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Behavior of Blast Furnace Slag in rigid Pavement (Flexural Strength)

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Abstract

The purpose of this study is to evaluate the effects of replacement of coarse aggregate with the slag of blast furnace on various properties of concrete. The objective of the study is to find out the alternate source of aggregate of high quality because quarries of natural stones are depleting with drastic speed due to lots of construction activities occurring in India. Thus the flexural strength is evaluated for beams and cylinders respectively. Slag which is a waste byproduct of steel and iron production gives an opportunity to use it as an alternative to available aggregate. The test results were obtained of concrete by mixing slag with coarse aggregate in various percentages i.e. 0, 20, 40, 60 and 100 percentages respectively. Before testing all the prepared specimens of concrete were cured for a period of 28 days. It has been observed from the study that the slag aggregate of blast furnace can be used as a good alternate of stone aggregate.

Keywords: *Flexural Behavior, Slag Concrete etc.*

1. Introduction

As we know that concrete is an age old material. It can be used easily in any shape and size of structural member. The main ingredients of concrete are cement, sand and aggregate. So, concrete can be an artificial stone obtained by binding together the particles of relatively inert coarse and fine materials with cement paste. As the aggregates are cheaper than that of cement also these aggregates give greater volume durability and stability of concrete. These aggregates are used for providing bulk to the concrete. These aggregates cover about the 70% to 75% of body of concrete and hence it is important to find out the influence of this. The stone aggregate produced by crushing of stone obtained from mountains. The quarrying of stone causes number of environmental problem. Hence to replace these aggregate by slag not only allow the use of waste product but also avoid environmental problem. Slag is a waste produced during the manufacturing of steel and pig iron. Slag consists oxides of magnesium, manganese, calcium, nickel, aluminum and phosphorous. Major component in the blast furnace slag is SiO_2. Large amount of industrial waste produced every year in developing countries. Total production of steel in the world has crossed over 1200 million metric tons. In India, output of slag obtained during the production of steel and pig iron is variable and it is basically affected by raw materials composition and furnace type. In ore feed shaving 60% to 65% iron, slag production in blast furnace varies from 300 kg to 540 kg per 1000 kg of crude iron production. Ores of lower grade produce higher slag, sometimes high as in one tone of slag produced per ton of pig iron.

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Figure 1: Blast Furnace Slag

Types of slag

Blast Furnace Slag

The slag which is floating over the molten pig iron i.e. hot metal in the blast furnace is poured in the slag pot and it is then poured to granulating plant. Slag is further divided into three categories on basis of cooling. These are granulated slag, air-cooled slag, and the expanded slag. In Air cooled slags formation, the slag is prepared in a pit by keeping the molten slag to the cool atmospheric conditions. Under these slow cooling conditions, gases leave the low-density and high porous aggregates with its physical properties which makesit suitable for many applications.

Steel Slag

The Steel slag is a solid waste which is produced from a steel production. From pretreatment slag, it can be separated as stainless-steel slag and carbon steel slag and according to the process of steelmaking it is than redevised into the basic oxygen furnace slag (BOFS), ladle refining slag(LFS) Electric Arcs Furnace Slag(EAFS), It has ferrites and calcium silicates, with some oxides and the compounds of magnesium, iron, alumina and manganese. EAF slag is also known as black slag.

2. Objective

Large amount of industrial waste produced in developing countries every year. Therefore, it is encouraged to utilize a secondary material in the construction field. The blast furnace slag is solid waste obtained during iron production. Amount of slag deposited leads toward the pollution of the ground water, land, farm and soil. Therefore, to realize sustainable development is improve the utilization of slag in the iron industries. In this study, slag of blast furnace is used as a replacement of coarse aggregate has been discussed. Therefore, this study introduced the effect of replacing use of blast furnace slag with stone aggregate partially or fully in making concrete.

