INFLUENCE OF GROUND COAL BOTTOM ASH WITH DIFFERENT GRINDING TIME AS CEMENT REPLACEMENT MATERIAL ON THE STRENGTH OF CONCRETE

Mohd Khairy Burhanudin[1], Mohd Haziman Wan Ibrahim[1], Mohd Syahrul Hisyam Mohd Sani[3] , Mohd Irwan Juki[1], Norwati Jamaluddin[1] , Ramadhansyah Putra Jaya[2], Shahiron Shahidan[1] , Nurul Fasihah Basirun[1], Mohamad Zulhairi Mohd Bosro[1]

[1]Jamilus Research Center,Faculty of Civil & Enviromental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia.

[2]Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.

[3]Faculty of Civil Engineering, Universiti Teknologi Mara Cawangan Pahang, 26400 Bandar Tun Razak, Pahang, Malaysia

Abstract

This study was conducted to determine the strength of concrete containing coal bottom ash (CBA) as cement replacement material. The original CBA were sieved passing 150 um sieve size then ground for 20, 30, and 40 hours using ball mill machine. The normal concrete were designed for grade 30 based on Department of Environmental method (DOE). The concrete were produced by replacement level of cement 10%, 20% and 30%. The fresh concrete were tested using slump cone to determine the workability of concrete. It is found that slump height was decrease with increasing the replacement level of CBA. The concrete cubical with size 100 × 100 × 100 mm were prepared and tested to determine the compressive strength. It is shown that, the 20% replacement level of cement with 30 hours grinding time contributed high compressive strength compared to others. The presence of CBA in cement as a binder was improves the strength of concrete. It can be concluding that, CBA can be used as cement replacement material by appropriate replacement level.

Keywords: *Coal bottom ash; Compressive strength; Workability; Replacement material*

INTRODUCTION

In developing country like Malaysia, the coal generation power plant is gaining favour due to the growing need for energy and the call for a clean technology. In the electricity industry, gas remains the main fuel source for the generation industry, but coal is still become favourable because it is only viable fuel option in terms of cost and supply (Abubakar & Baharudin 2012). Coal bottom ash (CBA) is a waste material that disposed after process of electricity. According to Cheriaf et al. (1999) mention that, CBA qualifies the requirements of European standard EN 450 for use in concrete. A study carried out by Ghafoori and Bucholc (1997) revealed that durable concrete could be made with high-calcium CBA as fine aggregate. CBA is formed when pulverized coal is burned in a dry bottom boiler. The type of CBA produced depends on the type of furnace and also the origins of coal. From the burning process of coal, about 80% of the product were captured and recovered as Fly Ash (FA) meanwhile, the remaining 20% classified as bottom ash (BA).

CBA collected in water-filled hoppers at the bottom of the furnace is physically coarse, dark grey, granular and porous. At the wet bottom boiler, the CBA is kept in a molten state and collected when it falls into the ash hopper. Hence, high-pressure water jets immediately fractures the molten material into crystallized pellets, and it is referred as Boiler Slag. The other remaining combustion products go out along the flue gas chimney. Figure 1 shows the combustion of coal to generate bottom ash in a thermal power plant.

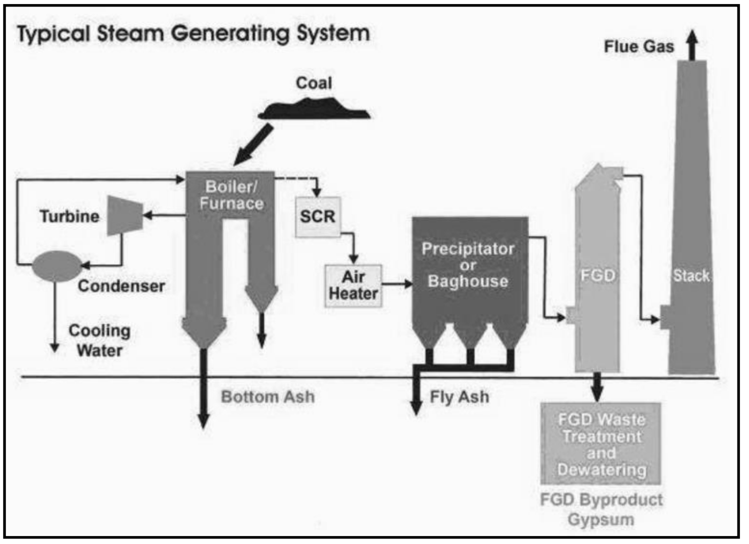

Figure 1. The production of coal combustion by-products in steam generating system (NETL, 2006)

