Investigation of water absorption and strength performances on concrete bricks containing Malaysian thermal power plant coal bottom ash (CBA)

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Abstract. Coal Bottom Ash (CBA) is normally associated as a by-product from the thermal power plants. Due to the current situation where the power plant is facing an increase in the production of CBA at an alarming rate reaching up to hundreds of thousands of tonnes in Malaysia alone, without known economic value CBA commonly ends up in ash ponds. As sustainable solid waste management has become a growing concern, this research presents the recent development achieved on the utilization of CBA as partial replacement of cement in concrete bricks manufacturing. The influence of different amount of CBA on the water absorption, compressive strength performances and UPV test on bricks are presented. With the addition of CBA as a partial replacement of cement also causes an increase in physical performance compared to regular bricks. As a conclusion, the bricks produced passed the required value of typical commercial bricks for water absorption, ultrasonic pulse velocity (UPV) and compressive strength test for industrial purposes. Hence, incorporating CBA in construction materials will significantly reduce the dumping of the by-products in landfills and thus reduce the adverse effect towards the environmental.

1. Introduction
Coal bottom ash (CBA) is one stream of waste product obtained from the combustion of coal in a thermal power plant amounted to 20% of the waste streams while the rest consisted of fly ash [1-4]. It is estimated that the annual production of coal ashes have reach up to 600 million tons worldwide, where bottom ash make up 100 million tons while the rest is fly ash [5]. Currently, the disposal method of CBA have created a growing environmental concern for the surrounding community and thus in the effort to alleviate this particular issue, utilization of CBA in construction is the best solution.

Industrial wastes such as silica fumes, coal fly ash and CBA are being adopted in recent studies as a replacement to cement in production of bricks [6-7]. These efforts do not only help to improve the quality of the environment but also reduce the disposal cost as well as construction cost without compromising the durability performances of the bricks [8-9]. CBA is known to have properties that resemble river sand and is rich in silica, alumina and iron. Due to these properties, CBA is seen to be a potential material as fine aggregate in the production of concrete bricks. Not only that, CBA was also discovered to be a potential material in improving the strength of cement.
Replacement of cement in concrete bricks could be a sustainable approach plus reduce the cost in construction. Therefore, the present study aim to investigate the strength performances of concrete bricks containing different portion of CBA at different curing time. In this study CBA composition of 5, 10 and 15% were selected to find the optimum CBA composition with the best performance in terms of water absorption, compressive strength and UPV.

2. Experiments

2.1. Materials

Materials used in this study include Ordinary Portland Cement, sand (fine aggregates), CBA with the details provided in table 1 and table 2, respectively and water. For the sand used, it is conforming to Zone-III (75-100%) based on IS-383. A finely ground CBA collected from one of the coal-fired power plant in Malaysia was used as partial replacement for cement in the concrete bricks making process. The durability performances were conducted on the concrete bricks having different portion of CBA varied at 0, 5, 10 and 15 wt%, respectively.

| Physical Properties | Value          |
|---------------------|----------------|
| Specific Gravity    | 3.15           |
| Initial Setting Time| 15 minutes     |
| Final Setting Time  | 60 minutes     |
| Size Produced       | 90µm           |

Table 2. Physical properties of sand and CBA.

| Properties   | Sand       | CBA       |
|--------------|------------|-----------|
| Specific Gravity | 2.65       | 2.12      |
| Bulk Density  | 1.6g/cc    | 0.641g/cc |
| Size Produced | 1.18-2.0mm | 90µm      |

2.2. Concrete mix preparation

Concrete bricks were prepared containing four different replacement portion of CBA (0, 5, 10 and 15 wt%) in order to find the optimum value. The required composition for each materials were calculated as listed in table 3. All the materials were weighed and mixed thoroughly for approximately 5 minutes. Moulding with all dimension of 70mm was performed in three layers. Each layers were tamped for 10 times. As the layers were filled up, it was smoothened out making sure the samples were sufficiently compacted and dense. The samples were let dry within 24 hours prior to demoulding the bricks. After the samples had dried, curing process was done for 7 days and 28 days which were then evaluated for its water absorption, compressive strength and ultrasonic pulse velocity (UPV) tests.

| Material   | CBA0 | CBA5 | CBA10 | CBA15 |
|------------|------|------|-------|-------|
| Cement (g) | 150  | 142.5| 135   | 127.5 |
| Sand (g)   | 435  | 435  | 435   | 435   |
| CBA (g)    | -    | 7.5  | 15    | 22.5  |
| Water (g)  | 90   | 90   | 90    | 90    |

2.3. Performance evaluation of bricks

2.3.1 Water absorption test

Bricks were immersed in a water tank for 24 hours. Initial and final weight were recorded in order to evaluate the water absorption.
2.3.2 Compressive strength test
The bricks should be removed from the water on day 7, 30 minutes prior to testing using compressive test machine. Test was also carried for day 28. Calculation for compressive test were performed using equation (1).

