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A Review on the Use of Ground Granulated Blast Slag (GGBS) in Concrete

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Abstract: *The four main ingredients in concrete are water, fine aggregate, coarse aggregate, and cement. A great deal of concrete is used because of the important function it plays in the construction of infrastructure, such as buildings, industrial structures, bridges, roads, and so on. Concrete, on the other hand, is costly because of the rare and expensive ingredients used to make it, which forces manufacturers to find cheaper substitutes. Because of this need, researchers have been looking for alternatives to traditional concrete components. Research into the properties of concrete that includes Ground Granulated Blast Furnace Slag (GGBS) as a partial cement substitute is the primary emphasis of this scientific study. The article covers the use of GGBS and the pros and cons of utilizing it in concrete. As a byproduct, this use of GGBS is an environmentally friendly alternative to dumping it on the ground, and it also acts as a substitute for traditional construction materials, which are already decreasing.*

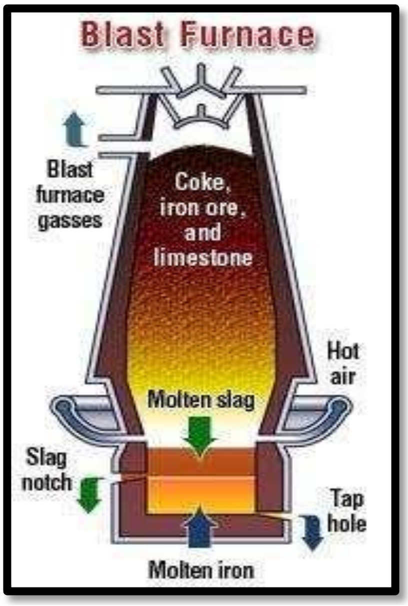
Keywords: *GGBS, GGBS in concrete, other materials with GGBS.*

I. Introduction

General:

As a waste product, blast furnaces produce ground granulated blast furnace slag, or GGBS [1]. These run on a precisely calibrated combination of limestone, iron ore, and coke, and reach temperatures of about 1500 degrees Celsius. After the iron ore is heated, it is transformed into iron and the byproducts of the smelting process, which are known as slag. This slag is periodically tapped off as a molten liquid and if it is to be used for the manufacture of GGBS it has to be rapidly quenched in large volumes of water. Granules resembling coarse sand are produced by quenching, which optimizes the cementitious characteristics. The resulting "granulated" slag is further dried and reduced to a fine powder.

Although normally designated as “GGBS” in the UK, it can also be referred to as “GGBS” or “Slag cement” Concrete is basically a mix of fine aggregate, coarse aggregate and cement. The main problem is the original conventional materials are depleting and we are in hunt for alternate building materials which lands us here on the purpose of GGBS. Being a by product and waste using it effectively up to some extent serves as a step for a greener environment and at the same time keeping in mind that the strength of the concrete doesn‟t degrade by the usage GGBS.



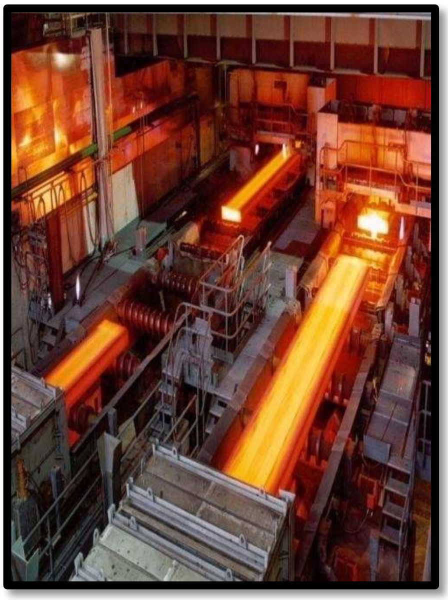


Fig 1: Sources of Ground Granulated Blast Slag

(Furnaces from Steel plants)

Effectively concentrating on both the factors have been successful up to a good extent and that‟s what we CIVIL ENGINEERS are very keen about in the present era of construction.

II. Chemical Composition Of GGBS

The chemical composition of a slag varies considerably depending on the composition of the raw materials in the iron production process. Silicate and aluminate impurities from the ore and coke are combined in the blast furnace with a flux which lowers the viscosity of the slag. In the case of pig iron production the flux consists mostly of a mixture of limestone and forsterite or in some cases dolomite. In the blast furnace the slag floats on top of the iron and is decanted for separation.

