Experimental Investigation on the Effect of use of Bottom Ash as a Replacement of Fine Aggregates

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Abstract

Bottom Ash produced by coal-fired boilers can be used in variety of construction and manufacturing applications which include structural and engineering fill, cement raw material, aggregates for concrete and asphalt products and general reclamation purposes. Physically, bottom ash is typically grey to black in color, is quite angular, and has a porous surface structure. Over a decade ago, removal of bottom ash in dry state was considered impractical. With the increased use of bottom ash, there is a greater interest in applying this in construction practices. This paper presents the experimental investigations carried out to study the effect of use of bottom ash (the coarser material, which falls into furnace bottom in modern large thermal power plants and constitute about 20% of total ash content of the coal fed in the boilers) as a replacement of fine aggregates. The various strength properties of concrete such as the compressive strength, flexural strength and splitting tensile strength are studied. The strength development for various percentages (0-50%) replacement of fine aggregates with bottom ash are carried out which can easily be equated to the strength development of normal concrete at various ages.
Keywords: Bottom Ash, Concrete, Fine Aggregate

I. INTRODUCTION

Cement concrete comes next to water in terms of usage of material upon our planet. Over a decade, concrete has become the sole material of choice for construction purposes such as residential and commercial buildings, infrastructural facilities such as highways, dams and bridges, canals, ports and other important facilities. Concrete is a mixture of cementatious material, aggregate, and water. Aggregate is commonly considered inert filler, and accounts for 60 to 80 percent of the volume and 70 to 85 percent of the weight of concrete. Although aggregate is considered inert filler, the concrete's thermal and elastic properties and dimensional stability are defined by aggregates. Aggregate is classified into coarse and fine. Fine aggregate is an important widely used construction material, and the cost of it is increasing which increases the cost of concrete, in construction works. To reduce the requirements and cost of concrete some alternative materials are needed to replace the conventional fine aggregate.

Energy is the main backbone of modern civilization of the world over. Over 70% of electricity generated in India, is by combustion of fossil fuels, out of which nearly 61% is produced by coal-fired plants. This results in the production of tons of ashes. Most of the ash gets accumulated over open areas or get mixed up with water bodies resulting in pollution in such water bodies and loss of productive lands.

The use of coal ash in normal strength concrete is a new dimension in concrete mix design and if applied on large scale would revolutionize the construction industry, by economizing the construction cost and decreasing the ash content.

Bottom ash is coarse, with grain sizes spanning from fine sand to fine gravel. Bottom ash can be used as a replacement for aggregate and is usually sufficiently well-graded in size to avoid the need for blending with other fine aggregates to meet gradation requirements. The porous surface structure of bottom ash particles make this material less durable than conventional aggregates and better suited for use in base course and shoulder mixtures or in cold mix applications, as opposed to wearing surface mixtures. This porous surface structure also makes this material lighter than conventional aggregate and useful in lightweight concrete applications.

Bottom ash applications include its use as a:

- Filler material for structural applications and embankments
- Aggregate in road bases, sub-bases, and pavement
- Feed stock in the production of cement
- Aggregate in lightweight concrete products
- Snow and ice traction control material
- Production of concrete blocks

This paper presents the experimental investigation carried out to study the effect of use of bottom ash as a replacement of fine aggregates. Although, fly ash is being generally used as replacement of cement, as an admixture in concrete, and in manufacturing of cement, the study on the use of bottom ash (the coarser material, which falls into furnace bottom in modern large thermal power plants and constitute about 20% of total ash content of the coal fed in the boilers) has been very limited.

II. EXPERIMENTAL INVESTIGATION

The entire study clearly followed an orderly and well-planned methodology. A vast literature review was conducted to fill the gaps of previous studies. It was found that the material source has a greater effect upon the experiments. Bottom ash from Hindustan Newsprint at Veloor, Kottayam, India was used in the study. The other materials used Portland pozzolana cement (PPC), river sand and coarse aggregate with a nominal size of 20mm. Preliminary material property tests for all the constituents were conducted and are tabulated below. The grading of bottom ash was done as per the provisions in IS: 2386 (Part 1)-1963. Mix design for all the mixes was conducted.

