USE OF AIR COOLED BLAST FURNANCE SLAG (ACBFS) AS COARSE AGGREGATES- A CASE STUDY

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ABSTRACT

Resources are depleting day by day due to non consumptive use by the mankind. Blast furnace slag has a great potential as it can be used as an artificial aggregate. Keeping this in view, the present study the present study encourages the utilization of waste material such as air cooled blast furnace slag (ACBFS) and fly ash in concrete. The combined effect of ACBFS as replacement for coarse aggregates and fly ash as a partial replacement of cement on the compressive and flexural strength of concrete has been investigated. Six mixes were prepared at different replacement levels of ACBFS (0%, 20%, 40%, 60%, 80% and 100%) with coarse aggregate and fly ash was at 10% constant in all mixes. The compressive strength of concrete and flexural strength was tested after 3, 7 and 28 days of curing. Results indicate that the compressive and flexural strength are in phase with each other. The replacement of ACBFS with coarse aggregates up to 40% increases the compressive and flexural strength of concrete and at 60% there is marginal decrease in both parameters. On further replacement up to 80% and 100% the compressive and flexural strength of concrete mix decreases significantly. As it was observed that compressive and flexural strength increases with replacement up to 40% ACBFS, it is recommended that up to 40% of ACBFS can be used as coarse aggregate in concrete.

Index Terms: Air cooled blast furnace slag (ACBFS), Fly ash, Compressive strength, Flexural strength

INTRODUCTION

Concrete is basically made of aggregates glued by a cementations materials paste, which is made of cementitious materials and water. Each primary constituent of concrete, to a different extent, has an environmental impact and gives rise to different sustainability issues [13]. The current concrete construction practice is thought unsustainable because not only it is consuming enormous quantities of stone, sand and water but also two billion tons a year of Portland cement, which is not an environment friendly material from the standpoint of energy consumption and release of green-house gases (GHG).The contribution of ordinary Portland cement (OPC) production worldwide to greenhouse gas emissions is estimated to be approximately 1.35 billion tons annually [3]. To meet the global demand of concrete in future, it is becoming a more challenging task to find suitable alternatives to minimize the consumption of cement and natural aggregates in concrete. This can be achieved by the use industrial waste in place of cement and natural aggregates. There are many waste products such as fly ash(thermal plant waste) and ACBFS (iron industry waste) which can be replaced with cement and coarse aggregate respectively.

The thermal power plants in India are primarily dependent on the combustion of high-ash bituminous coal in pulverized fuel fired systems. Pulverized lignite fired boilers and pressurized fluidized-bed combustion systems are in operation to a limited extent. Hence, the low-lime fly ash is the prime variety generated in India, although significantly smaller volumes of high-lime fly ash are available in the country [2].

In step with the progressively increasing capacity of coal-fired thermal power plants, the quantity of fly ash has been increasing in leaps and bounds. The use of Fly Ash in concrete was first carried out by Davis and his associates in University of California in 1937 [1]. The rate of generation of fly ash far exceeds the incremental growth rate of its utilization. In the next three or four years, the target of 100 per cent utilization of fly ash likely to be generated is by itself a daunting task. If one considers the expected generation of fly ash over the next two decades, the volume projected is gigantic and its utilization programme will have to be far more challenging than what is perceived today. It is also obvious that no niche utilization strategy would work and one will have to look for newer avenues of bulk usage. Further, deleterious reaction could be prevented by using low-alkali cement, by incorporating pumice (a pozzolan) in the mixture [14]. The ordinary Portland cement when replaced with 5 to 50% fly ash, it was observed that 10 % fly ash showed the highest compressive strength at all ages [5].

