Journal of Engineering Science and Technology
Vol. 15, No. 3 (2020) 2040 - 2050

COAL BOTTOM ASH AS SUPPLEMENTARY CEMENTITIOUS MATERIAL IN CONCRETE WITH AND WITHOUT PAPER PINS

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Abstract

The existing techniques of disposing of coal bottom ash (CBA) imposes multiple hazards to the environment. Proper utilization of this waste has become an essential need to avoid related threats. There has been a lot of research on the use of CBA as a fine aggregate material. This research work aims to check its suitability as a supplementary cementitious material in concrete. In this experimental programme paper pins (PP) were also used to enhance the capacity of the matrix to sustain higher load and crack at slightly higher stress. CBA was used as partial cement replacement material at 5%, 10% and 15% by weight and paper pins were used as new fibre material with a similar percentage. Considering the utilization of CBA and PP, the experimental work focused on the properties of concrete in the fresh and hardened state, including workability, compressive and tensile strength. The results of experimental work indicated that the workability of CBA concrete decreases marginally with an increasing amount of CBA and it was noticed to decrease further with the utilization of paper pins. The results of compressive strength revealed that 5% replacement of cement with CBA provided the highest strength, whereas, at 10% and 15%, it was still higher than conventional concrete. Further, the addition of paper pins increased both compressive and tensile strength of concrete.

Keywords: Coal bottom ash, Compressive strength, Concrete, Steel fibres, Tensile strength.

1. Introduction

Waste disposal has been one of the leading environmental concerns of the 21st century. It includes industrial waste, construction waste, household waste etc. Waste accumulation is becoming a serious concern not only for the environment, but it also poses hazards to human life [1]. Therefore, it has become imperative to look for environmental friendly measures to dispose-off waste material with minimum environment-related threats. The burning of coal in power plant furnace result in some non-combustible material, out of which finer and lighter particles get departed with flue gases which are extracted in electrostatic precipitators called fly ash and the heavier material gets collected at the bottom of furnace called CBA. CBA particles form 20% of the total ash, the remaining 80% escapes as fly ash [2].

Large quantities of CBA are produced by coal power plants as waste material, and its quantity has increased over the years in many countries [3]. Annual CBA production in India, United States of America, Europe, and Malaysia is about 25, 14, 4 and 1.7 million tonnes respectively [4] Disposing bottom ash and fly ash in ponds consume thousands of acres of valuable land. Environmental concerns are increasing with every passing day, the limited landfill area makes utilization of CBA very essential [5].

The classification of CBA as hazardous material imposes multiple threats to human life and its safety [5]. Also, the multiple problems posed by global warming through ejection of greenhouse gases notably CO_2 is alarming [6]. The emission of CO_2 from cement industry was 829 million metric tons in 2000 which has increased marginally with time [7]. The industrial waste has been extensively investigated as sustainable alternatives to cement in concrete production [8].

Currently, the worldwide cement production is over 4.0 billion tones [9], which adds more than 6% of total CO_2 to the environment and mainly global warming [10]. Previously the CBA has been used as fine aggregate in concrete [11] due to its similar particle size distribution as natural sand. It's chemical composition is almost similar to fly ash that is being used as successful cement replacement material, which implies that CBA also has a good potential to utilize as cement replacement material with suitable grinding [12].

It is recently declared that CBA after grinding possesses pozzolanic properties and it has good potential to utilize as a replacement material for cement in concrete production [13, 14]. Therefore, this work is carried out to examine the suitability of ground CBA as partial cement replacement material to produce concrete. The utilization of CBA in concrete is being extensively examined around the globe [11]. Its application brought many benefits including economic, environmental and strength performances. Research has revealed that workability and compressive strength were found to decrease with the use of CBA in concrete as fine aggregate and it has more influence on tensile than the compressive strength of concrete [15].

