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Original Article

Exploring the Feasibility of Unprocessed Lignite Bottom Ash as A Fine Aggregate in Cement Mortar

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Abstract - *The possibility of using bottom ash and their combination as a fine aggregate in mortar was studied by performing experiments. These materials were used without applying any preprocesses, such as sieving and grinding. The physical and mechanical strength studies on mortar with natural sand replaced with bottom ash at 10, 20, 30, 40, and 50% were examined at constant workability. Test results showed that it can be seen in cement mortar 1:2, 1:3, and 1:5, 1:6 that up to 20% replacement of sand by bottom ash increases and compressive strength decreases gradually compared to reference mix, which may be due to filler effects of bottom ash. In addition, The mortar strength of all mixes considered in the study (i.e., 1:2, 1:3 and 1:5, 1:6) for all replacement levels of sand (within the range considered in this study) satisfies the average compressive strength of cement mortar of comparable mix proportion as IS Specification, Hence, bottom ash can be used with confidence as masonry mortar.*

Keywords - *Cement, Bottom ash, Fine aggregate replacement, Mechanical properties, Masonry mortar.*

1. Introduction

The escalating demand for construction materials, coupled with a decline in the supply of traditional raw materials, has necessitated the exploration of novel alternatives to mitigate construction costs. In response to this challenge, there is a growing imperative to identify and develop new materials utilizing locally available industrial wastes and by-products. However, this pursuit must not compromise the essential attributes of strength and durability in construction materials. While conventional scientific investigations have predominantly focused on the beneficial applications of fly ash-a prominent waste product from thermal power stations-less attention has been directed towards exploring the potential of another significant by-product, namely ‘bottom ash.’ Comprising approximately one-third of the total waste generated by thermal power plants in India, bottom ash poses disposal and environmental challenges. Despite the proliferation of thermal power plants in the post-independence era, international and national research efforts have yet to explore the practical applications of bottom ash comprehensively.

The dearth of substantial studies on the utilization of bottom ash highlights a significant research gap. Currently, bottom ash is commonly disposed of as aqueous slurry or in dry form, contributing to environmental concerns in the surrounding areas. If effectively repurposed in the construction industry, bottom ash could not only fulfil the objective of reducing construction costs but also address the environmental and disposal challenges associated with its current management. This research seeks to bridge the existing gap by comprehensively investigating the potential applications of bottom ash in construction materials. By doing so; the study aims to contribute valuable insights that surpass the predominant focus on fly ash, offering a holistic solution to the disposal and environmental problems linked to thermal power plant wastes. Through a thorough review of existing literature, this work will establish the novelty of its approach and demonstrate how the proposed research significantly extends beyond the scope of previous findings.

2. Properties of Bottom Ash

2.1. Bottom Ash

For the present study, about 500 kg of bottom ash was collected from Neyveli Lignite Corporation, Thermal Power Station-1 (Expansion). Various tests, like the physical and mechanical properties of the bottom ash, were carried out in the laboratory.

2.1.1. Sieve Analysis of Bottom Ash

The appearance of the collected bottom ash sample indicates that the particle size lies between sand and cement. For determining the fineness of bottom ash, dry sieve analysis was conducted as per the IS method, and it was observed that 24% of the sample of bottom ash collected had particle sizes less than 150 microns.

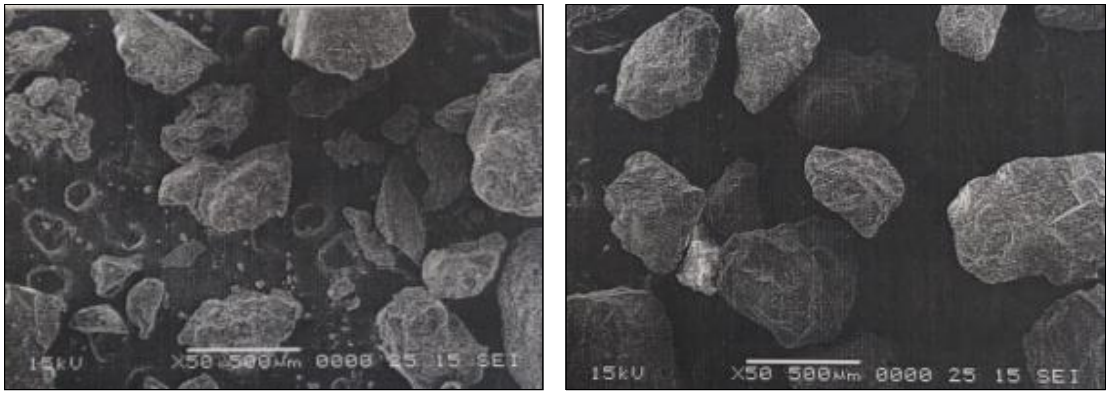

Fig. 1 Scanning Electron Microscope of bottom ash and rive sand

Hence, sieve analysis indicates that the bottom ash passing through 75 microns is 10%, and that of 150 microns is 4.6%. From the above results of the sieve analysis, it was decided to replace the natural partially fine aggregate with bottom ash, and the Fineness modulus 2.65 and 0.982 is reported.

