Improved performance of coal bottom ash co-mixture concrete

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Abstract. The present research aims to prepare concrete by adopting coal bottom ash (CBA) as a replacement of fine aggregate. Various strength and durability tests were performed by replacing fine aggregate with CBA in percentages varying from 0-80%. To achieve workability requirement in specimens with higher CBA content, higher water to cement ratio was adopted, which lead to variation in the water absorption behaviour. The results indicated that addition of higher CBA content lead to drop in workability and plastic density. Furthermore, replacement of CBA above 40% leads to a drastic drop in strength characteristics. In addition, increasing CBA content improved drying shrinkage, standard consistency and water permeability of the concrete. Finally, the results confirmed that concrete can be effectively manufactured by judicious utilization of CBA as partial replacement of fine aggregate.

Keywords: coal bottom ash, environmental hazard, cement, industrial waste, strength

1. Introduction

Due to large demand of concrete as a versatile construction material, natural resources in the form of aggregates get depleted at an alarming rate. Hence, to safeguard both the future as well as the construction industry, finding an ideal alternative material for the natural aggregate substitution becomes a challenging problem. Numerous industrial wastes and other by-products have immense potential to replace natural aggregates in concrete, partially or even completely [1-3]. It serves two purposes, firstly it prevents the depletion at the alarming rate, and secondly, it reduces the environmental hazards caused by dumping of these industrial wastes. Thus, serves as an environmental friendly sustainable solution to this grave global problem [4-9]. Coal bottom ash (CBA) is a commonly produced industrial waste that is present at the lower end of the coal furnaces in thermal power plants. Since India is a vast country in terms of area and population. The demand for electricity is enormous. A large portion of this demand comes from thermal plants, leading to large production of CBA wastes. Hence, the research studies on the inclusion of CBA as natural aggregate replacement is highly beneficial. Cachim et al, 2014[10] identified glass residue, metakaolin and diatomaceous earth as cement’s potential partial replacement alternative. Jaturapitakkul and Cheerrarat, 2003[11] found that replacement of cement in different proportions by bottom ash (BA) influences the strength of the manufactured concrete, but it can serve as a viable alternative to cement replacement. Bajare et al, 2013[12] revealed that grinded bottom ash (GBA) can reduce the carbon dioxide emission significantly. Andrade et al, 2007[13] studied the moisture kinetics aspects of concrete containing BA. The adoption of higher BA content due to its high porosity feature results in higher water absorption, thus, performs satisfactorily. Aramrraks, 2006 [14] evaluated the water requirement of concrete mixtures adopting CBA as an alternative to replace fine aggregate partly and or completely. It was observed that the mixes using CBA require nearly 50% higher water content than conventional concrete mixes for obtaining the desired flow. Yuksel and Gene, 2007 [15] studied the properties of concrete mixes containing varying percentage of CBA fine aggregate replacement. The slump values of mixes containing CBA initially increased up to 40%, later decreased marginally.
The paper presents a detailed investigation on the utilization of CBA as replacement of fine aggregate ranging from 0-80%. Various strength and durability tests were performed by replacing fine aggregate with CBA. For achieving suitable workability requirement in specimens with higher CBA content, higher water to cement ratio was adopted, which lead to variation in the water absorption.

2. Experimental study
2.1. Materials Adopted
2.1.1. Coal Bottom Ash. CBA that was collected from a thermal power plant at Panipat, Haryana was adopted in the present investigation. It’s specific gravity was 3.49 while as it’s fineness modulus was 1.48.

2.1.2. Cement. Portland cement from a single lot (grade 43) was used throughout the course of the investigation, which conformed to Indian Standard IS: 8112 [16]. All the tests were carried out as per recommendations of IS 4031 [17]. The contact of cement with moisture was prevented by proper storage, to retain its original properties.

2.1.3. Fine aggregate. River sand conforming to IS: 383 [18], zone II, was adopted as fine aggregate. Lumps present in clay and other foreign matter were separated out, before using it in concrete preparation.

2.1.4. Coarse aggregate. Locally available crushed stones of nominal maximum size ranging between 10-20mm conforming to IS 383 [18] were used as coarse aggregate.

2.1.5. Admixture. Sodium hydroxide and calcium hydroxide were used in the experiment in dosage of 0.7% by weight of cement. Admixtures conformed to IS 9103 [19].

