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Use of Blast Furnace Slag Aggregate in Concrete

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Abstract- The Iron industries produce a huge quantity of blast furnace slag as by–product, which is a non–biodegradable waste material from that only a small percentage of it is used by cement industries to manufacture cement. In the present investigation Blast Furnace Slag from local industries has been utilised to find its suitability as a coarse aggregate in concrete making. Replacing all or some portion of natural aggregates with slag would lead to considerable environmental benefits. The results indicate that the unit weight of Blast Furnace Slag aggregate concrete is lower than that of the conventional concrete with stone chips. The experimental result show that replacing some percentage of natural aggregates by slag aggregates causes negligible degradation in strength. The compressive strength of Blast Furnace Slag aggregate concrete is found to be higher than that of conventional concrete at the age of 90 days. It has also reduced water absorption and porosity beyond 28 days in comparison to that of conventional concrete with stone chips used as coarse aggregate.

Index Terms— Blast Furnace Slag, Coarse Aggregate, Compressive Strength, Environmental Benefits, Iron Industries, Non–Biodegradable Waste, Porosity

1. INTRODUCTION

CONCRETE is prepared by mixing various constituents like cement, aggregates, water, etc. which are economically available. Concrete is a composite material composed of granular materials like coarse aggregates embedded in a matrix and bound together with cement or binder which fills the space between the particles and glues them together. Almost three quarters of the volume of concrete is composed of aggregates. To meet the global demand of concrete in the future, it is becoming a more challenging task to find suitable alternatives to natural aggregates for preparing concrete. Therefore the use of alternative sources for natural aggregates is becoming increasingly important. Slag is a co-product of the iron making process. Iron cannot be prepared in the blast furnace without the production of its co-product i.e. blast furnace slag. The use of blast furnace slag aggregates in concrete by replacing natural aggregates is a most promising concept because its impact strength is more than the natural aggregate. Steel slag aggregates are already being used as aggregates in asphalt paving road mixes due to their mechanical strength, stiffness, porosity, wear resistance and water absorption capacity.

1.1. Ground Granulated Blast-Furnace Slag: Its Chemistry and Use with Chemical Admixtures

Paper by Grace Construction and Product Company [1] found that GGBFS was first used in lime mortar production as early as the 1700's. In Germany, it has been interground with Portland cement since 1892, and in other parts of the world it has been added to concrete as a separate constituent since the early 1950's. Although some of the GGBFS produced is used stabilizing mine tailings and industrial waste materials, the rest is used in Portland cement concrete. There are two primary advantages for adding GGBFS to concrete as a separate material, rather than intergrinding it in the cement: (1) Each material can be ground to its own optimum fineness (2) The proportions can be adjusted to suit the particular project needs. Compares the composition of a typical ground granulated blast-furnace slag to that of typical Type I Portland cement, a typical Class C fly ash and a typical Class F fly ash as shown in Table No 1.0 It can be noted that the GGBFS and the two fly ashes have the same kinds of oxides as the cement, which means that when GGBFS or fly ash is added to concrete, materials similar to Portland cement are being introduced into the system.

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TABLE NO. 1
SLAG ACTIVITY INDEX REQUIREMENTS OF ASTM C989

Chemical Constituents (as Oxide)	Type I Cement	Type C Fly Ash	Type F Fly Ash	GGBFS
SiO_2	21.1	33.5	43.4	40.0
Al_2O_3	4.6	22.9	18.5	13.5
CaO	65.1	27.4	4.3	39.2
MgO	4.5	4.6	0.9	3.6
Fe_2O_3	2.0	6.1	29.9	1.8
SO_3	2.8	2.2	1.2	0.2

1.2. Application of Ground Granulated Blast Furnace Slag in High-Performance Concrete in China

Wang Ling, Tian Pei, and Yao Yan from China Building Materials Academy [2] introduce studies and the application of ground granulated blast furnace slag (GGBS) in China. GGBS concrete is characterized by high strength, lower heat of hydration, and resistance to chemical corrosion. They used GGBFS in High-Strength HPC with different fineness level and through the result table we can see effects on workability and strength of concrete. It is characterized by energy savings, cement savings, low cost, environmental protection, and environmental and social benefits as well as economic profit. This kind of new building material can be called green concrete. It has good properties and its application should be more widespread.