Typical chemical composition:
Calcium oxide = 40%
Silica = 35%
Alumina = 13%
Magnesia = 8%

The glass Slag that is appropriate for mixing with Portland cement usually has a glass percentage ranging from 90% to 100%, depending on the cooling technique and the starting temperature for chilling. In quenched glass, the ratio of network-forming elements like si and Al to network-modifiers like Ca, Mg, and, to a lesser degree, Al determines the glass structure. Network DE polymerization and reactivity are both enhanced with increasing concentrations of network-modifiers. It is a granular material that hydrates similarly to Portland cement, has a highly cementitious character, is crushed to a cement fineness, and hardly forms crystals.

Typical physical properties:- Colour : off white
Specific gravity : 2.9
Bulk density : 1200 Kg/m^3
Fineness: 350 m^2/kg

III. Applications And Uses Of GGBS

GGBS is used to make durable concrete structures in combination with ordinary Portland cement and/or other pozzolanic materials. GGBS has been widely used in Europe, and increasingly in the United States and in Asia (particularly in Japan and Singapore) for its superiority in concrete durability, extending the lifespan of buildings from fifty years to a hundred years.

Two major uses of GGBS [2] are in the production of quality-improved slag cement, namely Portland Blast furnace cement (PBFC) and high-slag blast-furnace cement (HSBFC), with GGBS content ranging typically from 30 to 70% and in the production of ready-mixed or site-batched durable concrete.

Concrete made with GGBS cement sets more slowly than concrete made with ordinary Portland cement, depending on the amount of GGBS in the cementitious material, but also continues to gain strength over a longer period in production conditions. This results in lower heat of hydration and lower temperature rises, and makes avoiding cold joints easier, but may also affect construction schedules where quick setting is required.

Uses Of GGBS

The major use of GGBS is in ready mixed concrete, and it is utilised in a third of all UK [2] „ready-mix‟ deliveries. Specifiers are well aware of the technical benefits, which GGBS imparts to concrete, including:

- ✓ Better workability, making placing and compaction easier.
- ✓ Lower early age temperature rise, reducing the risk of thermal cracking in large pours.
- ✓ Elimination of the risk of damaging internal reactions such as ASR
- ✓ High resistance to chloride ingress, reducing the risk of reinforcement corrosion
- ✓ High resistance to attack by sulphate and other chemicals
- ✓ Considerable sustainability benefits.

In the production of ready mixed concrete, GGBS replaces a substantial portion of the normal Portland cement concrete, generally about 50 %, but sometimes up to 70%. The higher the portion, the better is the durability. The disadvantage of the higher replacement level is that early age strength development is somewhat slower. GGBS is also used in other forms of concrete, including site-batched and precast. Unfortunately, it is not available for smaller-scale concrete production because it can only be economically supplied in bulk. GGBS is not only used in concrete and other applications include the in-situ stabilisation of soil.

GGBS is used as a direct replacement for Portland cement, on a one-to-one basis by weight. Replacement levels for GGBS vary from 30% to up to 85%. Typically 40 to 50% is used in most instances.
For on the ground concrete structures with higher early-age strength requirement, the replacement ratio would usually be 20 to 30%. For underground concrete structures with average strength requirement, the replacement ratio would usually be 30 to 50%. For mass concrete or concrete structures with strict temperature rise requirement, the replacement ratio would usually be 50 to 65%. For the special concrete structures with higher requirement on durability i.e, corrosion resistance for marine structures, sewarage treatment plants etc,. the replacement ratio would usually be 50 to 70%.

IV. GGBS Concrete

GGBS Proportions

In order to make concrete, activated ground granulated blast furnace slag (GGBS) must be mixed with Portland cement since it hardens at a very slow rate when used alone. While 50% GGBS and 50% Portland cement is the standard ratio, GGBS ratios ranging from 20% to 80% are often used. The impact on concrete characteristics is proportional to the percentage of GGBS.

Setting Time

The setting time of concrete is influenced by many factors, in particular temperature and water/cement ratio. With GGBS, the setting time will be extended slightly, perhaps by about 30 minutes. The effect will be more pronounced at high levels of GGBS and/or low temperatures. An extended setting time is advantageous in that the concrete will remain workable longer and there will be less risk of cold joints. This is particularly useful in warm weather.

