Blast Furnace Slag Cements & Aggregates:
Slag Binders and Aggregates and Australian Standards

1. INTRODUCTION

Slag binders and aggregates have been used in concrete in construction projects in Australia since the early 1960's[1,2]. Improvements in workability mix efficiency with regard to binder optimisation and improved concrete performance characteristics have largely driven the use of ground granulated blast furnace slag and blast furnace slag aggregates in concrete since that time. Determination of economically optimum binder proportions in concrete, when using ground granulated iron blast furnace slag, (GGBFS) has been undertaken in various ways since that time. Examples of structures incorporating GGBFS include the Sydney Harbour Tunnel segments, footings for Anzac Bridge at Glebe and many conventional buildings involving both normally reinforced concrete and post-tensioned concrete.

With the wider availability and use of granulated blast furnace slag (GBFS) and blast furnace slag (BFS) aggregates, Australian standards for the material and its use in concrete have undergone change and now better reflect the capability of this material.

2. GROUND GRANULATED SLAG IN AUSTRALIAN STANDARDS

Figure 1 – Granulated Iron Blast Furnace Slag

2.1 SPECIFICATION AND DESIGN

The Building Code of Australia is produced and maintained by the Australian Building Codes Board on behalf of the Australian Government and State and Territory Governments. It largely defines requirements for building regulations in Australia. This code calls up Australian Standard AS3600 (Concrete Structures) to describe minimum requirements for the design of concrete structures[3]. AS3600 further references Australian Standard AS1379 in regard to the specification and supply of concrete[4]. AS1379 nominates Normal Class Concretes for more generalised applications of concrete and Special Class Concretes for all other concrete applications. In relation to GGBFS, AS1379 references two commonly used standards, AS3582.2, Supplementary Cementitious Materials for Use With Portland and Blended Cement, Part 2 – Slag – Ground granulated iron blast-furnace[5], and AS3972, General purpose and Blended Cements[6].

2.2 GROUND GRANULATED IRON BLAST FURNACE SLAG IN AS3582.2

Australian Standard AS3582.2 sets out the requirements for GGBFS as a cementitious material in concrete and mortar[5]. The definition of GBFS is given as "the glassy granular material resulting from the rapid chilling of molten, a non-metallic product , consisting essentially of silicates and aluminosilicates of calcium, produced simultaneously with iron in an iron blast-furnace slag."

The criteria for classification of GGBFS' are based on tests described in various parts of AS3583[7] with key specified properties noted below: -

- Loss on ignition,
- Sulphide sulphur (S) content,
- Magnesia (MgO) content,
- Alumina (Al_2O_3) content,
- Total iron (FeO) content,
- Manganese (MnO) content, and
- Insoluble residue.

In addition to the above, AS3582.2[5] lists the following as reportable properties:-

- Fineness,
- Sulphuric anhydride (SO3) content,
- Chloride ion (Cl) content,
- Relative water requirement,
- Relative strength, and
- Available alkali content (when required).

Figure 2 – Ground Granulated Blast Furnace Slag

2.3 THE ROLE OF SLAG IN GENERAL PURPOSE AND BLENDED CEMENTS IN AS3972

Australian Standard AS3972 defines Portland cement clinker as "a partially fused product resulting from mixing of calcareous and argillaceous or other silica, alumina, or iron-bearing materials or combinations of these materials, and burning them at clinkering temperatures"[6]. It defines **"mineral additions"** as selected fly ash, ground granulated iron blast furnace slag (GGBFS), limestone or combinations of these materials[6]. It further defines **"minor additional constituents"** as specially selected inorganic natural mineral materials, or inorganic mineral materials derived from the clinker production process

such as cement kiln dust. In AS3972 **Portland cement** is defined as a combination of Portland cement clinker and calcium sulphate. A range of general purpose and blended cement types are defined in that standard covering a range of applications.