3. Literature Review

The increasing demand for construction led researchers to search for an economic and ecological substitute of natural aggregate of concrete. Now days, there is a new trend to use the recycled waste or by product available from industries like iron and steel plant, rice mill, thermal power, aluminum and copper industries etc. These by-products include slag of blast, copper slag, steel slag, fly ash, rice husk etc. Many of the researchers have studied that strength and durability performance of concrete by incorporating these products. So a comprehensive literature review is presented under following heads:

Arivalagan S. reported that the use of copper slags i.e. waste product produced from Sterlite industries. Various experimental observations were found to study the way of using copper slag for replacing of sand in the concrete mixtures. The slag i.e. copper slag is treated in various proportions i.e. from 0,20,40,60,80 and 100 percentages. The, split tensile strength of cylinder, compressive strength of cubes and flexure strength of beams were found. Maximum compressive strength was obtained is 35.11 MPa for the 40% proportions and control mix strength was 30MPa and maximum split tensile strength obtained as 2.86 $N/mm^2$for cylinder in comparison to control mix of 1.55.

Chunlin L. *et al*. introduced the steel slag and scrap tire particle in place for natural aggregates in the convectional concrete. The flexural strength, compressive strength, and volume deformation of concrete containing Electric arc furnace slag as aggregate were investigated experimentally. It is found that steel slag prepared concrete has fine and coarse aggregate obtained the flexural strength of 9.3 MPa and high compressive strength of 59.6 MPa in comparison to ordinary concrete (OC).

Anastasiou E. *et al*. has studied experimentally that use of fined recycled aggregates in the concrete with steel slag and fly ash. Using different aggregate and binder combinations various concrete mixtures were prepared to find the feasibility of produced concrete with the maximum use of different materials. Various mixtures tested to determine the mechanical strength, freeze thaw resistance and durability measurement of chloride ion penetration. Concrete mixture prepared using demolition waste as fine aggregate, construction and steel slag as course aggregate obtained compressive strength of 30 MPa for 28 days and adequate durability of the low-grade application.

González-Ortega M.A *et al*. observed behavior of concretes mixed with electric arc furnace slag (EAF) having structural responsibility which is exposed to gamma radiation. Six experimental mixes were designed out of which four mixes of concrete were made with the EAF slag, one with the conventional concrete and one with a heavy weight concrete using barite aggregate. Few tests and experiments were performed for various properties such as occluded air, compressive strength, density, and gamma ray attenuation (μ) and modulus of elasticity. The mixes with EAF slag is approximately 25% higher density than that of concretes with use of limestone aggregates. Similar compressive strength was observed in mixes with the conventional concrete and EAF slag with value ranging from 45-50 MPa. It has been concluded from the results that the attenuation coefficient of the gamma rays for concrete with EAF slag are 11% higher than used with the conventional concrete.

G. Liat *et al.* experimentally studied the effect of combination of ground granulated blast-furnace slag fly ash (FA) on properties of high strength. The resistance against the attack H_2So_4 and compressive strength were also studied. It is observed from the results that the highest strength achieved was 96.3 MPa at 360 days and it is also observed that its strength is lowest before 56 days.

Based on above literature review, it was observed that various researchers studied different types of slag in concrete in different forms i.e. coarse aggregate, fine aggregate, Ultrafine aggregate. Various parameters of strength like split tensile strength, compressive strength flexural strength etc. are evaluated which showed that by incorporating slag partially or fully in the concrete, the mechanical properties can be improve. However, the use of slag of blast furnace as a coarse aggregate is not been studied till now. Hence, in this study, slag of blast furnace is utilized as coarse aggregate in different mixtures of 0%, 20%, 40%,60% and 100%. The, split tensile strength, compressive strength and flexural behavior of reinforced beams were calculated and has been compared with that the other strength of control mix.

Sarkar R. *et al*. uses the electric arc furnace slag, a waste product generate during steel melting through electric arc furnace. In this study electric arc furnace slag tried to utilize to develop vitreous ceramic tiles. At temperature 1100-1150^0 C, slags 30-40% by weight with other conventional raw material were used. The final product showed a very high density with use of short fire range and strength properties. Due to heavier iron oxide, the resulted tiles are having higher density value. When complete vitrification was obtained, there is decrease in flexural strength.

