International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Performance of High Strength Concrete Prepared by Partially Replacing Fine Aggregate with Bottom Ash

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Abstract— *There is a scarcity in availability of natural aggregates due to the rapid development in construction technology. Nowadays extraction of natural aggregates from river beds, lakes and other water bodies have resulted in huge environmental problems. The best way to overcome this problem is to find alternative aggregates for construction in place of conventional natural aggregates. In order to overcome these problems, bottom ash is used as a replacement to fine aggregate. The study was carried out to evaluate the suitability of utilizing bottom ash as a partial replacement to fine aggregate in high strength concrete (M60 grade). Experiments were conducted by replacing fine aggregate with bottom ash in varying percentages 0%, 5%, 10%, 15%, 20%, 25% and 30%. Mechanical properties such as compressive strength, splitting tensile strength and flexural strength were evaluated. Test results indicated that bottom ash is suitable for improving the mechanical properties of concrete.*

Keywords— *Bottom ash, high strength concrete, mechanical properties.*

I. INTRODUCTION

Concrete is a widely used construction material around the world, and its properties have been undergoing changes through technological advances. So far, numerous types of concrete have been developed. Concrete is designated as "high-strength concrete" on the basis of its compressive strength measured at a given age. Any concrete mixtures that shows 40 MPa or more compressive strength at 28-days are designated as high-strength concrete. The main applications of HSC are in the construction of high-rise buildings and long-span bridges. HSC offers many advantages over conventional concrete. The high compressive strength can be advantageously used in compression members like columns and piles.

Bottom ash is the byproduct of coal combustion. The rock detritus filled in the fissures of coal become separated from the coal during pulverization. In the furnace, carbon and other combustible matter burns, and the non-combustible matter result in coal ash. Swirling air carries the ash particles out of hot zone where it cools down. The boiler flue gas carries away the finer and lighter particles of coal ash. The boiler flue gases pass through the electrostatic precipitators before reaching the environment. In the electrostatic precipitators, coal ash particles are extracted from the boiler flue gases. The coal ash collected from the electrostatic precipitators is called fly ash. Fly ash constitutes about 80% of coal ash. During the combustion process some particles of the coal ash accumulate on the furnace walls and steam pipes in the furnace and form clinkers. These clinkers build up and fall to the bottom of furnace. In addition, the coarser particles, which are too heavy to remain in suspension with the flue gases, settle down at the base of the furnace. The ash collected at the bottom of furnace is called coal bottom ash.

It is proposed to ascertain the optimum replacement of fine aggregate with coal bottom ash and to undergo a comparative study of mechanical properties of control mix with bottom ash mix.

II. MIX MATERIALS

The materials used in the project should confirm certain properties which are given below.

A. Cement

Cement is the well-known building material with adhesive and cohesive properties, which is capable of binding mineral fragment into compact mass. Ordinary Portland cement 53 Grade with properties as give in table has been used in this experimental study.

TABLE I. Properties of cement.

Physical Properties	Result
Specific gravity	3.15
Standard consistency	34 %
Initial Setting Time	120min

B. Bottom Ash

Coal bottom ash is a coarse granular and incombustible by product from coal burning furnaces. It is composed of mainly silica, alumina and iron with small amounts of calcium, magnesium sulfate, etc. Bottom ash conforming to grading Zone II are used in this experimental work.

TABLE III. Properties of bottom ash.

Properties	Result
Specific gravity	2.2
Water absorption	15%

Chemical Composition

The test result was obtained from sophisticated test and instrumentation centre (STIC), Kalamassery Ernakulum.

TABLE III. Chemical properties of bottom ash (BA).

S. No	Element	Mass (%)
1	C	15.04
2	O	60.27
3	Al	9.02
4	Si	12.62
5	K	0.64
6	Ti	0.71
7	Fe	1.69

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C. Fine Aggregates

Aggregates mainly passing through 4.75 mm IS sieve and and retained on 75 microns IS sieve is permitted for fine aggregates. Aggregates conforming to grading Zone II are used in this experimental work.

TABLE IV. Properties of fine aggregate.

Properties	Result
Specific gravity	2.74
Water absorption	1.5%

D. CoarseAggregates

Aggregate which passes through 75 mm IS sieve and retained on 4.75 mm IS sieve is used as coarse aggregate. Coarse aggregates containing flat, elongated or flaky pieces should be rejected. Aggregates conforming to grading Zone II are used in this experimental work.

