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Performance of Coal Bottom Ash as Partial Cement Replacement in Mortar

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Abstract: Coal bottom ash is the granular by-product of burning coal to create steam and electricity. The amount of coal bottom ash (CBA) produced has increased cause disposal issues to arise. This study sought to investigate the effectiveness of CBA as a partial cement replacement in a mortar and the optimum percentage of CBA in a mortar. The percentage of CBA utilized to substitute cement in the concrete mixture ranges from 10% to 30%. Concrete with CBA as a cement replacement was tested for compressive strength, density, and water absorption. Based on this research, the ideal CBA content for compressive strength and water absorption is 10%. Compression strength tests demonstrated that 10% and 15% of CBA mixtures had surpassed the control specimen at 28 days.

Keywords: Concrete Material; Cement Replacement; Coal Bottom Ash

1. Introduction

Coal is a major energy source, accounting for about 40% of global power generation. Since 1988, multiple Malaysian power stations have used coal as a fuel source. Coal Bottom Ash (CBA) is a by-product of thermal power plants that is rapidly increasing in Malaysia. [1]. The presence of rock debris in coal seam fractures causes CBA to develop. The combustible components were burned during burning, while incombustible elements like rock fragments produced CBA. It is a well-known industrial waste produced by coal-fired power plants. Made comprised of agglomerated ash particles not lighter or finer than flue gases, thus its name.

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Adding CBA to the concrete mix, which has different mineralogical and physical characteristics than cement, may have a substantial influence on the mechanical properties of the cured concrete. [2]. Using waste materials like CBA as a cement additive may help alleviate environmental problems while saving money on building expenditures. [3]. Compressive strength 20-40 N/mm2 and density 1560-1960 kg/m3 may be achieved after 28 days of curing using CBA. [4]. The drying shrinkage of CBA concrete was much lower than the control samples. [5].

The tensile strength of CBA concrete grows like conventional concrete. Moreover, compared to concrete compressive strength, CBA had a stronger impact on split tensile strength growth. The splitting tensile strength of CBA concrete with 50% CBA enhanced by 11.01% above control concrete. [6]. The material's strength decreased dramatically with increasing bottom ash concentration if the sand replacement was used up to 10%. The tensile strength decreased as the proportion of CBA in the mixture rose. [5]. This study was emphasized to determine the optimum CBA composition that would provide the highest performance in terms of compressive strength, density, and water absorption characteristics.

2. Properties of Coal Bottom Ash

The physical and chemical properties of CBA vary not only according on the coal source, but also depending on the power plant where the ash is generated on a day-to-day basis. Naturally, it has a significant impact on its concrete performance. The color of CBA varies from grey to brown, although it may even be entirely black, and its form is typically angular. CBA has a chemical makeup that is similar to FA, however it has substantially less pozzolanic activity [7].

Accordingly, because each thermal power plant station's chemical composition is comprised of coal from a variety of different sources, the percentage of water absorption in each type of bottom ash, its specific gravity, and its fineness modulus have all revealed a broad variation in results [8]. A number of thermal power plant stations in India are represented in Table 1, which shows their specific gravity, water absorption percentage, and fineness modulus.

Table 1: Bottom ash properties in India's thermal power plants

Power plant station/ Physical properties	Guru Hargobind Thermal Power Plant Bathinda India	Panipat Thermal Power Plant Haryana, India	Eklahare Thermal Power Plant Nashik City Maharashtra, India
Specific gravity	1.30	2.66	1.93
Water absorption	31.58	12.00	10.06
Fineness modulus (%)	1.37	3.12	2.7

3. Material and Method

3.1 Specimen Detail

The cement utilized in this investigation was ordinary Portland Cement (OPC). The aggregate used in the concrete mixture was clean, firm, and evenly graded, as did the coarse aggregate. As a result, the aggregate that passed through a 4.75 mm filter was used in this investigation. This study made use of both freshwater and tap water. Coal bottom ash from the Tanjung Bin power plant were used. The replacement of cement with CBA varies from 10% to 30% by 5% increment accordance with BS EN (196-1) and BS 1881: Part 116: 1983 (Method of determination of compressive strength of concrete cubes) that are shown in Table 2 with the mix design in Table 3. Mortar cube with dimension of 50 mm x 50 mm x 50mm were used for testing. The mortar was removed from the mould after 24 hours and placed in a water tank to cure as shown in Figure 1.

