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EFFECTS OF GROUND COAL BOTTOM ASH ON THE PROPERTIES OF CONCRETE

SAJJAD ALI MANGI[1, 2], WAN IBRAHIM M. H.[1,*], JAMALUDDIN N.[1], ARSHAD M. F.[3], RAMADHANSYAH P. J.[4]

[1]Jamilus Research Center, Faculty of Civil and Environmental of Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Johor, Malaysia
[2]Department of Civil Engineering, Mehran University of Engineering and Technology, SZAB Campus Khairpur Mir's, Pakistan
[3]Faculty of Civil Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Selangor, Malaysia
[4]Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, 26300, Kuantan, Pahang, Malaysia
*Corresponding Author: haziman@uthm.edu.my

Abstract

Coal bottom ash is a waste material produced by the coal based thermal power plants. The annual production of coal bottom ash (CBA) in India is 25 million tons, in US 14 million tons, Europe 4 million tons and in Malaysia about 1.7 million tons, which creates environmental problems for the global society. Hence, the aim of this study is to utilize CBA in concrete as a partial cement replacement. In this study, the CBA was ground for three different grinding periods 20, 30 and 40 hours and concrete mix was prepared at a replacement rate of 10, 20 and 30% by weight of cement. Total 120 specimens were cast to assess the fresh and hardened properties of concrete at the age of 28 days. For the fresh mix concrete, workability reduced as quantity of ground CBA increased in the mix. However, the density of concrete was continuously declined due to addition of ground CBA and opposite behaviour was observed in water absorption capacity. The high rate of water absorption was observed as the fineness and replacement level increased in the mix. Furthermore, no significant rise in the compressive and flexural strength was recorded in this study but with 10% ground CBA as a replacement of ordinary cement the targeted compressive strength of concrete was achieved. Besides that, the splitting tensile strength was increased about 8% in concrete containing 10% ground CBA (obtained through 30 hours grinding period) as compared with the control specimen. Hence, it was concluded that the ground CBA has a good potential to be utilized as cement replacement in concrete which will reduce the construction cost and minimize the environmental burden.

Keywords: Coal bottom ash, Compressive strength, Flexural strength, Tensile strength, Workability.

1. Introduction

Concrete is very important material in construction. It's consumption raises the demand of portland cement every year globally, which created environmental pollution in terms of carbon dioxide emissions [1, 2]. The 600 kgs of cement production, released around 400 kgs of carbon dioxide (CO_2) in the atmosphere [3]. The best solution for the pollution is to meaningful use of industrial waste in construction. Previously several attempts have been made on the utilization industrial waste like fly ash, bottom ash, waste glass, slag, and silica fume in concrete [4-6]. This approach could reduce the cost of construction and produces environmental friendly material with high durability performances [7-9]. The annual production of coal bottom ash in India is around 25 million tons [9], United Sate is 14 million tons, Europe about 4 million tons [10] and in Malaysia about 1.7 million tons [11]. The proper landing of such waste is challenging job and it is an important environmental concern for the global society [11]. Therefore, it is imperative to utilize coal bottom ash (CBA) to minimize environmental problems.

The particle size of original CBA is fall within the range of 0.1 mm to 10 mm [12], which is comparable with natural sand. Due to its coarser size, it was previously adopted by many researches as fine aggregate replacement in concrete [13]. Considering the earlier inputs, is it possible to utilize CBA as a cementitious material? if so, what will be the optimum mix proportion and optimum grinding period/particle fineness and what are the effects of CBA on the properties of concrete? However, the application of CBA as cement replacement is very limited, due to its bigger size of particles as compared to fly ash. Although coal bottom ash has good pozzolanic properties due to that nowadays intention of advanced research is to develop CBA as alternative cementitious materials. Figure 1 shows the particles of original and ground coal bottom ash.

Fig. 1. Original and ground coal bottom ash.

