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BOTTOM ASH – POTENTIAL USE IN SELF-COMPACTING CONCRETE AS FINE AGGREGATE

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ABSTRACT

Nowadays, practicing ‘industrial ecology’ for sustainable industrial development is a common practice in the engineering field. This practice promotes recycling by-product waste of one industry by substituting/replacing them for the virgin raw material of another industry, thereby reducing the environmental impact of both. One of those by-product wastes is bottom ash, which produced from coal-fired power plant that faces an increasing production up to hundred and thousand tones over the continents. Previously, a significant amount of research has been conducted in order to explore the potential use of bottom ash in the production of concrete and mortar. Most of the research focused on its potential use as fine aggregate replacing natural sand, and exploring its beneficial properties in enhancing the properties of concrete and mortar. This present paper reviews the literature related to the properties of fresh and hardened concrete incorporating bottom ash as a partial or total replacement to fine aggregate. Comprehensive review on physical, chemical and mechanical properties of bottom ash are presented. The effects of bottom ash on setting time, bleeding and segregation, workability, strength and durability of fresh and hardened concrete are also presented. An effective utilization of bottom ash in the construction industry may help in promoting ‘green’ culture and sustainable development

Keywords: bottom ash, self-compacting concrete, waste by-product.

INTRODUCTION

Self-compacting concrete or commonly abbreviated as SCC can be defined as a concrete that displays excellent deformability and high resistance to segregation and that can be filled in heavily reinforced or restricted areas without the need of internal or external vibration (Uysal *et al.* 2012). It was first proposed by Okamura in 1986 in order to improve quality of the construction work in term of durability (Okamura and Ouchi 2003). SCC was then developed by Ozawa and Maekawa from University of Tokyo and the first SCC’s prototype had been completed in 1988.

Numerous studies have been conducted in order to develop better understanding of the behavior of SCC. For example, Mazloom and Ranjbar (Mazloom and Ranjbar, 2010) studied the relation between the workability and strength of SCC, while other researcher such as Assie (Assié *et al.* 2007) and Brouwers (Brouwers and Radix, 2005) studied the potential durability of SCC and the role of the particle distribution in the in the production of SCC. It has been well known that the productions of the SCC depending on the material proportion and chemical admixture in the mixture design. Therefore, there is also researcher whose studied and proposed a method in designing for SCC mixture (Nepomuceno *et al.* 2014), (Narendra *et al.* 2008), (Su *et al.* 2001)

Generally, the materials used in the conventional concrete are suitable used in the production of SCC, including mineral admixture such as fly ash, silica fume, metakoalin, granulated blast furnace slag, etc. Relatively lots of detailed study has been conducted to investigate the potential used of waste material in the production of SCC (Navaneethakrishnan 2012), (Bouzoubaa and Lachemi 2001)

However, there is not much study have been conducted in investigating the potential use of bottom ash in the SCC. This paper intended to present discussion on the existing literature regarding the utilization of bottom ash as a replacement material in the production of concrete and mortar. The result from this discussion will open the possibilities for bottom ash to be used in SCC.

BOTTOM ASH AS FINE AGGREGATE IN CONCRETE AND MORTAR

Bottom ash is a mineral by-product generated from coal-fired power plant. Generally, coal-fired power plants derive energy by burning coal either in pulverized coal-fired furnace or cyclone furnaces. The ashes collected from pulverized coal-fired furnace is fly ash (75% - 90%) and coal bottom ash in the range 10 to 25% (Canpolat, 2011). According to American Coal Ash Association, fly ash and bottom ash are typically produced and disposed in the ratio of 80:20 (fly ash: bottom ash by weight).

The particle size distribution of bottom ash made it a suitable substitute material for sand. It has the particle size range from fine gravel to fine sand with very low percentage of silt-clay sized particles. According to Canpolat (Canpolat, 2011), bottom ash typically composed of particle ranging from 2 μm to 20 mm in size. Though the bottom ash is usually a well-graded material, the particle size distribution of the ash is varied even it come from the same power plant. Figure-1 shows a sample of bottom ash collected from power plants.

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Figure-1. Particle size of bottom ash (Lee *et al.* 2010).

