Significance of Blast Furnace Slag as Coarse Aggregate in Concrete

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Abstract: In the present scenario carbon emission and basalt mining are major concern due to its hazardous effect to environment and making serious imbalance to the ecosystem. Various studies have been conducted to reduce severe effect on environment, using byproducts like ground slag as partial replacement of coarse aggregate. Different researchers have also revealed numerous uses of ground slag as a replacing agent in determining the strength of concrete. A comprehensive review of studies has been presented in this paper for scope of replacement of coarse aggregate from blast furnace slag in concrete.

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1. Introduction

The main properties of concrete, such as strength, durability and serviceability, depend mainly on the properties and the quality of the materials that are used in preparing it. Therefore, the use of waste materials, such as steel slag, in concrete may have positive or negative effect.

Utilizing blast furnace slag in concrete mixes has proved to be useful in solving some of the problems encountered in the concrete industry. Blast furnace slag was used in conventional concrete to improve its mechanical, physical, and chemical properties as shown herein. There is a big difference between steel slag and blast furnace slag, the later is produced from the conversion of iron ore to steel, while the other is produced from the oxidation of old steel during production in the arc furnace.

Geiseler. et al. [1-4] used Slag by-product of steel and iron producing processes, which was used in civil engineering projects tenths of years. Portland granulated ground blast furnace slag cement, which is produced from rapidly water-cooled blast furnace slag, has been successfully used in concrete mixes due to the high content of lime (40 -50%), which posses pozzolanic activity. ASTM C33 provides specifications for the use of blast furnace slag as aggregates in concrete, while there is no standard for the use of steel slag in concrete. Neville. et al. [2-3].

Electric Arc Furance Slag (EAFS) that contain low percentage of amorphous silica and high content of ferric oxides and consequently has low, or no, pozzolanic activities in comparison with Blast Furnace Slag (BFS), is not appropriate to be used in blended cement production. Although many studies have been conducted on the evaluation of steel slag usage in road construction and use of blast furnace slag in concrete mixes, few researches have been performed regarding the utilization of steel slag in concrete Kamal et al. [5].

Alizadeh et al. [4] carried out a research to evaluate the effect of using electric arc furnace steel slag on hardened concrete. Experimental results indicated that such steel slag aggregate concrete achieved higher values of compressive, tensile and flexural strength and modulus of elasticity, compared to natural aggregate concrete.

Shekarchi et al. [6] conducted comprehensive researches on the utilization of steel slag as aggregate in concrete. They concluded that the use of aircooled steel slag with low amorphous silica content and high amount of ferric oxides is unsuitable to be used in blended cement. On the other hand, utilization of steel slag as aggregate is advantages when compared with normal aggregate mixes.

Maslehuddin et al. [7] presented a comparative study about steel slag aggregate concrete and crushed limestone concrete. In the study, only part of the coarse aggregate was replaced by slag aggregate. The study concluded that the compressive strength of steel slag aggregate concrete was marginally better than that of crushed limestone aggregate concrete. Moreover, the improvement in the tensile strength of steel slag concrete was not significant.

Manso et al. [8] presented a study in which electric arc furnace slag was used to obtain concrete of better quality. It was concluded that arc furnace slag can be used to enhance concrete properties. However, according to the authors, special attention must be paid to the fine aggregate of steel slag concrete mixes, which can be obtained by mixing fine slag with filler material.

Ramachandran et al. [9] Stated that air-cooled slag is suitable as an aggregate in concrete. Also, slag fines may be used as a substitute for sand without any deleterious effect. Furthermore, volume stability, good sulphate resistance, and corrosion resistance to chloride solutions make reinforced slag concrete suitable for many applications.

Anastasiou E. et al. [10] experimentally studied the utilization of fine recycled aggregate in concrete with fly ash and steel slag. Various mortar and concrete mixtures were prepared using different aggregate and binder combinations to determine the feasibility of producing concrete with maximum use of alternative materials. Concrete prepared using construction and demolition waste as fine aggregate and steel slag as coarse aggregate obtained compressive strength of 30 MPa at 28 days and adequate durability of low grade application.