The sustainable construction can be accomplished through minimizing the practice of portland cement content. Therefore, in this study ground CBA was considered as replacement of ordinary portland cement. Hence, the purpose of this study is to evaluate the strength performances of concrete containing ground CBA with different grinding time/different fineness as partial replacement of cement without any super plasticizer. In this study, three different grinding periods (20, 30 and 40 hours) were selected to get the more fine particles, because the pozzolanic reactivity of CBA is greatly depends on its particle fineness [10]. In this study, at the initial stage, physical and chemical properties of CBA were evaluated before placed it in to concrete mix. Afterward, fresh mix concrete was evaluated for workability and hardened properties concrete like compressive, tensile and flexural strength were determined at the age of 28 days. Then, results were compared with control mix specimens. The strength and durability performances of concrete containing CBA under aggressive environment may be studied in future for the longer periods.

2. Materials and Methodology

2.1. Materials

Ordinary portland cement (OPC) of Type-I (Tasek Brand) with specific surface area 4870.81 cm^2/g was used in this study. The natural sand was used as fine aggregate in this study. The sand which passed through 5mm sieve with 2.7 of specific gravity was used and coarse aggregate maximum size of 10mm was used in the study. The larger size (>10mm) of coarse aggregates were removed and the rest of materials was used for preparation of concrete mixture. The water used for concrete mixing was supplied by Syarikat Air Johor, Malaysia. The ingredients used in this study are shown in Fig. 2.

The original CBA was collected from thermal power plant known as Sultan Salahuddin Abdul Aziz, situated in Selangor, Malaysia. The bottom ash was dried in an oven at a temperature of 110±5 ^{O}C for 24 hours, then it was placed in Los Angeles machine for 2 hours. After sieved through 300-micron sieve, it was placed in to ball mill grinder (capacity 10 kgs) for the period of 20, 30 and 40 hrs. The chemical composition of CBA and OPC are provided in Table 2, which shows that the CBA meet the requirements of ASTM C618 [14] and classified as class F ash. The colour of ground CBA was changes with the variation of grinding period. Original CBA has grey colour and due to effect of grinding, it changes from grey to dark grey in colour. Three different grinding periods were used to get the different particle fineness, which affects the physical properties of particles as well as it plays important role in the development of pozzolanic reaction [15]. The similar characters of ground CBA was reported by Kim [10].

Table 1. Chemical composition of OPC and CBA.

Oxides (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	TiO_2	LOI
OPC	20.61	3.95	3.46	63.95	1.93	3.62	0.20	2.18
CBA	53.80	18.10	8.70	5.30	0.58	0.90	1.20	4.02

Table 2. Physical characteristics of OPC and CBA.

Properties	OPC	CBA grinding period (hrs.)		
		20	30	40
Range of particle size (μm)	3.81 - 21.15	3.65 - 50.45	4.03 - 47.78	2.79 - 46.12
Specific surface area (cm^2/g)	4870.81	3835.75	3894.84	4637.78
Specific gravity (g/cm^3)	3.10	2.41	2.44	2.50
Passing from sieve 63 μm (%)	100	65.47	75.40	85.73
Colour	Grey	Grey	Dark grey	Dark grey

Fig. 2. Materials used in this study, (a) coarse aggregate, (b) sand, (c) OPC, (d) CBA with 20 hours grinding, (e) CBA with 30 hours grinding, and (f) CBA with 40 hours grinding.

2.2. Preparation concrete mix

Total ten batches of concrete were prepared with fixed water to binder ratio 0.5. The first batch of concrete was without ground CBA and other nine batches of concrete were containing ground CBA as cement replacement. In this study, three grinding periods (20, 30 and 40 hours) and three replacement levels (10, 20 and 30%) were considered for CBA to find out the optimum values. The cement was replaced with ground CBA by weight and all other ingredients were also calculated by weight method. The concrete grade of M35 was prepared through ACI method of concrete mix design. The required volume of concrete was calculated as per given concrete mix design provided in Table 3.

Table 3. Detail of concrete mix proportions (kg/m^3).

