FIFTY YEARS EXPERIENCE IN THE UK USING GGBS AS AN ADDITION TO CONCRETE

Denis Higgins, Cementitious Slag Makers Association, UK

ABSTRACT: Portland-slag cements have been manufactured in the UK since 1914, but were never widely used. Instead, a practice has developed where separate ground granulated blastfurnace slag (GGBS) is added at the concrete mixer as an addition. Generally, it comprises between 25% and 70% of the binder, with Portland cement comprising the remainder. Many of the ready-mixed concrete plants in the UK have a silo containing GGBS. This paper describes the development of the use of GGBS and the parallel evolution of relevant British Standards. Details are given of the conformity testing procedure which has to be satisfied for GGBS to count fully towards the 'cement content' in concrete.

1 PORTLAND-SLAG CEMENT

Blastfurnace slag, a by-product of iron manufacture, has excellent cementitious properties, particularly when combined with Portland cement. Its cementitious potential was discovered 150 years ago by Emil Langen in Germany, where commercial production of lime-activated ground blastfurnace slag commenced in 1865. Around 1880, slag was first ground together with Portland cement to produce Portland-slag cement and the potential of this combination was quickly realised, in particular its resistance to aggressive conditions in the ground. As early as 1889, slag cements were used in the construction of the French Underground Metro System. By the early 1900s Portland-slag and Blastfurnace cements were well established in Europe and subsequently have been two of the most commonly-used cement types.

In the UK, production and use of slag cement was confined mainly to the North (in Scotland), where manufacture commenced in 1914 and continued for over seventy years, Although used in Scotland for many major building and civil engineering projects, slag cement was not used in other parts of the UK, where the only cement normally available was Portland cement (CEM I).

2 SEPARATE GROUND GRANULATED BLASTFURNACE SLAG

In 1933, Victor Trief patented a process where granulated blastfurnace slag is wet ground and added in a slurry form to the concrete mixer, i.e. it is combined with the Portland cement at the same time as the aggregates. However, the wet slurry cannot readily be stored or transported and the Trief process is only applicable to major projects or to precast, works where the volume of concrete justifies the installation of a grinding mill on site. The Trief process was used in the UK in the 1950s in the construction of the Avon dam and has also been used for lightweight block production.

The limitations of the Trief process were overcome by a development in 1958 in South Africa. Here the granulated blastfurnace slag was dried before grinding; the resulting ground granulated blastfurnace slag can be transported and stored in the same way as Portland cement. It can then be combined with Portland cement in the concrete mixer, at the same time as mixing in the aggregates and water. Dried GGBS was first produced in the UK at Scunthorpe, in the early 1960s and was initially used for construction projects at steel works. Around 1968 the ready mixed concrete industry started to take an interest in the then new concept of within-mixer blending, and the construction of the Anchor Project Steel Works at Scunthorpe saw the successful use of separately ground slag in structural concrete of every type. The project ran into the early 1970s and during 1972 an Agrement Certificate was awarded for GGBS which recognised its use as a separate component for the production of concrete.

A British Standard for separate GGBS *BS 6699: "Specification for ground granulated blastfurnace slag for use with Portland cement"* was first published in 1986 and a revised version to take into account the European test methods for cement (EN 196) was published in 1992. Subsequently a European standard *EN 15167 "Ground granulated blast furnace slag for use in concrete, mortar and grout"* was published in 2006.

The use of GGBS as an addition to concrete is now a well-established UK practice, which is fully permitted within the British Standards for concrete. Fig. 2.1 shows the growth in its use since 1980 and GGBS now constitutes about 15% of all UK cement sales. In recent years its advantages in reducing the carbon dioxide emissions associated with concrete have also been recognised.