The porosity of the control mixtures as well as mixtures with High Calcium Fly ash HCFA and Electric Arc Furnace Slag (EAF) was 13.5-17.9 % and the porosity of mixtures with Construction & Demolition Waste CDW aggregate was observed as 18.8-20.7%. So, it was observed from the results that the use of fine construction and demolition waste aggregate increases the porosity in concrete, which reduces strength and durability but when it combines with steel slag aggregate, it partly recovers strength and durability loss. Concrete prepared with mixed construction and demolition waste as fine aggregate and steel slag as coarse aggregate gives 30 MPa compressive strength at 28 days. The cement replacement with 50% with high calcium fly ash and use only of steel slag and recycled aggregates resulted in concrete of adequate strength.

Arivalagan S. [11] reported the use of copper slag, a waste product from sterlite industries. Experimental investigations were carried out to study the possibility of using copper slag as a replacement of sand in concrete mixtures. The copper slag is used in various percentage ranging from 0%, 20%, 40%,60%,80% and 100%. The compressive strength of cubes, split tensile strength of cylinder and flexure strength of beams were evaluated.

The maximum compressive strength obtained was 35.11 MPa for 40% replacement and strength of control mix was 30MPa and maximum split tensile strength of cylinder were obtained as 2.86 N/mm2 in comparison to control mix of 1.55. Similarly the maximum flexural strength of beams was 28.80 N/mm2 and strength of control mix was 18.95 N/mm2. It was observed from the results that the addition of copper slag has improved the compressive strength, split tensile strength and flexure strength of concrete and it was also observed that sand replaced copper slag beams showed an increase in energy absorption capacity.

2 Experimental Techniques

2.1 Materials

Ordinary Portland cement of 52.5 was used in the investigation. Testing of cement was carried out as per ASTM Standard Specifications. The physical properties of the cement sample as a result of these tests are given in Table (1).

Table (1): Physical properties of cement

Property	Result
Specific gravity	3.17
Fineness	2000 cm^2/gm
Initial setting time	85 minutes
Final setting time	180 minutes
Compressive strength	Kg/cm^2
3 days	205
7 days	300
28 days	435
Soundness	1mm

Superplasticizer was used to improve the workability of concrete, Superplasticizer in the form of polycarboxylate ether based Superplasticizer is incorporated into all mixes. Superplasticizer have density 1.07± 0.02 kg/l, total soluble chloride ion content max 0.1% chloride free, pH Value 6-10 and brown liquid color.

Silica sand of natural sources, known locally as desert sand, has been used. Sieve Analysis was carried out on the natural sand according to ASTM. The results of the sieve analysis of the fine aggregate are shown in Table (2).

Table (2): Sieve analysis of standard sand

Sieve size	4.75	2.8	1.4	0.71	0.355	0.18
Residual %	0	0	19.3	52.5	74.1	90.1
Passing %	100	100	80.7	47.5	25.9	9.9

The aggregate used in this study was basalt. Basalt aggregate was obtained from Elmenia quarry. There are different sizes of basalt, but in this research have been using smallest size. Tests have been made of basalt for specific gravity, analytical sieves, crushing value and the percentage of absorption. The sieve analysis of basalt is given in table (3). The physical properties of basalt samples are given in Table (4).