Grinding Period (hrs)	% Rep.	OPC	CBA	Water	Fine Agg.	Coarse Agg.
Control	0	440	-	220	805	828
	10	396	44	220	805	828
20	20	352	88	220	805	828
	30	308	132	220	805	828
	10	396	44	220	805	828
30	20	352	88	220	805	828
	30	308	132	220	805	828
	10	396	44	220	805	828
40	20	352	88	220	805	828
	30	308	132	220	805	828

2.3. Experimental arrangements

The volume of concrete was calculated before starting mixing process and weight batching method was used in this study. Individual batch quantity was calculated based on the concrete required to cast the number of cubes, cylinders and prisms. The concrete amount was increased to 15% to counter the losses that may occur during mixing, workability test, and casting. The concrete mixture was prepared through mini drum mixer with revolving mixing and maximum capacity of 75 litters. It was run for the period of 5minutes. The concrete cubes of 100 mm in all dimensions were cast for the evaluation of compressive strength, density and water absorption. The cylindrical specimens of 100 mm diameter, 200 mm in length were cast for splitting tensile strength test. The prisms 100 mm in cross section and 500 mm in length were cast for the evaluation of flexural strength. After casting of concrete, the specimens were de-moulded after 24 hours, then the concrete specimens were placed in a water tank for the specified period of curing.

In this study, ASTM C192 [16] standard was adopted for the mixing, casting, curing, and testing and total 120 specimens were prepared for the period of 28 days to evaluate hardened properties of concrete with and without ground CBA. The number of specimens required for the study is provided in Table 4.

Table 4. Number of specimens required for the study.

Grinding Period (hrs)	% Rep.	Compressive strength	Splitting Tensile strength	Flexural strength	Density and water absorption
Control	0	3	3	3	3
20	10	3	3	3	3
	20	3	3	3	3
	30	3	3	3	3
30	10	3	3	3	3
	20	3	3	3	3
	30	3	3	3	3
40	10	3	3	3	3
	20	3	3	3	3
	30	3	3	3	3
Total			120		

2.4. Strength co-relation

After experimental findings, the strength co-relation will be developed through statistical procedures to evaluate the behaviour of compressive, tensile and flexural strength for the concrete containing ground CBA with different grinding time and varying proportions. In this study, a co-relation coefficients (R^2) was calculated through regression curve analysis. The regression curve line shows the relationship between the independent variable (x) and dependent variable (y) in the graphs. Finally, the calculated coefficients for three co-relationships will be compared with previous findings.

3. Results and Discussion

3.1. Workability

The slump test was conducted to evaluate workability of the fresh concrete with constant water quantity in all batches. The workability of concrete mixes was evaluated with and without ground CBA. The experimental study, declared that the control mix having high slump as compared with concrete containing ground CBA. The lowest slump was recorded 25 and 35 mm with 30% replacement of cement at every grinding time/fineness. It was noticed that slump values drops as the amount of CBA increased. This is due to particle fineness which increases the surface area; therefore, more water was absorbed by the concrete mix [17]. These findings are also matched with the study of Khan and Ganesh [17]. They declared that workability decreases as amount of ground CBA increases in the concrete mix, It was also agreed by Rafieizonooz et al. [11]. The slump test results are clearly presented in Fig. 3, and measuring setup is shown in Fig. 4.

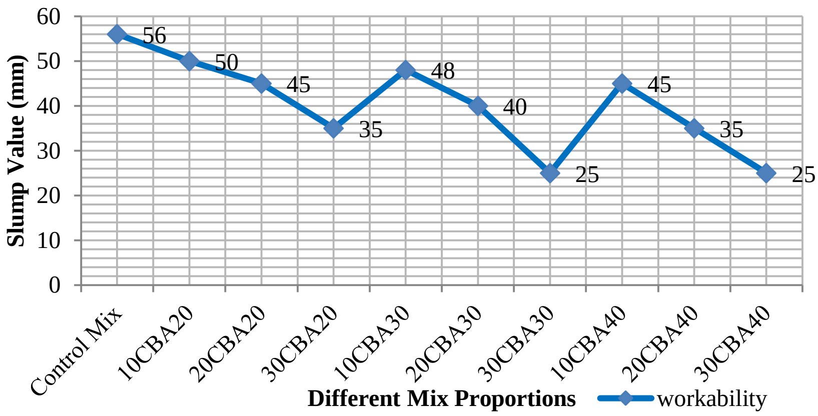

Fig. 3. Workability of concrete containing ground CBA.

