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Partial Replacement of Fly Ash & Modified Bottom Ash as a Cement & Fine Aggregates in Concrete

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Abstract. *This study envisaged the application of Bottom ash as a replacement of fine aggregate. In this study, bottom ash is thoroughly mixed with a PC-based High range superplasticizer (HRSP) having solid content more than 60%, this sand is called as modified bottom ash (MBA are mixed at doses of 0%, 0.25%, 0.5%, 0.75%, and 1% by weight of bottom ash. This prepared bottom ash is referred to as modified bottom ash (MBA). MBA is substituted for fine aggregates in ordinary concrete in varying amounts from 0 to 50% by river sand and the concrete has been tested for Compressive strength, flexural strength, split tensile strength, and other durability characteristics it has been found that 10% MBA produce superior outcomes, the purpose of use was not achieved. Therefore, MBA has been increased up to 60% replacement with fine aggregates, the strength and durability properties achieved for concrete produced by 50% MBA with fine aggregate (sand) are compared to 100% fine aggregate (sand) concrete and has observed similar results due to addition of HRSP. In the end, it can be concluded that High Range Superplasticizer HRSP is quite efficient for replacing Bottom ash with fine particles.*

Keywords: *Modified Bottom Ash (MBA), High Range Superplasticizer*

1 Introduction

Natural resources are in high demand in the recent years as the construction industry expands rapidly. The primary component of the construction industry is cement, which is a major contributor to CO2 emissions into the atmosphere, a greenhouse gas that contributes to global warming[1]. Cement production accounts for approximately 90% of industrial CO2 emission [2].On the Other hand, the power production industry is expanding at a rapid pace, this impact on the environment, animal life, and human existence for future generations will result in waste material release and harm to Sustainable Development goals. So, In this study using power plant industrial waste as a cement replacement would reduce the environmental impact by reducing cement production, lowering production and construction cost[3].

More than 11 billion tons of concrete are estimated to be manufactured globally each year [4]. The aggregate market is expected to expand at a 5.2% annual rate [5]. One of the ingredients, river sand, is a high-quality building material. [6]. This uncontrolled extraction destroys the river environment and various aquatic life species [7], [8]. The existing alternative solution of crushing quarried stone to fine aggregate also harms the environment[9], making it unsuitable for sustainable construction[10]. Although a significant amount of fly ash has already been used in the construction industry as a partial cement replacement and/or mineral additive in cement production, the use of bottom ash is limited due to its higher unburned carbon content and different structural properties than fly ash[11]. BA, a fine gravel-sized material collected at the bottom of the boiler, is commonly used as a low-cost replacement material, and its use is limited by IS Codes.

Many studies have been conducted on the replacement of fly ash with cement incorporating various ranges of Superplasticizer for finding out the mechanical and durability properties. Compressive strength development and flexural strength of fly ash concrete decreased as fly ash percentage increased, though the decrements were not consistent over time[12]–[14].By the use fly ash up to 50% found maximum flexural strength after 90 days i.e. 7.30 MPa [15], without the use superplasticizer the greatest strength reduction was at 7 days with smaller reduction at 28 days but subsequent increase in the strength at 365 days[16].As with 2% superplasticizer dosage and 60% Fly ash Replacement showed a 10% , 3.6% and 2.9% reduction at 7 ,28 and 365 days compared to 50% fly ash[14].Use of fly ash up to 20% with combined replacement of other materials such as Slag[17], Rice husk ash[18] and Nano-Silica[19].

Many researchers reported that combination of suitable amount of bottom ash enhance the compressive strength[20]–[24].Replacement of bottom ash advances compressive up to 10% in conventional concrete[25], [26]. Bottom ash in the range of 5 to 20% integrated as sand replacement exceeding the compressive strength up to 30MPA at the age of 28 days[27] [28]. Mix containing 25% Bottom Ash being slightly higher strength than rest of the mixes with varying SP[29].

