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UTILIZATION OF BOTTOM ASH FOR ALKALI-ACTIVATED (SI-AL) MATERIALS: A REVIEW

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ABSTRACT

In Malaysia, 180 tons/day of solid waste bottom ash are produced by a Tanjung Bin power station, which is one of the four coal power plants in Malaysia. Hence, to overcome this problem, the solid waste could be used as source material in construction industry using geopolymer technique. Alkali-activated materials are introduced as an alternative materials to ordinary Portland cement (OPC) in the construction industry. There are many types of alkaline activator raw materials such as bottom ash, fly ash, metakaolin and so on that can be substituted the materials existing such as cement and fine or course aggregate in the market now to make any production where the materials are coming from waste.The geopolymerization process involves a substantially fast chemical reaction under alkaline conditions with Si and Al minerals that results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O. The higher Si-O-Al-O bonds are contained in the geopolymer, the higher compressive strength results will find. Several types of building materials such as bricks and blocks can be formed for commercial exploitation using bottom ash with geopolymerization method.

Keywords: bottom ash, fly ash, geopolymer, sodium hydroxide, alkaline activator, bricks.

1. INTRODUCTION

Nowadays, researchers are finding solution to reduce environmental problem, according [1] using solid waste come from coal power plant. A large volume of bottom ash and fly ash generated from coal fired thermal power plants are currently dumped to landfill [2]. Bottom ash is produced from the burning coal in a dry bottom pulverized coal boiler. In 2009, Malaysia produced about 1 705 308 metric tonnes of waste are reported by industrial waste generation where the waste could harmful environmental effects [2]. Bottom ash is a glassy, porous, dark gray material with a grain size similar like a sand or gravelly sand [2, 3]. The Tanjung Bin power plant reported that about 18,000 tons/day of coal is used to generate electricity [3]. Hence, a great mass of coal ash as waste material will be produced because of large utilization of coal.

The huge amount of coal ash will be a considerable removal concern for power plants, firms due to the growth obligation for ash storage space [4]. Based on Figure-1, bottom ash showed at the bottom because it is a part of the non-combustible residues of combustion [5]. The bottom ash is collected at the bottom of the combustion chamber in a water-filled hopper and is detached by means of high-pressure water jets [5].

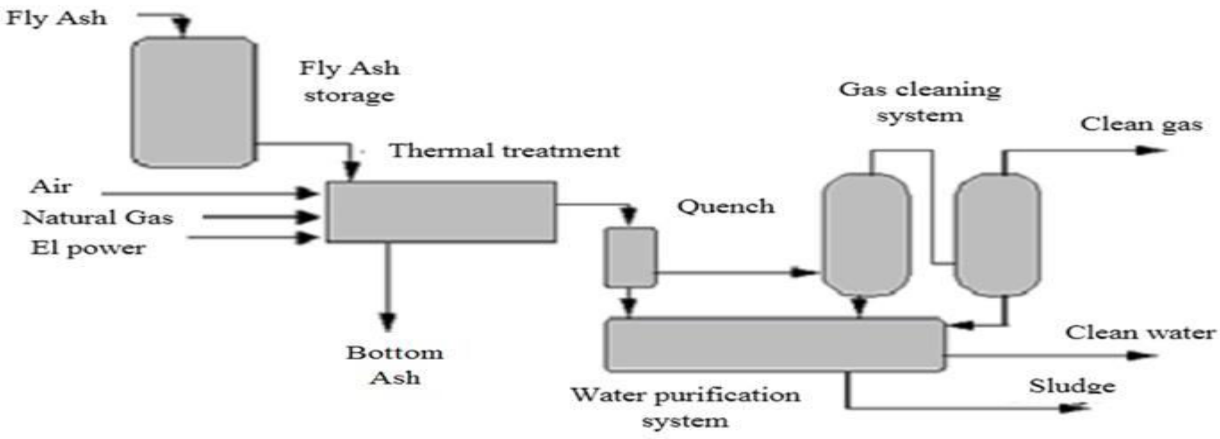

Figure-1. The schematic design of bottom ash in coal power plant [6].

