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Influence of Ground Coal Bottom Ash on the Properties of Concrete

Sajjad Ali Mangi¹, MohdHaziman Wan Ibrahim^{1*}, Norwati Jamaluddin¹, Shahiron Shahidan¹, MohdFadzil Arshad², Sheeraz Ahmed Memon³, Ramadhansyah Putra Jaya⁴, Sri Wiwoho Mudjanarko⁵, Muhammad Ikhsan Setiawan⁵

¹Jamilus Research Center, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Johor, Malaysia.

²Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia

³Institute of Environmental Engineering & Management, Mehran University of Engineering and Technology, Jamshoro, Pakistan.

⁴Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Kuantan, Pahang

⁵Faculty of Engineering, Narotama University, Surabaya, Indonesia

*Corresponding E-mail: haziman@uthm.edu.my

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Abstract

The coal based thermal power plant in Malaysia produces annually around 1.7 million tons of coal bottom ash (CBA) as a discarded material which poses great environmental problems. Hence, the objective of this study is to utilize ground CBA as a supplementary cementing material in concrete. The oven dried original CBA was grinded for 20 hours to achieve required fineness. The mixture of concrete was prepared with CBA proportion of 10, 20 and 30% by weight of cement. For the evaluation of density, water absorption, compressive and tensile strength of concrete, 48 specimens were cast. The workability of fresh mix concrete was also evaluated, and it was found to be decreased as the quantity of CBA increased in the mixture. However, the compressive and splitting tensile strength of concrete also reduced with the addition of ground CBA but with 10% replacement has attended the targeted compressive strength at the age of 28 days. Besides that, it was also observed that the influence of CBA on concrete is obvious in density as well as in water absorption. The density of concrete gradually decreased due to addition of ground CBA, concrete containing 10% ground CBA was likely to be similar to that of control mix and the opposite performance was noticed in water absorption. Hence, experimental findings of this study indicated potentiality of ground CBA as supplementary cementing material in concrete construction which will reduce the environmental concern.

Keywords: Coal bottom ash, setting time, workability, density, water absorption, compressive strength, tensile strength.

1.0 Introduction

The demand of Portland cement is increased gradually due to rise in the concrete development works around the world [1]. Since the huge production of Portland cement has great environmental concern in terms of carbon dioxide (CO₂) emissions [2], several studies have been carried out to find more environmentally friendly supplementary cementitious materials [1, 3-5]. In particular, utilization of industrial waste products as cement replacements could be an appropriate solution not only for the sustainable development in terms of minimizing environmental pollution [6-8] in order to deal with the blooming concern of CO₂ production due to cement production industries. Currently, the coal based thermal power plant produces two types of major wastes namely fly ash and bottom ash. Particularly in Malaysia around 6.8 million tons of fly ash and 1.7 million tons of coal bottom ash are being produced annually [7], which creates environmental distress regionally and globally. It was formerly agreed by Rafieizonooz et al., [8] that fly ash (FA) and coal bottom ash (CBA) have almost similar chemical characteristics

since both of them were produced through the same source, and likewise they have been categorized as class F ash according to ASTM C618 [8]. The major difference between FA and CBA is their particle size where CBA's particles are larger, porous and irregular in shape [10]. The size of CBA's particle is almost similar to that of the fine aggregate (sand), which currently has led to CBA being formally considered as fine aggregate replacement in concrete [11].

Hence, the grinding process is necessary for the CBA to make it useful as a supplementary cementitious material. Furthermore, it was also mentioned by Qian et al. [12] that grinding process can substantially increase the pozzolanic activity of the ash. Since usage of high volume FA has already been established [13] and standardized as cement constituent standard BS EN 197-1 [14] and it is being used in cement production globally; to overcome the problem of CO₂ emissions in the environment. However, the utilization of CBA as a cement replacement material still requires more serious attention and further investigations. Since CBA is an abundant waste produced by power plants in Malaysia which is around 1.7 million tons annually [8], immediate attention is therefore required to utilize CBA in the concrete construction particularly to solve the environmental hazardous concern. Considering the inherent properties of CBA, it is imperative to utilize it as a partial replacement of cement in concrete construction, which could reduce the dual environmental concerns; which comprise reduction in CO₂ emissions and minimize the solid waste generated from coal-based power plants. It is expected that this alternative technique could produce durable cement replacement material for the eco-friendly concrete construction.