Table – 1
Material Properties

Material Property	*Value*
Standard consistency of cement	*34%*
Specific gravity of cement	*3*
Initial setting time of cement	*28 mins*
Final setting time of cement	*65 mins*
Specific gravity FA	*2.71*
Fineness modulus of FA	*2.789*
Specific gravity CA	*2.87*
Fineness modulus of CA	*2.93*
Specific gravity BA	*2.45*
Fineness modulus of BA	*3.38*

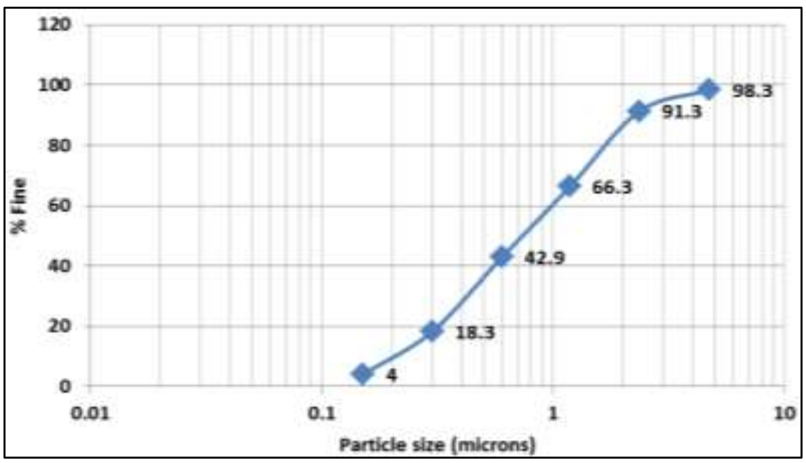

Fig. 1: Fine aggregate particle size distribution curve

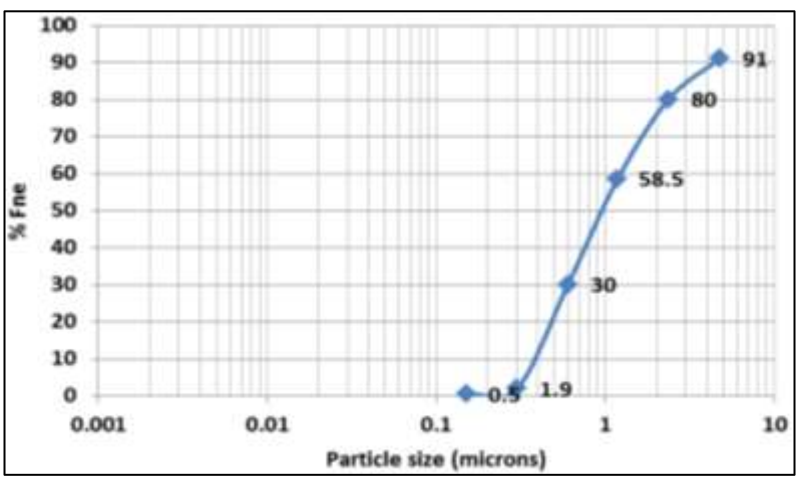

Fig. 2: Bottom Ash particle size distribution curve

III. MIX DESIGN FOR M20 CONCRETE

A. Design Stipulations

Characteristic compressive strength required in field at 28 days is 20 N/mm^2; Maximum size of aggregate is 20mm (angular); Degree of workability is 0.90 CF; Degree of quality control is Good; Type of exposure is Mild

B. Test Data for Materials

Specific gravity for cement is 3.0; Specific gravity of Coarse aggregate is 2.87 and Fine aggregate is 2.71; Water absorption for coarse aggregate is 0.5 % and for Fine aggregate is 1.0 %

C. Design

Target Mean Strength of Concrete - Assumed standard deviation as per IS 456-2000 referring the table (6) is S=3.6
Target mean strength = fck + ts = 20+1.65(3.6) = 25.94 N/mm^2

D. Selection of Water Cement Ratio

Taking moderate exposure condition from table 5, IS 456,
Max water cement ratio = 0.52

E. Selection of Water and Sand Content

From table 4, for 20 mm nominal maximum size aggregate and sand confirming to grading zone II, water content per cubic metre of concrete = 186 kg and sand content as percentage of total aggregate by absolute volume= 35%

F. Determination of cement content

Water cement ratio = 0.52
Water = 172 kg
Cement by mass = water content / water cement ratio
Cement content = 172/0.52 = **330.76 kg/m^3**

