Evaluation of use of bottom ash in cement masonry and concrete regarding their mechanical properties

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Abstract

Large quantities of ash are generated every year by the various manufacturing industries as a waste by-product. This study aims to utilize waste by-product in concrete and to reduce its cost by replacing cement in parts with bottom ash. This research presents the results of the experimental investigations to study the use of bottom ash as partial replacement for cement in concrete and masonry units. Bottom ash is the coarser material, which falls into furnace bottom and constitutes about 20% of total ash content. The strength development for various percentage replacements (5-15%) of cement with bottom ash has been compared to control specimens of concrete and masonry. Copyright © 2018 VBRI Press.

Keywords: Bottom ash, compressive strength, concrete, masonry.

Introduction

Manufacturing industries produce large quantities of ash as a by-product of their manufacturing, for example the coal based thermal power stations which account for close to 180 metric tons of ash produced in India annually accounting for about 60% of installed power generating capacity. The same trend is expected to continue in foreseeable future. Ash disposal has become a major problem for industries both environmentally and economically. The use of natural aggregate in construction is increasing with the progress in infrastructure. In order to reduce the usage of natural resources and mitigate the problem of ash disposal, Bottom Ash can be considered as an alternative for natural materials. The engineering and research community is confronting a problem of epic magnitude in order to realize sustainable development, using resilient materials at lowest possible economical and environmental costs.

The constant depletion of natural resources and the adverse environmental impact posed by the disposal of ash has reached disturbing levels; making the use of ash as a construction material a necessity. There is immense potential for improvement in construction materials with widespread utilization of bottom ash in normal strength concrete by mitigating construction costs as well as the problem of ash disposal. Currently, fly ash is being widely used right from the manufacture of cement to the replacement of cement, as well as an admixture in concrete. However, the study on the use of bottom ash as a construction material has been very limited. [**1**]

Around 240-260 billion bricks are estimated to be produced in India annually, making it the second largest brick producer in the world. With a coal and biomass consumption of 35-40 million tons of coal equivalent the brick manufacturing industry contributes an estimated 66 million tons in CO_2 emissions and large amounts of coal ash. The coal ash which is a waste by-product can be considered as an alternative material or as a part replacement in brick manufacturing to reduce additional environmental impact. [**2**]

Several studies are being carried out all over the world to use the ash as its disposal is a major issue. Due to its availability in such large quantities, usage of ash as a cheap and efficient construction material will help in lowering construction costs. The main goal of this research is to evaluate bottom ash as a raw material in manufacture of concrete and masonry.

Research significances

Bottom ash used as a construction material enables the utilization of a large quantity of waste by-product thereby reducing the adverse effects on the environment and the ever increasing pressure on natural resources. Use of bottom ash could also lead to favorable properties to concrete and masonry units because of its silica content. The health risks from use of ash in construction appear minuscule as compared to its advantages. Hence the performance of bottom ash as a raw material in manufacture of concrete and masonry has to be evaluated for its strength and durability.

Literature review

Though a large array of literature is available on the use of fly ash in concrete [**3-8**], there is not much literature available on the use of bottom ash as construction material [**1, 9-12**], with even less literature on the use of bottom ash as a replacement for cement [**13-16**] in concrete and masonry.

Experimental investigations carried out by Maslehuddin, et al. (1989) show that replacing sand by equal weight of fly ash increases compressive strength and corrosion resistance with sand replacement levels of up to 30% and w/c ratio varying between 0.35 to 0.50, keeping cement content constant at 350kg/m^3 (21.85lb/ft^3) in all test specimens. The study also showed that the corrosion rate of reinforcement was lowest in 30% replacement specimen. There was a distinct difference in mechanical strength properties between fly ash concrete specimens and plain concrete specimens after 28 days. [**3**]