Fig. 4. Slump cone for workability of concrete.

3.2. Density and water absorption

The concrete in hardened state was evaluated for density and water absorption at 28 days. The experimental data of density and water absorption are illustrated in

Fig. 5. From the graphs, it can be observed that the effect of ground CBA in concrete is obvious in density as well as in water absorption. The density of concrete continuously declined due to addition of ground CBA at 28 days. The density of concrete containing 10% of CBA20 and CBA30 were found to be very close to control specimen. Lower values were recorded in concrete containing ground CBA40 grinding period and opposite behaviour were observed in water absorption. Water absorption was found to be increased as the CBA fineness and replacement level increased, similar performances of concrete were noticed by Khan and Ganesh [17] while substituting cement with ground CBA.

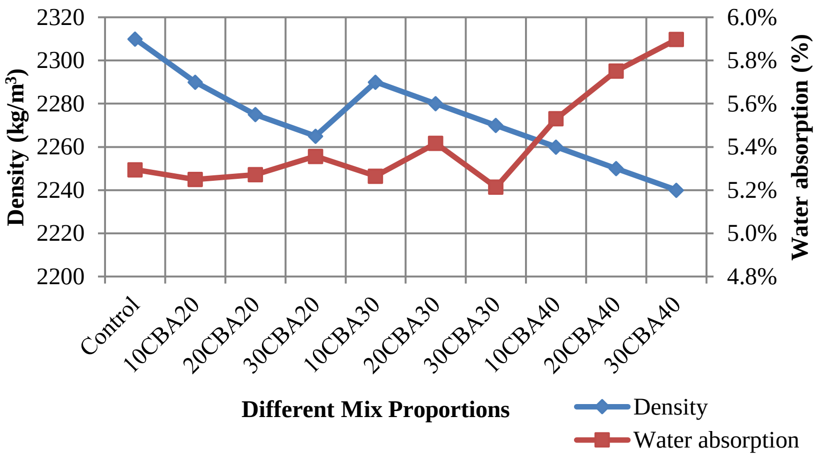

Fig. 5. Density and water absorption of concrete containing ground CBA.

3.3. Compressive strength

The compressive strength of concrete with and without ground CBA was evaluated in this study and results are illustrated in Fig. 6. Outcomes indicated that the compressive strength was gradually decreased as more quantity of CBA was added in the mix. The compressive strength of specimen 10CBA20, 10CBA30 is 12% and 5% lower than control specimen but 12% and 20% higher than the targeted strength respectively. This indicated that proper pozzolanic reaction to form C-H-S get in the matrix was not initiated at the curing age of 28 days [11, 18]. It was observed that the compressive strength of concrete containing ground CBA obtained through 40 hours was recorded lower as compared to the CBA received by 20 and 30 hours grinding period, which shows that more fine particles absorbed the available moisture in the mix, which reduces the hydration process. However, experimental results revealed that the concrete with 10% incorporation of CBA as a replacement of cement can satisfactorily achieve the designed / targeted strength (35MPa) of concrete. Therefore, adequate performance in terms of compressive strength was observed with 10% replacement of OPC with ground CBA. Similar results have been previously reported by Rafieizonooz et al. [11] and Khan and Ganesh [17]. They also suggested 10% CBA as an optimum replacement of cement in concrete. The replacement of ordinary cement has double benefits; one is reduction in corban dioxide (CO_2) emissions and second, it could reduce the cost of construction [17]. Hence, it could be considered as a cost effective and sustainable approach [18].

