australasian (iron & steel) slag association

REFERENCE DATA SHEET 5 - 2012

Blast Furnace Slag Cements & Aggregates: Enhancing Sustainability

1. INTRODUCTION

Sustainability in the construction industry refers to processes that are environmentally responsible and resource-efficient throughout the life-cycle of a structure: from siting to design, construction, operation, maintenance, renovation, and demolition. This practice expands and complements the classical building design concerns of economy, utility, durability and comfort[1].

Although new technologies are constantly being developed to complement current practices in creating greener structures, the common objective is that green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation[1]

Green buildings may incorporate sustainable materials in their construction, such as reused, recycled or recovered materials content, or materials made using renewable resources.

The resultant drive for sustainable construction in recent years has seen a high uptake of the use of iron blast furnace slag as supplementary cementitious materials with cements or as slag aggregates in concrete. Blast furnace slag is a co-product in the manufacture of iron and is thus considered a recovered resource material. Ground Granulated Blast Furnace Slag, or GGBFS, the ground form of granulated blast furnace slag (GBFS), is used as a supplementary cementitious material (SCM) replacing Portland Cement in concrete. Being a co-product material, GGBFS is manufactured in Australia from both domestic and international sources having a relatively small embodied energy or CO_2 emission attributable, ranging between 120kg to 160kgs CO_2-e/tonne with an industry average of 143kgs CO_2-e/tonne, when compared with Portland cement[2,3]. Portland cement makes use of significant amounts of resources and produces approximately 820kg CO_2-e/tonne[3]. The use of GGBFS can provide significant resource efficiency and CO_2 emission reductions in line with the objective of green building construction.

To encourage and recognise the reduction in CO_2 emissions and resource use, the Green Building Council of Australia has developed a Green Star Concrete Credit Rating System[4]. This rating system for concrete recognises that the use of slag as a cement replacement and/or aggregate can make a significant contribution to reducing the environmental impact of concrete. This data sheet details how the Green Star credit is applied with respect to the use of slag and how slag products enhance concrete sustainability.

Figure 1 – Granulated Iron Blast Furnace Slag

2. SATISFYING THE GREEN STAR CREDIT CRITERIA WITH THE USE OF SLAG CEMENT AND AGGREGATES

Up to three credit points are available for the use of slag products in concrete if the material cost of the concrete represents more than 1% of the project's contract value. Up to two points are available for the use of blast furnace slag as a SCM, while one point is awarded for the use of slag aggregates in concrete. The credit addresses all concrete uses including precast, cast in-situ or prestressed, and includes structural and non-structural uses such as paving, footpaths, kerbs, channels and gutters. Credit points are awarded on the following basis:

- **One Point** is available where the Portland cement content is reduced by 30% (by replacement with a suitable quantity of GGBFS) compared to the reference case (presented in Table 1).
- **Two Points** are available where the Portland cement content is reduced by 40% (by replacement with a suitable quantity of GGBFS) compared to the reference case in Table 1.
- **One Point** is available when at least 40% of the coarse aggregate in the concrete is crushed slag aggregate, measured across all mixes in the project, provided that the use of Portland cement is not increased by more than 5 kg/m^3.

Credit points are awarded on the premise of Portland cement content reductions, rather than the quantity of ground slag used.

3. REFERENCE CASE PORTLAND CEMENT

The standard grades of concrete described in AS13795 and the acceptable corresponding Reference Case Portland Cement Contents, as stipulated by the Green Star Concrete Materials criteria, are summarised in Table 1[4].

Table 1. Reference Case Portland Cement Contents for Use in Determining Portland Cement Reductions

Concrete Strength Grade, MPa*	Reference Case Portland Cement Content, kg/m³
20	≤280
25	≤310
32	≤360
40	≤440
50	≤550
65	≤550
80	≤610
100	≤660

* As defined by Australian Standard AS1379[5].

The Reference Case Portland Cement Contents are those quantities of Portland cement required to meet design and construction specifications for the concrete using Portland cement only, without accounting for any GGBFS contained in the cement. It is noted that not all concretes used in a project will strictly conform to the concrete classifications shown in Table 1. The project's concrete designer or the supplier's concrete technologist will need to make an engineering judgement as to the closest performing mix in Table 1 to that being proposed for a project. This will allow an appropriate reference case of Portland cement content to be chosen for cement reduction calculations.