Blast furnace slag is a nonmetallic material consisting of silicates and alumino silicates of calcium and magnesium together with other compounds of sulphur, iron, manganese, and other trace elements. It is produced from a molten state simultaneously with pig iron in a blast furnace. The solidified product is further classified according to the process by which it was brought from the molten state. Air-cooled blast furnace slag (ACBFS) is produced through relatively slow solidification of molten blast furnace slag under atmospheric conditions, resulting in crystalline mineral formation. ACBFS is one of the most commonly utilized reclaimed construction materials, being used as coarse aggregate in cement concrete, aggregate in hot-mix asphalt, road base material, and fill. There are economic, environmental, and social benefits derived from the effective use of ACBFS rather than disposing it as a waste. As a result, the beneficial use of ACBFS has broad positive impacts on sustainability, a consideration of increasing importance. However, the benefits go beyond simple economics, as the appropriate use of ACBFS also has wide-ranging environmental and social benefits. For example, when ACBFS is used, less natural material needs to be mined, transported, and processed. This means less disruption to the land, less energy consumed and less pollution and greenhouse gases generated from mining and transporting natural aggregate [12]. Besides, blast furnace slag has properties similar to natural aggregates and it would not cause any harm if incorporated into concrete [4]. The present study encourages the utilization of waste material such as ACBFS and fly ash in concrete.

MATERIALS AND METHODS

Materials

In the present study, ordinary Portland Cement (OPC) of 43 grade type cement and a fly ash obtained from Guru Nanak Dev Thermal plant located at Bathinda (Punjab) were used as binders in concrete mixtures. Properties of the OPC cement were given in Table 1. The physical and chemical properties of fly ash are given in Table 2 & 3 respectively. Locally available river sand and crushed stone aggregates stone having a 20 mm nominal maximum size were used as fine and coarse aggregate respectively. The sand was conforming to grading zone II as per IS 383-1970 [8]. The sieve analysis of fine aggregates and coarse aggregates are given in Table 4 & 5 respectively. The physical properties of these aggregates are given in Tables 6. Water used in the concrete mixture was drinkable water confirming to IS 456-2000 [9]. The physical and chemical properties of ACBFS are given in Table 7.

Table 1: Properties of OPC 43 grade cement

Sr. No.	Characteristics	Value Obtained experimentally	Values specified by IS: 8112 [11]
1.	Specific Gravity	3.15	-
2.	Standard consistency	31%	-
3.	Initial Setting time	132 minutes	30 minutes (minimum)
4.	Final Setting time	260 minutes	600 minutes (maximum)
5.	Compressive Strength 3 days 7 days 28 days	 25.15 N/mm^2 34.68 N/mm^2 46.48 N/mm^2	 23 N/mm^2 33 N/mm^2 43 N/mm^2

Table 2: Physical properties of fly ash
(Source: The Guru Nanak Dev Thermal Plant, Bathinda)

Sr. No.	Physical properties	Values	Requirements as per IS: 3812 [7]
1.	Specific gravity	2.22	_
2.	Fineness Blaine' Specific surface (m^2/kg)	369.7	320 Min
3.	Lime reactivity — Average compressive strength in (N/mm^2)	3.4	4.5 Min
4.	Particles retained on 45 micron IS sieve (%)	31	34 Max
5.	Soundness by autoclave test — Expansion of specimen (%)	0.23	0.8 Max

Table 3: Chemical properties of fly ash
(Source: Guru Nanak Dev Thermal Plant, Bathinda)

Sr. No.	Chemical component	Values	Requirements as per IS: 3812 [7]
1.	(SiO_2) + (Al_2O_3) + (Fe_2O_3) in percent by mass	91.02	70 Min
2.	Silicon dioxide (SiO_2) in percent by mass	86.72	35 Min
3.	Reactive silica in percent by mass	24.80	20 Min
4.	Magnesium oxide (MgO) in percent by mass	0.84	5 Max
5.	Sulphur trioxide (SO_3) in percent by mass	0.59	3 Max
6.	Sodium oxide (Na_2O) in percent by mass	0.50	1.5 Max
7.	Loss on ignition in percent by mass	2.3	5 Max

