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Characterisation of Ground Coal Bottom Ash With Different Grinding Times

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Abstract: The physical and chemical composition of Ground Coal Bottom Ash (GCBA) exposed to varying grinding periods is discussed in this article. CBA was pulverised for 20 hours, 30 hours, and 40 hours in a ball mill machine. Particle Size Analyzer (PSA) and X-ray Fluorescence (XRF) instrument were used to characterise GCBA. According to the results of the tests, GCBA with a grinding duration of 40 hours generates the largest percentage of the finest particle (50-1000 nm) at 4%, the specific surface area is 13528.18 cm2/cm3, and the specific gravity (SG) is 2.54. According to the XRF results, there are no significant variations in the chemical compositions of the CBA with varying grinding periods. At 20, 30, and 40 hours grinding time, the primary oxide element for SiO_2 is 51.5%, 53.8%, and 52.3%, while $Al2O_3$ is 14.3%, 15.1%, and 14.6%, and $Fe2O_3$ is 5.08%, 5.27%, and 5.07% respectively. The sum of three primary oxide constituents surpasses the 70% ASTM C618 limit for pozzolanic material Class F fly ash.

Keywords: Ground coal bottom ash, grinding time, chemical composition, surface area

1. Introduction

Coal bottom ash is a byproduct of the coal combustion process used in power plants to generate electricity. When pulverised coal is burned in a dry bottom boiler, approximately 80–90% of the unburned material or ash is entrained in the flue gas and recovered as fly ash. The remaining 10–20% of the ash is dry bottom ash, which is a dark grey, granular, porous, primarily sand-sized material collected in water-filled hoppers at the furnace's bottom. However, the precise amount of coal bottom ash produced is determined by the type of coal used and the temperature of the burning process (Sadon *et al.*, 2017). Bottom ash is kept molten in a wet bottom boiler and is collected when it flows into the

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ash hopper. The molten material in the hopper is immediately fractured into crystallised pellets by the water in the hopper. The bottom ash in this case is known as boiler slag (also known as "black beauty"), which is a hard, black, glassy material (Umar Abubakar & Baharudin, 2012).

Many researchers have investigated the characterization of coal bottom ash to figure out its suitability for use in the production of concrete. Because the original size of the particles of CBA is nearly identical to that of fine aggregate, many studies have used CBA to replace fine and coarse aggregate (Ahmad Maliki *et al.*, 2017). However, researchers have recently begun to investigate CBA as a cement substitute.

Before CBA is used in concrete manufacturing, its properties must be thoroughly investigated. Cheriaf and Cavalcante Rocha, (1999) have found that CBA has pozzolanic properties that can react with cement. Therefore, it generates a new idea for the researcher to use CBA as a cement substitution. But, a higher replacement level of CBA will result in a reduction of concrete strength (Justs *et al.*, 2015). CBA particles are much coarser than FA particles, and the particle shape is typically angular and irregular, with interlocking characteristics.

CBA has a particle size distribution ranging from 1 to 10 mm, with 90% passing through a 4.75-mm sieve, 10–60% passing through a 600-m sieve, and 0–15% passing through a 75-m sieve (Ramzi hannan *et al.*, 2017). The ranges of specific gravities of raw CBA are between 1.2 and 2.47, depending on the quality of coal used in thermal power plants and the source of coal (Singh & Siddique, 2015). To use CBA as a cement substitute and increase pozzolanic activity, the particle size should be the same as cement. To achieve the desired particle size, a grinding process was required. The finest CBA particles will increase CBA's pozzolanic activity (Qian, Jueshi, Shi, Caijun, Wang, 2001). The finest CBA particle increases the surface area of CBA and speeds up the hydration process in cement (Cheriaf and Cavalcante Rocha, 1999; Basirun *et al.*, 2017; Burhanudin *et al.*, 2018).

The specific gravity of CBA is recorded as lower than that of cement clinker (Rafieizonooz *et al.*, 2016; Mangi *et al.*, 2018(Pincha Torkittikul, Thanongsak Nochaiya, 2017); (Singh & Siddique, 2016). The lower specific gravity because of porous texture of CBA (Sadon *et al.*, 2017). The value of the specific gravity of CBA is also influenced by its chemical composition. It is believed that iron oxide content proportional directly with the specific gravity (Singh & Siddique, 2013). This also happened because of the different source of CBA, different processing, and different equipment used.

