Performance Evaluation of Concrete Using Bottom Ash as Fine Aggregate

Jawahar S, Magesh M, Jagen.V. Vasugi

Abstract: The engineering and construction industry has faced many challenge for consuming, "Sustainable green and recycled products" in manufacture of concrete. Coal Bottom Ash (CBA) has the potential to be used as concrete materials in place of fine aggregate. Bottom ash is the dominant solid residue generated in power stations. In this study, experimental investigation has been conducted to assess the performance of bottom ash as fine aggregate with various percentages (20 %, 40 %, 60 % & 100 %) in cement concrete subjected to chemical curing. The concrete specimens were casted and tested for compressive strength and tensile strength at 7, 28 and 90 days. The functional properties like Sorptivity, Water Permeability, Rapid Chloride Penetration, Sulphate and Acid Resistance were tested on 28, 56 and 90 days old specimens. It is observed that bottom ash replacement up to 40 % as fine aggregate in cement concrete is durable.

Keywords: Coal Bottom Ash, Cement Concrete, engineering properties, durability studies.

I. INTRODUCTION

Concrete is the important construction material used in the construction industry cement, coarse aggregate and river sand are its main constituent materials. Due to scarcity of nature sand and its abnormal price hike, the construction industry is forced to replace it with M sand. Coal fired thermal power plants in the country have been accumulating tremendous volumes of coal bottom ash for decades and bottom ash is one of the dominant solid residues generated in municipal solid waste incinerators and waste to energy plants. In India, coal fired thermal power plants are the main source of power generation and about 70% electricity requirements are fulfilled by them. Deposits of coal bottom ash are becoming an environmental menace to the surrounding community[1].

The coal ash collected at bottom of furnace is called bottom ash. Bottom ash particles are physically coarse, porous, glassy, granular and grayish in color [2]. Bottom ash forms up to 25% of the total ash while fly ash forms the remaining 75%. The replacement of quartz sand by bottom ash with high reactive silica had a positive effect on the forming of tober-morite [3]. In fresh state bottom ash incorporated concrete leads to bleeding and leads to water loss [4,5] and the higher the percentage of bottom ash used as a natural sand replacement the lower the deformation through plastic shrinkage. These results afftecs the strength and setting time of concrete, these observations are considered.

The engineering and construction industry have successfully engaged in a challenge for consuming, "Sustainable, green and recycled products" in manufacture of concrete. Bottom ash has potential to be used as concrete material in place of fine aggregates. In this study, experimental investigation has been conducted to assess the performance of bottom ash as fine aggregate with various percentages (20 %, 40 %, 60 % & 100 %) in cement concrete subjected to chemical curing. The concrete specimens were casted and tested for compressive strength and tensile strength at 7, 28 and 90 days. The functional properties like Sorptivity, Water Permeability, Rapid Chloride Penetration, Sulphate and Acid Resistance were tested on 28, 56 and 90 days old specimens.

II. MATERIALS

A. Materials Used

Cement: Portland cement is the common type of cement used. In this, Ordinary Portland cement is used for concrete.

Aggregates: Aggregates provide strength and durability to the concrete. Bottom ash and M sand is used as the fine aggregate. The specific gravity of Bottom ash is 1.7 and M sand is 2.56.Coarse aggregates of 20mm size were used and the specific gravity was 2.74.

Lignite bottom ash was collected from **NEYVELI LIGNITE CORPORAION LIMITED (NLC)** approximately 500 kg in ash handling department in new thermal power plant

Water: By the process of hydration, cementious material reacts with water and form a paste. This cement paste fills the voids and makes the aggregate together. Low water cement ratio makes a durable, strong concrete. High water cement ratio makes high slump concrete.

Chemical Accelerators: Chemical accelerators help in reducing the setting time and increasing the early age strength. The chemical accelerators used in this study are calcium nitrate and Triethanolamine.

Super plasticizer: To achieve the workability for concrete, superplasticizers are used. In this, polycarboxylic ether is used.