2.1.2. SEM Analysis of Bottom Ash

In order to understand the chemical constituents of the bottom ash, a Scanning Electron Microscope analysis of the sample was conducted at the Center for Central Instrumentation Facility, Pondicherry University, Puducherry. SEM analysis of bottom ash and river sand photographs are given (Figures 1(a) and 1(b)).

3. Cement

Ordinary Portland cement (Priya 53 grade) was used throughout this investigation. Various properties of the cement determined as per IS: 12269-1987. The results indicate that the sample satisfies the requirements of IS specification.

3.1. Fine Aggregate

Locally available river sand and bottom ash are the fine aggregates used in the mortar. Before sieve analysis, the sand was air dried and tested, and the properties of the sand were tested as per IS: 2386-1963.

4. Preparation of Mortar

In order to compare the suitability of bottom ash to be used in cement mortar applications, 1:2, 1:3, 1:5 and 1:6 mix proportions were considered. In the above reference mortar proportions, bottom ash was used to replace partially sand (by weight), from 0 to 50%. A total of 24 types of mixes were selected to study the strength aspects of bottom ash mortar with standard moulds of 50 sqcm area (70.5x70.5x70.5mm) used for preparing the mortar cubes. For each type of mix, nine mortar cubes were cast (i.e., to get the average strength, three specimens were considered for each age (i.e., at 7 days, 28 days, and 45 days of curing, respectively). Cement, bottom ash, and sand required for preparing mortar mixes were taken (by weight) according to the proportion (1:2, 1:3, 1:5 and 1:6) and thoroughly mixed.

4.1. Workability of Mortar

4.1.1. Flow Table Test

In order to prepare specimens for compressive strength initially, the blends have to be tested for their flow, based on which the water content for preparing mortar cubes has to be decided. Flow test was conducted in accordance with IS: 1727-1967. For maintaining constant workability for all mixes, quantities of water added were tried until a flow value of 105±5% (constant value) was achieved and maintained. After adding the required amount of water, mixing was done in the mechanical mixer as specified in IS: 1727-1967. After mixing, the mortar was smoothly transferred into the mould in three stages and compacted with the help of a tamping rod. After casting, the top surface is levelled with a small trowel. The specimens were then demoulded after 24 hours, weighed, and immersed under water for 7, 28 and 45 days. After corresponding days of curing, the specimens were weighed carefully, and a smooth loading surface was provided before testing. The mortar cubes were tested in a 3000KN compressive testing machine by applying the load at a constant rate under controlled conditions. The details of mix proportions used in the study partially replacing sand to determine flow value and water requirement of mortar are given in Figure 2.

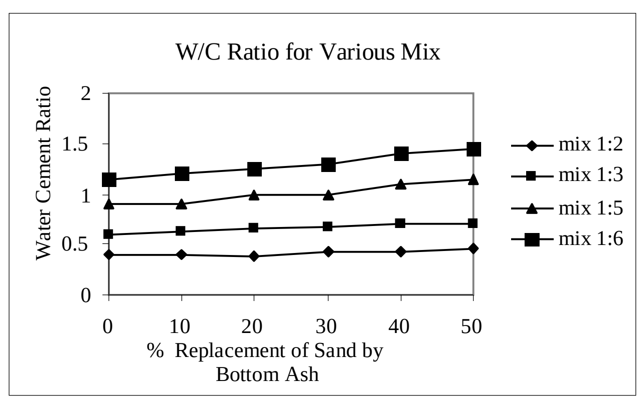

Fig. 2 W/C ratio vs % replacement of sand by bottom ash

Table 1. Details of mortar mix proportion (1:2) using bottom ash (to determine flow value & water requirement of mortar)

Mortar Mix	Mortar Design	Replt. of FA by BA (%)	Cement (gm)	Sand (gm)	Bottom Ash (gm)	Qty. of Water (ml)	W/C Ratio	Flow Value (%)
M1	M1-0	0	267	534	-	106.8	0.40	105.4
M1	M1-10	10	267	480.6	53.4	106.8	0.40	105
M1	M1-20	20	267	427.2	106.8	101.46	0.38	105
M1	M1-30	30	267	373.8	160.2	114.81	0.43	107.6
M1	M1-40	40	267	320.4	213.6	112.14	0.42	110.3
M1	M1-50	50	267	267	267	122.82	0.46	110.4