The proposed use of GGBFS as a replacement for Portland cement must result in the same structural and functional requirements and apply to the same location and season as if the project was using Portland cement based concrete, as required by the project specification and applicable standards.

The design of concrete is normally conducted in accordance with the provisions of AS3600[6] and specified following the requirements described in AS1379[5]. Details for concrete materials specifications will also include:

- AS3972 General Purpose and Blended Cements[7]
- AS3582.2 Slag – Ground granulated iron blast-furnace[8]
- AS2758.1 Concrete aggregates[9]
- AS1478.1 Chemical admixtures for concrete[10]

A statement showing compliance to the relevant specification for each of the proposed concrete constituent materials and mixes proposed for the project will be required. The source of each of the proposed materials must also be furnished. This will allow the concrete supplier to calculate the appropriate Portland cement reduction calculations.

4. REDUCING THE ENVIRONMENTAL IMPACT OF CONCRETE WITH SLAG

The hardened properties and performance advantages from the utilisation of slag in concrete have been well established and documented[11]. Other significant benefits offered by slag cement and aggregates is the potential to reduce the environmental impact that concrete poses through the following efficiencies:

- Reduction in CO_2 emissions[12]
- Reduction in natural resource use
- Efficient use of recovered resources; and
- Sustainability achieved through enhanced durability
- Increases concrete reflectivity

4.1 REDUCTION IN CO_2 EMISSIONS

The only accurate method of assessing the embodied energy and CO_2 emissions impact of a building system or structure and obtain a true measure of its level of sustainability is to perform a life-cycle assessment. This considers not only the construction phase but also the operational phase of the building over its whole service life. The methodology is well established in ISO 14040:2006[13] which sets out the process. In the case of a building, a life cycle assessment includes consideration of the extraction of raw materials, manufacture, construction, operation and re-use or recycle phase at the end of the structures life.

At the material production level, the total emissions embodied in concrete can be calculated from the sum of the emissions associated with production of the constituent materials:

- Portland cement,
- coarse and fine aggregates
- ground granulated blast furnace slag,
- transport of these materials to the batching plant; and
- transport of concrete to the construction site.

Typical embodied emission factors for the main concrete constituent materials have been reported by Flower, Sanjayan and Baweja and are summarised in Table 2[3].

Table 2. Emission Factors For Concrete Constituents*

Portland Cement	0.820	t CO_2-e/tonne
GGBFS (Slag)	0.143	t CO_2-e/tonne
Basakt Coarse Aggregates	0.036	t CO_2-e/tonne
Fine Aggregates	0.014	t CO_2-e/tonne
Concrete Batching	0.003	t CO_2-e/m³
Placement Activities	0.009	t CO_2-e/m³
Concrete Transport	0.009	t CO_2-e/m³

* based on Melbourne, Vic, concrete production figures

As can be seen from Table 2, the Portland cement component accounts for the greatest proportion of embodied CO_2 in concrete. There is approximately a 0.67tCO_2-e/tonne difference between emissions for Portland cement and GGBFS. In other words, the CO_2 emissions associated with the slag are only 17% of the emissions output for cement production. Hence by substituting a portion of the cement component with slag, a considerable reduction in CO_2 emissions can be achieved for the concrete. There is also a potential reduction in emissions associated with the production of slag aggregates when compared with natural coarse aggregates, but since the CO_2 emissions for aggregates are relatively small compared to that of cement, the aggregate component does not have a significant effect on total concrete emission reductions.

Emissions reductions can also be gained through the addition of GBFS, BFS and SFS to kilns as raw feed. Being pre-calcined, these materials directly reduce CO_2 emissions through replacement of limestone, shale and clay and also by reducing fuel use when added to wet kilns as a dry product.

Further minor emission reductions can be achieved through heat island effects when using GBBFS to produce lighter coloured concrete structures and elements. Generally, lighter coloured surfaces have a greater albedo effect (reflective ability). Using GGBFS to produce concrete may increase the reflection of incoming heat radiation and result in a reduction in global warming.

