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A Review on Ground Granulated Blast-Furnace Slag as a Cement replacing material

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Abstract - *Mixture of cement, fine aggregate, coarse aggregate and water is known as concrete. Concrete plays a very important role in the development of infrastructure i.e., buildings, bridges and highways etc. Ordinary Portland cement The main ingredients used for the production of concrete is Ordinary Portland cement . Unfortunately, a large amounts of carbon-dioxide gas emit into the atmosphere during the production of cement, which has a major contributor for green house effect and global warming. Hence, it is required either to search any other material or partially alternative of it. Ground Granulated Blast Furnace Slag is a by-product from the blast-furnace of iron and it is very beneficial in the concrete production. The present paper reviews the literature related to the utilization and efficiency of GGBFS which effect the properties of concrete. Number of properties of partially replaced GGBFS concrete were studied with the help of previous journals which include the properties like compressive strength, split tensile strength, flexural strength, workability, electrical conductivity, resistance against chloride and sulphate attack. The study revealed the performance and applications of GGBFS concrete in the construction world. Hence, GGBFS concrete can be used as a building material as well as reduce the dumping of GGBFS in environment.*

Key Words: *Ground granulated blast furnace slag, workability, compressive strength, tensile strength, flexural strength, conductivity, sulphate and chloride resistance*

1. INTRODUCTION

The most extensively used construction material in the world is probably Concrete with about six billion tones being produced every year. In terms of per capita consumption it is only next to water. The most massive individual material element in the built environment is concrete . Significant environmental and economic benefits may be realized if the embodied energy of concrete can be reduced without decreasing the performance or increasing the cost. Concrete is primarily comprised of Portland cement, aggregates, and water. Although Portland cement typically comprises only 12% of the concrete mass, still it accounts for approximately 93% of the total embodied energy of concrete and 6% to 7% of the worldwide emissions of CO_2. Some remedial measures can be taken to minimize some bitter properties of concrete.

The Ground Granulated Blast Furnace Slag is a by-product of iron manufacturing industry. Iron ore, coke and limestone are fed into the furnace and molten slag floats above the molten iron at a temperature of about 1500_0C to 1600_0C as a resultant. The composition of molten slag about 30% to 40% SiO_2 and about 40% CaO, which is almost equal to the chemical composition of Portland cement. The molten slag, is water-quenched rapidly, after the molten iron is trapped off which results in the formation of a glassy granulate. The molten slag consists of mainly siliceous and aluminous residue. This glassy granulate is dried and ground to the required size, which is known as Ground Granulated Blast Furnace Slag (GGBFS).

The production of GGBFS requires more energy as compared with the energy needed for the production of Portland cement. By replacing the Portland cement with GGBFS will results in reduction of carbon dioxide gas emission. It is therefore an environmentally friendly construction material. GGBFS from modern thermal power plants generally does not require processing prior to being incorporated into concrete and is therefore considered to be an environmentally free input material. We can replace about 80% of the Portland cement by using GGBFS in concrete. GGBFS has characteristics of better water impermeability as well as improved resistance to corrosion and sulphate attack. Due to lower heat hydration it reduces the risk of thermal cracking. It has higher durability, workability, reduces permeability to external agencies, which helps in making, placing and compaction easier. As a result, the service life of a structure is enhanced and the maintenance cost reduced.

2. LITERATURE REVIEW

Wang Ling et al. (2004)[1] Analyzed the performance and the effect of GGBS on fresh concrete and hardened concrete. The strength of GGBS concrete is high and heat of hydration is low and it is resistance to chemical corrosion.

Shariq et al.(2008)[2] studied the effect of curing procedure on the cement mortar and concrete incorporating ground granulated blast furnace slag compressive strength development. The compressive strength development of cement mortar is calculated by the 20, 40 and 60 percent replacement of GGBFS for different types of sand. Similarly the strength development of concrete is investigated with 20, 40 and 60 percent replacement of GGBFS on two grades of concrete. Tests results show that the incorporating 20% and 40% GGBFS is highly significant to increase the compressive strength of mortar after 28 days and 150 days, respectively.

Md. Moinul Islam et. al.[3] discussed the results of partial replacement of cement using slag in various percentages (10% – 70%). He tested various properties of concrete and found that the compressive strength and tensile strength of mortar mixes with slag when determined at the ages of 3, 7, 14, 28, 60, 90 and 180 days decreases at early ages of curing (3 and 7 days). However, the rate of decrease diminishes with the increasing age of curing. 40% of cement replacement is the optimum use of slag in the mortar because it has 19% compressive strength and 25% tensile strength when compared to OPC mortar. He concluded that the use of slag reduces the amount of cement content in a motar mix as well as heat of hydration which results in lower risk of thermal cracking. Thus the use of slag concrete in construction becomes economical and also environmentally safe.

