"Use of Blast Furnace Slag In Concrete – A Review"

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ABSTRACT

The Iron industries produce a emormous quantity of blast furnace slag (B.F.S) as by–product, which is a non–biodegradable waste material from that only a insignificant percentage of it is used by cement industries to manufacture cement. In this studyBlast Furnace Slag from industries has been utilised to find its suitability as a cement in concrete making. This topic also deals with the advantages and disadvantages of slag using in concrete. Replacing some portion of cement with slag would lead to moderately large environmental benefits.In this study it is observed that blast furnace slag could be used as alternative construction material.

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

I.INTRODUCTION

Concrete is prepared by mixing diverse constituents like cement, fine aggregate, coarse aggregates, water, etc. which are economically available. Concrete is a mixture of cement, sand, pebbles, crushed rock and water which bound together with cement and allow to cure become hard like a stone. Nearly three quarters of the volume of concrete is constitute of aggregates. To meet the global requirement of concrete in the future, it is becoming a challenging task to find suitable alternatives to cement for preparing concrete. The use of blast furnace slag aggregates in concrete by partially replacing cement is a most encouraging concept because its strength.

1.1. Slag- Manufacturing and Types

In the production of iron, iron ore, iron scrap, and fluxes (limestone and/or dolomite) are put into a blast furnace onward with coke as fuel. The coke is combusted to drawout carbon monoxide, which reduces the iron ore to a molten iron product. When the blast furnace is tapped to discharge the molten iron, it flows from the furnace with molten slag floating on its upper surface. These two materials are isolated using a weir, the molten iron being channelled to a holding duct and the molten slag to a point where it into be treated moreover. The final form of the blast furnace slag is dependent on the method of cooling and can be drawout in the following forms:

1.1.1.Air-Cooled Blast Furnace Slag : If the liquid slag is poured into beds and slowly cooled under surroundig conditions, a crystalline structure is formed, and a hard, lump slag is produced, which can succeeding be crushed and screened.

1.1.2.Granulated Blast Furnace Slag:If the molten slag is cooled and solidified by rapid water quenching to a glassy state, little or no crystallization occurs. This process results in the formation of sand size (or frit-like) fragments, usually with some friable clinker like material. When crushed or milled to very fine cement-sized particles, ground granulated blast furnace slag (GGBFS) has cementitious properties, which make a suitable partial replacement for or additive to Portland cement.

II.BLAST FURNACE SLAG CHEMICAL COMPOSITION

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.[1]

Typical physical properties:-

Colour : off white

Specific gravity : 2.9

Bulk density : 1200kg/m³

Fineness : 350m²/kg

CHEMICAL COMPOSITION	BLAST FURNACE SLAG
CaO	30-50%
SiO_2	28-38%
Al_2O_3	8-24%
MgO	1-18%

III.APPLICATION AND USES OF BLAST FURNACE SLAG

Blast furnace slag (BFS) have a long history of use as industrial by-products, going back almost 100 years in the United States and 150 years in Europe. Ground granulated blast furnace slag (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 granulated blast furnace slag (GBS). In the second half of the 19th century, its cementitious properties were discovered, and by the end of 19th century, the first cements containing GBS were produced. Since the late 1950s, the use of GGBS as a separately ground material added at the concrete mixer together with Portland cement has gained acceptance. In some countries, the term ‘slag cement’ is used for pure GGBS.

BFS have unique physical and chemical properties that make them particularly well suited to a variety of uses in construction and civil engineering projects. The properties of iron and steel slags can vary greatly, depending on the processing done once the slag is removed from the furnace.

Air-cooled BFS produces a durable aggregate that performs well in unbound applications as well as in Portland cement and asphalt concretes. Cooling the slag with water produces a lightweight aggregate for use in masonry blocks and lightweight concrete.

Granulated BFS can be ground and used to make slag cement. Compared to regular Portland cement, slag cement provides reduced heat of hydration and improved resistance to sulphate attack and alkali-silica reaction. It is also resistant to chloride penetration, sulphate and thaumasite sulphate attack. It has low risk of thermal cracking and a high electrolytic resistance.

