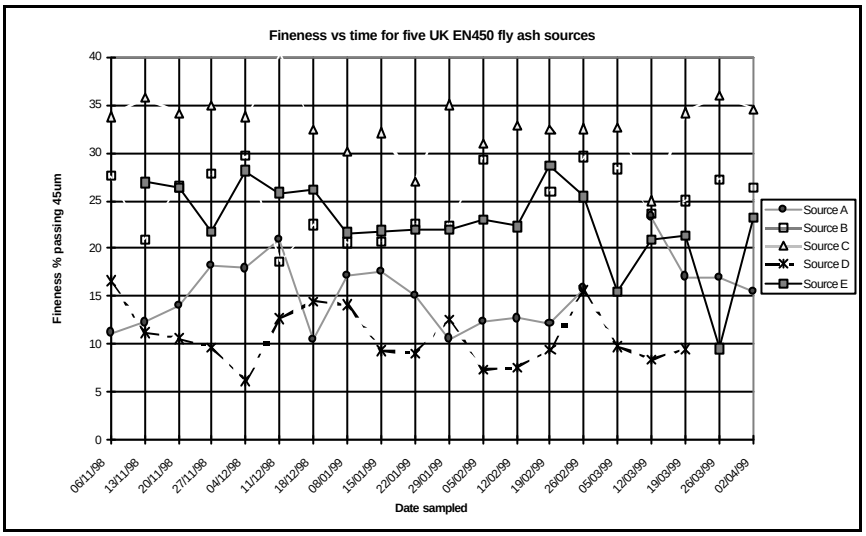

Figure 2 - EN450 fly ash has a wide range of finenesses

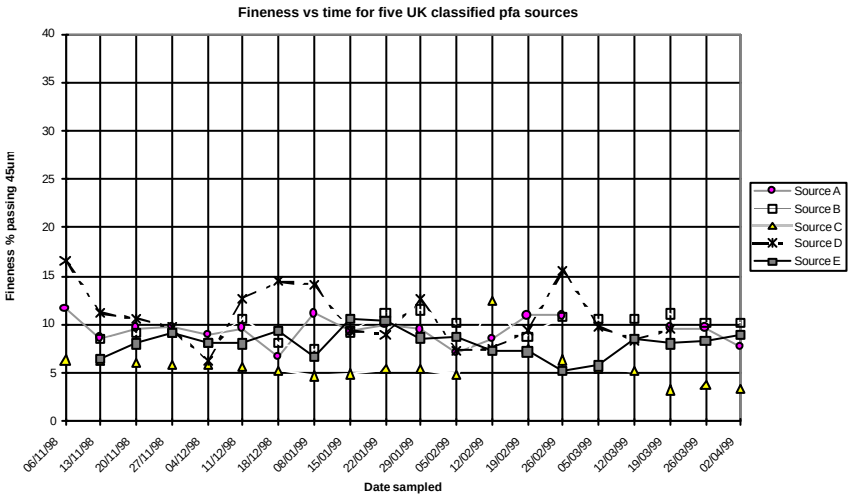

Figure 3 – Classification reduces the variability in fineness

With EN450 fly ash the differences in mean fineness between differing power stations was noticeable, see figure 2. Classification reduces the fineness variability significantly as seen in figure 3. The strength and water demand differences between sources are reduced to such an extent that many fly ashes can be classed as being demonstratively similar.
While all UK fly ashes are chemically similar and all siliceous and pozzolanic, these fineness differences in EN450 fly ashes are such that concrete consistency will be highly source dependent. However, it is interesting to note that the inherent variation in fineness for EN450 fly ash from a single source does not induce high strength variability in the concrete, as in figure 4. 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 of the water reductions found with Part 1 PFA.

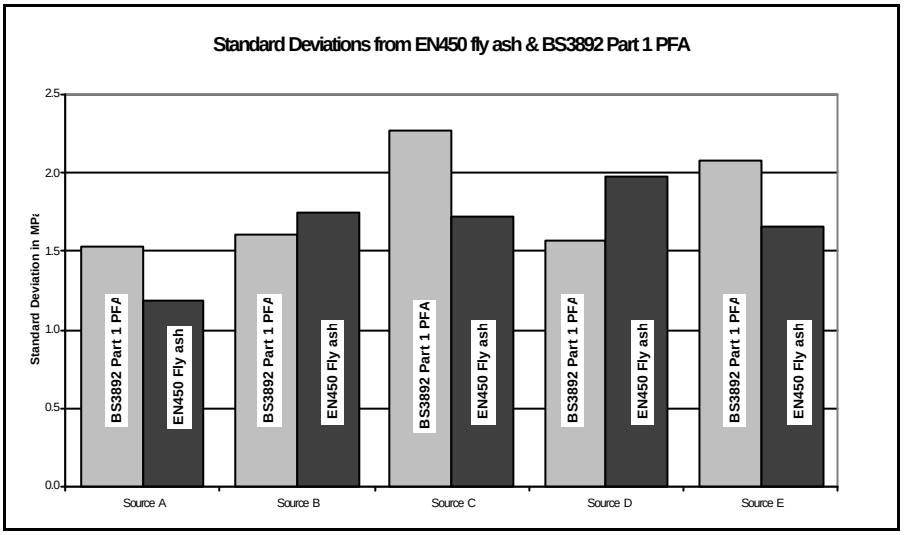

Figure 4 - EN450 fly ash is not excessively variable

RESEARCH WORK USING PFA

Much of research on durability carried out in the UK has been based around classified fly ash, e.g. BS3892 Part 1 PFA. Alkali silica reaction, sulfate resistance, chloride ingress, heat of hydration and freeze thaw properties have all been investigated by BRE and others. More recently, thaumasite is being researched using both BS3892 Part 1 and EN450 fly ashes spanning the full range of possible finenesses are being investigated.
To summarise much of this work, it is clear the surface area of the PFA within the concrete mix affects the pozzolanicity of the resulting concrete. In general terms, the low permeability of PFA concrete from the pozzolanic reaction gives it excellent durability properties. Therefore, finer PFA will react more quickly and thereby enhance the performance more quickly. In general, terms with coarser fly ashes lower periods are needed in order to achieve the same degree of pozzolanic reaction.

WHAT CAN WE LEARN ABOUT NOVEL FLY ASH PRODUCTS AND CONCLUSIONS

Fly ash has been studied by a wide number of researchers for many applications. A database of references owned by the UKQAA has in excess of 9,000 papers on the subject covering virtually all possible uses of the material. Though many of these are old projects, they are still valid, requiring only updating.

Within the UK it has been found that classified fly ash for concrete has significant advantages in both performance, e.g. increased strength, greater pozzolanic reactivity, lower water demand, etc. and able to command a higher price. In addition, BS3892 Part 1 PFA from a number of sources have been shown to be 'demonstratively similar' to the satisfaction of the various third party accreditation schemes within the UK. Currently, the BS3892 Part 1 PFA market is greater than £10,000,000 per annum. For these reasons, it is important to the UK that BS3892 Part 1 classified PFA and EN450 fly ash are allowed to coexist in the market. Alternatively, a further European standard or part to EN450 that details the requirements for classified ash should be prepared.

While classification is not 'novel' it is not widely used throughout the European community and yet UK experience has a long established history and shows it is beneficial to concrete.

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