EUROSLAG Technical Leaflet No. 1

Granulated Blastfurnace Slag

Granulated Blastfurnace Slag (GBS) is manufactured from molten blastfurnace slag, a co-product produced simulta-neously with iron. Rapid chilling with water or air forms a glassy granular material with latent-hydraulic properties. It is used for cement, concrete, mortar, grout and aggregates.

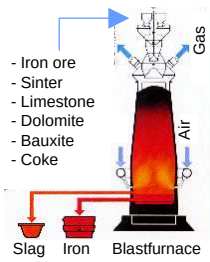
Material Characterisation

Molten slag is resembling natural liquid lava. If solidified, GBS is an inorganic, glassy material. The glassy nature is responsible for its cementitious properties. The four major chemical components, calculated as oxides, are CaO, SiO_2, Al_2O_3, and MgO. TiO_2 and MnO are also present and influence the latent-hydraulic properties. Due to the reducing conditions of the blastfurnace heavy metals are mainly transferred into the iron. Remaining trace elements are present in the same amount as it is in natural minerals.

Origin

Iron ores from around the world blended with limestone and/or dolomite and coke are used to produce iron prior to steelmaking process. The blend is sintered which removes moisture, some sulphur and causes the formation of nodules. Lump ore, sinter cake, fine ores pellets and additives form the blastfurnace burden. Precise mixtures of burden and coke are continually fed into the blastfurnace, where the hearth temperature is maintained at around 1500 °C. Molten iron and slag are drawn off at regular intervals from tap holes at the base of the furnace. The quenching of this liquid slag with an excess of water (granulation), air and water (pelletisation) or steam forms a granular product.

For each ton iron about 1.6 tons raw material, 330 kg coke, 150 kg coke coal powder and 900 m³ hot air are necessary. About 230 - 300 kg of slag is produced.

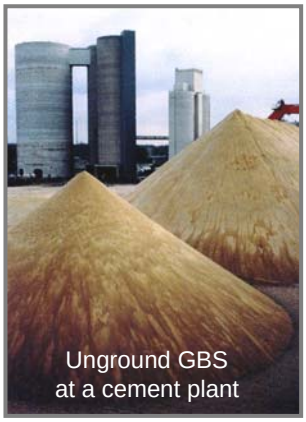


The production of high quality iron combined with efficient furnace operation, ensures consistent, high quality blastfurnace slag is produced.

The colour of GBS ranges from beige to dark to off white depending on moisture content, chemistry and efficiency of granulation. When it is ground it has usually white colour. In relation to OPC the material seems to be friendly, and pigments can be used more efficiently.

Physical Properties

Glass content	Vol.-%	60.4 - 100.0
True density	g/cm³	2.796 - 3.070
Apparent density	g/cm³	2.021 - 2.843
Bulk density	g/cm³	0.689 - 1.427
Porosity	Vol.-%	2.5 - 31.2
Sieve size < 0.5 mm	wt.-%	3.6 - 78.6
Sieve size < 3.2 mm	wt.-%	81.1 - 100.0



Unground GBS at a cement plant

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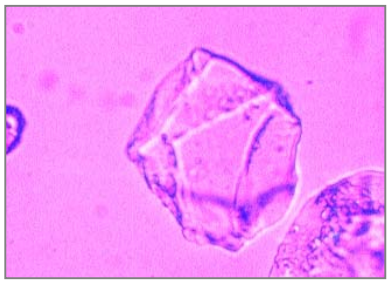
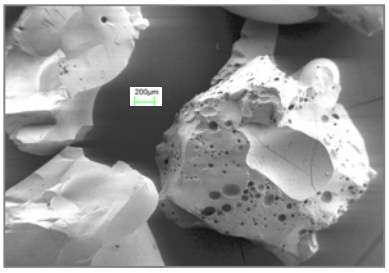
Granulated Blastfurnace Slag

Have a look at the glassy GBS:

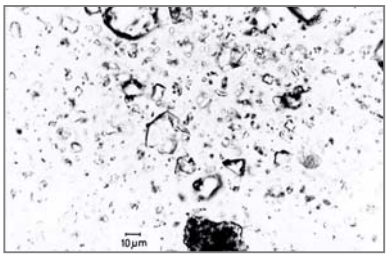
Unground GBS (LM)



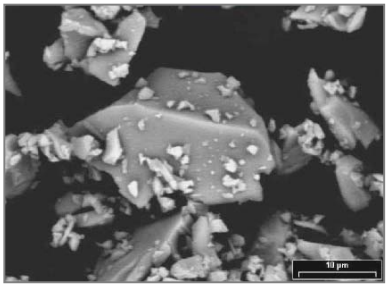
Unground GBS (LM)



Unground GBS (SEM)



Ground GBS 4900 cm²/g (LM)



Ground GBS 4200 cm²/g (SEM)

Chemical Composition (in wt.-%)

Component:	GBS			OPCC		
Insoluble residue	0.03	-	4.06	0.04	-	0.72
SiO_2	30.5	-	40.8	19.8	-	23.4
Al_2O_3	5.9	-	17.6	4.0	-	6.5
FeO	0.12	-	4.72	-	-	-
Fe_2O_3	-	-	-	1.50	-	3.80
TiO_2	0.07	-	3.70	0.13	-	0.30
MnO	0.07	-	3.12	-	-	-
Mn_2O_3	-	-	-	0.01	-	0.28
CaO_{total}	30.9	-	46.1	64.1	-	68.4
CaO_{free}	-	-	-	0.30	-	2.37
MgO	1.66	-	17.31	0.72	-	4.66
Na_2O	0.09	-	1.73	0.03	-	0.38
K_2O	0.08	-	1.51	0.37	-	1.30
Na_2O-Equivalent $Na_2O + 0{,}658 \cdot K_2O$	0.19	-	2.61	0.47	-	1.07
SO_3^{2-}	0.00	-	0.86	0.14	-	1.84
S^{2-}	0.42	-	2.29	-	-	-

Characteristics such as colour, moisture content, bulk density, porosity, grain shape, grading curve and grindability are affected by different chemistry, melting temperature and granulation process conditions.
The table is giving values for the oxide composition (in wt.-%) of GBS compared to Orinary Portland Cement Clinker (OPCC).

Depending on different chemistry, granulation methods and granulation parameters the morphology of GBS particles can vary from a dense structure without porosity to a very porous friable form. In general the particle shape is sharp-edged with occasionally elongated needled shaped forms.

Requirements & Standards

The European standard EN 197-1 (Common cements) contains requirements for glass content and basicity of GBS. The oxide composition of GBS may be used as a guide to possible reactivity. However, investigations have shown that the evaluation of GBS based only on the chemistry or other single parameter does not give entirely reliable results. The interaction of the slag with Portland cement clinker, calcium sulphates and other materials, as appropriate, have to be considered.

Grinding GBS

GBS is stockpiled to allow excess moisture to drain. If required, blending can take place. Magnets are used before and during the grinding process to remove any residual metallic iron. For slag cement production GBS can be ground separately (Ground granulated blastfurnace slag GGBS) or together with Portland cement

clinker and calcium sulphate. Depending on the plant configuration the granulated blastfurnace slag is partially dried in a rotary or in a vertical pre-drier. This material is fed at a prescribed rate into a high pressure roller mill and/or then into a ball mill where it is ground to the required finished fineness. Drying and milling can also be carried out in a vertical roller mill. Usually GGBS is ground to a fineness exceeding that of ordinary Portland cement to obtain an increased early strength.

What is GGBS Used For?

GGBS has been used in composite cements and as a cementitious component of concrete for many years. The first industrial commercial use (about 1859) was the production of bricks using unground GBS. In the second half of the 19th century the cementitious properties were discovered and by the end of 19th century the first cements containing GBS were produced. Since the late 1950's the use of GGBS as a separately ground material added at the concrete mixer together with Portland cement has gained acceptance. It should be noted that in some countries the term "slag cement" is used for pure GGBS. Practically, there are no concrete, mortar or grout applications which preclude the use of an appropriate amount of GGBS. World-wide, it can be expected that the expansion of GGBS use will continue for the foreseeable future.