2 Materials

In this investigation, Ultra-tech OPC 53 grade of cement that complied with IS 12269: 2013 was used. Before usage, Fly ash & Bottom ash was obtained from the Dhariwal Power Plant, Chandrapur and assessed in accordance with the standards outlined in IS 3812:2013 (Part-II) / ASTM C618[30]. Table 1 displays the physio-chemical analysis of cement and FA. In Pachgaon, Maharashtra, local sellers provided crushed basalt rock with maximum size of 20mm and River sand was collected from Kanhan River that complied with IS 383: 2016[31]. The following list includes aggregate physical characteristics.

Table 1. Chemical Composition of Materials:

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	Na_2O	TiO_2	SO_3	LOI
Cement	19.6	8.48	6.32	58.7	0.26	0.76	0.23	0.36	1.96	3.1
FA	52.32	26.29	5.96	5.83	0.81	1.57	0.04	1.66	0.45	4.48
BA	42.18	29.04	24.12	2.12	0.23	1.76	-	0.07	-	-

Table 2. Physical properties of Fine and Coarse Aggregate

Properties	River sand	10mm	20mm	Bottom Ash
Specific Gravity	2.63	2.89	2.94	1.96
Water absorption (%)	1.02	1.21	1.12	12.08
Crushing Value (%)	-	25.62	26.84	-
Impact Value (%)	-	6.75	6.20	-
Bulk Density (Kg/m3)	2693	2412	2390	1540
Clay Content (%)	0.097	-	-	0.75
Soundness (Na2So4)	9.6	8.7	8.9	-
Alkali aggregate Reaction (%)	0.085	0.081	0.04	-

2.1 Development of Modified Bottom Ash

Modified Bottom Ash is prepared by mixing bottom ash with high solid content poly-carboxylate ether (HSPCE) in the varying proportion 0.25 %, 0.5 %, 0.75% & 1% of weight of bottom ash.

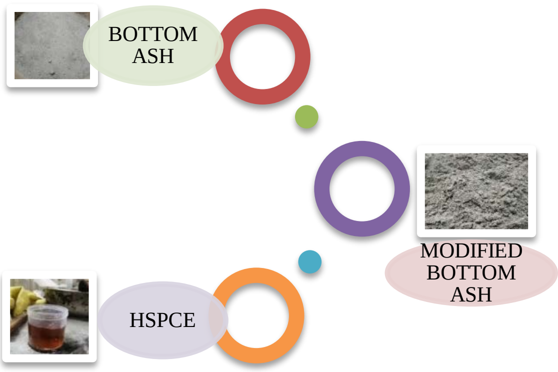

Figure 1. Process of Preparation of Modified bottom Ash

3 Experimental Methodology

216 Nos of cubes of size 150 mm x 150x150 mm, 36 Nos of cylinder 150 mm diameter x 300 mm height cylinders, and 36 Nos of 100 mm x 100 mm x 500 mm prisms were casted to evaluate compressive strength, split tensile strength, flexural tensile respectively. Also, workability of the concrete was tested using a slump cone. After 24 hours, all of the concrete specimens were carefully removed and placed in water for curing at 27 º C ± 2 º C for 7, 28, and 90 days.

4 Results and Conclusion

4.1 Test on Fresh Concrete

The fresh concrete properties of NCC and MBA were determined in terms of slump value and fresh density (unit weight) during casting. To examine the workability behavior of all types of concrete, the slump value of each concrete mix was initially examined at different dosages of high solid content poly-carboxylic ether (HSPCE) i.e. varying from 0 to 1% by weight of bottom ash as mentioned in the preparation of bottom ash.

