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Strength Analysis of Concrete using Ground Granulated Blast Furnace Slag

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ABSTRACT

Traditionally, Ordinary Portland Cement concrete is used for making the civil structures. Portland cement can be replaced by Ground Granulated Blast Furnace Slag (GGBFS). Ground Granulated Blast Furnace Slag is a non-metallic and non-hazardous waste of the Iron industry. It is suitable for concrete mix and improves properties of concrete like compressive strength, workability etc. It has been seen that when cement is replaced with GGBFS compressive strength increases. However, this increase in compressive strength continues up to a certain percentage of replacement, but higher ratios gives lower compressive strength. The main objective of this project work is to determine the optimum replacement percentage which can be suitably used under the Indian conditions. To fulfill the objective various properties of concrete using GGBFS have been evaluated. Further to determine the optimum replacement percentage comparison between the regular concrete and concrete containing GGBFS is done. For this project work the following tests are carried out - Compressive Strength, Slump Test, Setting Time, Modulus of Elasticity, Slag Activity Index Test and Electrical Conductivity Test.

1. Introduction

Ground Granulated Blast Furnace Slag (GGBFS) is a byproduct of the steel industry. Blast furnace slag is defined as “the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace”. In the production of iron, blast furnaces are loaded with iron ore, fluxing agents, and coke. When the iron ore, which is made up of iron oxides, silica, and alumina, comes together with the fluxing agents, molten slag and iron are produced. The molten slag then goes through a particular process depending on what type of slag it will become. Air-cooled slag has a rough finish and larger surface area when compared to aggregates of that volume which allows it to bind well with Portland cement as well as asphalt mixtures. GGBFS is produced when molten slag is quenched rapidly using water jets, which produces a granular glassy aggregate. GGBS cement can be added to concrete in the concrete manufacturer's batching plant, along with Portland cement, aggregates and water. The normal ratios of aggregates and water to cementations material in the mix remain unchanged. 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 [1].

The use of GGBS in addition to Portland cement in concrete in Europe is covered in the concrete standard EN 206:2013. This standard establishes two categories of additions to concrete along with ordinary Portland cement: nearly inert additions (Type I) and pozzolanic or latent hydraulic additions (Type II). GGBS cement falls in the latter category. As GGBS cement is slightly less expensive than Portland cement, concrete made with GGBS cement will be similarly priced to that made with ordinary Portland cement. It is used partially as per mix ratio. In contrast to the stony grey of concrete made with Portland cement, the near-white color of GGBS cement permits architects to achieve a lighter colour for exposed fair-faced concrete finishes, at no extra cost. To achieve a lighter colour finish, GGBS is usually specified at between 50% to 70% replacement levels, although levels as high as 85% can be used. GGBS cement also produces a smoother, more defect free surface, due to the fineness of the GGBS particles. Dirt does not adhere to GGBS concrete as easily as concrete made with Portland cement, reducing maintenance costs. GGBS cement prevents the occurrence of efflorescence, the staining of concrete surfaces by calcium carbonate deposits. Due to its much lower lime content and lower permeability, GGBS is effective in preventing efflorescence when used at replacement levels of 50% to 60% [2].

Concrete containing GGBS cement has a higher ultimate strength than concrete made with Portland cement. It has a higher proportion of the strength-enhancing calcium silicate hydrates (CSH) than concrete made with Portland cement only, and a reduced content of free lime, which does not contribute to concrete strength. Concrete made with GGBS continues to gain strength over time, and has been shown to double its 28-day strength over periods of 10 to 12 years [3].

Since GGBS is a by-product of steel manufacturing process, its use in concrete is recognized by LEED etc. as improving the sustainability of the project and will therefore add points towards LEED certification. In this respect, GGBS can also be used for superstructure in addition to the cases where the concrete is in contact with chlorides and sulfates. This is provided that the slower setting time for casting of the superstructure is justified [4].