Table 4: Sieve analysis of fine aggregates

IS- Sieve Designation	Weight Retained on sieve (g)	%age Weight retained on sieve	Cumulative %age weight retained on sieve	%age passing	%age passing for grading zone-II as per IS: 383 [8]
10 mm	Nil	Nil	Nil	100	100
4.75 mm	17	17	3.4	96.6	90-100
2.36 mm	52	69	13.8	86.2	75-100
1.18 mm	150	219	43.8	56.2	55-90
600 micron	61	280	56	44	35-55
300 micron	109	2389	77.8	22.2	8-30
150 micron	101	490	98.0	2.0	0-10

Table 5: Sieve analysis of proportioned of coarse aggregates

IS- Sieve Designation	Weight Retained on sieve (10 mm agg. (g)	Weight Retained on sieve (20mm agg. g)	50:50 Proportion (10 mm: 20mm) Weight Retained	Cumulative weight retained (g)	Cumulative %age weight Retained	% age passing	IS:383 Requirements [8]
80 mm	Nil	Nil	Nil	Nil	Nil	100	100
40 mm	Nil	Nil	Nil	Nil	Nil	100	100
20 mm	Nil	Nil	Nil	Nil	Nil	100	95-100
10 mm	796	1854	1325	1325	66.25	33.75	26-55
4.75 mm	1054	146	600	1925	96.25	3.75	0-10

Table 6: Physical properties of aggregates

Property	Fine aggregate	Coarse aggregate
Specific gravity	2.71	2.7
Fineness modulus	2.93	6.63
Water absorption	1%	0.5%
Moisture content	0.43%	0.1%

Table 7:Typical Physical and chemical properties of ACBFS (Source: Vardhman Steel Industries, Ludhiana)

Component	Percentage
Major components	**95**
Lime (CaO)	30 – 40
Silica (SiO_2)	28 – 42
Alumina (Al_2O_3)	5 – 22
Magnesia (MgO)	5 – 15
Minor components	**5**
Sulfur (CaS, other sulphides, sulfates)	1 – 2
Iron (FeO, Fe_2O_3	0.3 – 1.7
Manganese (MnO)	0.2 – 1

CONCRETE MIXES AND MIX PROPORTIONS

In the present study, one control mix R1 was designed as per Indian Standard Specifications IS 10262 [6] for M20 grade of concrete. The other five concrete mixes (R2, R3, R4, R5 and R6) were made by replacing coarse aggregate with 20%, 40%, 60%, 80% and100% ACBFS by mass respectively. The water/cement (w/c) ratio in all the mixes was kept at 0.55. The 10% fly ash was replaced with cement in all mixes. Mix proportions of concrete mixes are given in Table 8.

Table 8: Mix proportions of concrete mixes

Sample No.	Cement (kg)	Fly Ash (Kg)	10mm	20mm	ACBFS	Water
R1	31.27	3.47	54.4	54.4	0	17.36
R2	31.27	3.47	43.5	43.5	21.78	17.36
R3	31.27	3.47	32.635	32.635	43.51	17.36
R4	31.27	3.47	21.755	21.755	65.27	17.36
R5	31.27	3.47	1.0878	10.878	87.02	17.36
R6	31.27	3.47	0	0	108.78	17.36

Preparation and casting of test specimens
Compressive strength of concrete is determined from cube specimen of 150 mm x 150 mm x 150 mm in size. For determining the flexural strength of concrete, moulds of size 700 mm x 150mm x 150mm were used. All the specimens were prepared in accordance with Indian Standard Specifications IS 516 [10]. After casting, test specimens were removed from the moulds after 24 hours of casting and were placed in the water tank. Cube specimen were taken out from the curing tank for testing after 3, 7 and 28 days of curing.

Compressive strength of concrete
Concrete cube of size 150 mm x 150 mm x 150 was tested for compressive strength as per IS 516 [10]. For the compressive strength test, a loading rate of 2.5kN/s was applied. The test was performed at 3, 7 and 28 days of curing. Specimens were tested in surface dry condition after removal from the water.