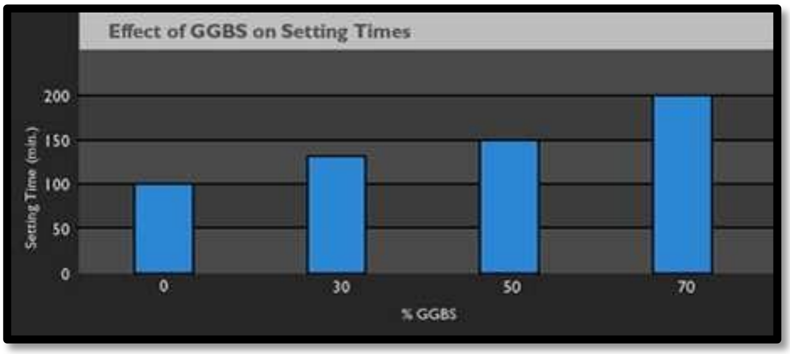


Fig 2: Effect of GGBS on Setting times.

Water Demand

The differences in rheological behaviour between GGBS and Portland cement may enable a small reduction in water content to achieve equivalent consistence class.

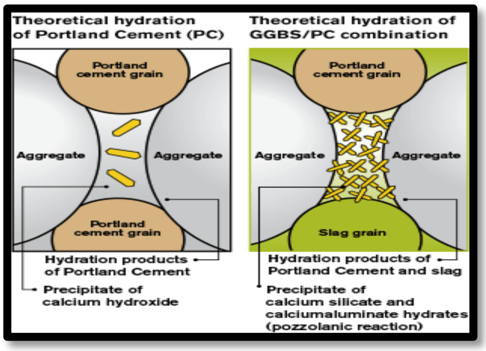


Fig 3: Hydration of GGBS

Consistency (SLUMP)

While concretes containing GGBS have a similar, or slightly improved consistence to equivalent Portland cement concrete, fresh concrete containing GGBS tends to require less energy for movement. This makes it easier to place and compact, especially when pumping or using mechanical vibration. In addition, it will retain its workability for longer.

Fig 4: Showing that workability is more and pumping will be easy.

Early Age Temperature Rise

The reduction involved in the setting and hardening of concrete generates significant heat and can produce large temperature rises, particularly in thick section pours. This can result in thermal cracking. Replacing Portland cement with GGBS reduces the temperature rise and helps to avoid early age thermal cracking. The greater the percentage of GGBS, the lower will be the rate at which heat is developed and the smaller the maximum temperature rise.

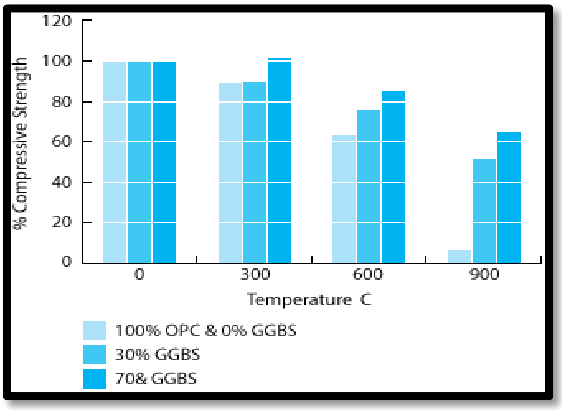


Fig 5: Strength variation to temperature.

Strength Gain In GGBS Concrete

Typically, when utilizing up to 50% GGBS, one may get 28-day strengths comparable to Portland cement with the same amount of cementitious material, which is the total weight of Portland cement plus GGBS. To attain the same 28-day strength at greater GGBS percentages, it may be necessary to increase the cementitious content. Compared to its Portland cement-based counterpart, GGBS concrete increases its strength at a more consistent rate. Early strength decline is most apparent at high GGBS levels and low temperatures, but overall, GGBS concrete has better long-term strength for the same 28-day strength. Between 28 and 90 days, a Portland cement concrete usually gains a minor increase of five to ten percent in strength, with seven days often achieving around 75 percent of that strength. In contrast, 50% GGBS concrete usually reaches 45–55 percent of its 28-day strength within seven days, and another 10–20 percent gains between 28 and 90 days. When done at 70% GGBS, the strength after seven days is usually around 40% to 50% of the strength after 28 days, and it keeps becoming stronger from 28 to 90 days, increasing by 15% to 30% each time. Concretes with up to 50% GGBS do not often have striking times that are too high to have a major impact on the construction schedule. On the other hand, at lower temperatures, with lower cementitious contents, and in thinner sections, concretes with greater amounts of GGBS may not always reach a strength after one day that permits the removal of vertical formwork.