Sangeetha S.P. *et al*. investigated the structural behavior of a beam of reinforced concrete with GGBS. Experimental investigation was designed to evaluate the possibility of use of GGBS in place of OPC. In the study, eight reinforced beams were tested with and without GGBS. The data in this study includes cracking behavior, load-deflection characteristics, of strain and moment curvature of beams with or without GGBS when tested after 28 days and after 56 days. The results showed that the ultimate moment capacity of GGBS was less when tested at 28 days

4. Experimental Study

The various properties of concrete depends upon number of factors like water-cement ratio, shape and size of aggregate and type of aggregate etc, but it was observed that type of aggregate influences its strength very much because concrete has about 70-80% coarse aggregate. In the present study, this part of concrete i.e. coarse aggregate has been formed after crushing of blast furnace slag. It proceed with the process of concrete specimen molding, curing of specimen, testing method and evaluation of various concrete strength such as split tensile strength, compressive strength, and flexural strength In this study, slag aggregate is used as a replacement of natural stone crushed coarse aggregate in proportions of 0%, 20%, 40%, 60% and 100% and above mentioned tests were conducted and results were compare with the result of control mix.

Materials used in experimentation

Cement (JK-OPC): Cement used is 43 grade OPC of mark JK. The various tests conducted are concluded in Table 1.

Table 1: Physical Properties of Cement

Sr. No.	Name of Test	Observed value	Standard value as per IS: 8112-1989
1.	Normal consistency Test (in %)	29%	………
2.	Setting Time in min (a) Initial setting Time (b) Final setting Time	27 minutes 480 minutes	Not more than 30 minutes Not more than 600 minutes
3.	Soundness(mm)	2mm	Not more than 10 mm
4.	Fineness (sieve method)	2%	Not more than 10 %
5.	Compressive strength(N/mm^2) At 3 days At 7 days	25.18N/mm^2 36.20N/mm^2	Not less than 23 N/mm^2 Not less than 33 N/mm^2

Fine aggregate

Material passing through sieve of 4.75 mm is called as fine aggregate. Fine aggregate i.e. used in this experiment, according to IS: 383-1970with properties tabulated in Table 2 and Table 3.

Table 2: Fine Aggregate Physical Properties

Physical Tests	Values(By Testing)
Specific Gravity Test	02.65
Modulus of Fitness	03.40
Bulk Modulus(compacted way)	1.46 Kg/m^3
Bulk modulus(loose way)	1.7 Kg/m^3

Coarse aggregate (natural stone)

The material which is retained on sieve of 4.75 mm is called as coarse aggregate. Crushed aggregate is generally used as coarse aggregate. Locally available coarse aggregate having 20 mm average size was used in the experiment confirming to IS: 383-1970, with properties as given in Table 3.4, 3.5 and 3.6.

Table 3: Physical Properties of Coarse Aggregate

Physical tests	Values (By Testing)
Specific gravity	2.7
Fineness modulus	3.72
Maximum size of coarse aggregate	20mm
Bulk modulus(compacted)	1.5 kg/m^3
Bulk modulus(loose)	1.7 kg/m^3

Blast furnace slag aggregate

Physical Tests

The slag is black glassy particle and in the form of boulders. First, the slag is crushed manually and passing through a 20-mm sieve and it is retained on 4.75 mm sieve. The various tests conducted are tabulated in Table 4.

Table 4 Slag Aggregate Physical Properties

Physical tests	Values
Specific gravity	2.3
Maximum size of coarse aggregate	20 mm
Bulk modulus(compacted)kg/m^3	1.5
Bulk modulus(loose) kg/m^3	1.2

Chemical Test

Chemical properties of the BFS have been evaluated using X-ray fluorescence which are shown in Table 5 From the chemical composition, it has been observed that the slag contains about 33% silica and 21% of calcium oxide**.** Similarly, it has been observed that it contain 23% of ferrous oxide**.** The slag content present in the slag can contribute to form silicates in the body of concrete and hence increases the strength.