The main applications of BFS

BFS (air-cooled):

- Uncrushed: fill and embankments (particularly areas subject to severe loading, such as mainline rail systems), working platforms on difficult sites pavements, where binding fines are produced by rolling to break the slag down to fill the voids
- Graded road base: on its own or blended with other slags and/or with other natural rocks and sands
- Crushed and graded: for concrete aggregates, concrete sand, glass insulation wool, filter medium, and use under concrete slabs as a platform

BFS (granulated BFS):

- Cement: the principal use is as cement replacement (when ground, GGBS), replacing 30–50% of Portland Cement in 'normal' concrete, but can replace up to 70% in specialist applications such as marine concrete. GGBS is probably the most applicable product in the cement industry. For slag cement production, GBS can be ground separately or together with Portland cement clinker and calcium sulphate. Usually, GGBS is ground to a fineness exceeding that of ordinary Portland cement to obtain an increased early strength.
- 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.
- Fill material: because of its sand-like texture, it is easy to work. Its self cementing properties cause it to set up over time.

- Other uses include glass making, concrete block manufacture, sporting field sub-base (for drainage), filtration medium, reinforced earth embankments, and mine backfilling and grit-blasting medium requiring fine etching.

Advantages of BFS

It is found that working with GGBFS is easy as it has greater mobility characteristics. This is due to its fineness and the particle shape of the GGBFS particles. These also possess a lower relative density.[2]

- The color is more even and light.
- Lower early age temperature rise, reducing the risk of thermal cracking in large pours.
- Increases the strength and durability of the concrete.
- The alkali-silica reaction is resisted highly.
- Lower chances of efflorescence.
- These make the concrete more chemically stable.
- Gives good surface finish and improves aesthetics.
- Considerable sustainability benefits.

Disadvantage of BFS

In the production of ready mixed concrete(RMC), GGBS replaces a considerable portion of the Portland cement concrete, generally about 45 % 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.

IV.GGBFS CONCRETE

4.1. GGBS Proportions

In the concrete manufacturing plant, the GGBFS can be added along with the Portland cement, water and aggregates. The normal ratio of the mixture remains the same. The studies show that the GGBFS can be replaced from 30 to 85 % of the cement weight. Most of the instances we replace 40 to 50%.

4.2 Setting Time

More the GGBFS amount, more will be the time taken for its setting. But the strength is gained with time. This slow setting would help in the formation of cold joints. But the situations where faster setting time is required, cannot go for this replacement.The GGBS composition stays plastic for a longer period that would help in making a smoother finish.The GGBFS have lesser demand for water and there is a chance of an increase in the setting time of the concrete. When the replacement amount of cement by GGBFS increases, the setting time also increases.[3]

A study conducted by Hoganet. Al showed that for 40%, 50% and 60% replacement of the GGBFS amount would almost increase one hour more than the setting time of OPC (For both initial and final setting time).

4.3Strength Gain In GGBS Concrete

Slag concrete compressive strength is mainly based on number of factors for instance slag type, finesses, activity index, and the amount employed in concrete mixtures in addition to other factors for example cement type and water to cementitious material ratio.[4]

By and large, compressive strength of slag concrete gradually increases from 1-5 days and lower than that of concrete without slag, but slag concrete strength matches strength of controlled concrete from 7-28 days. Moreover, slag concrete compressive strength surpasses strength of concrete with zero slag after 28 days.

By comparison, a 50 % GGBS concrete will achieve about 45 to 55 % of its 28 day strength at seven days, with a gain of between 10 and 20 % from 28 to 90 days. At 70 % GGBS, the seven day strength would be typically around 40 to 50 % of the 28 day strength, with a continued strength gain of 15 to 30 % from 28 to 90 days.

4.4. Water demand

The GGBFS as a replacement has lesser water demand because of their glassy texture. The glassy surface of GGBFS particles does not absorb water onto its surface.

Inadequate curing of concrete substantially affects degree and rate of hydration and consequently formation of strength-production hydration will be slow. The detrimental consequences of insufficient curing are more profound and outstanding in concrete incorporated with high percentage of slag.Therefore, to avoid uncertainty in the strength and durability, concrete incorporating more than 30% slag is cured for longer period compare with concrete with no slag.

Finally, the extension of slag concrete curing time is based on number of factors including ambient temperature, amount and types of cement, the temperature of utilized cement, and percentage of cement replacement.