The application of waste materials in concrete replacement has become popular an interesting topic in many research works. Concrete comprising three major substitutes which are cement, fine aggregate and coarse aggregate. Cement plays a vital role in concrete production. Its production is extremely energy-intensive and leads to excessive pollution, including SO_2 and CO_2 emissions (Azmi et al. 2017). The current cement production rate is approximately 1.2 billion tons/year and expected to grow about 3.5 billion tons/year by 2015 (Adesanya and Raheem, 2009). It is also the heaviest pollution industry and accountable for the 5–6% releases of CO_2, which causes about 4% of global warming (Rodrigues and Joekes, 2011). Such an enormous utilization of concrete calls for higher use of natural aggregates and cement, thus taking a toll on the environment. At least three-quarters of the total volume of concrete consist of coarse and fine aggregates (Rafieizonooz et al. 2016). Obviously, natural resources such as river sand are getting depleted (Aghabaglou, Tuyan and Ramyar, 2015). The prohibition on mining in some areas and the growing need for natural environment conservation further exacerbate the problem of river sand availability. Although aggregates are available at relatively low costs in most locales around the globe, availability is not universal. Some areas may be devoid of good quality sand and gravel, and a few others lack sources of crushed stone or rocks that can be mined easily and economically (Ramzi Hannan et al. 2016; Khalid et al. 2017). Furthermore, aggregates available locally may be unsuitable for use in construction due to poor quality, potential for chemical reaction and low strength.

Therefore, one of the most promising materials for replacing cement and sand material is coal bottom ash (CBA). CBA is one of the mineral by-product obtained from the combustion of coal used for power-generation purposes. CBA collected from electrical power generation is a dark grey, granular, porous and predominantly sand size material. These porous surfaces and very rough particle structure of CBA makes this material less durable (Bajare et al., 2013). Many research done use CBA as fine aggregate replacement as reported by Abidin et al.

(2017) and Torkittikul et al. (2017). Hence, with adequate grinding, CBA with pozzolanic activity can be used as a replacement material in Portland cement production (Cheriaf et al., 1999). Although grinding of CBA adds many good properties to concrete, it should be kept in mind that grinding is an expensive and time consuming process (Őzkan et al. 2007). Besides that, the quantity of coal bottom ash (CBA) to replace the cement for typical application is limited to 15-20% by mass of the total cementitious material. The small percentage is beneficial in optimizing the workability and low cost but it may not improve the durability (Suhendro, 2014).

The objective of this study is to determine the optimum replacement level of ground CBA in normal concrete. This study covers the physical properties of ground CBA and compressive strength of concrete incorporation with ground CBA as cement replacement material. The finding of these study are for further investigation on the use of ground CBA in different mix design grade.

MATERIAL AND METHOD

Ordinary Portland Cement (OPC) was used in this study supplied by Tasek Corporation Berhad and were certified by SIRIM compliance to MS EN 197-1:2014. The cement was stored in watertight drums to prevent unwanted solidification and humidity. The fine aggregates were used in this study is uncrushed river sand with 5 mm sieve passing. Meanwhile the coarse aggregate were sieve passing through 10 mm sieve size. The CBA that used in this study is a by-product from coal combustion process obtained from Kapar Energy Ventures power plant located at Kapar, Selangor. The original CBA physically dark grey and gravelly but after ground, the CBA become finer and the distribution size range is between 0.3 um and 40um.

