Fly ash standards, market strategy and UK practice

Lindon K A Sear[1]

[1]Technical Officer for the United Kingdom Quality Ash Association (UKQAA), Regent House, Bath Avenue, Wolverhampton, West Midlands, WV1 4EG, UK

Tel: +44 1902-576-586 Fax: +44 1902-576-596
Email: LKASear@UKQAA.org.uk

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THE HISTORY OF THE USE FLY ASH IN THE UNITED KINGDOM

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, Clatworthy and Lubreoch Dams in Scotland. Lednock[2] involved some 82,000 cu yards (62,500 m^3) of concrete saving some 3,000 tons of Portland cement. By the mid 1950's fly ash from coal combustion became known as Pulverised Fuel Ash (PFA) within the UK. This was to differentiate it from fly ashes derived from other processes.

Although the use of PFA in concrete was accepted by British Standards it was not until 1965 when the first edition of BS3892[3] was published that there was a standard for the PFA for use in concrete. In this edition, 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 PFA 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. Producing the PFA to a tightly controlled range of fineness involved either air classification of the ash, to remove the coarse fractions, or selection of the finer material by continual monitoring of the ash quality. In general, using finer ash enhances the pozzolanicity whilst reducing the water demand for a given workability. An Agrèment Board Certificate[4] was obtained for classified or selected fly ash, or PFA, in 1975. These changes were reflected within BS3892[5] in 1982 with the two parts of the standard describing the uses and quality of PFA. Classified PFA to BS3892: Part 1 was accepted as counting fully towards the cement content of a concrete mix, whereas the use of 'run of station' ashes are

permitted at the discretion of the site engineer. Run of station ash was considered as an inert filler and was covered by BS3892: Part 2: 1984 applying to both concrete and grouts. PFA for grouts was taken from BS 3892[6] Part 2 in 1996 and a separate part created, BS3892[7] Part 3: 1997. Selection as a method of producing finer material, was removed from Part 1 at this time as this had proven to be unreliable.

We should note that before 1985, an interground Portland fly ash cement had been produced by Blue Circle in the North of England, under an Agrément Certificate. Thereafter BS6588: 1985 permitted up to 35% classified PFA and BS6610 permitted >35% to 55% PFA in factory made cements.

Currently the use of classified PFA is widespread within the UK readymixed and precast concrete industries for both technical and economic reasons. 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[8]: 1995 'Fly ash for concrete' was introduced. BS EN206-1[9]: 2000 the 'Specification of concrete' introduces two types of 'additions' that can be added to concrete when it is being mixed.

- Type I addition – these do not count towards the cement content in the mix, e.g. BS 3892 Part 2 PFA. They are treated as inert filler materials.
- Type II addition - may count partially or fully towards the cement content, e.g. BS EN450 fly ash or BS3892[10] Part 1 PFA. BS EN206-1 gives details of the 'k' value route by which fly ash may count towards the cement content.

BS8500[11] 'The UK complementary standard to EN206-1' contains an annex with a series of strength equivalence rules by which an addition may be counted fully towards the cement content. This equates the combination of the addition and Portland cement to a standard strength, similar to the strength given in BS EN197-1: 2000[12]. Factory made 'Common Cements' complying with BS EN197-1 may be used in concrete and grouts. These always count fully towards the cement content.

With the exception of the UK and Ireland, no other European countries routinely classify fly ash for use in concrete. As BS EN450 allows a very wide range of fineness when compared with BS3892 Part 1 the use of BS EN450 fly ash in the UK is minimal to date. However, this is gradually changing and in December 2003, when BS EN206-1 is fully adopted throughout Europe, we predict increased usage. Table 1 lists the requirements for the various PFA/fly ash 'additions' permitted at the time of writing.

Attribute	Requirements			
Standard	Fly ash to BS EN450	Pulverised Fuel Ash to BS3892 Part 1	Pulverised Fuel Ash to BS3892 Part 2	Pulverised Fuel Ash to BS3892 Part 3
Application	Concrete	Concrete	Concrete	Grouts
Type of addition	II	II	I	N/A
Fineness retained 45μm sieve	≤ 40% ± 10% of declared mean	≤ 12%	≤ 60%	≤ 60%
Soundness	≤ 10mm based on 50% fly ash + 50% CEM I	≤ 10mm based on 30% fly ash + 70% CEM I	N/R	N/R
Sulfur present as SO3	≤ 3.0%	≤ 2.0%	≤ 2.5%	≤ 2.5%
Chloride	≤ 0.10%	≤ 0.10%	N/R	N/R
Calcium oxide	< 1.0% or ≤ 2.5% if soundness satisfactory – expressed as free CaO	≤ 10% expressed as total CaO	N/R	N/R
Loss on ignition	≤ 5.0% (7.0% permitted allowed in place of use including UK)	≤ 7.0%q	≤ 12.0%	≤ 14.0%
Moisture content	N/R	≤ 0.5%	≤ 0.5% unless conditioned ash used.	≤ 0.5% unless conditioned ash used.
Water requirement	N/R	≤ 95% of PC using 30% PFA + 70% PC mortar	N/R	N/R
Activity Index	≥ 75% @ 28 days ≥ 85% @ 90 days 25% fly ash + 75% CEM I 42.5	N/R	N/R	N/R
Strength factor	N/R	≥ 0.80 @ 28 days	N/R	N/R
Key: N/R = No requirement N/A Not applicable				

