UK PROCEDURES FOR THE USE OF ADDITIONS AS PART OF CEMENT IN CONCRETE

Chris A Clear

Technical Director of the British Ready-Mixed Concrete Association (BRMCA)

Abstract

The UK uses an Equivalent Performance of Combinations Concept (EPCC) where an addition added at the concrete mixer is considered to perform in the same way as would the same material incorporated into concrete as a constituent of cement to EN 197-1 or EN 14216. This mixer-blend of addition and cement is a 'combination' where BS 8500 (the British Complementary Standard to EN 206) defines this as: "restricted range of Portland cements and additions which, having been combined in the concrete mixer, count fully towards the cement content and water/cement ratio in concrete". The UK procedure for using additions as combinations is called the "Conformity Procedure for Combinations". It only applies for combinations of a CEM I cement of standard strength class 42,5 or greater with either: fly ash to EN 450-1: category A or B; ggbs to EN 15167-1; or limestone fines to BS 7979. On the basis of the established equivalence with respect to chemical, soundness and strength it is accepted that the combination has a durability performance equivalent to the EN 197-1/EN 14216 cement of the same nominal proportions.

Keywords: Additions, cement, combinations, durability, performance

1. INTRODUCTION

The UK ready-mixed concrete industry has played a pivotal role in the adoption of concrete mixer blended combinations of CEM I with additions such as ground granulated blastfurnace slag (ggbs) and fly-ash. Table 1 is a summary of the most significant standards and technical guidance that have played a part in the development of the UK procedures for the use of additions as part of cement in concrete. With hindsight it is possible to categorize these developments into those that could be considered as 'Equivalent Concrete Performance Concept, ECPC' or 'Equivalent Performance of Combinations Concept, EPCC' as defined in the current European Concrete Standard, EN 206. The current UK procedures for the use of additions as part of cement is described, and clearly falls under EPCC. In reality it is the enhanced performance of concretes containing ggbs or fly ash exposed to particular deterioration mechanisms that meant the EPCC was enthusiastically embraced. For this reason the pre-EPCC background is summarized.

2. 1950 TO 1980 - EQUIVALENT CONCRETE PERFORMANCE CONCEPT(ECPC)

Higgins[1] summarised the use of ggbs as an addition in concrete starting with the Trief process, a process whereby the use of wet ground material is added as a slurry at the concrete mixer. Due to the difficulties in storing and transporting wet slurry this process was limited to a small number of projects but included Cluanie and Loyne dams and tunnels constructed in the early 1950s. Notably the use of ggbs in this manner saved 20,000 tonnes of Portland cement and perhaps this inspired the trade name 'CEMSAVE' as used in the early 1960s by Frodingham Cement Ltd the manufacturer of the dry material[2]. The initial technical marketing was based on the performance of the material in concrete, showcasing projects in which the material was successfully used. One of these projects was at a steel works where it could be argued there was a vested interest in the use of the material.

The early marketing of fly ash in the UK, or pulverized-fuel ash (pfa) as it was then called, was mainly based on its performance in concrete supported by a British Standard covering its use in concrete, BS 3892. At this time although pfa was included as an ingredient for use in concrete by the current code for structural concrete CP110, and regular use in dam construction and electric power plant infrastructure[3], its use was not widespread. Essentially it was being left to the Engineer to consider on a case by case basis if the use of fly ash in concrete was technically and economically justified. Most notably pfa was used in construction of the Thames Barrier at Woolwich, where the lower heat generation helped reduce the heat of hydration to reduce the risk of early age thermal cracking making it a performance criterion.

In 1981 the Building Research Establish issued guidance, BRE Digest 250, that also included recommendations about using combinations of Portland cement with either ggbs or pfa for concrete exposed to sulfate bearing soils and groundwaters. At around the same time it became apparent that there was a risk of developing alkali-silica reaction, ASR, where high alkali cement was used with particular sources of aggregate. In 1983 the report of a Working Party Chaired by Hawkins included broad recommendations for the use of pfa and ggbs as effective means of minimizing the risk of damaging ASR. This was a significant driver that increased the use of additions in concrete.