Thus Ground Granulated Blast Furnace Slag is advantageous over various other cementitious materials because of the following reason:-

- Non-hazardous and non-metallic waste of the Iron industry.
- Eco-friendly and useful for construction work.

- Helps to improve the properties of concrete like compressive strength, workability etc.
- Low cost and easily available.

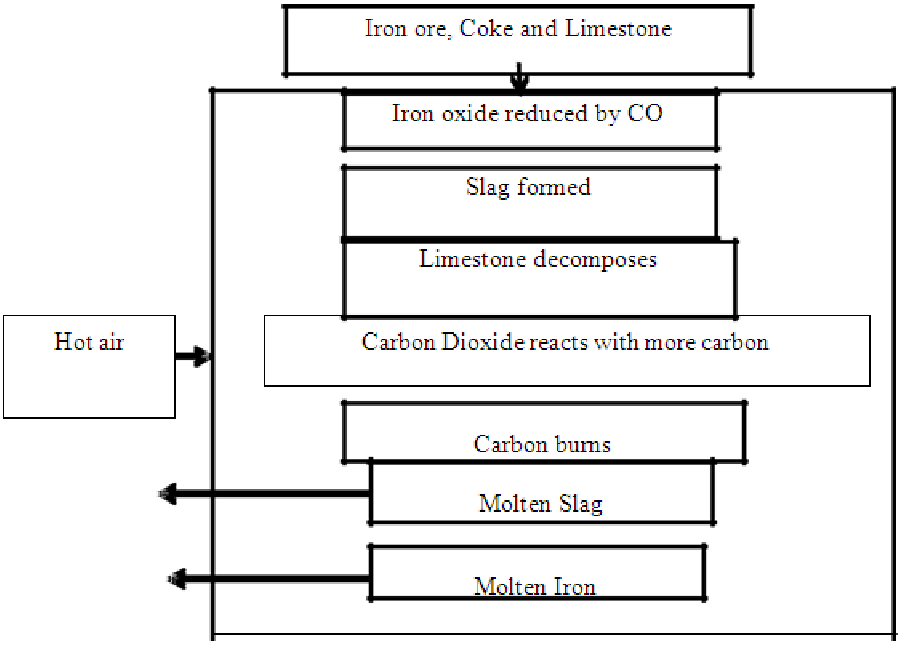

Fig 1: Schematic Representation showing Slag production

2. Literature review

The effect of GGBFS on fresh and hardened concrete had been analyzed. Characteristics of concrete like compressive strength, heat of hydration and resistance to chemical attack had been analyzed. Authors Wang Ling, Tian Pei and Yao Yan [1] concluded that curing temperature is a key factor of early strength, but curing should be under fit temperature and wet conditions [5].

Authors P.N. Rao, Venu Malagavelli [2] studied the characteristics of compressive and tensile strengths of M30 concrete with partial replacement of cement with GGBFS. They concluded that when 20-30%cement is replaced by GGBFS compressive strength of concrete improved by 8.03% and 19.64% at the age of 7 and 28 days. Also, when 50% of cement is replaced by GGBFS the compressive strength is increases by11.06% and 17.60% at the age of 7 and 28 days respectively. Finally it was concluded that GGBFS can be used as an alternative of cement.

The Mineralogical phases present in GGBFS has been analyzed, the X-Ray scattering diffraction analysis of GGBFS was done and the reaction of GGBFS with cement and role in heat of hydration were analyzed by authors Pallavi Patnaik and Shivani Kishore Dumpawar [6].

Experimental investigation to assess the durability parameters of high performance concrete with the GGBFS was done and the effects on workability of concrete were studied by Pazhani K. and Jeyaraj R.[4] They concluded that water absorption decreases by 4.58% when 30% cement is replaced by GGBFS. The pH value lies in the range of 8-10 when 30% cement is replaced by GGBFS. The chloride effect decreases and the Sulphate effect are negligible.

