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Sustainable Studies on Concrete with GGBS As a Replacement Material in Cement

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ABSTRACT

The utilization of supplementary cementation materials is well accepted, since it leads to several possible improvements in the concrete composites, as well as the overall economy. The present paper is an effort to quantify the strength of ground granulated blast furnace slag (GGBS) at various replacement levels and evaluate its efficiencies in concrete. Cement with GGBS replacement has emerged as a major alternative to conventional concrete and has rapidly drawn the concrete industry attention due to its cement savings, energy savings, cost savings, environmental and socio-economic benefits. This research evaluates the strength and strength efficiency factors of hardened concrete, by partially replacing cement by various percentages of ground granulated blast furnace slag for M35 grade of concrete at different ages. From this study, it can be concluded that, since the grain size of GGBS is less than that of ordinary Portland cement, its strength at early ages is low, but it continues to gain strength over a long period. The optimum GGBFS replacement as cementation material is characterized by high compressive strength, low heat of hydration, resistance to chemical attack, better workability, good durability and cost-effectiveness.

KEYWORDS: GGBS, Workability, Compressive strength, Tensile strength, Flexural strength.

INTRODUCTION

General

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^{o}C to 1600^{o}C. The molten slag has a composition of 30% to 40% silicon dioxide (SiO_2) and approximately 40% CaO, which is close to the chemical composition of Portland cement. After the molten iron is tapped off, the remaining molten slag, which mainly consists of siliceous and aluminous residues is then rapidly water- quenched, 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 (GGBS). The production of GGBS requires little additional energy compared with the energy required for the production of Portland cement. The replacement of Portland cement with GGBS will lead to a significant reduction of carbon dioxide gas emission. GGBS is therefore an environmentally friendly construction material. It can be used to replace as much as 80% of the Portland cement when used in concrete. GGBS concrete has better water impermeability characteristics as well as improved resistance to corrosion and sulphate attack. As a result, the service life of a structure is enhanced and the maintenance cost reduced. High volume eco-friendly replacement slag leads to the development of concrete which not only utilizes the industrial wastes but also saves significant

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natural resources and energy. This in turn reduces the consumption of cement.

Benefits of Using GGBS in Concrete

Sustainability

It has been reported that the manufacture of one tonne of Portland cement would require approximately 1.5 tonnes of mineral extractions together with 5000 MJ of energy, and would generate 0.95 tonne of CO_2 equivalent . As GGBS is a by-product of iron manufacturing industry, it is reported that the production of one tonne of GGBS would generate only about 0.07 tonne of CO_2 equivalent and consume only about 1300 MJ of energy.

Colour

Ground granulated blast furnace slag is off-white in colour. This whiter colour is also seen in concrete made with GGBS, especially at replacements greater than 50%. 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.

Setting Times

The setting time of concrete is influenced by many factors, in particular temperature and water/cement ratio. With GGBS, the setting time will be slightly extended, 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 for longer periods, therefore resulting in less joints. This is particularly useful in warm weather.

LITERATURE REVIEW

Shariq et al.(2008) studied the effect of curing procedure on the compressive strength development of cement mortar and concrete incorporating ground granulated blast furnace slag.The compressive strength development of cement mortar incorporating 20, 40 and 60 percent replacement of GGBFS for different types of sand and strength development of concrete with 20, 40 and 60 percent replacement of GGBFS on two grades of concrete are investigated. 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. Peter et al. (2010) studied the BS 15167-1 which requires that the minimum specific surface area of GGBS shall be 2750 cm^2/g (BS 15167-1:2006). In China, GGBS is classified into three grades; namely S75, S95 and S105. The GB/T18046 requires a minimum surface area of 3000 cm^2/g for grade S75 GGBS, 4000 cm^2/g for grade S95 and 5000 cm^2/g for grade S105, which are higher than the BS EN's requirements (GB/T18046-2008). It was reported that slag with a specific surface area between 4000 cm^2/g and 6000 cm^2/g would significantly improve the performance of GGBS concretes. Mojtaba Valinejad Shoubi et al. (2013) reviewed in their research the specifications, production method and degree of effectiveness of some industrial byproducts such as GGBS, Silica Fume and PFA as cement replacement to achieve high performance and sustainable concrete which can lead not only to improving the performance of the concrete but also to the reduction of ECO_2 by reducing the amount of PC showing how they affect economical, environmental and social aspects positively. Aveline Darquennes et al. (2011) determined the slag effect on cracking. Their study focuses on the autogenous deformation evolution of concretes characterized by different percentages of slag (0 and 42% of the binder mass) under free and restraint conditions by means of the TSTM device (Temperature Stress Testing Machine). Elsayed (2011) investigated experimentally in his study the effects of mineral admixtures on water permeability and compressive strength of concretes containing silica fume (SF) and fly ash (FA). The results were compared to the control concrete, ordinary Portland cement concrete without admixtures. The optimum cement replacement by FA and SF in this experiment was 10%. The strength and permeability of concrete containing silica fume, fly ash and high slag cement could be beneficial in the utilization of these waste materials in concrete work, especially in terms of durability. Reginald Kogbara et al. (2011) investigated the potential of GGBS activated by cement and lime for stabilization/solidification (S/S) treatment of a mixed contaminated soil. The results showed that GGBS activated by cement and lime would be effective in reducing the leachability of contaminants in contaminated soils. Martin et al. (2012) studied the influence of pH and acid type in the concrete. The conclusions were that concrete tested cannot adequately address the durability threat to all parts of wastewater infrastructure over a significant life span due to the extraordinarily harsh nature of this form of attack. Wang Ling et al. (2004) analyzed the performance of GGBS and the effect of GGBS on fresh concrete and hardened concrete. GGBS concrete is characterized by high strength, lower heat of hydration and resistance to chemical corrosion.

