e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:05/Issue:10/October-2023 Impact Factor- 7.868 www.irjmets.com

# UTILIZATIONS OF COAL BOTTOM ASH AS SAND REPLACEMENT TO PRODUCE SUSTAINABLE CONCRETE

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DOI : https://www.doi.org/10.56726/IRJMETS45556

## ABSTRACT

The escalating demand in the construction sector is causing the depletion of construction materials, like sand. In response, coal bottom ash (CBA) is being explored as a sand substitute. CBA is a by-product of coal combustion in power plants, featuring angular, irregular, porous particles with a rough surface texture. It shares visual and particle size characteristics with river sand, making it an appealing fine aggregate replacement in concrete .The study's objectives are to assess the properties of CBA concrete and determine the optimal CBA percentage for fine aggregate replacement. This experiment aims to not only conserve natural resources and reduce energy consumption but also recycle industrial by-products .In this project, we investigate the fresh, hardened, and durability properties of bottom ash concrete, considering factors such as the slump test, compressive strength, flexural strength and water absorption test. Sand is replaced with CBA at rate of 0%, 15%, and 35% by weight, while maintaining a constant water-cement ratio of 0.45. Fresh concrete slumps within the range of 70mm-130mm.The findings of this project seek to clarify the suitability of CBA as a fine aggregate in mortar and concrete for the construction industry and identify any limitations associated with its use. It was observed that up to 15-20% replacement compressive strength, flexural strength and water absorption is benefited after that quality of concrete deteriorates.

**Keywords:** Coal Bottom Ash (CBA), Sand Replacement, Concrete, Fineness Modulus, Workability, Mechanical And Durability.

## I. INRODUCTION

Concrete is the most important material in construction industries. Infrastructure development in such areas particularly in developing countries like India is more. Concrete is a mixture of cement, fine aggregate, coarse aggregate and water and Fine aggregate can obtained by river and rock but river sand is the mostly used as fine aggregate in the production of concrete. The natural sources of river sand are getting depleted gradually. The demand for the protection of the natural environment and the ban on mining in some areas is further aggravating the problem of availability of river sand. At present, the construction industry is plagued with the scarcity of this essential Constituent material of concrete. Therefore, in the present circumstances of scant sources of river sand and boom in infrastructure development, it becomes essential and more significant to find out its substitute material in concrete.

Global civilization's lifeblood is energy, largely sourced from thermal power plants. In India, over 70% of electricity is derived from fossil fuels, primarily coal (61%). This process generates around 100 tons of ash. Most of this ash is disposed of near plants or in lagoons and dumping yards after mixing with water, causing land loss and water pollution [5].CBA, or Bottom Ash (BA), results from incomplete coal combustion in the lower section of coal-fired furnaces in thermal power plants. Its accumulation in many coal-powered facilities is a persistent issue, raising concerns due to substantial stockpiles. About 25% of coal combustion byproducts are CBA, with Fly Ash (FA) constituting the remainder. Using CBA in concrete provides multiple benefits, including cost savings in production, reduced dependence on natural sand, lower CO2 emissions, and safeguarding the environment from open CBA disposal. M.P Kadam and Y.D Patil concluded that observed that up to a 30% replacement level, permeability decreased; however, from 60% to 100% replacement, permeability showed an upward trend [6].The water requirement for concrete workability primarily hinges on the fines content and fine aggregate characteristics. Natural river sand has smooth, weathered surfaces, and lacks weak minerals like mica, while bottom ash particles are angular, rough, and porous[7]. With an increase in curing duration, the flexural strength of fly ash-bottom ash combinations demonstrated a more significant rise in comparison to the control concrete. The initial delay in hydration and the sluggish pozzolanic processes of CFA and CBA during the early curing period may provide a possible explanation for the decrease observed in the flexural strength of fly ash-bottom ash concrete during its early stages [9].Bottom ash serves as landfill material and road construction foundation. In India, some fly ash is used in cement production, but bottom ash is neglected. Both unused fly ash and bottom ash are stored in vast ponds, spanning thousands of acres, posing risks to human health and the environment. By utilizing these wastes as sand replacement helps in depletion of natural sand.