G. Determination of coarse and fine aggregate content

1) Fine aggregate

$V = \left[w + \frac{c}{sc} + \frac{1}{p} * fa\ /\ Sfa\right] 1/1000$

Fa = 661.99kg

2) coarse aggregate

$V = \left[w + \frac{c}{sc} + \frac{1}{p} * Ca\ /\ SCa\right] 1/1000$

Ca = 1301.766kg

Table – 2
Mix Proportion

Water	*Cement*	*Fine aggregate*	*Coarse aggregate*
172kg	*330.76kg*	*661.99kg*	*1301.766kg*
0.5	*1*	*2*	*3.96*

IV. TESTS ON HARDENED CONCRETE

A. Compressive Strength of Concrete Cubes

Out of many test applied to the concrete, this is the utmost important which gives an idea about all the characteristics of concrete. For cube test, specimen cubes of 15 cm X 15 cm X 15 cm were used. Concrete was poured in the mould and tempered properly so as not to have any voids. After 24 hours these moulds were removed and test specimens were put in water for curing. The top surface of the specimen was made even and smooth. This was done by putting cement paste and spreading smoothly on whole area of specimen.

These specimens were tested by compression testing machine after 28 days. Load was applied gradually at the rate of 140 kg/cm^2 per minute till the Specimens failed. Load at the failure divided by area of specimen gives the compressive strength of concrete.

Fig. 3: Compression Testing on Cubes

B. Compressive Strength of Cylinders

For cylinder tests, concrete cylinders of size 150mm diameter and 300mm long are casted and cured for 28 days. The specimens are taken out after the period and excess water wiped off. The specimen is placed vertically on the platform of compression testing machine load is applied continuously without shock at the rate of 315 kN/min and continued until the specimen fails. The maximum load taken is recorded.

Fig. 4: Compression Testing on Cylinders

C. Tension Tests

Concrete is not normally designed to resist direct tension. However, knowledge of tensile strength is of value in

- Estimating the load under which cracking will develop.
- Understand the behavior of R.C.C
- Design for diagonal tension
- Unreinforced concrete structures like dams under earth quake loads.
- Design of highway and airfield pavements

There are 3 types of tension tests:

1) Direct tension tests
2) Flexure tests
3) Splitting tension

1) Flexural Strength Tests:

In these tests a plain unreinforced beam is subjected to flexure using a symmetrical two-point loading until failure occur, because the load points the load points are spaced 1/3 of the span the test is called a third point loading test. The theoretical maximum tensile stress reached in the bottom fiber of the test beam is known as the modulus of rupture.

Fig. 5: Flexural Testing on Beam

The modulus of rupture is calculated on the basis of ordinary elastic theory, and is equal to PL/ (bd2), where p=maximum load on the beam, L=span, b=width of beam, d=depth of beam.

2) Split Tensile Strength Test on Cylinder:

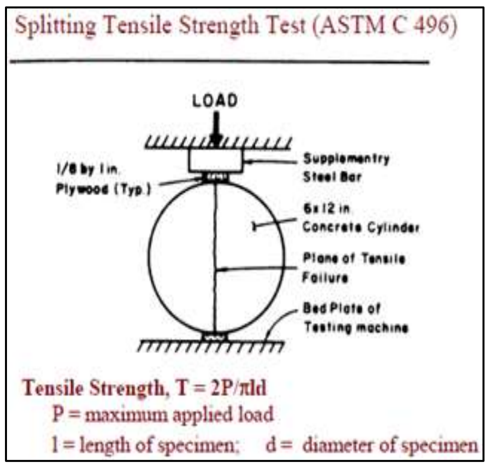

Fig. 6: Splitting Tensile Strength Test

The cylinder is of metal, 3mm thick. Each mould is capable of being opened longitudinally to facilitate the removal of the specimen and is provided with a means of keeping it closed while in use. The mean internal diameter of the mould is 15 cm ± 0.2 mm and the height is 30±0.1 cm. Each mould is provided with a metal base plate mould and base plate should be coated with a thin film of mould oil before use, in order to prevent adhesion of concrete. Diametric lines are drawn on each end of the specimen using a suitable device that will ensure that they are in the same axial plane. Centre one of the plywood strips along the centre of the lower bearing block. The specimen is placed on the plywood strip and aligned so that the lines marked on the ends of the specimen are vertical and cantered over the plywood strip.