Table 1 - Comparison of requirements of various standards

CEMENTS CONTAINING FLY ASH

BS EN197-1: 2000 details the requirements for factory made ‘Common Cements’ and contains a variety of cements of which a number contain fly ash. These are listed in Table 2.

Main cement type	Designation	Notation	Constituents Proportion by mass (%) based on the sum of the main and minor constituents.			Minor additional constituents (%)
			Clinker	Fly Ash		
				Siliceous	Calcareous	
CEM II	Portland fly ash cement	CEM II/A-V	80-94	6-20		0-5
		CEM II/B-V	65-79	21-35		0-5
		CEM II/A-W	80-94		6-20	0-5
		CEM II/B-W	65-79		21-35	0-5
CEM IV	Pozzolanic cement	CEM IV/A	65-89	11-35*		0-5
		CEM IV/B	45-64	36-55*		0-5
* May also be natural pozzolana.						

Table 2 – Extract from BS EN197-1, Table 1, Cement types containing fly ash.

There are few restrictions of the types of fly ash permitted in cement excepting:

- The reactive silica content shall not be less than 25.0% by mass.
- The loss on ignition (LOI) for the fly ash shall not exceed 5.0%. 7.0% LOI is permitted where allowed in the appropriate standards applicable in the place of use, i.e. the UK.
- Reactive CaO shall be less than 10% and free CaO less than 1.0%. Free CaO contents of higher than 1.0% and less than 2.5% are permitted subject to a requirement on soundness. It shall not exceed 10mm in when tested in accordance with BS EN196-3[13] (Testing for soundness) using a mixture of 30% fly ash and 70% by mass of a CEM I cement conforming to BS EN197-1.
- The fly ash shall be proven pozzolanic when tested in accordance with BS EN196-5[14].

Compliance with the various requirements for all common cements, e.g. soundness, LOI, sulfate content, etc, assures the user that unsuitable fly ashes are not used.

In addition to the cements permitted under the European standard, “Pozzolanic pulverised fuel ash cement” is permitted in the UK as BS 6610[15]. This was revised in 1991, with a minor revision in 1996, to bring it in line with BS EN197-1. The main features of BS 6610 are summarised in Table 3.

BS Number	BS 6610: Pozzolanic PFA cement 1995
Fly ash	Must meet the requirements of BS 3892 Part 1 PFA except for fineness if inter-ground
Fly ash level *	36 to 55%
Minor additional constituents	0 to 5%
Compressive strength - (BS EN196-1 mortar prism test)	7 days – 12 N/mm^2 28 days – 22.5 N/mm^2
*As % nucleus, i.e. clinker plus fly ash.	

Table 3 – Pozzolanic cement not covered by BS EN197-1

These cement standards form the basis of the equivalence rules, which govern the use of fly ash in concrete.

WHY CLASSIFY FLY ASH FOR USE AS AN ADDITION IN CONCRETE?

The reasons for the predominance of classified fly ash in the UK are mainly technical. They are cited as having a greater consistency, improved water reduction and consequently better strength performance. With the introduction of BS 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[16] for the UK Quality Ash Association.

All UK fly ashes are chemically similar, e.g. they are all siliceous and pozzolanic. However, the fineness of the ashes varies significantly from station to station and the resulting differences in BS EN450 fly ashes are such that concrete consistency is highly source dependent. This was due to the water demand differences between BS EN450 fly ash and BS 3892 Part 1 classified PFA. Part 1 PFA, being a finer ash, gave considerable water reductions for a given workability and greater reactivity/strength performance as seen in figure 1.

As many UK coal fired power stations are not ‘base load’ stations, the consistent sourcing of fly ash is a problem in the summer months. However, by classification the differences between sources, in the main, are removed. The UK suppliers of PFA adjust their classifiers to produce a material of similar fineness from all sources. Consequently these BS 3892 Part 1 PFA’s can be shown to be ‘demonstratively similar’ for use in concrete irrespective of ash source. This has been accepted by the Quality Scheme for Readymixed Concrete and the British Standards Institute third party quality assurance schemes for readymixed concrete, which allow multiple sourcing.