## II. MATERIAL AND METHODS

**Materials**

**Fig: 1** Materials used for investigations

For this experiment M-35 grade concrete is used to study, the cement used was 53grade of Ordinary Portland cement as per IS 12269-2013 adopted. The research utilized coarse and fine aggregates of 10 mm and 20 mm sizes and Natural river sand, conforming to Zone-II grading as specified in IS 383-2016 was taken. The coal bottom ash came from the Patratu Thermal Power Station in Patratu, Jharkhand, India. To enhance the workability of fresh concrete super plasticizer modified poly carboxylic solution approx 0.3-1.3% is used as per IS 9103-1999.

**Table 1:** Physical Properties of Materials

| Physical test | **Fine Aggregate** | | **Coarse Aggregate** | |
|---|---|---|---|---|
| | Natural sand (zone-II) | Bottom Ash | 20mm | 10mm |
| **Fineness modulus** | 3.15 | 2.68 | 7.18 | 5.62 |
| **Specific gravity** | 2.46 | 1.76 | 2.76 | 2.76 |
| **Water Absorption (%)** | 1.52 | 13.66 | 1.11 | 1.11 |

**Table 2:** Chemical Composition of bottom Ash

| **Compound** | **Bottom Ash (%)** |
|---|---|
| SiO2 | 35.10 |
| Al2O3 | 25.66 |
| MgO | 0.54 |
| CaO | 0.46 |
| Fe2O3 | 7.94 |

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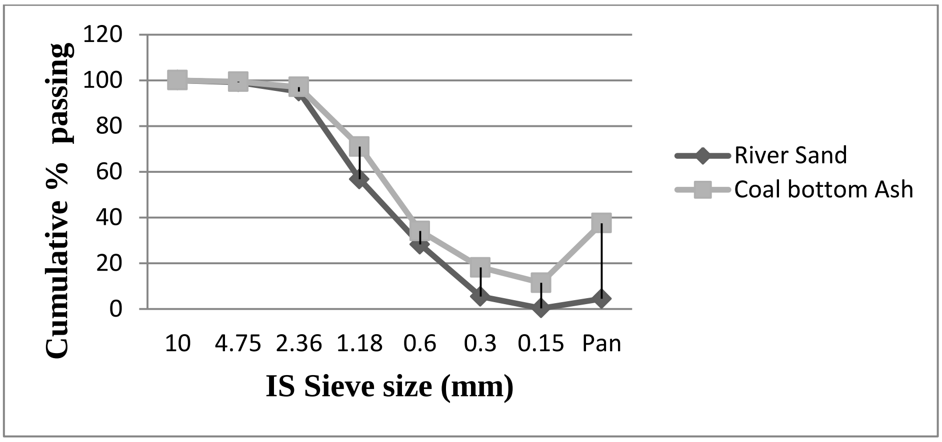


**Fig: 2** Particle size distribution of river sand and bottom ash

**Table 3:** Mix proportions (kg/m3)

| Mix | w/c | Cement | Fine Aggregate | | Coarse Aggregate | | Water (litters) | Super plasticizer |
|---|---|---|---|---|---|---|---|---|
| | | | River Sand | Bottom Ash | 20mm | 10mm | | |
| **BAC0%** | 0.45 | 438 | 624 | 0 | 664.5 | 426 | 197 | 3.23 |
| **BAC15%** | 0.45 | 438 | 530.4 | 93.6 | 664.5 | 426 | 197 | 3.23 |
| **BAC35%** | 0.45 | 438 | 405.6 | 218.4 | 664.5 | 426 | 197 | 3.23 |

**Preparation of test Specimen**

A→ Cube

21 cube of size 150mm×150mm×150mm were used. 18 cubes for compressive strength of BAC at 7 Days and 28 Days of casting and 3 cubes were used for water absorption of bottom ash concrete at 28 Days. Moulds are thoroughly washed and oiled. Filled the mould in three layers after 24hrs cubes are removed and kept for curing.