Mix Proportion Design

The mixed design of concrete is very important to ensure the concrete grade design is successful. In this study, the mixed proportion were design according to British method of concrete mix design also called DOE method. The mixtures are specified by the weights of the different materials contained in a given volume of fully compacted concrete. It is assumed that the volume of freshly mixed concrete is an equal to the sum of the air content and of the absolute volumes of its constituent materials. Therefore, the DOE method requires that the absolute densities of the materials be known in order that their absolute volumes may be calculated. In DOE method, it is assumed that the strength of a concrete mix depends on free water/cement ratio, coarse aggregate type and also cement properties. The mix proportion design for this study was tabulated at Table 1 below. The water cement ratio 0.5 was designed for this mixture. The specimen were prepared for four different volume fraction (0, 10, 20 and 30 %) of ground CBA with three different grinding time which is 20, 30 and 40 hours. The concrete cube size 100 × 100 × 100 mm were prepared and cured in wet condition for 7 and 28 days. The workability of fresh concrete were tested using slump cone and the slump value were recorded.

Table 1. Mix proportion design by British DOE method

Cement (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
460	230	958	722

Particle Size Distribution

The particle size of ground CBA were conducted using Fritsch Analysette 22 after grinding process. The analysis method is laser light scattering technique where measuring range between 0.01 to 2100 µm. The wet method analysis were carried out where the ground CBA was dispersed in distilled water on the machine and take 5 to 10 second for measuring time. The testing has been conducted for all 3 different grinding time which is 20, 30 and 40 hours to identify the change of size after grinding process.

Specific Surface Area

These results of surface area were obtain from testing particle size analyser using Fritsch Analysette 22. The testing is important to analyse different fineness of ground CBA with different grinding time. Small amount of ground CBA was placed onto machine and directly measured.

Compression Test

The concrete cube specimen size (100 ×100 ×100 mm) were tested using 3000 kN hydraulic compression machine. The testing were conducted according to BS EN 12390-3: 2009. The loading rate during testing was constant within range 0.6 ± 0.2 MPa/s. The testing were carried out for 7 and 28 days curing period. The maximum load were record in N and compressive strength were expresse by Equation 1 below.

$$f_c = \frac{F}{A_c} \tag{1}$$

where:

f_c compressive strength in MPa (N/mm^2)
F maximum failure load in N
A_c cross sectional area of specimen in mm^2

RESULT AND DISCUSSION

Particle Size Distribution

Particle size distribution (PSD) analysis is important when particles have high aspect ratios. PSD analysis are susceptible to large uncertainties due to measurement the smallest. In this study, the ground CBA was graded using PSD analyzer. The finer particle will increase the specific surface area of ground CBA then increased the pozzolanic activity in concrete (Basirun et al.,2017; Hannan et al. 2017).

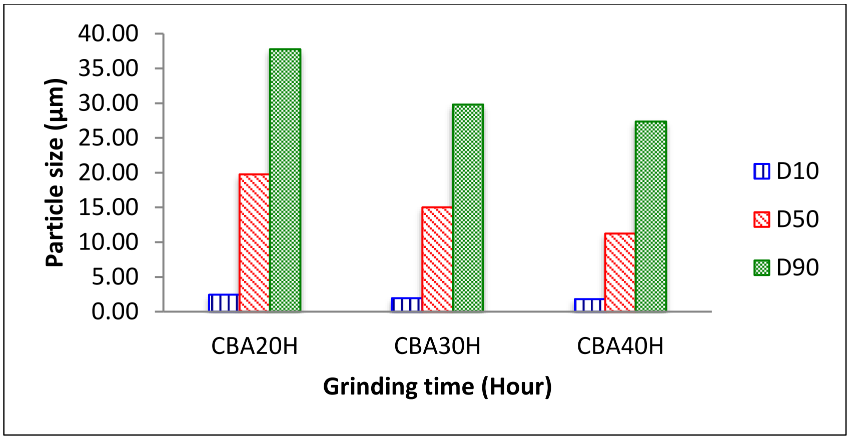

Figure 2. PSD analysis result for various grinding time of grinded CBA

Figure 2 shows, the particle size was decreased when the grinding time increases. The smallest particle size is at 40 hours grinding time, which is 1.819 µm, 11.254 µm and 27.356 µm at D10, D50 and D90 respectively compared to the others. While the narrowest particle is at 30 hours and coarsest particle are at 20 hours grinding time. The narrowest PSD value for D10, D50 and D90 is 1.948 µm , 15.036 µm and 29.807 µm respectively. Meanwhile, the coarsest PSD value for D10, D50 and D90 is 2.467 µm, 19.774 µm, and 37.749 µm respectively.