Table 2: Specimen details by percentage replacement

Specimen	Percentage Replacement (%)	Compressive Strength		Water Absorption
		7 days	28 days	28 days
OPC	0	3	3	3
CBA 10	10	3	3	3
CBA 15	15	3	3	3
CBA 20	20	3	3	3
CBA 25	25	3	3	3
CBA 30	30	3	3	3
Total		18	18	18

Table 3: Mortar mix design

Specimen	Cement (Kg)	Sand (Kg)	CBA (Kg)	Water (Kg/L)
OPC	0.900	1.800	0.000	0.540
CBA 10	0.810	1.800	0.090	0.540
CBA 15	0.785	1.800	0.135	0.540
CBA 20	0.720	1.800	0.180	0.540
CBA 25	0.675	1.800	0.225	0.540

Figure 1: Curing process of specimen

4. Result and Discussion

4.1 Compressive Strength

The specimen OPC is the controlled mortar specimen where 0% of percentage replacement of CBA. While the other specimen has the replacement of cement with CBA varies from 10% to 30% by 5% increment. Figure 2 shows the relationship between coal bottom ash percentage and compressive strength. In the 7 days, the compressive strength ranged from 32.53 MPa to 42.30 MPa, while in the 28 days, it ranged from 40.70 to 55.12 MPa. For 7 days, the maximum strength was obtained at 10% CBA replacements with a 13% increase over the control sample. Maximum strength was found at 15% CBA replacements, a 26% increase over the control sample after 28 days. Although the value of compressive strength at 10% CBA replacements is too near to the value at 15% CBA replacements by 0.7, it cannot be ignored. The results showed that specimens with 10% CBA replacements had the optimum compressive strength for both curing times. Similar results have been previously reported by Jamaludin [9] and Burhanudin [10]. This was probably due to lower cement content and lower CBA pozzolanic input [11]. As a result, it can be concluded that replacing 10% will result in a greater strength value.

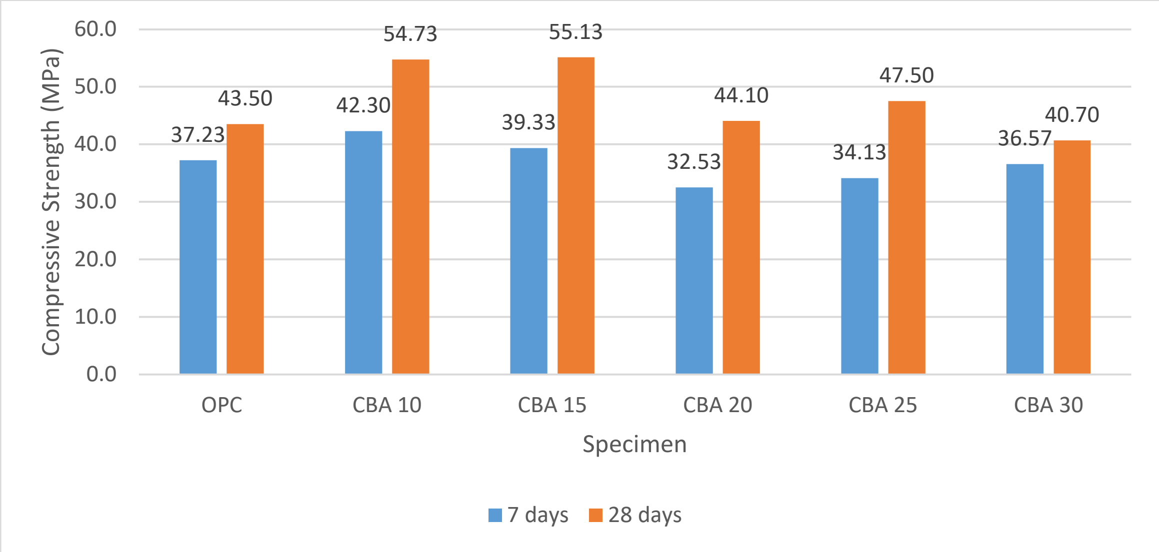

Figure 2: Compressive strength of CBA at age 7 and 28 days

4.2 Density

For this study, the determination of mortar density is also be considered. Figure 3 shows the result of the density of each specimen that has been taken. The density of mortar consists of different percentages of CBA ranging 2.12 g/cm³ to 2.21 g/cm³. It is recorded that the highest density was recorded is 30% CBA replacement while the lowest density was recorded is 20% CBA replacement with 7.8% and 4.4% respectively compared with the control sample. This also might be the possibility of human error during the mixing process because there was no similar result in the previous study. According to a previous study by Baco [12], the density of mortar consists of CBA as partial cement replacement varies from 2.4 g/cm³ to 2.5 g/cm³. This indicates that the value obtained in this finding is approximately the same as the value of the previous finding. Although inconsistent results were obtained, it can be seen that when the percentage of CBA as partial cement replacement in mortar increases, the density of the mortar increases.