Table 5: Chemical Properties of Blast Furnace Slag (BFS)

Chemical Component	Chemical components (%age)
MgO	0.8868
Al_2O_3	8.6925
SiO_2	33.6942
P_2O_5	0.4752
SO_3	0.9498
K_2O	0.8946
CaO	21.9869
MnO	2.4709
Fe_2O_3	23.7346
NiO	6.2144

Concrete mix proportion

In this study, for analyzing the effect of Blast concrete specimens were produced by replacing natural stone coarse aggregate with the blast furnace slag aggregate in 0 %, 20%, 40%, 60% and 100% proportions. The control mix i.e. without any replacing of coarse aggregate with any slag was designed as M 25 using codal provision IS 10262: 2009 for the experimental study. Ordinary Portland cement of 43 grade of brand name J.K. cement which is locally available in market was used and kept constant as 410 kg/m^3 in all the mixes. In the study water-cement ratio used was 0.45 in all the mixes. No water reducing agent as well as workability enhancing admixtures was used in this study. For the control concrete, the ratio of 20 mm coarse aggregate and 10 mm coarse aggregate was maintained as 50: 50 to have graded aggregate according to IS 383: 1970. The fine aggregate was kept constant in all mixes. The concrete mix proportion for different slag ratio is shown in the Table 6.

Table 6: Concrete Mix Proportions of M25 Grade

Proportions of Mix	Percentage variation of blast furnace slag				
	0%	20%	40%	60%	100%
Cement	410kg	410kg	410kg	410kg	410kg
Water-Cement Ratio	0.45	0.45	0.45	0.45	0.45
Coarse aggregate	1208.47kg	966.87kg	725.08kg	483.39kg	0
Fine aggregate	596.69kg	596.69kg	596.69kg	596.69kg	596.69kg
slag aggregate	0	241.6kg	483.39kg	725.08kg	1208.47kg

Specimens casting

The moulds prepared of cubes, beams and cylinders were thoroughly cleaned. Oil was applied onto the inner surface of moulds prepared to avoid adhesion of the concrete with the inner side.

In order to calculate the compressive strength in the experiment, moulds of cube having size of 150×150×150 mm used. Similarly, in order to calculate the split tensile strength cylindrical moulds having size 150mm diameter and of length 300 mm were used Also for calculating the flexural strength, the beam specimen of size 700× 150× 150 mm was used. Limited quantity of specimen were casted to have strength at 28 days because of scarcity of material i.e. blast furnace slag.

Testing

Flexural strength test of beams

It is essential to estimate Flexural strength of the load on which the concrete member cracked. The size of specimen cast for this test was 700 ×150× 150mm as shown in figure. Universal testing machine (UTM) of capacity 100 tones was used to obtain the flexural strength of beams. For the test two-point system of loading was adopted. The specimens were tested after 28 days of casting. The experimental set up of beams is shown in Figure 4.

Figure 4: Experimental test set up of flexural loading

Experimental results

Flexural strength of beams

Flexural strength or ultimate moment (strength) for reinforced beams is known as the moment exists just before the failure of beam. To calculate this moment, it is required to examine, stress, strains and forces in the beam.

Load vs deflection curve is drawn for different beams having different % ratio of slag. Flexural strength of beams with different quantity of slag are calculated and it is than compared with beams of control mix. The flexural response i.e. flexural behavior of beams at 28 days is shown in Table 3.13 and load vs deflection curve for different beams are shown in Figure 3.7. The first crack is also noticed for each beam.

The flexural test is simpler to conduct than the tension test. It stimulates the conditions like practical situations. These results permit toughness characterization through many methods like dimensionless indices related to energy absorption capacity, absolute energy absorption and equivalent flexural strength which are intended to characterize the material behavior, results are usually affected by the specimen geometry and size. In recognizing that energy absorption the ACI 544 toughness index gives the effort addition to strength.

The ACI 544 toughness index is known as ratio of area below the load-deflection curve i.e. up to a 1.9 mm to area under the curve up to the first deflection of curve. Problem with this way is that the first crack deflection is difficult to determine as the choice of the fixed deflection limit of 1.9 mm is not exactly.