Table 1: Showing the Compressive Strength values for different mixes

Mix	Strength (N/mm)				
Days	0	2	7	28	33
20% RG Powder/80% GGBS	0	0	2	39	42
40% RG Powder/60% GGBS	0	0	0	22	29
20% RG Cake/80% GGBS	0	0	3	38	43
30% RG Cake/80% GGBS	0	0	0	35	38
50% OPC/50% GGBS	0	15	28	55	-
100% OPC	0	31	46	59	-
90% GGBS/10% lime	0	0	2	12	-

Colour

Ground granulated blast furnace slag is off-white in colour and substantially lighter than Portland cement. This whiter colour is also seen in concrete made with GGBS, especially at addition rates of 50% and above. The more aesthetically pleasing appearance of GGBS concrete can help soften the visual impact of large structures such as bridges and retaining walls. For coloured concrete, the pigment requirements are often reduced with GGBS and the colours are brighter.

Fig 6: Colour of GGBS.

Sustainability

Ground granulated blast furnace slag „GGBS‟ is one of the „greenest‟ of construction materials. Its only raw material is a very specific slag that is a by product from the blast furnaces manufacturing iron. Manufacturing of „GGBS‟ utilises all of the slag and produces no significant waste.

As well as the environmental benefit of utilising a by product, „GGBS‟ replaces something that is produce by a highly energy intensive process. By comparison with Portland cement, manufacture of GGBS requires less than a fifth the energy and produces less than a fifteenth of the carbon dioxide emissions. Further „green‟ benefits are that manufacture of GGBS does not require the quarrying of virgin materials, and if the slag was not used as cement it might have to be disposed of to tip.

Each year, the UK uses up to two million tonnes of GGBS as cement, which:

- ✓ Reduces carbon dioxide emissions by some two million tonnes
- ✓ Reduces primary energy use by two thousand million Kwh
- ✓ Saves three million tonnes of quarrying
- ✓ Saves a potential landfill of two million tonnes

In 2010, the average emission by the membership of the CSMA to produce 1 tonne of GGBS was 67 kg CO2e. The apparent increase over the figure reported for 2007 is due to a widening of the boundaries and to the use of different conversation factors; the CO2e emissions for GGBS have not changed significantly since 2007.

V. Durability

Micro Structure

Concrete containing ground granulated blast furnace slag (GGBS) is less permeable and chemically more stable than normal concrete. This enhances its resistance to many forms of deleterious attack, in particular:

- ✓ Disintegration due to sulphate attack
- ✓ Chloride related corrosion of reinforcement
- ✓ Cracking caused by alkali silica reaction

Permeability And Chemical Stability

Compounds like GGBS, Portland cement, and water have complicated reactions. Hydration products, which are insoluble in water but do develop near cement particles when Portland cement interacts with it, are mostly calcium silica hydrates. Discrete crystals encircled by huge holes form when the more soluble byproduct of hydration, calcium hydroxide, migrates through the pore solution. Hydration of calcium silicate hydrates is a byproduct of the GGBS and Portland cement reactions when GGBS particles are present.

In addition, the bigger holes are filled with a finely distributed gel that is formed when the GGBS react with the excess calcium hydroxide. Cement paste that has solidified has fewer big capillary holes because there are less calcium hydroxide crystals in it. The chemical stability of concrete is improved by reducing free calcium hydroxide, and the diffusion of hostile chemicals is limited by the finer pore structure.

Corrosion Of Reinforcement By Chloride

Steel embedded in concrete is normally protected against corrosion by the alkalinity created inside concrete by hydrated cement. In such conditions, a passive layer forms on the surface of the steel and rusting is inhibited. However, if significant amounts of chloride are able to penetrate the concrete this protection can be destroyed and the embedded steel will rust and corrode. Because of its finer pore structure, GGBS concrete is substantially more resistant to chloride diffusion than Portland cement concrete. For reinforced concrete structures exposed to chlorides, the use of GGBS will give enhanced durability and a longer useful life. This applies in many situations, including highway structures (particularly bridge parapets), car parks subjected to de-icing salts and coastal environments. Generally the higher the proportion of GGBS, the greater will be the resistance to chloride penetration. Typically, use of 50% GGBS will give high resistance to chloride and use of 70% GGBS will give very high resistance.