Aggarwal, *et al*. (2007) conducted experimental investigations on various properties of concrete mixes having equal volumes of natural sand and bottom ash and compared the same against the natural sand control mix. The mixes were developed using superplasticizers (high-range water-reducing admixtures) and it was observed that the mixing water requirements of the concrete increases rapidly with addition of bottom ash. Due to the increased mixing water requirements the compressive strength is lowered in the bottom ash samples as compared to the control specimen. Also, addition of the bottom ash did not significantly impact the setting times or the entrapped air content of the samples. The workability of concrete reduced in bottom ash samples due to the increase in water demand, necessitating the increase in superplasticizer content. Increase in bottom ash content also reduced the density of concrete due to the low specific gravity of bottom ash as compared to fine aggregates. The study also indicates that the bottom ash concrete specimens showed lower compressive strength, splitting tensile strength and flexural strength as compared to control concrete specimens at all the ages. It was further observed that the strength difference between bottom ash concrete specimens and control specimens was less distinct after 28 days and strength was reported to grow with age. The study showed that the use of bottom ash as a replacement for fine aggregates enables the effective utilization of waste product. [**1**] Another study also showed that the drying shrinkage was found to be high in concrete containing sintered fly ash aggregates.

Furnace bottom ash is used in concrete masonry; pellets of fly ash can be bound by thermal fusion or chemically, using cement or lime to several lightweight concrete aggregates having desirable properties. [**6**]

Investigations of fly ash bricks have shown that the mechanical properties of fly ash bricks exceeded those of the standard load bearing clay bricks. The fly ash bricks showed 24% more compressive strength and nearly three times more tensile strength in comparison to good quality clay bricks. Fly ash bricks also showed a 44% increase in bond strength to mortar as compared to standard clay bricks owing to the micro-structural feature of the fly ash brick surface. Use of fly ash bricks for large scale construction can also yield savings in raw material and its transportation cost and also reduction in the structural load as fly ash bricks were found to have 28% less density than the standard bricks. [**9**]

Stabilization of waste bottom ash with fly ash and cement is an ideal way to use bottom ash in road construction. Bottom ash based bound materials have been found to be stronger than fly ash based bound materials which are already used in construction widely today. In comparison to fly ash bound materials, which show a higher drying shrinkage, the bottom ash bound materials show reduced risk of crack formation due to drying. Demonstration and further study of bottom ash as a construction material in the field is required to create a market for bottom ash in the construction industry. [**10**]

Bottom ash is recommended as an alternative to fine aggregate along with addition of suitable superplasticizers to maintain the workability to produce low density concrete as compared to conventional concrete. [**11**] Another study shows that bottom ash concrete did not achieve the target strength requirements when it was used alone as an aggregate. [**12**] The addition of bottom ash in concrete and masonry helps in stabilizing the drying and firing shrinkage. Addition of $BaCO_3$ to the bottom ash mixture helps to off-set the soluble salts present in the bottom ash which is a disadvantage. However, the cost benefit ratio is favorable. [**14**]

Another study shows that the bottom ash is far less reactive than OPC hence affecting the properties of mortars. The strength is not significantly affected at low levels of replacement (10%) but at high levels (40%) a marked decrease in performance was observed. The decrease in performance is majorly attributed to the increased water mixing requirement which leads to an increase in the porosity of the hardened mortar. This increased porosity along with the lowered OPC contents reduces the performance of mortar cubes and increases the total amount of creep. [**15**]

Another study on the blended cements found that due to soft and porous particle properties of bottom ash, the grinding of blended bottom ash cement was easier than that of OPC. Due to the high amount of unburned carbon and the porous and rough particles of ash, the water requirement of the blended cement was found to be much higher. [**16**]

Addition of ash as an admixture to clay for the production of fired clay bricks reduces the plasticity of the mix. This leads to a reduction in the drying time and shrinkage cracks and also improves the texture of the product. Also, the presence of un-burnt carbon in the ash reduces the external fuel requirement for burning of the green brick. [**17**]

All ash contains significant amounts of silicon dioxide or silica (SiO_2) and Calcium oxide or lime (CaO) along with other hazardous substances whose composition may vary based on the source and properties of the primary reactants. The ash may contain one or more of the hazardous elements or substances in quantities from trace amounts to several percent and have known and suspected impacts on human health. Due to these hazardous impacts the use of ash in construction is still a topic of debate in the civil engineering community.