TABLE V. Properties of coarse aggregate.

Properties	Result
Specific gravity	2.74
Water absorption	0.8%

E. Alccofine

Alccofine used in this study is a product based on slag of high glass content with high reactivity obtained through the process of controlled granulation. Alccofine is used as an additive for the design of high strength concrete for improving the strength Alccofine used in this work has a specific gravity of 2.9.

F. Super plasticizer (SP)

MasterGlenium SKY 8233 was used as superplasticizer for the study. It is an admixture based on modified polycarboxylic ether. The product has been primarily developed for applications in high performance concrete where the highest durability and performance is required. It is free of chloride and low alkali. It is compatible with all types of cements.

G. Water

Water used for the study was free of acids, organic matter, suspended solids, alkalis and impurities when present may have adverse effect on the strength of concrete. Potable water with pH value 7 conforming to IS: 456-2000 is used for casting as well as curing.

III. MIX PROPORTION

For concrete of compressive strength greater than M55, design parameters given in the Indian standard may not applicable and the values may be obtained from specialized literatures and experimental results. Here, the mix design was made by referring National Ready Mixed Concrete Association (NRMCA) journal and seeking the expert advice from Neptune RMC plant, Kalamassery. The Nomenclature for mixes used in the study is given in table VI.

TABLE VI. Nomenclature.

Mix	Concrete Mix Proportion
CM	Normal HSC mix
BA 0	HSC with 0 % replacement of fine with Bottom Ash
BA 5	HSC with 5 % replacement of fine with Bottom Ash
BA 10	HSC with 10 % replacement of fine with Bottom Ash
BA 15	HSC with 15 % replacement of fine with Bottom Ash
BA 20	HSC with 20 % replacement of fine with Bottom Ash
BA 25	HSC with 25 % replacement of fine with Bottom Ash
BA 30	HSC with 30 % replacement of fine with Bottom Ash

Different mixes were prepared by replacing fine aggregate with bottom ash. The mix designs of HSC and HSC with replacement are shown in table VI and table. VII

TABLE VII. Mix Proportion of normal HSC mix.

Mix	Cement (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Water (kg/m^3)	Alccofine (kg/m^3)	SP (kg/m^3)
HSC	450	786.4	1132	165	22.5	2.37

TABLE VIII. Mix Proportion of HSC Mixes with replacements.

Mix	BA 0	BA 5	BA 10	BA 15	BA 20	BA 25	BA 30
Cement (kg/m^3)	450	450	450	450	450	450	450
FA (kg/m^3)	786.4	747.1	707.7	668.4	629.1	589.8	550.5
BA (kg/m^3)	0	31.57	63.14	94.71	126.3	157.9	189.4
CA (kg/m^3)	1132	1132	1132	1132	1132	1132	1132
Water (kg/m^3)	165	165	165	165	165	165	165
Alcoofine (kg/m^3)	22.5	22.5	22.5	22.5	22.5	22.5	22.5
SP (kg/m^3)	2.37	2.53	2.59	2.67	2.74	2.81	2.88

IV. RESULTS AND DISCUSSIONS

A. Optimum Replacement of Bottom Ash

In order to determine the optimum replacement percentage of fine aggregate with coal bottom ash 3 day, 7 day and 28 day compressive strength of the resulting mixes were obtained

TABLE IX. Check for compressive strength.

Mix	Compressive strength (N/mm^2)			Slump (mm)
	3 Day	7 Day	28 Day	
BA 0	42.07	53.47	70.66	110
BA 5	42.1	53.9	71.1	110
BA 10	42.4	54	72.89	106
BA 15	43	54.8	74.2	105
BA 20	43.7	55.7	75.26	100
BA 25	43.1	55	73.56	90
BA 30	40.9	53.3	71.56	80

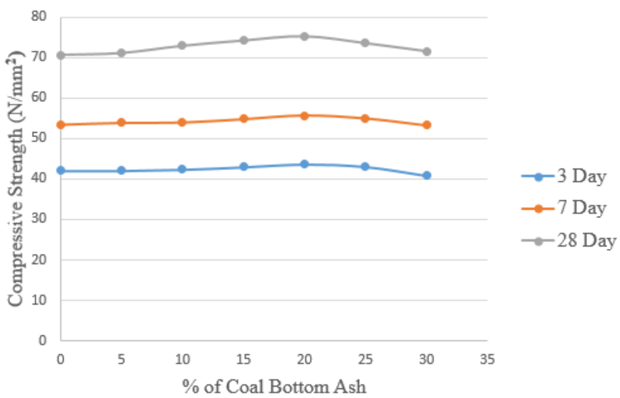

Fig. 1. Compressive strength for various percentage of bottom ash.