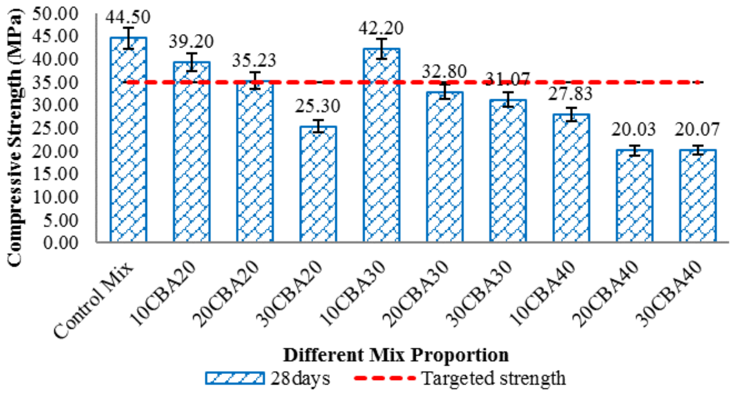

Fig. 6. Compressive strength performances of concrete containing ground CBA.

3.4. Splitting tensile strength

The splitting tensile strength performances of concrete with and without CBA are presented in Fig. 7. It was detected that the splitting tensile strength was increased around 8% by 10% replacement of portland cement with ground CBA obtained through 30 hours grinding period. However substantial change was observed in tensile strength due to addition of ground CBA in concrete. The lower values of splitting tensile strength were recorded with ground CBA having 40 hours grinding period. This is due to more fine particle sizes, which absorbed more water in the concrete mix. The performance of ground CBA having 40 hours grinding period was evaluated and significant reduction of 24%, 38% and 38.5% in tensile strength were observed for 10, 20 and 30% replacement level in concrete mix. Whereas, concrete containing 10% ground CBA of 30 hours grinding gives good strength development around 8% than the control mix. It could be a sign of C-S-H gel development in the concrete mix due to presence of ground CBA [11, 19]. The good spread of C-S-H was found in the mix containing 10% ground CBA of 30 hours grinding period and possibility of more tensile strength development for the longer curing periods [20]. The test results presented in this study were validated with previous studies of Rafieizonooz et al. [11] and Aggarwal and Siddique [21].

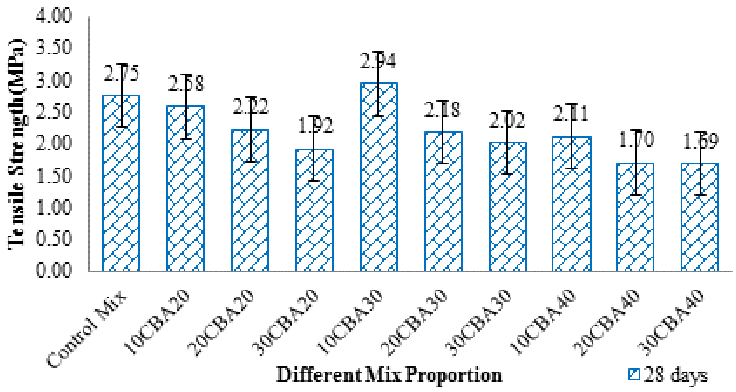

Fig. 7. Splitting tensile of concrete with and without ground CBA.

3.5. Flexural Strength

The concrete prisms containing ground CBA was evaluated for flexural strength at the age of 28 days. The test procedures was followed as per ASTM C78 [22] on third-point loading testing machine with continuous applied load at a speed of 0.04kN/s and the result of flexural strength test are presented in Fig. 8. Experimental results revealed that the flexural strength for ground CBA concrete at the age of 28 days was lower than the control mix. The flexural strength of concrete reduced as the amount of ground CBA increased in the mix [23]. However, the flexural strength of 10CBA20 and 10CBA30 is slightly near to the value of control specimen. It was experimentally determined that 10% cement replacement with ground CBA is optimum. The test results presented in this study are also comparable with the results obtained from the study of Kurama and Kaya [24].

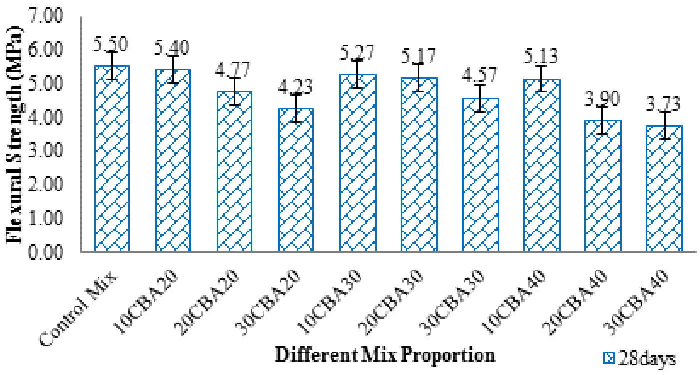

Fig. 8. Flexural strength of concrete containing ground CBA.