An important point to be taken into consideration from the above literature excerpts is the water absorption by the bottom ash. The provision for absorption of water by the bottom ash has to be taken into consideration while designing the mix for concrete or mortar. Also the reduction in external fuel for burning the bricks mixed with bottom ash is an important factor while choosing bottom ash as raw material in masonry units.

Experimental program

Materials

Cement

Ordinary Portland cement 43 grade conforming to IS: 8112-1939 was used. Its properties are shown in **Table 1**.

Table 1. Properties of Cement.

SL. NO.	PROPERTY	RESULT	As per IS 8112:1989
1	Fineness Test: By sieving	4% Retained on IS 90 μ sieve	<10% Hence, OK
2	Standard Consistency	P = 29%	Not Specified
3	Initial Setting Time	55 min	> 30 min, OK
4	Specific Gravity	3.15	3.15, OK
5	Compressive Strength	Cubes of CM 1:3 of 7.05 cm (27.75 in.) cast and average 7 day strength = 35.9 N/mm^2 (5206 psi)	>33 N/mm^2 (4786 psi) for 43 Grade Cement (OK)

Fig. 1: Grading Curve of Bottom Ash.

Bottom ash

Bottom Ash from the Hindustan Zinc Limited Smelter in Debari, Udaipur District of Rajasthan in India is proposed to be used for the investigations. The bottom ash is a by-product of the zinc smelting process. The Specific Gravity of the specimen was found to be 1.97.

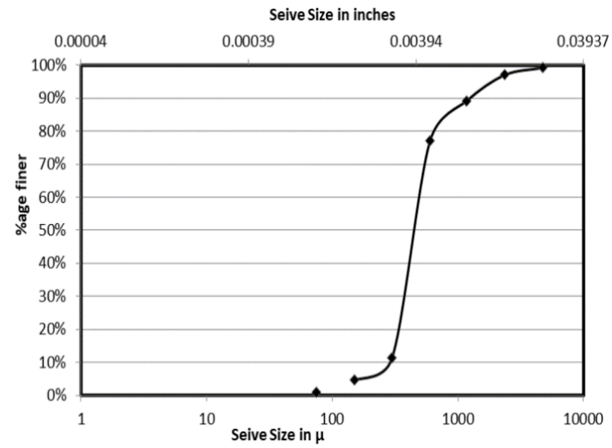

Fig. 1. Shows the sieve analysis results on the bottom ash sample.

The XRD analysis of the bottom ash specimen revealed that the major crystalline constituent compounds were Silica (SiO_2), Lime (CaO) and Alumina (Al_2O_3).

Fine aggregates

Natural sand conforming to Zone I with a specific gravity 2.42 was used. The maximum size of fine aggregate was taken to be 4.75 mm (0.187 in.). The testing of sand was done as per Indian Standard Specifications IS: 383-1970. The water absorption of the dry fine aggregate sample was found to be 13.57% and the free surface moisture of 2.5% was found in the sand. **Table 2** shows the grading of the fine aggregate.

Table 2: Grading limits of fine aggregate.

IS Sieve		Cumulative % Passing			Grading Limit as per IS 383-1970			
		Trial 1	Trial 2	Trial 3	Zone I	Zone II	Zone III	Zone IV
10 mm	(3.94E-04 in.)	100.00	100.00	100.00	100	100	100	100
4.75 mm	(1.87E-04 in.)	95.45	92.64	89.65	90-100	90-100	90-100	95-100
2.36 mm	(9.29E-05 in.)	86.00	84.77	82.32	60-95	75-100	85-100	95-100
1.18 mm	(4.65E-05 in.)	32.99	36.89	30.42	30-70	55-90	75-100	90-100
600 μ	(2.36E-05 in.)	32.79	35.99	28.81	15-34	35-59	60-79	80-100
300 μ	(1.18E-05 in.)	7.14	6.25	3.71	5-20	8-30	12-40	15-50
150 μ	(5.91E-06 in.)	3.32	1.31	1.10	0-10	0-10	0-10	0-10
Hence, Specimen is Graded as Zone I								

Coarse aggregates

Coarse aggregate of 20 mm (0.787 in.) nominal size and a specific gravity 2.765 was used. All tests were carried out as per Indian Standard specifications IS: 383-1970. The coarse aggregate had water absorption of 1.4% and the free moisture content of the aggregates was 0.3%. The sieve analysis results are shown in **Table 3**.