Bottom ash is typically composed of silica oxide, alumina oxide, iron oxide, and trace amounts of calcium oxide, magnesium oxide, sulphate, and other elements (Khongpermgoson et al., 2020); (Ibrahim et al., 2015). The chemical composition of coal varies depending on the source (Singh & Siddique, 2016; Argiz *et al.*, 2017; Sanjuán *et al.*, 2019). If the total composition of silica oxide, alumina oxide, and iron oxide exceeds 70%, the ash is classified as class F by ASTM. The high silica oxide content will increase the pozzolanic reactivity of the concrete (Embong *et al.*, 2021). Cheriaf and Cavalcante Rocha, (1999) discovered, the pozzolanic reaction progressed slowly at first but accelerated after 28 days of curing. Furthermore, Kim & Lee, (2011) stated that the pozzolanic performance was inconsistent when different particle sizes were used.

According to XRD analysis, quartz is the most prevalent mineral in CBA along with calcite, hematite, magnetite, and gehlenite (Wongsa *et al.*, 2017). The other minerals detected were silicates, aluminates, aluminosilicates, sulphates, oxides, and phosphates (Yang *et al.*, 2018). The existence of silica oxide and calcium oxide in CBA demonstrates its suitability as a cement substitute.

A limited study on the characterization of CBA with ground particles was discovered. As a result, this study was carried out to investigate the physical, chemical, and microstructural properties of ground CBA at various grinding times. The grinding times ranged from 20 to 40 hours, and the grinding was performed in a ball mill machine. The properties of the GCBA were investigated, including particle size distribution, specific gravity, surface area, chemical elements and composition, mineralogy, and morphology.

2. Material and Method

The coal bottom ash (CBA) used in this research comes from Kapar Energy Ventures in Selangor's Klang district (Malaysia). The raw CBA was dried in an oven at 105 °C 5 °C for at least 24 hours to ensure that all moisture was removed. The coal bottom ash was ground for 1 hour using a Los Angeles Abrasion machine. Following the grinding process, the ground CBA was sieved through 600m. The CBA that passed the 600m sieve size were sent to the ball mill machine for further grinding. The grinding time was 20 hours, 30 hours, and 40 hours. The particle size distribution will differ depending on the grinding time. To ensure the homogeneity and consistency of the coal bottom ash, necessary treatment measures such as the mass of CBA fed into the ball mill and milling speed were implemented. **Fig. 1** shows the raw CBA before grinding (a) and CBA after grinding 20 hours (b), 20 hours (c) and 40 hours (d).