In order to solve the problem, the bottom ash has been utilized in many applications. A number of fields have focused on new ceramics and glass-ceramics using waste materials such as bottom ash and sewage sludge ash [7].Besides that, bottom ash can be utilized forinorganic polymers or geopolymer synthesis where it is formed by alkaline activation of alumina-silicate and alkaline solution through geopolymerization process at ambient temperature because it has aluminium oxide-silicate [8]. The aluminium oxide-silicate based materials that have been found by the researchers are fly ash, kaolin, metakaolin and slag [8].The definition of alkaline geopolymer is a chemical process where a rapid change of some partial armorphous, specific structure into a compact cemented framework [8,9].According to the Skvara [9], the alkaline-activated materials is resulted from the reaction of aluminium-silicate materials in a strong alkaline environment which involves the results, breakdown of Si–O–Si bonds and later the arisen of, new phase. The mechanism of their formation seems to be a cognitive mental process that includes a solution ("synthesis via solution") [9]. The alkaline solution consisting of sodium hydroxide and sodium silicate are added to bottom ash to become ageopolymer or also known as alkaline-activated materials [10].

2. RAW MATERIALS

In the production of geopolymer, the two most significant things are raw materials and alkaline solutions [11]. The source of raw materials basically should come from a natural mineral where it is rich in silicon (Si) and alumina (Al) [11] such as clays and kaolinite. While, a by-product material like power plant fly ash, bottom ash, slag and metakaolin also a material that has a high silica and alumina [12-13]. However, bottom ash has advantages because it is a waste resource that was produce in huge amount by coal-fired power plant. So that, it was a environmental friendly product besides can reduce waste sent to the landfill [14].

In geopolymerization, the most alkaline solution used are sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) where there were suitable reacted with a high alumina and silica materials[15]. The ratio of alkaline solution was used usually is about 0.2-0.30 with the different molarity of the solution depending on raw material used [16]. Basically, the molarity used for brick or concrete geopolymer is about 10 to 16 M depends on te raw marials used. Besides that, alkaline activator that only contained hydroxides exposed in a lower rate of reaction than when soluble silicates were also applied as the activator [17].

3. PROCESSING OF ALKALI-ACTIVATED MATERIALS

The processing of geopolymer brick, concrete or mortar, bottom ash acting as replacement of fine aggregate or sand to get a product. To produce a geopolymer material, alkaline activator which is Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) was used with bottom ash [8, 18].According to Muhammad Fahem *et al.*, [18] in producing of kaolin-based geopolymer brick, the mix design was divided into three which is the ratio of kaolin to sand, the ratio of kaolin to alkaline activated and the ratio of sodium hydroxide to sodium silicate.Besides that, in production of geopolymer concrete, fly ash, bottom ash and ground granulated blast furnace slag (GGBS) are used as geopolymer materials. Fly ash and bottom ash based geopolymer is used as the binder and fillers, in the replacement of ordinary Portland cement (OPC) and fine aggregate/sand to produce geopolymer concrete [19]. Table-1 shows the mix proportion of making brick using bottom ash by adjusting percentage of water used with varying Si/Al ratio about 2 to 3 percentage [20].

Table-1. The mix proportion [20].

Mixture Sample No.	Bottom Ash (%)	NaOH (%)	Na_2SiO_3 (%)	Si/Al Ratio (%)	Water (%)
A	30	4	NA	2	36
B	30	6	NA	2	36
C	30	8	NA	2	36
D	30	4	28.043	2.5	17.5
E	30	6	26.453	2.5	17.5
F	30	8	24.874	2.5	17.5
G	30	4	44.835	3	7.5
H	30	6	43.041	3	7.5
I	30	8	41.248	3	7.5

Then, other researchers [22] concluded that the ratio of fly ash to bottom ash has been set by try and error mixing and varied from 1:2 to 1:5 ratio (by mass). After that, the ratio was fixed based on the high strength, good workability and less water absorption of the brick [22-23]. Mustafa *et al*., [24] in their research told the ratio of solid to liquid (bottom ash to alkaline activator solution) fixed at 2.0 ratio for all mixture and the ratio of sodium silicate to sodium hydroxide was fixed at 2.5 ratio by mass where it gives the best compressive strength results for geopolymer-based materials. In addition, for geopolymer mortar, the mixture of Potassium Silicate (K_2SiO_3) solution and Potassium Hydroxide (KOH) solution was selected as an alkaline activator as a binder with bottom ash [17, 24].