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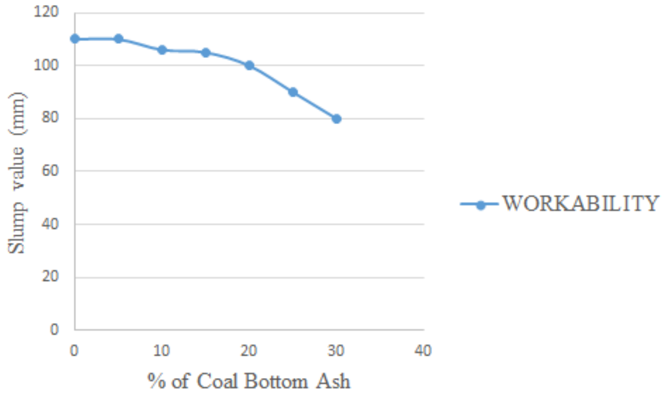

Fig. 2. Workability for various percentage of bottom ash.

The optimum replacement percentage of fine aggregate with coal bottom ash is found to be 20% (Figure 1). From figure 2, it is clear that the workability of concrete decreases with the increase in bottom ash content. It can be due to the extra fineness of bottom ash as the replacement level of fine aggregates is increased. Thus, increase in the specific surface due to increased fineness and a greater amount of water needed for the mix ingredients to get closer packing, results in decrease in workability of mix.

The mechanical properties such as compressive strength, flexural strength and split tensile strength were carried out in the laboratory. The compressive strength is measured using cube of size 150mm × 150mm × 150mm at 3, 7 and 28 days of curing. The Split tensile strength is conducted on cylinder of size 300 mm × 150 mm at 7 and 28 days of curing.The flexural strength of concrete is conducted on beam of size 100 mm × 100 mm × 500 mm at 7 and 28 days of curing. Table VIII, Table IX and Table X shows compressive, flexural and splitting tensile strengths of various mixes.

B. Control Mix

TABLE X. Compressive strength of CM.

Average Compressive Strength (N/mm^2)				
3 Day	7 Day	28 Day	56 Day	90 Day
42.07	53.47	70.66	79.65	82.78

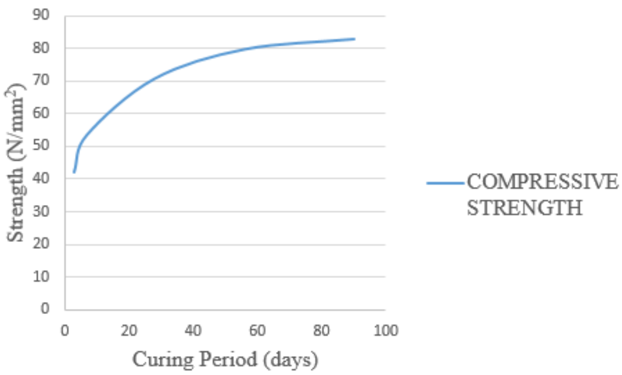

Fig 3. Compressive Strength of control mix.

TABLE XI. Splitting tensile strength of CM.

Average Splitting Tensile Strength (N/mm^2)	
7 Day	28 Day
3.04	4.03

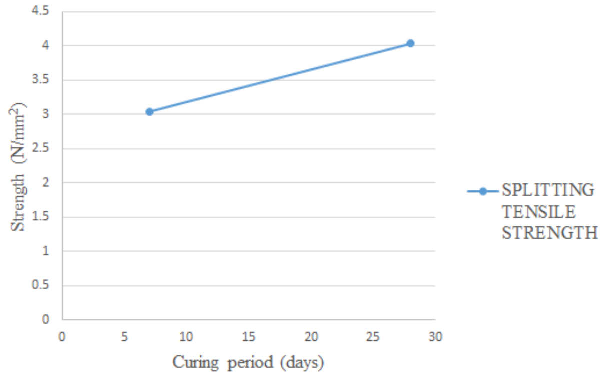

Fig. 4. Splitting tensile strength of control mix.