Flexural strength of concrete
The standard beam specimen of size 150 x 150 x 700 mm is casted and then tested in flexural testing machine under two point loading system. The bearing surfaces of the supporting and loading rollers was wiped clean and any looses and or other material removed from the surfaces of the specimen where they were to make contact with the rollers. The specimen was then be placed in the machine in such a manner that the load was applied to the uppermost surface as cast in the mould, at centre of the specimen. The load was applied without shock and increasing continuously at a rate of loading of 400 kg/min for the 15.0 cm specimens. The load was increased until the specimen fails and the maximum load applied to the specimen during the test was recorded. These specimens are tested for flexural strength after 3, 7 and 28 days curing.

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RESULTS AND DISCUSSION

Compressive strength of concrete

Fig 1 shows the variation of compressive strength of concrete with different replacement levels of ACBFS with coarse aggregates. It can be observed that the compressive strength of concrete increases up to certain limit and then decreases for all curing ages. It can be seen that reduction in compressive strength is minor up to 60% beyond which there is noticeable reduction in compressive strength. The percentage change in compressive strength when coarse aggregates were replaced with ACBFS at 20%, 40%, 60%, 80%, 100% was +8.66%, 17.32%, +11.91%, -6.14% and -11.91% respectively, implying that 40% ACBFS replacement gives maximum compressive strength. The absorption capacity of ACBFS is on higher scale as compared to natural aggregates, which results in low compressive strength. Therefore, 40% ACBFS is recommended as the maximum replacement level of coarse aggregates.

Table 9 : Test results for compressive strength of concrete

Mixes	ACBFS replacement(%)	3 days (N/mm^2)	7 days (N/mm^2)	28 days (N/mm^2)
R1	0	8.31	18.35	27.70
R2	20	10.92	20.97	30.10
R3	40	11.67	22.88	32.50
R4	60	12.42	20.81	31.00
R5	80	8.49	17.09	26.00
R6	100	8.19	15.092	24.40

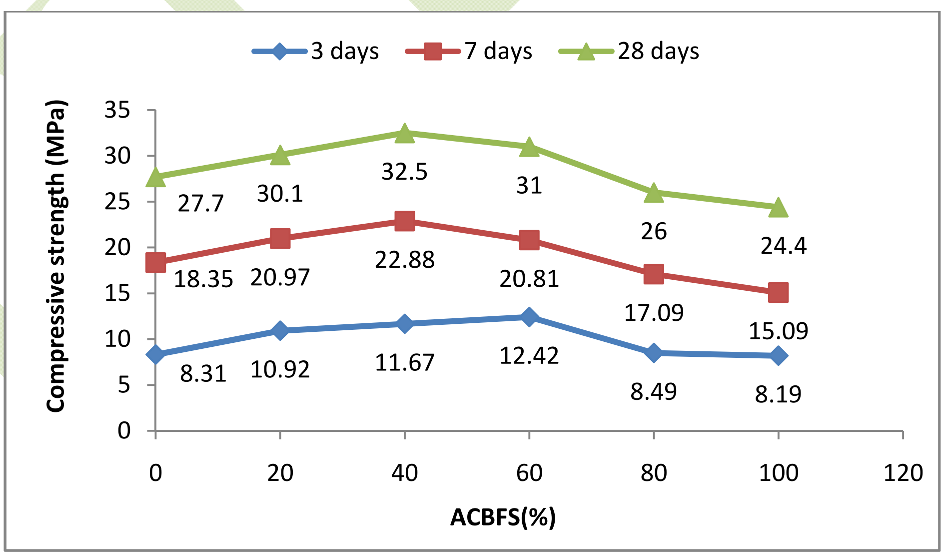

Figure 1: Compressive strength (MPa) verses ACBFS(%)

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FLEXURAL STRENGTH OF CONCRETE

The flexural strength of all the mixes were determined at the ages of 3, 7 and 28 days for various replacement levels of ACBFS are reported. The results shows the gain in flexural strength for different levels of ACBFS up to 40% and marginal decrease at 60% as reflected in Figure 2. The percentage change in flexural strength when coarse aggregates were replaced with ACBFS at 20%, 40%, 60%, 80% and 100% was +2.16, +8.33, +4.43, -14.2 and -17.16% respectively. It can be seen that the flexural strength test results supplement with compressive strength test results. The 40% ACBFS is recommended as the maximum replacement of coarse aggregates as maximum flexural strength of concrete is at this level (40%).