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TABLE NO. 2
MIX PROPORTION (KG/M^3) AND PROPERTIES OF HIGH STRENGTH HPC

No	Cement	Slag (m^2/kg)			water	Stone	Sand
		300	500	800			
1	500	-	-	-	150	1085	665
2	350	150	-	-	150	1085	665
3	350	-	150	-	150	1085	665
4	350	-	-	150	150	1085	665

No	Slump	Compressive strength (MPa)			
		3d	7d	28d	60d
1	23.0	56.4	60.0	70.7	74.1
2	22.0	61.5	70.0	79.5	84.3
3	23.0	64.7	74.2	81.3	84.1
4	23.0	76.7	88.3	93.6	99.0

Dr. D.K. Singha Roy [3] was presented that the compressive strengths of steel slag aggregate concrete were marginally same as those of the limestone aggregate concrete and water absorption of concrete with steel slag aggregate was somewhat better but no improvement in tensile strengths were observed. In this work an attempt is made to study the strength parameters, modulus of elasticity, water absorption, porosity and saltwater effect on two types of concrete mixes, i.e., one comprising blast furnace slag and the other comprising granite stone as coarse aggregates. The compressive strength of BFS aggregate concrete is higher than that of the stone aggregate concrete at the age of 90 days.

1.3. Slag- Manufacturing and Types

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

a) Air-Cooled Blast Furnace Slag

If the liquid slag is poured into beds and slowly cooled under ambient conditions, a crystalline structure is formed, and a hard, lump slag is produced, which can subsequently be crushed and screened.

b) 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.

Photograph No. 1: **Blast Furnace Slag**

2. MATERIALS AND EXPERIMENTAL DETAILS

2.1. Cement:

Ordinary Portland cement (Ultratech43 Grade) confirming to IS: 269-1976 was used throughout the investigation. Different tests were performed on the cement to ensure that it confirms to the requirements of the IS specifications.

2.2. Coarse Aggregates [Natural]

Locally available river sand, basalt stone chips were used for preparation of concrete. Machines crushed locally available hard basalt, well graded 20 mm and down size were used.

Specific gravity	3.10
Fineness modulus	3.44

2.3. Sand (Fine Aggregate)

Locally available river sand passing through 4.75mm sieve as per IS: 383 provisions were used as fine aggregates.

Specific gravity	2.85
Fineness modulus	2.79

Referring to 600 micron sieve, the percentage passing is 58.00 % which confirm that fine aggregate belongs to Zone –II as per Is: 383-1970.

TABLE NO. 3
PARTICLE SIZE DISTRIBUTION OF FINE AGGREGATE

Sieve size in mm	Cumulative %	% passing
4.75 mm	3.8	96.2
2.36 mm	10.0	90.0
1.18 mm	24.4	75.6
600 micron	42.0	58.0
300 micron	95.1	4.9
150 micron	103.7	0
Total	**279.0**	

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2.4. Blast Furnace Slag

Ghatge Patil Industry, a machine part manufacturing plant is situated Uchgaon, Kolhapur. When the blast furnace is tapped to release the molten iron, it flows from the furnace with molten slag floating on its upper surface. These two materials are separated using a weir, the molten iron being channelled to a holding vessel and the molten slag to a point where it is to be treated further and according to treatment the slag is classified. And it is dumped on the sides of artificial ponds which have now formed hillocks occupying a lot of space; hence considerable expenditure is involved in maintaining these sites and disposal of wastes.

Specific gravity	2.8
Fineness modulus	6.17

Photograph No. 1 shows Blast furnace slag is glassy black in colour. Its characteristics depend on the nature of iron ore used in the extraction of iron, which significantly differs from place to place. For the experimental work, blast furnace slag was procured from Ghatge Patil Industry. The material was crushed and sieved and blast furnace slag passing through 20 mm sieve and retaining on 4.75mm.

TABLE NO. 4
CHEMICAL COMPOSITION OF FURNACE SLAG

Components	Percentage
Calcium Oxide	34-43%
Silicon Dioxide	27-38%
Aluminium Oxide	7-12%
Magnesium Oxide	7-15%
Iron	0.2-1.6%

2.5. Mix Proportion

One of the ultimate aims of studying the various properties of the materials of concrete is to enable a concrete technologist to design a concrete mix for a particular strength and durability. Following are the some methods available for concrete design mix. As IS method more common and precise, therefore for this dissertation work IS Method was adopted to calculate the proportions of ingredients of concrete.