EXPERIMENTAL INVESTIGATION

Materials Used

Ordinary Portland cement, 43 Grade conforming to IS:8112-1989 was used. The specific gravity of cement was 3.15. Locally available river sand conforming to Grading zone II of IS: 383 1970 was also used. Its specific gravity was 2.6. Locally available crushed blue granite stones conforming to graded aggregate of nominal size,12.5 mm as per IS: 383 – 1970 were also used.

Ground Granulated Blast-furnace Slag(GGBS)

Ground granulated blast-furnace slag is the granular material formed when molten iron blast furnace slag is rapidly chilled (quenched) by immersion in water. It is a granular product with very limited crystal formation and is highly cementitious in nature. It is ground to cement fineness and hydrates like Portland cement. Properties of GGBS are shown in Table 1.

Table 1. Properties of GGBS

Calcium Oxide (CaO)	40%-52%
Silicon Dioxide (SiO_2)	10%-19%
Iron Oxide (FeO)	10%-40% (70%-80%, FeO_2, 20-30% Fe_2O_3)
Manganese Oxide (MnO)	5-8
Magnesium Oxide (MgO)	5-10
Aluminium Oxide (Al_2O_3)	1-3
Phosphorous Pentoxide (P_2O_5)	0.5-1
Sulphur (S)	<0.1
Metallic Fe	0.5-10

Table 2. Mix proportions of concrete with various proportions of GGBS replacing cement in M35 grade concrete

Mix propotions	Controlled concrete	20% GGBS	30% GGBS	40% GGBS
W/C ratio	0.41			
GGBS content %	-	20	30	40
GGBS content (wt)	-	0.8 kg	1.2 kg	1.6 kg
Cement content	4 kg	3.2 kg	2.8 kg	2.8 kg
Sand content	5.186 kg			
Sand content (with bulking)	6.979 kg			
Coarse aggregate	10.216 kg			
Water content	2.00 kg	1.942 kg	1.948 kg	2.006 kg

Mix Proportion and Mix Details

In this investigation, M35 mix concrete is considered to perform the test by-weight basis by replacing 20%, 30% and 40% of cement by GGBS.

[Adopted Mix Proportion: 1 : 1.6 : 2.907:0.41]

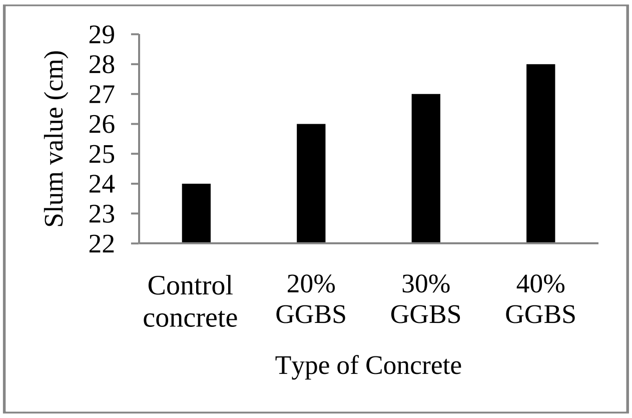


Figure (1): Slump values

Test Specimens and Test Procedure

150 mm concrete cubes and cylinders of 150 mm diameter and 300 mm length were used as test specimens to determine the compressive strength of concrete and split tensile strength of concrete for both cases (i.e., normal concrete and GGBS concrete). The ingredients of concrete were thoroughly mixed till uniform consistency was achieved. The cubes and cylinders were properly compacted. All the concrete cubes and cylinders were de-molded within 24 hours after casting. The de-molded test specimens were properly cured in water available in the laboratory at an age of 28 days. Compression test was conducted on a 100 tonne compression testing machine available in the laboratory as per IS 516-1959. The load was applied uniformly until the failure of the specimen. The split tensile strength was conducted as per IS 5816-1976. The specimen was placed horizontally between the loading surfaces of the compression testing machine and the load was applied without shock until the failure of the specimen. The concrete beams of size (100mm x 100mm x 750mm) were tested as per IS 516-1959 for flexural strength. The load was applied through two similar rollers mounted at one third points of the supporting span. The load was applied without shock until the failure occurs. The maximum load at failure is tabulated in Table 7.