Anne Oberlink, Thomas Robi [5] worked upon to reduce the harmful effects of OPC. They concluded that the amount of CO2 emitted in the atmosphere reduces with the use of GGBFS. Their work dealt with general interpretation of data referring the behavior of clinker-free Portland cement [7]

The binding effect of GGBFS replaced concrete and its reduced permeability compared to normal concrete is studied by V. Cervantes and J. Roesler [6]. The effect of compressive and flexural strength is also studied. They concluded that the binding property is better in GGBFS due to its rough and larger outer surface. They also observed that the compressive and the flexural strength of GGBFS replaced concrete is greater.

The suitability of GGBFS for specific application in construction engineering and the constructional value of GGBFS has been studied by author S.Milner[7]. He concluded that Ground Granulated Blast Furnace Slag can be used in mining and mineral industry structure like ballast, granular base and mineral wools.

The effect of curing temperature in GGBFS mix concrete was studied and the activation energies determined by authors S. J. Barnett, N. N Soutsos, S.G. Millard and J.H. Bungey[8]. They concluded that a 10◦C increase in the curing temperature above standard temperature of 20◦C considerably accelerates the strength development of mortars containing high level of GGBFS. And the apparent activation energy in normal Portland cement mix increases from 34 KJ/mole to 60KJ/mole in Ground Granulated Blast Furnace Slag-Portland cement mix.

Authors D. K. Jain, J. Prasad and A. K. Ahuja [9] performed the chloride resistance test, the sulphate resistance test and Silica Aggregate Reaction test on the GGBFS mix concrete. They concluded that the introduction of GGBFS in the concrete mix reduces the chloride and the sulphate attack and hence increases its resistance. The expansion due to Silica Aggregate Reaction also decreases.

He was analyzed b author W. R. Grace [10]. He concluded that other GGBFS is a better alternative as it can adjust many properties the comparison between the GGBFS and the other possible alternatives were studied and the chemical reactivity of the GGBFS with the admixtures of concrete just by using different percentage replacements.

The objective of the project work was to determine the optimum replacement percentage which would be suitable to the Indian conditions. In view of fulfilling the objectives, slag samples from two different steel plants in India were procured. The slag samples were procured from Rourkela and the Bhilai Steel Plant. For performing the various tests the mix ratios of 30%, 40%, 45% and 50% were decided [11].

3. Experimental tests and results

Workability Test:

The lubrication required for handling concrete without segregation, for placing without loss of homogeneity, for compacting with the amount of efforts forth-coming and to finish it sufficiently easily, the presence of a certain quantity of water is of vital importance. The quality of concrete satisfying the above requirements is termed as Workable Concrete. Every job requires a particular workability. The consistency of concrete mixes, in terms of millimeters (inches) of slump, is determined by their relative water contents. Thus, a given change in the water content of a mix will result in a corresponding change in slump. The percentage change in water content per millimeters (inches) of slump change is not constant over the whole range of consistency. It is greater at the dry end of the range and less at the wet end. Only use this procedure when the plant has held back water from the design mix and the slump is less than required by the mix design. The added water to increase the slump cannot exceed the design water by more than 4% per Specification 2461.3J (2). A concrete which is considered to be workable for mass concrete is not workable for concrete used in roof construction, or even in roof construction, concrete considered workable when vibrator is used is, is not considered workable when used concrete is to be compacted by hand [12].

The following methods are commonly used to measure workability:

a) Slump Cone Test
b) Compacting Factor Test
c) Vee-Bee Consistometer Test

In this project work, the first method of determining workability is employed. The other two methods were not used because they are suitable for concrete of lower water-cement ratio and dry concrete mixes. The Slump Cone Test is done with the help of a Slump Cone. The dimensions of the cone are as follows: -

Bottom diameter: 20 cm
Top diameter: 10 cm
Height: 30 cm

The concrete mix is filled into the cone in 3layers. Each time the concrete is filled up to 1/3rd of the cone height and then it is tampered with 25 even numbers of blows of the tamping rod. After filling the cone, the cone is removed vertically from the top. This allows the concrete to subside. This subsidence is called *Slump of Concrete.* The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured. The difference is recorded in mm (as per ASTM). The amount of cement used in these tests is replaced by 30%, 40%, 45% and 50% by slag sample [13].