B→ Beam

Beam of size 150mm×150mm×700mm is prepared. Oil was applied for easy removal of beam. 9 beams for 7 Days and 28 Days flexural strength test was casted. Concrete was poured after oiling the surface and compacted well. After 24 hrs of casting moulds are removed and kept for curing.

**Fig: 3** casting of concrete cubes and beams

## III. TEST RESULT AND DISCUSSIONS

**(A) Fresh Bottom Ash Concrete**

**Workability→** It is a crucial property of concrete, as it directly influences how well concrete can be handled and shaped during construction. Achieving the right workability is essential to ensure that the concrete can be properly placed and compacted to meet the project's structural and aesthetic demands. Workability is affected

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by several factors, including the water content, cement content, aggregate properties, admixtures, and the desired consistency of the concrete mix.

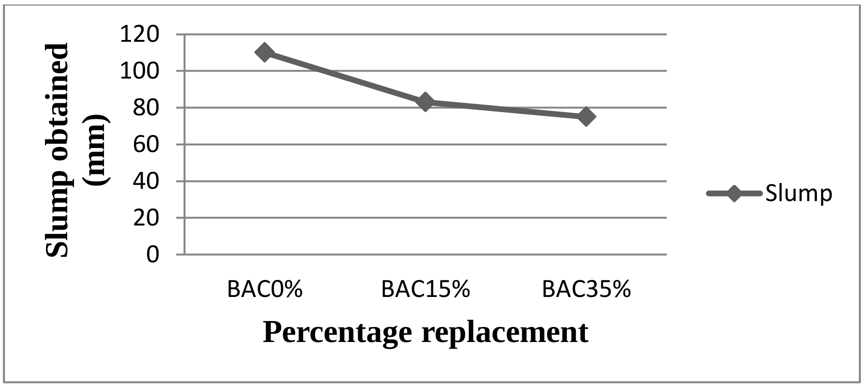


**Fig: 4** Graph for slump obtained from bottom ash concrete

Initially workability of control mix (BAC0%) concrete is 110mm. After 15% and 35% replacement of river sand by bottom ash cause decreased in workability by 24.55% and 31.82% respectively. The workability and water requirements of a concrete mix are significantly influenced by the aggregate proportions and their inherent characteristics. Bottom ash particles, less uniform compared to natural river sand, result in increase in inter-particle friction. Singh et al. have observed a decrease in workability when incorporating bottom ash into various concrete grades [13]. Impacting the flow of fresh coal bottom ash concrete due to increased inter-particle interactions [7]. M. Singh et al., who found that increasing the replacement of fine aggregate with bottom ash leads to decreased workability. Substituting 100% coal bottom ash for fine aggregate resulted in an 86% reduction in slump [12]. Similar pattern of decrease in slump observed by these researchers. Decreased in workability may caused by non uniform and finer size of bottom ash, also water absorption of bottom ash is higher.

**(B) Harden Concrete Properties**

**Compressive strength→** Compressive strength of control concrete at 7 day and 28 days are 28.12 N/mm2 and 43.62 N/mm2 respectively. At 15% replacement compressive strength for 7 days and 28 days increased by 13.79% and 7.75%, But at 35% replacement compressive strength decreased by 3.42% and 8.09%.