Grade of Concrete	M30
Target strength	38.0 MPa
Cement Content	340.0 gms
Chemical	Perma Plast Ex 1 % per kg of cement

TABLE NO. 5
MIX PROPORTION OF M30 GRADE CONCRETE WITH % REPLACEMENT OF BFS TO COARSE AGGREGATE

Mix	% Replacement of BFS to CA	Cement	Sand	CA	BFS Aggregate	Water
M1	0	1.0	2.29	3.73	--	0.45
M2	50	1.0	2.29	1.69	1.87	0.45
M3	75	1.0	2.29	0.93	2.53	0.45
M4	100	1.0	2.29	--	3.37	0.45

3. RESULT ANALYSIS & DISCUSSION:

3.1. Compressive Strength:

Compressive Strength of the concrete design mix was check by casting and testing of cubes (size 150 mm x 150 mm x 150 mm) after the curing period of 3 days, 7 days, 14 days, 28 days & 60 days.

TABLE NO. 6
COMPRESSIVE STRENGTH OF DIFFERENT CONCRETE MIXES

No	% Replacement of BFS to CA	Slump (CF)	Compressive strength (MPa)		
			7d	28d	60d
M1	0	0.965	26.8	39.4	44.3
M2	50	0.948	25.2	38.7	41.6
M3	75	0.933	22.9	33.4	41.5
M4	100	0.941	24.9	38.7	39.0

a) Flexural Strength :

Flexural strength of the concrete design mix was check by casting and testing of beams (size 100 x 100 x 500 mm3) after the curing period of 7 days, 28 days and 60 days.

TABLE NO. 7
FLEXTURAL STRENGTH OF DIFFERENT CONCRETE MIXES

No	% Replacement of BFS to CA	Slump (V Bee)	Flexural Strength (MPa)		
			7d	28d	60d
M1	0	5	3.73	6.25	7.00
M2	50	7	2.93	5.80	6.50
M3	75	6	3.45	5.00	5.25

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M4	100	6	3.27	5.12	5.33

3.2. Split Tensile Strength:

Tensile strength of the concrete design mix was check by casting and testing of 100 mm diameter & 200 mm depth size Cylinders after curing period of 7 days, 28 days and 60 days.

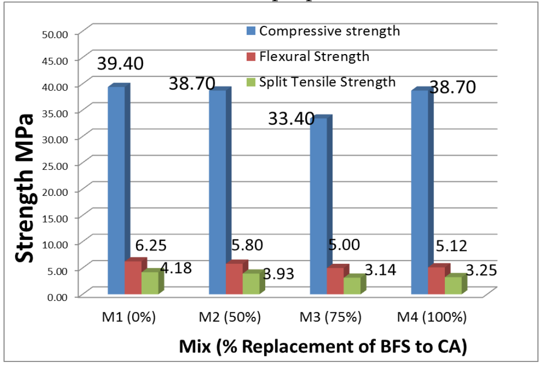
TABLE NO. 8
SPLIT TENSILE STRENGTH OF DIFFERENT CONCRETE MIXES

No	% Replacement of BFS to CA	Slump (mm)	Split Tensile Strength (MPa)		
			7d	28d	60d
M1	0	145	3.65	4.18	4.59
M2	50	155	3.31	3.93	4.20
M3	75	160	2.62	3.14	3.73
M4	100	160	2.69	3.25	3.65

4. CONCLUSION

Blast furnace slag is a by product and using it as aggregates in concrete will might prove an economical and environmentally friendly solution in local region. The demand for aggregates is increasing rapidly and so as the demand of concrete. Thus, it is becoming more important to find suitable alternatives for aggregates in the future.

The results showed that it has properties similar to natural aggregates and it would not cause any harm if incorporated into concrete. The research were encouraging, since they show that using blast furnace slag as coarse aggregates in concrete has no negative effects on the short term properties of hardened concrete.



Graph No. 1: **28 Days Strength of BSF Concrete for different Mixes**

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