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Table 1. Properties of bottom ash

Physical Properties of BA		
S.no	Property	Value
1	Specific gravity	1.7
2	Water absorption by mass (%)	30.2
3	Fineness modulus	1.37
4	Percentage of Air Voids (%)	60

B. Mixture Proportions

The mix proportioning for M30 grade concrete has been done as per IS10262. River sand replaced by Bottom ash as fine aggregates and the water absorption taken care in the calculation. As a result of various trial mixes, the ratio of ingredients obtained as 1: 1.8: 3.2. The fresh concrete test was taken before casting. Slump Test done to ensure the concrete workability and consistency. Table 2 gives the value obtained for the slump test.

Table 2. Slump Test

S.No	TEST	MINIMUM VALUE TO BE OBTAINED	VALUE OBTAINED	REMARKS
1	SLUMP TEST	75 mm (IS 7320 : 1974)	100 mm	Consistency

C. Curing Condition

Chemical curing has been adopted throughout the study. **CERA POLYCURE-R** was used for chemical curing of concrete specimen

Table 3. Quantities of Conventional Concrete

S.NO	MATERIALS	QUANTITY
1	Cement content	376 kg/m^3
2	Fine Aggregates	710 kg/m^3
3	Coarse Aggregates	1220 kg/m^3
4	Water cement ratio	0.55

Table 4. Replacement Porportions of bottom ash and M-Sand

Percentage	0% BA	20% BA	40% BA	60% BA	100% BA
M SAND (kg/m^3)	710	568	426	284	-
BOTTOM ASH (kg/m^3)	-	93	186	278	464

III. EXPERIMENTAL PLAN

The cubes had been casted for Mechanical and Functional properties of concrete and tested. The physical properties of the Bottom Ash are studied and Specimen ID were given to the cubes cased and tested respectively.
BA0 – Control concrete , with M-Sand
BA20- 20 % replacement of M-Sand is with BA.
BA40- 40 % replacement of M-Sand is with BA.
BA60- 60 % replacement of M-Sand is with BA.
BA100- 100 % replacement of M-Sand is with BA.

Table 5. Quantities of Various Mix

Specimen ID	Cement kg/m^3	Fine Aggregate kg/m^3		Coarse Agg. kg/m^3
		BA	M Sand	
BA0	376	-	710	1220
BA20	376	93	568	1220
BA40	376	186	426	1220
BA60	376	278	284	1220
BA100	376	464	-	1220

IV. RESULTS AND DISCUSSION

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A. Compressive Strength Test

The specimens were tested as per standard proceedings of BIS 516-59 by compression testing machine after particular days (7 days ,28 days and 90 days) [11].

Table6. Compressive Strength (N/mm²)

Sp.ID/ No. of days	7 days N/mm²	28 days N/mm²	90 days N/mm²
BA0	33.9	39.23	45.52
BA20	26.21	30.5	32.62
BA40	20.7	26.67	30.52
BA60	17.86	24.39	27.7
BA100	12.31	17.49	26.4

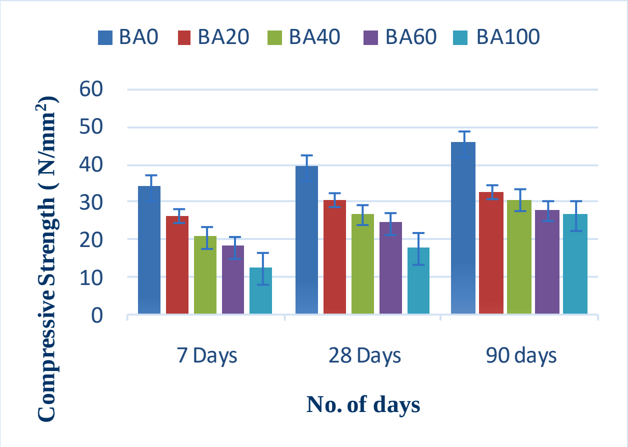

Fig.1.Variation of Compressive Strength

From Table 6 and Figure 1 it is observed that there is no significant change in the compressive strength and mass of specimen up to 20-40% replacement level is safe. Beyond 40% replacement of bottom ash in cement concrete the compressive strength found to be decreased .