In general, pozzolanic reactivity of coal ash is directly related to its fineness. The filler effect of these fine pozzolanic materials is partly responsible for the increasing strength of concrete. As reported by Cheriaf et al. (1999), the pozzolanic activity of the CBA can be improved with adequate grinding. Thus, the strength will increase with decreasing particle size (Walker and Pavía, 2010). Hence, the finest of CBA having a greater contribution towards the strength of concrete.

Specific Surface Area

Specific surface areas of ground CBA directly obtained from Fritsch Analysette 22 machine and the results are shown in Table 2. The results shows the specific surface area of ground CBA become larger when grinding time increased to 30 hours and 40 hours. The specific surface area of 20 hours, 30 hours and 40 hours grinding time is 9627.76 cm^2/cm^3 , 12921.92 cm^2/cm^3 and 13528.18 cm^2/cm^3 respectively. The specific surface area ground CBA for 30 hours increased about 1.34 times while 1.40 times for 40 hours compared to 20 hours. This finding is very important to identify and understand the physical characteristic of ground CBA after grinding process. This outcome is similar with Khalid et al. (2016) on their report when they grinded POFA.

Table 2. Specific surface area of ground CBA

Parameter	20 hours	30 hours	40 hours
Specific surface area	9627.76 cm^2/cm^3	12921.92 cm^2/cm^3	13528.18cm^2/cm^3

Workability of Concrete

Slump test of fresh concrete was performed to ensure its consistency in that specific batch. The result for slump were shown in Figure 3. The workability of concrete was decrease with increasing the replacement level of grinded CBA. Increasing the replacement of grinded CBA will increase the specific surface area thus required more water demand to become workable. Kim and Lee (2011) also proved that black spots appeared on the surface of the fresh concrete with bottom ash due to suction of the water and cement paste by bottom ash. This factor also contributed towards lowering in slump value.

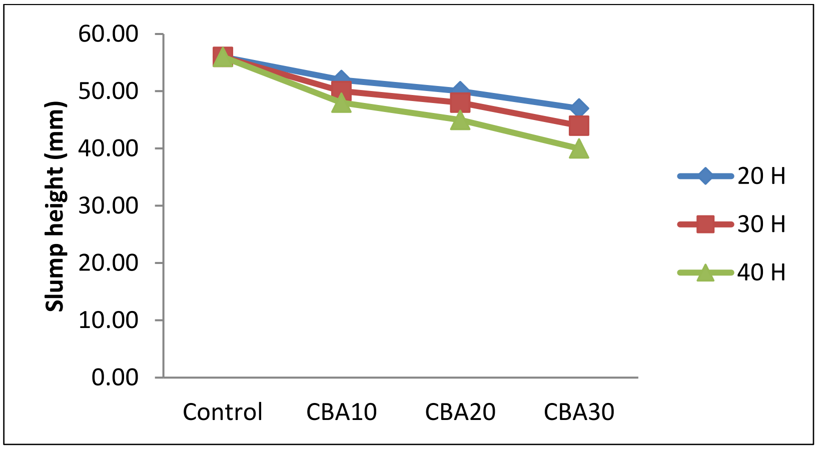

Figure 3. Slump value for ground CBA replacement in cement

Moreover, the workability of the fresh concrete for 40 hour grinding time is the lowest among the others. The slump decrease about 33% compared with control sample. As the grinding time increase, the slump value also linearly decreasing. It indicated that, the fine particle of the ground CBA are also one of the factor that contributes to decreasing the slump value. Finer particles require more water to wet their larger specific surface thus resulting in lowering the slump value. A fixed water cement ratio, the hydration process will result porosity in concrete occurs due to insufficient water demands. As reported by Abidin et al. (2014), the decrement of slump is because of the porosity of coal bottom ash, which absorbed more water with higher content of CBA replacement. Thus, increasing the water cement ratio, it will drop the strength of the concrete. The water cement ratio give major influence on designing concrete with CBA (Hamzah et al., 2016).