Using the factors in Table 1, it is possible to determine the emission reductions for a typical 32 MPa concrete mix at various slag replacement contents when compared with a 32 MPa mix using the reference case Portland cement content. This is illustrated in Figure 1.

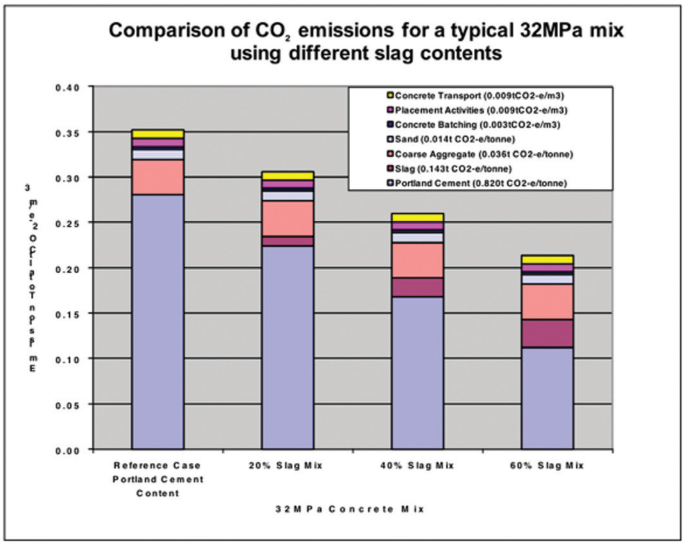

Figure 1. Comparison of Total Emissions For a Typical 32MPa Concrete Mix Using Different Slag Contents

Reduction in CO_2 emissions for the mixes containing slag, relative to the reference case, can be summarised as follows:

Typical 32 MPa Concrete Mix	Reference Case Mix (360kg Cement)	20% Slag Mix	40% Slag Mix	60% Slag Mix
t CO2-e/m3	0.3520	0.3060	0.2600	0.2140
Reduction in CO2 Emissions Campared to Reference Case (%)	-	13%	30%	53%

Table 3. Reduction in CO_2 Emissions for a Typical 32MPa Concrete Mix at Different Slag Contents

The reduction in CO_2 emissions for concrete can be effectively and readily achieved using GGBFS as a cement replacement. Care needs to be taken in determining the most appropriate proportion of GGBFS for the specific application. When properly used, slag can not only reduce emissions impact, it can also enhance the plastic, hardened and durability characteristics of the concrete within which it is used[14].

Using a different analytical approach, O'Moore and O'Brien[15] determined that for production of commercial concrete, at a typical batching plant, with characteristic strength f'c = 32 MPa and a target slump of 80 mm, the greenhouse gas emissions could be calculated from the relationship
GHG, kg CO2-e m^{-3} = 320-2.15*GGBFS, where GGBFS is the % mass content of milled slag of the cementitious binder.

Figure 2 shows the effect of GGBFS replacement on emissions and emission reductions for f'c = 32 MPa concrete.

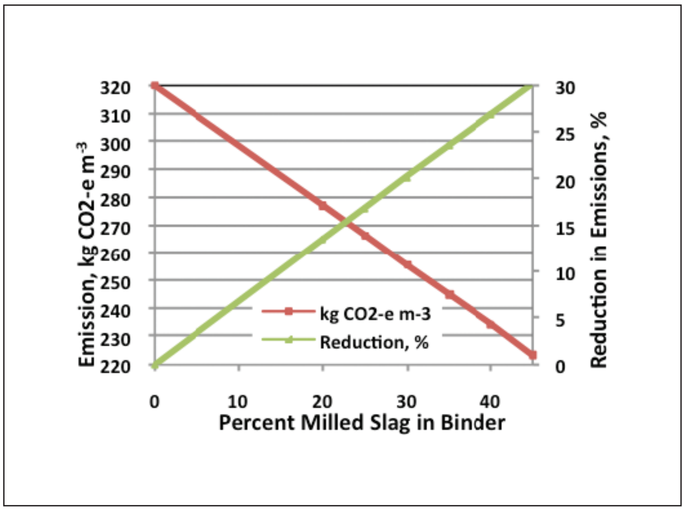

Figure 2. Emission and Emission Reduction for f'c=32MPa concrete.