Table 3: Grading limits for coarse aggregates.

IS Sieve		Cumulative % Passing			As per IS 383-1970 for 20 mm (0.787 in.) aggregate
		Trial 1	Trial 2	Trial 3	
20 mm	(7.874E-04 in.)	95.68	86.17	87.2	95-100
10 mm	(3.937E-04 in.)	38.38	48.6	40.5	25-55
4.75 mm	(1.870E-04 in.)	4.8	6.51	6.0	0-10

Mix proportions

Initially three mix proportions were prepared by replacing the 5%, 10% and 15% cement with bottom ash by weight. The mix proportion for the preliminary tests was a nominal mix of 1: 2: 4 where the mix comprised of 1-part cement, 2 parts of fine aggregates and 4 parts of coarse aggregates by weight. The water-binder ratio of 0.5 was used for all tests. From the results of tests conducted on these specimens the final proportions of 7.5%, 11% and 12.5 % (all ranging around 10%) for replacement of cement by weight were selected for further testing. The mix proportion for the final specimen designed as per IS 10262:2009 was used as 1: 2.190: 3.456 to achieve a target mean strength of 20.78 MPa (3014 psi) for M15 mix. The water-binder ratio of 0.6 was used for the final mix proportions. The final mix proportions taken for the compressive strength testing of concrete are shown in **Table 4**. The proportions of cement and fine aggregate used for mortar to make the masonry units were 1:4. The proportion of bottom ash used in the mortar was same as that in the concrete cubes. 7.5%, 11% and 12.5% cement was replaced by the bottom ash specimen for casting the blocks. The water-binder ratio used while casting the masonry units was 0.5.

Table 3: Mix Proportions for 1 m^3 of concrete.

DESCRIPTION	Mix with 7.5% Bottom ash replacement		Mix with 11.0% Bottom ash replacement		Mix with 12.5% Bottom ash replacement	
Cement in kg	301.088 kg	(664 lbs)	289.695 kg	(639 lbs)	284.813 kg	(628 lbs)
Bottom Ash in kg	24.413 kg	(54 lbs)	35.805 kg	(79 lbs)	40.688 kg	(90 lbs)
FA in kg	712.870 kg	(1572 lbs)	712.870 kg	(1572 lbs)	712.870 kg	(1572 lbs)
CA in kg	1124.780 kg	(2480 lbs)	1124.780 kg	(2480 lbs)	1124.780 kg	(2480 lbs)
Water in kg	195.300 kg	(431 lbs)	195.300 kg	(431 lbs)	195.300 kg	(431 lbs)

Preparation and casting of test specimen

Three cubes of 150 mm (5.9 in.) size were cast for testing the compressive strength of the preliminary specimens. After casting, all the test specimens were finished with a steel trowel. All the test specimens were stored at temperature of about 30˚C in the casting room. They were de-molded after 24 hours, and were put into a water-curing tank.

After testing the preliminary mixes, six cubes each of finalized proportions were cast for testing the compressive strength. Six blocks sized 0.23m × 0.115m × 0.075 m (9.055 in. × 4.527 in. × 2.953 in.) were also cast for testing their compressive strength.

Testing of specimen

Fresh concrete properties such as slump, etc. were also observed according to Indian Standard specification IS: 1199-1959. The compressive strength tests for the preliminary mixes were performed at 28-days in accordance with the provisions of the Indian Standard Specification IS: 516-1959.

