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Strength and Chloride Penetration Performance of Concrete Using Coal Bottom Ash as Coarse and Fine Aggregate Replacement

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Abstract. Since 1987, Malaysia had used coal as a product to generate electricity. One of the main or the largest power plant in Malaysia is Tanjung Bin power plant at Kukup, Johor. As a coal-based power plant, tonnes of coal bottom ash had been burned every day and the waste is wasted without specific economic benefit. Other than that, the waste generated are dangerous as it involved in environmental risk such as landfill ash reservoir. Therefore, this paper presents one of the alternative ways to manage the coal waste by cooperative it into concrete. This research study focuses on strength and durability performance of the concrete containing coal bottom ash as a coarse and fine aggregates replacement. The tests conducted was workability on fresh concrete, compressive strength test and chloride penetration test in 5% sodium chloride. The results show that the concrete containing coal bottom ash has low workability compare with normal concrete without coal bottom ash. Compressive strength test with coal bottom ash resulted higher than normal concrete. In chloride solution, the concrete containing coal bottom ash replacement shows better performance compare to normal concrete. Thus, it can be concluded that by using coal bottom ash in concrete as fine and coarse aggregates replacement, the performance in term of strength and chloride resistance are better compare to normal concrete. On the other hand, by using it in concrete, the waste generated dump in landfill can be reduced.

1. Introduction

The rapid growth of construction sector, in conjunction with economic growth, consequently, indirectly requires considerably high amount of production and consumption of construction minerals, such as rock materials (aggregate) and sand. Concrete is the most valuable material in the construction industry. Rock materials and sand are depended upon as a main source of raw construction material. Thus, the mining and quarry industry, should guarantee the adequate and continuous supply of raw materials as a producer of construction minerals to the construction sector to sustain the economic development of the country [1]. Concrete is a mixture of different materials content such as cement, fine aggregate, coarse aggregate, and water. Concrete is the most widely used for construction over the world because it is easy to cast and cheaper than other materials. The used of coarse aggregate and fine aggregates in concrete are common but unfortunately, it causes a depletion of natural aggregates on earth [2]. To overcome this problem, several research had been conducted to find an alternative way to reduce the use of natural aggregates. The use of industrial waste and by-product materials is now widely recognized as one of the preferred options towards the achievement of sustainable



development [3]. The by-product waste materials available and had been recently study are palm oil fuel ash, fly ash, rice husk ash, eggshell and bottom ash. All these materials show a promising result to be use as one of the construction materials. However, the percentage of replacement is quite low. Thus, this research used 100% replacement of coal bottom ash as fine and coarse aggregates in concrete. Coal Bottom ash (CBA) or Bottom Ash (BA) is a by-product of the combustion of pulverized coal in the coal power plants. CBA is the unburnt matter of the coal incineration and it is formed at boiler and constitutes about 10–20% of coal ash [4, 5]. Usually, the product of burned coal which is the waste will be thrown at the landfill or in the ponds. In certain power plants, the bottom ash is put collectively with fly ash before cleared [5]. In fact, disposal of coal bottom ash in open air causes threat to humans and environments [6]. The CBA have uneven spongy textured structured with angular and irregular shape. It is also dark grey ash is asymmetrical and porous [7]. This porous ash condition leads to higher water absorption. Therefore, this paper focus on the strength performance and chloride penetration of concrete containing CBA as fine and coarse aggregates replacement.

2. Materials and Methodology

2.1 Coal Bottom Ash

Coal bottom ash (CBA) is an industrial waste from coal power plant and it was declared as a pozzolanic material class F. CBA can also be used to utilized as one of supplementary cementitious material because it contains high proportion of silica. It was previously agreed by Jaturapitakkul and Cheerarot that the compressive strength of concrete increases with the use of CBA as partial cement replacement in concrete [8]. CBA is divided into two waste materials after a combustion process which are Fly Ash and Coal Bottom Ash. The form of the coal bottom ash is in coarse or rock condition after the combustion. Figure 1 show the raw CBA particle collected from Tanjung Bin, Southern Malaysia, which is grey and coarse size. In this research, the size of CBA is divided by two sizes which are for fine aggregate, the size is 2.75 mm while for coarse aggregate, the size is between 5mm to 10mm.