This study showed that the critical factor for the total greenhouse gas emissions embodied in concrete is not the emissions factor of the GGBFS or other SCM's, but the difference between the emissions factors of Portland cement and the SCM's with which it is replaced. This equally applies to the coarse and fine aggregates used in the production of concrete.

4.2 REDUCTION IN NATURAL RESOURCE USE

Cement production places a demand on natural resources in terms of the processes involved in manufacture and inputs. It requires mining of natural raw materials including limestone, clay and shale and it also requires coal for energy to drive the clinkering process. Cement replacement is a simple, cost effective, fundamental strategy for positively impacting on these resource demands.

GGBFS is commonly used as a SCM in concrete. It can be added to Portland cement at the manufacturing stage, in proportions greater than 7.5% to produce a Blended cement (following AS3972[7]), or as a direct SCM addition during batching in proportions of 20% to 80% of the total binder in concrete[16]. A significant reduction in the amount of cement required in a concrete mix can result either way. GGBFS can also be included as a mineral addition to Type General Purpose (GP) cement during its manufacture (following AS3972[7]). In this way, up to 7.5% slag can be added to Type GP cement.

Aggregates typically contribute approximately 80% of the mass of concrete. The global production of concrete utilises massive amounts of crushed aggregate and sand and the mining, processing and transport operations involve considerable amounts of energy as well as possible impacts on land ecology. The use of slag aggregates can certainly help to conserve our natural aggregate deposits and reduce environmental impacts.

4.3 EFFICIENT USE OF WASTE MATERIAL

As long as iron is produced in Australia, slag will be produced as a co-product material and will represent a substantial recoverable and renewable national resource with significant environmental benefits. The acceptance of GGBFS has grown since its first use in 1965 to the current demand in excess of 871,000 tonnes per annum for use in cementitious applications[14].

4.4 SUSTAINABILITY ACHIEVED THROUGH ENHANCED DURABILITY

It has been shown that in many cases, slag enhances the hardened properties and durability of concretes, generally improving and often surpassing those resulting from concrete made with natural aggregates and Portland cement alone[16,17,18]. The link between enhanced durability and sustainability has been explored in the literature[19]. Durable structures that are better designed to withstand chemical attack and physical stress have an increased service life and reduced need for maintenance. This maximises the return on the original capital as well as the natural resource use in the structure, translating into a higher level of sustainability measured over the life cycle of the concrete structure.

4.5 LIMITATIONS WITH SLAG USE

Whilst it is relatively easy to quantify the benefits of replacing Portland cement with GGBFS and natural aggregates with slag aggregates in terms of CO_2 emissions, there are constraints which restrict wider use of these materials in concrete structures.

Some of these constraints are:
- location of slag aggregates,
- availability of GBFS and installed milling capacity to produce GGBFS,
- transportation costs, and
- prescriptive specifications and early age strength requirements that sometimes limit the content and choice of slag aggregates and GGBFS.

Currently, key drivers impacting on blast furnace slag cement and slag aggregate use in concrete are the delivered cost of GGBFS slag, current local availability of slag cements, GGBFS and slag aggregates. The use of significant quantities of SCM's in concrete can result in construction issues, if not managed, such as extended setting times and slower strength gain up to 28 days. This can have an impact on construction cycles, which in turn can impact on construction costs.

Such a cost analysis, however, may alter in the near future due to carbon cost which is now a legislated requirement commencing in July 2012. These costs may have an impact on production costs of Portland cement and hence improve the financial drivers for the use of blast furnace slag cement in concrete.

CONCLUSIONS

The utilisation of GGBFS as a SCM in cement or as aggregates in concrete can offer immense benefits towards achieving concrete sustainability:-
- Slag makes efficient and economical use of a co-product material;
- The use of slag lessens the environmental impact of concrete by reducing CO_2 emissions and the use of natural resources; and
- Slag cement and aggregates can lead to concrete with increased durability, which also benefits sustainability in the long-term.

Slag is recognised by the Green Star Concrete Materials credit that awards up to 3 points for enhancing sustainability with concrete use. The maximum of 3 points can often be attained with the use of slag products in concrete. Importantly, however, the technical benefits of using slag cements and aggregates in concrete, that have been reported elsewhere in the technical literature, should also always be harnessed to produce a total design, construction and sustainable project solution.