The factors contributing to reduced slump may involve, increase in the proportion of angular, roughly textured and porous particles of CBA. The angular and roughly textured particles of CBA may supposedly increase interlocking characteristics, hindering the flow of concrete hence reducing the slump value [16]. Coal bottom ash does not show its pozzolanic properties initially, however it was reported to have similar strength to conventional concrete after 90 curing days [4]. The reduction in strength increases with increasing amount of CBA [16]. CBA has good potential to use as pozzolanic material due to the presence of silica in high amounts [17]. The presence of SiO_2 and Al_2O_3 imparts pozzolanic properties to CBA. It reacts with $Ca(OH)_2$ during hydration of cement particles to form additional calcium silicate hydrate and calcium aluminate hydrate which improve density and strength of concrete [18]. The attributes of CBA reuse are determined more by business decision-making behaviours compared to market or institutions [19].

Multiple experiments have been carried out with the successful use of steel fibres in concrete as they arrest any cracks in the matrix and ultimately increase the tensile strength [20]. It has been recommended that the cracking strain of brittle matrices, such as cement paste, mortar and concrete, could be increased by the addition of closely spaced Fibres [21, 22]. The research studies showed that there is a greater possibility of increasing the stress at which a brittle matrix will crack by using high modulus fibres. When the matrix cracked, considerable modification in the behaviour of the material was observed [23]. The fibres bridge a gap across the cracks, therefore, it provides post-cracking ductility [24]. The research so far carried out mostly focused on utilization of CBA as fine aggregate, very little data is available on its utilization as cement replacement. Therefore, there exist a gap to study the utilization of CBA with sufficient grinding. This research work aims to find suitability of CBA as cement replacement material with and without paper pins. The use of PP has been introduced to increase the capacity of concrete to crack at higher stress.

2. Materials

The strength performance of concrete, by replacing cement with CBA, along with PP and without PP was evaluated. The experimental programme included evaluation of fresh and hardened properties of concrete. The water-cement ratio used in this study was fixed to 0.5. The results obtained were compared with conventional concrete. The mix design was prepared as per the DOE method. The mix proportions used in this experimental programme are provided in Table 1. In this research work, ordinary Portland cement conforming to ASTM Type-I was used. It showed 3, 7 and 28 days compressive strength of 25.4, 34.4 and 45.8 MPa respectively. The observed Blaine surface area was 3510 cm^2/g. The chemical composition of OPC and CBA was determined using XRF test. In order to determine chemical composition test pellets were prepared for both materials with 8 grams of material and 2 gram of wax powder. The test results showed CBA possessed main oxide compounds including silicates, aluminates and Iron oxide along with a host of other compounds in smaller percentages. The combination of SiO_2, Al_2O_3 and Fe_2O_3 was more than 70% which classified it as class F pozzolan as per ASTM C618 [25]. The mix design and XRF test results are provided in Tables 1 and 2 respectively.

Table 1. Mix design of concrete (kg/m^3).

Mix	Cement (kg/m^3)	CBA (kg/m^3)	PP	Fine aggregate	Coarse aggregate
Control	445	-	-	790	970
5% CBA	423	23	-	790	970
10% CBA	400	45	-	790	970
15% CBA	378	67	-	790	970
5% CBA +5% PP	423	23	23	790	970
10% CBA +10% PP	400	45	45	790	970
15% CBA +15% PP	378	67	67	790	970

Table 2. Chemical composition of OPC and CBA.

Elements	CBA (%)	OPC (%)	Class F ASTM C618
SiO_2	51.5	14.6	70% (min) $SiO_2 + Al_2O_3 + Fe_2O_3$
Al_2O_3	14.3	3.95	-
Fe_2O_3	5.08	3.46	-
CaO	1.28	57.10	-
K_2O	0.99	0.51	-
TiO_2	0.91	-	-
MgO	0.47	1.62	-
Na_2O_3	0.19	-	-

Fine and coarse aggregates used in this experimental work were obtained locally. Fine sand with a specific gravity of 2.55 and water absorption of 1.02% whereas the coarse aggregate with a specific gravity of 2.68 and water absorption of 0.95% were used. Steel paper pin of 25 mm in length, 0.7 mm in diameter and 1.22 mm diameter of the head were used. PP was purchased from local market. The paper pins and prepared pellets for XRF test are shown in Figs. 1 and 2 respectively.