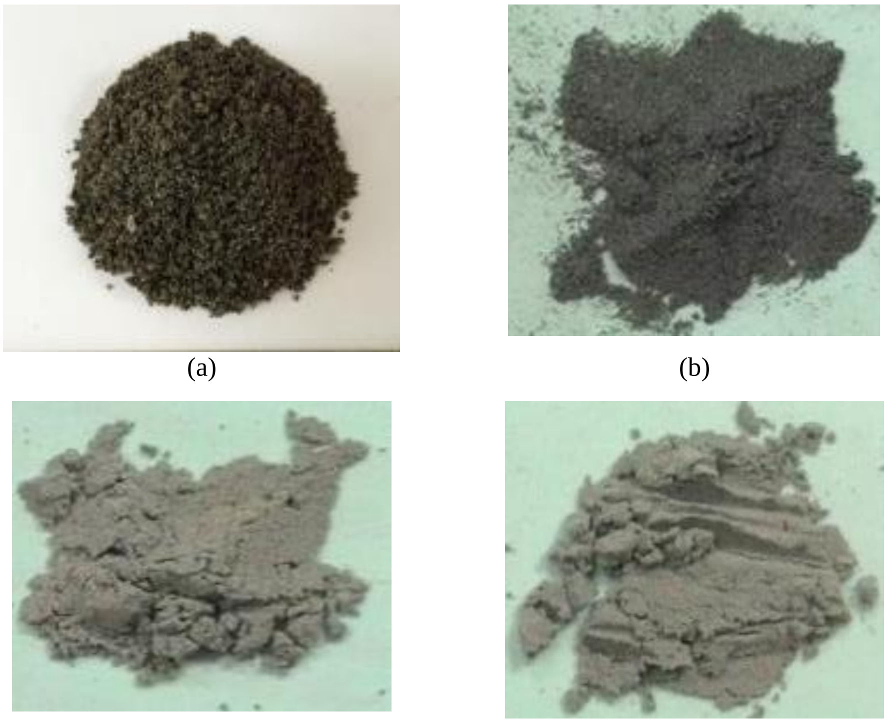

Fig. 1 - (a) Raw CBA; (b) CBA 20 hours; (c) CBA 30 Hour; (d) CBA 40 Hour

2.1 Particle Size Distribution Analysis

The Fritsch Analysette 22 was used to analyse the GCBA's particle size when grinding process was finished. The method of analysis is laser light scattering, with a measuring range of 0.01 to 2100 m. The GCBA was dispersed on the machine, and it takes between 5 and 10 seconds to analyse a particle. This test was done on all of the samples, which had been ground for 20, 30, or 40 hours.

2.2 Surface Area

The surface area was determined using the results of particle size analysis performed on the Fritsch Analysette 22. This testing is essential to determining the fineness of GCBA at different grinding times. A small amount of ground CBA was loaded onto the Fritsch Analysette 22 machine and PSD analysis was performed simultaneously.

2.3 Specific Gravity

The specific gravity (SG) of ground CBA varies depending on the particle's texture or size. The density of the ground CBA is determined by the SG property. It is useful to calculate the amount of substitute material to be used. The specific gravity was calculated using BS EN 1097-3: 1998.

2.4 X-Ray Fluorescence (XRF*)*

The X-ray fluorescence (XRF) test is more effective at sorting and analysing chemical element composition. This test was carried out at Environmental and Analysis laboratory at UTHM. prepare samples, 8g of GCBA and 2g of CH2 wax (binding agent) were mixed and compacted for 10 seconds by pressing the sample into a 35 mm diameter pallet at a load of 20 tonnes. This testing was performed using a German-made Bruker AXS S4 pioneer model XRF equipment.

3. Result and Discussion

3.1 Particle Size Distribution

Coal bottom ash was ground for different grinding times of 20 hours, 30 hours, and 40 hours. The grinding period was used to determine the particle size distribution of coal bottom ash. The outcome of the PSD analysis is depicted in **Fig. 2**. Table 1 displays particle size divisions D10, D50, and D90.

Table 1 - PSD result for grinded CBA

	D10 µm	D50 µm	D90 µm
CBA 20-H	2.467	19.774	37.749
CBA 30-H	1.948	15.036	29.807
CBA 40-H	1.819	11.254	27.356