Bottom ash commonly used as low-cost replacement material for quartz sand as fine aggregate in normal and high-performance concrete production (Kula *et al.* 2002). It also used in the production of geopolymer mortar and autoclaved concrete as fine aggregate as studied by Sathonsaowaphak and Kurama (Sathonsaowaphak *et al.* 2009), (Kurama *et al.* 2009). The utilization of bottom ash helps in improving the concrete properties as it affected by the size of particles and replacement ratios. Ground bottom ash increased the surface area and eliminated micro pore hence improving workability and concrete strength (Kula *et al.* 2002). Moreover, by controlling the crushing and particle size classification method, the amount of unburned carbon in the bottom ash can be set to desirable level or as accepted by concrete industry (<6%) (Kurama *et al.* 2009). The 10% of bottom ash replacing sand in the production of geoploymer mortar gave comparable strength to the geopolymer mortar without bottom ash (Hardjito dan Why 2011). Whilst 30% and 50% replacement ratio of non-ground granulated blast furnace slag and non-ground coal bottom ash as fine aggregate single or mutually leads to sufficient durability properties (Bilir, 2012). Even though the strength development is less for bottom ash concrete, it can be compared to low grade of normal concrete. Concrete containing 50% of bottom ash as fine aggregate gave compressive strength more than 20 Mpa at 28 days is acceptable for most structural application (Aggarwal *et al.* 2010)

EFFECT OF BOTTOM ASH ON THE FRESH PROPERTIES OF MORTAR AND CONCRETE

Setting State

Setting state can be defined as the moment when the fresh concrete stiffed, solid and able to withstanding substantial load. The setting state (initial and final time) influenced by several factors such as cementitious material finesses, cementitious material contents, the addition of water reducing admixture and pozzolan properties. The inclusion of bottom ash as fine aggregate in the concrete was proven to increase the setting time of concrete mix (Singh and Siddique, 2013). Due to the porosity of the bottom ash, the water required to achieve certain level of workability is increase. Therefore, with the increase of water in the concrete mixture, it lowers the pH value of the concrete and increase the distance between cement hydration products and thus results in delays or decrease in hydration activities of cement particles. The quantity of cement and the addition of admixture also influenced the setting time of concrete with bottom ash. The concrete incorporating bottom ash with a high cement content and high admixture dosage decreased the setting time of the mixture. It was found out that, the final setting time decrease about 10% for every 370mL dosage of admixture per 45Kg of cement used (Ghafoori and Bulholc 1996).

Bleeding

Bleeding occurs due to the different weight of material in concrete paste. The heavy material such as aggregates and particles tend to occupy the points closest to the bottom of mould, whereas the water tends to rise to the top. The rising of the water is called bleeding. As for concrete with bottom ash, it is believed that due to the porous particle of bottom ash, it tends to absorb water internally during the concrete mixing process. However, bottom ash particles have lesser water retention compared to natural sand (Singh and Siddique, 2013). Therefore, the absorbed water by bottom ash particle will eventually release to the concrete, which result in higher loss of water through bleeding compared to concrete with natural sand concrete. The higher water/cement (w/c) ratios, the higher rate of water loss by bleeding and the greater the bottom ash content the higher these values are (Andrade *et al.* 2009). Nevertheless, with 100% replacement of bottom ash as fine aggregate, the bleeding percentage in concrete decreased (Singh and Siddique, 2014). In study conducted by Ghafoori and Bucholc (Ghafoori and Bulholc, 1996) shows that water- reducing chemical admixture had a profound effect on the amount of bleeding exhibited by the bottom ash concrete. The magnitude of bleeding was found significantly lower and equivalent to those control specimens when a high dosage of admixture was used.

Workability

The termed workability use to describe the state of concrete, which is consistence or in other words, the firmness of form of a substance or the ease with which it will flow (Neville and Brooks, 2010). Concrete incorporating bottom ash normally less workable compared to normal concrete. This is due to the physical properties of bottom ash, which is very porous and having irregular shape. In a study by Hardjito and Fung (Hardjito and Fung, 2012), the replacement of bottom ash up to 75% replacing fine aggregate had demonstrated reduction in workability. The decrease of workability with the increment of the replacement level of bottom ash with fine aggregate may result from the extra fineness of bottom ash as the replacement level increased. These were explained that the extra fineness of bottom ash will increase the specific surface area, hence result in decrease in workability of the mixture (Aggarwal *et al.* 2010). However, the workability of fresh concrete incorporating bottom ash can be improved by grinding the bottom ash (Sathonsaowaphak *et al.* 2009), (Singh and Siddique, 2013), (Jaturapitakkul and Cheerarot, 2003). The process of grinding destroyed the pore exists and smoothing the surface area, hence improving the workability of the mixture.