Essentially the late 1970s to early 1980s saw the publication of substantial evidence that combinations of Portland cement and additions are beneficial for particular applications. However, the use of these combinations were not readily accepted by the construction industry for normal building or housing projects, and they were not included as options within the materials and construction standards, an omission that needed to be addressed.

Table 1: UK procedures for combinations – associated standards and technical guidance

First Published	Developments in standards or technical guidance	Equivalent European Standards, cement/addition types or explanatory notes
1904	BS 12 for Portland Cement	EN 197-1 CEM I
1923	BS 146 Portland Blastfurnace Cement	EN 197-1 CEM III/A
1965	BS 3892 Pulverized-fuel ash (pfa) for use in concrete	EN 450 Fly ash
1966	BS 4027 Sulfate-resisting Portland Cement	EN 197-1 CEM I-SR0 & CEM I -SR3
1968	BS 4246 Low heat Portland Blastfurnace Cement	EN 197-1 CEM III/B & C
1972	CP 110 Code of Practice for The Structural use of concrete. Part 1 Design, materials and workmanship.	EN 206 EN 1992, EN 13670
1975	Agrément Certificate No. 75/283. Pozzolan – a selected fly ash for use as a cementitious component in structural concrete.	Covers the use of fine fly ash for use as part of the cement in structural concrete
1981	BRE Digest 250 Concrete in sulphate bearing soils and groundwaters	Recommends the use of ggbs and fly-ash to resist damage from sulfate attack
1982	BS 3892-1 Pfa as a cementitious component in structural concrete	Fine ash, EN 450-1 Category S
	Agrément Certificate Certificate No. 82/1023. Cemsave Ground Granulated Blastfurnace Slag.	Test results comparison with equivalent cements
1983	Hawkins Report. Alkali aggregate reaction - Minimizing the Risk of Alkali-Silica Reaction (ASR) Guidance Notes	Recommends ggbs and fly ash to resist ASR
1984	Quality Scheme for Ready-Mixed Concrete, Technical requirements.	Reference to ‘combinations equivalent to cement…

Table 1(cont.):UK procedures for combinations – associated standards and technical guidance

First Published	Developments in standards or technical guidance	Equivalent European Standards, cement/addition types or explanatory notes
1985	BS 5328: 1981 Specifying concrete including ready-mixed concrete, as amended 1985	Reference to ‘combinations equivalent to cement…
	BACMI and BRMCA Combination procedures for CEM I and ggbs	BACMI & BRMCA are Ready-Mixed Concrete Associations
	BS 6588 Portland pfa cements	CEM II/A & B-V
	BS 6610 Portland pozzolanic cement	CEM IV/A & B (V)
1986	BRMCA Combination procedures for Portland Cement and ggbs or pfa	
1986	BS 6699 Ggbs for use with Portland cement	EN 15167 Ggbs
1987	Concrete Society Alkali Silica reaction – minimizing the damage to concrete – Guidance Notes and model specification clauses	Recommends ggbs and fly ash to resist ASR
1988	BRE Digest 330 Alkali aggregate reactions in concrete	Recommends ggbs and fly ash to resist ASR
1990	BS 5328 Concrete	Includes guidance for durability
1992	BS 6699 Revised	Revised to include combination procedures
1993	BS 3892-1 Revised	Revised to include combination procedures
1996	EN 450 Fly ash for concrete	To supersede BS 3892
2000	EN 197-1 Common cements	Portland cement became CEM I
2001	BRE Special Digest 1 Concrete in aggressive ground	Recommends ggbs and fly-ash to resist the thaumasite form of sulfate attack (TSA)
2002	BS 8500 Standard for concrete	Includes conformity procedure for combinations, durability requirements including ASR and sulfate attack
2004	EN 197-4 Low early strength blastfurnace cements	Required to cover blastfurnace cements
2006	EN 15167 for ggbs published	To supersede BS 6699
2011	EN 197-1 Common cement	Incorporates low early strength blastfurnace and SR cements
2013	EN 206 Concrete — Specification, performance, production and conformity	EPCC incorporated in the European Standard for Concrete