Table 1: Workability Test using the Rourkela Slag Sample

WORKABILITY TEST		
ROURKELA SAMPLE		
PERCENTAGE REPLACED	HEIGHT OF SUBSIDENCE	
	M20	M25
30%	45	55
40%	60	70
45%	73	82
50%	85	103

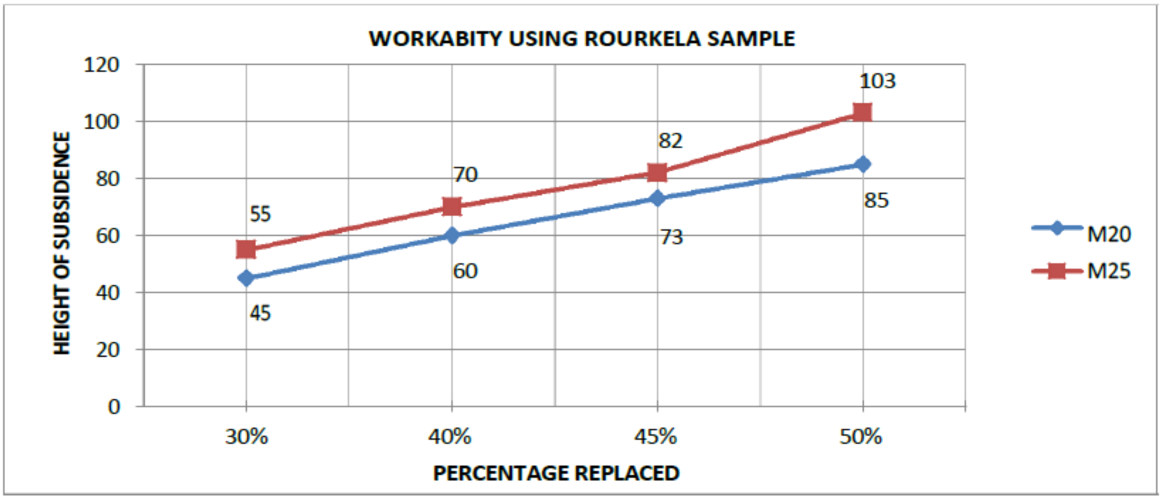

Fig 2: Variation of the Height of subsidence with varying mix ratios

Table 2: Workability Test Using Bhilai Slag Sample

WORKABILITY TEST		
BHILAI SAMPLE		
PERCENTAGE REPLACED	HEIGHT OF SUBSIDENCE	
	M20	M25
30%	48	50
40%	65	65
45%	75	80
50%	90	105