B. Splitting Tensile Strength

Tensile strength test was conducted as per standards of IS 5816, cylinder specimens of size 100mm diameter and 200mm length were casted, then testes at the age of 7, 28 and 90 days and the results are computed as given in Table 7..

Table 7. Tensile Strength (N/mm²)

Sp.ID/ No. of days	7 days N/mm²	28 days N/mm²	90 days N/mm²
BA0	2.9	3.5	3.89
BA20	2.21	3.5	3.62
BA40	2.15	2.41	3.58
BA60	1.4	2.4	2.73
BA100	1.17	1.66	2.56

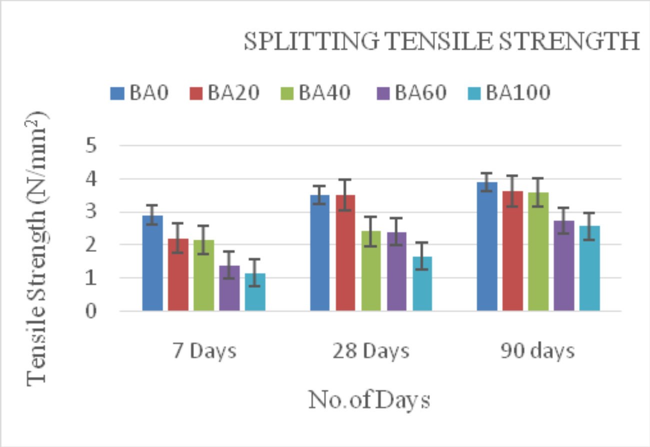

Fig.2. Variation of Tensile Strength

From Table 7 And Figure 2 it is observed that the 20% and 40 % replacement of bottom ash concrete strength show similar strength to control concrete. The 60% and 100 % of replacement attains initial strength of control concrete after only a prolonged curing of about 90 days .

C. Acid attack tests

As per standards of ASTM C – 267 the test were conducted and the specimen were kept in 5% of sulphuric acid solution and the pH values were maintained periodically for every 28 days and checked for weight and compressive strength. It is noticed that there is a change in weight as the outer layer gets degraded. Also, there is a decrease in the compressive strength of the sample as compared to the initial strength.

Table 8. Percentage of change in strength in acid attack

Mix Proportions	% of change		
	28 days	56 days	90 days
BA0	8.1	13	15
BA20	13.1	14.47	14.5
BA40	13.7	17.32	20
BA60	16.35	18.8	26
BA100	18	41.10	41.16

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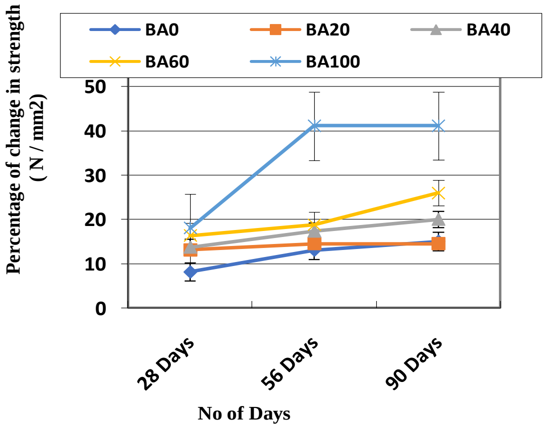

Fig.3. Change in Strength in Acid Attack

From Table 8 And Figure 3 for BA 20 and BA 40 there is 13 to 20% of change in strength and for BA100 there is major deterioration of 40% change in strength when compared to its initial strength.

D. Sulphate attack tests

The test has been done as per the standards of ASTM C 1012-10. In sulphate attack, sulphate reacts and there will be disruption of cement paste that leads to loss in strength and cohesion. Samples were immersed in 5% of magnesium sulphate solution after curing.