Institute of Japanese concrete (JCI) gives toughness definition as TJCI, as the area below the load deflection curve up to limiting deflection curve up to the limiting deflection as L/150. The limitation of this definition is that limiting deflection is large and it does not reflect a very useful serviceability for much application. The Dutch, Belgian, and German specifications have overcome this limitation by energy absorption computation at smaller deflection limits. In same way energy absorption capacity of the plain concrete beam of standard size is idealized as P_f ($ð_f$+l/2000)/2, here Pris are first crack load and $O_f$is deflection at first crack load. In addition to measure of energy-based toughness T_{JCI}, the Japanese standard suggest the use of an equivalent flexural toughness factor which is expressed as $T_{JCI}l/ð_{limit}bd^2$here T_{JCI}= toughness of beam, ,ð= limiting deflection, L= span,b= width of beam and d= effective depth of beam.

Table 9: Flexural behaviour of Beams at 28 Days

Specimen	Load (KN)		Energy absorption capacity			Flexural toughness factor
	First crack load	Ultimate load	ACI	JAPANESE (Kn-mm)	INDIAN (Kn-mm)	
0%	61.67	156.8	7.89	306.5	306.5	0.020
20%	64	163	8.22	268.01	268.01	0.018
40%	70	179.3	10.77	179.9	179.9	0.012
60%	72	190	12.31	275.96	275.96	0.018
100%	47.86	136.9	10.4	177.72	177.72	0.011

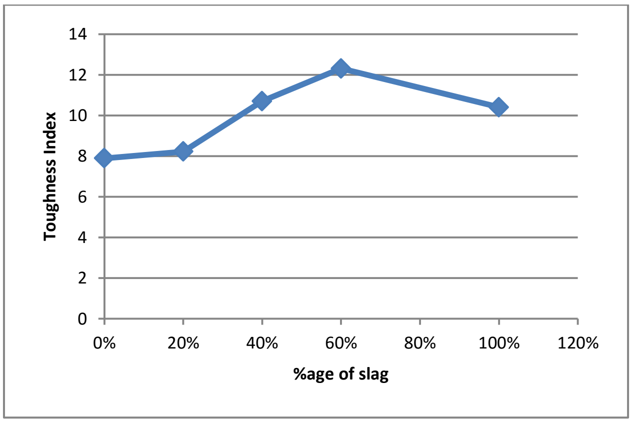

Figure7: Variation of Toughness Index of Reinforced Beam

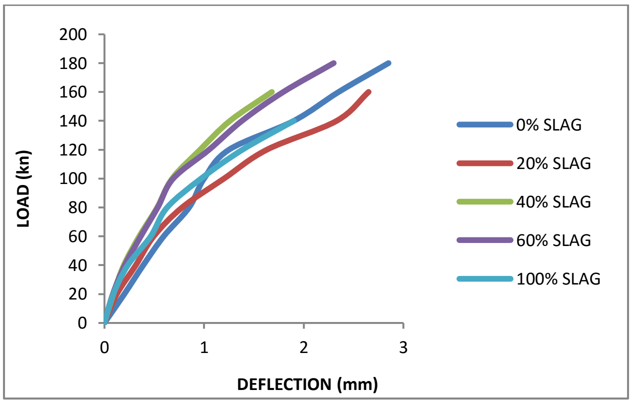

Figure 8: Load vs deflection of beams with different %age of slag

Conclusion

Concrete is an age old material. Mainly it is constituted of cement, sand and aggregate made up of natural stone. In this study, blast furnace slag's aggregate is used as a replacement of natural stone coarse aggregate in proportion of 0%, 20%, 40%, 60% and 100% in concrete. The flexural strength of concrete made up of blast furnace slag has been evaluated in this study. Flexural behavior of reinforced beam with different slag ratio has been studied and energy absorption capacity, first crack load, ultimate load, flexural toughness factor is observed experimentally and theoretically. The following conclusion has been made from the present study.

1) The maximum value of first crack load has been observed as 72KN with 60% replacement of slag correspondence to 61.67 KN in case of conventional concrete with stone aggregate.
2) The ultimate flexural load was observed maximum with 60% slag aggregate i.e. 190 KN and the ultimate flexural load in case of conventional concrete beam with stone aggregate was observed as 156.8KN.
3) The energy absorption capacity and flexural toughness factor of concrete having 100% slag aggregate has been decreased up to 42% and 45%

respectively which shows the brittle behaviors of slag concrete.

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