Table (3): Sieve analysis of basalt

Sieve size	37.5	31.5	22.4	19	16	9.5	4.75
Residual %	0	0	0	0	5.73	42.98	95
Passing %	100	100	100	100	95.1	55.92	5

Table (4): Physical properties of basalt

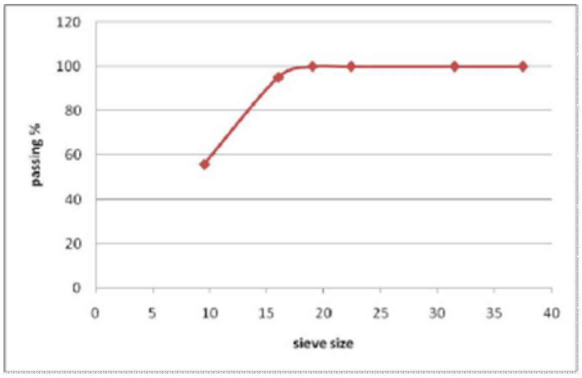
Property	Result
Specific gravity	2.75
Crushing value	19.5%
Percentage of absorption	0.5%

Fig. 1. Blast furnace slag

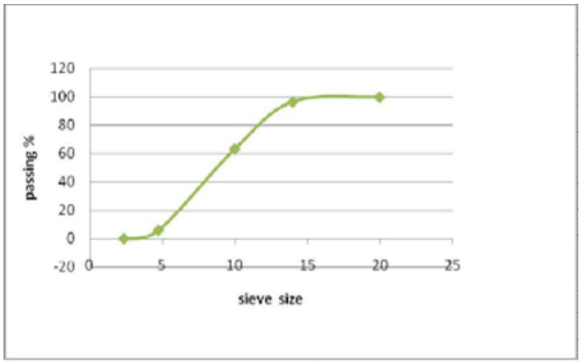
Fig. 2. Crushed blast furnace slag aggregate

Table (5): Sieve analysis of blast furnace slag

Sieve size	20	14	10	4.75	2.36
Residual %	---	3.3	36.6	93.92	99.86
Passing %	100	96.70	63.40	6.08	0.14



(A) Crushed Basalt



(B) Blast furance slag

Figure 3: Sieve analysis of basalt and blast furnace Slag sample

The various physical properties of blast furnace slag (BFS) as shown in Fig. 1 and 2, has been find out for making concrete. The sieve analysis of ground slag is given in table (5) and shown in Figure.3. The properties are given in Table-5, which Water absorption and crushing value are 1.0 %and 11.04% respectively. The Chemical Composition percentages of BFS shown in Table (6). The table explains the highest percentage of CaO, and SiO2, which helping to improve the concrete properties.

Table (6): Chemical Composition of blast furnace slag

Chemical Composition (as oxides)	%
SiO2	40
Al2O3	13.5
CaO	39.2
MgO	3.6
Fe2O3	1.8
SO3	0.2
L.O.I	0.0

2.2 Proportioning of Concrete mix

Six mixture proportions were made according to (ASTM). First was control mix (without blast furnace slag), and the other five mixes contained slag. Coarse aggregate (basalt) was replaced with slag by weight. The proportions of coarse aggregate replaced ranged from 10% to 50%. Mix proportions are given in Table 7. The control mix without slag was proportioned as per ASTM. A fresh concrete property such as slump was determined according to ASTM presented in Table 7.

Table (7): Mixture proportions

Mix. No.	C-1	C-2	C-3	C-4	C-5	C-6
Cement (kg)	390	390	390	390	390	390
Slag (%)	0	10	20	30	40	50
Slag (kg/m^3)	0	102	204	306	408	510
Water (liter)	164	164	164	164	164	164
W/C	0.42	0.42	0.42	0.42	0.42	0.42
Sand	560	560	560	560	560	560
Bazalt	1020	918	816	714	612	510
Slump (mm)	100	90	65	40	30	20

2.3 Casting and Testing of Concrete cubes

The concrete cubes of size 150x150x150 mm were cast under strictly controlled water-cement ratio. The admixture was added in the water prior to add in the dry mix. After thoroughly mixing of aggregates, the concrete was filled in cubes and vibrated on table to avoid any air voids in the body of concrete. The casting room as shown in Figure. 4. The cubes were removed from moulds after 24 hours and kept in curing tank at a temp of 25 to 27 degree centigrade. The cubes were tested after 7, 14 and 28 days under compression. Similarly the cylinders of size 150mm x 300mm sizes were cast, cured and tested after 28 days under Splitting tensile test.