Figure 2. Workability Test of Fresh Concrete

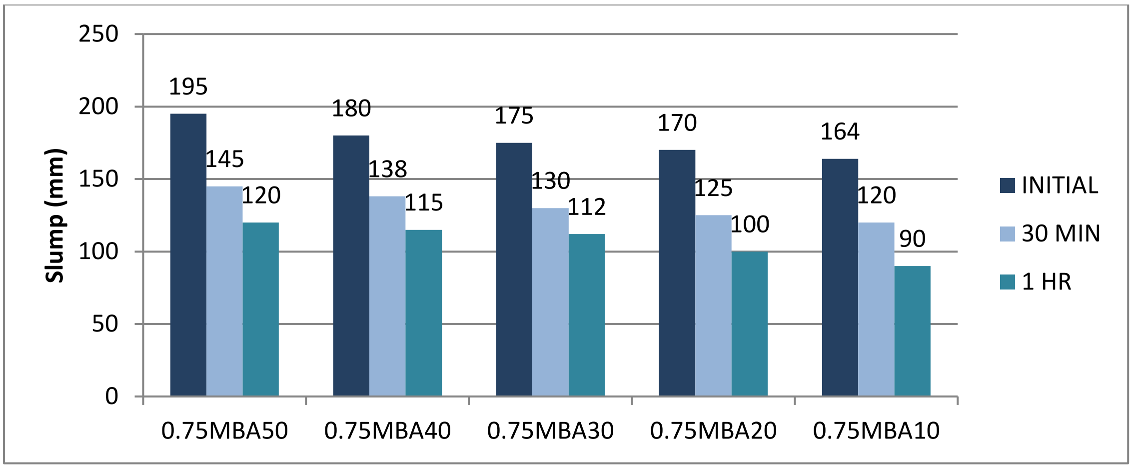

Figure 3. Variation of Slump with % of HSPCE and % of Replacement of MBA

4.2 Test on Hardened Concrete

4.2.1 Compressive Strength

The compressive strength (CS) findings of NCC and MBA (with or without bottom ash) at 7, 28 and 90 days of curing designed by codal approaches. As can be noticed, the compressive strength of all concrete mixtures enhanced as the curing ages increased. The variations in compressive strength of the concrete mixes showed a similar trend in both of the mix design methods. At Curing ages, MBA with fly-ash increased compressive strength in all stages. The 7, 28 and 90 days compressive strengths are shown.

Table 3. Compressive Strength at 28 Days

28 Days Compressive Strength (MPa)						
% of SP	Natural Sand	MBA 10	MBA 20	MBA 30	MBA 40	MBA 50
1 % HSPCE	41.23	61.02	60.41	56.06	48.60	43.87
0.75 % HSPCE	40.53	51.47	50.59	48.73	44.58	43.33
0.50 % HSPCE	39.95	46.72	44.46	43.67	40.35	37.60
0.25 % HSPCE	38.5	44.53	42.57	42.57	38.47	36.53
0 % HSPCE	37.56	42.37	39.42	38.20	36.56	34.53