Table 2. Details of mortar mix proportion (1:3) using bottom ash (to determine flow value & waterrequirement of mortar)

Mortar Mix	Mortar Design	Replt. of FA by BA (%)	Cement (gm)	Sand (gm)	Bottom Ash (gm)	Qty. of Water (ml)	W/C Ratio	Flow Value (%)
M2	M2-0	0	200	600	-	120	0.60	105
M2	M2-10	10	200	540	60	125	0.625	105
M2	M2-20	20	200	480	120	130	0.65	111.2
M2	M2-30	30	200	420	180	135	0.675	105
M2	M2-40	40	200	360	240	140	0.70	105
M2	M2-50	50	200	300	300	140	0.70	110.4

Table 3. Details of mortar mix proportion (1:5) using bottom ash (to determine flow value & water requirement of mortar)

Mortar Mix	Mortar Design	Replt. Of FA by BA (%)	Cement (gm)	Sand (gm)	Bottom Ash (gm)	Qty. of Water (ml)	W/C Ratio	Flow Value (%)
M3	M3-0	0	133.3	666.6	-	120	0.90	107.3
M3	M3-10	10	133.3	599.9	66.66	120	0.90	107.7
M3	M3-20	20	133.3	533.28	133.32	133.3	1.00	105
M3	M3-30	30	133.3	466.62	199.96	133.3	1.00	109.5
M3	M3-40	40	133.3	399.96	266.64	146.63	1.10	105
M3	M3-50	50	133.3	333.3	333.3	153.29	1.15	105

Table 4. Details of mortar mix proportion (1:6) using bottom ash (to determine flow value & water requirement of mortar)

Mortar Mix	Mortar Design	Replt. of FA by BA (%)	Cement (gm)	Sand (gm)	Bottom Ash (gm)	Qty. of Water (ml)	W/C Ratio	Flow Value (%)
M4	M6-0	0	114.28	685.71	-	131.42	1.15	105
M4	M6-10	10	114.28	617.14	68.57	137.13	1.20	107.3
M4	M6-20	20	114.28	548.57	137.14	142.85	1.25	106.8
M4	M6-30	30	114.28	479.99	205.71	148.56	1.30	106.6
M4	M6-40	40	114.28	411.43	274.28	159.99	1.40	110.4
M4	M6-50	50	114.28	342.86	342.86	165.70	1.45	108.7

5. Test on Hardened Mortar

5.1. Compressive Strength

A total of 216 (54x4) specimens have been used to determine the compressive strength (cube) of bottom ash cement mortar mixes, 70.5x70.5x70.5mm cubes specimens are cast and are cured for 7, 28, and 45 days. At the end of the above curing period, the specimens are tested in an automatic compressive testing machine of 3000KN capacity under a uniform rate of loading (at 140kg/cm^2/min), and the compressive strength is calculated as per IS: 1727-1967. The compressive strength is calculated by dividing the crushing load (N) by the cross-sectional area (mm^2) and is expressed in N/mm^2. Tables 5 to 8 shows the compressive strength test for cement mortar cube specimens.

6. Results and Discussions

6.1. Properties of Bottom Ash

Comparing the various physical properties of sand and bottom ash, it is observed that the specific gravity is slightly higher. In contrast, the water absorption of bottom ash is substantially higher than that of sand. The particle shape (angular) and surface texture (rough) of bottom ash are identical to that of sand. The loose and rodded bulk density of bottom ash is almost equal (i.e., 98%) when compared to that of sand.

The sieve analysis results indicate that the predominant particles of bottom ash lie in the range of 75 to 300 microns, i.e., the particle size distribution of the sample of bottom ash lies between the lower range of sand-sized particles and the upper range of cement-sized particles. Hence, the fineness modulus of bottom ash was significantly less when compared to sand (FM of BA is 0.982 & FM of sand is 2.56). As the surface area of the sample of bottom ash is higher than the sample of sand used in this study, it requires more water during the mixing of concrete.

6.2. Workability Characteristics

From the flow, values are presented in Tables 5 to 8. The following observations are made. For all mix proportions, as the percentage of replacement of sand with bottom ash increases, the quantity of water required to obtain constant workability increases (Figure 2). This may be due to the fact that the water absorption of bottom ash is (4.00%) which is greater than that of sand (1.00%). Hence, the workability of the mortar decreases with an increase in the percentage replacement with bottom ash.

