Empirical research on strength and durability properties of bottom ash for sustainable concrete practice

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Abstract: The prime constituents utilized in the construction field are concrete because of its easy availability and also by considering strength properties and cost-effective factors. It is composed essentially of fine aggregate, coarse aggregate and cement, where the fine aggregate manipulated during manufacturing is natural sand. The requirement for sand is thriving due to its abundant utilization in the construction industry, thereby the natural resource is becoming diminished. In sequence to overcome the depletion of sand, empirical research has been done on strength characteristics of concrete with bottom ash to partially counterbalance fine aggregate. Bottom ash is a residue obtained at the thermal power plant by combusting coal. It can be utilised in concrete as a partial replacing material for cement or fine aggregate or coarse aggregate. The practice of bottom ash in construction makes the disposal eco-friendly and hence reduces sand quarrying. In this paper, it is affirmed that bottom ash can partially (15%, 25%, 30%) replace fine aggregates without compromising the qualities of concrete.

1. Introduction
Natural river sand is more usually employed as fine aggregate which is one of the important components of concrete. Due to the wide usage of concrete around the world, the global consumption of natural river sand is increasing. The growth of the construction industry is meeting a great problem in many parts of the country because of the unavailability of sufficient quantity of ordinary river sand [1]. On the other side, the effective disposal of solid wastes from both municipal and industrial sector is a challenging task as it causes an impact on the environment. In those cases, the waste can be used in concrete making as a replacement to aggregate or cement to enhance the properties, which in turn reduces the wastage and its disposal [2, 3]. Utilization of residues and waste in concrete production leads to green environment and those concrete manufactured are known as green concrete. When bottom ash is employed, the cost of manufacturing of concrete gets reduced to a certain scale. Carbon-di-oxide emission and landfill deposition is reduced and protects the environment from degradation [4].

The ultimate aspiration of this study is to examine the feasibility of bottom ash in concrete and to find the optimum value for replacing aggregate in concrete. Also, it aims at improving the compressive strength by partly displacing sand by bottom ash without negotiating the properties of concrete [5].

2. Materials and properties
2.1. Cement
Cement is a binding material utilised in concrete production with the property of hardening and setting. Ordinary Portland cement is highly durable and feasible. It is Limestone which is silicious in nature is
burnt at 1450°C to manufacture OPC and is ground with gypsum. The optimum particle size distribution of OPC renders strength and durability to the structure [6].

Table 1. Physical properties of OPC cement.

| Cement                      | CCN | Mass%   |
|-----------------------------|-----|---------|
| Calcium Oxide, CaO          | C   | 61-67%  |
| Silicon oxide, SiO2         | S   | 19-23%  |
| Aluminium Oxide, Al2O3      | A   | 2.5-6%  |
| Ferric Oxide, Fe2O3         | F   | 0-6%    |
| Sulphate                    | S   | 1.5-4.5%|

Table 2. Chemical properties of OPC cement.

| Name of the test          | Value          |
|---------------------------|----------------|
| Consistency               | 30%            |
| Setting time - Initial    | 30 minutes     |
| Setting time - Final      | 600 minutes    |
| Fineness Modulus          | 3.5 %          |
| Specific gravity          | 3.15           |

2.2. Coal Bottom Ash (CBA)
When the crushed coal is burnt in a boiler, 80% of unburnt material is collected. During the process of burning the crushed coal in a dry bottom boiler, nearly 80 percent of the unburnt material or ash is retrieved in the fly ash form while the rest 20% of the unburnt material is washed out at the bottom and recovered as bottom ash [7].

Table 3. Physical properties of coal bottom ash.

| Property       | Bottom ash |
|----------------|------------|
| Specific gravity | 2.7        |
| Dry unit weight  | 15.72kN/m  |
| Plasticity      | None       |
| Absorption      | 1.5%       |

Table 4. Chemical properties of coal bottom ash.

| Composition | Percentage |
|-------------|------------|
| SiO₂        | 33.5       |
| Al₂O₃       | 15.8       |
| Fe₂O₃       | 8.4        |
| CaO         | 19.4       |
| MgO         | 2.0        |
| SO₃         | 9.3        |
| ZnO         | 0.8        |
| Na₂O        | 3.6        |
| K₂O         | 1.9        |
| TiO₂        | 1.5        |
| Cl           | 1.1        |
| SiO₂        | 33.5       |
2.3. **Fine Aggregate**
Riverbed sand available in the nearby area that is free from debris is used as fine aggregate. One of the most significant characteristics is its grading. The various test has been conducted for the fine aggregate conforming to IS: 2386 (Part III) - 1963 and has been used successfully [8].