The compressive strength tests for the finalized mixes were performed after 7-days and 28 days of water tank curing for 3 cubes each. The blocks of finalized Mix proportions were cured for a period of 7 days and air dried for a period of 14 days. Compressive strength tests were then carried out on the masonry units

Results and discussions

Concrete testing

The results of the 28-day compressive strength tests carried out on the cubes with preliminary mix proportions (1:2:4) are tabulated. From the results (**Table 5 and Fig. 2**), it is clear that the compressive strength of concrete with 10% replacement of cement with bottom ash gave higher strength values. Hence, percentages of cement replacements close to 10.0% (i.e., 7.5%, 11.0% and 12.5%) were chosen for the final mixes. Another important observation from the preliminary mix proportions is that the workability in green state is poor and not up to the desirable values. Hence, to improve the workability of the mix, water-binder ratio was increased from 0.5 in the preliminary mixes to 0.6 for the final mixes.

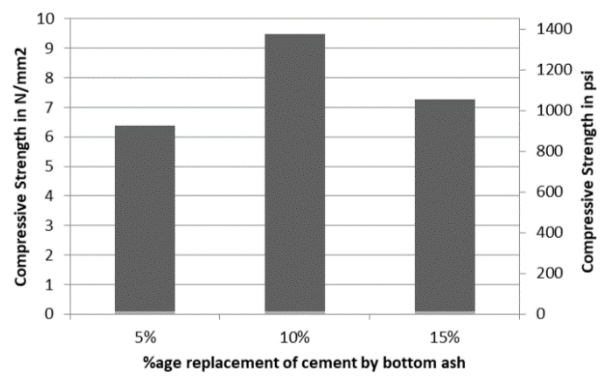

Fig. 2. Results of 28-day compressive strength tests on preliminary mixes.

The results of the 7-day compressive strength tests conducted on the concrete specimens prepared from the finalized mix proportions are shown in **Table 5**.

Table 5. Compressive Strength Test Results on Concrete Cubes.

Description	28-day Results for Preliminary Mix			7-day Results for Final Mix			28-day Results for Final Mix		
%age Replacement	5%	10%	15%	7.5%	11%	12.5 %	7.5%	11%	12.5 %
Avg. Strength (N/mm^2)	6.370	9.481	7.259	9.630	7.555	7.704	14.222	13.185	13.778
Avg. Strength (psi)	923.9	1375.1	1052.8	1396.7	1095.8	1117.4	2062.7	1912.3	1998.3

As expected the 7-day compressive strength of the concrete specimen is less than expected 70% of characteristic mean strength. This can be attributed to the reduction in quantity of cementatious binder material which has been replaced by bottom ash. From the above test results it is clear that the strength achieved by the concrete specimen after 7 days is only about half the expected strength of 15 N/mm^2 (2175 psi). The strength of concrete is expected to improve with time as the pozzolonic material present in the bottom ash reacts and increases the strength of the concrete. The results of 28-day compressive strength tests are as shown in the following **Table 5**.

From the above test results it is clear that higher strength values have been achieved with time by all specimens. The strengths attained by the specimen are less than the expected mean characteristic strength of 15 N/mm^2 (2175 psi). It is evident from **Fig. 3** the mix with 7.5% cement replaced by bottom ash has yielded higher compressive strength values at all ages. This can be attributed to the relatively higher cement content in the 7.5% bottom ash concrete cube specimens. It is expected that the strength of concrete will increase more over time and with age the strength of all specimens is expected to become almost equal.

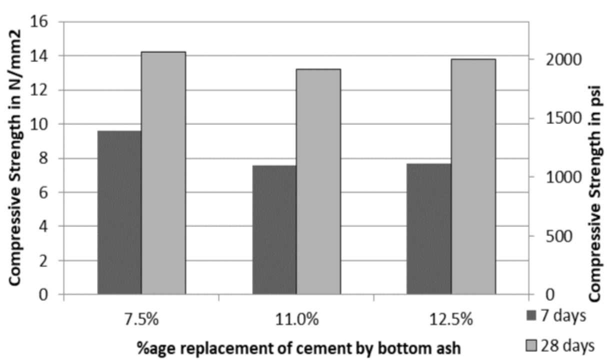

Fig. 3. Comparison of 7-day and 28-day Compressive Strength of bottom ash concrete.