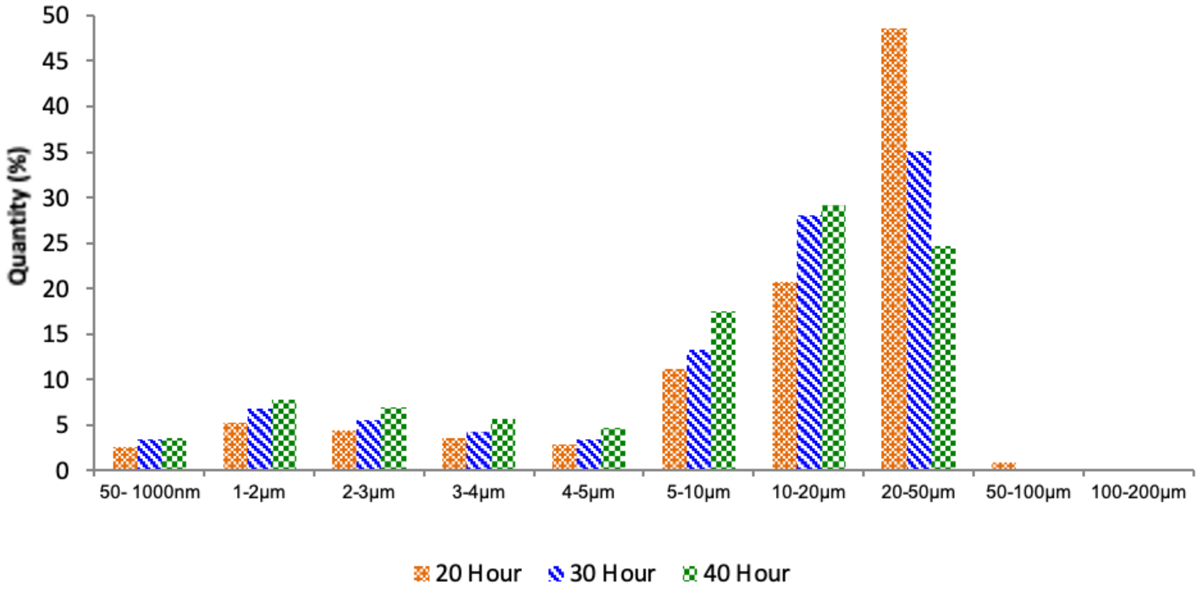

Fig. 2 - Particle size distribution

Fig. 2 illustrates the percentage of particle size distribution (PSD) for GCBA at various grinding times of 20 hours, 30 hours, and 40 hours. According to the graph, GCBA was well graded, with sizes ranging from silt to fine sand. With a percentage of 48.59%, the majority of the sizes fall between 20-50µm. When the grinding time is increased to 30 hours, the particle size distribution GCBA decreases by about 14% when compared to 20 hours. However, when CBA was ground for 40 hours, the particle size became finer than when it was ground for 20 or 30 hours. However, the quantity size particle at 10-20µm is not significantly different for grinding times of 30 and 40 hours when compared to 20 hours.

3.2 Surface Area

The results of the surface area test are displayed in Table 2. The Fritsch Analysette 22 was used to determine the PSD and specific surface area of GCBA.. The surface area was recorded as 9627.76, 12921.92 and 13528.18 cm^2/cm^3 for 20, 30 and 40 hours grinding time respectively. It was discovered that the longer grinding time, the finer particle GCBA will produces a greater specific surface area.

Table 2 - Specific surface area of GCBA with different grinding time

	GCBA-20H	GCBA-30H	GCBA-40H
Specific surface area	9627.76 cm^2/cm^3	12921.92 cm^2/cm^3	13528.18 cm^2/cm^3
Mode	27.161µm	21.86 µm	19.611 µm
Median	19.746 µm	15.028 µm	11.239 µm
mean	1.004 µm	1.021 µm	1.159 µm

3.3 Specific Gravity

The specific gravity (SG) of Ordinary Porland Cement (OPC) and Ground Coal Bottom Ash (GCBA) was investigated. The results of the testing for GCBA 20, 30, and 40 hours grinding time are shown in Fig. 3. It was found that the SG for OPC is 3.15 and GCBA is 2.06, 2.32, 2.54 at the grinding time 20, 30 and 40 hours respectively. The finding result shows the increment of grinding time of CBA was increased the SG value.

Fig. 3 - Specific gravity of OPC and GCBA for different grinding time

3.4 Chemical Composition of GCBA

The chemical analyses of CBA were perform using an X-ray fluorescence spectrometer. The XRF determines the oxides compounds of the OPC and CBA. The chemical element composition for GCBA 20, 30, and 40hours grinding time were compared with OPC as listed in Table 3. It shown that the GCBA comprises of SiO_2 is about 51-53%, Al_2O_3 is 14-15% and Fe_2O_3 around 5%. However, chemical element for OPC is slightly different as it contains the highest calcium oxide, CaO compared to GCBA. According to ASTM C618 the total amount (%) of SiO2, Al2O3, and Fe2O3 must be greater than 70% to be classified as pozzolanic material Class F- fly ash. The analysis result shows, this GCBA can be classified as pozzolanic material Class F – fly ash base on total amount (%) of SiO_2, $Al2O_3$, and Fe_2O_3 for 20, 30 and 40 hours is 70.88%, 71.97% and 74.17% respectively.