Alkali-Silica Reaction (ASR) [5]

Portland cement contains sodium and potassium ions, which are alkali ions. When cement hydrates, it releases these substances into the concrete's pore solution; they're easily soluble in water. An alkali-silicate gel may be created by their gradual reaction with certain forms of aggregate silica. When exposed to moisture, this gel expands to the point that it presses on the concrete, cracking it. In some cases the resultant cracking is sufficient to endanger structural integrity. Severe effects may result from ASR, and there is currently no remedy for buildings that have been harmed. An effective way to minimize the possibility of harmful ASR is to add the right percentages of GGBS. Building Research Establishment Digest 330:2004, "Alkali Silica Reaction in concrete," provides detailed advice. BS8500:2006 no longer includes explicit ASR guidelines but instead makes reference to this summary. It is usually easy to meet the BRE digest criteria using GGBS. Incorporating GGBS usually makes it easy to meet the BRE digest standards, which restrict the reactive alkali level of the concrete. The GGBS is considered to not contribute to the reactive alkali content when the aggregates have normal reactivity and the fraction is at least 40%.

Addition To Concrete

In the UK [2], GGBS is normally supplied as a separate material and added at the concrete mixer. However, it can also be blended with Portland cement in a cement factory and marked as „Portland slag" or „Blast furnace" cement. The British Standard for Concrete [7] [BS 8500] allows either approach to be used. These alternative routes have little effect on the properties of the finished concrete and the savings in carbon dioxide emissions are broadly similar. Generally, adding the GGBS at the concrete mixer:

- ✓ Reduces transport burdens, because the addition can be delivered directly to the concrete plant without having to go via a cement factory.
- ✓ Provides more accurate proportions, because the materials are weigh-batched in a concrete plant

A major advantage of adding GGBS[5] at the concrete mixer, rather than at the cement factory, is the flexibility to vary the proportion and thereby optimise the technical performance of the concrete. The most widely used GGBS proportion is 50% but it is advantageous to be able to vary the proportion to meet specific requirements, e.g.

- ✓ 66 to 80% GGBS may be best for high sulphate resistance or for high resistance to chloride ingress.
- ✓ 50 to 70% GGBS may be best to reduce heat of hydration and control early-age cracking.

- ✓ 25 to 40% GGBS may be best to avoid extended finishing times for applications such as power-floated floors.
- ✓ 20 to 40% GGBS may be best to ensure high early strength.
- ✓ 80 to 95% GGBS may be best to achieve very low early-strength gain in applications such as secant piles.
- ✓ 30 to 45% GGBS may be best to avoid excessive retardation in cold weather.

Soil Stabilisation

Stabilisation of soil with cementitious binders is widely used in road, pavement and foundation construction, to improve the engineering properties of the soil, by:

- ✓ Increasing the strength and bearing capacity.
- ✓ Controlling the volume stability against swell-shrink caused by moisture changes.
- ✓ Increasing the resistance to erosion, weathering and traffic loading.

Stabilisation of the existing soil will normally be a much more sustainable solution than importing aggregate. Use of a lime + ggbs combination offers significant advantages for soil stabilisation. The major advantage is in inhibiting the deleterious swelling that can occur with clays containing sulphates.

Health & Safety

GGBS is a fine powder that may cause mechanical irritation to the eyes and respiratory system, if appropriate dust control measures are not implemented [7].

Manufacturers and suppliers of GGBS provide Safety information Sheets to enable appropriate risk management measures to be identified and applied.

VI. Conclusion

The movement of moisture of GGBS mixes, probably due to the dense and strong microstructure of the interfacial aggregate/binder transition zone are probably responsible for the high resistance of GGBS mixes to attack in aggressive environments such as silage pits. The mineral composition of GGBS cement paste (with less aluminates and portlandite than Portland cement) probably contributes to this resistance.

As we have seen GGBS is a good replacement to cement in some cases and serves effectively but it can‟t replace cement completely. But even though it replaces partially it gives very good results and a greener approach in construction and sustainable development which we are engineers are keen about today.

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