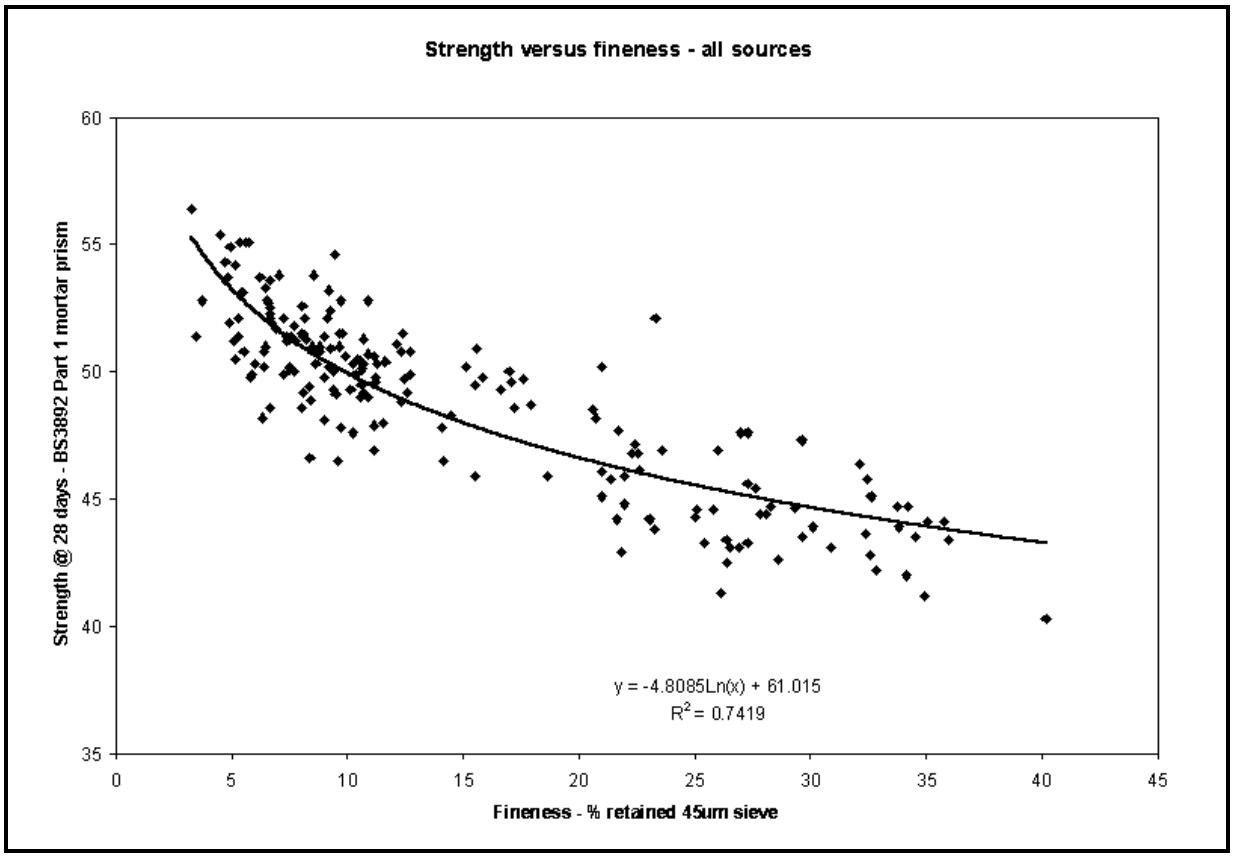

Figure 1 - Strength at 28 days - MPa from BS EN197-1 mortar prisms (made to BS3892 Part 1 requirements) with a range of PFA/fly ash sources and finenesses.

However, it is interesting to note that the inherent variation in fineness for BS EN450 fly ash from a single source does not induce excessive strength variability in the concrete. Once a particular source has been adopted this should 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 ashes available do not give any of the water reductions as found with BS 3892 Part 1 PFA.

MARKET STRATEGY

Clearly there are a considerable number of options within the UK for using PFA/fly ash in cementitious systems. Within the standardisation process, many European countries would like the UK to withdraw BS3892 Part 1 and adopt BS EN450 as the only standard. However, the UK is not prepared to forgo such a large sector of the market for fly ash, as classified PFA is a high value product with a market totalling £12,500,000 per annum. Currently in UK thinking, BS EN450 sits uncomfortably between the specification of BS3892 Part 1 and Part 2. However, the other European Union members are not prepared to encompass the more restrictive requirements we feel necessary for a classified fly ash. These problems will have to be resolved in the very near future, as the UK will not permit the demise of classified PFA to BS3892 Part 1.