3.6. Strength co-relation

3.6.1. Compressive and flexural strength

The co-relation between compressive and flexural strength of concrete containing ground CBA with different grinding time / fineness and varying proportions are presented in Fig. 9. Eq. (1) was developed to show the compressive and flexural strength association as provided below.

$$f_f = 2.9996e^{0.0143fcu} \qquad R^2 = 0.792 \tag{1}$$

where fcu is compressive strength (MPa) and f_f is flexural strength (MPa). The coefficient of determination R^2 points indicated the favourable co-relation between regression curve and test results.

3.6.2. Compressive and tensile strength

The concrete compressive and tensile strength co-relationship was developed with CBA and without CBA at different grinding time / fineness and varying proportions, prepared through computational analysis and a graph was plotted as shown in Fig. 10. The following Eq. (2) indicates the compressive and tensile strength co-relation along with R^2 coefficients of determination, as follows:

$$f_t = 1.1037e^{0.0213\mathrm{fcu}} \qquad R^2 = 0.9459 \tag{2}$$

where f_{cu} is compressive strength (MPa) and f_t is splitting tensile strength (MPa).

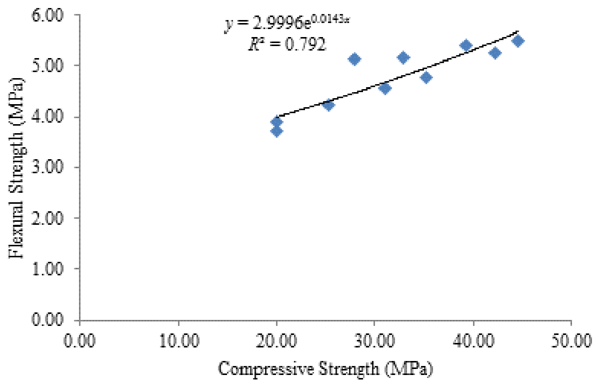

Fig. 9. Compressive and flexural strength co-relation.

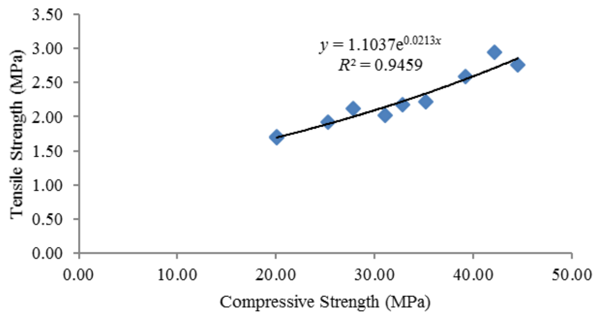

Fig. 10. Compressive and tensile strength co-relation.

3.6.3. Flexural and tensile strength

The co-relation of flexural and tensile strength of concrete containing ground CBA and computational graph was prepared as shown in Fig. 11. Eq. (3) indicated the flexural and tensile strength association, along with coefficients of determination R^2 obtained from this study.

$$f_t = 0.6004e^{0.2702ft} \qquad R^2 = 0.819 \qquad (3)$$

where f_f is flexural strength (MPa) and ft is tensile strength (MPa).

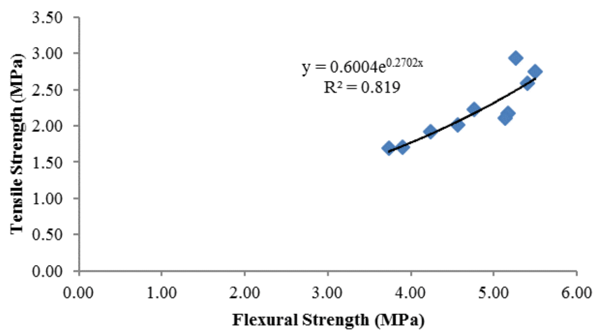

Fig. 11. Flexural and tensile strength co-relation

In this experimental study, favorable co-relationship between regression curve and test results were evaluated for strength performance of concrete containing 10% ground CBA. The coefficient of R^2 values for three co-relationships was found comparable with those obtained by the previous researcher, Rafieizonooz et al. [11], they considered coal bottom ash and fly ash as sand and replacement of cement respectively.

