Compressive and tensile strength for concrete containing coal bottom ash

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Abstract. The increasing demand in the construction industry will lead to the depletion of materials used in construction sites such as sand. Due to this situation, coal bottom ash (CBA) was selected as a replacement for sand. CBA is a by-product of coal combustion from power plants. CBA has particles which are angular, irregular and porous with a rough surface texture. CBA also has the appearance and particle size distribution similar to river sand. Therefore, these properties of CBA make it attractive to be used as fine aggregate replacement in concrete. The objectives of this study were to determine the properties of CBA concrete and to evaluate the optimum percentage of CBA to be used in concrete as fine aggregate replacement. The CBA was collected at Tanjung Bin power plant. The mechanical experiment (compressive and tensile strength test) was conducted on CBA concrete. Before starting the mechanical experiment, cubic and cylindrical specimens with dimensions measuring 100x100x100mm and 150x300mm were produced based on the percentage of coal bottom ash in this study which is 0% as the control specimen. Meanwhile 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% of CBA were used to replace the fine aggregates. The CBA concrete samples were cured for 7 days and 28 days respectively to maintain the rate of hydration and moisture. After the experimental work was done, it can be concluded that the optimum percentage of CBA as fine aggregate is 60% for a curing period of both 7 days and 28 days with the total compressive strength of 36.4Mpa and 46.2Mpa respectively. However, the optimum percentage for tensile strength is at 70% CBA for a curing period of both 7 days and 28 days with a tensile strength of 3.03MPa and 3.63MPa respectively.

1. Introduction
Concrete Coal bottom ash (CBA) is a by-product of coal combustion. The rock detritus filled in the fissures of coal becomes separated from the coal during pulverization. Swirling air carries the ash particles out of the hot zone where it cools down. The boiler flue gas carries away the finer and lighter particles of coal ash. The boiler flue gases pass through the electrostatic precipitators before reaching the environment. In the electrostatic precipitators, coal ash particles are extracted from the boiler flue gases [1-5]. The coal ash collected from the electrostatic precipitators is called fly ash. Fly ash constitutes about 80% of coal ash. During the combustion process some particles of the coal ash accumulate on the furnace walls and steam pipes in the furnace and form clinkers. These clinkers build up and fall to the bottom of furnace. In addition, the coarser particles, which remain in suspension with
the flue gases, settle down at the base of the furnace. The ash collected at the bottom of furnace is called coal bottom ash. Coal bottom ash constitutes about 20% of coal ash and the rest is fly ash [6-9].

CBA is a coarse granular and incombustible by-product from coal-burning furnaces. It is composed of mainly silica, alumina and iron with small amounts of calcium, magnesium sulphate and etc. The appearance and particle size distribution of CBA is similar to that of river sand. These properties of coal bottom ash make it attractive to be used as fine aggregate in the production of concrete [8,10,11]. CBA is a potentially viable material to be used as fine aggregate in the production of concrete [12]. Bottom ash exhibits high shear strength and low compressibility [13-15]. These engineering properties make bottom ash an ideal material in the design construction of dams and other civil engineering applications. Bottom ash also exhibits a relatively high permeability and grain size distribution that allows the design engineer to use it in direct contact with impervious material. Bottom ash has proven to be an economical material and a good engineering property. The previous studies in which coal bottom ash has been targeted as a substitute for sand in the production of concrete demonstrated that the strength development pattern of CBA concrete is similar to that of conventional concrete [14-19].

A research was conducted by Yahya et al. [2] on the properties of concrete using Tanjung Bin power plant CBA and fly ash. CBA and fly ash were utilised to partly replace fine aggregates and cement respectively in varying percentages of 0%, 5%, 10%, 15% & 20%. The results showed that grade M35 concrete combined with CBA and fly ash can achieve 30MPa in strength after a curing period of 28 days. Kurama et al. [10] and Ramzi [11] concluded that the use of CBA and fly ash in concrete has the potential to produce durable and strong concrete. Singh and Siddique [1] studied the effects of coal bottom ash as sand replacement on the properties of concrete with different w/c ratio. Ramzi [11] concluded that the compressive strength, split tensile strength and flexural strength of concrete increased after a curing period of 7 days, 10 days, 14 days, 28 days, 56 days and 90 days when up to 30% of CBA is used to replace fine aggregates. Besides that, the research work carried out by Ramzi [11] indicated that the compressive strength of concrete mixtures made of CBA as a substitute for sand was not strongly affected. However, the flexural strength and modulus of elasticity of concrete decreased with the increase in the content of CBA. Even though a lot of research has been conducted, there is still a lack of research on the use of CBA in concrete. Thus, this study will emphasise on the incorporation of CBA in concrete in varying percentages.

2. Material and Procedure

2.1. Materials

The constituent materials used in this research were cement, coarse aggregate with a nominal size of (4.75-20) mm, water, fine aggregate and coal bottom ash (CBA). Coal bottom ash (CBA) was collected at the Tanjung Bin power plant. The coal bottom ash will be used in this test as a partial replacement of fine aggregate to produce concrete. Figure 1 shows example of coal bottom ash.

![Coal Bottom Ash](image.png)

**Figure 1.** Coal Bottom Ash.
2.2. Mix design

The cement content, aggregate content and water content for concrete was determined by using standard mix design of concrete (DOE Method). Table 1 presented the design of mixture used in this study.