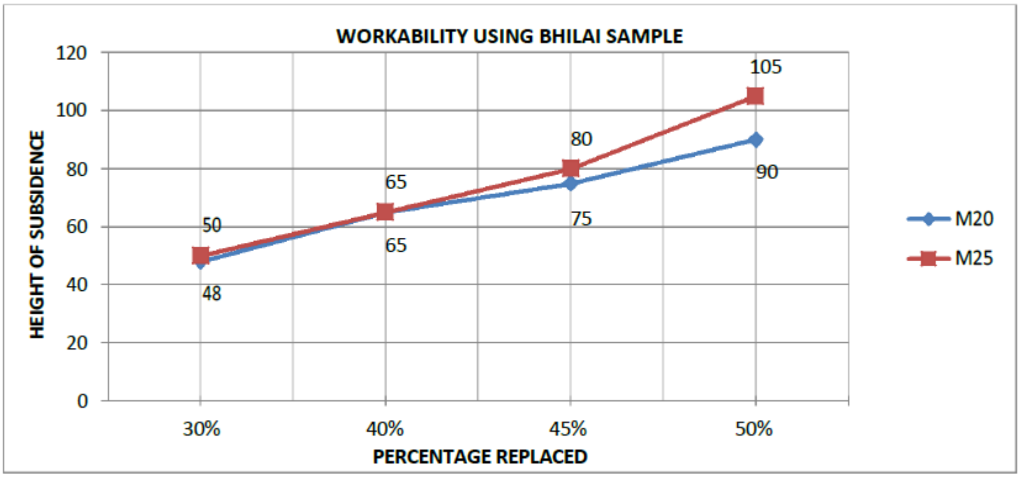

Fig 3: Variation of the Height of subsidence with varying mix ratios

It is seen from the above results that the M20 mix is generally of the medium workable nature. These mixes are suitable for manually compacted flat slabs using crushed aggregates. Normally reinforced concrete manually compacted and heavily reinforced sections with vibration can also be used. However, the M25 mix, which is mostly of the high workable nature, is suitable for sections with congested reinforcement. But they are not normally suitable for vibration. They can also be used for pumping and tremie placing [14].

Compression Test:

The compression test of concrete is the ultimate test for any concrete mix. The compression test refers to the strength the concrete mix attains at the end of 28 days of curing. Although compressive strength is checked at the end of 28 days, the compressive strength at 3, 7 and 14 days are also recorded. In this project work, the compressive strength of slag replaced concrete and that of normal concrete (0% replacements) is determined and compared. The compressive strength at the end of 3, 7 and 28 days are recorded. Test specimens are stored in water at a temperature of 24˚C to 30˚C for 48 hours before testing. They are immediately tested on removal from water while they are still wet condition. The dimension of each specimen should be noted before testing. No preparation of the surfaces is required [15].

Table 3: Compressive strength of M20 Concrete using Rourkela slag sample

COMPRESSIVE STRENGTH OF M20 MIX USING ROURKELA SAMPLE			
PERCENTAGE REPLACED	COMPRESSIVE STRENGTH(N/mm^2)		
	DAYS OF CURING		
	3 DAYS	7 DAYS	28 DAYS
0%	8.14	13.33	17.21
30%	5.12	8.42	18.67
40%	7	9.35	19.11
45%	7.72	10.01	16.88
50%	7.32	11.21	14.22

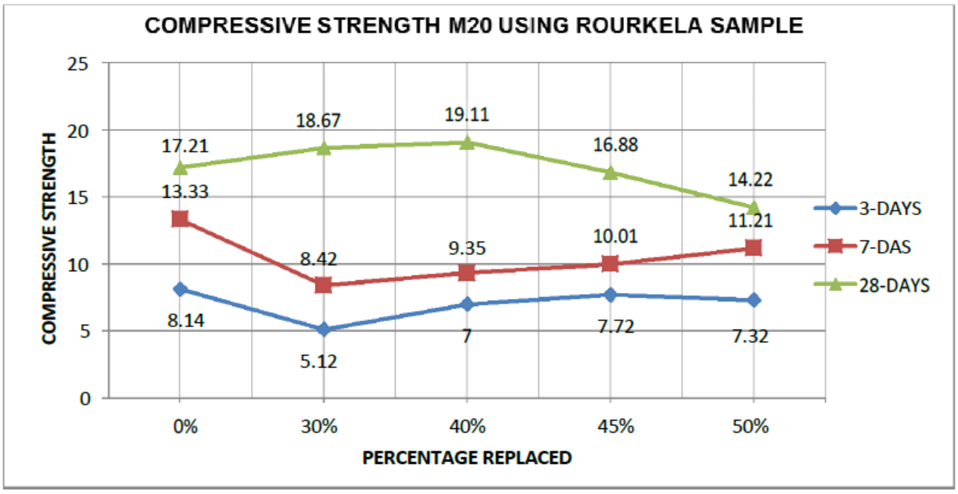

Fig 4: Variation of compressive strength with varying replacement percentage

Table 4: Compressive strength of M20 Concrete using Bhilai slag sample

COMPRESSIVE STRENGTH OF M20 MIX USING BHILAI SAMPLE			
PERCENTAGE REPLACED	COMPRESSIVE STRENGTH(N/mm^2)		
	DAYS OF CURING		
	3 DAYS	7 DAYS	28 DAYS
0%	8.14	13.33	17.21
30%	5.33	8.44	18.66
40%	7.11	9.33	18.92
45%	7.91	10.22	16.44
50%	7.55	11.11	14.56