Table 3 - Chemical composition for GCBA-20, GCBA-30 and GCBA-40 and OPC

Chemical name and symbol		20-H CBA (%)	30-H CBA (%)	40-H CBA (%)	OPC
SiO_2	Silicon oxide	51.50	53.8	52.30	14.6
Al_2O_3	Aluminium oxide	14.30	15.1	14.60	3.95
Fe_2O_3	Iron oxide	5.08	5.27	5.07	3.46
CaO	Calcium oxide	1.28	1.32	1.31	57.1
K_2O	Potassium oxide	0.99	1.00	0.99	0.51
TiO_2	Titanium dioxide	0.91	0.91	0.91	-
MgO	Magnesium oxide	0.47	0.53	0.49	1.62
Na_2O	Sodium oxide	0.19	0.23	0.19	-
C	Carbon	0.10	0.10	0.10	3.43

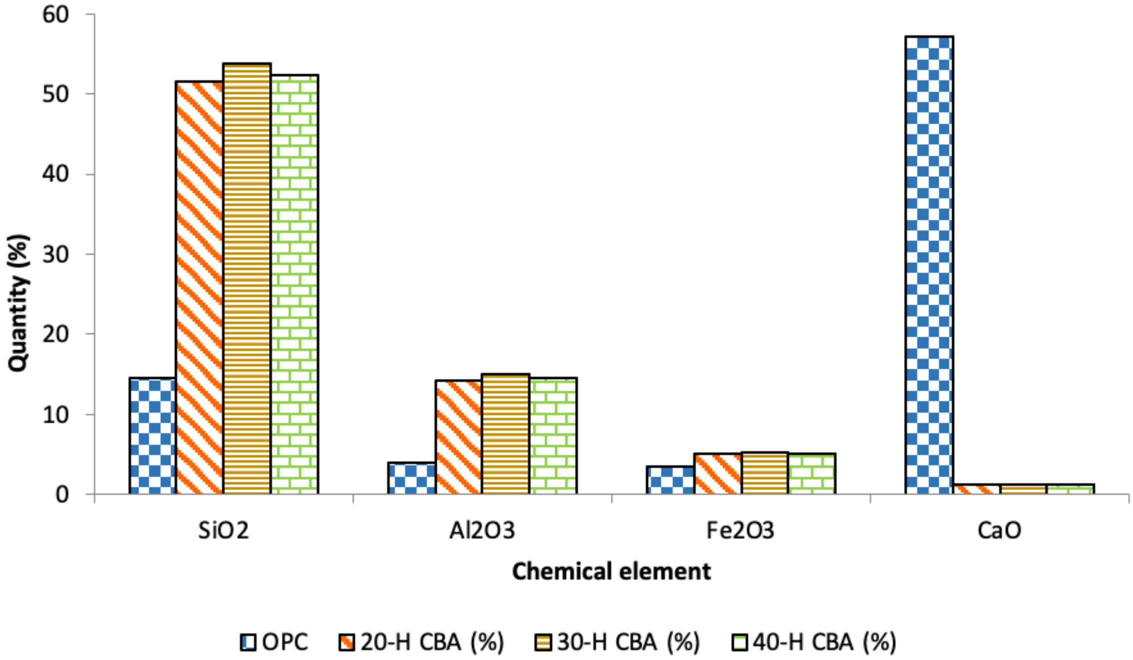

Fig. 4 - Major chemical element in CBA with different grinding time

The major chemical element of GCBA at different grinding time 20, 30 and 40 hours is shown in Fig. 4. The percentage of the major chemical element of GCBA quite higher compared to OPC. The amount chemical element for SiO_2 is 51.5%, 53.8% and 52.3% while Al_2O_3 is 14.3%, 15.1%, and 14.6% next Fe_2O_3 is 5.08%, 5.27%, and 5.07% for 20, 30 and 40 hours grinding time respectively. The highest chemical element in OPC is CaO about 57.1% because it is due to binding effect in the OPC. Due to the GCBA's classification as pozzolanic material Class F- fly ash,, it can be use as cementitious material in production of concrete.