2.0 Materials and Methods

2.1 Materials

In this study the ordinary Portland cement (OPC) of Type-I, natural sand (fine aggregate) and coarse aggregate nominal maximum size of 10mm were used. The tap water was used for concrete mixing. The coal bottom ash (CBA) was collected from the thermal power station in Selangor, Malaysia known as Kapar Energy Ventures (KEV). Primarily, the collected CBA was placed in an electric oven for drying at a temperature of 110±5 °C for 24 hours. Then, Los Angeles (LA) grinder machine was used to grind the dried CBA initially for 2 hours. After the first stage grinding process, it was sieved using 300-micron sieve. The ground CBA which passed through the 300-micron sieve was then proceeded for the second stage grinding in a ball mill for 20 hours until fine CBA was achieved where almost 75% passed through 63-micron sieve. Moreover, the ground CBA's particle size and specific surface area was evaluated through particle size analyzer (i.e. advanced laser diffraction and CCD camera); its specific gravity was determined by pycnometer; its colour was assessed through visual observations; and its chemical composition was analyzed through XRF. It was observed from the analysis that the chemical compositions of ground CBA obtained through 20 hours of grinding period contain SiO₂ + Al₂O₃ + Fe₂O₃ of about 80.60%. As the chemical composition of ground CBA is more than 70%, thus it can be categorized as Class F pozzolanic material as mentioned in ASTM C 618-05 [9]. The details of physical and chemical properties are provided in Table 1.

Table 1: Physical and chemical properties of cement and CBA

Description	OPC	CBA
Physical Properties		
Range of particle size (µm)	3.81 - 21.15	3.65 - 50.45
Specific surface area (cm ² /g)	4870.81	3835.75
Specific gravity (g/cm ³)	3.10	2.41
Fineness (wt.%) passed through 63 µm sieve	100%	65.5%
Colour	Grey	Dark grey
Chemical properties		

SiO ₂	20.61	53.80
Al ₂ O ₃	3.95	18.10
Fe ₂ O ₃	3.46	8.70

Table 1(continued):Physical and chemical properties of cement and CBA

Description	OPC	CBA
Chemical properties		
CaO	63.95	5.30
MgO	1.93	0.58
SO ₃	3.62	0.90
TiO ₂	0.20	1.20
Loss on ignition (LOI)	2.18	4.02

2.2 Experimental Work

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 The concrete of grade M35 was prepared through ACI method with fixed water to binder(w/b) ratio of 0.5, with the concrete mix proportions as provided in Table 2. The concrete mix was prepared through a revolving drum mixer machine with maximum capacity of 75 litres and it was operated for 5 minutes as shown in Fig.1 (a), the specimens were de-moulded after 24 hours of casting and were immersed in a water tank for curing period of 7 and 28 days as shown in Fig.1 (b). First batch of concrete was prepared to cast control specimens without ground CBA, afterward in second batch the cement was replaced by weight method in concrete with ground CBA at the proportion of 10, 20 and 30%. The concrete cubes of size 150 mm were cast for the evaluation of compressive strength, density and water absorption. The cylindrical specimens of 100 mm in diameter, 200 mm in length were cast for splitting tensile strength test. The specimens for the compressive and splitting tensile strength were tested under a compression machine having a loading capacity of 3000kN. For each test, a set of three (3) specimens were prepared and mean average value was obtained to represent the designated proportion. In this study, total of 48 specimens were cast, including 24 cubes for compressive strength and 24 cylinders for splitting tensile strength test. All the tests were performed at Materials and Structural laboratory of the Universiti Tun Hussein Onn Malaysia (UTHM).