General purpose cement (Type GP) is defined as a hydraulic cement containing Portland cement and, at the discretion of the cement manufacturer, may contain a combination of mineral additions alone or in combination with minor additional constituents (maximum 5%) up to 7.5% by mass of the total cement.

General purpose limestone cement (Type GL) is defined as a hydraulic cement that contains Portland cement and, at the discretion of the cement manufacturer, may contain limestone alone or in combination with minor additional constituents (maximum 5%) of 8–20% by mass of the total cement.

Blended cement (Type GB) is defined as hydraulic cement that contains general purpose cement and which, at the discretion of the cement manufacturer, may contain one or both of the following:

a. Greater than 7.5% of fly ash or ground granulated iron blast-furnace slag, or both.
b. Up to and including 10% amorphous silica.

Special purpose cement may be general purpose cement or blended cement and are identified as follows:

a. Type HE—high early strength cement.
b. Type LH—low heat cement.
c. Type SR—sulphate-resisting cement.
d. Type SL—shrinkage limited cement.

Each of the above cements have further requirements for compressive strength, soundness and SO3, as well as peak temperature, expansion and shrinkage as defined by standard mortar tests where appropriate [8].

2.4 GROUND GRANULATED SLAG IN AS1379 AND THE DEFINITION OF CEMENT

In AS1379, the term “cement” is defined as a hydraulic binder composed of Portland or blended cement used alone or combined with one or more supplementary cementitious materials[4]. GGBFS therefore fits within the definition of cement in AS1379 and can be incorporated into Normal or Special Class Concrete either as a blended cement, or added directly into the concrete at a batch production facility. There are specific requirements for compressive strength, workability and other fresh and hardened concrete properties in this Standard[4].

The level of use of GGBFS and other supplementary cementitious materials in concrete is limited in AS1379 by the requirement of minimum 7 day compressive strengths for the different grades of Normal Class Concrete. These requirements