**Fig: 5** UTM machine

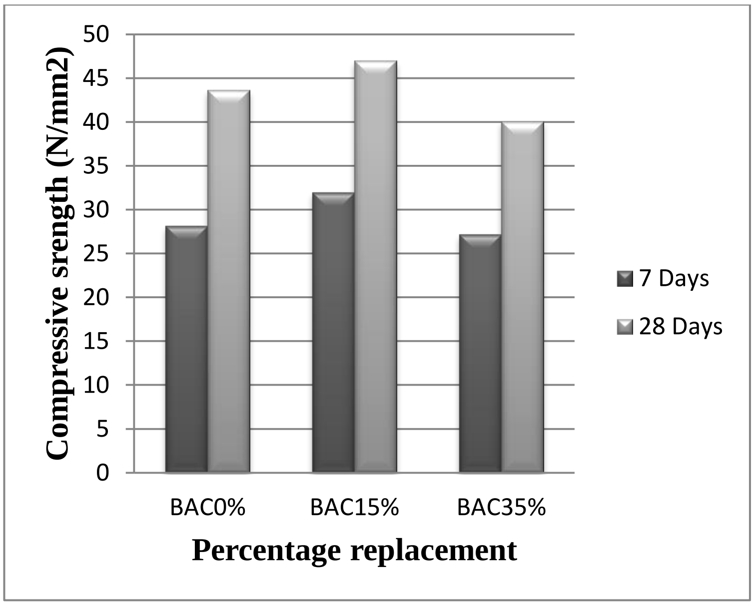


**Fig: 6** Graph for compressive strength of BAC

Kim et al. reported that when maintaining a constant water-cement ratio with different amounts of bottom ash content, the concrete's strength may decline due to the initially high free water content, resulting in reduced bleeding and weaker bonding between aggregates and cement paste [14]. In the early curing stage, normal concrete exhibits higher compressive strength compared to the average compressive strength but in case of bottom ash concrete, it is relatively lower [15]. However, with extended curing, the strength of bottom ash concrete nearly matches that of normal concrete [16]. In this examination initially compressive strength increased up to 15-20% replacement this may due to finer bottom ash fills the gap and act as binder initially and irregular shape of bottom ash which increase friction against failure. The initial strength development in bottom ash concrete is gradual, followed by a more rapid strength gain after 28 days, due to pozzolanic activity of the bottom ash.

**Flexural Strength→** The flexural strength is calculated as per IS 456 – 2000 and IS 516 – 1959.Here flexural strength was tested by two point loading. The Flexural Strength or modulus of rupture($f_b$) is given by $f_b = pl/bd^2$ (when **a** > 20 cm for 15cm specimen ) or $f_b = 3pa/bd^2$ (when **a** < 20cm but > 17 for 15cm specimen )

Where, a = the distance between the line of fracture and the nearer support, b = width of specimen (cm), d = failure point depth (cm), l = supported length (cm) and p = max. Load (kg)

**Fig: 7** two point loading

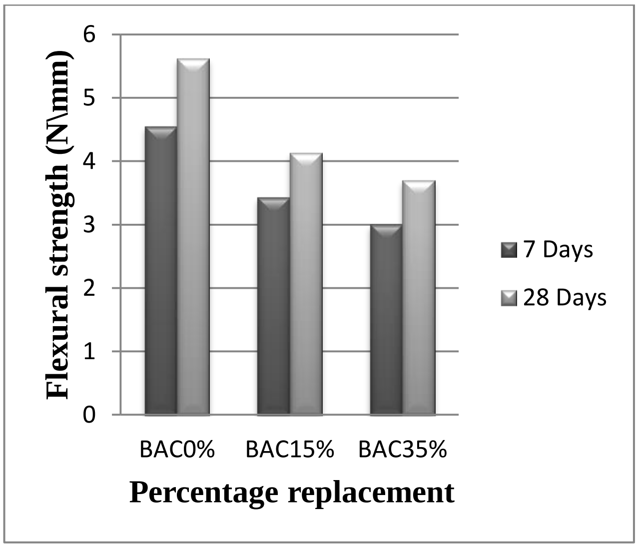


**Fig: 8** Graph for Flexural strength for BAC

Here Flexural strength for 15% replacement decreased by 24.62% and 26.51% for 7 days and 28 days respectively as compare to control concrete also for 35% replacement again decreased by 34.06% and 34.16%.Raju et al. found, through their flexural strength tests on bottom ash concrete, that replacing natural fine aggregates with bottom ash leads to a decrease in flexural strength [17]. Moreover, the inclusion of both fine and coarse bottom ash results in a minor reduction in the flexural strength of bottom ash concrete [18]. Additionally, the size variations in bottom ash particles affect flexural strength. Previous research has indicated that when fine aggregates are entirely substituted with fine or coarse bottom ash, the modulus of rupture decreases. Park et al. [19] observed that as the proportion of bottom ash in the mixture increases, the flexural strength of bottom ash concrete tends to decline, regardless of aggregate grading. In summary, the reduced flexural strength in bottom ash concrete is attributed to the ease with which cracks propagate through bottom ash particles, contrasting with normal aggregates that offer greater resistance to crack penetration. This disparity in crack propagation direction has a notable impact on normal concrete made with conventional aggregates.