6.3. SEM Analysis of Bottom Ash

The morphological characteristics of the particles depend both on their exposure conditions and chemical composition. Automated particle analysis using a scanning electron microscope revealed that over 70% of the bottom ash sample consists of (SiO_2, CaO, Fe_2O_3, Al_2O_3) and the remaining are (MgO, K_2O, Na_2O). Among all particles, noncrystalline domains are frequently observed. As the presence of SiO_2 is 87.73%, indicating high siliceous content and the loss on ignition is much less (LOI is 0.8%, which is much less than the maximum, i.e., 12 % presented in IS 1727-1967, it can be used as a fine aggregate.

6.4. Compressive Strength of Bottom Ash Mortar Mixes

From the Tables 5 to 8 show the details of the compressive strength of various bottom ash mortar mixes at various ages (partial replacement of sand by bottom ash) for 1:2, 1:3, 1:5, and 1:6, respectively. From the above tables, it is observed that the compressive strength of all mortar specimens (sand partially replaced by bottom ash) increases as the (curing) age increases from 7, 28 and 45 days. Figures 3 to 10 show the variation in the compressive strength of mortar with respect to various replacement levels and ages.

It can be seen for cement mortar 1:2 and 1:3 for up to 20% replacement of sand by bottom ash, the compressive strength increases, i.e., up to 15% of the compressive strength of reference mortar mix, and thereafter, compressive strength decreases gradually up to 50% replacement, from Figures 3 to 6 in 1:2 mortar mixes, maximum compressive strength (that is 39.67 @ 45 days) is obtained for M1-20 mortar mix (i.e., for 20% of partial replacement of sand by bottom ash). This is 15% greater than the compressive strength of the reference mortar mix (35.47 @ 45 days).

Similarly, in 1:3 mortar mixes, maximum compressive strength (that is 29.67 N/mm^2 @ 45 days) is obtained for M2-20 mortar mix (i.e., for 20% of partial replacement of sand by bottom ash). This is 15% greater than the compressive strength of the reference mortar mix (26.47 N/mm^2 @ 45 days). Since which may be due to the filler effects of bottom ash.

The filler effects are mainly responsible for improving the physical and mechanical properties of mortar. Since pozzolanic reactions primarily occur after longer curing time, the early strength gains that occurred with bottom ash are attributed to decreasing the void volume, thus reducing the amount of cement required to fill the voids.

From the Figures 7 to 10, it can be seen for cement mortar 1:5 and 1:6, as the % replacement of sand by bottom ash increases, the corresponding compressive strength decreases gradually, irrespective of the age and mix proportion considered in this study, which may be due to the additional water added, to maintain constant workability.

In 1:5 mortar mixes, maximum compressive strength (that is 10.87 N/mm^2 @ 45 days) is obtained for M3-10 mortar mix (i.e., for 10% of partial replacement of sand by bottom ash). This is almost comparable with the compressive strength of reference mortar mix M3-0 (11.02 @45 days), and for more excellent replacements (20 to 50%), the compressive strength decreases gradually. In 1:6 mortar mixes, maximum compressive strength (that is 8.33 N/mm^2 @ 45 days) is obtained for M4-10, which implies that there is no substantial variation with the compressive strength of reference mortar mix M4-0 (8.87 @45 days) and for greater replacements (20 to 50%) the compressive strength decreases gradually. In spite of the above trend, the compressive strength of all 1:5 and 1:6 mortar mixes (at 28 days) is higher than the corresponding average compressive strength (i.e., 6.25 N/mm^2 and 4 N/mm^2). Since this may be due to a lack of filler effects, and the decrease in compressive strength may be partly due to the amount of water added to maintain the consistency of mortar to the specified flow.

Table 5. Compressive strength for mix proportion 1:2

Mortar Mix	Mortar Design	Replt. of FA by BA (%)	Average Crushing Load (KN)			Average Compressive Strength (N/mm^2)		
			7 days	28 days	45 days	7 days	28 days	45 days
M1	M1-0	0	113.41	129.87	176.29	22.82	26.13	35.47
M1	M1-10	10	115.75	154.02	185.08	23.29	30.99	37.24
M1	M1-20	20	129.87	162.32	197.16	26.13	32.66	39.67
M1	M1-30	30	100.9	151.39	171.61	20.30	30.46	34.53
M1	M1-40	40	100.09	147.46	169.58	20.14	29.67	34.12
M1	M1-50	50	19.95	128.38	168.33	19.95	25.83	33.87