| Property                     | Value |
|------------------------------|-------|
| Specific gravity             | 2.44  |
| Fineness modulus             | 2.87  |
| Grading                      | Zone –II |

2.4. **Coarse aggregate**
Aggregates used must be free from impurities and must be clean. Coarse aggregate of size 20mm size conforming to grading Zone-II has been used. The coarse aggregate of fineness modules 6.67 conforms to IS: 383-1970. The size of the coarse aggregate should range between 10mm and 20mm such that optimum compressive strength is offered with high cement content and low W/C ratio [9], [10].

| Property                     | Value |
|------------------------------|-------|
| Specific gravity             | 2.72  |
| Fineness modulus             | 6.67  |
| Grading                      | Zone –II |

2.5. **Water**
Water is also a crucial ingredient in making concrete, as it helps to cause chemical reaction with cement. The durability of concrete is achieved due to the binding action. Water is an important constituent in attaining strength. The maximum strength is obtained by proper proportion and workability. When the quantity of water increases, thereby the strength of the concrete gets decreased. So it is inherent to maintain water-cement ratio throughout [11, 12, 13].

3. **Tests and discussions**
3.1. **Strength test**
3.1.1 **Compressive strength**
One of the most prominent and useful properties of concrete is its compressive strength which depends on various factors such as water-cement ratio, quality of materials used, quality control during production of concrete etc. Concrete is strong in compression and thereby used to resist compressive stress in the structure. The compressive strength test on concrete is carried out to measure the properties of the compressive strength [14, 15]. The research has been carried out for finding the values of compressive strength for different replacement of Coal Bottom Ash at different curing ages. The test has been conducted and the results are given below.

|                  | 0% CBA | 15% CBA | 25% CBA | 30% CBA |
|------------------|--------|---------|---------|---------|
| 7th day          | 11.7   | 9.76    | 11.52   | 11.20   |
| 14th day         | 15.6   | 14.87   | 15.20   | 14.95   |
| 28th day         | 26     | 23.25   | 25.50   | 25.30   |
The results show the difference in compressive strength of concrete with and without replacement of CBA with fine aggregate at different curing ages. It is apparent from the figure, that compressive strength increases up to 25% replacement and on further replacement, it becomes nearly alike to that of conventional concrete [16, 17].

3.1.2. Split tensile strength

The split tensile strength is one of the most significant properties that considerably affect the size and depth of cracking in structures. As the concrete is brittle in nature, it is weak in tension and does not counter direct tension. So, when tensile forces exceed its tensile strength cracks develop [18].

Table 8. Split tensile strength test result at 7th, 14th and 28th day.

|          | 0% CBA | 15% CBA | 25% CBA | 30% CBA |
|----------|--------|---------|---------|---------|
| 7th day  | 1.17   | 1.02    | 1.22    | 1.15    |
| 14th day | 1.93   | 1.68    | 2.03    | 1.90    |
| 28th day | 2.55   | 2.25    | 2.50    | 2.30    |

The results show the contrast of the tensile strength of concrete with and without replacement of CBA with fine aggregate at different curing ages. The figure apparently shows that tensile strength
increases up to 25% and on further replacement, it becomes almost equal to that of conventional concrete [19].

3.1.3. Flexural strength
The flexural strength of concrete is employed in resisting compressive stress. The dimension of the beam the pattern of loads has a significant impact one the value of modulus of rupture. The flexural strength of concrete with 0%, 15%, 25% and 30% of replacements were determined as per I.S. 516-1959 [19].

| Table 9. Flexural strength test result at 7th, 14th and 28th day. |
|-----------------|----------------|----------------|----------------|----------------|
|                 | 0% CBA         | 15% CBA        | 25% CBA        | 30% CBA        |
| 7th day         | 2.17           | 2.12           | 2.31           | 2.35           |
| 14th day        | 3.12           | 3.06           | 3.21           | 3.26           |
| 28th day        | 3.45           | 3.37           | 3.48           | 3.44           |

The results show the variation of flexural strength of concrete with the replacement of CBA with fine aggregate at different curing ages. It is clear from the figure, that tensile strength increases upto 25% replacement and on further replacement, it becomes almost similar to that of conventional concrete.

3.2. Durability test
The durability of a structure is the ability to exhibit the life span of a structure which can withstand chemical attack and physical impairment. Mix proportion, selection and quality of materials used majorly influence the durability of the structure [20, 21].