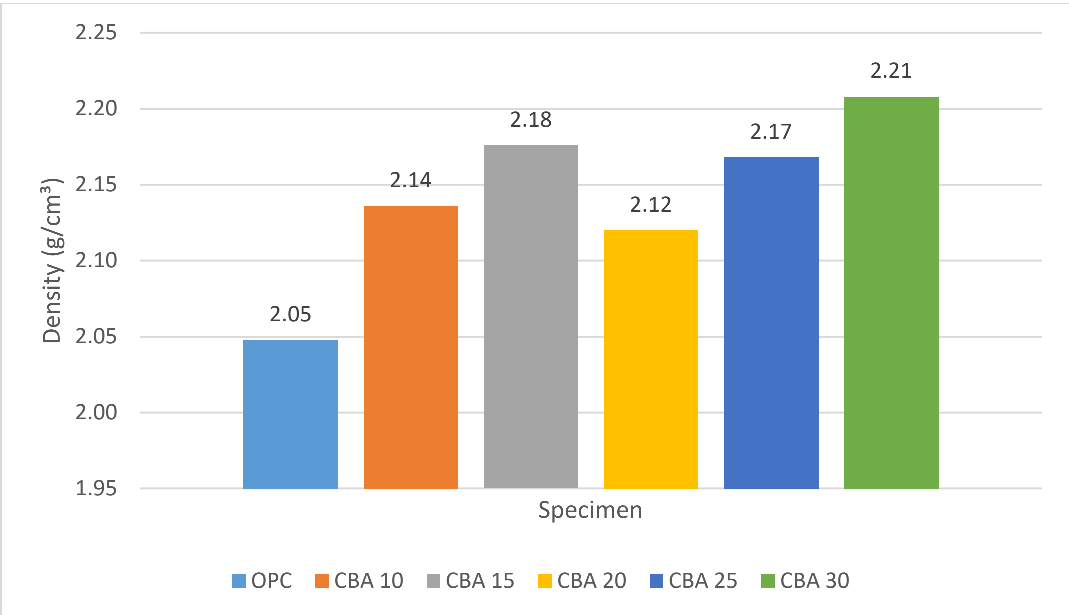

Figure 3: Density of CBA as cement replacement

4.3 Water Absorption

Water absorption is used to determine block conservativeness since block pores absorb water. Water absorption is linked to porosity, impacting probable weakness [9]. The effect of replacing cement with CBA varies from 10% to 30% by 5% increment in water absorption was done in 28 days. The experimental data on the water absorption are shown in Figure 4. OPC specimen that has 0% of CBA replacement act as the control specimen for this finding. It can be observed that on day 28, the highest percentage of water absorption was recorded is 30% CBA replacement while the lowest density was recorded is 10% CBA replacement with 45% and 14% respectively compared with the control sample. A similar result can be seen by Jamaludin [9] that water absorption increased as the CBA content in the concrete bricks increased. This is because the specimen with CBA absorbs the water more and affects the weight of the mortar sample. This high-water absorption could be due to the high pore content.