Table 6. Compressive strength for mix proportion 1:3

Mortar Mix	Mortar Design	Replt. of FA by BA (%)	Average Crushing Load (KN)			Average Compressive Strength (N/mm^2)		
			7 days	28 days	45 days	7 days	28 days	45 days
M2	M2-0	0	93.14	118.83	131.56	18.74	23.91	26.47
M2	M2-10	10	99.25	120.92	135.38	19.97	24.33	27.24
M2	M2-20	20	105.66	129.62	147.46	21.26	26.08	29.67
M2	M2-30	30	91.75	118.63	131.85	18.46	23.87	26.53
M2	M2-40	40	89.75	110.73	124.85	17.98	22.28	25.12
M2	M2-50	50	89.36	109.24	123.6	17.03	21.98	24.87

Table 7. Compressive strength for mix proportion 1:5

Mortar Mix	Mortar Design	Replt. of FA by BA (%)	Average Crushing Load (KN)			Average Compressive Strength (N/mm^2)		
			7 days	28 days	45 days	7 days	28 days	45 days
M3	M3-0	0	27.98	43.39	54.77	5.63	8.73	11.02
M3	M3-10	10	27.43	43.39	54.02	5.52	8.83	10.87
M3	M3-20	20	26.89	41.40	50.74	5.41	8.33	10.21
M3	M3-30	30	25.94	40.36	49.90	5.22	8.12	10.04
M3	M3-40	40	25.09	39.91	49.15	5.05	8.03	9.89
M3	M3-50	50	23.91	38.81	45.28	4.81	7.81	9.11

Table 8. Compressive strength for mix proportion 1:6

Mortar Mix	Mortar Design	Replt. of FA by BA (%)	Average Crushing Load (KN)			Average Compressive Strength (N/mm^2)		
			7 days	28 days	45 days	7 days	28 days	45 days
M4	M4-0	0	21.42	33.40	44.08	4.31	6.72	8.87
M4	M4-10	10	20.92	33.40	41.40	4.21	6.72	8.33
M4	M4-20	20	19.38	31.46	40.80	3.90	6.33	8.21
M4	M4-30	30	18.44	31.01	39.11	3.71	6.24	7.89
M4	M4-40	40	17.44	29.92	35.63	3.51	6.02	7.17
M4	M4-50	50	16.90	28.93	34.19	3.40	5.82	6.88