TABLE XII. Flexural strength of CM

Average Flexural Strength (N/mm^2)	
7 Day	28 Day
8.67	11.5

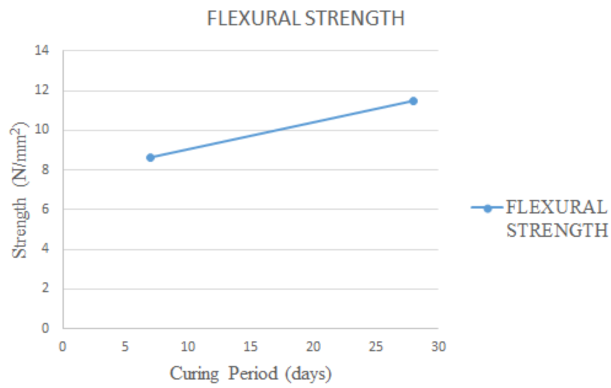

Fig. 5. Flexural strength of control mix.

C. Bottom Ash Mix

TABLE XIII. Compressive strength of BA mix.

Average Compressive Strength (N/mm^2)				
3 Day	7 Day	28 Day	56 Day	90 Day
43.7	55.7	75.26	82.07	84.74

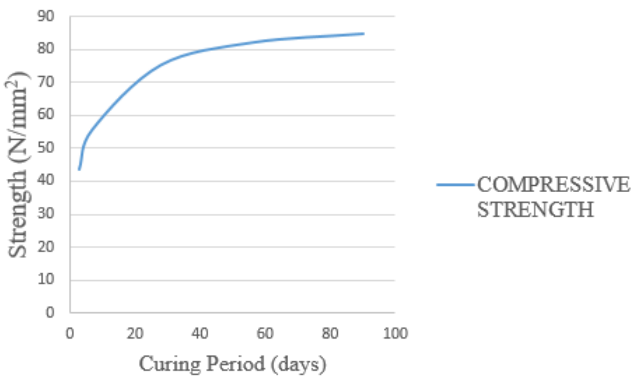

Fig. 6. Compressive strength of bottom ash mix.

TABLE XIV. Splitting tensile strength of BA Mix.

Average Splitting Tensile Strength (N/mm^2)	
7 Day	28 Day
3.49	4.6

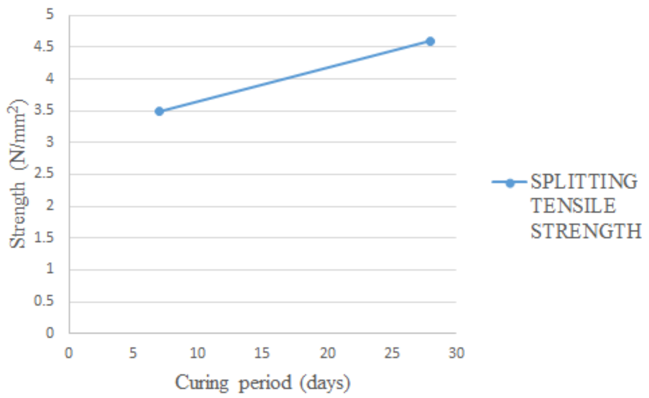

Fig. 7. Splitting tensile strength of bottom ash mix.

TABLE XV. Flexural strength of BA Mix.

Average Flexural Strength (N/mm2)	
7 Day	28 Day
9.42	12.42

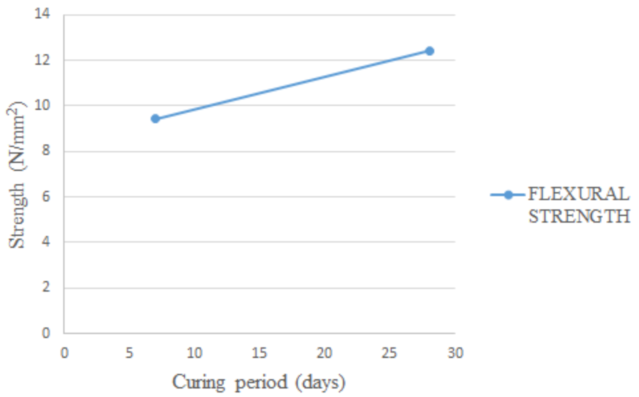

Fig. 8. Flexural strength of bottom ash mix.