2.2. Mix design
Different mixes were prepared by varying the fine aggregate replacement percentages and were later compared with control mix for M45 grade concrete. Proportions of the mix are shown in Table 1. The mix design has been prepared as per the recommendations given by Indian standard IS: 10262 [20].

| Mix designation | % of CBA | Water | Cement | Fine aggregate | Coarse aggregate | Calcium Hydroxide | Sodium Hydroxide |
|-----------------|----------|-------|--------|----------------|------------------|-------------------|------------------|
| Control mix     | 0        | 194.6 | 389    | 712.22         | 1096.87          | 1.36              | 1.36             |
| SS-1            | 20       | 194.6 | 389    | 569.82         | 1096.87          | 1.36              | 1.36             |
| SS-2            | 30       | 194.6 | 389    | 498.55         | 1096.87          | 1.36              | 1.36             |
| SS-3            | 40       | 194.6 | 389    | 427.33         | 1096.87          | 1.36              | 1.36             |
| SS-4            | 60       | 194.6 | 389    | 284.88         | 1096.87          | 1.36              | 1.36             |
| SS-5            | 80       | 194.6 | 389    | 142.44         | 1096.87          | 1.36              | 1.36             |

All contents were measured in kg/m³

3. Results/ discussion
Different tests were performed on fresh as well as hardened concrete specimens. Soon after the manufacturing of concrete, workability tests were performed, while as strength and durability tests were carried out on hardened concrete after 7 days and 28 days. The details of these tests are given in the sections below.

3.1. Workability Test
Immediately after preparing concrete, the workability test on wet concrete was determined by slump cone test as well as compaction factor test conforming to IS 1199 [21]. The results of both tests are given in Table 2.
### Table 2: Results of workability tests

| Mix  | Slump value [mm] | Acceptable limit as per [20][mm] | Compaction value [mm] | Acceptable limit as per [20][mm] |
|------|------------------|----------------------------------|-----------------------|----------------------------------|
| SS-C | 98               | 100-150                          | 0.91                  | 0.7-0.95                         |
| SS-1 | 105              |                                  | 0.92                  |                                  |
| SS-2 | 110              |                                  | 0.94                  |                                  |
| SS-3 | 115              |                                  | 0.96                  |                                  |
| SS-4 | 100              |                                  | 0.90                  |                                  |
| SS-5 | 102              |                                  | 0.89                  |                                  |
| Average | 105               |                                  | 0.92                  |                                  |

3.2. Drying Shrinkage
Drying shrinkage test was conducted on three prisms for different percentages of fine aggregate replacement by CBA. The results of this test are shown in Figure 1.

3.3. Plastic Density
The plastic density on fresh concrete was carried out, just after the batching. The results of this test are shown in Figure 2.

3.4. Compressive Strength Test
The guidelines given in IS 516 [21] were adopted for carrying out compressive strength tests on various mixes and the results of this test are shown in Figure 3.

3.5. Flexural Strength Test
The guidelines given in IS 516 [22] were adopted for carrying out flexural tests on various mixes and the results of this test are shown in Figure 4.

3.6. Split Tensile Strength
The guidelines given in IS 516 [22] were adopted for carrying out split tensile strength tests on various mixes and the results of this test are shown in Figure 5.

3.7. Ultrasonic pulse velocity
The test involves determination of pulse velocity through concrete as given in ASTM C 597-02 [23]. Figure 6 shows the variation of ultrasonic pulse wave in different mix samples.

3.8. Water Absorption
Figure 7 shows variation of water absorption in different mix samples. The water absorption of the concrete cylindrical specimens was determined according to conventional method as given in IS 1199 [21].

The adoption of CBS resulted in the drop in drying shrinkage. However, it did not vary much when the CBS quantity adopted was higher. Since CBA has very low specific gravity, its adoption lead to drop in the plastic density of the specimens. The compressive strength of concrete increased when the fine aggregate was replaced up to 40% for both 7-day strength as well as 28-day strength. Beyond 30% replacement, there was a drop in the compressive strengths. A similar behavior was observed in flexural tests. However, the gain in strength for 7-day test was higher, when the fine aggregate was replaced from 20-30%. The split tensile strength showed a gradual rise, up to a fine aggregate replacement of 40% for both 7-day strength as well as 28-day strength. The ultrasonic pulse velocity test results indicate that replacement of fine aggregate by CBA is acceptable from durability consideration. All the mixes containing CBA absorbs more water as compared to control mix. Water absorption increased hence in small replacements it proved durable.
Figure 1. Drying shrinkage variation

Figure 2. Plastic density variation

Figure 3. Compressive strength variation

Figure 4. Flexural strength variation

Figure 5. Split tensile strength variation

Figure 6. Ultrasonic pulse wave variation

Figure 7. Water absorption variation
4. Conclusions and recommendations

In present investigation, different series of the experiments have been conducted on concrete with the addition of CBA as alternative to replace fine aggregate. The results show that workability and plastic density decreases by adding more CBA content. It was observed that as CBA content increases in concrete, the drying shrinkage improved. It was found that CBA can suitably replace fine aggregate up to 30% only, beyond that the strength as well as durability characteristics drop sharply. Concrete containing CBA was found to absorb more water than normal concrete and can be adopted up to 40%, thus provides an ideal partial replacement to natural fine aggregate.

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