Chao-Lung Hwang and Chao-Yin Lin [4] replaced cement with BFS in various percentages (0 – 80%) with three different w/c ratios (0.35, 0.47 and 0.59) in his research and found that the use of slag reduces the strength of mortar at early age (3 days) but it enhance after 7 days. It was also found out that when the specimens demoulded at the age of one day had significantly less strength as compared with those demoulded at one and half days. Three different temperatures were used during curing and specimens cured under 50_0C have the best results. He also concluded that the bleeding of the mortar will also reduced when the mortar is mixed with slag. The pores tend to become smaller when slag is used in the mix. This may increases the durability of the cement mortar when it is exposed to adverse environment.

Peter et al. (2010)[5] studied the BS 15167-1 which requires that the minimum specific surface area of GGBS shall be 2750 cm2/g (BS 15167-1:2006). GGBS is classified into three grades in China ; S75, S95 and S105. Minimum 3000 cm2/g surface area is required for the GB/T18046 for grade S75 GGBS, 4000 cm2/g for grade S95 and 5000 cm2/g for grade S105, which are higher than the BS EN's requirements (GB/T18046-2008). Slag with a specific surface area between 4000 cm2/g and 6000 cm2/g would significantly improve the performance of GGBS concretes.

Veena G. Pathan et. al.[6] investigated on partial replacement of cement with GGBFS which is obtained from Bhilai and Rourkela steel plants. In her research she noticed that the fineness of slag sample was high so it was grounded further to match the fineness of the cement sample. Cement consistency was also higher at 28% of the weight of sample taken in comparison to 26% of the weight of slag sample taken. The initial setting time of slag sample was lower than the cement sample and the final setting time was much higher than the cement sample. Cement sample had lower higher specific gravity than Slag sample. She also concluded that by increasing the percentage of GGBFS the workability of both M20 and M25 grade of concrete will increased. Compressive strength test was conducted on test specimens of M20 and M25 grade of concrete at 3, 7 and 28 days with replacements varying from 30 – 50 %. At 40% and 45% cement replacements Compressive strength of both grade of concretes of both plants increased. There are basically three strength grades (80, 100 and 120) of GGBFS.TH all strength grades are determined by their respective mortar strength when they are mixed with equal mass of OPC. She found that only 100 and 120 grade GGBFS results in greater compressive strength and hence should be used. Slag replaced concrete is not a very good conductor of electricity also concluded by her .

Atul Dubey et. al. [7] examined the effects on compressive strength of concrete by partial replacing of cement with 5 to 30 % of BFS. The test was conducted on cubes made of standard size of 150 mm x 150 mm x 150 mm at 7, 14 and 28 days. He concluded that the strength of concrete decreases as the percentage of BFS increase. The depreciation in 28 days compressive strength is being near about only 5 % on replacement of OPC with 15% blast furnace slag powder.

A. Oner and S. Akyuz [8] conducted a study in which he replaced cement by weight partially with GGBS in various percentages from 15% - 110%. Compressive strength test was conducted on test specimens which cured at 7, 14, 28, 63, 119, 180 and 365 days and it was found that early age strength values of GGBS concrete mix are lower than the strength after more passing days. This is because of the strength gain which takes longer time for the GGBS concrete because the pozzolanic reaction is slow and depends on the calcium hydroxide availability. It was also observed that as the percentage of GGBS is increased, the strength gain increases. The optimum level of GGBS content is 55% – 59% for maximizing strength. He also found out that the GGBS has positive effects on the workability as the GGBS content increases, the water/binder ratio decreases for the same workability.

Sabeer Alavi.C et. al. [9] studied the effects of partial replacement of cement with 10 - 50% of GGBFS and found that 30% GGBFS replacement is good as beyond that the compressive strength starts decreasing. He also concluded that the split tensile strength and flexural strength conducted at 7 and 28 days increases with increase in GGBFS content. It was also found that the workability increases with the increase in percentage of GGBFS.

Santosh Kumar Karri et. al. [10] researched by using 30%, 40% and 50% as cement replacement levels and cured the specimens of M20 and M40 grade of concrete for 28 and 90 days. He tested various properties of concrete and found that the compressive strength and tensile strength of mortar mixes with slag when determined at the ages of 7, 14, 28 and days decreases at early ages of curing (3 and 7 days). The specimens showed increase in compressive strength when tested at 7 and 28 days, for 20% replacement of cement. Concrete cubes were also exposed to H_2SO_4 and HCl of 1% and 5% concentration and were tested for compressive strength at 90 days and 28 days respectively.