3. 1980 ONWARDS, THE EQUIVALENT PERFORMANCE OF COMBINATIONS CONCEPT

Ggbs had been used as a constituent of Portland blastfurnace cement in the UK since 1914 and the British Standard for this cement, BS 146, was published in 1923. This was less than twenty years later than the British Standard for Portland cement, BS 12, which was first published in 1904. Although BS 146 cement was only manufactured and supplied in Scotland it meant that the option to use it was included on most concrete specifications, and included in the code for the structural use of concrete CP 110. This meant that engineers were open to the argument that if they accepted BS 146 cement then they should also accept the equivalent within-mixer blend of ggbs and CEM I. At first this argument was supported by an Agrément Certificate, an early UK version of a European Technical Approval. The most significant section of these certificates simply listed test results of a particular combination of Portland cement and ggbs with the requirements of BS 146, but also included background notes and guidance on manufacture and use.

In 1985 the ready-mixed concrete industry Associations, BACMI and BRMCA, introduced procedures to demonstrate and certify that combinations of Portland cement and ggbs as equivalent to cement-factory Portland blastfurnace or low-heat Portland bastfurnace cements of the same nominal proportions. Also in 1985 British Standards were published for Portland pfa cement and Portland pozzolanic cement which were quickly followed in 1986 by ready-mixed concrete Association procedures for their equivalent combinations. At that time there was only a single national third party quality assurance scheme for ready-mixed concrete, the Quality Scheme for Ready-mixed Concrete, QSRMC. When QSRMC explicitly accepted the combination procedures as confirmation that mixer-blended material was technically equivalent to a cement-factory material of the same nominal proportions then much of the prejudice against using combinations subsided.

After this it became apparent that the most appropriate place to maintain the combination procedures were in British Standards. For this reason the procedures were placed in the British Standard for each addition, that is BS 6699 for ggbs and BS 3892-1 for fly ash. With time these British Standards were to be superseded by their harmonized European versions, BS 15167 for ggbs and EN 450 for fly ash. These European standards would not cover the combination procedures and so a new home would be required. This tied in with developments within Europe where it was agreed that the standards for additions would be appropriately maintained under the concrete committee, rather than the cement committee. So in 2002 the UK combination procedures were unified and moved to the British complementary concrete standard BS 8500, which is where it is today.

4. UK BS 8500-2 ANNEX A. CONFORMITY PROCEDURE FOR COMBINATIONS

Essentially the procedure is a means for establishing limits on the proportions of a single source of addition with a single source of CEM I cement to ensure that the conformity criteria for strength are met. Four stages are involved:

a) The relationship between compressive strength and proportion of addition are established for each CEM I cement, an example of which is shown in Figure 1 for ggbs;

b) Monthly composite samples of the addition and each CEM I cement are tested in combination, and running means of the early and standard strengths are calculated over not less than 6 months and not more than 12 months;
c) Statistical margins are established, or assumed to be 3 or 5 N/mm^2 for early and 28 day strength respectively;
d) The relationships, the running means and the statistical margins, together with the EN 197-1 or EN 14216 requirements for strength class are used to determine the permitted proportions.