Table 2: Concrete Mix Proportions

Code	Repl.	Cement	CBA	Water	Fine Agg.	Coarse Agg.
Unit	%			Kg/m ³		
CM	0	440	-	220	805	828
M1	10	396	44	220	805	828
M2	20	352	88	220	805	828
M3	30	308	132	220	805	828

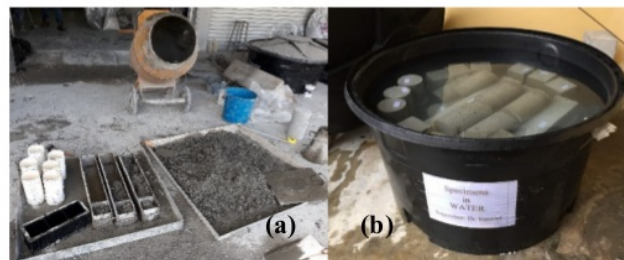
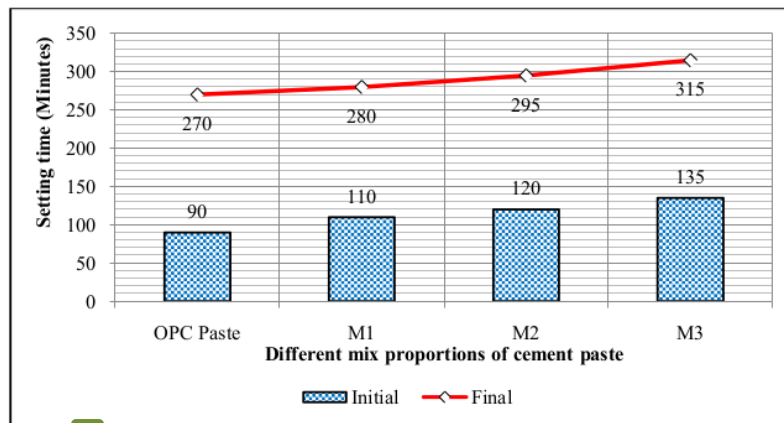


Fig. 1:(a) Concrete mixing and casting, and (b) Curing of specimens

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3.0 Results and Discussions

3.1 Consistency and setting time of cement paste

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 The initial and final setting time hydraulic cements paste was evaluated through vicat apparatus. This test was conducted to check the volume of water required to make a cement paste of standard consistency [27], suitable setting time. The normal consistency of cement paste was evaluated as 30%, with initial and final setting time of 90 and 270 minutes respectively. The normal consistency of ordinary Portland cement (OPC) paste was recorded at 32% of water and OPC with replacement levels of 10, 20 and 30% with CBA were recorded as 32, 34, and 36% of water in paste respectively. After that the initial and final setting times were also evaluated, and results obtained are illustrated in Fig.2. It was experimentally observed that initial setting time is with 10, 20 and 30% replacements were 15, 25 and 45 minutes higher than OPC paste. Whereas, final setting time with replacement levels of 10, 20 and 30% were recorded as 10, 30 and 45 minutes higher than that of OPC paste. Thus, relating the results with OPC paste, comparable results were obtained with 10% CBA [21] a replacement of OPC. Hence, it was experimentally agreed that consistency of OPC paste increases with the increase in the amount of CBA in the paste. The consistency was found to be increased because the presence of CBA in the paste absorbed more water than the normal OPC paste [15]. Since the cement replacement with ground CBA reduces the amount of tri-calcium-silicate (C_3S) in cement paste, thus resulting in longer setting time in the cement paste [16].