Figure. 4: Compressive and Splitting tensile tests

3 Results and Discussion

3.1 Compressive strength

Compressive strength of concrete specimens made with and without blast furnace slag was determined at 7, 14 and 28 days of curing. The test results are given in Table 8 and shown in Figures 5. Figure.5 shows the variation of compressive strength with age for various blast furnace slag percentages at different ages. From the test results, it can be seen that the compressive strength of blast furnace slag concrete mixes with 10%, 20%, 30%, 40%, and 50% coarse aggregate replacement with blast furnace slag, were higher than the control mix (C-1) at all ages. It is evident from Table 8 and Figure. 5that the compressive strength of all mixes continued to increase with the increase in age. From Figure. 5, it can be seen that there is an increase in strength with the increase in blast furnace slag percentages; however, the rate of increase of strength decreases with the increase in blast furnace slag content. This trend is more obvious 30% replacement level. However, maximum strength at all ages occurs with 30% coarse aggregate replacement. This increase in strength due to the replacement of coarse aggregate with blast furnace slag is attributed to the pozzolanic action of blast furnace slag. In the beginning (early age), blast furnace slag reacts slowly with calcium hydroxide liberated during hydration of cement and does not contribute significantly to the densification of the concrete matrix at early ages. Concrete with blast furnace slag shows higher strength at early ages because inclusion of blast furnace slag as partial replacement of basalt starts pozzolanic action and densification of the concrete matrix and due to this strength of blast furnace slag concrete is higher than the strength of control mix even at early ages.

Table (8) Compressive Strength test result

Mix	C-1	C-2	C-3	C-4	C-5	C-6
Ground slag (%)	0	10	20	30	40	50
Test age (days)	Compressive strength (N/mm^2)					
7	20.52	22.41	23.62	24.00	23.53	22.54
14	23.61	25.65	27.51	28.83	27.64	25.21
28	27.42	31.19	32.43	34.72	33.82	31.00

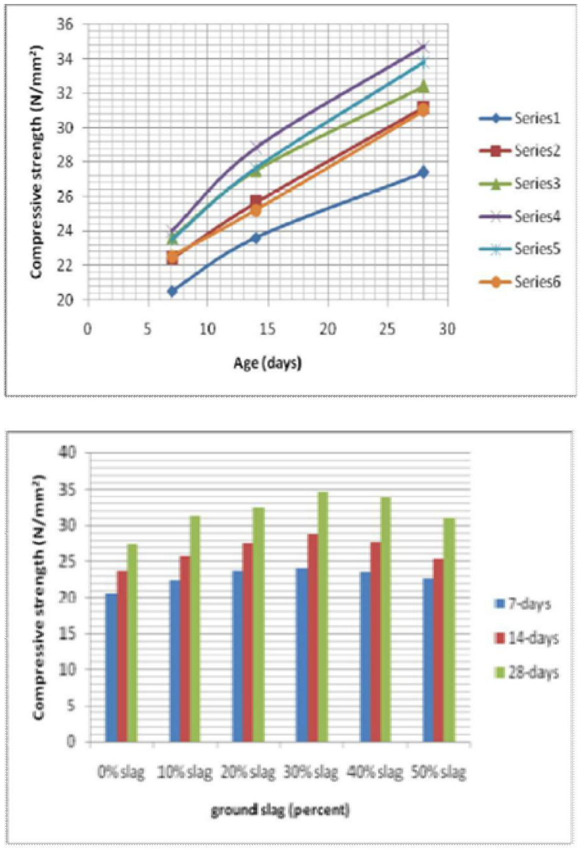


Figure5: Compressive strength at different ages and Slag percentage

3.2 Splitting tensile strength

The Splitting tensile strength test results of blast furnace slag concrete are given in Table 9 and shown in Figures 6 that shows the Splitting tensile strength development with age and the variation of splitting tensile strength with various percentages of blast furnace slag. It is evident from Table 9 and Figure. 6 that the splitting tensile strength of blast furnace slag continued to increase with the age. It can be seen that splitting tensile strength continued to increase with the increase in blast furnace slag percentages at all ages, and there is significant increase in strength with that of strength of control mix. This is belived to be due to the large pozzolanic reaction and improved interfacial bond between paste and aggregates. As blast furnace slag is available free of cost and it may only involve transportation cost of bringing it to either laboratory or site, it does not incur any additional cost in making concrete as money will be saved on use of lesser basalt.