4. Conclusions and recommendations

On the basis of experimental results presented in this study, following conclusions were made;

i. The workability of concrete containing ground CBA with fixed water quantity was lower corresponding to that of control mix; due to more water absorbed by ground CBA in the concrete mixture.
ii. Incorporation of ground CBA in concrete greatly affects the density and water absorption in hardened concrete. Increased amount of ground CBA reduces the concrete density. Higher the grinding period creates finer particle, which absorbed more water in the concrete mix.
iii. The compressive strength was slowly declined due to presence of ground CBA in concrete. Concrete containing 10% ground CBA obtained from 20 and 30 hours grinding period was found to be satisfactorily as to achieve the targeted strength (35MPa). Concrete containing 10% of ground CBA with 20 and 30 hours was observed 12 and 5% lower than the control mix but 12% and 20% higher than the targeted strength respectively.
iv. The splitting tensile strength of concrete containing ground CBA was higher than the control mix. It was increased around 1% and 7% with 10% of ground CBA with 20 hours and 30 hours grinding period respectively. Increase in tensile strength is an evidence of C-S-H gel development in the concrete due to presence of ground CBA.
v. The flexural strength for ground CBA concrete was lower than control specimen. The flexural strength values of 10CBA20 and 10CBA30 were noted slightly close to the value of control mix.
vi. The favorable co-relation between regression curve and test results was observed for strength performances of concrete containing 10% ground CBA.

Hence, the coal bottom ash poses the good pozzolanic properties and it is experimentally determined that concrete containing 10% cement replacement with ground CBA, delivers satisfactory strength performances and declared as optimum replacement level. Therefore, it is recommended for future works to carry out further research on the strength and durability performances of concrete containing ground CBA as a cementitious material under aggressive environment such as exposed to sulphate and chloride conditions.

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Nomenclatures

f_{cu}	Compressive strength
f_f	Flexural strength
f_t	Tensile strength

Abbreviations

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
CBA	Coal Bottom Ash
CBA20	CBA obtained through 20 hrs grinding process
CBA30	CBA obtained through 30 hrs grinding process
CBA40	CBA obtained through 40 hrs grinding process
C-S-H	Calcium Silicate Hydrate
FDP	Faculty Development Program
OPC	Ordinary Portland Cement

References

1. Ramos, T.; Matos, A.M.; and Sousa-Coutinho, J. (2013). Mortar with wood waste ash: Mechanical strength carbonation resistance and ASR expansion. *Construction Building Materials*, 49, 343-351.
2. Argiz, C.; Moragues, A.; and Menéndez, E. (2018). Use of ground coal bottom ash as cement constituent in concretes exposed to chloride environments. *Journal of Cleaner Production*, 170, 25-33.
3. Flatt, R.J.; Roussel, N.; and Cheeseman, C.R. (2012). Concrete: An eco material that needs to be improved. *Journal of the European Ceramic Society*, 32(11), 2787-2798.
4. Yüksel, I.; and Bilir, T. (2007). Usage of industrial by-products to produce plain concrete elements. *Construction Building Materials*, 21(3), 686-694.
5. Topçu, İ.B.; and Canbaz, M. (2004). Properties of concrete containing waste glass. *Cement and Concrete Research*, 34(2), 267-274.
6. Mangi, S.A.; Wan Ibrahim, M.H.; Abdullah, A.H.; Abdul Awal, A.S.M.; Sohu, S.; and Ali, N. (2017). Utilization of sugarcane bagasse ash in concrete as partial replacement of cement. *IOP Conference Series: Materials Science and Engineering*, 271, 1-8.
7. Hamzah, A.F.; Wan Ibrahim, M.H.; Jamaluddin, N.; Jaya, R.P.; and Zainal Abidin, N.E. (2015). Cementitious materials usage in self-compacting concrete: A review. *Advanced Materials Research*, 1113, 153-160.
8. Putra Jaya, R.; Wan Ibrahim, M.H.; Dewi, S.J.; Abu Bakar, B.H, and Salwa. M.Z.M. (2013). Performance of RHA cement concrete under marine environment via wetting and drying cyclic by rapid migration test. *International Journal of Integrated Engineering*, 5(2), 27-31.
9. Singh, M.; and Siddique, R. (2015). Properties of concrete containing high volumes of coal bottom ash as fine aggregate. *Journal of Cleaner Production*, 91, 269-278.