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 Fig. 2: Initial and final setting time of cement paste with and without ground CBA

3.2 Workability

The fresh concrete mix was evaluated for workability with the conical shaped cone, having internal diameter 100mm at top, 200mm at bottom and 300mm in length. The cone was filled with freshly mixed concrete in 3 layers, where each layer was tampered for 25 times with 6mm diameter and 600mm long bull nosed metallic rod. The end of concrete was smoothed at the top peak of the cone and it was then lifted vertically upward, so as not to disturb the shape of concrete cone. The slump of concrete was measured through distance between top of metallic cone and top of concrete cone. The workability was measured in terms of slump value and it was determined 56mm for the control mix and 50, 45 and 35mm were recorded for 10, 20 and 30% ground CBA as OPC replacements in the concrete respectively. The results of workability of concrete with and without CBA are provided in Fig.3. It was experimentally observed that

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workability of concrete mix decreases as the quantity of ground CBA in the mix increases and it was also agreed by Jamaluddin et al. [17] that the concrete flow is reduced due to addition of ground CBA in concrete and it absorbed more water present in the mixture. In this study, the workability was reduced by 10.71, 19.64 and 37.50% at 10, 20 and 30% replacements of Portland cement with CBA respectively. Thus, relating the results of control mix (CM) and concrete with CBA, nearly similar results were noticed with 10% ground CBA as cement replacement in concrete mix.

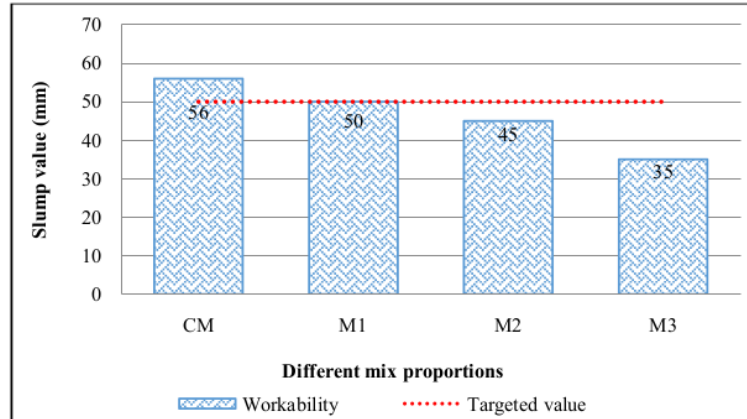


Fig. 3: Workability performances of concrete with and without ground CBA

3 3.2 Density and Water absorption

The experimental results of density and water absorption of concrete cubes with and without ground CBA at the age of 28 days are presented in Fig. 4. It was observed that the influence of ground CBA on concrete is obvious in density as well as in water absorption. The density of concrete gradually decreased due to addition of ground CBA, because it is lighter in weight as compared to that of the ordinary cement. The hardened density of concrete with and without CBA shows that the concrete containing 10% ground CBA (M1) is adequate, which absorbed less water as compared to other mixes of M2 and M3. The density of M1 is almost similar to the control mix (CM). Besides that, the opposite performance was noticed in water absorption. The absorption of water was found to increase as the amount of ground CBA in the concrete increases. These experimental outcomes are comparable with previously results obtained by Khan and Ganesh [15].

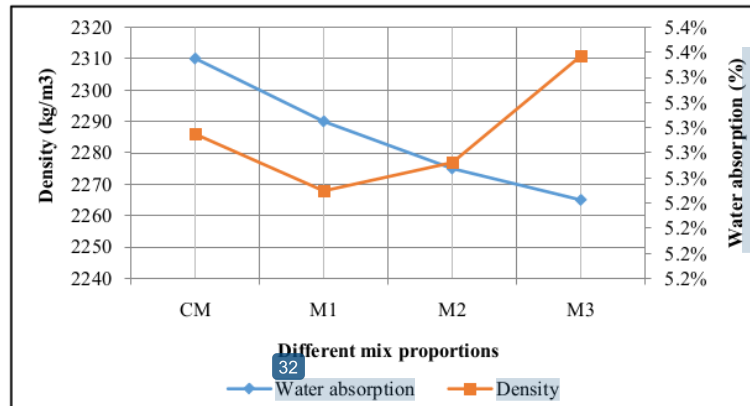
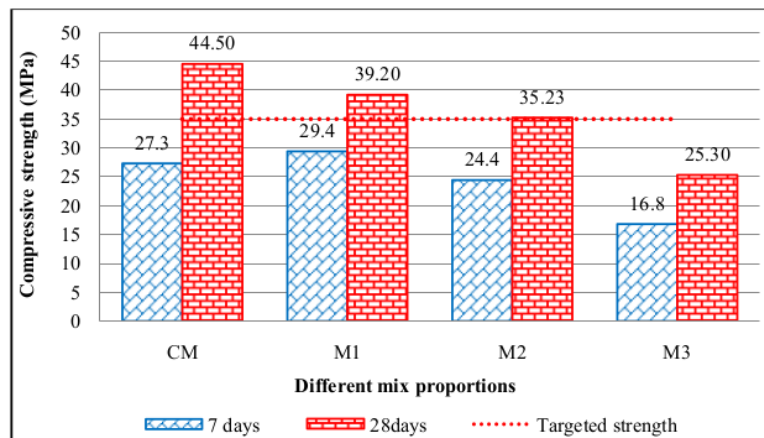