Fig. 1. Paper pins.

Fig. 2. Pellets for XRF.

The CBA used in this experimental programme was collected from Lakhra power station, located near Jamshoro, Sindh, Pakistan. The collected CBA was dried for any moisture in the oven for 24 hours at a temperature of $110\pm5^{0}C$. It was ground in Los Angeles machine with 10 numbers, 48 mm diameter balls for 10 hours. The ground ash was then sieved through 63-micron sieve, which had specific surface area of 3635.7 cm^2/g. The ground and un-ground CBA are shown in Figs. 3(a) and (b) respectively.

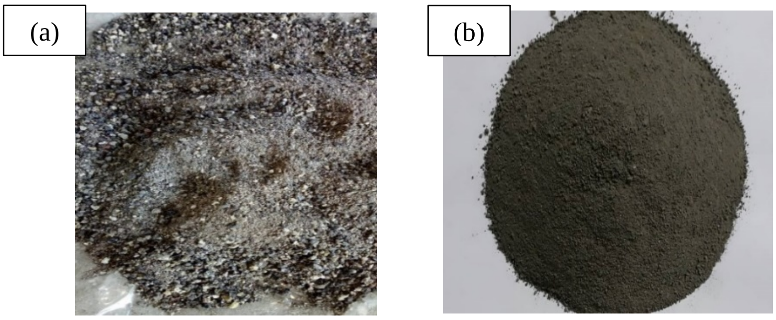

Fig. 3. (a) Un-ground CBA, (b) Ground CBA.

3. Physical Properties

The specific gravity of CBA was observed in the Material Laboratory Department of Civil Engineering, Quaid-e-Awam University of Engineering Science and Technology, Larkana Campus. The specific gravity of CBA was measured with a specific gravity bottle as shown in Fig. 4 in accordance with ASTM D854-14. The values of specific gravity and water absorption were observed as 2.3 g/cm^3 and 11% respectively. The values of physical properties fine aggregate, coarse aggregate and bottom ash are tabulated in Table 3.

Table 3. Physical properties of materials

Property	Fine Aggregate	Coarse Aggregate	OPC	CBA
Specific gravity	2.55	2.68	3.0	2.3
Fineness modulus	2.34	-	-	-
Water Absorption (%)	1.02	0.95	-	11
Surface area (cm^2/g)	-	-	4805.8	3635.7
Size	<4.75 mm	<20 mm	<63 micron	<63 micron

Fig. 4. Specific gravity bottle.

4. Experimental Details

Mix proportions were designed for evaluating the properties of concrete in a fresh and hardened state incorporated with CBA, with and without pp. The mixes were designed for replacing cement partially with CBA in the first phase and replacing cement with CBA and adding PP as fibre material in the second phase. Total of 36 cube and cylindrical specimens were prepared for compressive and tensile strength tests of concrete. The CBA was used as partial cement replacement material at 5%, 10%, and 15% in the first phase. In the second phase same percentage replacement of cement with CBA was used along with paper pins. In order to compare the results control specimens were also prepared with conventional concrete. The materials excluding water were mixed dry for three minutes. Water was added to the dry mix, and mixing was continued for 3 more minutes. The slump of the fresh mix was measured in accordance with BS

1881-2:1983 [26]. 150x150x150 mm size of cubes for testing compressive strength and 150x300 mm size of cylinders for tensile strength were prepared. After 24 hours specimens were demoulded and placed for curing in the water tank. The cubes and cylinders were removed from curing tank after 28 days for testing. The compressive and tensile strengths of concrete were determined as per British Standards specifications BS EN 12390-3:2009 [27] and BS EN 12390-6:2009 [28].