Table 10: Test results for flexural strength of concrete

Mixes	ACBFS replacement(%)	3 days (N/mm^2)	7days (N/mm^2)	28 days (N/mm^2)
R1	0	1.63	2.8	4.08
R2	20	1.79	2.83	4.17
R3	40	1.67	3.04	4.42
R4	60	1.57	2.92	4.26
R5	80	1.38	2.42	3.50
R6	100	1.25	2.19	3.38

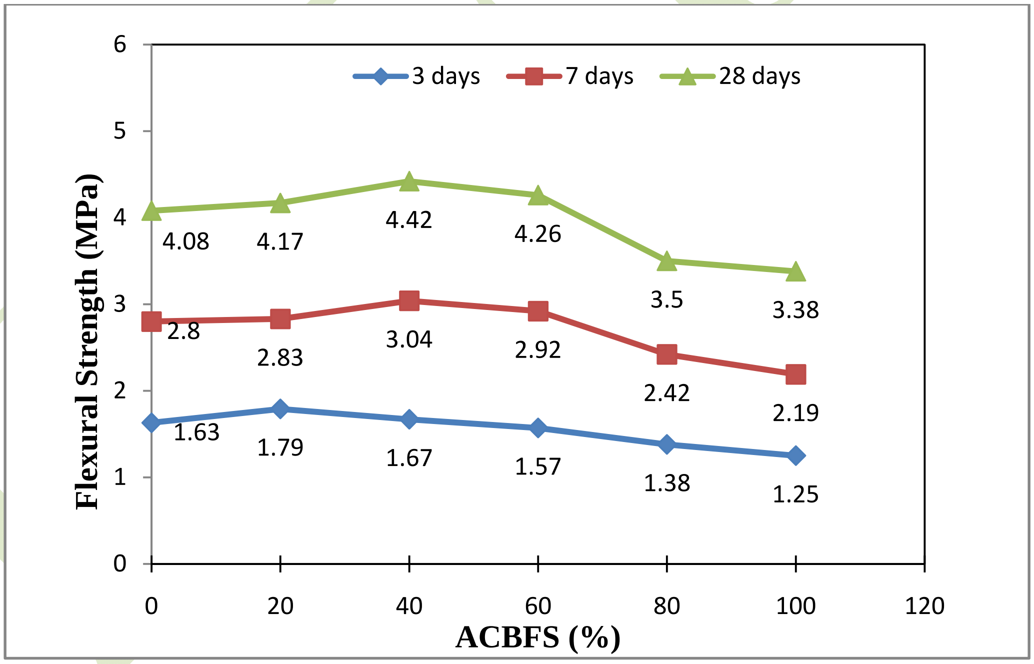

Figure 2: Flexural strength (MPa) verses ACBFS (%)

CONCLUSION

The following conclusions are drawn from this investigation:

- The compressive strength of concrete increases as ACBFS replacement increases up to 40% at all curing ages. The reduction in compressive strength is minor up to 60% replacement of ACBFS but beyond 60% ACBFS replacement, there is significant reduction in compressive strength due to high absorption capacity of ACBFS which effects the w/c of mix.
- ACBFS can be utilized as supplementary coarse aggregate replacement material in concrete. The combination of (40% ACBFS +10% fly ash) is recommended for use in concrete .
- The flexural strength of concrete also increases up to 40%, similar to the trend shown by compressive strength.
- The maximum increase in flexural strength at 28 days curing is 8.33%.

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