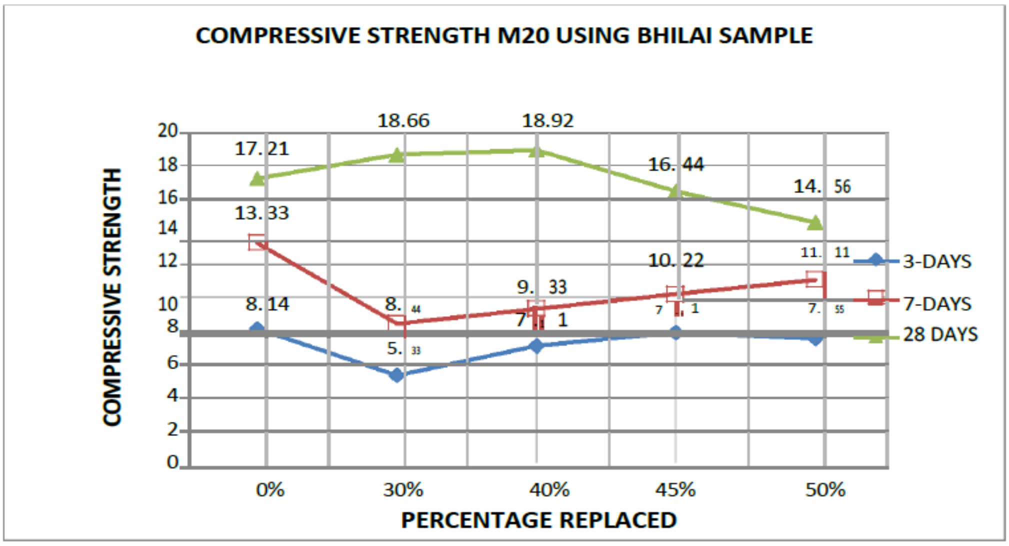

Fig 5: Variation of compressive strength with varying replacement percentage

Table 5: Compressive strength of M25 Concrete using Bhilai slag sample

COMPRESSIVE STRENGTH OF M25 MIX USING BHILAI SAMPLE			
PERCENTAGE REPLACED	COMPRESSIVE STRENGTH(N/mm^2)		
	DAYS OF CURING		
	3 DAYS	7 DAYS	28 DAYS
0%	9.87	16.25	21.25
30%	8.33	11.52	21.21
40%	10.72	12.67	23.11
45%	11.11	13.01	25.77
50%	10.98	12.98	24.01

4. Conclusion

The Ground granulated blast furnace slag is better replacement of cement than various other alternatives. The rate of strength gain in slag replaced concrete is slow in early stages but with proper curing the strength goes on increasing tremendously.

After performing the above discussed tests and analyzing their results, we can conclude the following:

- Concrete mix with 40% replacement of cement with GGBFS gives higher compressive strength.
- The compressive strength decreases when the cement replacement is more than 50%.
- There is a need for proper curing because of the increased heat of hydration and reduced rate of strength gain at early ages.
- Setting time of concrete containing slag increases as the slag content increases. An increase of slag content from 35 to 65% by mass can extend the setting time by as much as 60 minutes.
- Grade 100 GGBFS cement concrete has high compressive strength at later ages.
- GGBFS cement concrete shows low electrical conductivity.

From the above conclusions it is evident that 45% replacement of cement by GGBFS gives the highest amount of compressive strength. But keeping in view the high heat of hydration produced by GGBFS and the high temperature fluctuations in India, it is suggested that the replacement of cement with slag should be limited to 40%.

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