10. Kim, H.-K. (2015). Utilization of sieved and ground coal bottom ash powders as a coarse binder in high-strength mortar to improve workability. *Construction Building Materials*, 91, 57-64.
11. Rafieizonooz, M.; Mirza, J.; Salim, M.R.; Hussin, M.W.; and Khankhaje, E. (2016). Investigation of coal bottom ash and fly ash in concrete as replacement for sand and cement. *Construction Building Materials*, 116, 15-24.
12. Jamaluddin, N.; Farhan, H.A.; Wan Ibrahim, M.H.; Jaya, R.P.; Arshad, M.F; Azinal Abidin, N.E.; and Dahalan, N.H. (2016). Fresh properties and flexural strength of self-compacting concrete integrating coal bottom ash. *MATEC Web Conferences*, 47, 01010(1-6).
13. Wongkeo, W.; and Chaipanich, A. (2010). Compressive strength, microstructure and thermal analysis of autoclaved and air cured structural lightweight concrete made with coal bottom ash and silica fume. *Material Science and Engineering A*, 527(16-17), 3676-3684.
14. ASTM C618 (2005). Standard specification for coal fly ash and raw or calcined natural pozzolan for use. *Annual Book of ASTM Stanard*, Retrived from https://www.astm.org/Standards/C618.htm
15. Putra Jaya, R.; Abu Bakar, B.H.; Megat Azmi, M.J.; and Wan Ibrahim, M.H. (2011). Strength and permeability properties of concrete containing rice husk ash with different grinding time. *Central European Journal of Engineering*, 1(1), 103-112.
16. ASTM C192/C192M-16a. (2016). Practice for Making and Curing Concrete Test Specimens in the Laboratory. *ASTM International*. Retrived from https://www.astm.org/Standards/C192
17. Khan, R.A.; and Ganesh, A. (2016). The effect of coal bottom ash (CBA) on mechanical and durability characteristics of concrete. *Journal of Building Materials and Structures*, 3(1), 31-42.
18. Aydin, E. (2016) Novel coal bottom ash waste composites for sustainable construction. *Construction Building Materials*, 124, 582-588.
19. Cheriaf, M.; Rocha, J.C.; and Péra, J. (1999). Pozzolanic properties of pulverized coal combustion bottom ash. *Cement Concrete Research*, 29(9), 1387-1391.
20. Wan Ibrahim, M.H.; Hamzah, A.F.; Jamaluddin, N.; Ramadhansyah, P.J.; and Fadzil, A.M. (2015). Split tensile strength on self-compacting concrete containing coal bottom ash. *Procedia - Social Behavioral Science*, 195, 2280-2289.
21. Aggarwal, Y.; and Siddique, R. (2014). Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates. *Construction Building Materials*, 54, 210-223.
22. ASTM C78-02. (2002). Standard test method for flexural strength of concrete (using simple beam with third-point loading). *Annual Book of ASTM Standard*. Retrived from https://www.astm.org/Standards/C78
23. Ramzi Hannan, N.I.R.; Shahidan, S.; Ali, N.; and Maarof, M.Z. (2017). A comprehensive review on the properties of coal bottom ash in concrete as sound absorption material. MATEC Web of Conferences, 103, 1-10.
24. Kurama, H.; and Kaya, M. (2008). Usage of coal combustion bottom ash in concrete mixture. *Construction Building Materials*, 22(9),1922-1928.