Thejaskumar HM and Dr V. Ramesh [11] studied the effects of partial replacement of cement with BFS on various properties of concrete. Compressive strength of concrete mixtures that were kept in water, 10% HCl and 15% H_2SO_4 solutions were determined at the ages of 7, 28 and 56 days with cement replacement ranging between 40 – 60%. It showed that as the ages goes up, the compressive strength, split tensile strength and flexural strength soars up but it decreases with the increase in percentage of BFS. However, replacement up to 55% does not affect the strength negatively. After 56 days the samples having 53% of BFS, didn't face a decrease in resistance, gained more compressive resistance in the solution of HCl and H_2SO_4.

Magandeep et. al. [12] in there paper observed that when replacement of GGBFS increases from 10 to 40 %, the slump values of various mix proportions of GGBFS concretes increased. Compressive strength and flexural strength decreases with increase in percentage of GGBFS at the age of 7 and 28 days but it increases with the increase in percentage of GGBFS at the age of 56 days. He also observed that the split tensile strength of the mix with 20% and 30% cement replacement better performed than at age of 56 days where as the mix with 40% cement replacement showed a decrease in strength at 56 days. The sulfate resistance and chloride resistance increased in the specimens with 30% GGBFS content than the specimens without GGBFS. This is because of the strength gain which takes longer time for the GGBS concrete because the pozzolanic reaction is slow and depends on the calcium hydroxide availability.

T. Vijaya Gowri et. al. [13] investigated the effects on compressive strength, split tensile strength and flexural strength of concrete at 28, 90, 180 and 360 days by partial replacement of cement with GGBFS on .He used 50% GGBFS as replacement material of cement an also used various water/binder ratios i.e. 0.55, 0.50, 0.45, 0.40, 0.36, 0.32, 0.30 and 0.27. He observed that the strength gain by replacement of slag is inversely proportional to the water/ binder ratio and slag concrete gains appreciable amount of strength at later ages (90 days onwards). He found out that the strength of high volume of slag concrete is more at later ages because rate of hydration of slag with $Ca(OH)_2$ and water is slow. He concluded that on replacement of cement by 50% GGBFS helps to reduce the cement content of concrete, thereby reducing the cost of concrete and also protecting the environment from pollution.

M. Ramalekshmi et. al. [14] discussed the results of partial replacement of cement using slag in various percentages (50% – 80%). He tested various properties of concrete and found that the compressive strength and tensile strength of mortar mixes with slag when determined at the ages of 7, 14, 28 and days decreases at early ages of curing (3 and 7 days). She concluded that slag replacement decreases the strength of concrete in short term when compared to control OPC. However, in long term it exhibits greater final strength. Thus 50% GGBFS as replacement showed maximum compressive strength at 28 days. Experiments were also conducted on beam-column with and without GGBFS with 50% replacement. The specimen were tested at 28 days under constant axial load and varying lateral load which showed increase in load carrying capacity of the specimen by 6.6 %. Thus 50% GGBFS as replacement can be used in RC specimens.

S. Arivalagan [15] investigated the effects of partially replacing cement with 20% , 30% and 40% GGBS at different ages on strength and strength efficiency factors of hardened concrete. The specimens showed increase in compressive strength when tested at 7 and 28 days, for 20% replacement of cement. Split tensile strength and flexural strength of concrete also increased at 20% cement replacement.

Reshma Rughooputh and Jaylina Rana [16] studied the effects on various properties of concrete including compressive strength, tensile strength, splitting strength, flexure strength, modulus of elasticity, drying shrinkage and initial surface absorption by partial replacement of OPC by GGBFS on. The tests were conducted with replacement ranging from 30 % to 50 % at 7and 28 days. It was found that compressive strength is lower at the early age but increase after the later age time . Flexural strength of test specimens increased by 22% and 24%, tensile strength increased by 12% and 17% for 30% and 50% replacement respectively. Drying shrinkage increased by 3% and 4%. Static modulus of elasticity increases by 5% and 13%. Based on the results the optimum mix was the one with 50% GGBFS.

Yogendra O. Patil et. al. [17] researched on the effects on compressive strength and flexural strength of concrete when cement is partially replaced with various percentages of GGBS. The tests were conducted with replacement ranging from 10 % to 40 % at 7, 28 and 90 days. It was observed that the strength of concrete is inversely proportional to the percentage of replacement of cement with GGBS. The result shows the marginal reduction of 4 – 6 % in compressive and flexural strength for 90 days curing with replacement of OPC by GGBS up to 20% and beyond that of more that 15%. He concluded that, the cost of concrete reduces at the current market rate by 14% by 20% replacement of OPC with GGBS.