3.2.1. Acid attack test
Concrete is generally susceptible to acid attack due to its alkaline nature. The cement paste normally breaks down when it reacts with acid. The cube is taken and casted. After 28 days curing, the specimens were taken out. For acid attack, sulphuric acid is diluted in water by 5% of volume of water. After 45 days of immersion in acid, the cubes were taken out. The surface of cubes are cleaned and left for 24 hours and compressive strength test is done.
3.2.2. Sulphate attack test
Sulphate attack is a chemical breakdown mechanism where sulphate ions attack components of the cement paste. The cube is taken and casted. After 28 days curing, the specimens were taken. For sulphate attack, magnesium sulphate is diluted in water by 5% of volume of water. After 45 days of immersion in acid, the cubes were taken out. The surface of cubes are cleaned and left for 24 hours and compressive strength test is done.

Table 10. Compressive Strength of cubes before and after Acid Attack

| % Bottom ash | Compressive strength of concrete (N/mm²) | Before attack | After attack |
|--------------|-----------------------------------------|---------------|-------------|
| 0%           | 26                                      | 23.5          |
| 15%          | 23.25                                   | 21.4          |
| 25%          | 25.5                                    | 21.2          |
| 30%          | 25.3                                    | 20.4          |

3.2.3. Chloride attack test
The cube is taken and casted. After 28 days curing, the specimens were taken. The sodium chloride solution was prepared by adding 3.5% sodium chloride (by volume of water) to water. Then the concrete cubes are immersed in 3.5% sodium chloride (1N NaCl) solution. After 45 days of immersion in solution, the cubes were taken out. The surface of cubes are cleaned and left for 24 hours and compressive strength test is done.

Table 11. Compressive Strength of cubes before and after Sulphate Attack.

| % Bottom ash | Compressive strength of concrete (N/mm²) | Before attack | After attack |
|--------------|-----------------------------------------|---------------|-------------|
| 0%           | 26                                      | 24.2          |
| 15%          | 23.25                                   | 21.46         |
| 25%          | 25.5                                    | 23.1          |
| 30%          | 25.3                                    | 23.2          |

Table 12. Compressive Strength of cubes before and after Chloride Attack.

| % Bottom ash | Compressive strength of concrete (N/mm²) | Before attack | After attack |
|--------------|-----------------------------------------|---------------|-------------|
| 0%           | 26                                      | 25.2          |
| 15%          | 23.25                                   | 22.4          |
| 25%          | 25.5                                    | 23.6          |
| 30%          | 25.3                                    | 23.45         |
3.2.4. Alkaline attack test
The cube taken was casted and cured for 28 days. Then 3.0% of sodium hydroxide was added with water and the solution was prepared. The concrete cubes were then immersed in the solution for a period of 45 days. Then the specimens were taken out from the alkaline water (sodium hydroxide solution). After 45 days of immersion in acid, the cubes were taken out. The surface of cubes are cleaned and left for 24 hours and compressive strength test is done.

| % Bottom ash | Compressive strength of concrete (N/mm²) |
|--------------|----------------------------------------|
|              | Before attack | After attack |
| 0%           | 26            | 25.1         |
| 15%          | 23.25         | 22.1         |
| 25%          | 25.5          | 23.4         |
| 30%          | 25.3          | 23.2         |

3.2.5. Water absorption test
The rate of absorption of water by hydraulic cement concrete can be determined by this method. This can be done by measuring the increase in the mass of a specimen resulting from absorption of water (1) as a function of time when only one surface of the specimen exposed to water. The exposed surface is immersed in water and water ingress of unsaturated concrete dominated by capillary suction during initial contact with water.

\[
\text{Water absorption} = \frac{\text{saturated weight} - \text{dry weight}}{\text{dry weight}}
\]

| % Bottom ash | Initial weight in grams | Final weight in grams | % of water absorption |
|--------------|-------------------------|-----------------------|-----------------------|
| 0%           | 2520                    | 2551                  | 1.23                  |
| 15%          | 2347                    | 2382                  | 1.49                  |
| 25%          | 2431                    | 2496                  | 2.67                  |
| 30%          | 2315                    | 2366                  | 2.2                   |

4. Conclusion
From the research work carried over the strength and durability of concrete, the following observations are made:
The CBA is a low cost available industrial solid waste which on incorporation with concrete helps in attaining strength, thereby paving way for an eco-friendly environment. From the results, it’s been inferred that 25% replacement of CBA is found to be expedient. Therefore the optimum percentage is
found to be 25%. The durability properties also show optimal results which help in indulging CBA in concrete.

![Figure 4. Comparison of strength properties.](image)

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