Strength of the Concrete and Mortar Incorporating Bottom Ash

Strength of concrete is commonly considered to be as the most valuable property of concrete. It is usually gives an overall picture of the quality of the concrete since it is directly related to the structure of the cement paste (Neville and Brooks, 2010). In this section, the development of strength of the concrete and mortar sample incorporating bottom ash, which had been studied by previous researchers will be discussed. Previously, many studies have reported that the utilization of the bottom ash in the concrete contributes an acceptable strength which comparable to control specimens (Kurama *et al.* 2009), (Andrade *et al.* 2007), (Ramme *et al.* 1998). However, the strength was developed at later ages due to the pozzolanic action of bottom ash. It was explained in the study conducted by Andrade (Andrade *et al.* 2007) by using methods developed by Ambroise in investigating and measuring the pozzolanic activity of bottom ash. As observed in the Table-1 and Table-2, the strength development pattern of bottom ash concrete at all replacement levels is parallel with the strength development of control concrete (Aggarwal *et al.* 2010), (Syahrul *et al.* 2010). The pattern shows that the strength increased with the increase of curing days. However, the strength of the concrete with a bottom ash decrease as the level of replacement of bottom ash increased. Nonetheless, the decreased of compressive strength in bottom ash concrete at the early curing age of 7 days was probably due to the increased porosity of concrete and later pozzolanic reactivity. The low development of strength related to bottom ash concrete can be due to the fact that, many bottom ash particle remain unreacted with calcium hydroxide until days 14 of curing age (Sruthee *et al.* 2012) [28]. Then the strength is gradually improved after 14 days of hydration and at day 28, the bottom ash particles reacted with calcium hydroxide and form C-S-H gel and needle as shown in Figure-2 and Figure-3.

Table-1. Result of compressive strength at different ages of bottom ash (Syahrul *et al.* 2010), (Aggarwal *et al.* 2010).

Mixture	Syahrul et al., 2010			
	3 days	7 days	28 days	60 days
0%	28.07	34.21	39.52	43.52
10%	17.56	16.52	21.41	23.71
20%	19	20.03	23.78	23.92
30%	18.79	20.81	24.65	27.44
40%	15.83	17.87	19.99	23.44
50%	14.4	17.3	21.2	22.44

Table-2. Result of compressive strength at different ages of bottom ash (Aggarwal *et al.* 2010).

Mixture	Aggarwal et al., 2007			
	7 days	28 days	56 days	90 days
0%	24.74	33.33	35.4	37n.18
10%	-	-	-	-
20%	23.26	30.43	32.15	36.07
30%	22.48	29.55	31.78	36.74
40%	21.7	28	30.6	35.26
50%	20.15	26.37	30.44	35.18

Figure-2. The scanning electron micrograph of hydrated bottom ash at the 14 day. Unreacted ash particles (Cheriaf *et al.* 1999).

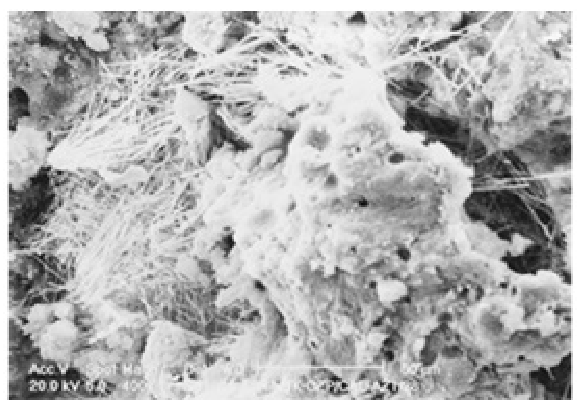

Figure-3. The scanning electron micrograph of hydrated bottom ash at the 28 day. Formation C-S-H gel (Cheriaf *et al.* 1999).

In a study conducted by Jaturapitakkul and Cheerarot (Jaturapitakkul and Cheerarot, 2003), the result of experimental study shows that the strength of the mortar and bottom ash concrete can be improved by grinding the bottom ash to finer particles. The strength development of the mortar and concrete are as presented in Table-3 and

Table-4. As shown, the compressive strength of mortar and concrete with ground bottom ash is either comparable to or greater than control specimens. This result suggested that the fineness of the bottom ash did affect the strength development of the mortar and concrete. The same result shown in the study conducted by Sathonsaowaphak (Sathonsaowaphak *et al.* 2009) where the strength of mortar increased from 46.0 Mpa to 48.0 Mpa with the increase in fineness of bottom ash to 18% and 3% retained on sieve no. 325. From this study, it can be concluded that the fineness of bottom ash exhibit better pozzolanic reactivity.