In making of kaolin based-geopolymer brick, the geopolymer materials and alkali activated will be weighed accordingly based on the mixed design and standard used. Then, the mixing of solid and liquid was mixed in a rate of 10 rotations per minute speed in a brick machine before it was ready to press [18, 25-26]. Besides that, in the mixing process of geopolymer mortar, the ratio used of sodium silicate and sodium hydroxide was kept as 0.4 then the fine aggregates or can be replace with bottom ash and fly ash with specific ratio by weight were mixed in a dry condition [26]. In the other hand of preparation geopolymer concrete using bottom ash and fly ash as raw materials, the ashes and GGBS were mixed in a jar using 2 hour ball milled. Then, the Si/ Al ratio was used are 2, 2.5 and 3 by adjusting the amount of sodium silicate (Na_2SiO_3) solution for the samples before it was cast in cylindrical plastic molds [27]. In mixing process of curing for mortar, it was done with sealed about 48 hours at 60 °C and the compressive strength was measured at 3, 7, 14 and 28 days. In addition, the curing of concrete was done by casted the sample in a plastic mold, including 50 tapping for each sample to remove air bubbles. Then the sample was curing about 24 hours at 60 °C [17, 27].

Due to another study about the production of mortar, raw materials such as fly ash, bottom ash and fine aggregate was dry mixed in the mixer about 2 minutes before it was mixed with an alkaline activator with mixture of K_2SiO_3 solution and KOH solution about 10 minutes [27-28]. A ratio by mass was used for preparing K_2SiO_3 solution and KOH solution. After that, the preparation of mortar using 14 M sodium hydroxide solution prepared by dissolving the solution pellets in water. Then, the bottom ash, water glass, sodium hydroxide and water were mixed for 10 minutes in a ball mill to get the homogenized slurry paste of mortar before put it into the mold [17, 24, 28].

4. PROPERTIES OF ALKALINE-ACTIVATED MATERIAL BASED ON BOTTOM ASH

a) X-Ray Flurescence (XRF)

Table-2 shows the chemical composition of bottom ash analysed by using X-Ray Flurescence (XRF) [29]. From the table, the highest percentage of 29.15% of silicon dioxide (SiO_2) followed by 26.685% aluminium oxide (Al_2O_3) were shown. Then, slightly lower sulfur trioxide (SO_3) content may be present in bottom ash. This may be due to the presence of lower porous of bottom ash particles [30].Then, in order obtain granulated blast, it was milled for two hours in a ball mill [31].

Table-2. Chemical composition of bottom ash [30].

Chemical Composition	Percentage by weight (%)
SiO_2	29.15
Al_2O_3	26.68
SO_3	0.51
CaO	16.36
MgO	1.51
Na_2O	1.15
LOI, (Loss of Ignition)	1.15
K_2O	0.53
Fe_2O_3	7.28

b) X-ray diffraction (XRD)

The XRD pattern showed in Figure-2 done by Qin Li *et al*., [32] for geopolymer mortars using bottom ash as fine aggregates. The crystalline peaks goes to mullite and quartz from the original coal bottom ash and fly ash. As seen in Figure-2, the peak of quartz become much stronger in the pattern using bottom ash as fine aggregates compared of mortar using standard sand [32].

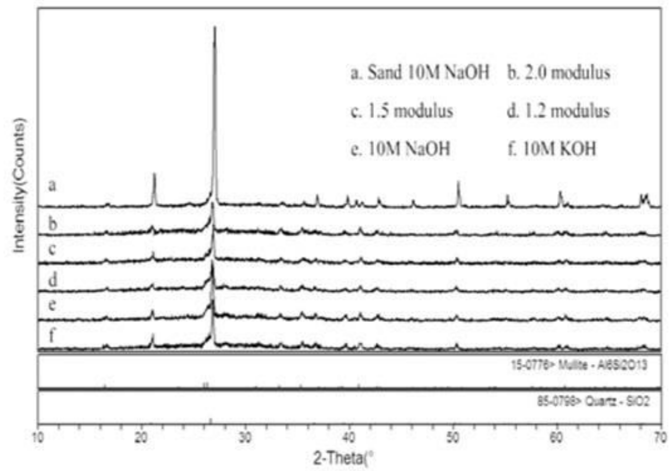

Figure-2. XRD pattern of geopolymer mortar [32].

c) Scanning Electron Microscope (SEM)

Figure-3 reveals the SEM images of ground bottom ash and Tanjung Bin bottom ash, respectively [33]. The ground bottom ash in Figure-3 was spherical in shape same like fly ash particle with glassy structure and angular [33-34]. Figure-4 shows the combination of fly ash and bottom ash SEM in geopolymer mortar. As figure below, bottom ash particle (6 b) seen much larger and porous with many tiny pores compared to fly ash particle (6 a) where it was very tiny. The water absorbed and adhered to surface, so that the tiny pores occurs. Since excess water might be damaging to the geopolymers properties, attention should be conducted while using bottom ashes [30, 34-35].They should either be dried prior to use or less amounts of water should be applied in the slurry.