Figure 1 Raw Coal Bottom Ash collected from Tanjung Bin Malaysia

2.2 Material Preparation

The size of CBA is granite and rock condition from power plant and need to be crush using crushing machine before incorporating in concrete. Besides CBA, fly ash which one of the coal wastes also will be replace 20% of cement content in the mixture. The size of 100mm × 100mm × 100 mm was prepared for strength and durability test as according with ASTM C39-20 [9]. The mix proportion of concrete containing CBA was calculated based on the ACI Mix method of concrete mix as shown in Table 1. All specimens were undergone water cured for 28 days.

Table 1. Mix proportion of concrete with CBA replacement

Description	Cement (kg/m ³)	Fly Ash (kg/m ³)	Coarse Aggregates (kg/m ³)		Fine Aggregates (kg/m ³)	
			Granite	CCBA	Sand	FCBA
Control			780	0	881	0
100% CCBA 0% FCBA			0	780	881	0
50% CCBA 0% FCBA	440	88	390	390	881	0
100% CCBA 50% FCBA			0	780	441	441
100% CCBA 100% FCBA			0	780	0	881

*Notes: CCBA = Coarse Coal Bottom Ash; FCBA = Fine Coal Bottom Ash

2.3 Chloride Ion Penetration Test

Chloride ion penetration test was conducted to observe the effect of chloride ion to specimens. The test was conducted in according with ASTM C 1202-19 [10]. After initial curing was done, matured specimens were immersed in 5% sodium chloride solution for 28, 56 and 90 days. The changes in mass and strength were measured after the period of immersion ended.

3. Results and Discussions

3.1 Workability Test

The fresh concrete workability was evaluated by slump cone test method in according with ASTM C143-20 [11]. The workability of concrete is work when the distance of top concrete mix is measure with the iron rod from the cone height. The detailed of the workability result is shown in Figure 2. The result of the CBA replacement had slightly reduction compared to control mix. The reduction of the slump in workability are due to the presence of CBA replacement as coarse and fine aggregates in concrete mix which absorbed extra water in the mixture, and it was also confirmed by Khan & Ganesh [12]. Due to it pores structures, it absorbs more water compared to natural coarse aggregates and sand.

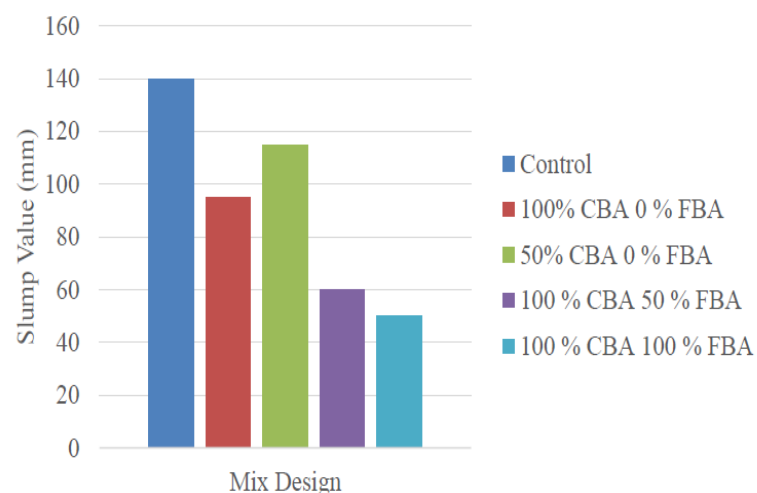


Figure 2. Workability of concrete mixture with various mix proportions

3.2 Compressive Strength Test

Compressive strength of hardened concrete specimens was determined at age of 7 days 14 days, 28 days, 60 days and 90 days. The compressive strength test results of concrete with and without CBA is shown in Figure 3.