Table 9. Percentage of change in strength in sulphate attack

Mix Proportions	% of change		
	28 days	56 days	90 days
BA0	3.16	4	4.8
BA200	3.6	4.6	4.8
BA40	4.3	6	6.6
BA60	5.2	6.9	7.1
BA100	6.8	8.5	9

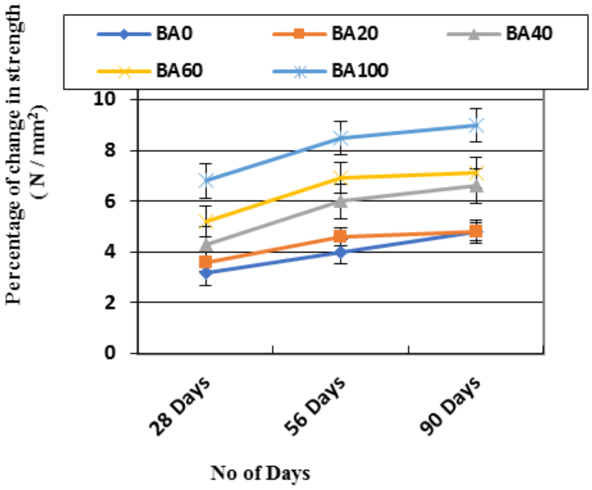

Fig 4. Change in Strength in Sulphate attack

From Table 3 and Figure 4, it has been observed that in Sulphate attack the percentage of change is between 3 to 6 % of initial strength for 20% and 40 % replacement of bottom ash when compared to controlled concrete which is allowable.For 60% replacement at the end of prolonged curing the deterioration in concrete is high and for 100% replacement deterioration is 9% to that of controlled concrete.

E. Salt Water Resistance

The chloride resistance of control concrete and BA concrete were evaluated by measuring the residual compressive strength after chloride exposure. Cubes were immersed in solution after 28days of curing period. Sodium Chloride (NaCl) solution with 5% concentration was used as the standard exposure. The specimens were immersed in the Sodium Chloride solution in a tank. The test where carried as per IS code specifications.

Table 10. Percentage of change in strength in Chloride attack

Mix Proportions	% of change		
	28 days	56 days	90 days
BA0	1.24	3.2	3.4
BA200	1.97	4.9	6.3
BA40	2.52	5.05	6.4
BA60	2.8	6.9	7.2
BA100	3.37	8.5	8.9

As per test results reported in Table 10 the concrete is durable and resistance in salt water penetration.

F. Rapid chloride penetration test (RCPT)

In this test, the chloride ion penetration is tested by passing current. The procedure for the RCPT test is given in ASTM C 1202. The cylinder is cut into the disc cylinders of 50 mm thickness and 100 mm thickness diameter using cutting machine.

Table 11. Rcpt results

RAPID CHLORIDE PENETRATION TEST					
No.of days	CC	20%	40%	60%	100%
28	1100	1410	1440	1750	2410
56	1250	1470	1590	1900	2600
90	1300	1600	1670	2100	2870

Table 12. Chloride Permeability Based on Charge Passed

Charges passed (columbs)	Chloride pearmiability
>4000	High
2000 – 4000	Moderate
1000 - 2000	Low
100 – 1000	Very low
<100	negligible

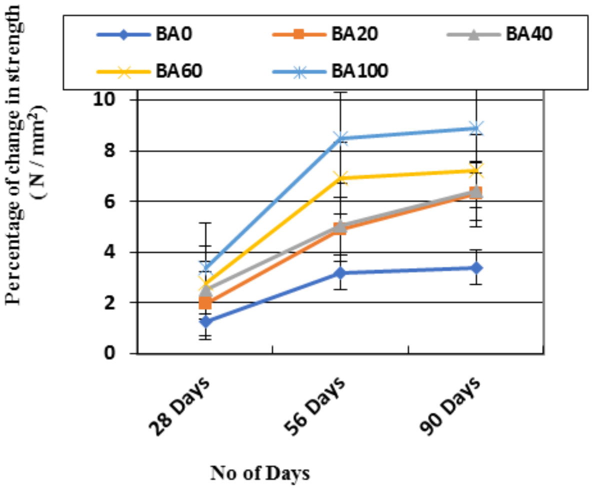

Fig 5.Change in Strength in chloride penetration

Table 12 represents the standard values and comparing it with the results obtained it shows that the samples are resistant to chloride penetration, where the conventional concrete is resistant with the category of very low and the other mix proportion are low. Thus, BA concrete is resistant to chloride attack since they are less permeable, less porous.