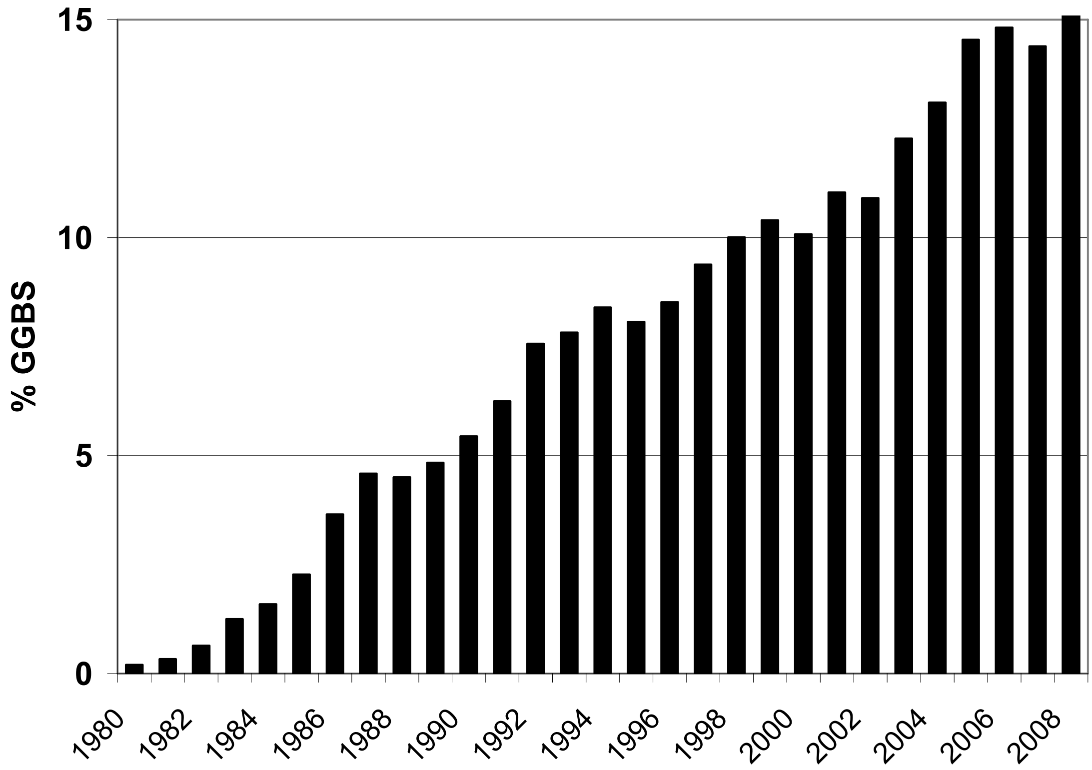

Fig. 2.1. GGBS as % of total UK cement sales

The major use of GGBS is by the readymixed concrete industry and in the UK, a great many readymixed concrete plants have both a silo of Portland cement (CEM I) and a silo of GGBS. These two silos give the concrete producer the flexibility to supply either Portland cement concrete or concrete containing a range of blends of Portland cement with GGBS. In the case of GGBS, the flexibility to vary the percentage of the addition is more important than it is with other additions. This is because of the wide range of percentage replacement that is possible with GGBS. In the case of fly ash, a fixed replacement level of e.g. 30% will probably cover all needs for a fly ash cement. However a single replacement level for GGBS will not cover all needs. For applications where early strength is important e.g. power-floated floors or concrete in cold weather, 30% GGBS blends may be needed. For normal applications, 40% or 50% GGBS is commonly supplied. For applications requiring high chemical resistance or low-heat properties, the GGBS percentage will have to be increased to more than 65%. For some specialist applications requiring very low early strength, up to 85% GGBS is used.

3 CEMENT EQUIVALENCE CONCEPT FOR GGBS

British Standards for concrete use an ‘equivalent cement performance’ approach, where an addition added at the concrete mixer is considered to perform similarily to the same material incorporated into concrete as a constituent of cement. The assumption is that the performance of the concrete is not affected by whether the ground slag is added at the cement factory or at the concrete mixer.

This ‘equivalent cement performance’ approach is only permitted when a continuous programme of control testing of the specific addition with the specific cement, is carried out. The blend of addition and cement is called a ‘combination’ and BS 8500, the British Standard for concrete [BSI06] contains the following definition:

> *Combination: “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 notation for combinations is shown in Table 3.1 and parallels that for EN 197-1 cements [CEN00a]. Combinations are used in concrete in the same way as cements of the same composition and strength class, e.g. a CIIB-S combination can be used in the same way as a CEM II/B-S cement conforming to EN 197-1.