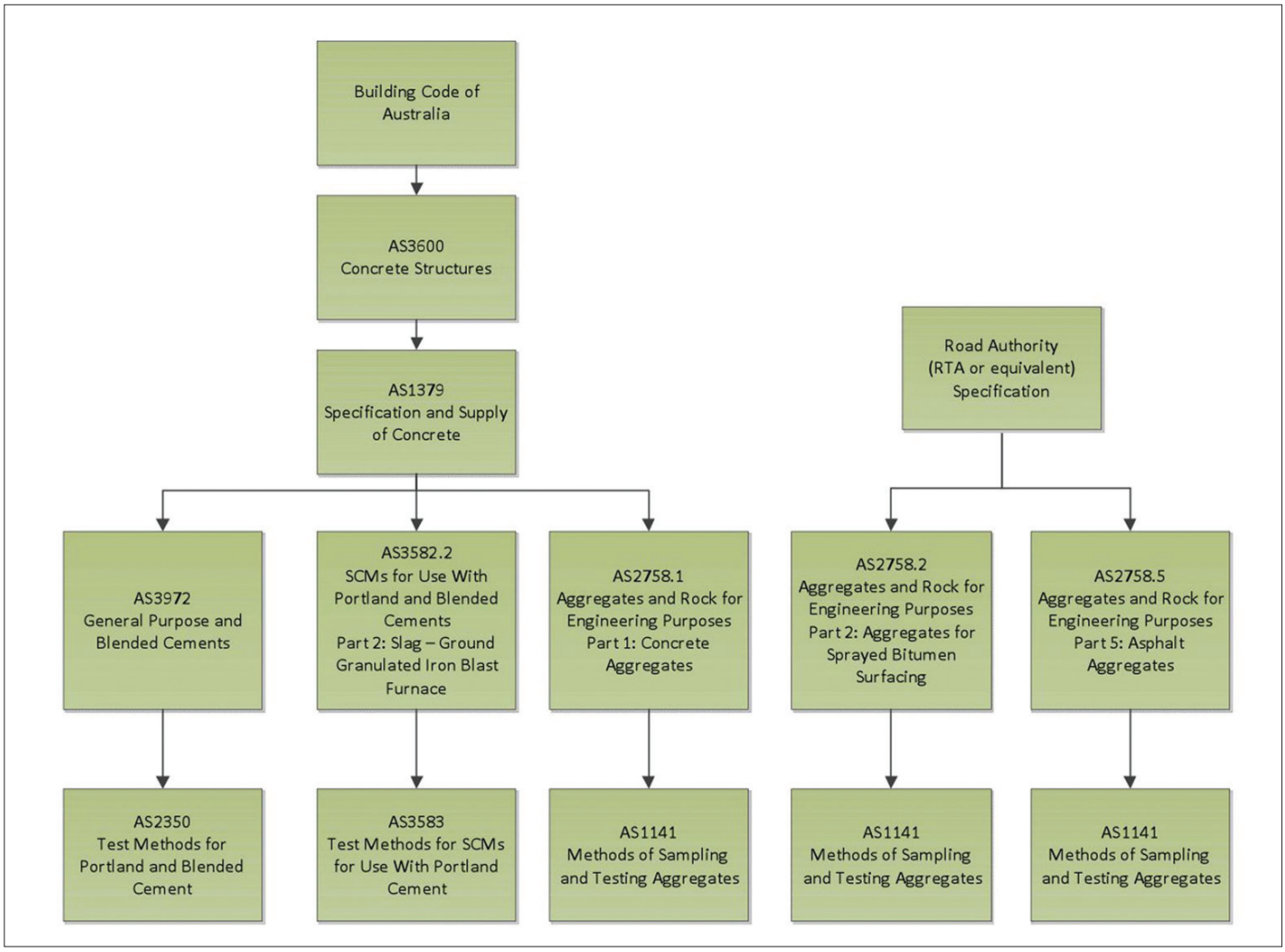

Fig. 3: Codes and Standards Relating to GGBFS and Slag Aggregates for Use in Concrete in Australia

can be overridden allowing greater levels of GGBFS to be incorporated into concrete using Special Class prescriptive requirements and appropriately addressing 7 day compressive strength requirements to suit the application.
A summary of the relevant codes and standards for GGBFS for use in concrete in Australia and their relationships is presented in Figure 1.

3. OPPORTUNITIES WITH USING GGBFS IN CONCRETE

On the basis of the Australian Standards definitions for GGBFS, the opportunities for using the material and concretes are as follows: -

- At less than 7.5% as mineral addition in a general purpose cement
- At less than 7.5% as mineral addition in a blended cement where slag is not otherwise used in the blend
- At greater than 7.5% in a special purpose cement
- By direct addition into AS1379 Normal Class Concretes (20 MPa, 25 MPa, 32 MPa, 40 MPa and 50 MPa grades) to levels where minimum 7 day compressive strength requirements are achieved.
- By direct addition into AS1379 Special Class Concretes where imposed performance requirements are achieved.

GGBFS is a valuable product that will allow efficient design and construction solutions in areas such as: -

Plastic concrete

- Workability enhancement
- Placement and finishing efficiency
- Pumping efficiency
- Reduced concrete water demand

Hardened concrete

- Engineering design efficiency
- Reduced drying shrinkage where lower water demands are achieved
- Increased long-term compressive strength development

Durability and other properties

- Increased sulphate resistance
- Increased chloride resistance
- Increased resistance to alkali-silica reaction
- Achieving greater sustainability with supplied materials.

It should be noted, however, that issues relating to the use of GGBFS in concrete can be highly complex. Often, desired outcomes in one area may be in conflict with desired outcomes in other areas on construction projects. E.g GGBFS specified at high replacement percentages for durability properties, may result in lower early age strengths. It is desirable to obtain expert advice in key project areas to ensure successful outcomes and to ensure GGBFS can be used to achieve such outcomes.