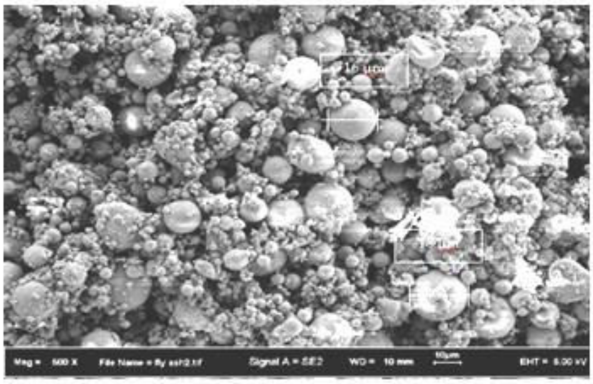

Figure-3. The SEM of ground bottom ash [33].

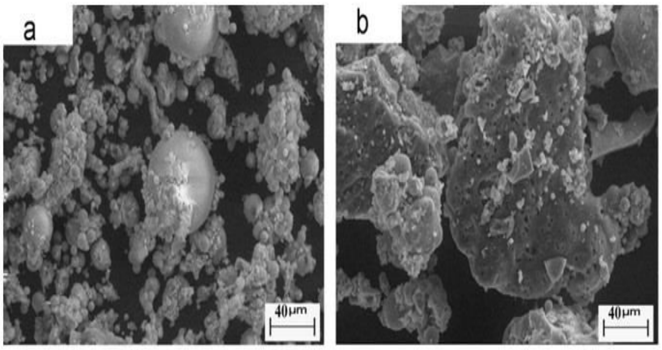

Figure-4. SEM micrographs of ashes.

d) Fourier Transform Infrared Spectroscopy (FTIR)

Figure-5 shows the Fourier Transform Infrared Spectroscopy (FTIR) of bottom ash [36]. The peak at 3468 cm^{-1} is associated to water (H_2O) and the absorbtion bond at region of 1634 cm^{-1} to1599cm^{-1} is due to H_2O bending. FTIR absorption spectroscopy is well known for its sensitivity to characterize materials with short-range structural order, and is considered as a useful tool to characterize geopolymer matrices [37]. In addition, the FTIR for geopolymer bottom ash mortar shows in Figure-6 using Bruker Vector 22 Fourier transform spectrometer used KBr pressed disc also the optima inductively coupled of optical emission spectrometer plasma was used to identify the conformation of leaching solutions [32, 36-38].

Based on Figure-6, due to O-H stretching and bending vibration, the FTIR spectrum of coal bottom ash was about 3443 $cm^{-1}$and 1634 cm^{-1}, respectively. Then, according to molecular and hydroxyl bonding of water was about 1432 cm^{-1}. In asymmetric stretching vibration of Si-O-Si group, the bands are 1093 cm^{-1} and 798 cm^{-1} due to Si-O-Si stretching vibration quartz [32, 34 38].

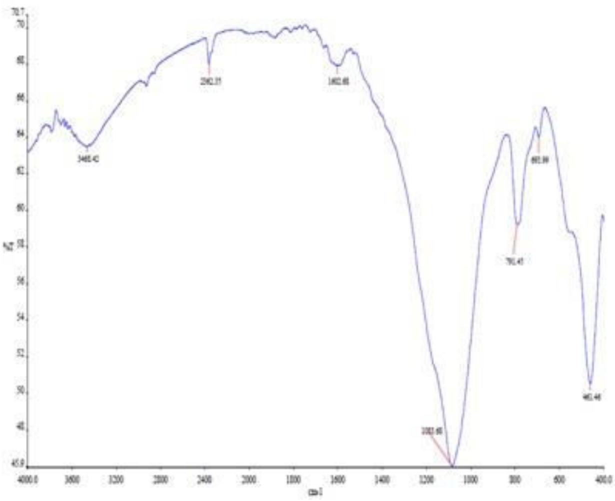

Figure-5. The FTIR spectrum of raw bottom ash.