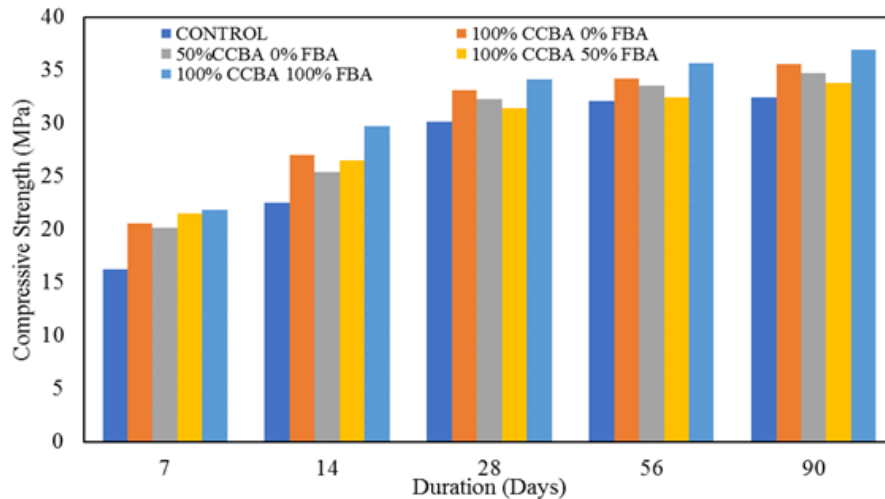


Figure 3. Compressive strength in different mix proportions at 7, 14, 28, 56 and 90 days

From the figure, it shows that the concrete containing CBA as fine and coarse aggregates shows slightly higher in compressive strength compare to control specimen. The different of the compressive strength is about 5% higher between control and concrete with replacement. Therefore, fully CBA replacement which fine and coarse; concrete has comparable compressive strength with the control concrete which casts using granite and sand. This is because, fully CBA replacement concrete consists of higher amount of filler compare to conventional concrete. The fine particles of CBA will fill up the spaces between the porous and thus increase the bonding strength between aggregates and cement. Thus, the concrete containing CBA will produce denser concrete compare to normal concrete.

3.3 Flexural Test

Figure 4 shows the flexural strength of the concrete design at 28 days after casting. As shown in the figure, the flexural strength of control concrete is 5.24 MPa whereas the flexural strength of CBA replacement concrete is 6.34 MPa. The CBA replacement concrete has slightly 17.35% higher in flexural strength than conventional concrete. This is due to the presence of filler compare to control mix concrete; thus, it will increase the bonding between aggregates. Moreover, concrete is weak in tension but strong in compression.