Table 3.1. Notation for Cements and Combinations

Notation for		Composition
factory-blended EN197-1 cement	within-mixer combination	
CEM I	not applicable	Portland cement
CEM II/A-S	CIIA-S	6 to 20% GGBS
CEM II/B-S	CIIB-S	21 to 35% GGBS
CEM III/A	CIIIA	36 to 65% GGBS
CEMIII/B	CIIIB	66 to 80% GGBS

In the UK, the procedure for establishing the restricted range of combinations that can count fully towards the cement content and water/cement ratio is known as the “Conformity Procedure for Combinations”. It can be applied for combinations of an EN197-1 CEM I cement of standard strength class 42,5 or greater, with one of the following additions:

- fly ash
- GGBS

- limestone fines

Establishment of suitability is based on strength testing on EN 196-1 mortar prisms [CEN95], using average monthly samples of the CEM I and the addition. The combination must:

- exceed requirements for early- and 28-day strength by a statistical margin
- not exceed an upper limit on 28-day strength

The strength requirements are based on the strength classes specified in EN 197-1.

In its simplest form, the procedure can be carried out for a fixed proportion of addition to cement and determines (pass/fail) whether that specific proportion meets the strength requirements. If it passes, it is a “permitted proportion”. In practice, the procedure is normally carried out by the suppliers of additions who use a more complex approach in order to determine the range of “permitted proportions” (rather than determine whether one specific proportion is permitted). An example of the procedure carried out by the manufacturers of GGBS is shown in Annex 1.

The procedure parallels the testing regimes used by the cement industry: samples of CEM I and addition are taken regularly through the month and testing is carried out on the homogenised samples. Compared with the k-factor approach [CEN00b], which is often used for additions, the UK Combinations Conformity Procedure is more complex and requires a considerable amount of extra testing. The UK procedure does however, provide confidence that the behaviour of a specific addition with a specific cement, is tightly controlled and that consistent concrete can be produced.

4 CONCLUSIONS

The use of GGBS is now a well-established British practice, with British Standards fully recognising the material and its use in concrete. GGBS is stocked by a large number of UK readymixed concrete plants, which have the ability to vary the GGBS proportion to optimise the technical properties of the concrete, depending on the requirements for the structure.

REFERENCES

[BSI06] BSI, BS 8500: Concrete – Complementary British Standard to BS EN 206-1, 2006

[CEN00a] CEN, EN197-1:Cement - Part 1: Composition, specifications and conformity criteria for common cements, 2000

[CEN00b] CEN, EN206-1: Concrete - Part 1: Specification, performance, production and conformity, 2000

[CEN95] CEN, EN196-1:Methods of testing cement - Part 1: Determination of strength, 1995

ANNEX I EXAMPLE OF CONFORMITY PROCEDURE FOR GGBS

This example describes the testing procedure that a manufacturer of GGBS would carry out to demonstrate the conformity of one source of GGBS with several sources of CEM I. The testing procedure establishes limits on the proportions of GGBS with each specific CEM I cement source, to ensure that the conformity criteria for combination strength class 42,5N are met. The requirements for combination strength class 42.5N are the same as those for the 42.5N strength class in EN197-1, i.e.

- strength at 2-days > 10,0 MPa and
- strength at 28-days > 42.5MPa and < 62,5 MPa.

Four stages are involved.

1) The relationships between compressive strength and the proportion of GGBS are established for each CEM I cement (see **A.1**).
2) The monthly composite samples of the GGBS and each CEM I cement are tested in combination, and the running means of the early and standard strengths are calculated over not less than 6 months and not more than 12 months (see **A.2**).
3) The statistical margins are established (see **A.3**).
4) The relationships, the running means and the statistical margins, together with the requirements for combination strength class 42,5N, are then used to determine the permitted proportions (see **A.4**).

A.1 Establishment of the relationship between compressive strength and proportions

A composite sample of the GGBS is obtained by blending not less than eight spot samples of similar mass obtained at regular intervals over at least one calendar month. A composite sample of each CEM I cement is similarly obtained.

For each source of CEM I, strength tests in accordance with EN 196-1, are carried out at 2 days and at 28 days, for blends at 0%, 30%, 50% and 70% GGBS

A.2 Monthly tests on individual Portland cement with addition

Monthly bulk average samples of the addition and each CEM I cement source are obtained either from the material suppliers or by blending not less than eight spot samples of similar mass, taken regularly throughout the month. These composite samples are combined in the ratio 50:50 for GGBS to CEM I cement;

Tests for strength are carried out in accordance with EN 196-1 at 2 days and at 28 days. The mean strength, 'M', 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.

