Effect of Ground Granulated Blast Furnace Slag as Partial Cement Replacement on Strength and Durability of Concrete: A Review

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Abstract - *Ordinary Portland cement is one of the main ingredients used for the production of concrete. Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor for green house effect and global warming. Hence, it is inevitable either to search for another material or partially replace it by some other material. 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 on the properties of concrete. Various properties of partially replaced GGBFS concrete were studied with the help of a number of journals which include compressive strength, split tensile strength, flexural strength, workability, electrical conductivity, resistance against chloride and sulphate attack. The study revealed the properties, performance and applications of GGBFS concrete in the real world. Hence, GGBFS concrete can be used as a building material in an effective way and it is one of the ways to reduce the dumping of GGBFS in environment.*

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

1. INTRODUCTION

Concrete is typically the most massive individual material element in the built environment. If the embodied energy of concrete can be reduced without decreasing the performance or increasing the cost, significant environmental and economic benefits may be realized. Concrete is primarily comprised of Portland cement, aggregates, and water. Although Portland cement typically comprises only 12% of the concrete mass, it accounts for approximately 93% of the total embodied energy of concrete and 6% to 7% of the worldwide CO_2 emissions. Some remedial measures can be taken to minimize some bitter properties of concrete.

Waste is one of the main challenges to dispose and manage. It has become one of the major environmental, economical and social issues. Recycling is the most promising waste management process for disposal of materials like agricultural waste and Industrial by-products like blast furnace slag, fly ash, silica fume ,rise husk, phosphogypsum etc.

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 the resulting molten slag floats above the molten iron at a temperature of about 1500^{0}C to 1600^{0}C. The molten slag has a composition of about 30% to 40% SiO_2 and about 40% CaO, which is close to the chemical composition of Portland cement. After the molten iron is tapped off, the remaining molten slag, which consists of mainly siliceous and aluminous residue is then water-quenched rapidly, resulting in the formation of a glassy granulate. This glassy granulate is dried and ground to the required size, which is known as Ground Granulated Blast Furnace Slag (GGBFS).

The production of Ground Granulated Blast Furnace Slag requires little additional energy as compared with the energy needed for the production of Portland cement. The replacement of Portland cement with GGBFS will lead to significant 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. It can be used to replace as much as 80% of the Portland cement used in concrete. It has better water impermeability characteristics as well as improved resistance to corrosion and sulphate attack. It enhances lower heat of hydration which 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. In view of the potential advantages of using GGBFS, the Standing Committee on Concrete Technology (SCCT) endorsed in 2008 the proposal by the Public Works Central Laboratory (PWCL) to conduct a research study to investigate the strength development and durability of GGBFS concrete.

2. LITERATURE REVIEW

Santosh Kumar Karri et. al. [1] selected 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 found out that the workability of concrete increases with the increase in GGBS replacement level. He observed that the maximum compressive strength, split tensile strength and flexural strength is achieved at 40% cement replacement for both M20 and M40 grade concrete, beyond which the strength decreases slightly. 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. It was observed that the resistance power increases up to 40% replacement beyond which it decreases but the compressive strength values of acid affected concrete decreases on comparison with normal concrete. It was also seen that the compressive strength of GGBS concrete affected to HCL was greater than that of H_2SO_4.

Thejaskumar HM and Dr V. Ramesh [2] 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. [3] in there paper observed that the Slump values of various mix proportions of GGBFS concretes increased when replacement of GGBFS increases from 10 to 40 %. Compressive strength and flexural strength decreases as the percentage of GGBFS increases 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 control mix at 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.

T. Vijaya Gowri et. al. [4] investigated the effects of partial replacement of cement with GGBFS on compressive strength, split tensile strength and flexural strength of concrete at 28, 90, 180 and 360 days. He used 50% GGBFS as replacement material of cement for 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 High Volumes of slag concrete gains appreciable amount of strength at later ages (90 days onwards) and it increases with decrease in water/binder ratios. He found out that the strength of high volume of slag concrete is more at later ages because of slower hydration of slag with $Ca(OH)_2$ and water. 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. [5] discussed the results of partial replacement of cement with 50% - 80% of GGBFS on compressive strength of concrete at 7, 14 and 28 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 [6] investigated the strength and strength efficiency factors of hardened concrete, by partially replacing cement with 20% , 30% and 40% GGBS at different ages. The specimens when tested at 7 and 28 days, showed increase in compressive strength for 20% replacement of cement. Split tensile strength and flexural strength of concrete also increased at 20% cement replacement. The increasing strength is due to filler effect of GGBS. It was also found that the degree of workability of concrete was normal and it increased with the addition of GGBS.

Reshma Rughooputh and Jaylina Rana [7] studied the effects of partial replacement of OPC by GGBFS on various properties of concrete including compressive strength, tensile strength, splitting strength, flexure strength, modulus of elasticity, drying shrinkage and initial surface absorption. Cement was partially replaced by 30 % and 50 % of GGBFS by weight and test was performed at 7 and 28 days. It was found that GGBFS in concrete leads to lower early compressive strength gain but higher later compressive strength gain. 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%. She also observed that the initial surface absorption decreases as the GGBFS content increases because GGBFS decreases the permeability of concrete. Based on the results the optimum mix was the one with 50% GGBFS.