D. Comparison of Control Mix and Bottom Ash Mix

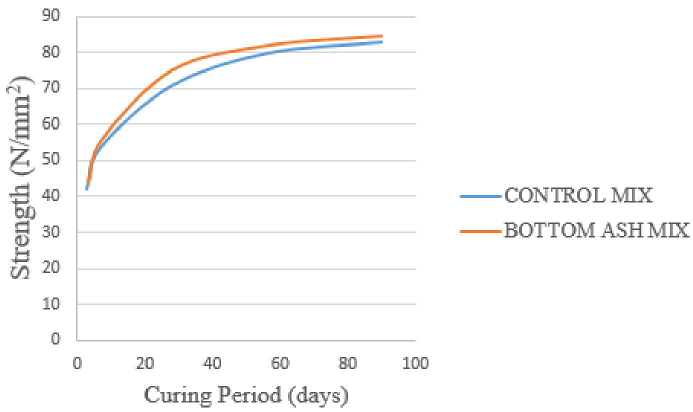

Fig 9. Comparison of compressive strength.

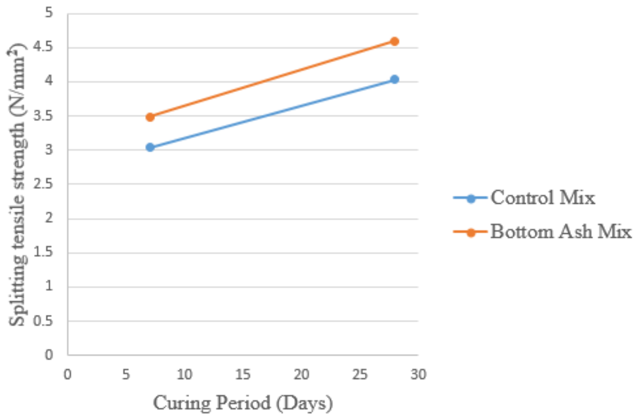

Fig. 10. Comparison of splitting tensile strength.

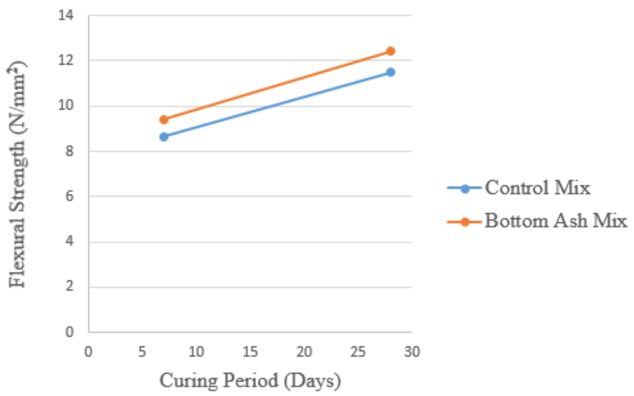

Fig. 11. Comparison of flexural strength.

V. CONCLUSION

The study was carried out to evaluate the suitability of utilizing bottom ash as a partial replacement to fine aggregates in M60 grade concrete. Experiments were conducted by replacing fine aggregate in varying percentages 0%, 5%, 10%, 15%, 20%, 25% and 30%. Mechanical properties such as compressive strength, splitting tensile strength and flexural strength were evaluated. Test results indicated that bottom ash is suitable for improving the mechanical properties of concrete. The following conclusions were arrived at.

- The workability of concrete decreased with the increase in bottom ash content. It was due to increased fineness of bottom ash and a greater amount of water needed for the mix ingredients to get closer packing. Increase in water demand was incorporated by increasing the content of superplasticizer.
- The optimum replacement percentage of fine aggregate with bottom ash was found to be 20%.
- Compressive strength for 3, 7 and 28 days were increased up to 20% replacement and after that gradually decreased for further replacement.
- Bottom ash mix showed about 3.9%, 4.2% and 6.5 % increase in the 3 day, 7 day and 28 day compressive strength as compared to control mix

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- There was a slow rate of increase in the 3 day and 7 day compressive strength due to the slow pozzolanic action of bottom ash.
- Bottom ash mix showed about 14.8% and 14.1 % increase in the 7 day and 28 day splitting tensile strength as compared to control mix
- Bottom ash mix showed about 8.7% and 8 % increase in the 7 day and 28 day flexural strength as compared to control mix
- Mix containing 20% bottom ash, at 56 and 90 days, attained the compressive strength equivalent to 116% and 119% of compressive strength of normal concrete at 28 days

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