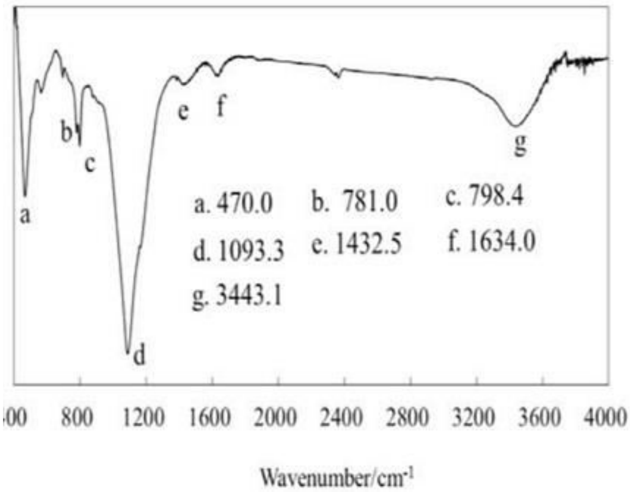

Figure-6. Fourier Transform Infrared Spectroscopy (FTIR) of bottom ash geopolymer [32].

e) Compressive Strength

In technical test for the compressive strength of geopolymer mortar using bottom ash, Figure-7 showed the outcomes from previous inquiry. When the bottom ash increased, the compressive strength of geopolymer mortar was decreased because the water discharged into the mixture of bottom ash. The lower compressive strength of geopolymer mortar also because of the higher porosity of the bottom ash [17]. According to Sinha *et al.*, [27], compressive strength increased when Si/Al ratio increased with the increasing percentage NaOH for example percentage of alkali 8 and Si/Al ratio 3.In concrete, compressive strength depended on the curing time and curing temperature because when the curing time and temperature increased, the compressive strength also increased [11, 30, 38]. The compressive strength of concrete was obtained approximately 40 to 50 MPa within a range time about one day to three days at 60 to 90 °C. Usually using sodium silicate (Na_2SiO_3) as an activator. Sodium silicate was suitable using in alkaline activator because of partially polymerization silicon whereas it easily join and react to the properties of the samples.

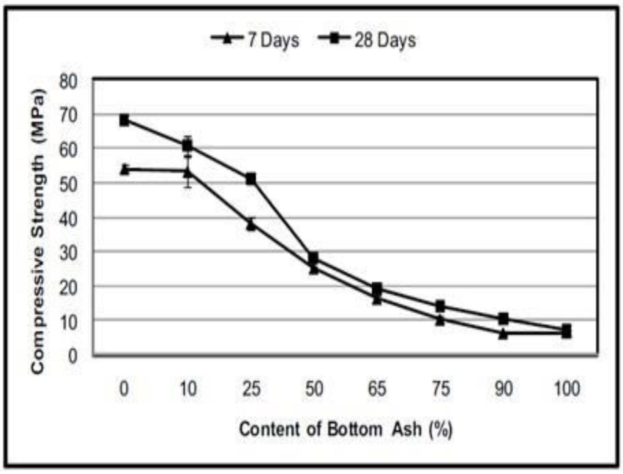

Figure-7. The compressive strength of bottom ash [17].

f) Density Analysis

In the production of mortar using bottom ash based geopolymer material, the bulk densities are decreased than the previous research for the same composition of bottom ash because the porosity of bottom ash mortar is 33 percent due to post heat-treatment where water molecules produce micropores during discharge through the network [39]. Due to Komljenovia *et al*., [40], the average density of geopolymer bottom ash brick was found to be 1516.5 kg/m^3 where it was easy compared to clay brick. In summation, the geopolymer brick at 60 days has higher density compared to the geopolymer brick at 1 day of ageing because the complete reactions of geopolymerization occurred to the brick. So, the compressive strength also increased when the density was increased [22, 30, 40].

5. CONCLUSIONS

Using the alkali-activation method, several types of building materials such as bricks and blocks or concrete can be formed for commercial exploitation using bottom ash. So, as a conclusion, bottom ash hasa potential to use with alkaline activator. Established on the reviews [39-40] shown that it is possible to create non-load bearing bricks by using alkali-activated materials. According to this study, further work on a compounding of a variety of different source materials to the geopolymer performance can be extended.

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