

Ground Granulated Blast-Furnace Slag: Its Chemistry and Use with Chemical Admixtures

Introduction

Ground granulated blast-furnace slag (GGBFS), sometimes simply referred to as “slag”, is a glassy granular material formed when molten blast-furnace slag is rapidly chilled, as by immersion in water. It is a non-metallic product, consisting of silicates and aluminosilicates of calcium and other bases, developed in a molten condition simultaneously with iron in a blast furnace. It is used as a cementitious material in Portland cement concrete. GGBFS was first used in lime mortar production as early as the 1700’s. In Germany, it has been interground with Portland cement since 1892, and in other parts of the world it has been added to concrete as a separate constituent since the early 1950’s. Although some of the GGBFS produced is used stabilizing mine tailings and industrial waste materials, the rest is used in Portland cement concrete.

There are two primary advantages for adding GGBFS to concrete as a separate material, rather than intergrinding it in the cement:

1. Each material can be ground to its own optimum fineness
2. The proportions can be adjusted to suit the particular project needs.

Relevant Documents

Documents that specify or describe the chemical and physical properties of GGBFS are:

- ASTM C989, “Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars”
- ASTM C595, “Standard Specification for Blended Hydraulic Cements”
- CSA A3001, “Cementitious Materials for Use in Concrete”
- ACI 233, “Slag Cement in Concrete and Mortar”.

Classifications

According to ASTM C989, GGBFS is classified into three grades according to its performance in the “slag activity test”. The three grades are: Grade 80, Grade 100 and Grade 120. Slag activity is determined by the following formula:

$$\text{Slag activity index, \% (SP / P) } 100$$

Where:

SP = average compressive strength of slag-reference cement mortar cubes at designated ages, MPa (psi)

P = average compressive strength of reference cement mortar cubes at designated ages, MPa (psi).

Table 1 shows the requirements of ASTM C989 for each grade of Ground Granulated Blast-Furnace Slag.

Table 1: Slag Activity Index Requirements of ASTM C989

Slag Activity Index, min%	Slag Activity Index, Consecutive Samples	Any Individual Samples
7 day index		
Grade 80	—	—
Grade 100	75	70
Grade 120	95	90
28 day index		
Grade 80	75	70
Grade 100	95	90
Grade 120	115	110

Comparison of Portland Cement, GGBFS and Fly Ash

Table 2 compares the composition of a typical ground granulated blast-furnace slag to that of a typical Type I Portland cement, a typical Class C fly ash and a typical Class F fly ash. You will note that the GGBFS and the two fly ashes have the same kinds of oxides as the cement, which means that when GGBFS or fly ash is added to concrete, materials similar to Portland cement are being introduced into the system.

Table 2: Slag Activity Index Requirements of ASTM C989

Chemical Constituents (as Oxides)	Type I Cement	Type C Fly Ash	Type F Fly Ash	GGBFS
SiO ₂	21.1	33.5	43.4	40.0
Al ₂ O ₃	4.6	22.9	18.5	13.5
CaO	65.1	27.4	4.3	39.2
MgO	4.5	4.6	0.9	3.6
Fe ₂ O ₃	2.0	6.1	29.9	1.8
SO ₃	2.8	2.8	1.2	0.2
L.O.I.	1.4	1.2	1.2	0.0

Like Portland cement, most of the calcium oxide (CaO) found in GGBFS is tied up as calcium silicate, calcium aluminate and calcium aluminosilicate. Although these compounds are not identical to those found in Portland cement (i.e., tricalcium silicate, tricalcium aluminate, etc.), they hydrate when activated by calcium hydroxide (lime), which is one of the by-products of Portland cement hydration. Since GGBFS is almost 100% glassy, it is generally more reactive than the most fly ashes. Substitutions of cement by GGBFS have been reported as high as 65%.

Just like Portland cement, GGBFS must be finely ground before it can be used in concrete. If the GGBFS is ground by itself, it can be blended mechanically with cement at the cement mill to make ASTM C595, Type IS, Portland blast-furnace slag cement, or it can be added at the concrete plant to make slag concrete. The ingredients, proportions and physical requirements of Type IS cement are listed in ASTM C595, "Standard Specification for Blended Hydraulic Cements."

Chemical Admixtures and Ground Granulated Blast-Furnace Slag

Since most chemical admixtures perform well in plain Portland cement mixtures and in Portland cement and fly ash concrete, it is not surprising that they provide similar performance when used in slag concrete.

Since there is little or no carbon in GGBFS, concrete containing it usually responds well to air entrainment. However, if the GGBFS is ground excessively fine, additional amounts of air-entraining agent may be required to attain the specified air content.

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