4.5. Consistency (SLUMP*)*

The GGBFS particles have a very glassy texture that makes them increase the workability. This can help in reduction of water as well as Superplasticizers to get adequate workability in common situations.They also have fewer chances to get segregated during handling as well as pumping of the material. Pumping is facilitated by the lower relative density and flowing ability of the mix, that is owned by GGBFS.

While concretes containing GGBFS 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.

4.6. Early Age Temperature Rise

After the placing of concrete, their is thermal cracking due to the reduction in the setting and hardeningof concrete.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.

4.7. Colour

Due to light colour of blast furnace slag, colour of slag concrete is lighter in comparison with conventional concrete. Moreover, deep blue-green colour shown by interior part of slag concrete and can be noticed from slag concrete broken parts. This colour would be lost after adequate exposure to air. The degree of the colour is based on curing condition, percentage of blast furnace slag employed, and oxidation degree

4.8. Sustainability

Ground granulated blast furnace slag is one of greenest of construction material. Manufacturing of GGBFS utilises all of the slag and produces no substantial amount of waste. In comparison to PPC, manufacturing of GGBFC requires less than 1\5 energy and produces less than 1\15 of the carbon dioxide emissions.

- Unlike cement, GGBFS does not produce carbon dioxide, sulphur dioxide or nitrogen oxides.
- Use of GGBFS reduces primary energy use by thousand of million Kwh.
- Save million of tones of quarrying.
- Saves a potential landfill of million of tonnes.
- The maintenance and repair cost of structures are reduced thus increasing the life cycle of concrete structures.

V.DURABILITY

5.1. Microstructure

Studies have shown that GGBS help in decreasing the pores within the concrete thus making the concrete denser. The hydration reaction of GGBS gains two reactions. The first reaction involves the activation of GGBS particles to make them prepare for hydration. This is done by the alkali environment of calcium hydroxide ($Ca(OH)_2$) created by the primary reaction of cement with water.[5]

This alkali environment facilitates the formation of hydration product by the pozzolanic reaction carried out by the GGBS and the alkali. This gives C-S-H gel in the paste initially. This rate of formation is slow down and strength development is carried out with time. The hydration product C-S-H makes the concrete mass denser.

More the GGBS replacement, more the C-S-H formation, hence denser the concrete. Denser concrete help in denser microstructure and lower porosity. Low porosity is a factor that has resistance to water penetration, thus conveying a guaranty on the durability of the concrete.

Compared with the hydration products of Ordinary Portland Cement(OPC), there is the difference in the rate of products produced in GGBFS concrete. The hydration products $Ca(OH)_2$ due to the primary reaction will activate the slag reaction to form a low amount of CaO / SiO2 ratio or C/S ratio. This also reduces the AF products (Products formed by the hydration of alumina and calcium hydroxide in the cementitious products) also.

It is found that the pozzolanic activity increases the C/S ratio, because of the unstable C-S-H and the $Ca(OH)_2$. The use of GGBFS not only reduces the porosity but also change the pores to be finer nature. This will help in change the mineralogy of the hydration of cement. This promotes the reduction of chloride ion penetration.

5.2. Chloride Resistance of Concrete with GGBFS

A study conducted by Dhir et al. (1996) showed that the chloride resistance of ordinary portland cement concrete in increased with the addition of ground granulated blast furnace slag.

The study was conducted by testing the chloride binding capacity of OPC concrete and replacement samples with GGBS in 33.3, 50,60 percentages. The test was carried out by not varying the water cement ratio at 0.55.

The results were:

- The chloride binding capacity of concrete increase with increase in GGBS content
- A higher replacement above 50 % showed 5 times greater chloride binding capacity
- If the chloride exposure increases, the binding capacity also increase. Letting it know that they are proportional to each other.

The chloride resistance can also be measured by means of determining the strength and the permeability of the concrete. The permeability of concrete with GGBS is observed lesser compared to OPC concrete. This would help in resisting the movement of chloride ions and chloride attack is resisted.

5.3. Sulphate Resistance of Concrete with GGBFS

The sulphate attack is an undesirable factor to which most of the hardened concrete are subjected to. It results in deterioration of the respective concrete structure. Now how extend the sulphate attack persists depend upon the time of sulphate ion and the cement type.