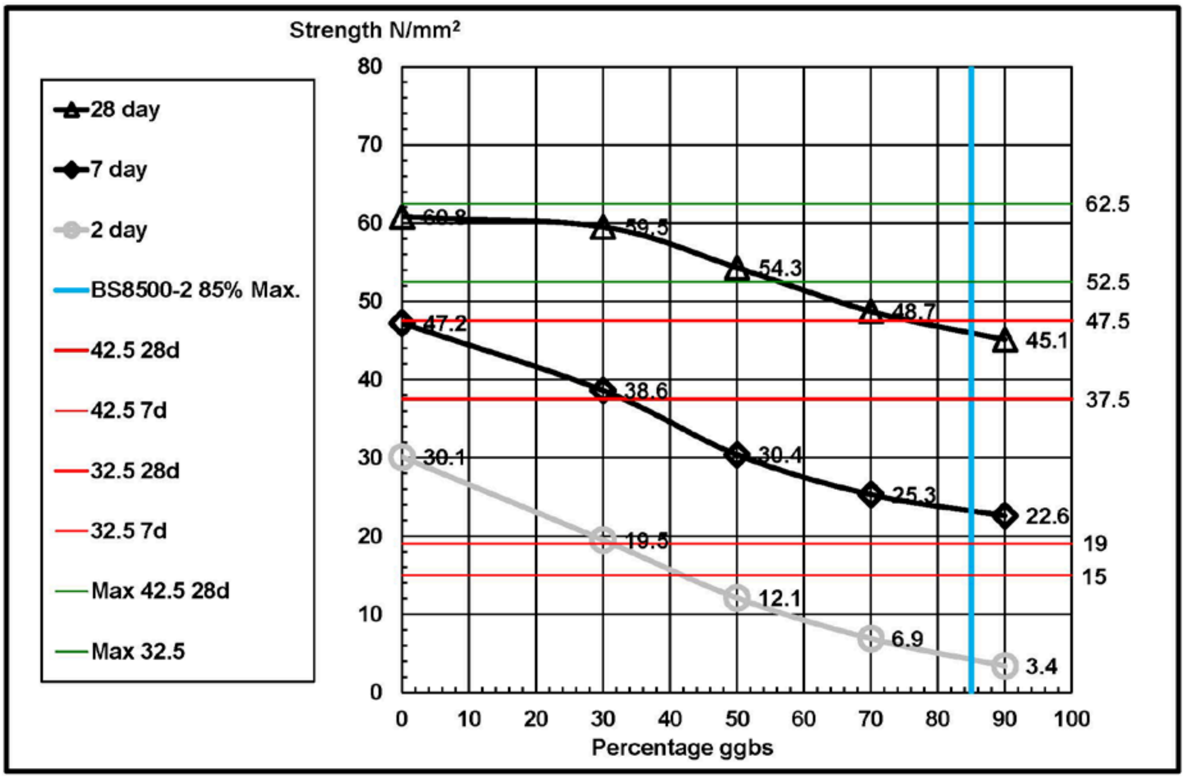

Figure 1: Determination of conformity limits for combinations of CEM I and ggbs

For determining the relationship separate composite samples of the addition and the CEM I are obtained by blending not less than eight spot samples of each material obtained at regular intervals over at least one calendar month. These are used for EN 196-1 strength tests at 2 days, 7 days and at 28 days to cover the range of additions used. For example combinations of CEM I with 0%, 30%, 50% 70% and 90% ggbs to cover the full range for blastfurnace cements. For fly-ash levels up to 60% and for limestone fines up to 20% cover the necessary range.

Once a month bulk average samples of the addition and the CEM I are combined in the ratios:

- 50:50 for ggbs to CEM I cement;
- 30:70 for fly ash to CEM I cement.
- 15:85 for limestone fines to CEM I cement

Again tests for strength are carried out in accordance with BS EN 196-1 at 2 days, 7 days and 28 days. The mean strength of each combination of addition and a specific CEM I cement is the average of the most recent monthly strength tests taken over a period of not less than 6 months and not more than 12 months.

As a simple example to show how the limits on proportions for the conformity of combinations to a strength class are derived it is assumed that the average monthly 2 day, 7 day and 28 day are the same as the values established for the main relationship, as shown in Figure1.

The minimum EN 197-1* requirements for a strength class 42,5L at 7 days and 28 days are 16 N/mm^2 and 42.5 N/mm^2 respectively. With their respective margins these become 19.0 N/mm^2 and 47.5 N/mm^2. From Figure 1 it is evident that even at 90% ggbs the minimum strength at 7 days is 22.6 N/mm^2, higher than the 19 N/mm^2 required for strength class 42,5L. From Figure 1 it is evident that to meet the minimum strength at 28 days of 47.5 N/mm^2 then no more than 75% should be permitted. In practical terms this does not restrict the use of ggbs at 80% because even at this level the combination meets the requirements for strength class 32,5L that is a minimum 28 day strength of 37.5 N/mm^2. Figure 2 is an idealised and simplified example of a Certificate of test in accordance with BS 8500.