5. Results and discussion

5.1. Workability

Workability of fresh concrete comprising of CBA was found decreasing at a constant water-cement ratio. The workability decreased in proportion with the percentage of cement replacement. The reduction in workability values can be attributed to high water absorption of CBA particles measured as 11%, leaving less quantity for lubrication of concrete constituents. The roughly textured CBA particles can show interlocking characteristics and hindering the flow of concrete [16]. The decline in the values of workability can also be attributed to the increase in surface area of CBA particles due to the grinding effect which absorbs more water and reduced workability. The use of paper pins further decreased the slump value as they hinder the flow of concrete due to different head and tail sizes [29]. The variation observed in the values of workability is provided in Fig. 5.

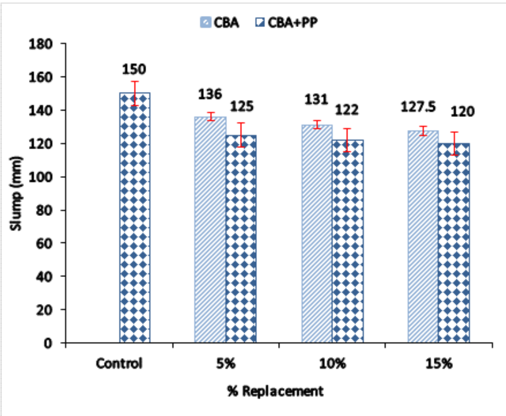

Fig. 5. Workability CBA & CBA+PP.

5.2. Compressive strength

The compressive strength of conventional and CBA concrete cubes was measured in the Universal testing machine after 28 days of curing. The cubes were placed in the machine opposite to their casting phase. The compressive strength of cubes containing 5% CBA showed a 2.8% increase in compressive strength. This trend of variation in the results was also reported by Singh et al. [30] and Sadon et al. [31]. The higher percentages of replacement showed a reduction in compressive strength. However, instead of declining path observed in the strength, the test results of CBA incorporated concrete were still higher related to conventional concrete specimens at 10% and 15% replacement levels. Kim and Lee [15] attributed this reversed pattern of strength to the delayed pozzolanic activity of CBA particles. This decreasing strength with increase in CBA percentage can also be due to more silica in the mix provided by CBA and not enough portlandite (C-H) to form a cementitious gel (C-S-H). This excess silica replaces the cement particles but does not take part in chemical reaction hence decreasing the strength [32]. The other mix which contained CBA as cement replacement material and paper pins as fibre material showed the highest compressive strength for all the mixes compared to CBA mixes. This increased strength can be attributed to higher strength provided by paper pins [33]. The compressive strength results observed in the experimental programme are provided in Fig. 6.

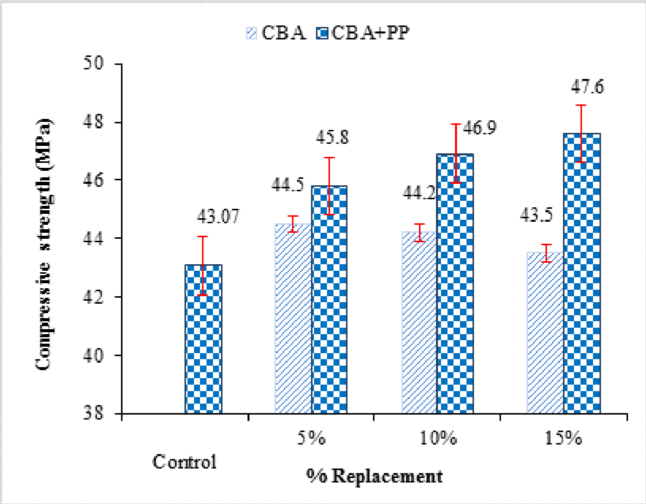

Fig. 6. Compressive strength of CBA & CBA+PP concrete.