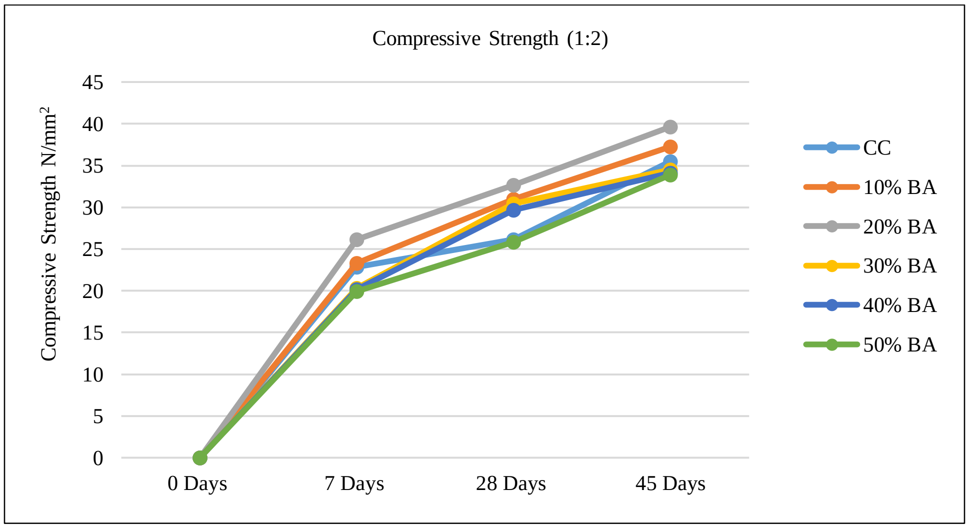

Fig. 3 Compressive strength vs Days

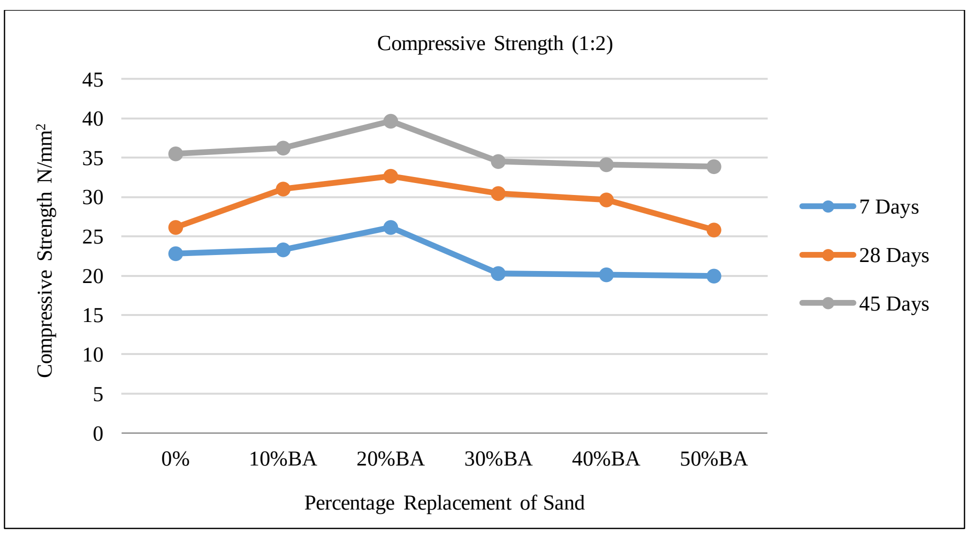

Fig. 4 Compressive strength vs % sand replace

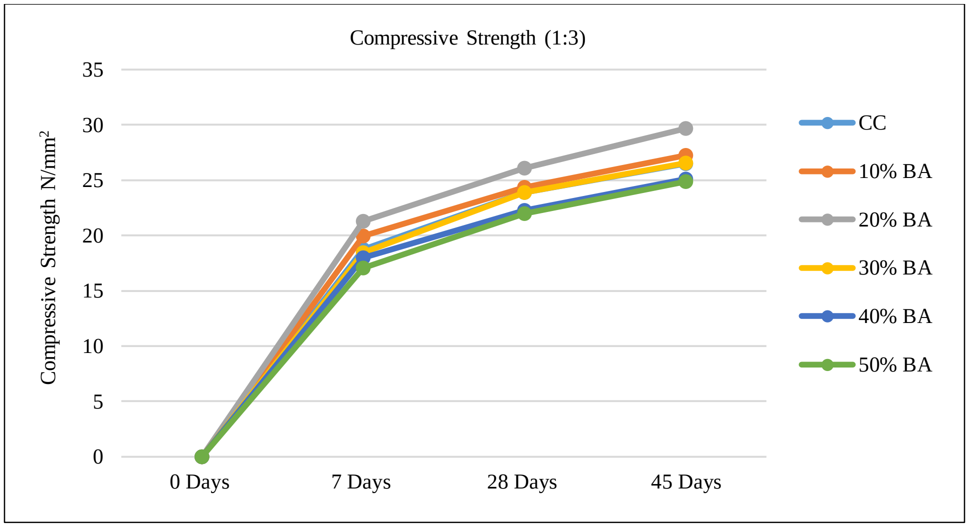

Fig. 5 Compressive strength vs Days

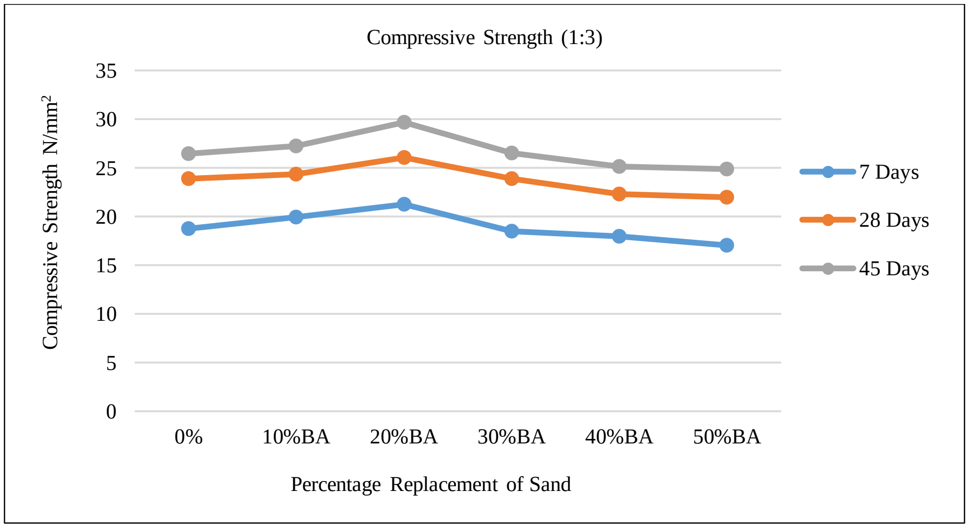

Fig. 6 Compressive strength vs % sand replace

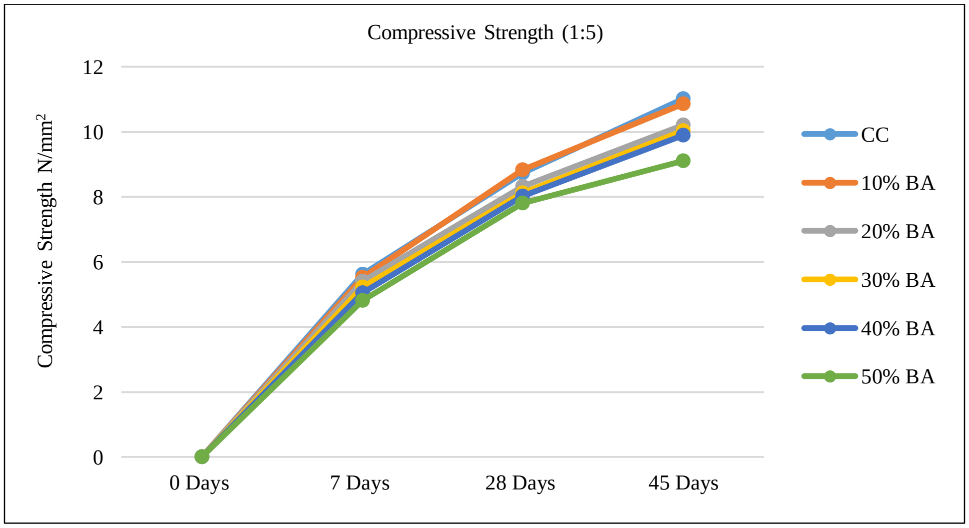

Fig. 7 Compressive strength vs Days

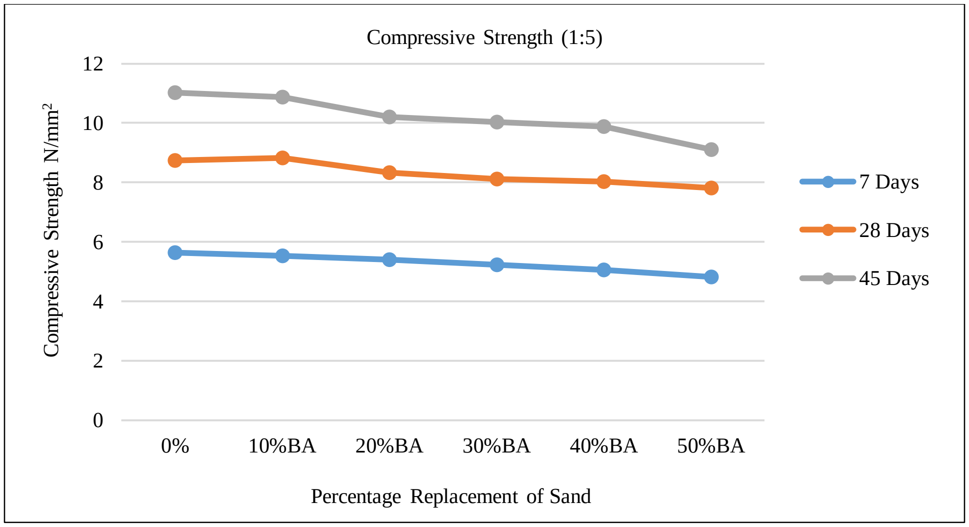

Fig. 8 Compressive strength vs % sand replace

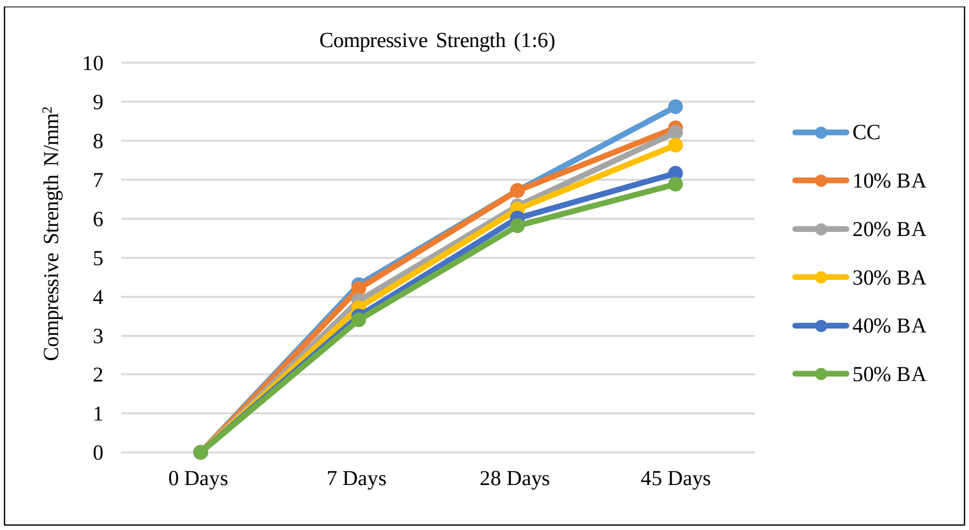

Fig. 9 Compressive strength vs Days

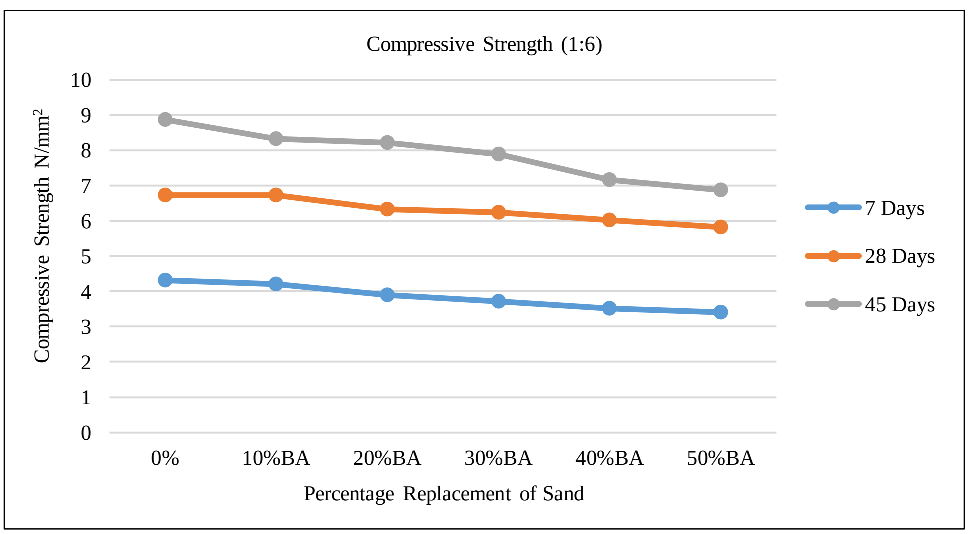

Fig. 10 Compressive strength vs % sand replace

7. Conclusion

Based on the experimental studies carried out on the effect of bottom ash on cement mortar, the following conclusions are drawn.

- In all mortar mix proportions of the work mix proportions, the workability of mortar decreases as the percentage of bottom ash increases.