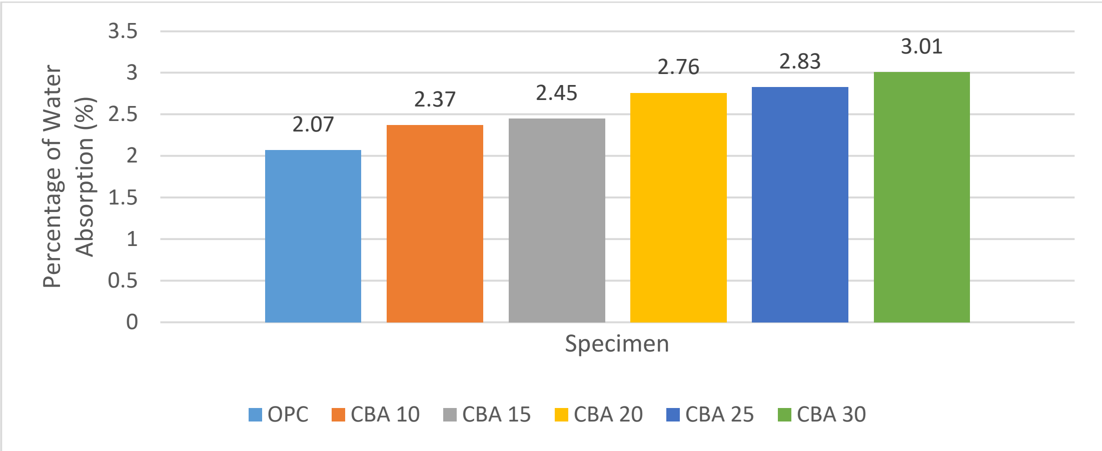

Figure 4: Water absorption of CBA as cement replacement

4.4 Relationship Between Compressive Strength and Water Absorption

After being cured for 28 days, the relationship between compressive strength and water absorption can be shown in Figure 5. From the bar chart that indicates the compressive strength, the highest strength was found with 10% CBA replacements. Meanwhile, the line chart has been used to represent the percentage of water absorption. It can be observed that 30% of CBA replacement was observed as the greatest percentage of water absorption. The figure shows that compressive strength has no clear relationship with water absorption.

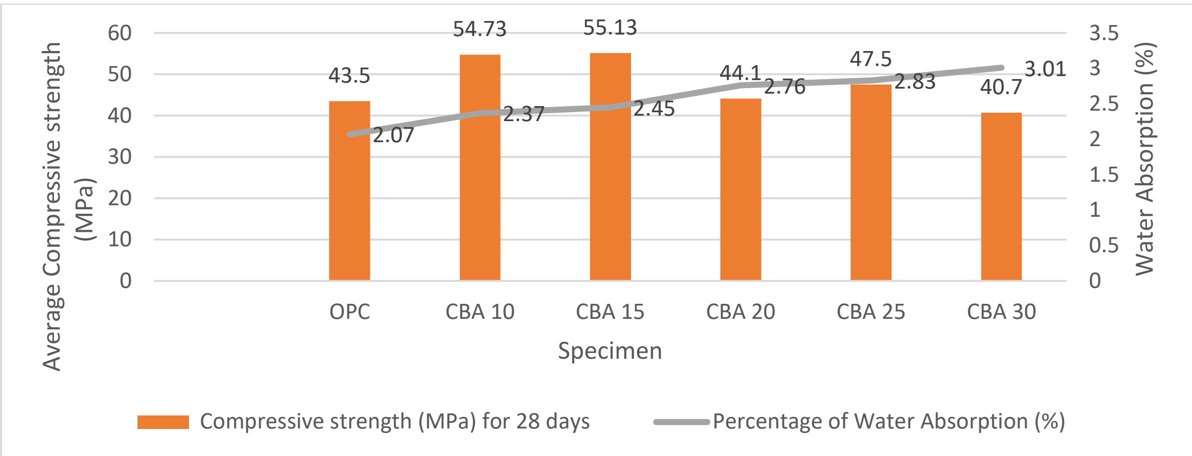

Figure 5: Relationship between compressive strength and water absorption

4.5 Relationship Between Compressive Strength and Density

Results in Figure 6 show the relationship between compressive strength and density of mortar added with different percentages of CBA. Mortar containing 30% of CBA had the highest density while mortar containing 15% of CBA had the highest strength for compressive strength. Same as the relationship between compressive strength and water absorption, there is no clear relationship between compressive strength and density.