5.3. Tensile strength

The tensile strength of cylindrical specimens was carried out after 28 days of curing. The test results showed that initially, the strength is increasing up to 5% replacement of cement with CBA. The strength was 6.3% higher compared to conventional concrete. Thereafter, a declining path in said strength was observed. The fractured surface of the concrete specimen containing bottom ash showed a flatter surface. It can be established at this stage that the tensile strength of CBA concrete decreases due to cracks in bottom ash particles [33].

It is further established that crack propagation in bottom ash particles occurred more easily than cement particles which resulted in decreased strength [34]. However, when the mixture of CBA with pp was tested, it showed an increase in the strength at all the replacement levels. The increase in the strength of specimens having CBA with pp at all levels of replacement is due to additional strength provided by steel paper pins. The increase in strength of CBA concrete with pp was 18.2% compared to conventional concrete. The higher strength values are due to pp bridging the gap and providing higher resistance to cracks which results in increased strength [20].

The use of fibres is supposed to provide additional ductility and increased strength [21-35]. The variation in the values of the tensile strength of CBA concrete with and without pp are provided in Fig. 7.

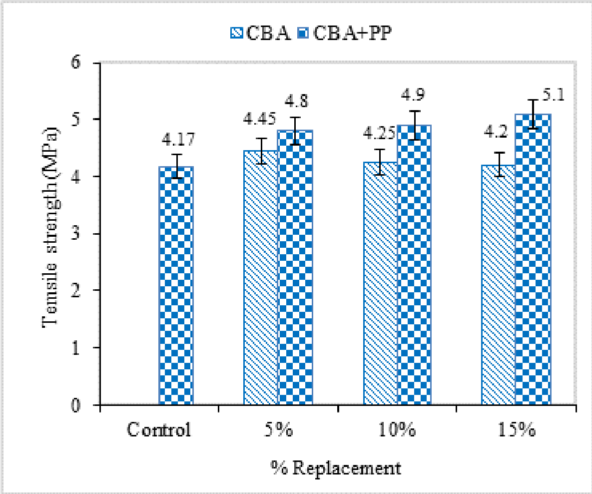

Fig. 7. Tensile strength CBA & CBA + PP Concrete.

6. Conclusions

It was concluded from the experimental programme that coal bottom ash (CBA) has good potential to utilize as cement replacement material up to certain replacement level. The mechanical strengths obtained were higher related to conventional concrete. From the results experimental programme following conclusions were drawn;

- The workability of CBA concrete decreased, due to more water absorption and interlocking characteristics of coal bottom ash particles. Hence suitable water-reducing admixture is recommended for workability.
- The maximum difference in the values of compressive strength was observed at 5% replacement of cement with CBA.
- The CBA concrete showed an increase in compressive strength at all replacement levels when paper pins were used.
- The cylindrical specimen showed maximum tensile strength at 5% replacement of cement with CBA. It was further observed that tensile strength increases at all replacement levels in CBA concrete along-with Paper pins.
- The research work showed that coal bottom ash can be an innovative material, as supplementary cementitious material in concrete production. The use of Paper pins further enhanced its capacity to sustain higher loads and it improved the ductility of the matrix. It is recommended to carry out further research using different grinding times of CBA as cement replacement material. It is also recommended that long-term studies should be carried out to have a deeper insight into the pozzolanic behaviour of coal bottom ash at different exposures.

Acknowledgement

The authors would like to acknowledge the support of laboratory staff of Civil Engineering Department, Quaid-e-Awam University of Engineering, Science and Technology Larkana Campus during experimental work.

Abbreviations

CA	Coarse aggregate
CBA	Coal bottom ash
FA	Fine aggregate
OPC	Ordinary Portland cement
PP	Paper pins

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