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Portland cement replacement: within-mixer or factory-blend?

There are two routes for using cement replacements. They can be blended with Portland cement to produce factory-blended cement or used as a separate 'addition' and combined with the Portland cement in the concrete mixer. This article outlines the sustainability advantages arising from the use of cement replacements and discusses the pros and cons of incorporating them at the cement factory, versus incorporating them at the concrete mixer.

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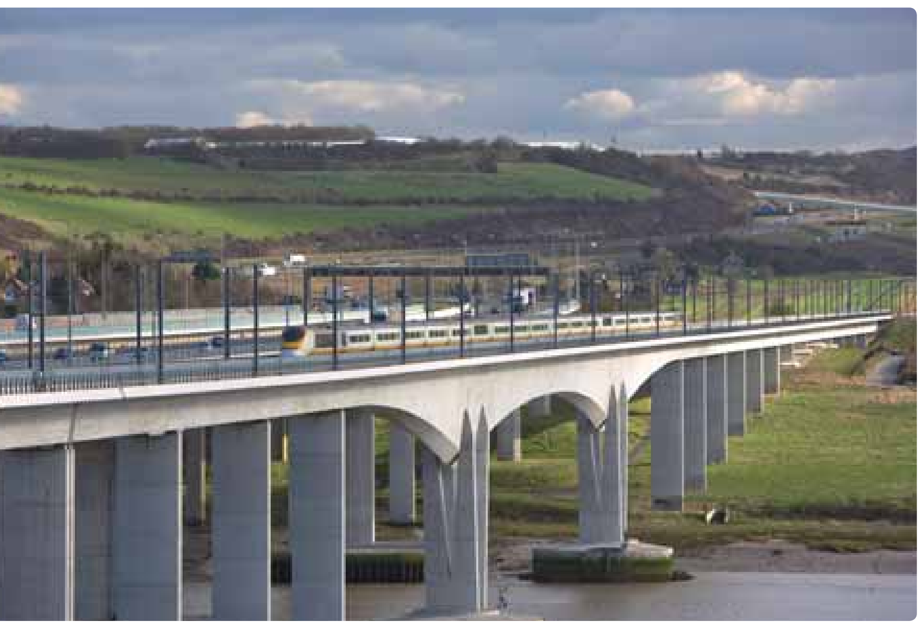

Figure 1: Channel Tunnel Rail Link where GGBS was used at up to 70% replacement.

The construction industry is under increasing pressure to become 'greener' and help tackle the issues of global warming and diminishing natural resources. It is affected by a multitude of initiatives, including EU legislation, Government targets and the Code for Sustainable Homes.

A major priority for the producers of cement and concrete is to minimise carbon dioxide emissions and the cement industry has taken significant steps in this direction, particularly by improving the energy efficiency of manufacturing Portland cement. Substantial reductions in carbon dioxide are also being achieved by the partial replacement of Portland cement by cementitious materials such as ground-granulated blast-furnace slag (GGBS) or fly ash. Currently, the UK uses 2.5 million tonnes of GGBS and fly ash as cement replacements every year, saving over 2 million tonnes of carbon dioxide emissions.

EU emissions trading scheme

The major legislative pressure on carbon dioxide emissions is the EU Emission Trading Scheme (EU ETS), which aims to 'promote reductions of greenhouse gas emissions in a cost-effective and economically efficient manner'. The EU ETS was set up by a European Directive and applies to specific industrial processes, including the production of cement clinker. The first phase ran from 2005 to 2008 and the second phase from 2008 to 2012.

Essentially, each 'installation' covered by the scheme has to surrender a 'carbon allowance' in exchange for every tonne of carbon dioxide that it emits. The allowances are issued by governments (generally for free). However, for each phase EU Member States are subject to overall limits on the allowances that they can issue and have to develop a National Allocation Plan to allocate their overall allowance among the installations operating in their country. If an installation cannot operate within its allocated allowances, it has to purchase additional carbon allowances on the open market. Conversely, if an installation is allocated more allowances than it needs, it can sell excess allowances.