- **Slag Cement:** Factory produced can be made in one of two ways. Either the individual components (the GBS and the Portland cement clinker) can be ground separately and subsequently blended or they can be interground which mixes and grinds in a single operation. In the European cement standard EN 197-1, nine cements containing slag are listed which may have slag contents between 6 wt.-% and 95 wt.-%. Slag cements are available through most of Europe and, indeed, most of the world.

- **Concrete:** Besides as a constituent of slag cement in some parts of Europe GGBS is available as a separately ground material which can be used by the concrete producer as a cementitious component.
Properties: Using slag cements or GGBS as a concrete addition result in several advantageous concrete properties. Slag cements have a low heat of hydration. Concrete made with blastfurnace slag cement or with GGBS as an addition has a high durability as a result of the low capillary porosity. It is resistant to chloride penetration, sulphate and thaumasite sulphate attack. Protection against alkali silica reaction, a low risk of thermal cracking, a high electrolytic resistance and a consistent light colour are further advantages. A better workability and an easier finishability are documented. These properties favour the use of slag cements or mixtures of Portland cement with GGBS in all situations especially where high levels of durability are called for. Using GGBS may locally cause a blue-green coloration of the fresh demoulded surface of hardened concrete. With air the typical colour vanishes within a short time.

- **Mortar:** Slag used as a cementitious component in mortars enhances their workability and can allow further working time for the bricklayer.

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TV Tower "Florian", D

Europe school, L

Humber bridge, UK

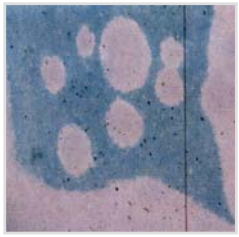
Church relief, D

Oosterschelde barrage, NL

Marina construction, UK

Road construction, F

- **Grout:** Grouts containing slag have been used on many occasions to control temperature rise during hydration and in areas of aggressive conditions.
- **Aggregate:** Unground GBS is suitable as a normal weight aggregate in concrete.
- **Road Making:** Unground GBS can be used as a base layer material in road construction.



Fresh concrete surface ...

... 6 weeks later

Environmental Benefits

In Europe the production of 1 t Portland cement generates about 1.2 t CO_2 on average, while the production of 1 t blast-furnace slag cement containing 50 wt.-% GGBS generates only 0.54 t CO_2. These data include emissions from the calcination process, the fossil fuel burning, and the use of electricity. For some countries maybe the potential saving is much more higher. Thus the use of slag is a very effective and economic method to reduce the energy consumption and the CO_2-emissions inherent in cement production.

Beyond that mortar and concrete made with GGBS have a lower content of Chromium-VI, which can be responsible for skin irritations of workers handling the material manual without any skin protection.

More informations

The literature on GBS is very extensive. Therefore only three examples for important standards are listed:

- European Standard EN 197-1: Cement - Part 1, Composition, specifications and conformity criteria for common cements (2000)
- British Standard BS 6699: Ground granulated blastfurnace slag for use with Portland cement (1992)
- ASTM C 989: Ground granulated blast-furnace slag for use in concrete and mortars (1999)

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About EUROSLAG:

In 2000 slag producers and processors in Europe have come together to form EUROSLAG, the association of organisations and companies concerned with all aspects of the manufacture and utilisation of slag products. It seeks
- to promote and develop the utilisation of slag in all appropriate situations
- to ensure slag products are made by the best possible processes
- to provide and encourage communication between slag producers and processors
- to co-ordinate technical working parties and research and development
- to bring together people from both the supply and utilisation side of the industry
- to provide a co-ordinated approach to European Standardisation.

Health & Safety Information:
CAS 65996-69-2, EINECS 266-002-0, EU safety data sheets 401/402