- It can be seen in cement mortar 1:2 and 1:3 that up to 20% replacement of sand by bottom ash increases, and compressive strength decreases gradually compared to reference mix, which may be due to filler effects of bottom ash. Since pozzolanic reactions primarily occur after longer curing time, the early strength gains that occurred with bottom ash are attributed to decreasing the void volume, thus reducing the amount of cement required to fill the voids.
- Bottom ash mortar with higher cement content (Mortar Mix 1:2 & 1:3) has a moderate development rate of compressive strength with 20% replacement of bottom ash.
- Test results of compressive strength indicated increases in bottom ash content beyond 20% and up to 50% decrease in compressive strength.
- The pozzolanic activity of bottom ash proceeds slowly at early ages and acceleration after 28 days, resulting in a gradual increase in compressive strength. This gradual increase in strength may be related to the pozzolanic activity of bottom ash.
- For mortar 1:5 and 1:6, the replacement of sand by bottom ash increases the corresponding compressive strength decreases gradually; this may be due to lack of filler effects, and the decrease in compressive strength may be partly due to the amount of water added to maintain the consistency of mortar to the specified flow. Specified in IS 2250-1981 for cement mortar 1:5 and 1:6.
- Mortar mixes with partial replacement of sand by bottom ash do not pose any problem during casting when constant workability is maintained for all types of mortar mixes. Hence, no-place ability problems are anticipated when using bottom ash in mortar.
- When 10% of sand is partially replaced by bottom ash, comparable strengths are obtained for 1:5 and 1:6 mortar proportions. On the other hand, there is a marginal reduction in strength, which may be due to the low pozzolanic activity of bottom ash.
- The mortar strength of all mixes considered in the study (i.e., 1:5 and 1:6) for all replacement levels of sand (within the range considered in this study) satisfies the average compressive strength of cement mortar of comparable mix proportion as IS. Specification and, hence, the above mortar can be used with confidence as masonry mortar.

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