*28 days Strength are average of 3 numbers of cubes

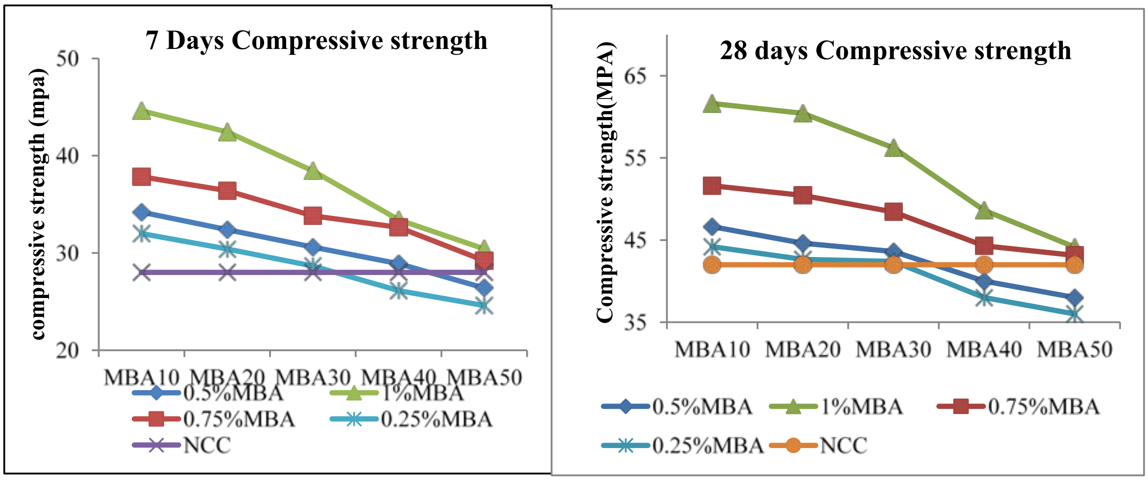

Figure 4. Compressive Strength of Cubes at 7 Days & 28 Days

4.2.2 Tensile Strength

The tensile strength properties of the studied concrete were assessed in terms of split tensile strength (STS) and flexural tensile strength (FTS). Fig. and 9 highlight the results of STS and FTS of all concrete mixtures after 28 days of curing respectively. Analyzing the data, one can observe that the STS and FTS behavior of concrete mixtures followed a similar trend as of CS. The highest STS and FTS were observed in the case 0.75MBA50 in comparison to NAC. This is most likely due to MBA rough surface area and intrinsic strength, which allows it to mechanically interlock with cement paste in concrete, increasing tensile strength. Since tensile strength is the main parameter that controls the first cracking and progression of crack growth, these findings indicated that the application of modified bottom ash-based results might be beneficial in structural member. This is because addition of HSPCE in bottom enhances the solids contents of the mixtures, which promotes particle interlock and consequently improves the tensile properties of concrete

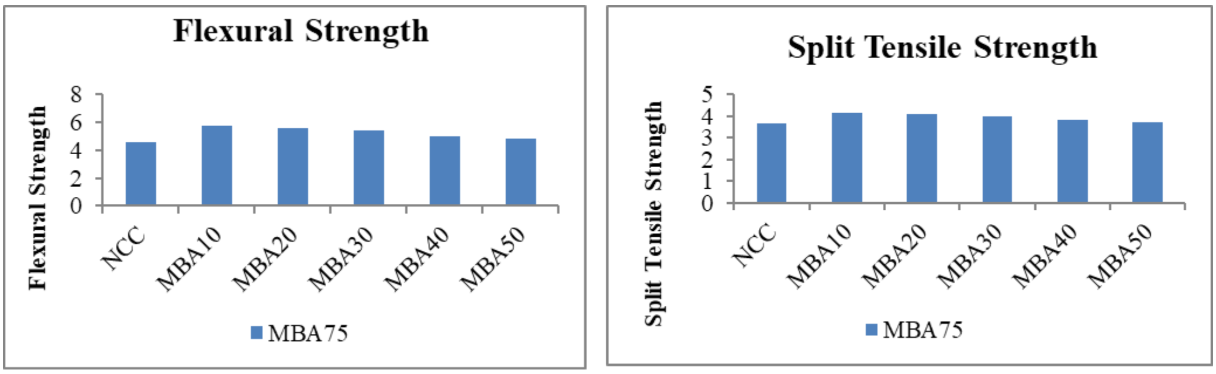

Figure 5. Flexural Strength and Split Tensile Strength

4.2.3 Relation between Tensile Strength and Compressive Strength

The correlation between tensile strength (STS and FTS) and compressive strength of concrete was investigated using empirical formulae published in different codes or literature, as shown in Table. A correction factor of 0.8 is followed to convert the cube strength to cylinder strength. Fig depicts the relationship between STS and compressive strength of concrete. A good correlation with R^2 as 0.98 was obtained from the regression analysis between the experimental STS and computed STS obtained from ACI 318 (2011).