Of all the industries covered by the EU ETS, manufacture of quick-lime and Portland cement emits the most car-

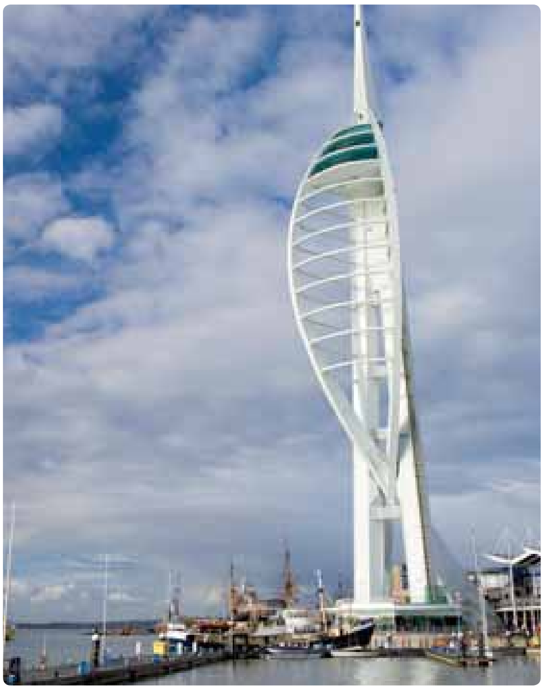

Figure 2 far left: Spinnaker Tower in Portsmouth, where GGBS was used at 50% replacement.

Figure 3 left: Wales Millennium Centre, where GGBS was used at 55% replacement.

bon dioxide relative to 'value of product'. Consequently, they are the industries most affected by its financial implications. In 2008, the price of an EU ETS allowance varied between £10 and £20 and purchasing the allowances necessary to manufacture 1 tonne of Portland cement would have cost between £8 and £16. If a cement factory increases its output above its allocation, it could effectively be 'taxed' £8 to £16 for each extra tonne. Conversely, a cement factory, which invests in becoming more efficient and emitting less carbon dioxide, may have more allowances than it requires and be able to recoup some of its investment in energy efficiency, by selling excess allowances.

Cement replacements

Within the EU ETS, the use of a 'cement replacement', such as GGBS or fly ash, has an obvious attraction because these materials are by-products from other industries, and using them does not directly incur the surrender of carbon allowances. Although they do not have truly cementitious properties, limestone fines can also be used as a cement replacement.

The cementitious activity determines the extent to which it is possible to use an addition to replace Portland cement and indicative replacement proportions are shown in Table 1. The more Portland cement that is replaced, the greater the saving in carbon dioxide emissions.

Standards for cements and combinations

The European Cement Standard BS EN 197-1[1] specifies the requirements for factory-blended cements. The requirements for within-mixer combinations can be found in the British Standard for Concrete BS 8500[2]. The cements and combinations likely to be available in the UK are shown in Table 2. Those in shaded boxes may not be readily available.

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Table 1 – Replacement proportions

	Permitted by British Standard for concrete (BS 8500)	Typical proportion
GGBS	6–85%	50%
Fly ash	6–55%	30%
Limestone fines	6–20%	15%

Table 2 – Cements and combinations

Notation: Factory-blended cement	Notation: Within-mixer blend	Composition
CEM I		Portland cement
CEM II/A-S	CIIA-S	6–20% GGBS
CEM II/B-S	CIIB-S	21–35% GGBS
CEM III/A	CIIIA	36–65% GGBS
CEMIII/B	CIIIB	66–80% GGBS
CEM II/A-V	CIIA-V	6–20% fly ash
CEM II/B-V	CIIB-V	21–35% fly ash
CEM IV/B	CIVB-V	36–55% fly ash
CEMII/A-LL	CIIA-LL	6–20% limestone fines

** Those in shaded boxes may not be readily available*

Table 3 – Proportions of GGBS for various applications

Technical requirement	Proportion of GGBS required
Sulfate resistance	Moderate sulfate resistance is achieved with 36–65% GGBS and high resistance with 66–80%
Chloride ingress	Enhanced chloride resistance is achieved with 36–65% GGBS and high resistance with 66–80%
Avoidance of alkali–silica reaction	A minimum of 40% GGBS is required for the alkali from the GGBS not to have to be taken into account
Heat of hydration	The normal range of GGBS for controlling temperature rise is 50–70%
Setting time	In applications such as power-floated floors, where extended finishing time is undesirable, between 25 and 40% GGBS is normally used
Early strength	Some applications require a relatively high early-age strength and 20–40% GGBS may be appropriate
Low ambient temperatures	GGBS may be limited to a maximum of 50%
High ambient temperatures	GGBS may be required to be at least 50%
Very low early-strength gain	For secant piling, GGBS may need to be in the range 81–95%