A.3 Estimation of statistical margin

The statistical margin, 'm', is either taken as +5 MPa on the lower limits for standard strength and +3 MPa on early strength limits (see A.1), or may be calculated by testing spot samples of GGBS with spot samples of the CEM I source considered to be the most variable.

No statistical margin is required for the upper limit because the possibility of a combination occasionally exceeding an upper limit is unlikely to substantially reduce the suitability of the combination for its intended use.

A.4 Establishment of limits on proportions

To determine the limits on proportions for the conformity of combinations to strength class 42,5N, a diagram is constructed that shows the relationship obtained in accordance with A.1 between 28-day strength and proportions for the addition with a specific CEM I cement (see Fig. A.1). On this diagram, a lower limit of '42.5 MPa + m' is drawn, corresponding to the lower limiting value from Table A.1 plus the margin. An upper limit of 62.5 MPa corresponding to the upper limiting value, is also drawn.

The point corresponding to the mean strength 'M', determined in accordance with A.2, is marked and a line is drawn through this point, commensurate with the relationship between 28-day strength and proportion. Conformity with strength class 42,5N is achieved for proportions where this line is between the upper and lower limits. A similar exercise is carried out for the 2-day strength results (in this case no upper limit is applicable).

The proportions that conform to combination strength class 42,5N are those for which both early and 28-day strength requirements are met, subject also to their not exceeding 85%.

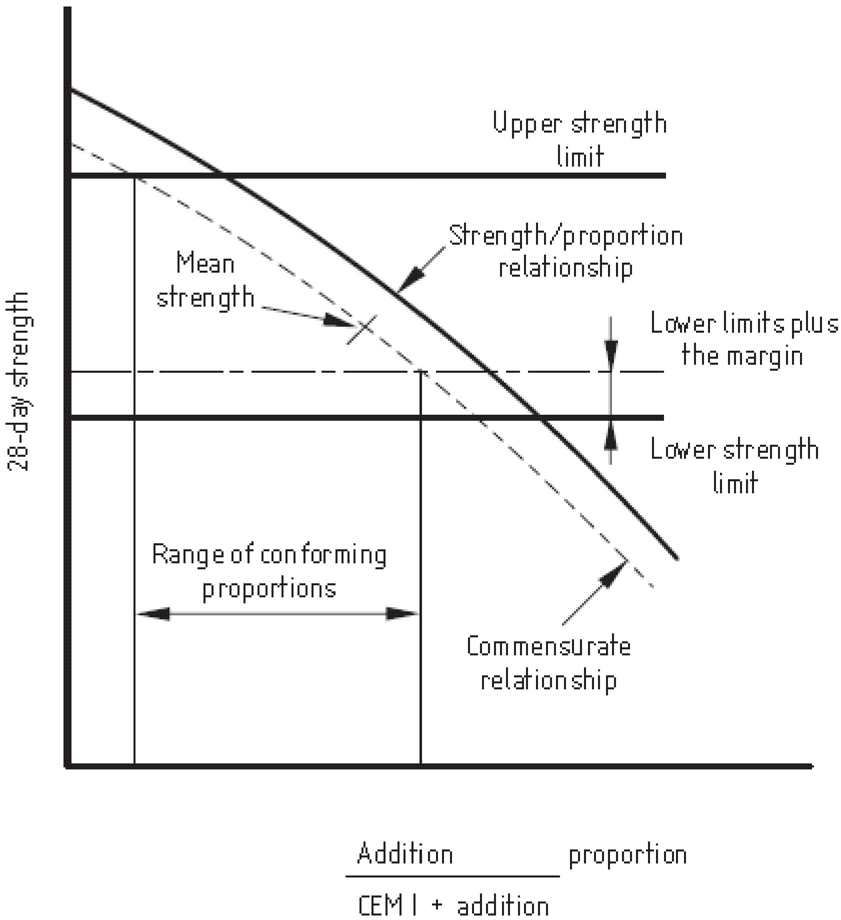

Fig. A.1 Determination of conformity limits for combinations