The sulphate attack can be spread through different ion concentration of the clayey soil to which the concrete is in contact with. Clayey soils mostly consist of salts which are either in the form of magnesium or calcium sulphates. These salts have a possibility to react with the calcium hydroxide ions or the calcium aluminate hydrate (C_3A) that is present in the concrete.

The products formed in the reaction are calcium sulphoaluminate and gypsum which occupies a larger volume than their parent compounds. This inadequacy in space results in expansion and with temperature changes, contraction also takes place. This is the root cause of the disruption.

Now all these are only possible if the sulphate ions are allowed to penetrate into the concrete. Here comes the role of GGBS that they give a concrete highly impermeable, thus limiting the impact of sulphate.

It is seen that higher the replacement amount of GGBS lesser is the expansion.

The figure-1 below shows expansion rate of concrete for 0,25,35 and 50% of cement by GGBS. It is seen that higher the replacement amount of GGBS lesser is the expansion.

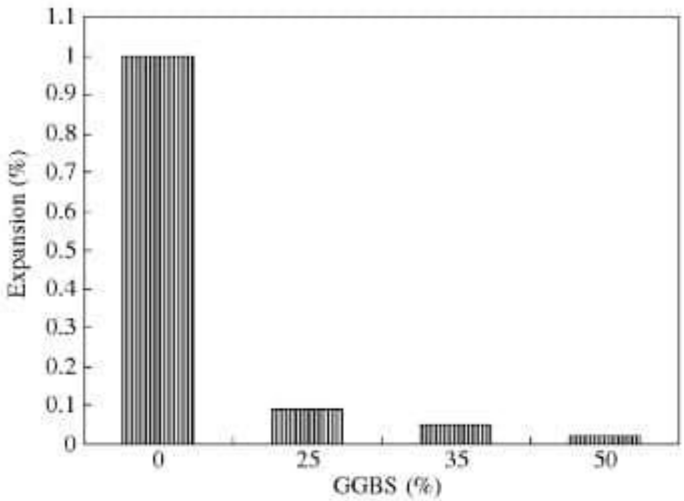

Fig.-1: Expansion Rate of Concrete with GGBFS

5.4. Freezing and Thawing of Concrete with GGBFS

The variation of concrete properties with the change in temperatures is an important factor questioning the durability of the structure. Both freezing and thawing are primarily caused due to the entrainment of water with the concrete.

This water behaves differently for cold and hot temperatures. This behaviour is freezing and thawing. This increase and a decrease of volume with the concrete creates small cracks which later propagates to larger ones.

This rapid deterioration of concrete is highly resisted by good quality concrete mix. The GGBS incorporated concrete gives a good quality concrete. The GGBS particles help in reducing the porosity which is core reason of water entrainment. This itself give an entirely different mineralogy for the concrete.

5.5. Corrosion of Reinforcement in Concrete with GGBFS

Studies have shown that there are a great relation and dependence between the porosity and the corrosion activity of a concrete. The exposure of concrete with sea water have chances of chloride ion penetration that in turn results in the corrosion of reinforcement.

The replacement of GGBS with silica fume with the concrete conventional mix have proved better performance that OPC concrete under corrosion resistance

VI.CONCLUSION

Based on the investigations, the following conclusions were drawn.

- The utilisation of blast furnace slag in concrete provides additional environmental as well as technical benefits for all related industries. Partial replacement of GGBFS in fine aggregate and cement reduces the cost of making concrete.
- The initial and final setting time of GGBFS admixed concrete is higher than control concrete.
- Utilisation of GGBFS as Portland cement replacement in concrete and as a cement raw material has the dual benefit of eliminating the costs of disposal and lowering the cost of the concrete.

- It was observed that, the BFS replacement for sand is more effective than cement.
- we have seen that the GGBS is a excellent replacement to cement in some cases it serves effectively but it can't replace cement completely. But even though it replaces partially it gives convenient results and a greener approach in construction and sustainable development which we are engineers are keen about today.

REFERENCES

[1.] https://en.wikipedia.org/wiki/Ground_granulated_blast-furnace_slag

[2.] https://theconstructor.org/concrete/ggbfs-concrete-advantages/15274/

[3.] https://theconstructor.org/concrete/slag-concrete-properties/15338/

[4.] https://theconstructor.org/concrete/slag-concrete-properties/15338/

[5.] https://theconstructor.org/concrete/durability-concrete-ggbs/15583/