A second plywood strip is placed lengthwise on the cylinder, cantered on the lines marked on the ends of the cylinder. Apply the load continuously and without shock, at a constant rate within, the range of 14-21kg/cm2/minute splitting tensile stress until failure of the specimen

The maximum applied load indicated by the testing machine at failure is noted.

V. RESULTS AND DISCUSSIONS

A. Compressive Strength of Concrete Cubes

Table – 3
Test Result of Compressive Cube Strength

Bottom Ash (%)	*0%*	*10%*	*20%*	*25%*	*35%*	*50%*
Compressive Strength of Cubes(N/mm^2)	*22*	*23.02*	*21*	*20.6*	*20.1*	*17.62*

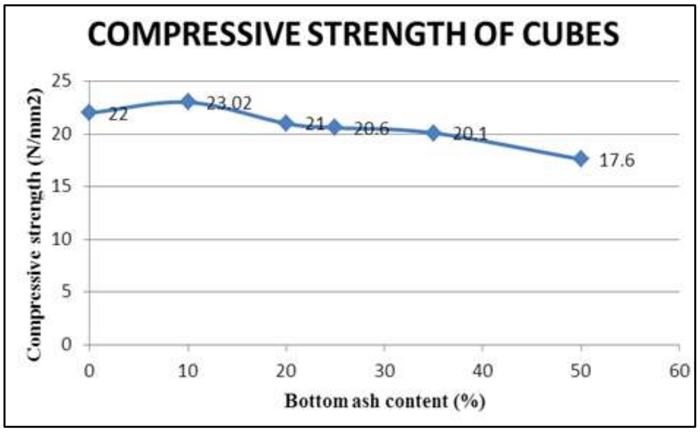

Fig. 7: Compressive Strength of Cubes

B. Compressive Strength of Cylinders

Table – 4
Test Result of Compressive Stregth of Cyclinders

Bottom Ash (%)	*0%*	*10%*	*20%*	*25%*	*35%*	*50%*
Compressive Strength of Cylinder (N/mm^2)	*18.67*	*19.02*	*16.8*	*16.56*	*15.1*	*12.89*

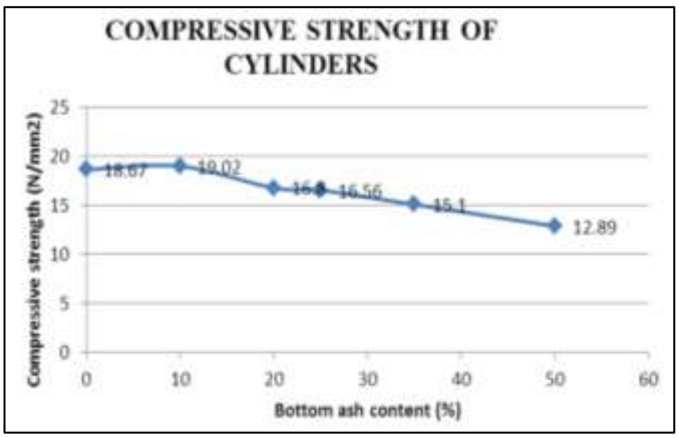

Fig. 8: Compressive Test of Cylinders

C. Flexural Strength Tests

Table – 5
Test Result of Flexural Stregth of Beams

Bottom Ash (%)	*0%*	*10%*	*20%*	*25%*	*35%*	*50%*
Flexural Strength(N/mm^2)	*8.34*	*8.01*	*7.65*	*7.33*	*6.21*	*5.76*

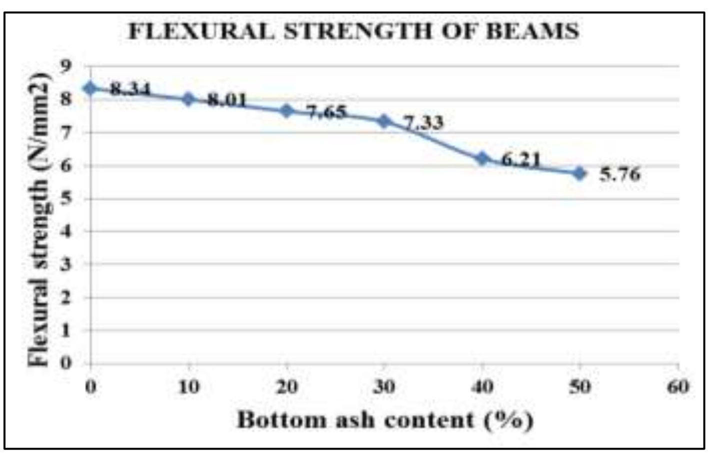

Fig. 9: Flexural Strength on Beams

D. Split Tensile Strength Test on Cylinder

Table – 6
Test Result of Split Tensile Stregth of Cylinders

Bottom Ash (%)	*0%*	*10%*	*20%*	*25%*	*35%*	*50%*
Split Tensile Strength(N/mm^2)	*1.83*	*2.53*	*1.76*	*1.7*	*1.67*	*1.55*