G. Sorptivity

Sorptivity test is carried as per ASTM C1585-13. It determines the absorption of water in concrete over time. The samples were cut into disc cylinders of 65mm thick using concrete cutter .The equation for calculation of sorptivity is

M (t) =c* t1/2

Table 13. Sorptivity results

Sorptivity S (*10^-4) mm/min $^{(1/2)}$					
No of days	BA0	BA20	BA40	BA60	BA100
28	3.91	4.64	4.7	4.71	4.81
56	4.36	4.71	4.79	4.9	4.96
90	4.67	4.8	4.91	5.11	5.31

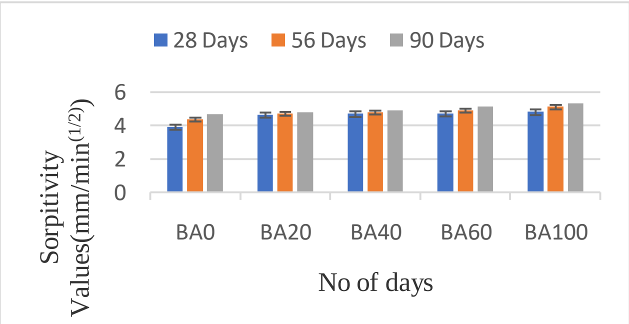

Fig.6.Variation in water absorption

From Table 13, it is observed that greater the Sorptivity coefficient, the greater is the Sorptivity of the sample and the durability of the sample reduces. Since it is below 6 for all the mixes, the quality of concrete is good

H. Ultra Sonic Pulse Velocity Test

Ultrasonic pulse velocity (UPV) is a meant for assessing variations in the apparent strength of concrete; it is a non destructive test.UPV equipment is also used for detecting the presence of voids, honeycombing or other discontinuities.

Table 14. Ultra Sonic Pulse Velocity Range

PULSE VELOCITY	CONCRETE QUALITY
>4.0 km/s	Very good to excellent
3.5 – 4.0 km/s	Good to very good, slight porosity may exist
3.0 – 3.5 km/s	Satisfactory but loss of integrity is suspected
<3.0 km/s	Poor and los of integrity exist.

Table 15. Ultra Sonic Pulse Velocity Observation

MIX	Velocity (km/s)	
	7 days	28 days
BA0	4.14	4.23
BA20	4.1	4.13
BA40	3.82	3.9
BA60	3.3	3.4
BA100	2.28	3.1

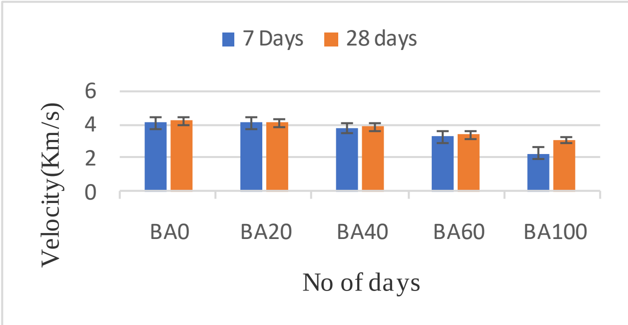

Fig.6.Variation in charges Passed

Comparing the recorded values of sample from Table 15 to the standard value on Table 14, it is observed that BA0, BA20 mix are of excellent quality and BA40, BA60 mix is Satisfactory but loss of integrity is suspected.

V. CONCLUSION

Based on the results obtained from the experiments the subsequent conclusions can be derived regarding the performance of the concrete.

1. In fresh concrete properties the BA mix is workable and consistent.
2. It is observed that with an increase in bottom ash percentage beyond 40% decrease in compressive and tensile strength of concrete. Mix BA20 and BA 40 have high potential to meet the strength and workability properties.
3. Based of the NDT test it is observed that on various percentage of concrete mix they produced good results.
4. The optimum mix is BA 40, it has been evaluated based on performance evalution.

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