Where, *fsp* = Split tensile strength at 28 days in MPa, *ft* = Flexural tensile strength at 28 days in MPa, *fc*=cube compressive strength at 28 days in MPa and *f'c* = cylinder compressive strength at 28 days in MPa

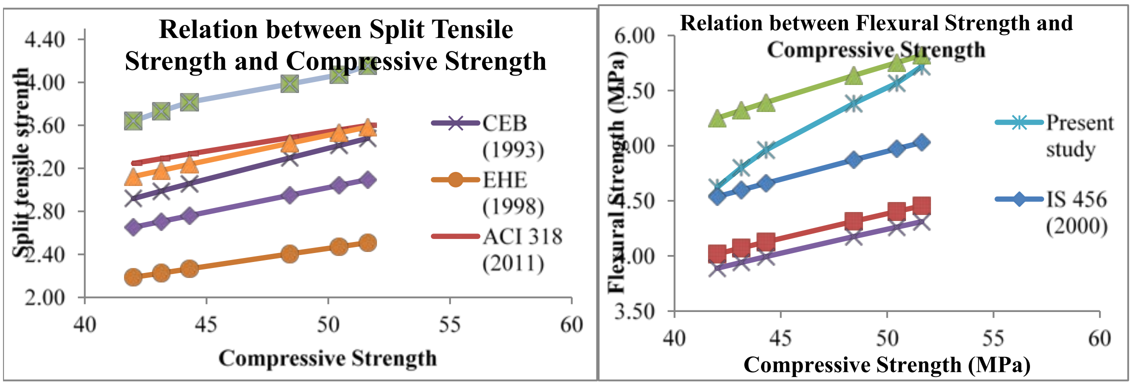

Figure 6 & 7. Relation between Split Tensile Strength and Compressive Strength

Similarly, comparing the experimental findings of FTS set with different established relations it was found that the present FTS data follow a similar pattern to the estimated results obtained using IS: 456 (2000) code formulation with a strong correlation coefficient R^2 of 0.97. However, the other formulae overestimate or underestimate the FTS values.

4.2.4 Rapid Chloride Penetration Test

Concrete deteriorates over time and measures to prevent such damage are required to increase the durability of concrete structures. Frozen and thawed concrete, alkali-aggregate reaction (AAR), aggressive chemical exposure, metal corrosion, abrasion, fire resistance of concrete, and cracking should all be considered at all stages. Predicting the service life of concrete structures and Quality control is based on durability of concrete. Therefore, Rapid ion chloride test is carried out. Reading of 100–1000 coulombs are indicative of "Very Low" chloride ion permeability.

Table 4. RCPT Analysis

Normal Conventional Concrete Block	Initial Reading	30 min	60 min	90 min	120 min	150 min	180 min	210 min	240 min	270 min	300 min	330 min	360 min
	5.7	5.6	5.9	6.8	6.4	7.0	6.5	6.4	6.8	7.4	7.1	6.9	6.2
	142												
75MBA50 Block	Initial Reading	30 min	60 min	90 min	120 min	150 min	180 min	210 min	240 min	270 min	300 min	330 min	360 min
	8.6	6.3	5.1	4.6	4.3	4.8	3.2	2.8	3.0	2.8	2.7	2.4	2.6
	86												

4.2.5 Acid Attack

Concrete is more vulnerable to acid attack owing to its high alkaline content. The consequence of sulphuric acid attack on concrete is more aggressive and damaging, since it includes the combined impact of acid and Sulphate attack. In the following subsections, the combined effect of alternative materials mix design on acid resistance in terms of compressive strength loss is addressed.

4.2.6 Loss in Compressive Strength

The loss of CS after 28 days and 90 days immersing period for the studied concrete mixes are depicted in Fig. All concrete mix specimens' CS losses are calculated as a percentage of their respective concrete mix's 28-day water-cured specimens. Regardless of concrete type, the loss in CS for all concrete specimens increases the immersion time advances. The loss of strength at 28 days exposure of cubes 0.75MBA10, 0.75MBA20, 0.75MBA30, 0.75MBA40, 0.75MBA50 and NCC are Reported below.