REFERENCES

1. U.S. Environmental Protection Agency. (October 28, 2009). Green Building Basic Information, from www.epa.gov/greenbuilding/pubs/about.htm

2. Heidrich, C., I. Hinczak, et al. (2006). GGBFS lowering Australia's greenhouse gas emissions profile. Global Slag Conference, Bankok, Thailand, GBC.

3. Flower, D., Sanjayan, J. and Baweja, D., "Environmental Impacts of Concrete Production and Construction", Proceedings, Concrete Institute of Australia Biennial Conference, Melbourne, Australia, 2005.

4. Flower, D., Sanjayan, J. and Baweja, D., "Environmental Impacts of Concrete Production and Construction", Proceedings, Concrete Institute of Australia Biennial Conference, Melbourne, Australia, 2005.

5. Flower, D., Sanjayan, J. and Baweja, D., "Environmental Impacts of Concrete Production and Construction", Proceedings, Concrete Institute of Australia Biennial Conference, Melbourne, Australia, 2005.

6. Standards Australia, Australian Standard AS3600, "Concrete Structures", ISBN 0 7337 9347 9, Standards Australia International, 2009.

7. Standards Australia, Australian Standard AS3972, "General Purpose and Blended Cements", ISBN 978 0 7337 9698 2, SAI Global Limited, 2010.

8. Standards Australia, Australian Standard AS3582.2, "Supplementary Cementitious Materials for Use With Portland and Blended Cement – Part 2 : Slag – Ground Granulated Iron Blast-furnace", ISBN 0 7337 4054 5, Standards Australia International, 2001.
9. Standards Australia, Australian Standard AS2758.1, "Aggregates and Rock for Engineering Purposes – Part 1: Concrete Aggregates", ISBN 0 7337

1730 6, Standards Australia International, 1998.

10. Standards Australia, Australian Standard AS1478.1, “Chemical Admixtures for Concrete, Mortar and Grout- Part 1: Admixtures for Concrete”, ISBN 0 7337 3513 4, Standards Australia International, 2000.

11. Australasian (Iron & Steel) Slag Association, “Blast Furnace Slag Cements, Properties, Characteristics and Applications”, Reference Data Sheet 3, 2011, available from www.asa-inc.org.au, 5p

12. http://www.asa-inc.org.au/documents/ASA_survey_results_2010.pdf [Accessed Nov 2011]

13. ISO 14040:2006, “Environmental management – Life cycle assessment – Principles and framework”

14. Australasian (Iron & Steel) Slag Association, “Blast Furnace Slag Aggregate & Cementitious Products”, Reference Data Sheet 1, 2011, available from www.asa-inc.org.au, 4p

15. O’Moore, L.M. and O’Brien, K.R., “Impact of Supplementary Cementitious Material Content and Transportation Distance on Greenhouse Gas Emissions Embodied in Concrete”, Concrete Solutions 09 – adding value in changing climates”, 24th. Biennial Conference of the Concrete Institute of Australia, September 2009, Luna Park, Sydney, Australia.

16. Australasian (Iron & Steel) Slag Association, VicRoads and the Roads and Traffic Authority of NSW”, A Guide to the Use of Iron Blast Furance Slag in Cement and Concrete”, ISBN 0 9577051 15, April 197, 32p.

17. Australasian (Iron & Steel) Slag Association, “A Guide to the Use of Iron and Steel Slag in Roads”, ISBN 0 9577051 58, Revision 2, 2002, Availalbe from www.asa-inc.org.au, 27p.

18. Concrete Institute of Australia, “Ground Granulated Iron Blast Furance Slag and Its Use in Concrete”. CUrrent Ptarctice Note 26, ISBN 0 909375 62 3, November 2003, 8p

19. Mehta, P.K., “Durability – Critical Issues for the Future”, Concrete International, Vol. 19, No. 7, July 1997, pp 27-33.

AUSTRALASIAN (IRON & STEEL) SLAG ASSOCIATION

Suite 2, Level 1, 336 Keira Street,
Wollongong NSW 2500 Australia

PO Box 1194
Wollongong NSW 2500 Australia

Telephone: +61 2 4225 8466
Fax: +61 2 4228 1777
Email: info@asa-inc.org.au