RESULTS AND DISCUSSION

Slump Test

Slump values of various mix proportions of GGBS concretes are shown in Table 3.

Table 3. Slump values with various proportions of GGBS replacing cement in M35 grade concrete

Type of Concrete	Slump Value
Control concrete	24 cm
20% GGBS	26 cm
30% GGBS	27 cm
40% GGBS	28 cm

Compressive Strength

The compressive strength of concrete was determined at the age of 7 days and 28 days as presented in Table 4 and Table 5. The specimens were cast and tested as per IS: 516-1959.

Table 4. Compression test at 7th day with various proportions of GGBS replacing cement in M35 grade concrete

Type of Concrete	Crushing Load (kg)	Compressive Strength N/mm^2
Control Concrete	547	24.32
20% GGBS	460	20.45
30% GGBS	440	19.56
40% GGBS	420	18.67

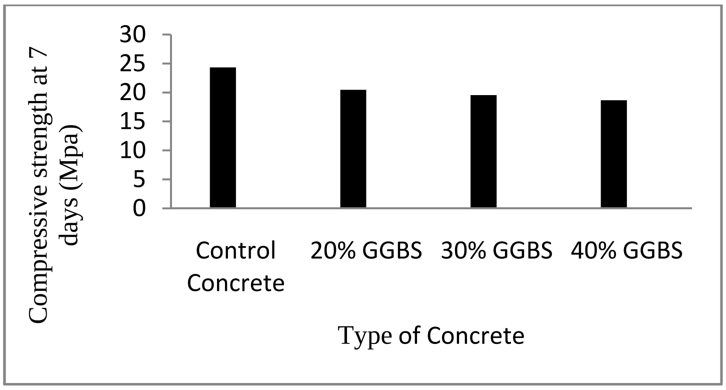


Figure (2): Compressive strength at 7 days

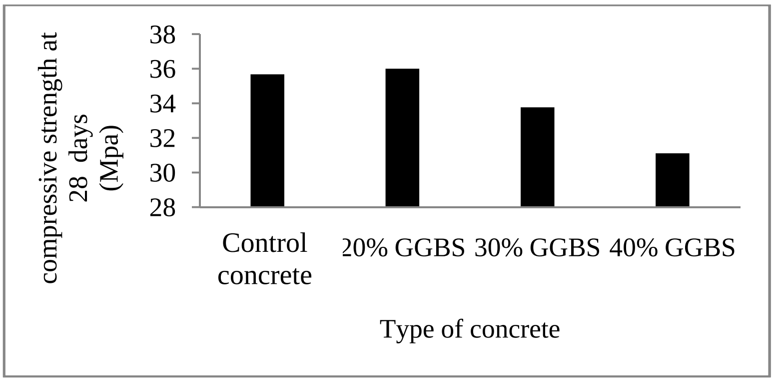


Figure (3): Compressive strength at 28 days

Table 5. Compression test at 28th day with various proportions of GGBS replacing cement in M35 grade concrete

Type of Concrete	Crushing Load (kg)	Compressive Strength N/mm^2
Control Concrete	803	35.68
20% GGBS	810	36.00
30% GGBS	760	33.77
40% GGBS	700	31.11

Split Tensile Strength

Split tensile strength was tested as per IS 5816-1976. The results are given in Table 6.

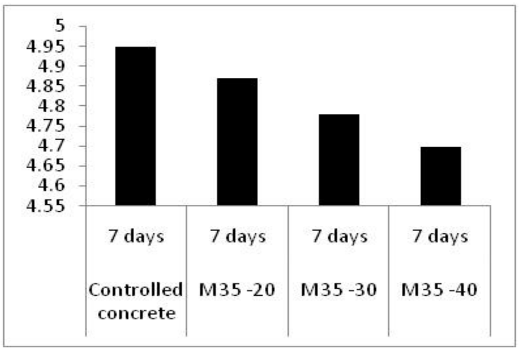
Flexural Strength Test

Flexural strength of concrete prisms was tested based on IS: 516-1959.