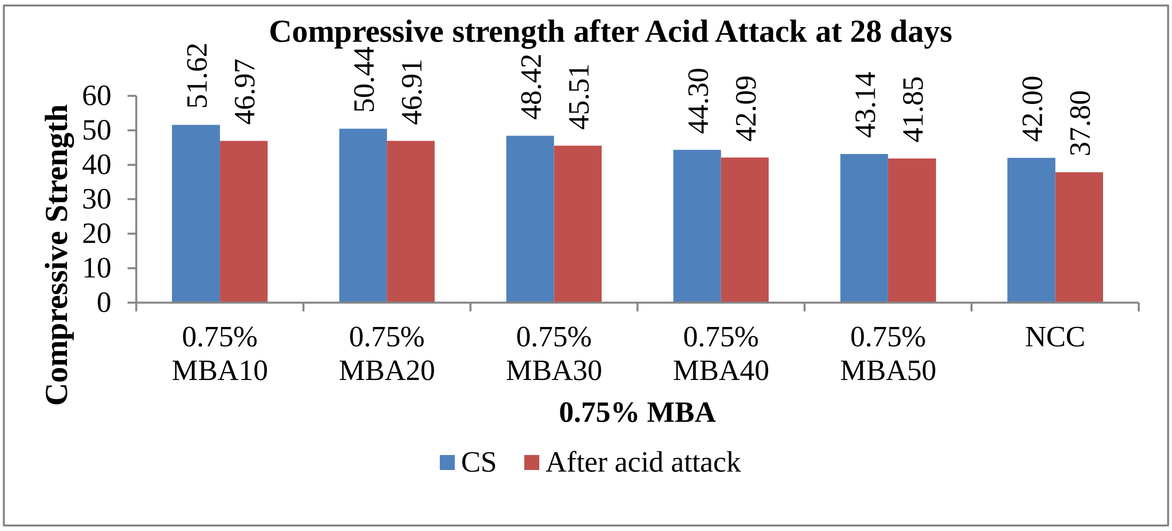

Figure 8. Compressive Strength after Acid Attack

4.2.7 Abrasion

The contact and opposite faces of the specimen was placed parallel and flat to determine the thickness reduction, as described in Annexure E-4 [32]. After 16 cycles of testing, the abrasive wear of the specimen were calculated as the mean loss in specimen volume ΔV using the equation:

$$\Delta V = \frac{\Delta M}{PR}$$

Where, ΔV = Volumetric loss of sample after 16 cycles in mm^3,
Δm = Loss in mass after 16 cycles in g, and
PR = Density of the sample in g/mm^3

Figure 15. Abrasion Resistance Test Samples

Trial	Abrasion Resistance
Conventional	1642
0.1MBA50	1931
0.75MBA50	1725
0.5MBA50	1675

Table 5. Results of Volumetric Loss

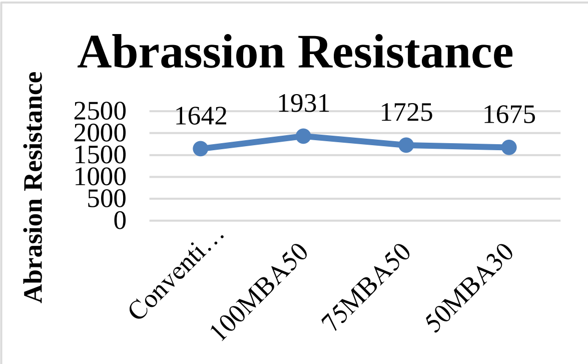

Figure 9. Results of Volumetric Loss

5 Conclusion

1. In this study, results shows that optimum amount of replacement of MBA by rivers sand is upto 50%. Beyond 50% the compressive strength is decreasing.
2. The split tensile strength and flexural strength also shows satisfactory results when 50% of natural river sand is replaced with 0.75% MBA in the mix
3. Durability tests, including RCPT, acid resistance test, and abrasion resistance test, were conducted using a 50% replacement of sand with 0.75% MBA. The results of these tests indicate that the concrete specimens meet the durability requirements of normal conventional concrete (NCC). Therefore, it is proposed that a replacement of up to 50% of 0.75% MBA is suitable for achieving varying concrete requirements such as slump, compressive strength, flexural strength, as well as durability tests including RCPT, acid resistance, and abrasion resistance.

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