Compressive Strength

The compressive strength of concrete containing ground CBA as cement replacement material for 20 hours grinding time are shown in Figure 4. The concrete with 10% replacement level shows the highest compressive strength (37.90 MPa) compared among others replacements. Compressive strength start decrease at 20% and 30% replacements level about 1.5% and 4% respectively compared with control sample.

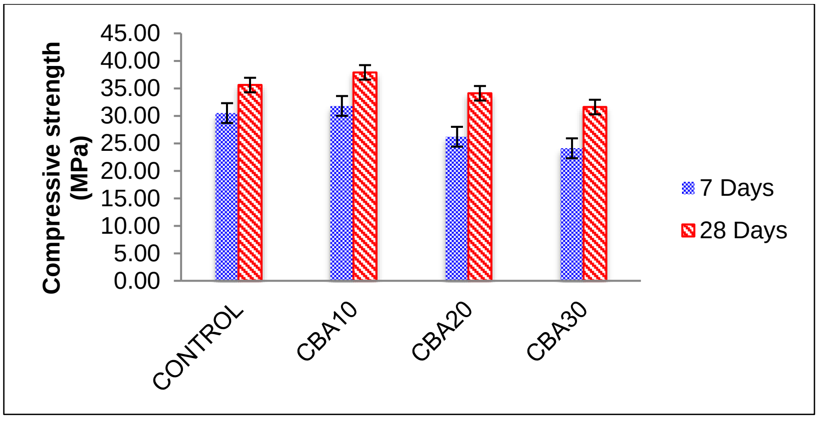

Figure 4. Compressive strength of concrete containing various CBA percentage for 20 hours grinding time

The reduction in strength is mainly considered due to the increasing replacement level of bottom ash that producing more porous concrete with more pores distributed around the bottom ash aggregate surface (Abidin et al. 2014),. The result were similar as reported by Ghafoori and Bucholc, (1996), that due to high water absorption rate, angular shape and very porous surface of the bottom ash, the strength of the concrete were decreased as the amount of replacement CBA increase, thus higher water content is required to achieve the degree of lubrication needed for a workable mixtures. Hence, it can be concluded that by 10% of 20 hours grinding time of CBA will present the higher strength value with small amount of CBA replacement.

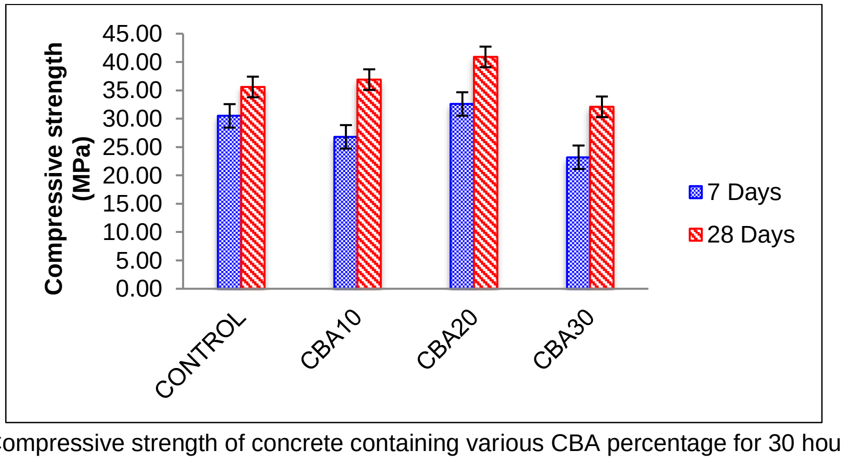

Figure 5. Compressive strength of concrete containing various CBA percentage for 30 hours grinding time

Figure 5 shows, the compressive strength of concrete containing various ground CBA percentage for 30 hours grinding time. The compressive strength value was rise up from 36.9 MPa at 10% replacement level to 40.9 MPa at 20% replacement level then dropped to 32.1 MPa in 30% CBA replacement level. It is noted that the highest strength were recorded at 20% CBA replacements with 15% increment compared with control sample. This result was in line with research by Jaturapitakkul et al. (2003) found, the compressive strength increase by replacing 20% CBA in production of concrete.