As well as the ‘additions’ market there is increased utilisation from the cement industry. The use of fly ash both as a raw feed to the cement kiln and as a material to combine with the Portland cement clinker has a number of advantages. The reduction in overall CO_2 emissions is cited as a significant environmental benefit, the amount of natural aggregate used is reduced, technical benefits of lower cement alkalinity can be found with some PFA sources and, of course, the long term durability benefits found with concretes containing a pozzolana.

It must be remembered there exist many other markets for PFA/fly ash. These range from aerated block and lightweight block manufacture, grouting for mine and caverns, fill and embankment applications, etc as shown in figure 2.

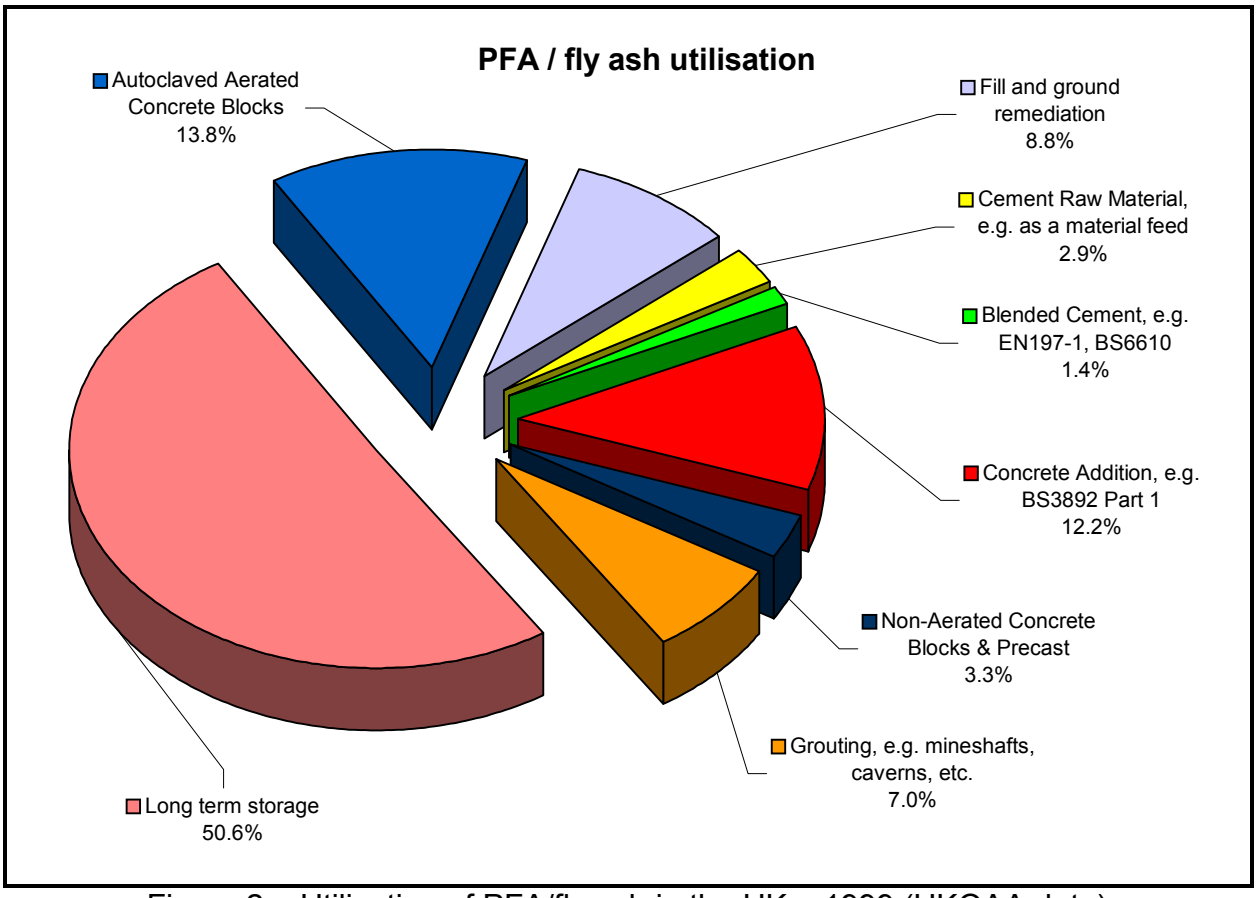

Figure 2 – Utilisation of PFA/fly ash in the UK – 1999 (UKQAA data)

CONCLUSION

The UK has many British and European standards for PFA/fly ash for use in concrete and grouts. However, there is a significant difference in philosophy between the UK and the other European Union members. These differences have to be addressed in that the more exacting needs of a classified fly ash should be reflected in the European standard. However, we believe these problems can be overcome in time and the market for PFA will continue to develop for many years into the future.

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