Fig. 4: Density and water absorption of concrete with and without ground CBA

3.3 Compressive Strength

Concrete cubes were prepared with and without CBA and tested under a compression machine of 3000kN loading capacity at the age of 7 and 28 days. The mean values were taken from the three cubes tested results in order to confirm the perfection of the test. The compressive strength performances of concrete with and without ground CBA are presented in Fig.5. It was observed through the experimental results that the concrete containing 50% CBA (M1) was found to be acceptable, because its compressive strength value is very close to that of control mix (CM). For the early age of 7 days performances, the highest compressive strength was recorded at 29.4 MPa with 10% ground CBA. The compressive strength of control mix (CM) concrete at the age of 28 days was recorded as highest strength as 44.5 MPa, while the reduction in the compressive strength was observed with the increase in the amount of CBA in the concrete mix [18]. Besides that, concrete containing 10% CBA was noticed to have satisfactory compressive strength of 39.20 MPa at 28 days, which achieved the targeted compressive strength of 35 MPa. Similar compressive strength performance was observed by Khan and Ganesh [15] and Khalid et. al. [19]. However, Rafieizonooz et al. [8] explained that the cause of strength reduction is due to the low pozzolanic activity at the early age of 28 days. Furthermore, it can be concluded from the experimental results that concrete with 10% of cement replacement with CBA is found to be good so as to achieve the targeted / designed strength at 28 days.



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Fig. 5. Compressive strength of concrete with and without ground CBA

3.4 Splitting Tensile Strength

The concrete cylindrical specimens were cast with and without ground CBA and cured under water for period of 7 and 28 days. The cylinders were tested under a compression machine of 3000kN loading capacity. The splitting tensile strength of each cylinder was taken from the average of 3 cylinders in order to confirm the correctness of results. The splitting tensile strength results have been provided in Fig. 6. It was noticed through the experimental results that splitting tensile strength of concrete decreases as the amount of CBA in the concrete mix increases. It shows that the pozzolanic reaction did not initiate at the age of 28 days [15][20][21]. In the CBA concrete, the amount of ordinary cement is less as compared to the control mix (CM), therefore less strength was observed at the age of 28 days. However, the 10% replacement of ordinary cement with ground CBA (M1) gives the closer value of splitting tensile strength as compared with the control mix (CM).