**(C) Durability test of bottom ash concrete**

**Water Permeability of Concrete→** Water permeability at 28 days curing was Measured as per IS 516(part 2/section 1).The setup includes a compressor operating at 5kg/cm2 of pressure. Concrete cubes were positioned on the permeability apparatus and subjected to a 72-hour exposure to a water pressure of 5 kg/cm2. Upon completing this phase, the cubes were removed from the apparatus, wiped off surface water and placed in CTM, cube split into two equal parts. Without delay, the water penetration of these split cubes was measured. Maximum penetration of water should not be more than 25mm.

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**Fig:9** water permeability test at 28 days

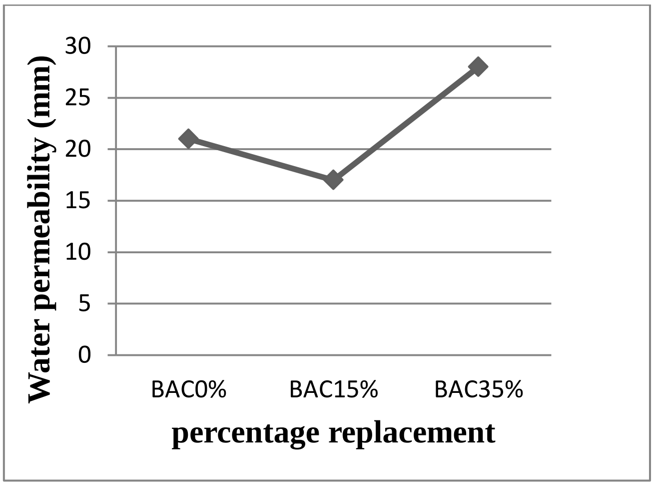


**Fig:10** Graph for water permeability in BAC

It was found that at 15% replacement water permeability is reduced by 19.05%. Further replacement to 35% results in increased in permeability by 33.33%, which is huge. Initially permeability increased this could be due to finer particle distribution of bottom ash as compare to river sand as finer particle fills all voids. But as replacement is increased water absorption of bottom ash concrete increased rapidly. This could be due to higher water absorption of bottom ash.

## IV. CONCLUSION

In this experimental report we checked feasibility of utilization of bottom as concrete as partial replacement of river sand and conclusion is as follows:

►Workability of bottom ash concrete decreased for all percentage of replacement but after more than 35% replacement it up to 38.82%. This is due to irregular and rough surface of bottom ash as compare to river sand also water absorption of bottom ash is more so require more water.

► To maintain workability appropriate super plasticizer should be used or water-cement ratio also be increased with increase in replacement.

► Optimum replacement should be 15-20% to get higher compressive strength than control concrete. At 15% replacement compressive strength for 7 days and 28 days increased by 13.79% and 7.75%, But at 35% replacement compressive strength decreased by 3.42% and 8.09%.

► Flexural strength for 15% replacement decreased by 24.62% and 26.51% for 7 days and 28 days respectively as compare to control concrete also for 35% replacement again decreased by 34.06% and 34.16%.Upto 15% replacement, reduced flexural strength is less than 35% replacement.

► At 15% replacement water permeability is reduced by 19.05%, which is beneficial. Further replacement to 35% results in increased in permeability by 33.33%, which is huge. Increasing the bottom ash content in the concrete raises its permeability due to the porous microstructure of the bottom ash.

Given the outcomes of this investigation and previous studies, it is strongly recommended to utilize coal bottom ash and as partial substitutes for river sand in concrete. This recommendation is justified by their capacity to enhance mechanical properties while promoting sustainable and environmentally responsible practices.

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