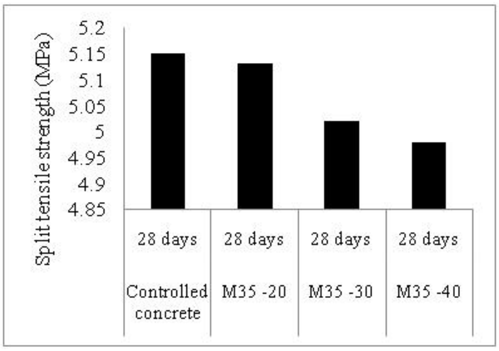
The optimum percentage level of 20% GGBS replacement to the weight of the cement is taken with the M35 mix ratio of 1: 1.6: 2.907:0.41 which gave better results when compared to the control mix. The compressive strength of 36 N/mm^2 is achieved in the mix due to the presence of GGBS which exhibits more filler effect. Figure 2 and Figure 3 represent the compressive strength, Figure 4 shows the split tensile strength and Figure 5 explains flexural strength of different replacement levels of GGBS at the age of 7 and 28 days. The presence of GGBS in concrete results in denser micro-structure of the concrete matrix which enhances the durability properties. GGBS has a high value percentage of strength-enhancing calcium silicate hydrates (CSH) than concrete made with Portland cement. Slump values achieved are nearly the same for control concrete and GGBS concrete. Medium workability was achieved with the given 0.41 w/c ratio, which gives an increase in compressive strength. Split tensile strength of 5.20 N/mm^2 and flexural strength of 5.32 N/mm^2 are achieved by 20% replacement of cement.

Table 6. Split tensile strength

Type of concrete and mix proportions	Days of curing	Split tensile strength (N/mm^2)
Control concrete	7 days	4.95
M35 -20	7 days	4.87
M35 -30	7 days	4.78
M35 -40	7 days	4.70
Control concrete	28 days	5.15
M35 -20	28 days	5.13
M35 -30	28 days	5.02
M35 -40	28 days	4.98



(a) Split tensile strength at the age of 7 days

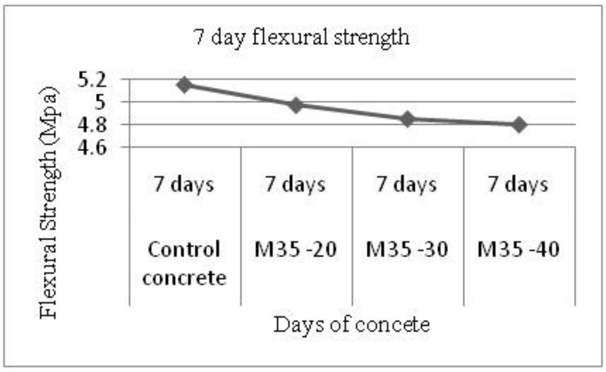


(b)Split tensile strength at the age of 28 days

Figure (4): Split tensile strength

Table 7. Flexural strength of concrete

Type of concrete and mix proportions	Days of curing	Flexural strength (N/mm^2)
Control concrete	7 days	5.15
M35 -20	7 days	4.97
M35 -30	7 days	4.85
M35 -40	7 days	4.80
Control concrete	28 days	5.27
M35 -20	28 days	5.32
M35 -30	28 days	5.23
M35 -40	28 days	5.19



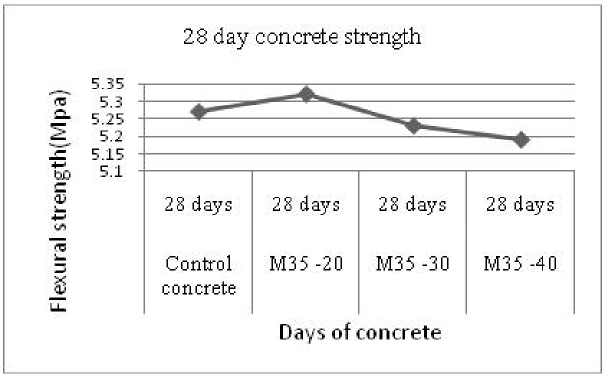


Figure (5): Flexural strength at the age of 7 days and 28 days

CONCLUSIONS

Based on the experimental investigation, the following conclusions can be drawn:

1. It is observed that GGBS-based concretes have achieved an increase in strength for 20% replacement of cement at the age of 28 days. Increasing strength is due to filler effect of GGBS.
2. The degree of workability of concrete was normal with the addition of GGBS up to 40% replacement level for M35 grade concrete.
3. From the above experimental results, it is proved that GGBS can be used as an alternative material for cement, reducing cement consumption and reducing the cost of construction. Use of industrial waste products saves the environment and conserves natural resources.

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