Yogendra O. Patil et. al. [8] researched on the effects on compressive strength and flexural strength of concrete with partial replacement of cement with various percentages of GGBS. The tests were conducted at 7, 28 and 90 days with replacement ranging from 10 % to 40 %. It was observed that the strength of concrete is inversely proportional to the percentage of replacement of cement with GGBS. The replacement of OPC by GGBS up to 20% shows the marginal reduction of 4 – 6 % in compressive and flexural strength for 90 days curing and beyond that of more that 15%. He concluded that, GGBS as replacement of OPC by 20% results in reduction in cost of concrete at the current market rate by 14%.

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.

Veena G. Pathan et. al. [10] investigated on partial replacement of cement with GGBFS obtained from two plants mainly Bhilai and Rourkela steel plant. She found 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 very low and the final setting time was much higher than the cement sample. Slag sample had lower specific gravity than cement sample. She also concluded that the workability of both M20 and M25 grade of concrete increased as the percentage of GGBFS increased. Compressive strength test was conducted at 3, 7 and 28 days on test specimens of M20 and M25 grade of concrete with replacements varying from 30 – 50 %. Compressive strength of both grade of concretes of both plants increased at 40% and 45% cement replacements. There are basically three strength grades (80, 100 and 120) of GGBFS which 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 should be used because it results in greater compressive strength. She also conducted the electrical conductivity test which resulted that the slag replaced concrete is not a very good conductor of electricity.

Atul Dubey et. al. [11] examined the effects of partial replacement of cement with 5 to 30 % of BFS on compressive strength of concrete. The test was conducted at 7, 14 and 28 days on cubes made of standard size of 150 mm x 150 mm x 150 mm. He concluded that as the percentage of BFS increases, the strength tends to decrease. On replacement of OPC with 15% blast furnace slag powder, the depreciation in 28 days compressive strength is being near about only 5 %.

A. Oner and S. Akyuz [12] conducted a study in which he replaced cement partially with GGBS in various percentages from 15% - 110% by weight. Compressive strength test was conducted on test specimens 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 control mixtures but as the curing period is extended the strength values increases. This is because the pozzolanic reaction is slow and depends on the calcium hydroxide availability so the strength gain takes longer time for the GGBS concrete. It was also observed that as the percentage of GGBS is increased, the strength gain increases. The optimum level of GGBS content for maximizing strength was found out about 55% – 59% by Bolomey and Feret strength equation. He also found out that as the GGBS content increases, the water/binder ratio decreases for the same workability and thus, the GGBS has positive effects on the workability.

Kamran Muzaffar Khan and Usman Ghani [13] studied the utilization of GGBS as a cementitious constituent in concrete. He prepared four mixes namely 1:2:4, 1:1:5:3, 1:1.25:2.50 and 1:1:2 at three different replacement levels of cement i.e. 0%, 25% and 50% by GGBS and found that the workability increases with the increase in percentage of GGBS. He tested all the test specimens and concluded that there was a decrease in early age compressive strength (3 and 7 days) but an appreciable gain in strength after 7 and 28 days as the replacement level was gradually increasing. However 50% replacement level had yielded slightly lower strengths. It was also seen that minimum percentage strength reduction was in case of mix 1:1:2 and maximum in case of 1:2:4, which meant that with the increase in the cement quantity, strength reduction can be minimized. He also observed that if water cement ratio is decreased using water reducers, percentage strength reduction can be minimized. Splitting tensile strength test was also conducted and it was found that there was a decrease in early age strength which was less pronounced when compared to compressive strength. Even up to 50% replacement levels, there was no substantial decrease in 28 days strength. The reduction in percentage of flexural strength was low as replacement levels increased.

Md. Moinul Islam et. al. [14] discussed the results of partial replacement of cement using slag in various percentages (10% – 70%). He tested various properties of concrete in which he found that the compressive strength and tensile strength of mortar mixes with slag 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. The optimum use of slag in the mortar was observed to be 40% of cement replacement because it shows 19% higher compressive strength and 25% higher 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 construction work with slag concrete becomes economical and also environmentally safe (reduced CO_2 emission).

Chao-Lung Hwang and Chao-Yin Lin [15] conducted a research in which he replaced cement with BFS in various percentages (0 – 80%) with three different w/c ratios (0.35, 0.47 and 0.59) and found that the use of slag lowers the strength of mortar at early age (3 days) but the strength development starts after 7 days. It was also found out that 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 and specimens cured under 50^0C tend to have the best results. He also concluded that the bleeding of the mortar with higher slag content is less than that of pure cement mortar during mixing. 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.

3. CONCLUSIONS

Based on the studies of different researchers on partial replacement of cement with GGBFS, some salient conclusions are drawn which are as follows:-

- Workability of concrete increases with the increase in GGBFS replacement level.
- As the GGBFS content increases, the water/binder ratio decreases for the same workability and thus, the GGBFS has positive effects on the workability.
- 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.
- 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.
- 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 $Ca(OH)_2$
- It was also found that in some cases the increase in percentage of GGBFS resulted in lower strength but because of which the reduction in cost of concrete at current market rate was of about 14 – 20%
- Heat of hydration is slower in case of GGBFS cement which lowers the risk of thermal cracking.
- Chloride and sulfate resistance of concrete increased as the percentage of GGBFS increased.
- Load carrying capacity increased when the specimens with GGBFS were tested under constant axial load and varying lateral load.
- GGBFS fails the initial absorption confirming that the surfaces of their concrete mixes were practically impermeable.
- Electrical conductivity test resulted that the slag replaced concrete is not a very good conductor of electricity.
- On replacement of cement by GGBFS helps to reduce the cement content of concrete, thereby reducing the cost of construction because the price of GGBFS is about 25 - 50% less than that of OPC.
- Reuse of the slag helps to protect the environment from pollution (reduced CO_2 emission) and conserves natural resources.

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