4. SLAG AGGREGATES IN AUSTRALIAN STANDARDS

4.1 SPECIFICATION AND DESIGN - CONCRETE AGGREGATES

As with binders, aggregate requirements for concrete are noted initially in AS3600[3], which further references AS1379 in relation to the specification and supply of concrete[4]. In relation to BFS aggregates, AS1379 references three commonly used standards. These are AS2758.1, Aggregates and Rock for Engineering Purposes - Part 1: Concrete Aggregates[9], AS1141, Methods of Sampling and Testing Aggregates[10] and AS1012, Methods of Testing Concrete, Part 20, Determination of Chloride and Sulfate in Hardened Concrete and Concrete Aggregates[11].
BFS aggregates must comply with all requirements specified for natural aggregates plus two additional requirements for iron unsoundness and falling or dusting unsoundness:

4.2 IRON UNSOUNDNESS

Iron unsoundness, which occurs as disintegration of the slag when immersed in water, is highly likely when the slag contains more than 3% ferrous oxide and at least 1% of sulphur. Australian Standard AS2758.1[9] notes that iron unsoundness has not been observed in Australian sourced BFS aggregates. Chemical analyses of BFS aggregates show that ferrous oxide and sulphur contents are significantly below the maximum values noted in AS2758.1[9].

4.3 FALLING OR DUSTING UNSOUNDNESS

When some iron blast furnace slags cool from the molten state to around 490°C, an inversion of β-dicalcium silicate to the gamma form in the slag may result in disruption of the slag structure. This leads to a condition in the slag known as falling or dusting unsoundness. Australian Standard AS2758.1[9] notes that “No evidence has been found either in Australia or overseas of delayed inversion of beta dicalcium silicate in iron blast furnace slag, or of deterioration of concrete due to the presence of beta dicalcium silicate”. Therefore, BFS aggregates in general are deemed to comply with the provisions of Australian Standard AS2758.1.

As a result of the manufacturing process, BFS aggregates are vesicular with individual particles containing an unconnected void structure that results in water absorptions of 3% to 6% by mass. Some natural aggregates exhibit water absorptions in the order of 4%. To avoid potential difficulties with the batching, pumping and placement of concrete, BFS aggregates are supplied in a saturated surface dry (SSD) condition that needs to be maintained at the concrete batching plant by utilising control sprays normally fitted to storage bins. Generally, the use of BFS aggregates in concrete produces plastic properties not dissimilar to those resulting from natural aggregates. Concrete made with vesicular aggregates, such as BFS aggregate, can be successfully pumped, placed and finished. They have had extensive use in concrete both in standard and high performance concrete applications. It is, however, recommended that the lower density of slag aggregate be taken into account when designing concrete mixes to ensure that the volume of coarse material is not excessive.

CONCLUSIONS

GGBFS can be used in binders for concrete in different ways as described below: -

- At less than 7.5% as mineral addition in a general purpose cement
- At less than 7.5% as mineral addition in a blended cement where slag is not otherwise used in the blend
- At greater than 7.5% in a special purpose cement

- By direct addition into AS1379 Normal Class Concretes (20 MPa, 25 MPa, 32 MPa, 40 MPa and 50 MPa grades) to levels where minimum 7 day compressive strength requirements are achieved.

By direct addition into AS1379 Special Class Concretes where imposed performance requirements are achieved.
BFS aggregates can also be used as a component in concrete following requirements described in AS2758.1 (Aggregates and Rock for Engineering Purposes: Part 1 - Concrete Aggregates) as well as for spray sealing applications (AS2758.2) and as asphalt aggregate (AS2758.5).

Further opportunities exist for increasing the use of GGBFS and BFS aggregates in concrete through a better understanding of the materials and how they influence concrete properties within which they are included. Importantly, the ASA advocates the inclusion of both GGBFS and BFS aggregates in concrete where appropriate design, constructional, sustainability and other project factors are considered in taking account of relevant technically based information. The aim is always to develop ways in which complex project issues can be resolved using the beneficial properties of slag products.

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