3. HISTORY OF USING GGBS IN CONCRETE

There are many worldwide examples of using the GGBS concrete in the construction; following are some examples where the GGBS concrete were used.

1. World Trade Centre in New York city with about 40% replacements.

2. Airfield Pavement of Minneapolis Airport with about 35 % replacement.

3. World's one of the largest aquarium- Atlanta,s Georgia Aquarium with about (20% to 70% replacements).

4. Detroit Metro Terminal Expansion with about 30% Replacement.

5. The Air Train linking New York's John Kennedy International Airport with Long Island Rail Road Trains with about 20%-30% replacements.

6. Tsing Ma Bridg in Hong Kong city with about 59%-65% replacement.

Above examples shows that the world is aware of the advantages of GGBS replacement in concrete. The main aims of the replacement of GGBS are:

- To improve the durability
- Reduce the maintenance cost
- To increase the service life
- Increase the economy of the construction with using the cheaper material as a replacement of the cement
- Reduce the cement consumption.

Today it is necessary to reduce the carbon footprints from the atmosphere as it affects the environment and ultimately affects the life on the planet and around 5% CO2 equivalent is produced from the cement industry.

It is necessary to find some alternative material instead of the cement which has cementitious because of the large consumption of natural resources and formation of large amount of CO2 as in production of one ton of cement it consumes about 5000MJ of energy, 1.5 tonnes of mineral extraction, and produces 0.95 tonnes of CO2 equivalent.

4. CHEMICAL COMPOSITION OF GGBS

Depending on the composition of the raw materials in the iron production process, the chemical composition of a slag varies considerably. Silicate and aluminates 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 content of slag's suitable for blending with Portland cement typically varies between 90-100% and depends on the cooling method and the temperature at which cooling is initiated. The glass structure of the quenched glass largely depends on the proportions of network-forming elements such as si and Al over network-modifiers such as Ca, Mg and to a lesser extent Al. Increased amounts of network-modifiers lead to higher degrees of network DE polymerization and reactivity. It is a granular product with very limited crystal formation, is highly cementitious in nature and, ground to cement fineness, and hydrates like Portland cement.

Typical physical properties:-

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

5. BENIFITS OF USING GGBS IN CONCRETE

Sustainability

As GGBS is a by-product of iron manufacturing industry, it is reported that the production of one tonne of GGBS would consume only about 1300 MJ of energy which is lesser than the 5000MJ of energy which is required for the manufacture of one tonne of Portland cement.

Manufacturing of Portland cement would require approximately 1.5 tonnes of mineral extractions and would generate 0.95 ton of CO2 equivalent. On The other hand GGBS would generate only about 0.07 ton of CO2 equivalent.

Colour

Ground granulated blast furnace slag is off-white in colour. If the replacement is greater than 50% this whiter colour is also seen in concrete made with GGBS, The more aesthetically pleasing appearance of GGBS concrete can help soften the visual impact of large structures such as bridges and retaining walls. For colored concrete, the pigment requirements are often reduced with GGBS and the colors are brighter.

5. CONCLUSIONS

Some salient conclusions based on the studies of different researchers on partial replacement of cement with GGBFS, are as follows:-

1. Reuse of the slag as a by-product helps to reduce the pollution from environment as it reduced CO_2 emission and conserves natural resources.

2. In most of the cases, compressive strength decreases with the increase in percentage of GGBFS at early age but it increases with increase in percentage of GGBFS at later ages.

3. The GGBFS has positive effects on the workability , as the water/binder ratio decreases with the increase in GGBFS content increases, for the same workability.

4. In case of GGBFS concrete, risk of thermal cracking is reduced as heat of hydration is slower in case of GGBFS cement.

5. Split tensile strength and flexural strength also decreases with the increase in percentage of GGBFS at early age but it increases with increase in percentage of GGBFS at later ages.

6. It was also found that in some cases the increase in percentage of GGBFS resulted in lower strength.

7. The increase in strength is up to a certain limit of replacement, beyond which it starts decreasing and the later age strength increases due to slower reaction of GGBFS with $Ca(OH)_2$

8. Chloride and sulfate resistance of concrete also increased with the increase in the percentage of GGBFS.

9. When the specimens with GGBFS were tested under constant axial load and varying lateral load, it is found that load carrying capacity of concrete increases.

10. GGBFS fails the initial absorption confirming that the surfaces of their concrete mixes were practically impermeable.

11. The slag replaced concrete is not a very good conductor of electricity.

12. The price of GGBFS is about 25 - 50% less than that of OPC and hence on replacement of cement by GGBFS helps to reduce the cement content of concrete, thereby reducing the cost of construction.

13. With the increase in GGBFS replacement level ,workability of concrete increases.

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