Proceedings of the Institution of Civil Engineers
Construction Materials 160
August 2007 Issue CM3
Pages 99–101
doi: 10.1680/coma.2007.160.3.99
Paper 700023

Keywords:
concrete structues/concrete technology & manufacture/environment

ice
Institution of Civil Engineers

Briefing: GGBS and sustainability

D. Higgins, *Cementitious Slag Makers Association, UK*

Concerns about climate change have heightened interest in sustainable construction materials. Ground granulated blast-furnace slag offers civil engineers a high-quality, environmentally-friendly material, which can replace much of the Portland cement used in concrete. This article looks at its manufacture and environmental impact and gives examples of its use.

1. INTRODUCTION

With a worldwide production of 1·4 billion tonnes per annum, the manufacture of Portland cement is responsible for 5% of global carbon dioxide emissions. It is extremely energy-intensive and the chemical processes inherent in its manufacture release large quantities of carbon dioxide.

The use of 'cement replacements' with lower environmental burdens offers opportunities for significant reductions in energy use and carbon dioxide emissions. An effective alternative to Portland cement is ground granulated blast-furnace slag (ggbs), which typically replaces 50% of the Portland cement in a concrete mix but greater proportions of up to 70 or even 80% can be used with advantage in suitable situations.

2. MANUFACTURING PROCESSES FOR CEMENT AND GGBS

The raw materials for the manufacture of Portland cement are limestone and clay, with 1·5 t of these being quarried to make 1 t of cement. The limestone and clay are blended together and heated in a rotating kiln to a temperature of 1350°C. Burning the fuel to heat the kiln gives off carbon dioxide, but even more carbon dioxide is released when the limestone ($CaCO_3$) is heated and decomposes to calcium oxide (CaO).

GGBS is manufactured from blast-furnace slag, a by-product of the iron-making industry. The blast furnaces used to make iron operate at temperatures up to 2000°C and are fed with a carefully controlled mixture of iron ore, coke and limestone. The iron ore converts to iron and this sinks to the bottom of the furnace. The remaining materials form a slag that floats on top of the iron. The molten iron and slag are drawn off at regular intervals through tapping holes in the base of the furnace. As the slag is drawn off, its chemistry is monitored as a check on the performance of the furnace and this ensures that blast-furnace slag is very consistent in chemical composition. When the blast-furnace slag is to be used for the manufacture of ggbs, it has to be rapidly quenched in water. This process is known as granulation because it produces glassy granules, which are similar in appearance to coarse sand, and these granules have excellent cementitious properties. In order to produce ggbs, this granulated blast-furnace slag is dried and ground to a fineness that is similar to that of Portland cement. Much less energy is required for drying and grinding blast-furnace slag than for the production of Portland cement.

3. ENVIRONMENTAL BURDENS

Table 1 presents a comparison of the environmental impacts of ggbs and Portland cement.[1]

As a result of its low environmental impacts, the use of ggbs can significantly reduce many of the environmental burdens associated with concrete. Table 2 shows the environmental benefits of replacing 50% of the Portland cement in a typical concrete mix, with ggbs.[2] The effect of using 30% pulverised fuel ash (pfa) is also shown in the table. PFA is normally used in concrete without any processing, and therefore has negligible climate-change and energy-use burdens. Despite this, it is not as effective as ggbs in reducing the environmental burdens of concrete because it is less cementitious and replaces less Portland cement.

To allow a comparison of building products, the Building Research Establishment has produced a scoring system that allocates 'Ecopoints' to materials; the more Ecopoints, the larger the impact on the environment.[3] Under this method ggbs scores 0·47 Ecopoints whereas Portland cement scores 4·6. This classes ggbs as having only one-tenth of the environmental impact of Portland cement.

4. SOUTH HOOK LIQUEFIED NATURAL GAS STORAGE TANKS

GGBS from Civil and Marine, a subsidiary of the building materials company Hanson, is being used to build five liquefied natural gas storage tanks on the coast at South Hook, Milgord Haven, South Wales, for South Hook LNG (a joint venture between Qatar Petroleum and Exonmobil Qatargas) (Fig. 1). The tanks are 97 m in diameter and stand 40 m high and each of their double-skinned walls contains 6804 m^3 of concrete. They will store liquefied natural gas before it is warmed and pumped into the UK's natural gas transmission system. The project will

Environmental issue	Measured as	Impact: Manufacture of 1 t of ggbs*	Impact: Typical manufacture of 1 t of Portland cement
Climate change	CO_2 equivalent	0·07 t	0·95 t
Energy use	Primary energy†	1300 MJ	5000 MJ
Mineral extraction	Weight quarried	0	1·5 t
Waste disposal	Weight to tip	1 t saved‡	0·02 t

*The profile for ggbs consists of the impacts involved in processing granulated blast-furnace slag to produce ggbs. No account has been taken of the impacts of iron-making because the slag evolves, irrespective of whether or not it can be used.
†Includes energy involved in the generation and distribution of electricity.
‡The use of slag for the manufacture of ggbs potentially saves it from having to be disposed of to tip.

Table 1. Comparison of the environmental impacts of ggbs and Portland cement

Environmental issue	Effect of using 50% ggbs: % reduction	Effect of using 30% pfa: % reduction
Emission of carbon dioxide	40	27
Acidification	35	15
Winter smog	35	15
Eutrophication	30	13
Primary energy requirement	30	17

Table 2. Environmental benefits of replacing 50% of the Portland cement in a typical concrete mix, with ggbs or pfa

use a total of 87 000 m^3 of ready-mixed concrete, containing up to 65% ggbs. This will save more than 16 000 t of carbon dioxide emissions, which is equivalent to the amount emitted each year by 5000 cars, as well as 27 000 t of mineral extraction.

5. CHANNEL TUNNEL RAIL LINK

As well as its environmental credentials, ggbs can also offer a number of other benefits to major projects. In the construction of the Channel Tunnel rail link, the durability of the concrete was paramount (Fig. 2). It was constructed through ground that included London clays with high sulphate content, giving the

Fig. 1. South Hook liquefied natural gas storage tanks

Fig. 2. Channel Tunnel rail link

potential for conventional sulphate attack on the concrete. Furthermore, limestone aggregate was used for both high-strength mixes and also to lower the coefficient of thermal expansion of the concrete to minimise the risk of thermal cracking. This use of limestone aggregate in sulphate soils presented the additional risk of the thaumasite-type of sulphate attack. To combat the possibility of both forms of sulphate attack, ggbs was used in accordance with the recommendations in BRE Special Digest 1, *Concrete in Aggressive Ground*.[4] The use of ggbs also provided protection to the steel reinforcement against the ingress of chloride from de-icing salts and ensured a highly durable structure, at the same time also significantly reducing the carbon dioxide emissions associated with the concrete.

REFERENCES

1. Higgins D. D. Sustainable concrete: how can additions contribute? *Proceedings of the Institute of Concrete Technology Annual Technical Symposium*. Institute of Concrete Technology, Camberley, UK, 2006.
2. Higgins D. D., Parrott L. and Sear L. *Effects of GGBS and PFA upon the Environmental Impacts of Concrete*. British Cement Association, Camberley, 2000, CIA/DETR Partners in Technology Project.
3. See http://www.bre.co.uk/filelibrary/cap/076.pdf (last accessed October 2007).
4. Building Research Establishment. *Concrete in Aggressive Ground*. BRE, Watford, 2005, BRE Special Digest 1.