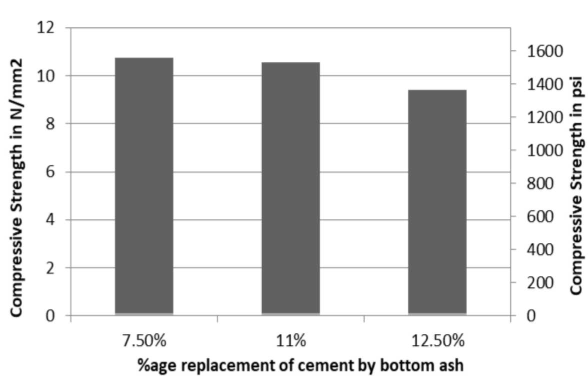

Fig. 4. Compressive strength of bottom ash blocks.

Testing of blocks

Compression test was carried out on the blocks after 7 days of curing and 14 days of air drying and the results of the tests conducted are as shown in **Table 6.**

Table 6. Compressive Strength Test Results on Masonry Blocks.

Description	28-day Results for Masonry Blocks		
%age Replacement	**7.5%**	**11%**	**12.5%**
Avg. Strength (N/mm^2)	10.756	10.571	9.396
Avg. Strength (psi)	1560.0	1533.2	1362.8

The compressive strengths were 10.76 N/mm^2 (1550 psi), 10.57 N/mm^2 (1533 psi) and 9.40 N/mm^2 (1363 psi) for 7.5%, 11.0% and 12.5% replacement of cement by bottom ash in the blocks respectively as shown in **Fig. 4**. The blocks were tested as per standard procedure given in IS 3495:1992. The blocks were easy to mould and have water absorption values of 6.80%, 7.04% and 8.23% respectively. It can be noted from **Fig. 5** that as bottom ash content increases, water absorption of the blocks also increases. The water absorption of normal blocks should not be more than 20.0% by weight up to class blocks 12.5 as per IS 1077:1992. Hence the water absorption by all the blocks is within acceptable limits.

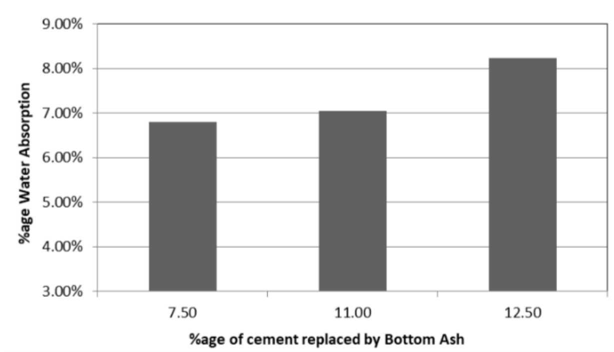

Fig. 5. Water Absorption of bottom ash blocks.

Conclusions

The following conclusions can be drawn from the research work carried out:

1. The workability of concrete decreased significantly with the increase in bottom ash content due to the increased water demand of the bottom ash, thus the final mixes were prepared with higher water-binder ratio of 0.6. The large increase in strength can be attributed to increase in water-binder ratio from 0.5 in the preliminary mixes to 0.6 in the final mixes. The water-binder ratio can be reduced by adding a super-plasticizer.
2. The Compressive strength of bottom ash concrete specimens was lower than expected strength at all the ages. The difference in 28-day compressive strength is less significant.
3. Compressive strength of bottom ash concrete containing 7.5% bottom ash maybe acceptable for use since the observed compressive strength is very close to 15 MPa (2175 psi) at 28 days. Mixes with lower water-binder ratio and added super-plasticizer are expected to yield the desired strength values for the same mix design.
4. Since the bottom ash concrete exhibits lower strength, it can be used as lower grade of normal concrete. Utilization of the waste by product and reduction in cost of natural aggregates can rationalize the use of bottom ash in the concrete mix with low strength.

5. The bottom ash blocks can be used as masonry units in normal construction where heavy loads are not expected on walls. The blocks conform to 10.0 class blocks as per IS 1077:1992.
6. The water absorption values for the blocks are within acceptable limits but it increases with increase in the bottom ash content. This can be attributed to the high water absorption by the bottom ash.
7. Bottom ash used as replacement for cement in certain proportions enables the utilization of waste product in large quantities and reducing environmental pollution.

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