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\text{Compressive strength} = \frac{\text{Maximum Load Applied (kN)}}{\text{Cross Sectional Area (mm}^2\text{)}}
\] (1)

2.3.3 Ultrasonic Pulse Velocity (UPV) test
UPV test was conducted according to ASTM C67-03 in assessing the non-destructive properties of the bricks which include the compaction, uniformity of the bricks, presence of cracks and honey comb and strength estimation. There are three basic ways of transducer arrangement in performing the test. It can either be direct transmission through opposite faces, indirect transmission at the same face and semi-direct through adjacent faces. As the bricks dimensions were 70mm x 70mm x 70mm which were quiet small in size, a direct transmission was chosen to conduct the test. Calculation for UPV were performed using equation (2).

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\text{Pulse Velocity (km/sec)} = \frac{\text{Path length (m)}}{\text{Transit time (microsec)}}
\] (2)

3. Results and discussions
3.1 Water absorption
Water absorption is normally employed to determine the compactness of the bricks as pores of the bricks absorb water. Water absorption can be related to porosity, thus affecting the eventual deterioration. The effect of the concrete bricks consisting of 0, 5, 10 and 15 wt% CBA in water absorption was performed at 7 and 28 days, respectively. The concrete bricks at 0 wt% of CBA act as the control specimen for all tests. The experimental data on the water absorption are shown in Figure 1.

It can be observed that on day 7, the concrete bricks containing different composition of CBA does not varies much in terms of the water absorption percentage (0.14-0.18%) however the values are quite low as compared to the control brick. On day 28, much higher values were recorded for all bricks with which concrete brick containing CBA15 yielded 3.04% of water absorbed. Meanwhile, concrete bricks with CBA10 was observed to have the lowest percentage of water absorbed as compared to the control specimen and CBA5. Although an inconsistent results were obtained, it can be observed that as the content of CBA increased in the concrete bricks so as the water absorption. A similar results can be seen by Mangi et al [10] and Khan and Ganesh [11].

![Figure 1. Water absorption of concrete bricks containing CBA](image-url)
3.2. Compressive strength
The results for compressive strength of concrete bricks containing CBA are summarized in figure 2. For day 7, the values range from 6.12 MPa to 17.14 MPa whereas for day 28, the compressive strength observed were lower with the values range from 8.16 MPa to 10.61 MPa. The results indicated that for both curing duration, concrete bricks containing CBA10 achieve the highest compressive strength as compared to CBA5, CBA15 and control specimens. Similar results have been previously reported by Rafieizonooz et al [12] and Khan and Ganesh [11]. Although the compressive strength of the concrete bricks tend to decrease as the curing age of 28 days, the bricks containing CBA passes the minimum requirement with the satisfying values of compressive strength obtained. The difference gradually reduced due to pozzolanic reaction starts and calcium hydroxide reacts with CBA increasing the strength of bricks [11].

![Figure 2. Compressive strength results on concrete bricks containing CBA](image)

3.3. UPV
This method of testing bricks is influenced by the body defects of samples [13]. UPV is affected by material structure of bricks. Increasing of moisture content in bricks can increase the pulse velocity. The length of travel path can be longer if the bricks suspected some cracks and voids. For the samples, it is consider as concrete bricks which has < 6% absorptivity. Figure 3 illustrate the experimental results of UPV. It is observed that range of UPV values for bricks with or without CBA on day 7 were from 1496 m/s to 2564 m/s. For day 28, the UPV values were from 814 m/s to 1628 m/s. A researcher recorded the UPV value for bricks in the range of 1453 m/s to 2758 m/s [14]. Another research concluded that the UPV value for bricks is < 3700 m/s with the compressive strength among 10-40 MPa [15]. The results shows UPV test value is decreasing when the curing time is longer. If the velocity is slow, the bricks may cracks and have weak spots. Based on the results obtained, the performance of bricks containing CBA are acceptable. A high UPV performances can be achieved when more aggregates are used in terms of amount and size [16]. The composition of CBA used to substitute the cement in the bricks were quite low (5-15%) and it does not work as fine or coarse aggregate. The value did not pass higher than 3000 m/s as the properties used for coal bottom ash is 90µm same as cement and not substitute the fine aggregate, sand. It can be concluded that the amount of CBA affect the decreasing of UPV value. Cement incorporates well with low-carbon ash as it contain less loss-on-ignition (LOI) in order to obtain the required pozzolanic properties [17].
Figure 3. UPV testing on concrete bricks containing CBA

Conclusion

For a typical commercial brick, the water absorption should range below than 7% for better resistance towards damage. From the results obtained, the water absorption test for the bricks ranged below 7% for both 7 and 28 days of curing time. The value of UPV has been recorded to be inconsistent with increase of percentage of coal bottom ash. Factors that may contribute to the inconsistent value are void and cracks on surface of bricks as smooth surface of bricks are required to achieve accurate value of UPV. UPV test value decreases with the increase of curing time. The minimum required compressive strength of a brick is 70 kgf/cm$^2$ (6.8 MPa). The value of compressive strength reduced on day 28. However, the value of compressive strength are still in range of minimum compressive strength. Based on the result of the investigation, it has been discovered that the properties of bricks made from coal bottom ash as partial replacement of cement passed the required properties of a good commercial brick. The bricks passed required value of typical commercial bricks for water absorption, ultrasonic pulse velocity (UPV) and compressive strength test. It is recommended that more in depth and detail investigation on the durability performances of bricks containing higher percentage of CBA are to be performed in the future.

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