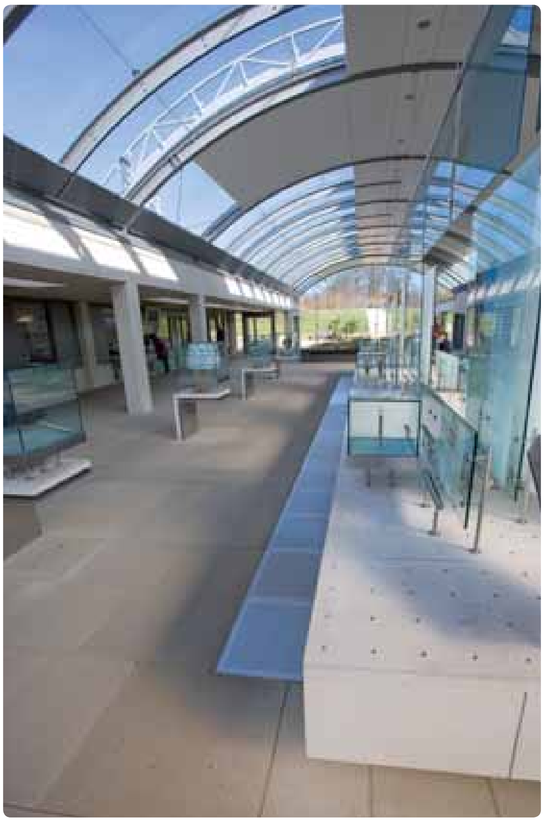

Figure 4 above: Liquefied natural gas (LNG) storage tanks at Milford Haven where GGBS was used at up to 65% replacement.

Figure 5 right: The Wellcome Trust Millennium Building, which is home to the Millennium Seed Bank Project, used 70% GGBS.

"Within-mixer combinations are likely to remain the preferred option for the ready-mixed concrete producer, while those who are content with a single replacement percentage offered by factory-blended cement may well prefer this option."

Use of blended cements and combinations is not 'new'. Factory-blended cements containing blast-furnace slag were first produced around 1914 in Glasgow and their production continued until the end of the 1990s. Factory-blended cements containing fly ash have been available since the 1980s and those containing limestone since the 1990s. In ready-mixed concrete, GGBS has been used as an addition at the mixer since the 1960s, as has fly ash since the late 1980s. Currently well over half of all UK ready-mixed concrete contains GGBS or fly ash added at the concrete batching plant to produce a mixer combination. Nowadays, bagged cement is frequently a blend with either limestone or fly ash.

Factory versus mixer blending

In a cement factory, blast-furnace slag and Portland cement can readily be blended by feeding them simultaneously into a grinding mill. Although intergrinding is an efficient method of mixing, it has the disadvantage of not achieving the optimum particle size distribution. Blast-furnace slag is harder to grind than Portland cement, and intergrinding results in the cement being ground finer than the slag, which is the opposite of what is normally desired for strength-gain reasons. Best practice for factory blending is to grind the blast-furnace slag and cement separately and subsequently blend the two powders.

The savings in carbon dioxide emissions are similar, irrespective of whether the cement replacement is added at the cement factory or at the mixer. Equally, the point of addition makes little difference to the properties of the finished concrete.

The major advantage of blending at the mixer rather than the cement factory is the flexibility to vary the proportions to optimise the technical performance. For limestone fines and fly ash the range of proportions is not large and a fixed blend may be adequate. However, for a ready-mixed concrete plant supplying a range of GGBS concretes to many different customers, flexibility will be a major consideration. Fifty percent is the most widely used proportion and is commonplace for ready-mixed, site-mixed and precast concretes in all types of applications. However, as shown in Table 3, variations in proportion may be required to meet specific technical requirements.

In contrast, other users, such as certain precast concrete factories producing only a small range of products requiring similar properties, will not want to incur the expense of the additional silo needed to blend at the mixer and may prefer a factory-blended cement.

It is sometimes suggested that a factory-blend may be a more consistent product, however, the converse is likely to be the case. The ready-mixed concrete plant weigh-batches its materials to an accuracy of ±3% (BS EN 206-1[(3)]), while a cement factory may use less accurate volume batching methods such as belt feeds. Concern about homogeneous mixing of components has never proved a problem with ready-mixed concrete. If the mixer can mix in cement then it can mix in cement and GGBS.

The within-mixer blend will almost always result in lower transport burdens. For a factory-blended cement, the slag needs to be brought to the cement factory to be blended with the cement and the blend is then sent to the concrete producer. In many cases the slag will be partially retracing its journey to the cement factory. When the slag is ground adjacent to the steel works and then sent directly to the customer, it avoids the 'detour' via the cement works.

Concluding remarks

The use of GGBS, either in factory-blends or in within-mixer combinations, has considerable sustainability benefits, particularly in reducing carbon dioxide emissions. The within-mixer approach gives the concrete producer the flexibility to alter the GGBS proportion to optimise the technical properties of the concrete. However, it does require the capital cost of a further silo. Within-mixer combinations are likely to remain the preferred option for the ready-mixed concrete producer, while those who are content with a single replacement percentage offered by factory-blended cement may well prefer this option. ■

References:

1. BRITISH STANDARDS INSTITUTION, BS EN 197-1. *Cement. Composition, specifications and conformity criteria for common cements,* BSI, London, 2000.
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