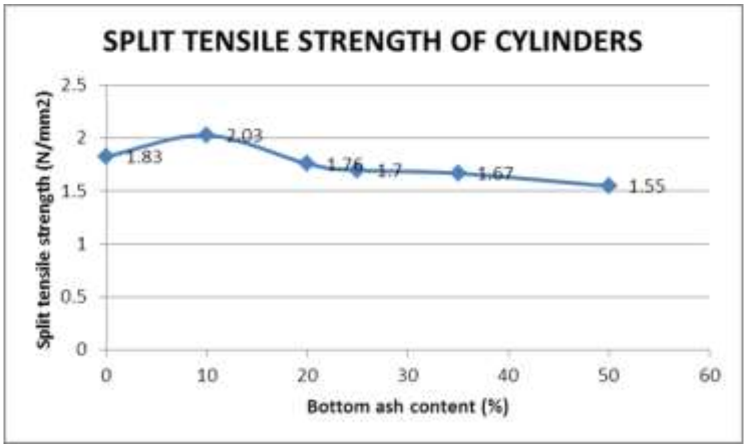

Fig. 10: Split Tensile Strength

Table – 7
Tabulated Results

Bottom ash (% replacement)	*0%*	*10%*	*20%*	*25%*	*35%*	*50%*
Compressive strength of cubes (N/mm^2)	*22*	*23.02*	*21*	*20.6*	*20.1*	*17.62*
Split Tensile Strength (N/mm^2)	*1.83*	*2.53*	*1.76*	*1.7*	*1.67*	*1.55*
Compressive strength of cylinder (N/mm^2)	*18.67*	*19.02*	*16.8*	*16.56*	*15.1*	*12.89*
Flexural Strength (N/mm^2)	*8.34*	*8.01*	*7.65*	*7.33*	*6.21*	*5.76*

VI. CONCLUSION

- 28-days compressive strength, split tensile strength and flexural strength of concrete with varying proportions of bottom ash were determined.
- Compressive strength, split tensile strength increased at 10% replacement of fine aggregate. Flexural strength gradually decreased at increasing percentage of bottom ash.
- Even though the strength development is less for bottom ash concrete when the percentage replacement is higher, it can be used in lower grade concrete.
- The utilization of waste material justifies the use of bottom ash in concrete mix.
- It can be seen that bottom ash can be used for the fine aggregate replacement upto 10% without affecting strength and higher percent replacement of fine aggregate can be used in low strength concrete.

Further detailed research on the subject is required to assess the exact properties and advantages obtained due to the use of bottom ash.

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REFERENCES

[1] Andrade L.B., J.C. Rocha, M. Cheriaf, (2009), "Influence of coal bottom ash as fine aggregate on fresh properties of concrete", Construction and Building Materials, Vol. 23,pp.609-614.
[2] Aggarwal P. , Aggarwal Y, Gupt S.M.,(2007), "Effect of bottom ash as Replacement of fine aggregates in concrete", Asian journal of civil engineering (building and housing),Vol. 8, no. 1 Pages 49-62.
[3] Chai Jaturapitakkul and Raungrut Cheerarot, (2003), "Development of Bottom Ash as Pozzolanic material", journal of materials in civil engineering, Vol.15, pp.48-53
[4] H.K.Kim, H.K. Lee, (2011), "Use of power plant bottom ash as fine and coarse aggregates in high- strength concrete", Construction and Building Materials, Vol.25, pp.1115-1122.
[5] IS: 383-1970.Specifications for coarse and fine aggregates from natural sources for concrete, Bureau of Indian Standards, New Delhi, India.
[6] IS: 10262-1982. Recommended guidelines for concrete mix design, Bureau of Indian Standards, New Delhi, India.
[7] IS: 516-1959.Indian standard code of practice methods of test for strength of concrete, Bureau of Indian Standards, New Delhi, India.