Table-3. The compressive strength of mortar with bottom ash (Jaturapitakkul and Cheerarot, 2003).

Type of Mortar	Compressive Strength (Mpa)					
	3 days	7 days	14 days	28 days	60 days	90 days
CONTROL	22.8	30.7	36.3	40.8	45.6	47.5
OBM10	17.2	22	25.8	28.4	32.2	33.6
OMB20	10.7	14	16.8	20.1	22.7	24
OBM30	6.6	10	11.9	13.6	16.6	18.5
GBM10	22.6	30.2	35.4	40.5	48.3	51.6
GBM20	21.3	29.2	34.4	39.7	48.5	52
GBM30	18.5	25.4	31.7	38.3	49.4	53.1

Table-4. The compressive strength of concrete with bottom ash (Jaturapitakkul and Cheerarot, 2003).

Type of Mortar	Compressive Strength (Mpa)					
	3 days	7 days	14 days	28 days	60 days	90 days
CC25	12.3	17.3	21	25.5	26.7	27
GBC25	9.8	15.5	19.2	23.6	26.7	27.8
CC35	19.7	28.4	33	36.6	38.1	38.9
GBC35	16.4	24.4	31.5	37.1	40.1	40.8
CC45	26.2	34.3	40.4	45.8	46.7	46.9
GBC45	22.6	31.1	40.5	46.2	49.4	501

In terms of flexural and split tensile strength, the bottom ash concrete exhibits the same pattern of strength development as compressive strength. This was shown in the study conducted by Aggarwal (Aggarwal *et al.*2010). It was observed that both flexural and split tensile strength showed that the specimens gain its strength with the increase of curing aging. However, the strength was acceptable but less than the reference sample. This is probably due to the spherical shape of bottom ash, which may result in poor interlocking between fine and coarse aggregate. The result obtained from this study contrary with the result obtained by Sruthee et al (Sruthee *et al.* 2012a), (Sruthee *et al.* 2012b) where the flexural and split tensile strength gained was slightly higher compared to control specimens. However, the strength decreased when the replacement level of 40% bottom ash.

CONCLUSIONS

Up until now, a lot of research studies have been conducted by many researchers on the behavior of conventional SCC as well as SCC with various types of additive and replacement material to enhance the properties of the conventional SCC. Previous studies has shown that the application of bottom ash in concrete and mortar as either partial or total replacement to fine aggregate gives a remarkable improvement on the properties of concrete such as the strength of the concrete. It is undeniable that the utilization of bottom ash in concrete decreases the strength of the concrete; however, it can be solved by longer curing period since bottom ash promotes later strength due to pozzolanic reaction. Moreover, with appropriate percentage replacement, bottom ash performances are better or comparable to the reference concrete. It has been found out that the replacement level of 10% to 30% of bottom ash is an ideal level for the best performance of concrete. However, when using bottom ash as a raw material in concrete or mortar, it is necessary to pay extra attention mainly to the dosage parameter such as water-to-cement ratio. This is due to the angular shape and rough texture of bottom ash which create higher friction force between particle, hence decreasing the workability of mortar and fresh concrete. Moreover, water released from the interior of bottom ash may result in bleeding and segregation. Therefore, if bottom ash is intended to be used in the SCC, such consideration should be taken; (1) water-to-cement ratio, since bottom ash is a porous material, it tends to absorb water, therefore, a large amount of water is required in order to achieve required workability. However, bear in mind that higher water-to-cement ratio will reduce the strength of concrete. (2) Replacement ratio of bottom ash, since quantity of bottom as proportional to the strength of concrete. (3) Curing period, since concrete with bottom ash tend to developed later strength due to the pore refinement resulted from pozzolanic reaction. Firefly algorithm is considering new algorithm in the swarm intelligence family. Despite that, the usage of the firefly algorithm in the various types of problem shows that the anticipation from the researcher to use this algorithm. This algorithm already proves that it is superior compared to the previous introduce swarm intelligence from the research done before. Even though the firefly algorithm has proven to be superior compared to the previous swarm intelligence, some modification can be done to improve the local search a well as global search to ensure the solution obtains is the optimum and not premature solution.

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