### Table 1. Design mix of concrete.

| Percentage (%) | Coal Bottom Ash (Kg) | Cement (kg) | Water (kg/L) | Fine aggregate (kg) | Coarse aggregate (kg) |
|----------------|-----------------------|-------------|--------------|---------------------|-----------------------|
| 0              | 0                     | 5.89        | 2.65         | 5.94                | 12.10                 |
| 10             | 0.31                  | 5.89        | 2.65         | 5.35                | 12.10                 |
| 20             | 0.62                  | 5.89        | 2.65         | 4.75                | 12.10                 |
| 30             | 0.93                  | 5.89        | 2.65         | 4.16                | 12.10                 |
| 40             | 1.24                  | 5.89        | 2.65         | 3.56                | 12.10                 |
| 50             | 1.55                  | 5.89        | 2.65         | 2.97                | 12.10                 |
| 60             | 1.87                  | 5.89        | 2.65         | 2.38                | 12.10                 |
| 70             | 2.18                  | 5.89        | 2.65         | 1.78                | 12.10                 |
| 80             | 2.49                  | 5.89        | 2.65         | 1.19                | 12.10                 |
| 90             | 2.80                  | 5.89        | 2.65         | 0.59                | 12.10                 |
| 100            | 3.11                  | 5.89        | 2.65         | 0.00                | 12.10                 |

2.3. Specimens and tests

Concrete cubes of 150 x 150 x 150 mm (66 numbers of Samples) were used to evaluate the compressive strength. However, concrete cylinders of 150 x 300 mm (66 numbers of sample) were used to evaluate the tensile strength. Compressive strength test was conducted based on BS EN 12390-3: 2009 [9]. Three cubes were tested for each percentage and age. However, tensile strength was carried out as specified in BS1881-117 (Testing Concrete - Method for determination of tensile splitting strength. British Standards Institute, London). Three cylindrical specimens were tested for each age and percentage. Figure 2 and figure 3 shows those specimens under compressive and tensile strength test.

![Figure 2. Compressive strength test.](image1)
![Figure 3. Tensile strength test.](image2)

3. Result and discussion

In this paper, all the results and analysis from the laboratory work that had been conducted are presented. The optimum percentages of CBA as a partial sand replacement and the suitability of CBA in concrete are explained in detail.

3.1. Slump test

Figure 4, summarized the slump values of CBA concrete mixtures decreased with the increase of percentage of CBA in concrete. By replacing 10% up to 40% of CBA in the mixture, its indicate in range
of true slump compare to others. However the slump value for 100% containing of CBA, shown drastically reduce compared to control sample approximately 25 mm of slump. Consequently, the good percentages for replacing the CBA in concrete mixtures are between range 10%-40%. The range also supported by previous researcher with the range of 5% - 45% of CBA [10-11].

![Figure 4](image-url)  
**Figure 4.** Relationship between slump and concrete containing different percentage of CBA.

3.2. **Compressive strength**

Figure 5 and figure 6, summarized the values of compressive strengths for all mixes at 7 and 28 days of curing respectively. From the figures, it can be observed that the graph trend shows the strength decreased significantly at 10% of CBA in concrete but the strength increased slowly between 20% until 40% CBA concrete. At 50%, the strength of the concrete decreased again. At 60% of CBA concrete, the strength value increased significantly and gradually decreased until it reached 100% of CBA concrete.

![Figure 5](image-url)  
**Figure 5.** Compressive strength of CBA for 7 days.
The optimum percentage to achieve the maximum strength is 60% of CBA as sand replacement in concrete. However, according to Singh [1], the optimum strength was achieved by 30% CBA concrete cured for 7 and 28 days. The delay in hydration due to the use of CBA as fine aggregate in concrete may be a possible explanation for the varying results achieved in terms of optimum strength. This may also be due to the strength of individual constituent materials of concrete which can also influence the strength of concrete as stated by Ramzi [11].

### 3.3. Tensile strength

Figure 7 and figure 8 show the results of tensile strength. It can be summarised that all percentages of CBA in concrete as sand replacement for 7 days achieved lower strength than the target requirement of control concrete which is 32.9 MPa. However for 28 days, the varying percentages of CBA as fine aggregate replacement significantly increased in strength compared to concrete cured for 7 days. The strength of 90%, 100% and 70% CBA concrete surpassed 3.0 MPa in strength. However, 70% CBA concrete achieved a value exceeding the tensile strength of control concrete which is 3.63 MPa. Currently, the tensile strength of control concrete is 3.50 MPa. Therefore, the optimum percentage of CBA in concrete to be used as fine aggregate replacement is 70%.

![Figure 6. Compressive strength of CBA for 28 days.](image_url)

![Figure 7. Tensile strength of CBA for 7 days.](image_url)
There are varying results of tensile strength based on previous research studies. According to Singh [1], the optimum strength for 28 days is at 50%. However, according to Ramzi [11] the optimum tensile strength is up to 30%. The data obtained from this research shows that the optimum tensile strength achieved was at a higher percentage compared to other researchers.

4. Conclusion
In a nutshell, the optimum percentage of CBA as a fine aggregate replacement is range of 40% - 70%. This range is according to the testing of slump, compressive and tensile strength. The optimum percentage of CBA as a fine aggregate replacement from this paper indicated that slightly different compared to other researchers. Therefore its need more detail investigation on durability and detail percentage of CBA in mixture.

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