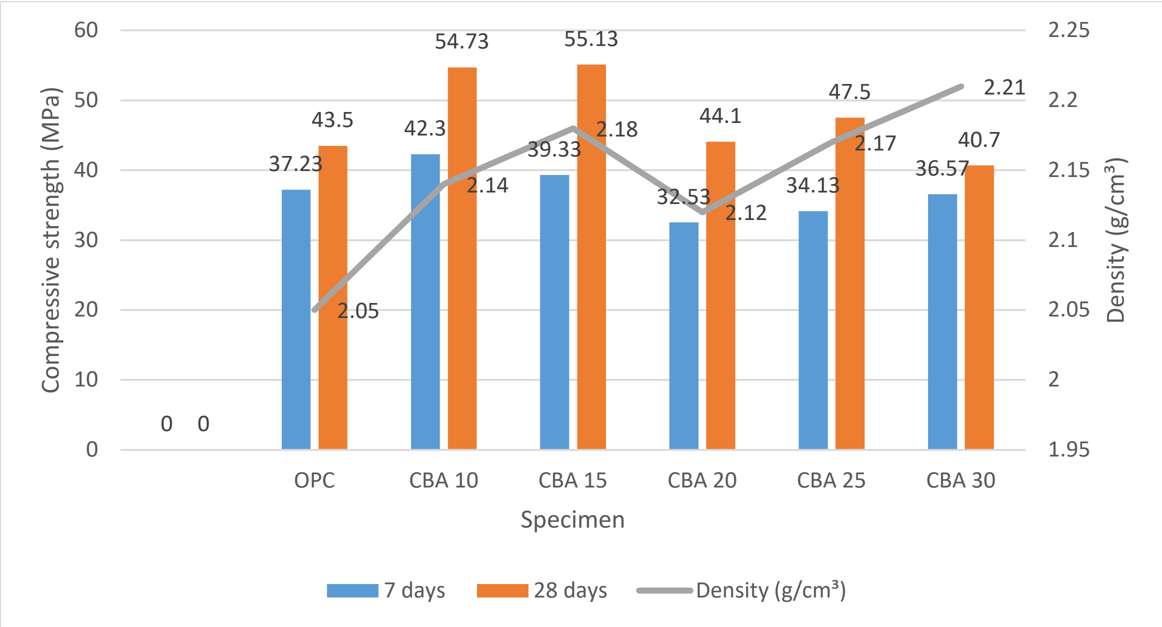

Figure 6: Relationship between compressive strength and density

4.6 Relationship Between Density and Water Absorption.

The relationship between density and water absorption of mortar added with different percentages of CBA is shown in Figure 7. In general, water absorption will be reduced due to the low density of the material [13]. As for this study, the statement is refuted as the density of a mortar containing CBA increases, the percentage of water absorption also increases. As shown in the figure, mortar containing 30% of CBA had the highest density and percentage of water absorption. Despite the fact that the findings were varied, it can be observed that as the content of CBA increased in the mortar so as the density and water absorption.

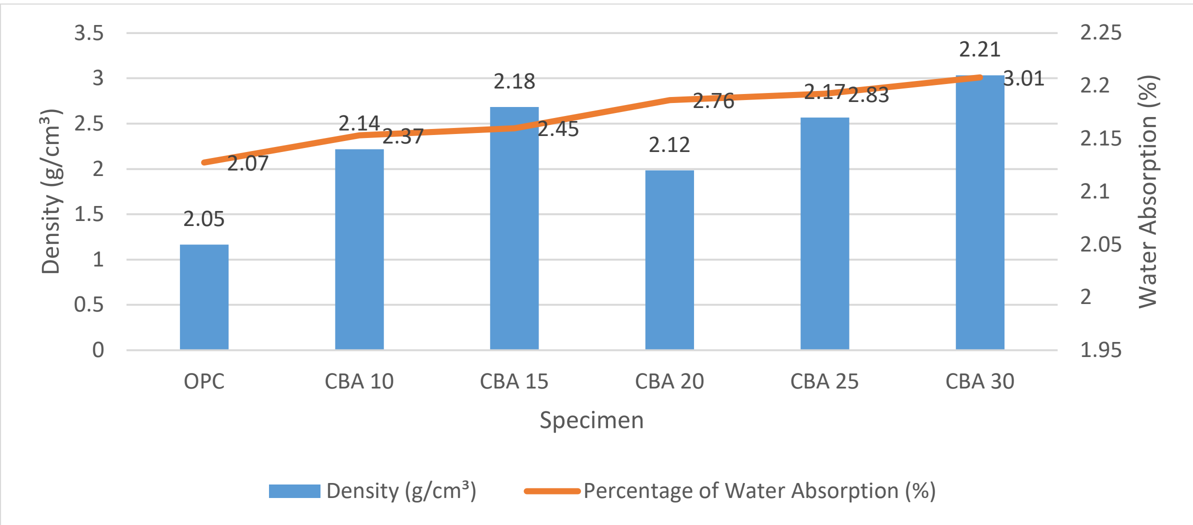

Figure 7: Relationship between density and water absorption

5. Conclusion

As conclusion, this study's findings show that CBA can be used as a partial cement replacement in mortar. The optimum CBA content for compressive strength and water absorption is 10%. Compression strength tests demonstrated that 10% and 15% of CBA mixtures had surpassed the control specimen at 28 days. In the water absorption test, using 10% CBA as a cement replacement is the best option. The water-cement ratio appears to affect the mix's strength. It looks to be suitable for low partial cement substitution, especially in low-strength concrete. Finally, this study found that the Tanjung Bin power plant's waste may be used to substitute cement. Using CBA as a cement replacement in concrete may assist reduce cement usage while preserving resource sustainability.

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