Table (9) Splitting tensile Strength test result

Mix	C-1	C-2	C-3	C-4	C-5	C-6
Ground slag (%)	0	10	20	30	40	50
Test age (days)	Flexural strength (N/mm^2)					
7	2.4	2.5	2.6	2.7	2.65	2.61
14	2.5	2.7	2.8	3.0	2.9	2.8
28	2.8	2.9	3.1	3.4	3.2	2.9

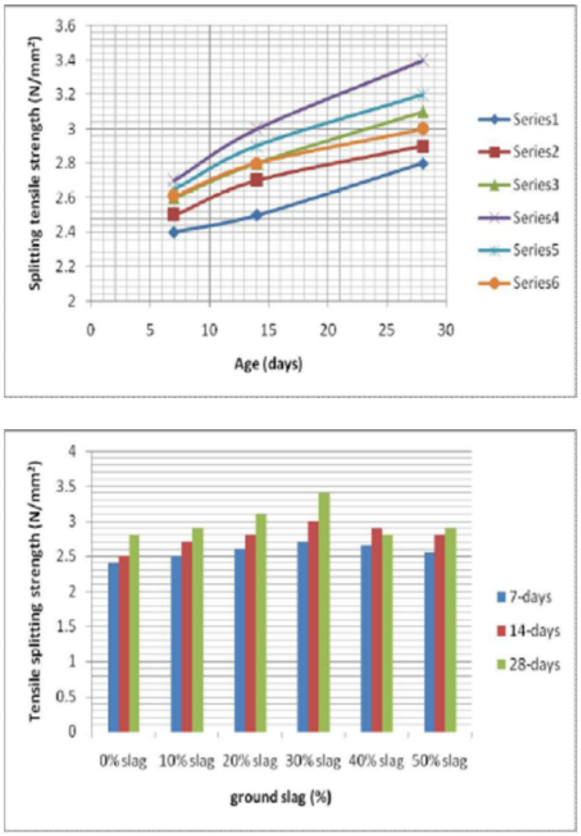


Figure 6. Splitting tensile strength at different ages and Slag percentage

4 Conclusions

In trying to find a possibility to reduce cost and saving environment of construction materials in conjunction with improving the performance of Portland cement concrete, waste materials ground-granulated blast-furnace slag (GGBFS) was used by means of partial replacement of fine aggregates in concrete.

Six of different mix proportions were designed to estimate the effect of GGBFS as a replacement of basalt on the fresh and hardening properties of concrete.

Results showed that up to 30 % of Ground slag, as a replacement of basalt, gives good results in increasing a compressive and splitting tensile strength of concrete. The following conclusions can be drawn:

1. Compressive and Splitting tensile strength of basalt replaced BFS concrete specimens were higher than the plain concrete specimens at all ages. The strength differential between the specimens with ground slag basalt plain concrete specimens became more distinct after 28 days. The effect on different properties continued to increase with age for all BFS percentages.
2. Optimum improve percentage of BFS was 30% in compressive and splitting tensile strength tests with decreases in percentage 40 and 50%. In the same way the curing age7, 14 and 28 days had the big enhancement of different strengthen.
3. Results of this investigation suggest that BFS could be very conveniently used in structural concrete with low cost.
4. The chemical composition of the BFS is characterized by high calcium oxide (CaO) and silicon oxide (SiO2), so it is a hydrolytic substance (reacts with water such as cement) and a potassium substance (reacts with the calcium hydroxide produced by the reaction of water with water).

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