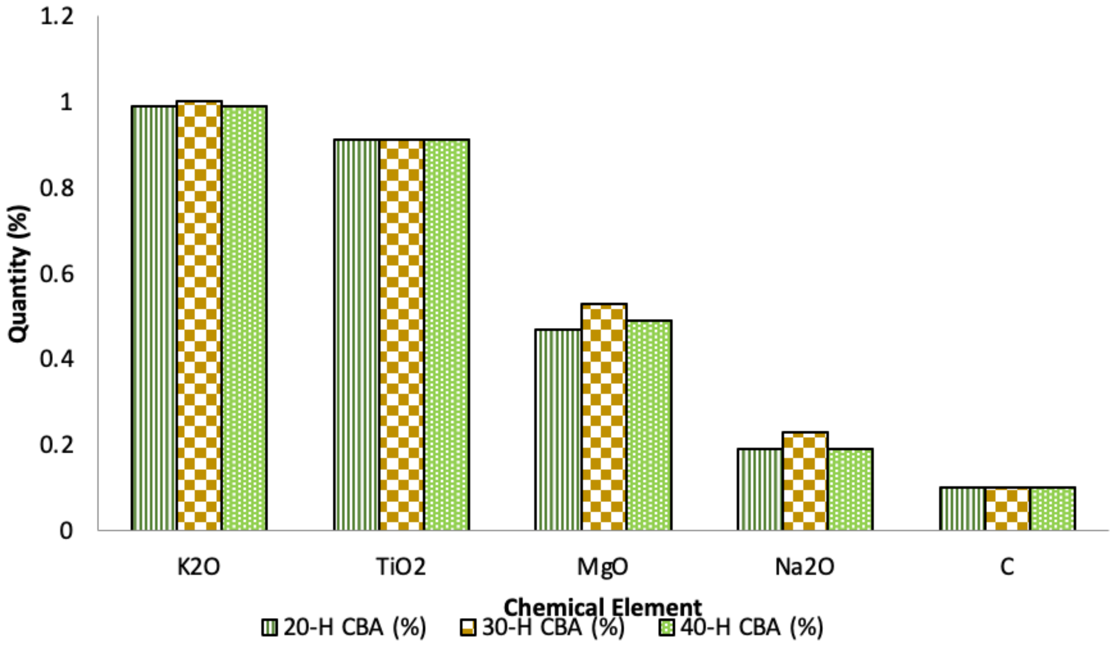

Fig. 5 - Minor chemical element in CBA with different grinding time

The quantity (%) minor chemical element in GCBA with different grinding time 20, 30 and 40 hours is shown in Fig. 5. The percentage for K_2O is 0.99%, 1% and 0.99% while MgO is 0.47%, 0.53%, 0.49% and Na_2O is 0.19%, 0.23%, 0.19% for 20, 30 and 40 grinding time respectively. Besides, TiO_2 is 0.91% and C is 0.1% for all grinding time.

The amount of minor element in GCBA not much differences for all three time periods. Therefore, the presence of this elements in GCBA will not affect the quality of concrete when used as cement substitute in production of concrete.

4. Conclusion

The GCBA material was found is well particle size distribution for all three grinding period as 20, 30 and 40 hours. The highest percentage particle size is 20-50 μm for all three grinding time periods but quite surprise there are a size that achieve 50-1000 nm. The specific surface area was increased by increment of periods of grinding time where 40 hours grinding time produces the highest specific surface area is 13528.18 cm^2/cm^3. The SG was increase by increment of grinding time periods. The high specific gravity shows at 40 hours grinding time by 2.54 while 20 and 30 hours is 2.06 and 2.32 respectively. The major oxide elements in GCBA are SiO_2, Al_2O_3 and Fe_2O_3. The presence of this element complies with ASTM C618 and qualifies this GCBA as pozzolanic material Class F- fly ash. As a result, this GCBA was suitable for use as a cement replacement material in the manufacture of concrete.

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