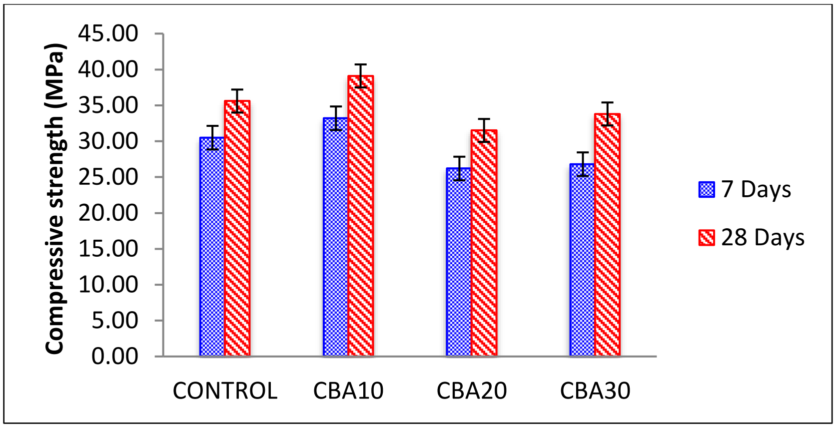

Figure 6. Compressive strength of concrete containing various CBA percentage for 40 hours grinding time

Figure 6 shows, the compressive strength of concrete containing ground CBA for 40 hours grinding time. The result shows, highest compressive strength obtained at 10% replacement level compared with control. Then, the strength was dropped at 20% replacement level and turn rise up at 30% replacement level. The 10% CBA replacement is the optimum CBA replacement as expected as it obtained the higher strength value for 40 hours grinding time. Based on PSD analysis conducted, the sample of CBA subjected to 40 hour grinding time is the finest particles among the others. The fineness of CBA is important to ensure a dense microstructure when hardened (Basirun et al., 2017). Chengzhi et al. (1996) have concluded, the addition of pozzolanic material influences the packing state and decreases the amount of filling water. This role depends on the fineness of pozzolanic materials.

In addition, finest particles of ground CBA will result high water demand. It can be seen when the slump height was decrease with increase of ground CBA replacement. This situation have proven that the CBA absorbed water faster during fresh state. Based on the discussion, 20% CBA of 30 hour grinding time is the selected replacement level as optimum CBA replacement in cement content. It is due to the high strength concrete grade value obtained besides minimal grinding time requirements. As mentioned by Pan et al. (2008), annual cement production in Taiwan is 20 million tons. Hence, by utilizing up to 20% CBA replacement in their cement production, the amount of cement production will be reduce by almost 4 million tons per year. Even though the contribution seems small, it is still considered as sustainability approach in reducing the amount of pollution occurred effect from cement production industry.

CONCLUSIONS

This paper has been discussed about the influence of fine coal bottom ash as cement replacement material in normal concrete. There are some conclusions that have been made:

(1) The different grinding time period were changed the physical characterictis of granular CBA to fineness particle. The size of particle become finness after grinding process and increase the specific surface area of ground CBA.
(2) The ground CBA have affecting the workability of concrete at fresh state. Workability of concerete were decreased linearly with increament of grinding time period. It

related to change of granular CBA to finness particle which specific surface area was increase and required more water to become workable.

(3) The normal concrete incorporation with ground CBA about 20% replacement level of cement at 30 hours grinding time shows the highest compressive strength compared to others. It is because of finness particle of ground CBA can reduce pore structure in concrete and produce dence packing structure.

(4) Ground CBA is cementitious material that can be used as supplementary cement material in concrete. The additional finness particle of CBA in concrete will increasing packing factor which helps minimise the voids and continues pozzolanic activity in cement matrix.

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