Certificate of test in accordance with BS 8500-2: 2006+A1:2012 Annex A

Results of tests carried to determine the EN 196 compressive strength of a combination:

50% ggbs	to EN 15167	Slag Company, West Ham London Works
50% CEM I	to EN 197-1	Cement Company, Manchester Works

Compressive strength at 7 days 30.4 N/mm^2
Compressive strength at 28 days 54.3 N/mm^2

Combination	Strength Class 32.5L		Strength Class 42.5L		Strength Class 52.5L	
	min	max	min	max	min	max
CII-S			6%	35%		
CIIIA			36%	65%		
CIIIB	66%	80%	66%	75%*		

* Value restricted by 28 day strength

Signature:

Date: 06-Jun-15

Figure 2: Certificate of test for combinations of West Ham ggbs with Manchester CEM I.

5. THE MARKET FOR CEMENT AND ADDITIONS

Figure 3 show the annual cement and addition consumption in Great Britain, GB, from 1980 to 2013, as well as the percentage share of additions compared to the total cementitious sales.

* The current BS 8500-2 Annex A limit is 20 N/mm^2 at 7 days as it was set before EN 197-1:2011 established the value as 16 N/mm^2.

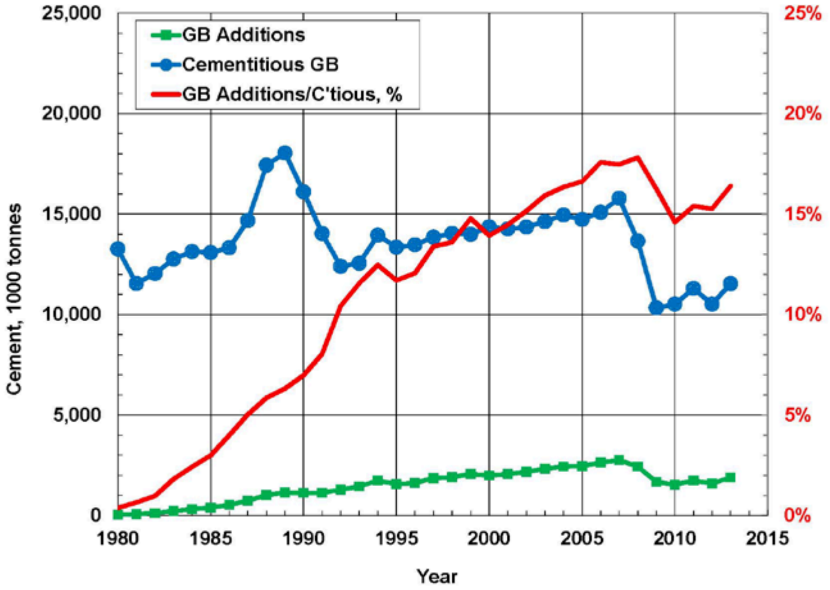

Figure 3: GB cement and addition consumption 1980 to 2013

From Figure 3 it is evident that there has been a steady increase in the market share of additions, peaking at around 18% in 2008 prior to a sharp recession. It is not possible to give a definitive reason why the growth in the use of additions levelled off from 2008. It could be an unknown factor related to the recession, constraints in availability of fly ash and ggbs which depend on the level of pulverised-coal used in power stations and the volume of iron made in the UK, or a combination of both. Notwithstanding this, a 16% or so share of the market is a significant proportion and there are indications that increased sustainability pressures would see the share increase should suitable volumes of additions be available.

6. CONCLUSIONS

There are many advantages in incorporating additions such as ggbs, fly ash and limestone fines with cement for use in concrete and there has been a steady growth in their use in the UK from around 1980. This has only been possible due to substantial technical marketing in terms of making representations to engineers and other specifiers, where a necessary support was the establishment of a formal Equivalent Performance of Combinations Concept. To be credible the EPCC should include some level of third party certification that the combinations used are technically indistinguishable from their equivalent cement-factory products at the same nominal proportions. This was initially achieved in the UK by a third party quality assurance scheme for ready-mixed concrete recognising the ready-mixed concrete Association's own procedures. The ready-mixed concrete industry then helped ensure these procedures were incorporated into National Standards from which recognition was formalised as an EPCC procedure to the European Standard for Concrete, EN 206: 2013.

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