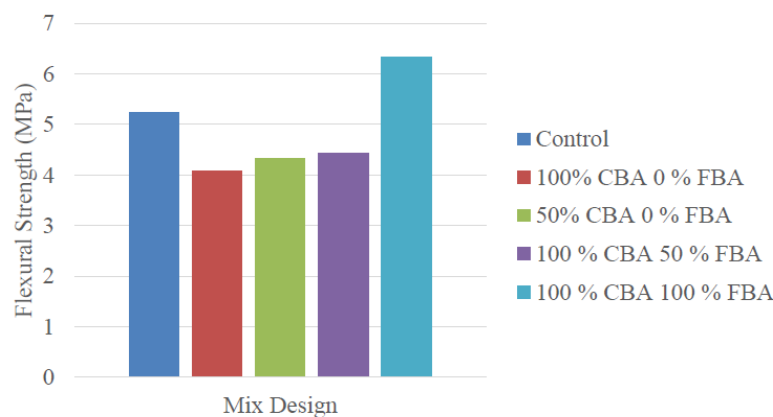


Figure 4. Flexural strength in different mix proportions for 28 days

3.4 Density Test

The design density of hardened concrete is 2350 kg/m^3 . Figure 5 shows the hardened density of different mix proportions at 28 days. As shown, the density of CBA concrete is 1865 kg/m^3 whereas the density of conventional concrete is 2313 kg/m^3 . The density of CBA concrete is 19.37% lower than the conventional concrete which consists of granite and sand as aggregates. This is due to the low density of bottom ash aggregates compare to granite and sand aggregates. Therefore, lightweight aggregate concrete is made up of lightweight aggregate to replace river sand and granite.

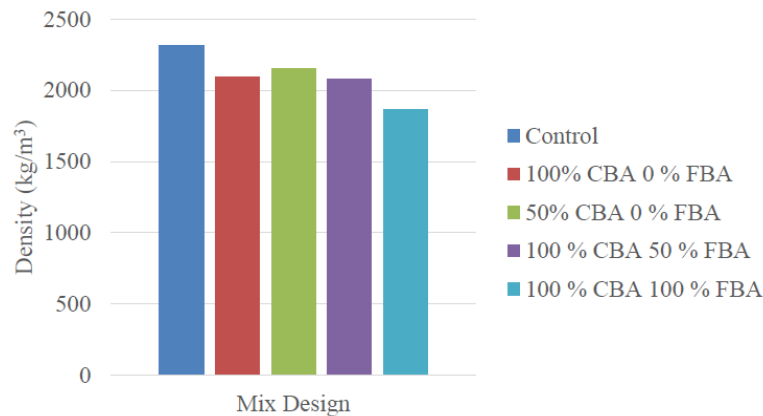


Figure 5. Hardened density in different mix proportions for 28 days

3.5 Durability Chloride Penetration Test

Based on the strength performance, the replacement of 100% natural aggregate with coarse CBA and replacement of natural sand with 100% fine CBA was chosen as an optimum mix design. The specimen was casted and test for chloride penetration test. After the specimen was matured, it was immersed in 5% of NaCl solution for 28, 60 and 90 days and the result are shown in Figure 6.

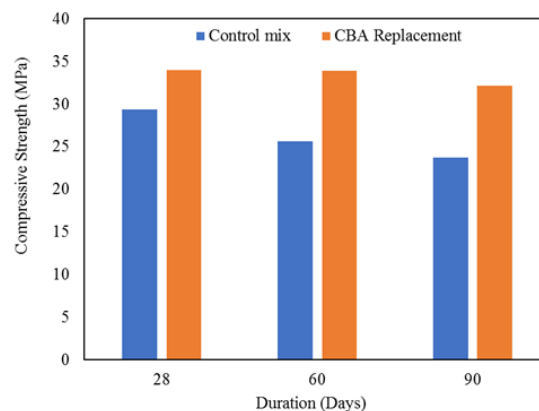


Figure 6. Compressive strength of specimen immersed in chloride solution

From the figure, it shows that the concretes containing CBA replacement are durable in chloride solution as the compressive strength only reduce 2% within 90 days of immersion. As compare with control mixture, the compressive strength reduces about 10% in 90 days of immersion. This is due to the condition of CBA which is porous. Moreover, the reaction occurred between cement, fly ash and CBA had strengthen the bonding inside the concrete [13]. Therefore, it can be concluded that the CBA concrete is durable in chloride solution even after 90 days immersion.

4 Conclusions

From the present study, it shows that by incorporation coarse and fine CBA as a natural aggregate and sand replacement in concrete can produce a comparable strength with normal concrete. From the results it shows that the replacement of 100% natural aggregate with coarse CBA and 100% sand with fine CBA gives the higher compressive strength and chosen as optimum mix proportion. The results also shown that the CBA replacement concrete show a resistance towards chloride ion when exposed it up to 90 days immersion.

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