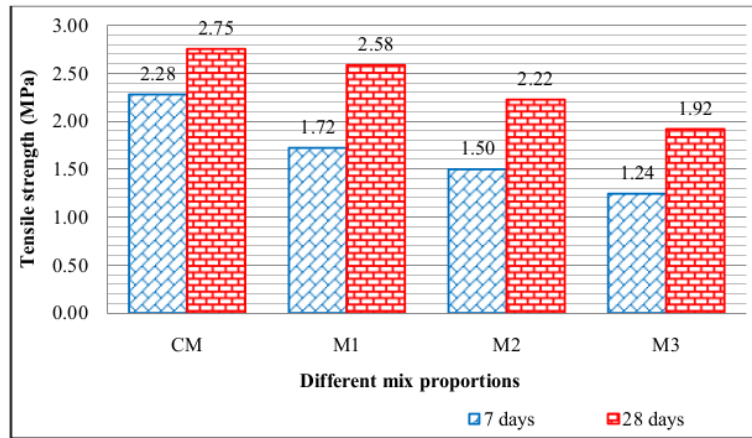


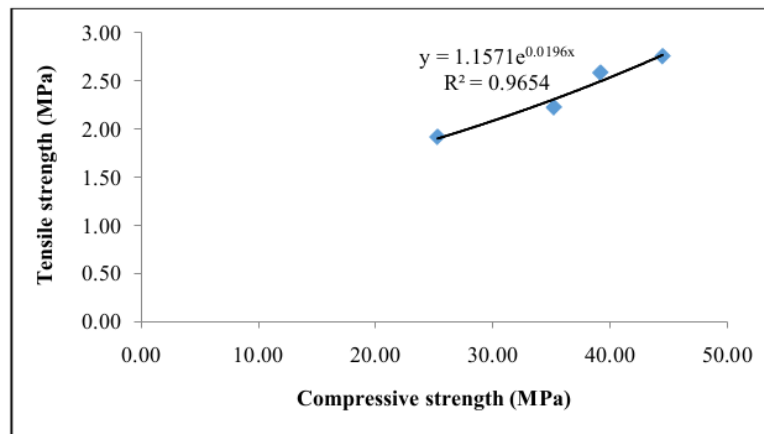
Fig.6: Splitting tensile strength of concrete with and without ground CBA

3.5 Compressive and Tensile Strength Relationship

The relationship between compressive and tensile strength of concrete with ground CBA and without CBA was developed at varying proportions, and prepared through computational analysis and a graph was plotted as shown in Fig. 7. The following Equation (1) indicates the compressive and tensile strength correlate along with R^2 coefficients of determination, as follows:

$$y = 1.1571e^{0.0196fx} \quad R^2 = 0.9654 \quad (1)$$

where, x-axis is the compressive strength (MPa) and y-axis is splitting tensile strength (MPa).



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Fig.7:Relationship of compressive and tensile strength of concrete

In this study, the experimental results indicated the satisfactory relationship between regression curve and test results were evaluated for strength performance of concrete containing CBA as supplementary cementing material. The coefficient of R^2 value was found comparable with the previous values obtained by Rafieizonooz et al. [8].

4.0 Conclusions

Based on the experimental findings, the following conclusions could be drawn;

- i. It was observed that original CBA required appropriate grinding process to converting it to cementitious material.
- ii. The physical and chemical properties the ground CBA validated that, it poses pozzolanic belongings and can be used as cement replacement material in concrete construction.
- iii. The consistency and setting time of OPC paste increases as the amount of ground CBA increased in the cement paste.
- iv. The addition of ground CBA influences the workability of concrete, higher the quantity of ground CBA, lower the workability of concrete mix; due to more water captivated by ground CBA in the mix.
- v. The density and water absorption of hardened concrete is greatly influenced by ground CBA. Concrete density reduces as the amount of ground CBA increased and more water absorbed in the concrete mix.
- vi. The compressive strength of concrete was found to be decreased as the quantity of ground CBA increased in the mix. Whereas designed/targeted strength of concrete was achieved with 10% CBA at the age of 28 days.
- vii. Similarly, the splitting tensile strength of concrete was also declined with the addition of CBA. But concrete containing 10% CBA was found to have closer results to that of control mix.
- viii. The opportunity of replacing Portland cement with industrial discarded material such as coal-based power plant waste known as bottom ash offers substantial technical, economic and environmental benefits which are of prominence in the current situation of sustainable concrete production.

Hence, it was explored in this study that the ground CBA has a great tendency to be utilized as partial cement replacement in concrete construction and it was concluded that concrete containing 10% of CBA as partial replacement cement in the concrete could achieve the acceptable compressive as well as tensile strength performances. Therefore, future studies are further required with 10% CBA to investigate its long-term strength and durability performances of concrete exposed to sulphate and chloride conditions.

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